Oil and Gas

A Roadmap for unlocking future growth opportunities for Australia

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CSIRO FUTURES

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ACKNOWLEDGEMENTS

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CSIRO Foreword

Australia has had a wealth of resources at its fingertips, and our oil and gas sector has been a strong contributor to Australia's economy for decades. However, a shifting international market means the industry must invest today in the innovation that will allow it not just to remain competitive, but actually lead tomorrow. While the rapid pace of change has created challenges, there is also an opportunity for the Australian industry to redefine a future that realises gains from reduced costs of exploration and production, improved safety and efficiency of operations, reduced environmental impacts, and by embracing diversified products and services. CSIRO is uniquely placed to drive technological innovation for the oil and gas industry, given our expertise, track record and deep engagement across the sector.

CSIRO's Strategy 2020 is to be Australia's Innovation Catalyst, driving a collaborative approach across research, education, government, business and investor communities to build a stronger future for the sector. 'Customer First' is the first pillar of our strategy, and we've prioritised the way we work side-by-side with our customers and partners to foresee and tackle the big challenges facing their industries. We're committed to responding with agility and creativity to find the right solutions for unique projects, and spending more time understanding the specific needs of our customers. This customer-centric approach doesn't just extend to how we work with our partners; it is also reflected in our broader research agenda. For example, we are investing heavily to improve the characterisation of our resource base with a recent investment in the Deep Earth Imaging Future Science Platform. This multi-year strategic investment is focused on developing new technology to analyse subsurface imaging and better characterise oil, gas, and mining resources.

CSIRO studies the markets that matter – using science to conceptualise, predict, and model the major trends shaping Australia's future, including the *Australia 2030 Report, Our Future World: Global Megatrends* report, and the *Australian National Outlook*. We believe the Oil and Gas sector has an opportunity to reshape its future, led by world-class science and solutions. This Industry Roadmap discusses enablers for unlocking these opportunities which rely on a collaborative approach from the research, education, government, industry and investor communities. CSIRO is committed to continuing to channel resources into this effort, including bringing our world-class science and solutions to the table.

Responding to the disruption facing every part of the Australian landscape requires nothing short of deep collaboration to drive breakthrough innovation. We are proud to stand shoulder to shoulder with National Energy Resources Australia (NERA) and the other Industry Growth Centres as they further map out their roads to success. Together, we can apply world-class scientific and technological expertise to our unique Australian challenges. Together we will chart a course for long term sustainable prosperity for our nation. Together, there is no problem we can't solve.

Dr Larry Marshall
CSIRO Chief Executive

NERA Foreword

It is my pleasure to jointly endorse the CSIRO Roadmap for Australia's oil and gas industry. The collaboration between NERA and CSIRO provides a powerful example of the way collaboration can force multiply our efforts and talents and assist to create a competitive, exciting and sustainable future for the oil and gas sector in Australia.

In 2016, NERA (National Energy Resources Australia) was formed as part of the Australian Government's Industry and Innovation Agenda. NERA's role is to assist the energy resources sector adapt to a disruptive energy market and in an increasingly automated world. The only way we can achieve this is to transform our thinking and processes and become better equipped to deliver innovative questions and solutions for the sector. NERA is creating vital connections for growth. Through collaboration, we will deliver innovation and improved productivity, direct research to industry needs and deliver the future work skills required for a digital and low emissions economy.

The global and local economies are changing and at an ever-faster pace. We now live in a globally connected and networked marketplace and technological innovation continuously opens new opportunities and ways for delivering and experiencing goods and services, including energy. Global commitments to reducing carbon emissions are driving investment in clean technologies and making alternative energy sources more economic.

Australia's oil and gas sector is in transition. The industry is transitioning from decades of massive investment and construction to operations and maintenance. Managing costs while improving efficiency and productivity is critical. At the same time, oil and gas companies are finding new partnerships, customers and markets, investigating diverse ways of creating and realising value through the value chain to the generation of electricity and exploring what value renewable and clean energy technologies can create for the sector. To maximise these opportunities, we must challenge our beliefs around what makes us competitive and transform our questions, our thinking and our approach to how we innovate.

The NERA Sector Competitiveness Plan (SCP) and this Roadmap complement one another in assisting the Australian oil and gas sector transition to a fundamentally different digital and energy marketplace.

NERA's SCP provides a detailed international competitiveness benchmarking analysis, strategic knowledge priorities and key focus areas. Together with the CSIRO Roadmap, the SCP provides industry and sector stakeholders with the evidence to guide the initiatives needed to create a future orientated and sustainable industry. Building this strong future will rely heavily on a collaborative approach from all parties – research, education, government, business and investor communities.

CSIRO brings world-class science and solutions to the mix and we are proud to be working with this world-class institution. The CSIRO Oil and Gas Roadmap provides an important contribution to the combined efforts required to address the sector's challenges and will assist us all in working together to improve our global connections and competitiveness.

Miranda Taylor
Chief Executive

NERA NATIONAL ENERGY RESOURCES AUSTRALIA
Creating connections for growth

Executive Summary

Executive summary

This report was informed by industry consultation and is based on the opinions of executives and managers from oil and gas operators, service firms and Government agencies. Dozens of interviews with technical experts from universities and CSIRO provide the report with a solid perspective on technology developments. In all, approximately 80 interviews were conducted to inform this report during the first half of 2017. Analysis of the content of these interviews, and additional desktop research helped to shape this report. It therefore represents a consensus view of the trajectory of the industry, developed by synthesising executive opinions, technical expertise and scientific research.

Introduction

Despite prior successes, the Australian oil and gas sector faces many challenges. Overcoming them will require innovation and new collaboration strategies. To help in this endeavour, the Oil and Gas Roadmap identifies four high-impact pathways to growth that are enabled by science and technology.

Australia's oil and gas sector sits on the world stage, contributing strongly to the country's position as a leading energy exporter. The nation's world-class gas resources, geopolitical stability, proximity to lucrative markets and skilled workforce have long made it an attractive target for investment. Decades of investment, including that recently in LNG, have transformed the sector into the major global force it is today.

However, any assumption that this pattern will continue indefinitely fails to acknowledge a number of challenges facing the sector. Oil prices have plunged and are likely to remain low for the foreseeable future. This, coupled with the ongoing commoditisation of LNG, is damaging the economics of existing assets. In terms of attracting new investment, fierce competition from new low-cost producers, and 'sovereign risk' may mean that capital for future projects may not flow into Australia. On the demand side, rapid technological change makes the future energy mix difficult to predict. This difficulty is exacerbated by regulatory uncertainty and pressures on the energy sector to decarbonise. All of these forces challenge the future of the industry.

To remain globally competitive in such times, Australia's oil and gas sector cannot be complacent. A robust strategy is needed to deal with the challenges facing the industry and the uncertainties underlying them.

This oil and gas industry roadmap provides a high-level guide to addressing some of these challenges and uncertainties, to assist with ensuring the long-term viability of the sector.

Four major strategic opportunities are identified herein. Each represents a high-impact pathway to growth that is grounded in science and technology. If these opportunities are pursued collectively by companies and government entities, the Australian sector may become more competitive and innovative, thereby, unlocking its potential and solidifying its place as a major oil and gas player in the decades ahead.

In addition to these technology pathways, the sector will need to focus on a number of 'business ecosystem' improvements to unlock its full potential. These include engaging in new approaches to collaboration, focusing on energy security, streamlining the costs of doing business and reducing regulatory uncertainty. Critically important will be improving the sector's public image. This will be achieved, in part, by enhancing social performance by fostering trust between government, industry and other stakeholders to establish robust social licence to operate – particularly in unconventional oil and gas.

FIGURE 1: REPORT STRUCTURE

CHAPTER 2: GLOBAL OIL AND GAS MEGATRENDS

What global trends are shaping the sector?

CHAPTER 3: AUSTRALIAN OIL AND GAS COMPETITIVE LANDSCAPE

What are the Australian trends and issues facing the sector?

CHAPTER 4: STRATEGIC OPPORTUNITIES

What can the sector do to ensure its long-term viability?
What technologies can help unlock these opportunities?

What other changes are needed to help the industry capitalise on these strategic opportunities?

CHAPTER 5: CREATING THE RIGHT BUSINESS ECOSYSTEM

Trends and competitive landscape

The sector faces a confluence of global trends and domestic challenges that require new ways of thinking about the exploration and production oil and gas, and the future of the energy sector more generally.

CONSIDERABLE CHALLENGES FACE THE AUSTRALIAN OIL AND GAS SECTOR

To establish the state of play for the Australian oil and gas industry, CSIRO undertook *megatrends* and *competitive landscape* analyses. The former focused on global shifts, and the latter on the advantages and challenges facing the Australian oil and gas sector.

Findings point to five megatrends that will shape the global oil and gas industry over the next decade. Combined, they indicate that businesses and government must find economically-viable ways to produce increasingly challenging resource plays in a cost-constrained environment, in order to supply rapid demand growth (from the developing world especially), while at the same time excelling in the environmental and social aspects of doing business. These megatrends are shown in Figure 2.

FIGURE 2: GLOBAL OIL AND GAS MEGATRENDS

ENERGY HUNGRY

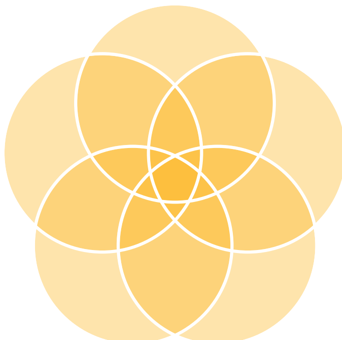
Global primary energy demand is predicted to grow rapidly in the coming years, driven by a swelling population, increased urbanisation, and the rise of the middle class particularly in the developing world. However, uncertainties remain about the energy mix that will meet this demand.

DIGITALLY ENABLED

Rapid improvements in digital technologies hold the promise to dramatically improve the way businesses operate. From embedded sensors to advanced analytics and AI, the industry is creating tools to improve how they create, deliver and capture value. The challenge for this sector is the integration of multiple technologies to capitalise on the next wave of the digital-enabled future.

MORE COMPLEX AND COSTLY

Large conventional oil and gas resources are becoming harder to find and the sector is moving toward more complex resource plays. These have different cost profiles and many will require new technology to produce economically – particularly in a cost-constrained business environment.



SOCIALLY CONCERNED

Global citizens are increasingly adept at shifting public sentiment around issues important to them. Using such tools as social media, groups of people can create strong opposition to business interests, shape public discourse, and influence government policy. A key challenge for the oil and gas sector in this regard is earning and retaining social licence for its resource projects.

CARBON CONSTRAINED

Rising concentrations of CO_2 and other greenhouse gases are believed to have increased average global temperatures and disrupted weather patterns. Government regulation, subsidies, and rapid cost reductions of renewables are all pointing to the fact that the decarbonisation of the energy sector has begun, which will impact the global oil and gas sector.

A more granular focus on the competitive landscape of Australia's oil and gas sector reveals a number of advantages that can be leveraged, in addition to a series of challenges that need to be addressed (see Figure 3). Importantly, the tremendous value of Australia's resource base risks being locked up for the foreseeable future due to a number of issues; including high development costs, lack of domestic innovation, adjusting to the new fiscal realities of remote and higher-risk unconventional resources, regulatory uncertainty and troubles with gaining social licence to operate. The potential solutions for many of these challenges are not technological, but will instead come from a concerted and proactive effort by the business community, government and stakeholders.

FIGURE 3: AUSTRALIAN OIL AND GAS ADVANTAGES AND CHALLENGES

Advantages

- **Strong position in LNG** – Australia is a leading LNG exporter with the significant potential to cultivate a world-leading operations and maintenance (O&M) capability.
- **Considerable conventional resources** – Considerable proven and contingent gas reserves appear ready to meet future market demand, if they can be developed economically.
- **Large untapped unconventional prospective and contingent resources** – Australia may be well placed to meet future demand using CSG and Shale gas, if these can be proven and produced economically.
- **Proximity to Asian markets** – Australia is in a prime position to supply the increasing demand for oil and gas from developing Asian nations.
- **Leading research institutions and capability** – Australia is home to many sector-focused research groups with scientific outputs that are among the best in the world.

Challenges

- **High-cost environment** – Australia's high costs of exploration, development and production of remote prospective resources may dissuade future capital investment.
- **Regulatory uncertainty** – Bans and moratoria on unconventional gas, unclear greenhouse gas emissions policy, and LNG export restrictions all create investment uncertainty.
- **Establishing Social Licence to Operate** – Building trust between stakeholders, companies and government is critical to opening up the exploration and production of Australia's vast oil and gas wealth.
- **Low prices, commoditisation, and declining exploration** – Exploration for new oil and gas resources in Australia has dropped, potentially affecting the sector's ability to meet future demand.
- **Domestic innovation and commercialisation challenges** – Limited commercialisation of research activities and very few new products being developed by Australian oil and gas businesses mean that the sector is reliant upon technology from overseas.
- **Low levels of collaboration** – Collaborations are important for innovation; however, not enough of this specific type of collaboration occurs in Australia's oil and gas sector.

Advantages can erode without sustained investment →

← Challenges can become advantages if they are prioritised and addressed

Strategic opportunities to help address the sector's challenges and improve global competitiveness

Four strategic opportunities that harness the power of science and technology have the potential to transform existing operations and create entirely new business prospects.

This report asks '*What can the Australian oil and gas sector do, in the face of considerable obstacles, to remain viable into the coming decades?*' and '*What investments in science and technology are needed to prevail?*' Questions like these framed the industry consultation approach, with the aim of identifying the major strategic opportunities for the sector, specific enabling technologies, and research priorities over the next ten or more years.

The result of these efforts was the identification of four strategic opportunities as shown in Figure 4.

FIGURE 4: OIL AND GAS OPPORTUNITIES ALONG THE VALUE CHAIN

1 Enhanced basin productivity

Technology breakthroughs will help lower the cost of locating resources and producing reserves, thereby improving the global cost-competitiveness of the industry.

Potential applications

- Improved exploration success
- Advances to drilling and well completions
- Improving hydrocarbon recovery

3 Advanced environmental solutions and processes

Developing technologies and processes that reduce the environmental and social impacts of field developments and processing plants, may also provide financial benefits to the Australian oil and gas sector.

Potential applications

- Water quality and reuse
- Reducing greenhouse gas emissions
- Efficient and environmentally-sound decommissioning

2 Digital operations and maintenance

Rapidly evolving digital technologies provide opportunities for safer and more efficient O&M of oil and gas assets.

Potential applications

- Robotics and automation and remote operations
- Optimising operations and supply chains

4 High-value diversification

Businesses should consider adapting their business models and diversifying into higher-value product and service offerings to gain competitive advantage and hedge against an uncertain future energy mix.

Potential applications

- Integrated energy services
- Small and mini-LNG and small floating LNG for small and marginal fields
- LNG for heavy transport
- Higher-value products

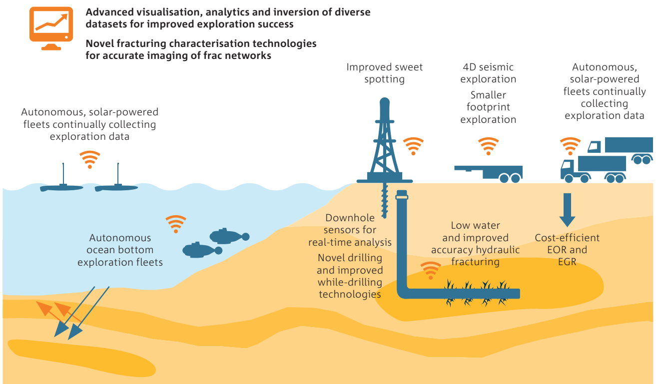
Enhanced basin productivity

Technology breakthroughs will help lower the cost of locating resources and producing reserves, thereby improving the global cost-competitiveness of the industry.

With the recent downturn in oil prices, a gas market undergoing commoditisation, and stiff international competition for capital, reducing costs in the subsurface is a paramount activity for the continued health of the Australian sector. Locating and proving resources can be done more efficiently, drilling and completions can be done more economically, and recovery rates can be improved. These ideas are expanded below.

Firstly, exploration efficiency can be improved in a number of ways. Technologies that enable autonomous collection of seismic data might help to drive down costs, particularly in frontier basins. More detailed pre-competitive datasets, together with tools like cloud computing and Artificial Intelligence (AI), may help to locate and better characterise resources 'pre-drill'. Inversion of multiple existing imaging modes can provide higher resolution of the subsurface and enable improved outcomes. New technological paradigms, such as those based on quantum gravity sensors, may be used to locate oil and gas more readily in the future.

Secondly, drilling and well completions are important targets for cost reduction. With large numbers of onshore wells to be drilled in Australia over the next decade, focus should be on increasing drilling efficiencies and improving supply chains and infrastructure that support drilling and completions. If done correctly, the potential exists for businesses to apply some of the technological know-how about high-volume onshore drilling to other regions.



The third approach is to use advanced technologies to improve hydrocarbon recovery and extend the life of oil and gas fields. For example, advanced characterisation of reservoirs can improve targeting of hydrocarbons, and enhanced oil recovery technologies can help improve ultimate recovery factors. One interesting potential technology applicable to Coal Seam Gas (CSG) is microbially-enhanced coal-bed methane,[1] also known as Reservoir Rejuvenation Technology (R2T).[2]

1 CSIRO Energy (2015). *Enhanced oil recovery,* [Online] Available from: http://research.csiro.au/oilandgas/wp-content/uploads/sites/49/2015/10/Enhanced-oil-recovery-2015.pdf Accessed 2/06/2017

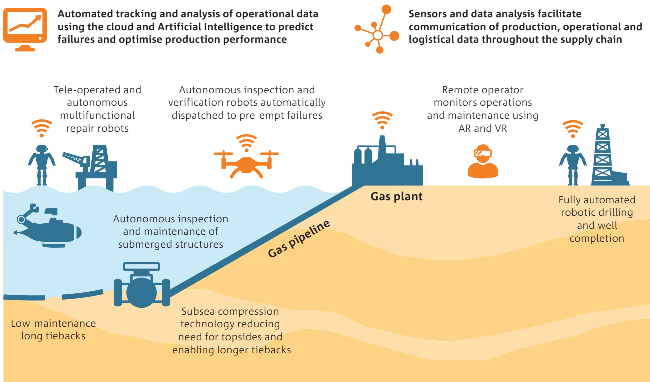
2 CSIRO (2017). Reservoir rejuvenation technology (R2T), [Online] Available from: https://www.csiro.au/en/Research/EF/Areas/Oil-gas-and-fuels/Onshore-gas/Microbes Accessed 17/07/2017

Digital operations and maintenance

Rapidly evolving digital technologies provide opportunities for safer and more efficient O&M of oil and gas assets.

The fourth industrial revolution is well underway, and the convergence of sensors, nanotechnology, robotics and AI will change the way every company conducts business – regardless of sector. The oil and gas industry is in a prime position to use advanced robotics to reduce risks to personnel and decrease costs, and AI – such as machine learning – to drive faster and better decision making. Together, these applications will help to transform operations and maintenance of Australian oil and gas.

Robotics and automation will play an increasingly important role in driving cost efficiencies. Importantly, these technologies will play a critical role in Australia, given the remoteness of its resources. Such technologies will help to remove employees from the field, improve safety and reduce labour costs. For example, robotic drilling and completions will become increasingly common. Unmanned Aerial Vehicles (UAVs) and Autonomous Underwater Vehicles (AUVs) will enable remote inspection and will eventually undertake maintenance interventions. Virtual reality (VR) and augmented reality (AR) will allow experts in central locations to guide workers in remote areas. In the subsea environment, digital production technologies and other low-maintenance processing equipment will enable long tie-backs of remote and stranded assets, reducing the need for traditional infrastructure.



Improved utilisation of data represents another large opportunity for the sector. For example, low-cost sensors and AI can transform the way plants are operated and contribute to a step change in performance. These technologies can enable more precise predictive maintenance, increase uptime, and even help to coordinate supply chains. However, very few operators have fully embraced the decision making power that improved data collection and analysis can provide.

Advanced environmental solutions and processes

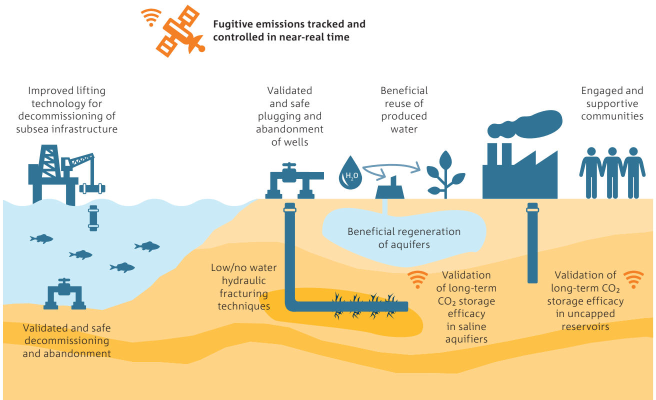
Developing technologies and processes that reduce the environmental and social impacts of field developments and processing plants may also provide financial benefits to the Australian oil and gas sector.

Facing several environmental and social challenges, Australia's oil and gas sector should continue to focus on coordinated, sector-wide investment in environmental technologies and processes to ensure best-practice management of oil and gas activities. Such investments could go some way towards addressing social concerns. For example, industry-wide activities, such as cost-effective baseline studies, or developing integrated approaches to spill preparation and response, will help build trust with stakeholders. (Such issues are also partly covered in Chapter 5 – *Improving the sector's public image*.) Moreover, pursuing the elimination of waste, addressing Greenhouse Gas (GHG) emissions, finding more sustainable uses for produced water, and addressing the sector's decommissioning liabilities may actually pay long-term dividends. For example, demonstrating leadership in areas like carbon capture and storage may position the industry for a new revenue stream: sequestration as a service for other industries.

Three examples of the application of new environmental technologies and processes are highlighted below.

Firstly, ensuring water quality and dealing with produced water more sustainably are factors vitally important for the Australian sector. Technologies that treat and recycle water and minimise salt by-products, particularly in relation to CSG, are needed to reduce the environmental impact of operations. In future shale gas developments, well stimulation techniques that require water will be a problem in Australia's dry areas. This will require well-fracturing techniques that use low-quality water, lower volumes of water, or no water at all.

Secondly, improved management of GHG emissions is an important element of demonstrating environmental stewardship. Fugitive GHG emissions such as methane pose a risk, especially in unconventional gas infrastructure, due to the high number of wells and long-distance pipelines. Techniques to measure and mitigate this risk are needed. Likewise, Carbon Capture, Utilisation and Storage (CCUS) technologies offer solutions for preventing CO_2 being released into the atmosphere. New techniques for



separating carbon from gas streams are needed to drive down the costs of capture. Proving the efficacy of novel geological formations for storage is another opportunity. For example, moving beyond the traditional 'capped' reservoir paradigm would open up Australia's geography to many more potential sequestration sites. Oil and gas businesses could provide geological and engineering sequestration services both here and abroad, allowing coal-fired power plants to cost-effectively meet obligations for future emissions regulations. However the economics of these opportunities will depend upon governments placing cost on carbon emissions.

The third potential application of advanced environmental solutions is in the efficient and environmentally-responsible decommissioning of infrastructure. New technologies and processes are required to enable flexible approaches to decommissioning, while ensuring optimal social, economic and environmental outcomes are achieved. Technologies which allow for more efficient well plugging and abandonment, infrastructure disassembly, transport and waste disposal will be important. More research is also needed to assess the environmental and social impacts of various decommissioning alternatives, from the complete removal of infrastructure to leaving it in place.

High-value diversification

Businesses should consider adapting their business models and diversifying into higher-value product and service offerings to gain competitive advantage and hedge against an uncertain future energy mix.

Although this report assumes continued robust demand for oil and gas, the energy mix of the future is not predictable. Technological and regulatory uncertainty looms large in this equation. Rapidly falling costs of grid-scale solar photovoltaics (PV), energy storage technology (including batteries) and electric vehicles are likely to influence the future energy market. Future regulations in the area of GHG management could stimulate this shift. While such matters are not the explicit focus of this report, they have the potential to decrease demand for oil and gas. For example, a rapid decarbonisation of the energy sector could completely undermine the ostensible role of gas as the bridge to a zero-carbon future – a potentially large risk for the Australian gas export industry. In the face of such uncertainty, the sector would be remiss to take a 'business as usual' approach. Instead, it must proactively pursue new products and services and devise new business models that diversify revenue streams. Four potential diversification approaches are highlighted.

Firstly, Australia's remoteness provides an opportunity to investigate off-grid/distributed energy systems, since Australia's remote resource developments and regional communities need clean and reliable energy. There are also opportunities to export these systems to energy-impoverished developing nations that lack grid infrastructure. A foray into this area is simply the integration of renewables into existing oil and gas operations. This takes advantage of the rapidly falling costs of renewables, especially solar PV, but includes wind and tidal, leveraging them to produce power for operations instead of burning valuable product.

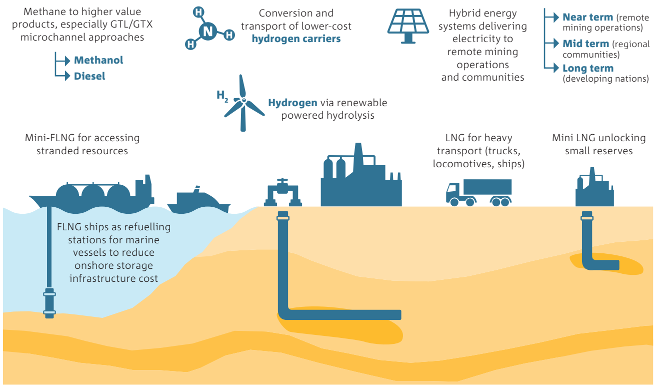
This activity would enable companies to build new capability in the area, and provide the opportunity to forge new partnerships. The more strategic second step is to develop fully-integrated hybrid energy systems. Such systems combine, for instance, a petroleum fuel source and renewable energy (typically solar) to provide consistent base and peak load for off-grid or micro-grid applications. Remote mines and regional communities could serve as domestic test beds for such technologies, (many of which, such as micro-grids, are already under development), with the ultimate goal of creating of large export market in developing nations.

The second example is the development of small stranded gas fields using small-scale Liquefied Natural Gas (LNG), and Floating LNG (FLNG). These approaches allow the monetisation of fields where typical infrastructure such as pipelines would be cost prohibitive. Stranded gas is a global challenge, and Australia has a number of small stranded fields. Offshore, cost-effective mini-FLNG (e.g. using repurposed ships) is particularly appealing since these systems can be used domestically, or be easily redeployed to new markets when needed.

Thirdly, there is significant potential for the use of LNG as a transport fuel (in domestic and international markets) for heavy road transport, locomotion and maritime shipping. Annual demand for such applications is estimated to exceed 100MTPA by 2030.[3] Increased regulatory scrutiny on ship emissions, in particular, opens up a potentially large market for LNG-powered vessels, and represents about one-third of the anticipated demand. To enter this market, advanced storage and bunkering technologies are needed.

3 MacDconald-Smith, A., (2016). *Shipping to become 'major new sector' for LNG: Shell, Australian Financial Review,* [Online] Available from: http://www.afr.com/business/energy/gas/shipping-to-become-major-new-sector-for-lng-shell-20161101-gsfw74 Accessed 2/06/2017

Fourthly, businesses must consider developing energy and chemical products that can command larger profit margins. The renewed interest in hydrogen in many parts of the world represents an appealing way to diversify and to help contribute to lowering the carbon intensity of the energy sector. Its appeal for end-users is that with few changes to equipment, clean burning hydrogen can be directly used in combustion applications including stationary power generation, as well as used directly in fuel cells for power and transport. While making hydrogen by reforming methane is one approach, economical methods of deriving it from less carbon-intensive routes are needed. For example, using solar PV to power water electrolysis can lessen the carbon footprint of hydrogen production. Furthermore, the logistics of hydrogen production need to be improved since hydrogen liquefaction is costly. Hydrogen carriers such as ammonia, that require less energy to transport, are needed. However, these alternatives will only be economically viable once affordable conversion technologies are commercialised to support the point-of-use hydrogen applications.



Value-added petroleum products, such as chemical intermediates and liquid fuels, represent another opportunity to diversify. Instead of traditional petrochemical refining routes, the sector chould leverage the next generation of gas-to-liquid (GTL) and gas-to-product (GTX) plants based on micro-channel technology. This technology is smaller and more nimble, and could be coupled with small gas field developments or appended to existing LNG plants. Due to their high efficiency, these technologies may provide more affordable routes than traditional refining to various liquid fuels and chemical intermediates, such as methanol and diesel. Their small scale and nimbleness means that the product mix could be quickly changed in response to market signals, thereby maximising profit margins at any given time.

Creating the right business ecosystem

In order to unlock these strategic opportunities, several changes in the business ecosystem may be required. Figure 5 summarises two types of changes: opportunity-specific and cross-cutting.

Opportunity-specific changes focus on (a) processes, standards and regulations, as well as (b) people, skills and collaboration.

The cross-cutting changes deal with broad themes that affect the sector and that may be hindering innovation and collaboration. Importantly, the sector needs to act on these points soon, or risk being overtaken by international competition.

FIGURE 5: SUMMARY OF BUSINESS ECOSYSTEM CHANGES

		STRATEGIC OPPORTUNITIES			
		ENHANCED BASIN PRODUCTIVITY	**DIGITAL OPERATIONS AND MAINTENANCE**	**ADVANCED ENVIRONMENTAL SOLUTIONS AND PROCESSES**	**HIGH-VALUE DIVERSIFICATION**
Opportunity-specific business ecosystem changes	**Processes, standards and regulations**	Support collection, publication and smart analytics on geoscience data from underexplored Australian regions.	Address interoperability and integration issues though development of common standards for IoT sensors and associated technology. Work to improve shared digital infrastructure to enable full use of the cloud, including cybersecurity.	Investigate and prepare for future decommissioning efforts and potential changes in carbon regulations. Support development of standards for fugitive emissions measurement. Development of CCS standards and protocols for novel formation types.	Assess need for incentives to develop appropriate market conditions to encourage technology development for value-adding technologies such as GTL or GTX. Support development of standards for technologies that create new markets for LNG.
	People, skills and collaboration	Improve exploration efficiency through multidisciplinary collaboration and skills development.	Foster skills development and collaboration to drive digital transformation and integration. Collaborate across value chain in terms of scheduling and work-loading to drive efficiencies in O&M	Strive to improve collaboration and planning of developments at the basin scale, including lifecycle planning for decommissioning activities, and sharing of common infrastructure.	Explore new business models, partnerships and technology investments. Upskill staff on diversification technologies.
Cross-cutting business ecosystem changes		**Pursuing diverse collaborations for innovation** – Companies must collaborate in new ways. Bold collaborations will be needed to build competencies new to the business and to crack new markets. **Reducing the cost of doing business** – Australia has a growing reputation for high costs, which may deter industry investment. Investments in digital infrastructure and reducing the costs of physical infrastructure through shared models may help. **Improving Australia's energy security** – Additional analysis of the supply side of the energy market from an energy security perspective is needed. This may develop support for opening up exploration and production of Australia's resource base, and decrease its reliance on imported liquid fuels. **Reducing regulatory uncertainty** – Common standards, streamlined approval processes, and stable greenhouse gas emissions policy will help to provide investment stability in the upstream oil and gas sector. **Improving the sector's public image** – Improving the sector's public image and social licence to operate – through strong and productive trust-based relationships with local communities, stakeholders and the Australian public – is critical to the future viability of the sector. Continued research around issues pertaining to social licence, improved integrated basin-wide planning, and strengthened science communication with the public may help.			

Contents

Introduction

1 Introduction

A VISION FOR AUSTRALIAN OIL AND GAS

A globally competitive, sustainable, collaborative and innovative sector that fully supports domestic energy needs and maintains a leadership position in energy export markets.

The Australian oil and gas industry is at a cross-roads. Recent successes, such as the billions of dollars of capital used to develop natural gas resources and infrastructure for LNG export, have made it an energy leader. Future expansions to existing LNG plant infrastructure can maximise the returns from these initial investments. However, the industry faces significant challenges, including increasing competition, rising costs, low commodity prices, changing social expectations, regulatory uncertainty and environmental concerns. This report is an effort to identify routes to navigating these turbulent waters and ensure the viability of the industry over the coming decades.

1.1 This report

This report outlines four major strategic opportunities, each representing a broad area that may hold the keys to unlocking Australian resources and reducing costs. The collective pursuit of these opportunities will be essential to achieving the stated vision for the sector.

The report is meant for public consumption. Anyone with a vested interest in the future of the Australian oil and gas sector should find it insightful, including:

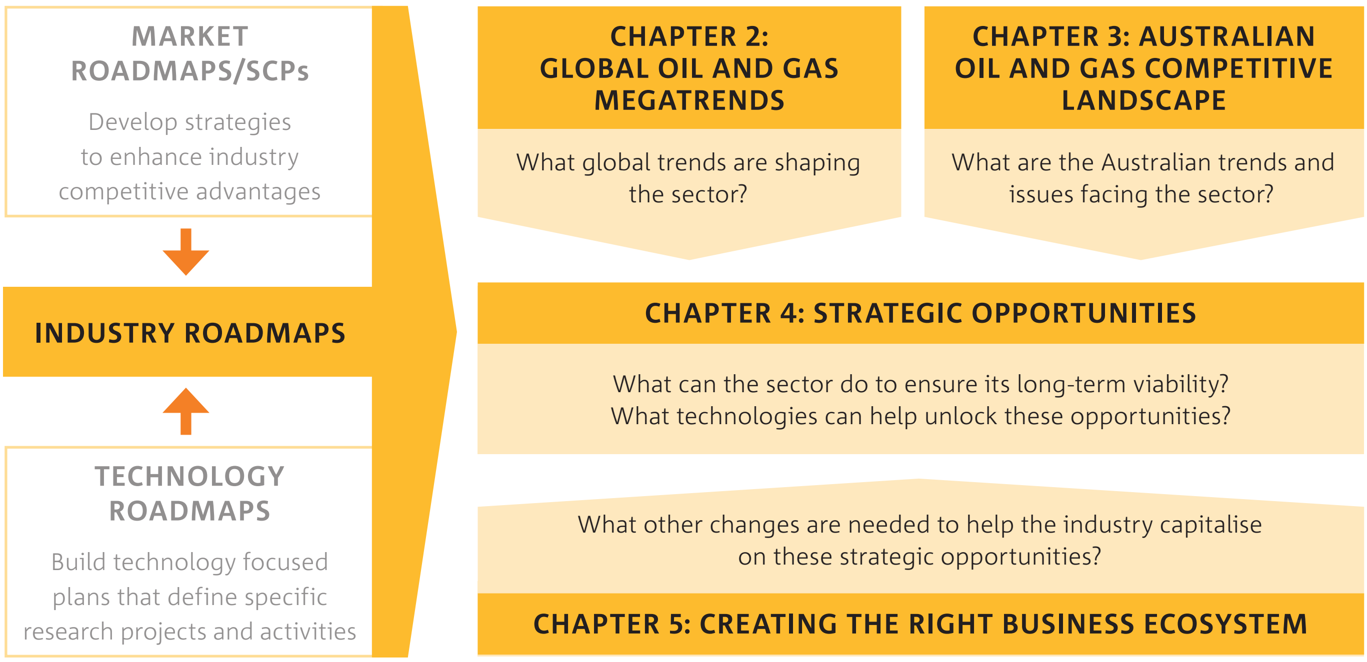
- **Explorers, operators and oilfield services firms** seeking guidance for, or validation of, technology investment planning efforts.
- **Executives and managers** wanting to look beyond annual planning cycles to consider longer-term strategic opportunities.
- **Research and Development (R&D) managers and academics** looking for a customer-focused lens into their research agendas.
- **Government stakeholders** wanting to identify drivers and targets for new policy, or remove impediments to action.
- **Industry observers** wanting to understand challenges facing the sector and possible pathways that will help to ensure a profitable future.

This report was informed by industry consultation. The perspective on the future of the sector, including major opportunities and challenges, was based on the opinions of executives and managers from oil and gas operators, service firms and Government agencies. Dozens of interviews with technical experts from Universities and CSIRO provide the report with a solid perspective on technology developments. In all, approximately 80 interviews were conducted to inform this report during the first half of 2017. Analysis of the content of these interviews, and additional desktop research helped to shape this report. It therefore represents a consensus view of the trajectory of the industry, developed by synthesising executive opinions, technical expertise and scientific research.

This document directly supports the Department of Industry, Innovation and Science (DIIS) Growth Centre Initiatives, specifically National Energy Resources Australia (NERA). It is an industry roadmap, meant to sit beneath high-level market roadmaps and Sector Competitiveness Plans (SCPs) that focus on market trends and national competitiveness, and above technology roadmaps that dictate specific innovation pathways. This report bridges the two (see Figure 6). It uses top-down trends and bottom-up technology insights to identify strategic business opportunities important to the long-term success of the sector.

The report directly supports each of the nine knowledge priority areas outlined in NERA's SCP, each of which cover major issues or knowledge gaps that need to be addressed to best position the sector for the future.[4] Appendix 1 provides a map of these relationships.

FIGURE 6: POSITION OF THE OIL AND GAS ROADMAP IN THE CONTEXT OF OTHER REPORTS AND STRUCTURE OF REPORT

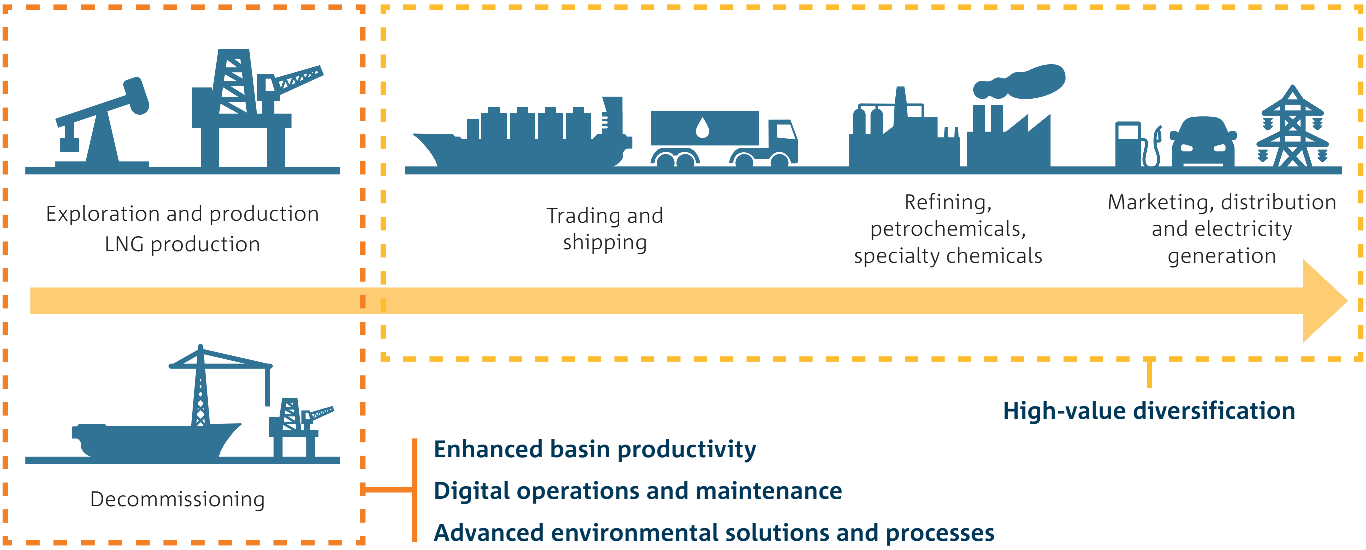


4 National Energy Resources Australia (2017). *Sector Competitiveness Plan*, Kensington.

1.2 Scope and assumptions

The majority of the report focuses on the upstream oil and gas industry of Australia, covering the exploration for oil or gas resources and their extraction and transport, LNG production and transport, as well as decommissioning. The report expands beyond this to cover chemicals, fuels and (to a limited extent) distributed electricity generation since these represent high-value diversification options for the sector (see Figure 7).

FIGURE 7: POSITIONING OF REPORT IN THE BROADER OIL AND GAS, PETROCHEMICAL AND ENERGY CONTEXT



Broadly, the ideas and opportunities discussed in this report are applicable to both conventional and unconventional resources. Basic definitions for conventional and unconventional are:

Conventional

These resource types were the traditional targets of the oil and gas industry. Such resources have structure, seal and reservoir components. Resources can be extracted using traditional methods of drilling down through a structured 'cap' rock and allowing petroleum to flow up the well. Conventional resources typically have moderate to high hydrocarbon mobility (permeability divided by fluid viscosity) and thus require relatively few wells for effective field development.

Unconventional

Unconventional resources like CSG and shale gas, despite their large volumes, were not traditionally considered viable targets for commercial oil and gas development. These resources may have no structure or seal elements, and are characterised by low to very low hydrocarbon mobility. As such they require high well counts and/or the application of non-traditional technologies (e.g. horizontal wells and hydraulic fracture stimulation) for effective field development.

This report does not cover uranium or coal, and thus departs from NERA's remit. This is a conscious decision to enable in-depth focus on the oil and gas sector. Furthermore, there are existing reports that directly address uranium and coal. For example, both rely on the mining equipment, technology and services (METS) sector which has its own industry growth centre and corresponding industry roadmap.[5]

The report does not go into great detail about renewable energy, although some forms are mentioned as potential diversification strategies for the sector. While there is little question as to the strong potential for renewable energy in Australia, these opportunities are well documented elsewhere, such as in the activities and reports of the Australian Renewable Energy Agency[6] (ARENA) and the recently released roadmap for low emissions technologies.[7]

1.2.1 MAJOR ASSUMPTIONS

This roadmap uses primary energy demand assumptions based largely on the International Energy Agency's (IEA) projections. As this report is not a scenario analysis, it uses these assumptions as a starting point, with the caveat that there is significant associated technological, regulatory, and social uncertainty in the future energy mix. Nonetheless, the IEA's projections show that both oil and gas have a role to play at least for the next 20 years, even taking into account projected increases in renewable generating capacity and energy efficiency gains (see Section 3.1 – *Global demand picture* for more information).

5 CSIRO Futures (2017). *Mining equipment, technology and services roadmap,* CSIRO, Canberra.
6 Australian Renewable Energy Agency (2016). *2015/16 ARENA Annual Report – Accelerating Australia's shift to renewable energy,* Canberra.
7 Campey, T., et al (2017). *Low Emissions Technology Roadmap.* CSIRO, Australia.

Global oil and gas megatrends

2 Global oil and gas megatrends

Australia's oil and gas sector is just one part of a global industry. As such, the Australian sector is heavily impacted by global trends and must ensure that future planning takes into account the broader implications of these trends.

CSIRO has identified five megatrends evident in the global oil and gas sector that will have significant impact on the development and success of the Australian sector over the next 20 years. These megatrends represent substantial shifts in social, economic, environmental, technological or geopolitical conditions that in combination may reshape the way the industry operates in the long term.[8] They occur at the confluence of many sub-trends; they are not mutually exclusive and the trends that influence one can also influence or contribute to another.

These megatrends were developed by applying CSIRO's Global Megatrends[9] to the oil and gas sector and refining the output with both research and business communities (see Figure 8).

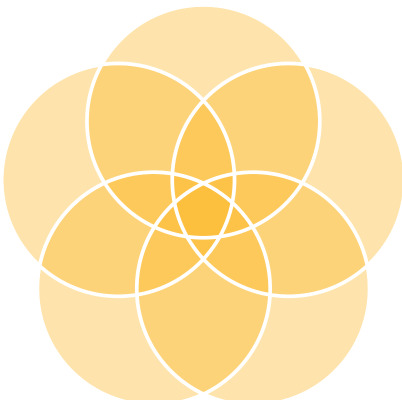
FIGURE 8: GLOBAL OIL AND GAS MEGATRENDS

ENERGY HUNGRY

Global primary energy demand is predicted to grow rapidly in the coming years, driven by a swelling population, increased urbanisation, and the rise of the middle class particularly in the developing world. However, uncertainties remain about the energy mix that will meet this demand.

CARBON CONSTRAINED

Rising concentrations of CO_2 and other greenhouse gases are believed to have increased average global temperatures and disrupted weather patterns. Government regulation, subsidies, and rapid cost reductions of renewables are all pointing to the fact that the decarbonisation of the energy sector has begun, which will impact the global oil and gas sector.



DIGITALLY ENABLED

Rapid improvements in digital technologies hold the promise to dramatically improve the way businesses operate. From embedded sensors to advanced analytics and AI, the industry is creating tools to improve how they create, deliver and capture value. The challenge for this sector is the integration of multiple technologies to capitalise on the next wave of the digital-enabled future.

SOCIALLY CONCERNED

Global citizens are increasingly adept at shifting public sentiment around issues important to them. Using such tools as social media, groups of people can create strong opposition to business interests, shape public discourse, and influence government policy. A key challenge for the oil and gas sector in this regard is earning and retaining social licence for its resource projects.

MORE COMPLEX AND COSTLY

Large conventional oil and gas resources are becoming harder to find and the sector is moving toward more complex resource plays. These have different cost profiles and many will require new technology to produce economically – particularly in a cost-constrained business environment.

8 Hajkowicz, S. (2015). *Global Megatrends – Seven Patterns of Change Shaping Our Future,* CSIRO Publishing, Canberra.
9 CSIRO Futures (2016). *Australia 2030: Navigating our uncertain future*, CSIRO, Canberra.

2.1 Energy hungry

Global primary energy demand is predicted to grow rapidly in the coming years, driven by a swelling population, increased urbanisation, and the rise of the middle class particularly in the developing world. However, uncertainties remain about the energy mix that will meet this demand.

The global population is expected to increase by 2.4 billion people by 2050.[10] During this same time even more people – an estimated 2.5 billion – are expected to move into urban areas, with 90% of them moving from rural areas in sub-Saharan Africa and Asia into burgeoning city centres.[11,12] Based on these trends, the International Energy Agency (IEA) predicts a 30% rise in global energy demand to 2040 as its main scenario, driven mostly by developing nations.[13] In OECD countries, energy demand is expected to remain flat due to a combination of energy efficiency and the increased integration of renewables.[14]

The global population will increase from 7.3 billion in 2015 to 9.7 billion in 2050.[15]

Global electricity demand is expected to increase by 65% between 2014 and 2040, at which point it will comprise 40% of total energy usage.[16] Most of this growth – approximately 85% – will come from non-OECD nations, resulting from an increased urbanisation of the new middle class.[17] Electricity demand in the developed world could come from, among other things, the expected rise in the number of electric vehicles.[18]

Although energy demand growth for electricity may be met in part by renewables and non-carbon energy forms, demand for oil and gas is expected to remain strong for some time to come. Oil will continue to have strong global demand into the future, driven mainly by the transport sector. Similarly, demand for gas is expected to remain strong, with power generation and industry being key to demand growth. It is predicted that 50% of the world's primary energy demand will be met by oil and gas by 2040.[19]

UNCERTAINTY IN SUPPLY AND DEMAND

Predicting future energy supply and demand is extremely difficult given continued geopolitical uncertainty and unforeseen technology improvements. Geopolitics will continue to have an impact on energy production and use, arising from situations including economic sanctions in energy-rich countries like Russia and Iran, and lack of long term political stability in many developing nations.[20] For example, oil supply onto the global market from the Middle East, particularly Libya and Iran, remains unpredictable in the face of continued unrest.[21]

10 United Nations (2015). *World population Prospects – Data Booklet*, [Online] Available from: https://esa.un.org/unpd/wpp/Publications/Files/WPP2015_DataBooklet.pdf Accessed 31/05/2017

11 International Energy Agency (n.d.). *Energy poverty,* [Online] Available from: http://www.iea.org/topics/energypoverty/ Accessed 31/05/2017

12 United Nations, Department of Economic and Social Affairs, Population Division (2014). *World Urbanization Prospects: The 2014 Revision*.

13 *The IEA's main scenario is the New Policies Scenario, incorporates existing energy policies as well as an assessment of the results likely to stem from the implementation of announced intentions, notably those in the climate pledges submitted for COP21.*

14 Exxon Mobil (2016). *The Outlook for energy: a view to 2040*, Exxon Mobile Corporation, Texas.

15 United Nations (2015). *World population Prospects – Data Booklet*, [Online] Available from: https://esa.un.org/unpd/wpp/Publications/Files/WPP2015_DataBooklet.pdf Accessed 31/05/2017

16 International Energy Agency (2016). *World Energy Outlook 2016,* OECD/IEA, Paris.

17 Exxon Mobil (2016). *The Outlook for energy: a view to 2040*, Exxon Mobile Corporation, Texas.

18 Sussams, L., Leaton, J., (2017). *Expect the Unexpected: the disruptive Power of low carbon technology,* Grantham Institute, London.

19 International Energy Agency (2016). *World Energy Outlook 2016,* OECD/IEA, Paris.

20 PwC (2016). *19th Annual Global CEO Survey: Oil and gas industry key findings*, [Online] Available from: https://www.pwc.com/gx/en/ceo-survey/2016/industry-focus/oil-and-gas-key-findings-global-ceo-survey-2016.pdf Accessed 31/05/2017

21 PwC (2016). *New Energy Futures Perspectives on the transformation of the oil and gas sector,* [Online] Available from: https://www.pwc.com/gx/en/oil-gas-energy/pdf/new-energy-futures.pdf Accessed 4/08/2017.

Technology development is one of the biggest variables, and has wide-ranging impacts. For example, the US recently unlocked shale oil resources that have long been considered uneconomical to produce, using several key technologies including horizontal well drilling, directional steering, hydraulic fracturing and advances in completion technologies.[22] The continued downward cost trajectory of renewables, including wind and solar, is driving rapid adoption and causing governments around the world to reassess incentive structures and grid infrastructure.[23] Energy efficiency gains and the electric vehicle revolution have many thinking that peak oil demand will occur in the not-too-distant future.[24] Exemplifying such trends are recent pronouncements by France, Britain and India about eliminating the sale of internal combustion engine-powered cars in the coming decades.[25]

Global electricity demand will increase by 65% between 2014 and 2040.[26]

HOW CAN THE SECTOR ADDRESS UNKNOWN DEMAND?

The world (and developing nations, in particular) needs more energy. Conveniently, an estimated 20% of the world's oil and gas reserves are located in Asia and Sub-Saharan Africa, where most urban growth will occur and from where increased energy demand will stem.[27] If developed properly, these reserves can help raise an estimated 1.2 billion people out of energy poverty by providing them with an affordable and reliable energy supply.[28] Doing so will be a priority of developing nations, in line with United Nations (UN) Sustainable Development Goals.[29]

Fossil fuels will likely remain an important part of the global energy mix for some time into the future, and will be critical in reducing energy poverty. However, concerns about climate change, the rapid pace of cost reductions for renewables and potential advances in energy storage, paint an uncertain future for companies that rely on fossil fuel business models.

22 Hardy, P., (2015). *Introduction and Overview: the Role of Shale Gas in Securing Our Energy Future,* Royal Society of Chemistry.

23 The Economist (2017). *Wind and solar power are disrupting electricity systems*, [Online] Available from: http://www.economist.com/news/leaders/21717371-thats-no-reason-governments-stop-supporting-them-wind-and-solar-power-are-disrupting Accessed 1/06/2017.

24 Cook, L., Cherney, E., (2017). *Get Ready for Peak Oil Demand*, Wall Street Journal, [Online] Available from: https://www.wsj.com/articles/get-ready-for-peak-oil-demand-1495419061 Accessed 15/08/2017

25 International Energy Agency (2016). *World Energy Outlook 2016,* OECD/IEA, Paris.

26 Petroff, A. (2017). *These countries want to ditch gas and diesel cars*, CNNMoney, [Online] Available from: http://money.cnn.com/2017/07/26/autos/countries-that-are-banning-gas-cars-for-electric/index.html Accessed 15/08/2017

27 Narich, C., et al (2014). *Creating the 21st Century Energy System: The role of the oil and gas industry in tackling energy poverty*, Accenture.

28 International Energy Agency (n.d.). *Energy poverty,* [Online] Available from: http://www.iea.org/topics/energypoverty/ Accessed 31/05/2017

29 United Nations (n.d.). *Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all,* [Online] Available from: http://www.un.org/sustainabledevelopment/energy/ Accessed 01/06/2017

2.2 Carbon constrained

Rising concentrations of CO_2 and other greenhouse gases are believed to have increased average global temperatures and disrupted weather patterns. Government regulation, subsidies, and rapid cost reductions of renewables are all pointing to the fact that the decarbonisation of the energy sector has begun, which will impact the global oil and gas sector.

The global energy sector accounts for around two-thirds of global greenhouse gas emissions.[30]

The impacts of rising global temperatures range from altered rainfall patterns, rising sea levels, and increased frequency and severity of severe weather like cyclones, flooding and droughts. These impacts will threaten energy and food security, and therefore the social and economic wellbeing of citizens.[31] In recognition of this growing threat, the international community acted. The Paris Agreement, which aims to reduce the threat of climate change by keeping a global temperature rise this century to below 2°C, was adopted by over 190 countries at the 21st Conference of the Parties United Nations Framework Convention on Climate Change (COP21) in 2015.[32]

Accomplishing this goal will require limiting CO_2 and other GHG emissions, while simultaneously meeting rapid energy demand growth. This will require fundamental changes to the way the world produces and consumes energy, and investments in less carbon-intensive energy production and energy efficiency technologies. Such innovations will be critical in enabling populations to continue to have high living standards while at the same time meeting climate goals.[33]

30 International Energy Agency (2016). *Energy, climate change and Environment*, OECD/IEA, Paris.
31 Wheeler, T., von Braun J., (2013). *Climate Change Impacts on Global Food Security,* Science, Vol. 341, Issue 6145, pp. 508–513.
32 United Nations (n.d.). *Climate change affects everyone,* [Online] Available from: http://www.un.org/sustainabledevelopment/climatechange/ Accessed 1/06/2017
33 International Energy Agency (2016). *Energy technology perspectives 2016*, OECD/IEA, Paris.

MOVING TOWARD GREENER FOSSIL FUELS

One way to reduce the amount of CO_2 going into the atmosphere is by reducing the carbon intensity of the energy supply mix.[34] This trend is already well underway through the use of fuel switching, particularly in fuel used for electricity generation. Some aggressive estimates suggest peak demand for coal will occur sometime after 2020, giving way to less carbon-intense fuels like natural gas.[35,36] Gas is one of the least carbon-intensive fossil fuels[37] and as such, the IEA estimates a nearly 50% increase in demand for natural gas through to 2040.[38]

Although the energy mix in 2040 is expected to remain dominated by fossil fuels, technologies can assist in reducing the impact of CO_2 emissions. Importantly, CCS will be needed to meet global climate goals.[39] There is also an opportunity to co-fire biofuels or biogas to lower emissions from coal and gas-fired power plants, and further decrease the carbon intensity of the energy supply.[40]

The biggest contribution to CO_2 reduction will come from integration of renewables and adoption of energy efficiency technology developments, both of which will reduce fossil fuel demand. Furthermore, development of these technologies represents a significant reallocation of capital from recent years where fossil fuel investment dominated.

Australia's target is to reduce emissions to 26%–28% on 2005 levels by 2030.[41]

WHAT ARE THE IMPACTS OF AN UNCERTAIN FUTURE ENERGY MIX?

Although a lower-carbon future is coming into focus, there is still uncertainty around the political instruments that will deliver on it. Lack of clarity around global climate policy increases the risks of investing in new resource development projects and in building new electricity generating capacity.

Significant uncertainty surrounds the largest CO_2 emitters, China and USA, and how these countries will meet the Paris Agreement. It is not known to what extent market-based mechanisms, like a price on carbon, will be employed, or whether prescriptive regulations will be used instead. These unforeseen outcomes will likely change the economics of new resource development projects.

Despite an unclear and non-uniform policy environment, the near-unanimous agreement to limit CO_2 emissions should prompt oil and gas companies, working with the power generation and transportation sectors, to continue to find ways to reduce their emissions through the mitigation of fossil fuel emissions and by developing new energy technologies. In terms of proving new reserves and investing in new developments, this may mean shifting focus toward natural gas or pursuing low and non-carbon energy supply options, including renewables.

34 International Energy Agency (2016). *Energy, climate change and Environment*, OECD/IEA, Paris.
35 Exxon Mobil (2016). *The Outlook for energy: a view to 2040*, Exxon Mobile Corporation, Texas.
36 Sussams, L., Leaton, J., (2017). *Expect the Unexpected: the disruptive Power of low carbon technology,* Grantham Institute, London.
37 International Energy Agency (2016). *Energy, climate change and Environment*, OECD/IEA, Paris.
38 International Energy Agency (2016). *World Energy Outlook 2016, pg. 169,* OECD/IEA, Paris.
39 International Energy Agency (2016). *Energy, climate change and Environment*, OECD/IEA, Paris.
40 International Energy Agency (2016). *Energy, climate change and Environment*, OECD/IEA, Paris.
41 Australian Government (2015). *Australia's 2030 climate change target,* [Online] Available from: http://www.environment.gov.au/system/files/resources/c42c11a8-4df7-4d4f-bf92-4f14735c9baa/files/factsheet-australias-2030-climate-change-target.pdf Accessed 1/06/2017

2.3 Socially concerned

Global citizens are increasingly adept at shifting public sentiment around issues important to them. Using such tools as social media, groups of people can create strong opposition to business interests, shape public discourse, and influence government policy. A key challenge for the oil and gas sector in this regard is earning and retaining social licence for its resource projects.

The ability (or failure) to ensure that health, environment, ecological, and economic interests of the populace are well served has been shown to have an impact on the business interests of companies across a range of industries, from pulp and paper to genetically modified food.[42] Social licence to operate has been a critical issue for the oil and gas sector for many decades. Presently, stakeholder discontent can be amplified more quickly than ever before, creating new issues and risks that must be dealt with in extremely short time frames.[43]

On average, 6,000 'tweets' are sent every second globally, each having the potential to reach millions of people and dramatically shape perceptions of industry activity.[44]

Social media platforms are tailored to the interests of consumers, and often reinforce and support an individual's existing view on issues. These platforms, with their ability to disseminate information quickly, have allowed stakeholder groups to become better organised and more efficient at changing public opinion and creating conditions for policy changes.[45] Activist investors are also on the rise, and can have the power to influence how business is conducted. Australia is expected to see an increase in this type of activity in the coming years.[46]

FOR THE OIL AND GAS SECTOR, THERE IS SIGNIFICANT RISK ATTACHED TO NOT EARNING THE SOCIAL LICENCE TO OPERATE.

The global oil and gas sector faces numerous community concerns associated with resource extraction, ranging from climate change and air pollution to water quality and health impacts. If these concerns are not addressed, deteriorating community relationships may prevent projects from proceeding.[47] The ability to gain and maintain social licence to operate is based, in part, on proving that the resource projects will positively impact on the community, and on addressing concerns about potential environmental damage.[48]

Not building strong social licence can have detrimental impacts on energy supply. An example is the increased scrutiny on onshore development projects in Australia. In 2016, the Victorian Government announced a permanent ban on hydraulic fracturing, exploration and development of coal seam gas.[49] In the same year, the Northern Territory Government implemented a moratorium on hydraulic fracturing of unconventional gas reservoirs subject to an independent scientific inquiry.[50] Such bans may restrict local supply in areas of heavy demand.

WHAT SHOULD THE INDUSTRY DO TO OVERCOME THESE CHALLENGES?

These challenges provide unique opportunities to develop better approaches to managing the social components of resource developments, and provide impetus to invest in outreach and education. However, they should also catalyse a new wave of technology aimed at reducing or eliminating environmental and health impacts altogether.

42 Library of Congress (2015). *Restrictions on Genetically Modified Organisms: England and Wales,* [Online] Available from: https://www.loc.gov/law/help/restrictions-on-gmos/england-wales.php Accessed 1/06/2017
43 Glindemann, R. (2017). *Galvanising the opposition: social media campaigns and the new risks for the oil and gas industry,* The APPEA Journal 2017, 57, 448–451.
44 Glindemann, R. (2017). *Galvanising the opposition: social media campaigns and the new risks for the oil and gas industry,* The APPEA Journal 2017, 57, 448–451.
45 Boulianne, S. (2015). *Social media use and participation: A meta-analysis of current research*. Information, Communication & Society, Vol.18, Iss.5.
46 Activist Insight (2016). *Shareholder activism in Australia*.
47 World Economic Forum (2016). *Future of Oil & Gas – Executive Summary,* Geneva.
48 Walton, A., McCrea, R., and Leonard, R. (2016). *The 2016 CSIRO Community wellbeing and responding to change survey: Western Downs region, Queensland – Changes between 2014 and 2016 in the Context of Coal Seam Gas Development,* CSIRO, Australia
49 Premier of Victoria (2016). *Victoria bans fracking to protect farmers,* [Online] Available from: http://www.premier.vic.gov.au/victoria-bans-fracking-to-protect-farmers/ Accessed 1/06/2017
50 Northern Territory Government (2016). *Fracking Inquiry Consultation*, [Online] Available from: https://nt.gov.au/news/2016/september/fracking-inquiry Accessed 1/06/2017

2.4 More complex and costly

Large conventional oil and gas resources are becoming harder to find and the sector is moving toward more complex resource plays. These have different cost profiles and many will require new technology to produce economically – particularly in a cost-constrained business environment.

Oil and gas projects are becoming more complex due to the need to explore for new resources in more hostile environments. Companies are increasingly pursuing opportunities in unconventional resources such as shale oil, shale gas and coal seam gas, and conventional 'frontier' plays like the Arctic and ultra-deep water. Often these resources are characterised by more challenging operating conditions and complexity of exploration and production that must be overcome to successfully locate these reserves and produce them economically.[51]

In 2015, global spending on exploration fell by approximately 30%.[52]

LOW PRICES

It is possible that the era of '100 dollar oil' will never return. The convergence of increased global supply of oil and gas, together with slowing growth in some markets, has created an oversupply, resulting in suppressed prices.[53] Even though the price of oil has improved from its near record lows in 2016, oil prices have the potential to remain suppressed for many years because of the structural market changes stemming from the US shale revolution. Many now consider the US to be the marginal-cost producer, able to quickly ramp up production to capitalise on higher oil prices, and just as quickly retreating to dormancy when the oil price drops.[54]

These market dynamics have resulted in decreased exploration activity globally. In response to supressed prices, many have prioritised cuts in exploration spending in order to sustain cash flow, which consequently has resulted in a 60-year low in discoveries.[55] Similarly, a slowdown in exploration activity has occurred in Australia.[56] This slowdown in exploration activity may jeopardise the future pipeline of greenfield developments. Low prices may also accelerate the pace of asset decommissioning as some existing resource plays become increasingly uneconomic.

HOW WILL THE SECTOR COMPETE IN A COST-CONSTRAINED ENVIRONMENT?

New and improved technologies are required to locate and produce new, more complex fields and to drive down the cost of these activities.[57] New reservoir discovery is increasingly difficult, with most basins already explored and often only small discoveries made, usually involving more complex geologies. This calls for new and novel means to efficiently explore and locate new resources, including low-cost autonomous solutions.

New cost-efficient production technologies are required in order to enable margins to be made on the back of weak market prices, especially for unconventional plays. As these enabling technologies are developed, production of gas and oil resources will become more economic.

Existing fields will increasingly become targets for operational cost reductions driven by the need to eliminate inefficiencies that were previously hidden by high oil prices.[58] Additional investments in innovation will be focused on addressing declining production profiles and expanding the life of existing assets.[59]

Discoveries of new oil and gas deposits dropped to a 60-year low in 2015.[60]

51 International Energy Agency (2016). *World Energy Investment 2016,* OECD/IEA, Paris.
52 International Energy Agency (2016). *World Energy Investment 2016,* OECD/IEA, Paris.
53 International Energy Agency (2013). *Resources to Reserves 2013*, OECD/IEA, Paris.
54 EY (2017). *From volume to value: the transformation of National Oil Companies*.
55 The Economist (2015). *The oil industry After OPEC, American shale firms are now the oil market's swing producers,* [Online] Available from: http://www.economist.com/news/business/21651267-american-shale-firms-are-now-oil-markets-swing-producers-after-opec Accessed 23/08/2017
56 International Energy Agency (2016). *World Energy Investment 2016,* OECD/IEA, Paris.
57 National Energy Resources Australia (2017). *Sector Competitiveness Plan*, Kensington.
58 World Economic Forum (2017). *Digital Transformation Initiative: Oil and Gas Industry*, Geneva.
59 EY (2015). *Driving operational performance in oil and gas*.
60 International Energy Agency (2016). *World Energy Outlook 2016,* OECD/IEA, Paris.

2.5 Digitally enabled

Rapid improvements in digital technologies hold the promise to dramatically improve the way businesses operate. From embedded sensors to advanced analytics and AI, the industry is creating tools to improve how they create, deliver and capture value. The challenge for this sector is the integration of multiple technologies to capitalise on the next wave of the digital-enabled future.

The oil and gas sector has a long history of digital technology uptake, starting as early as the 1980s, primarily to deal with vast quantities of subsurface characterisation data.[61] This trend continued through the 1990s in a wave of digital oilfield efforts focused, in part, on increasing connectivity to improve communication and collaboration between sites. For example, advancements in sensors, communication, computation and analytics has progressed to the point that drill-line data can be utilised to inform drilling operations in near-real time.[62]

Globally, digitalisation has the potential to create around $1 trillion of value for oil and gas firms.[63]

ROOM FOR IMPROVEMENT

Many digital initiatives within the sector have been conservative and incremental. The sector has not yet fully leveraged the benefits of AI, machine learning and distributed sensor networks, and thus these technologies are having a limited impact on existing operating and business models.[64]

Analytics can help oil and gas companies improve production by 6% to 8%.[65]

Increasingly large amounts of data will be generated through installed sensors across operations, producing several orders of magnitude more information than that available just a few years ago. However, only a small fraction of generated data is being used for decision making. Added-value can be gained by using this data to derive, via advanced analytics, insights that will directly improve decision making across the value chain, from exploration to production and operations, thus helping to reduce costs. Fully capitalising on digital technologies has the potential to create an estimated $1 trillion of value for oil and gas companies globally (2016–2025).[66]

Modern offshore drilling platforms have about 80,000 sensors.[67]

HOW CAN THE SECTOR MAKE EVEN BETTER USE OF DIGITAL TECHNOLOGIES?

The digital transformation of the sector will be further enabled through the convergence of numerous digital technologies, including operational technology, information technology, and the Industrial Internet of Things – the integrated digital connection of people, equipment and processes. Data generated from these technologies will be analysed by various AI applications, which will transform how vast data stores are analysed and actionable insights derived. In gas field developments and operations, for example, the collection and analysis of geologic, microseismic, operational and performance data can improve the process of drilling and connecting wells by reducing lag time, and optimising drilling parameters, well spacing and completion techniques.[68]

Taken together, digitally-enabled operations will provide meaningful outcomes for the sector. Remotely controlled operations and automation are key areas of interest, as is the increasing ability to integrate data to improve operational and strategic decision making.

61 World Economic Forum (2017). *World Economic Forum Digital Transformation Initiative in collaboration with Accenture, Oil and Gas Industry*, *Executive Summary,* Geneva.
62 BP (n.d.). *Digital Technology*, [Online] Available from: http://www.bp.com/en/global/corporate/technology/technology-now/digital-technology.html Accessed 1/06/2017
63 World Economic Forum (2017). *Digital Transformation Initiative: Oil and Gas Industry*, Geneva.
64 World Economic Forum (2017). *Digital Transformation Initiative: Oil and Gas Industry*, Geneva.
65 Bertocco, R., Padmanabhan, V., (2014). *Big Data analytics in oil and gas,* Bain and Company.
66 World Economic Forum (2017). *Digital Transformation Initiative: Oil and Gas Industry*, Geneva.
67 World Economic Forum (2017). *Digital Transformation Initiative: Oil and Gas Industry*, Geneva.
68 Bertocco, R., Padmanabhan, V., (2014). *Big Data analytics in oil and gas,* Bain and Company.

Australian oil and gas

competitive landscape

3 Australian oil and gas competitive landscape

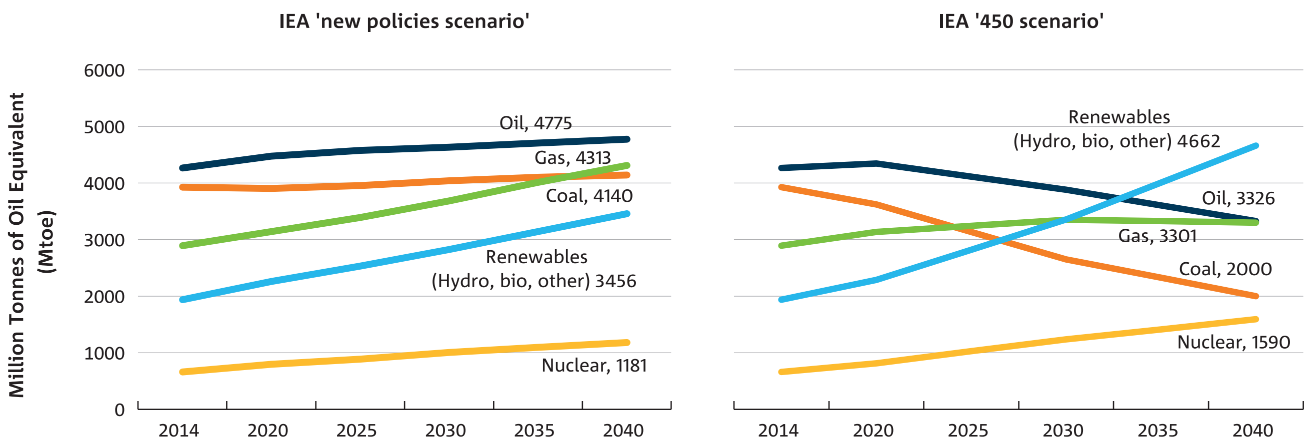
3.1 Global demand picture

Global primary energy demand is rapidly increasing and will require an estimated US$44 trillion of investment in new infrastructure by 2040.[69] During this time, oil and gas will continue to play a role in the world's future energy mix according to projections, though the size of its role will vary depending on the pace of technological change and the regulatory actions taken to combat climate change.

Healthy demand for oil and gas is demonstrated by the IEA's 'New Policies Scenario', which reflects current measures and declared policy intentions aimed at limiting global warming.[70] This scenario projects a primary energy demand increase of 30% by 2040. Combined oil and gas would comprise approximately 50% of the energy mix – nearly equal to today's proportion. However, the relative contribution of each would shift, with oil demand increasing by 12% and gas demand by 50% over 2014 levels.

More tepid demand for oil and gas is demonstrated by the IEA's '450 scenario'. This scenario assumes more steps are taken to limit CO_2 concentrations to 450ppm, coinciding with a 50% probability of limiting global warming to 2°C. In this scenario, renewables (e.g. hydropower, bioenergy, wind, geothermal and solar PV) will increase dramatically, contributing over 30% of the primary energy mix by 2040. Even though oil and gas would together comprise 45% of this mix, higher efficiencies and more electrification in the energy sector mean that total energy demand will only increase 10% over 2014 levels. Thus, oil demand would actually decline 22% from 2014 levels and gas would increase a meagre 14% (see Figure 9).[71]

FIGURE 9: WORLD TOTAL PRIMARY ENERGY DEMAND (MTOE) BY FUEL, 2014 THROUGH TO 2040



Source: IEA, World Energy Outlook 2016

69 International Energy Agency (2016). *World Energy Outlook 2016, p.22,* OECD/IEA, Paris.
70 International Energy Agency (2016). *World Energy Outlook 2016, p.31,* OECD/IEA, Paris.
71 International Energy Agency (2016). *World Energy Outlook 2016, p.65,* OECD/IEA, Paris.

3.2 Australian oil and gas

Australia is the OECD's third largest energy producer behind Canada and the United States, and is a leading energy exporter.[72] Australia's total energy exports[73] in 2015–16 amounted to approximately $59.8 billion, with oil and gas accounting for 40%, and coal accounting for 57%.[74] Domestically, oil and gas extraction contributes around 2% of GDP (more than $31 billion 2015–16).[75] Although it currently employs an estimated 29,000 people,[76] the sector's GDP impact is on par with Australia's agricultural sector, which employs 10 times that number.[77]

Natural gas is playing an increasingly important role in Australia's export mix, with LNG accounting for approximately two-thirds of Australia's oil and gas exports in dollar terms in 2015–16. LNG exports have more than doubled in value since 2009–10.[78] Asian trading partners account for much of this increased demand. By 2020, a large portion of Japan's and China's LNG demand will be met by Australian exports.[79] Over half of all Australian-produced gas destined for export markets,[80] the country will compete with the world's leading exporters of LNG in the years past 2020, fuelled by Queensland's LNG projects, and those in Western Australia and the Northern Territory.[81]

Domestic gas consumption by gas-powered electricity generation is forecasted to rise over the next decade, in order to support the nation's climate commitments by replacing coal generation and complementing the growth in renewables. The ability to meet this domestic demand through Australian resources is important, but some are forecasting supply challenges through to the mid-2020s.[82]

At the same time, Australia remains a net importer of oil with a heavy reliance on imported liquid fuels, especially refined petroleum products. The reliance on imported refined fuels introduces energy security risks for Australia.

3.2.1 INDUSTRY STRUCTURE

Geographically, Australia's upstream oil and gas industry has distinct offshore and onshore segments. Australia's onshore operations are widely distributed in remote areas, with conventional operations in Western Australia, the Northern Territory, South Australia and Queensland and unconventional operations mostly concentrated in Queensland's Coal Seam Gas (CSG) fields and the smaller shale resources in South Australia. Offshore operations are predominantly located off of Western Australia, the Northern Territory and in the Bass Strait off of Victoria.

As part of a highly globalised industry, Australia's oil and gas sector relies heavily on many large international companies. These companies have a global reach, financial backing and extensive expertise which is leveraged by Australia's domestic oil and gas projects. Similarly, the technology used in Australian projects comes from a global network of service firms that generate a large proportion of the industry's innovations.[83] In well-known hubs like Houston (US) and Aberdeen (UK), service companies develop technology and deploy it to oil and gas fields around the globe.

72 International Energy Agency (2016). *World Energy Balances,* OECD/IEA, Paris.

73 *Includes crude oil, LPG, bunker fuel (international ships and aircraft stores.), other petroleum products, LNG, metallurgical coal, thermal coal, uranium (estimate only), and other energy (excludes coke and semi-coke of coal, of lignite or of peat from June 2016).*

74 Office of the Chief Economist (2017). *Resources and Energy Quarterly – March 2017 Historic data,* Table 2, [Online] Available from: https://industry.gov.au/Office-of-the-Chief-Economist/Publications/Pages/Resources-and-energy-quarterly.aspx Accessed: 27/03/2017

75 Office of the Chief Economist (2017). *Resources and Energy Quarterly – March 2017 Historic data,* Table 9, [Online] Available from: https://industry.gov.au/Office-of-the-Chief-Economist/Publications/Pages/Resources-and-energy-quarterly.aspx Accessed: 27/03/2017

76 Office of the Chief Economist (2017). *Resources and Energy Quarterly – March 2017 Historic data,* Table 10, [Online] Available from: https://industry.gov.au/Office-of-the-Chief-Economist/Publications/Pages/Resources-and-energy-quarterly.aspx Accessed: 27/03/2017

77 PwC & APPEA (2014). *Value-adding: Australian Oil and Gas Industry*.

78 Office of the Chief Economist (2017). *Resources and Energy Quarterly – March 2017 Historic data,* Table 2, [Online] Available from: https://industry.gov.au/Office-of-the-Chief-Economist/Publications/Pages/Resources-and-energy-quarterly.aspx Accessed: 27/03/2017

79 The Australian Trade Commission (2016). *Investment opportunities in Australian oil and gas*.

80 National Energy Resources Australia (2017). *Sector Competitiveness Plan*, Kensington.

81 Australian Energy Market Operator Limited (2016). *National gas forecasting report for eastern and south-eastern Australia*.

82 Australian Energy Market Operator Limited (2016). *National gas forecasting report for eastern and south-eastern Australia*.

83 Perrons, R.K., (2014). *How innovation and R&D happens in the upstream oil & gas industry: Insights from a global survey*. J. Pet. Sci. Eng. 124, p301–312.

AUSTRALIA'S OIL AND GAS SECTOR 2015–16[84]

$24.3 billion
Oil and gas exports

-0.81%
5 year CAGR

$24.7 billion
Oil and gas imports

	LNG	Crude oil	LPG, petroleum products and other
EXPORTS	$16.6 billion	$5.4 billion	$2.3 billion
IMPORTS	n/a	$7.9 billion	$16.8 billion

29,000
Employment

1,380[85]
Businesses

2% GDP
contribution

$31 billion in 2016
$70 billion by 2020[86]

84 Office of the Chief Economist (2017). *Resources and Energy Quarterly - March 2017 Historic data*, Table 2.2, Table 4, Table 9, Table 10, [Online] Available from: https://industry.gov.au/Office-of-the-Chief-Economist/Publications/Pages/Resources-and-energy-quarterly.aspx Accessed: 27/03/2017

85 ABS (2017). 8165.0 *Counts of Australian Businesses, including Entries and Exits, Jun 2012 to Jun 2016* – 'Businesses by Main State by Industry Class by Employment Size Ranges, June 2016', Canberra. Includes businesses engaged in oil / gas extraction, petroleum exploration, petroleum refining and petroleum fuel manufacturing, gas supply and pipeline transport.

86 APPEA (2017). *Submission to the Review of Commonwealth Petroleum Resource Taxes*, [Online] Available from: https://www.appea.com.au/wp-content/uploads/2017/03/APPEA-PRRT-Submission_10-Feb-2017.pdf Accessed 1/06/2017.

3.3 Australia's comparative advantages and disadvantages

Australia has strong oil and gas sector, and a long history of oil and gas exploration and production. From the Bass Strait and the North West Shelf, to the CSG fields of Queensland, Australia has developed its unique conventional and unconventional resources and in doing so, has developed several comparative advantages.

However, it also faces many challenges and future threats that will test the growth of the sector. A number of Australia's current challenges, including project costs and regulatory stability, were once recognised as advantages. This section highlights the fact that advantages can be easily lost. Figure 10 illustrates a number of Australia's advantages and challenges which are further detailed below.

FIGURE 10: AUSTRALIAN OIL AND GAS ADVANTAGES AND CHALLENGES

Advantages

- **Strong position in LNG** – Australia is a leading LNG exporter with the significant potential to cultivate a world-leading operations and maintenance (O&M) capability.
- **Considerable conventional resources** – Considerable proven and contingent gas reserves appear ready to meet future market demand, if they can be developed economically.
- **Large untapped unconventional prospective and contingent resources** – Australia may be well placed to meet future demand using CSG and Shale gas, if these can be proven and produced economically.
- **Proximity to Asian markets** – Australia is in a prime position to supply the increasing demand for oil and gas from developing Asian nations.
- **Leading research institutions and capability** – Australia is home to many sector-focused research groups with scientific outputs that are among the best in the world.

Challenges

- **High-cost environment** – Australia's high costs of exploration, development and production of remote prospective resources may dissuade future capital investment.
- **Regulatory uncertainty** – Bans and moratoria on unconventional gas, unclear greenhouse gas emissions policy, and LNG export restrictions all create investment uncertainty.
- **Establishing Social Licence to Operate** – Building trust between stakeholders, companies and government is critical to opening up the exploration and production of Australia's vast oil and gas wealth.
- **Low prices, commoditisation, and declining exploration** – Exploration for new oil and gas resources in Australia has dropped, potentially affecting the sector's ability to meet future demand.
- **Domestic innovation and commercialisation challenges** – Limited commercialisation of research activities and very few new products being developed by Australian oil and gas businesses mean that the sector is reliant upon technology from overseas.
- **Low levels of collaboration** – Collaborations are important for innovation; however, not enough of this specific type of collaboration occurs in Australia's oil and gas sector.

Advantages can erode without sustained investment →

← Challenges can become advantages if they are prioritised and addressed

3.3.1 ADVANTAGES

Strong position of Australian LNG

More than $200 billion has been invested in Australian LNG projects in the past decade,[87] pushing Australia into the top tier of LNG-exporters that includes Qatar, and increasingly the US.[88] This investment has catalysed the development of new expertise in areas such as logistics planning, international trade, and LNG production. This expertise affords operators in Australia a unique opportunity to become world-leaders in LNG operations and maintenance, helping to solve industry-wide challenges in the short to mid-term. In the longer term, these capabilities can help Australia to play a lead role in the development of new LNG capacity.

Significant conventional resources

Australia also has considerable conventional reserves. Natural gas proven reserves plus contingent resources were measured at 169tcf at the end of 2014 – nearly twice that of CSG and shale gas. This represents a large portion of Australia's total prospective conventional gas resources of 214tcf.

Nearly 9.4 billion barrels (bbl) of crude oil and Natural Gas Liquids (NGL) have been produced from nine major basins across Australia, with about 5.4 billion bbl remaining. Prospective petroleum estimates are anticipated to be even higher. For example, prospective NGL alone amounts to nearly 7 billion bbl, and there is thought to be 14.5 billion bbl of crude yet to discovered. Australia's total proven oil reserves rank 25th globally, an estimated 0.2% of the global reserves.[89]

Large untapped unconventional prospective and contingent resources

Unconventional oil and gas has transformed the global oil and gas market. By 2040, unconventional resources are expected to meet significant portions of the world's energy demand.[90]

Australia can capitalise on these trends by developing its potentially large unconventional prospective resources. However, the extent of these resources will remain uncertain until they are more extensively appraised with exploration and test wells – a costly endeavour. Currently, proven unconventional proven reserves plus contingent resources are relatively small, with CSG at 75tcf and shale gas at 11tcf.[91] Prospective estimates are much higher. Australia may possess 6% of the world's CSG resources (235tcf), alongside the world's seventh largest shale gas resource (437tcf) and sixth largest shale oil resource (18 billion barrels).[92]

Proximity to Asian markets

Australia's location gives it a key advantage over many other oil and gas jurisdictions. Australia is perfectly situated to export oil and gas to Asian markets. As the majority of energy demand growth to 2040 is projected to come from developing nations,[93] Australia is well positioned to deliver to the market, with lower transportation costs than other global competitors.

87 Ellis, M., Heyning, C., Legrand, O., (2013). *Extending the LNG boom: Improving Australian LNG productivity and competitiveness*, McKinsey&Company.

88 International Energy Agency (2017). IEA sees global gas demand rising to 2022 as US drives market transformation, [Online] Available from: https://www.iea.org/newsroom/news/2017/july/iea-sees-global-gas-demand-rising-to-2022-as-us-drives-market-transformation.html Accessed 23/08/2017

89 Geoscience Australia (2016). *Australian Energy Resources Assessments (AERA) Interim report, see table: 2016_AERA_data_tables-Oil_chapter.xlsx* [Online] Available from: http://www.ga.gov.au/aera Accessed 27/06/2017

90 International Energy Agency (2016). *World Energy Outlook 2016, p. 180,* OECD/IEA, Paris.

91 Geoscience Australia (2016). *Australian Energy Resources Assessments (AERA) Interim report, see table: 2016_AERA_data_tables-Oil_chapter.xlsx* [Online] Available from: http://www.ga.gov.au/aera Accessed 27/06/2017

92 APPEA (2016). *Report to the CoAG Energy Council – Unconventional Gas in Australia.*

93 *The IEA's main scenario is the New Policies Scenario, incorporates existing energy policies as well as an assessment of the results likely to stem from the implementation of announced intentions, notably those in the climate pledges submitted for COP21.*

Leading research institutions and capability

Australia has well-regarded research institutions and consortia that focus on oil and gas in a range of areas, from subsea engineering systems[94] and geosequestration[95] to the engineering and socio-economic issues related to unconventional oil and gas.[96] These entities comprise a research capability that can be leveraged to solve Australian-specific exploration and development challenges.

3.3.2 CHALLENGES

High-cost environment

Exploration and production costs in Australia are high. The cost of drilling an onshore exploration well is more than two and a half times that in the US.[97] Offshore, costs have increased by a factor of nine in the North West Shelf over the past decade.[98] Construction costs are also high, exemplified by significant cost overruns on several multi-billion-dollar projects in recent years.[99]

As Australia's costs increase, low-cost competition abounds. Costs of a greenfield LNG project in East Africa is estimated to cost 20% to 30% less than in Australia.[100] The threat of cheaper LNG sourced from the US shale revolution (transported easily across the country in existing pipeline infrastructure) is becoming real, as exports increase at a record pace.[101]

Taken together, high costs and cheaper competition mean that Australia may miss out on the next wave of oil and gas investment. This would diminish Australia's role in supplying the new LNG capacity needed to meet future gas demand projections past 2020.[102] At risk is at least $243 billion worth of LNG, gas and petroleum projects.[103] High costs also mean that Australia could struggle to economically develop its unconventional resources (those which require a high number of wells to be drilled). This would have an impact on the economics of existing east coast LNG infrastructure, as well as the prospects for unlocking shale gas resources in the future.

Regulatory uncertainty

Historically, the Australian oil and gas sector has had great success with attracting investment due to Australia's stable economy and robust democratic systems. However, in recent years, this picture of stability has eroded and companies now consider political risk to be high in Australia.[104] Four types of regulatory uncertainty challenge future investment in Australian resource developments.

Firstly, constraints on onshore exploration will deter discovery and development of Australia's unconventional resources. Bans, moratoria or restrictions are already in place (covering practices such as onshore exploration and hydraulic fracturing) in the Northern Territory, Victoria, New South Wales and Tasmania, with calls for similar measures in South Australia and Western Australia.[105]

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94 University of Western Australia (n.d.). *Centre for Offshore Foundation Systems – About the Centre,* [Online] Available from: http://www.cofs.uwa.edu.au/about Accessed 01/06/2017

95 National Geosequestration Laboratory, WA:ERA (n.d.). *Welcome to WA:ERA,* [Online] Available from: http://www.waera.com.au/ Accessed 1/06/2017

96 The University of Queensland (n.d.). Centre for Coal Seam Gas, [Online] Available from: https://ccsg.centre.uq.edu.au/about-us Accessed 27/07/2017

97 CSIRO (2017). *Resourceful magazine – New Depths, p26,* Issue 11.

98 Energy Quest (2014). *Oil and Gas Industry Cost Trends,* APPEA, [Online] Available from: https://www.appea.com.au/wp-content/uploads/2014/11/APPEA-Cost-Report_Final.pdf Accessed 26/06/2017

99 Ellis, M., Heyning, C., Legrand, O., (2013). *Extending the LNG boom: Improving Australian LNG productivity and competitiveness*, McKinsey&Company.

100 National Energy Resources Australia (2017). *Sector Competitiveness Plan*, Kensington.

101 Bloomberg (2017). *America's Shale Gas Bounty Is Heading Overseas at a Record Clip*, 1 June 2017 [Online] Available from https://www.bloomberg.com/news/articles/2017-05-31/america-s-shale-gas-bounty-is-heading-overseas-at-a-record-clip, Accessed on 6-7-17

102 APPEA (2016). *Report to the CoAG Energy Council - Unconventional Gas in Australia.*

103 Office of the Chief Economist (2016). *Resources and Energy Major Projects December 2016*, Australian Government, [Online] Available from: https://industry.gov.au/Office-of-the-Chief-Economist/Publications/Documents/req/Resources-and-Energy-Major-Projects-December-2016.pdf Accessed 14/07/2017

104 Chambers, M. (2017). *ExxonMobil, BP fearful of 'political risk'*, The Australian, [Online] Available from: http://www.theaustralian.com.au/business/mining-energy/exxonmobil-bp-fearful-of-political-risk/news-story/9c9626e1d2a245dc314af017d5863acd Accessed 14/07/2017

105 Victoria State Government (2017). *Onshore Gas, Community Information,* [Online] Available from: http://onshoregas.vic.gov.au/ Accessed 2/06/2017

Secondly, there is uncertainty about future emissions policy,[106] which primarily concerns the future viability of high-concentration CO_2 gas fields. Numerous policies and regulations aimed at managing climate change have been introduced and repealed in Australia over the past decade.[107] As a result, investment delays are occurring across many sectors,[108] including oil and gas.[109]

The third challenge is gas export restrictions. The Australian Domestic Gas Security Mechanism (ADGSM), announced in June 2017,[110] may challenge individual companies' ability to fulfil existing international supply agreements. If it succeeds in momentarily reducing domestic gas prices, State royalties will be reduced and private investment will be discouraged. This may undermine current and future oil and gas contractual agreements in Australia.

The fourth challenge is high levels of regulatory complexity, including multiple overlapping regulatory bodies, particularly for the onshore sector. More than 50 agencies are involved in regulating the Australian oil and gas industry,[111] adding to the complexity of the system and creating uncertainty that may undermine industry investments. Regulatory compliance requires an understanding of Commonwealth and State regulations, covering everything from health and safety and industrial practice to environmental management and land tenure issues.

Establishing Social License to Operate

Gaining social licence to operate is an important activity across both onshore and offshore operations.[112] The loss of social licence may manifest in investment delays and even project cancellations, which will in turn hinder domestic energy security, damage the country's image as an attractive investment destination, and ultimately slow Australia's economic growth.

Low prices, commoditisation and declining exploration

With low oil prices and the ongoing commoditisation of LNG, global investments in upstream oil and gas exploration have declined in recent years.[113] In Australia, offshore petroleum exploration has dropped by nearly 90% since 2008.[114] In Queensland, exploration expenditure dropped by nearly 27% between 2015 and 2016.[115] Reduced exploration activity will ultimately reduce the industry's reserve replacement performance. More acutely, a lack of exploration investment will delay the appraisal and development of Australia's significant unconventional resources. Outside of Queensland's CSG industry, unconventional gas exploration remains in its infancy. Unconventional resources remain undeveloped in South Australia and Northern Territory in particular and, with the right development pathways and policies in place, these could be matured to supply domestic users or export markets.[116]

106 Finkel A. et al (2017). *Independent Review into the Future Security of the National Electricity Market: Blueprint for the Future*, pg 88 Commonwealth of Australia.

107 Talberg, A., Hui, S., Loynes K., (2016). *Australian climate change policy to 2015: a chronology,* Parliament of Australia, [Online] Available from: http://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/rp1516/Climate2015 Accessed 14/07/2017

108 Herd, E. (2017). *Submission to: Independent review into the future security of the national electricity market,* Investor Group on Climate Change, [Online] Available from: http://www.igcc.org.au/resources/Pictures/IGCC%20Submission%20Finkel%20FINAL%203March2017.pdf Accessed 6/6/2017

109 CSIRO (2013). *Change and choice*, [Online] Available from: https://publications.csiro.au/rpr/download?pid=csiro:EP1312486&dsid=DS13 Accessed 2/06/2017

110 Department of Industry, Innovation and Science (2017). *The Australian Domestic Gas Security Mechanism,* [Online] Available from: https://industry.gov.au/resource/UpstreamPetroleum/AustralianLiquefiedNaturalGas/Pages/Australian-Domestic-Gas-Security-Mechanism.aspx Accessed 4/07/2017

111 National Energy Resources Australia (2017). *Sector Competitiveness Plan*, Kensington.

112 National Energy Resources Australia (2017). *Sector Competitiveness Plan*, Kensington.

113 International Energy Agency (2016). *World Energy Investment 2016,* OECD/IEA, Paris.

114 National Energy Resources Australia (2017). *Sector Competitiveness Plan*, Kensington.

115 Queensland Exploration Council (2016). *Queensland Exploration Score Card*.

116 APPEA (2016). *Report to the CoAG Energy Council – Unconventional Gas in Australia.*

Domestic innovation and commercialisation challenges

Despite Australia's robust research sector, there are a relatively low proportion of research activities that deliver commercial outcomes. The most recent Global Innovation Index report placed Australia 76th out of over 127 countries for innovation efficiency – a ratio of innovation outputs to inputs.[117] In 2014–15, only 8.4% of all Australian companies introduced a product that was 'new to the world'. Instead, an estimated 75% of all product innovations reported by firms operating in Australia are simply adopted from other firms.[118]

Innovation in the oil and gas sector is even more difficult, with uptake of new technology across the sector recognised as being relatively slow. It often takes many years to achieve high levels of technology adoption. Consequently, supply chain businesses tend to focus on developing incremental improvements to existing products rather than pursuing truly novel solutions.[119] Furthermore, operators in the sector are extremely risk adverse when it comes to trialling new technologies in ongoing operations. Operators prefer well-tested technologies and reliability over the promise of a novel piece of equipment that could potentially disrupt a viable production well or compromise on safety, regardless of the potential savings.[120]

A 2013 global survey of oil and gas companies reported that, in the three years prior, 60% of new technologies deployed came from companies headquartered in the US, compared to less than 1% from Australian businesses.[121] A lack of local investment is one probable cause – only about half of the oil and gas companies operating in Australia actually conduct any research and development,[122] a slightly lower average than Australian industry as a whole. Although these figures are only indicative, they suggest that Australian oil and gas companies rely upon international companies or their foreign parent companies for technology. With a lack of R&D investment, it may be challenging for Australian companies to develop breakthrough technology that can help to unlock Australia's oil and gas resources. There is risk in Australia relying solely on international oil and gas companies to make the significant R&D investments needed to unlock the specific resource plays located here.

Low levels of collaboration

Closely related to innovation and commercialisation is collaboration. Collaboration between business entities and research institutes is critical to a healthy innovation ecosystem. Australia regularly ranks very low among the 27 OECD nations when measuring the percentage of businesses that collaborate with research institutions.[123]

Although oil and gas firms regularly form joint ventures to share costs and risks of new oil and gas developments, they rarely do so for the explicit purposes of innovation. In one study, more than one quarter of Australian oil and gas firms were found to have no formal strategic collaborations with external parties, which significantly decreased their chances of producing a new product or service innovation.[124] Another study showed that oil and gas firms with fewer formal collaborations were also likely to have low organisational productivity levels.[125] Even within the oil and gas sector, there are relatively few formal collaborations between companies in the same line of business.[126]

117 Dutta, S., Lanvin, B., Wunsch-Vincent, S., (2017). *The Global Innovation Index 2017, Innovation Feeding the World,* Cornell University, INSEAD, WIPO, Ithaca, Fontainebleau, and Geneva.

118 Innovation and Science Australia (2016). *Performance Review of the Australian Innovation, Science and Research System 2016,* Canberra.

119 Daneshy, A., & Donnelly, J. (2004). *A JPT roundtable: The funding and uptake of new upstream technology.* Journal of Petroleum Technology, 56(6): 28–30.

120 Bower, D. J., Crabtree, E., & Keogh, W. (1997). *Rhetorics and realities in new product development in the subsea oil industry*. International Journal of Project Management, 15(6): 345–350.

121 Perrons, R.K., (2014). *How innovation and R&D happens in the upstream oil & gas industry: Insights from a global survey*. J. Pet. Sci. Eng. 124, p301–312.

122 Ford, J., et al (2014). *Confronting the productivity challenge in the high cost economy: evidence from the Australian oil and gas industry,* In Göran Roos and Narelle Kennedy (Ed.), Global perspectives on achieving success in high and low cost operating environments (pp. 153-171) London, United Kingdom.

123 Australian Government (2016). *Australian Innovation System Report 2016,* Canberra.

124 Ford, J., Steen, J., Verreynne, M.L., (2014). *How environmental regulations affect innovation in the Australian oil and gas industry: Going beyond the Porter Hypothesis.* Journal of Cleaner Production. Vol 84, pp204–213.

125 EY (2013). *Delivering a step change in organisational productivity: Findings from the Australian Oil & Gas Productivity and Innovation Survey.*

126 PwC (2013). *Gateway to growth: innovation in the oil and gas industry.*

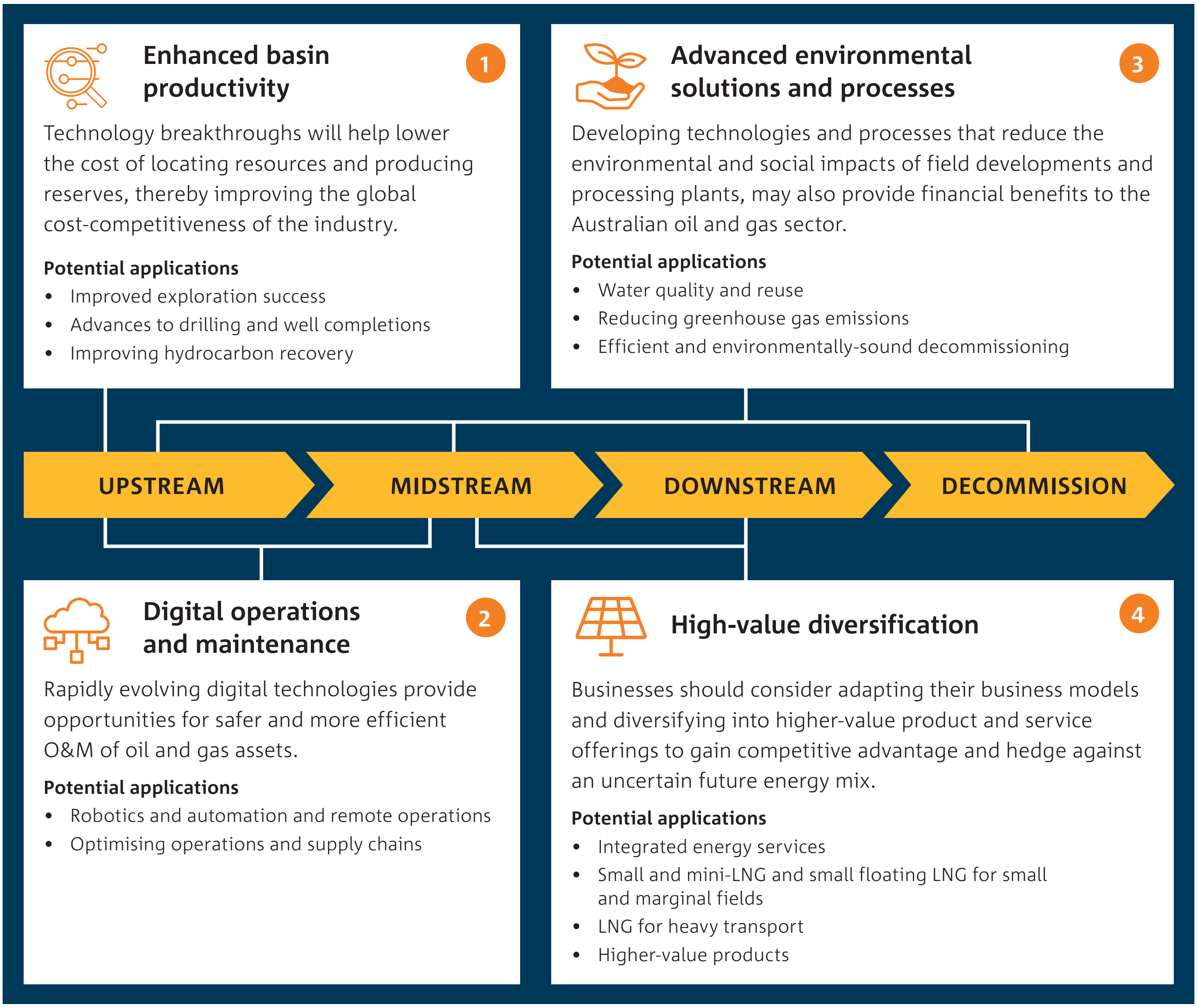
Strategic opportunities

4 Strategic opportunities

This Roadmap presents four strategic opportunities that could support the long-term growth of the Australian sector, by addressing some of its most pressing challenges. These opportunities (identified through consultation with oil and gas operators and service firms) are driven by the megatrends and leverage Australia's comparative advantages. The alignment of each opportunity with NERA's sector knowledge priorities are outlined in Appendix 1.

Each of the four opportunities are detailed in this chapter, supported by potential applications for oil and gas companies, and in some cases, the broader supply chain (see Figure 11). Importantly, the potential applications listed in this section are not intended to be an exhaustive list, but rather a starting point for discussion and consideration. Each potential application listed is supported by a number of short-, medium- and long-term prospective technology outputs and solutions.

FIGURE 11: OIL AND GAS OPPORTUNITIES ALONG THE VALUE CHAIN



Enhanced basin productivity

Technology breakthroughs will help lower the cost of locating resources and producing reserves, thereby improving the global cost-competitiveness of the industry.

RELATED MEGATRENDS

- More complex and costly
- Digitally enabled
- Energy hungry

KEY STATISTICS

- Historically, less than 28% of Australian exploration wells (both onshore and offshore) have been successful, and fewer than 14% led to commercial production.[127]
- The average exploration cost for offshore Western Australia has increased from $10 million to $90 million per well over the decade to 2013.[128]
- Exploration costs in the Cooper Basin have doubled over the past decade.[129]
- Exploration costs in Queensland have tripled since 2008, reflecting CSG activities.[130]
- While drill rigs already generate terabytes of data, generally only a small fraction of it is used for real-time decision-making.[131]

127 APPEA (2017). *Submission to the Review of Commonwealth Petroleum Resource Taxes*, [Online] Available from: https://www.appea.com.au/wp-content/uploads/2017/03/APPEA-PRRT-Submission_10-Feb-2017.pdf Accessed 1/06/2017.

128 Energy Quest (2014). *Oil and Gas Industry Cost Trends,* APPEA, [Online] Available from https://www.appea.com.au/wp-content/uploads/2014/11/APPEA-Cost-Report_Final.pdf Accessed 26/06/2017

129 Energy Quest (2014). *Oil and Gas Industry Cost Trends,* APPEA, [Online] Available from: https://www.appea.com.au/wp-content/uploads/2014/11/APPEA-Cost-Report_Final.pdf Accessed 26/06/2017

130 Energy Quest (2014). *Oil and Gas Industry Cost Trends,* APPEA, [Online] Available from: https://www.appea.com.au/wp-content/uploads/2014/11/APPEA-Cost-Report_Final.pdf Accessed 26/06/2017

131 World Economic Forum (2017). *Digital Transformation Initiative: Oil and Gas Industry*, Geneva.

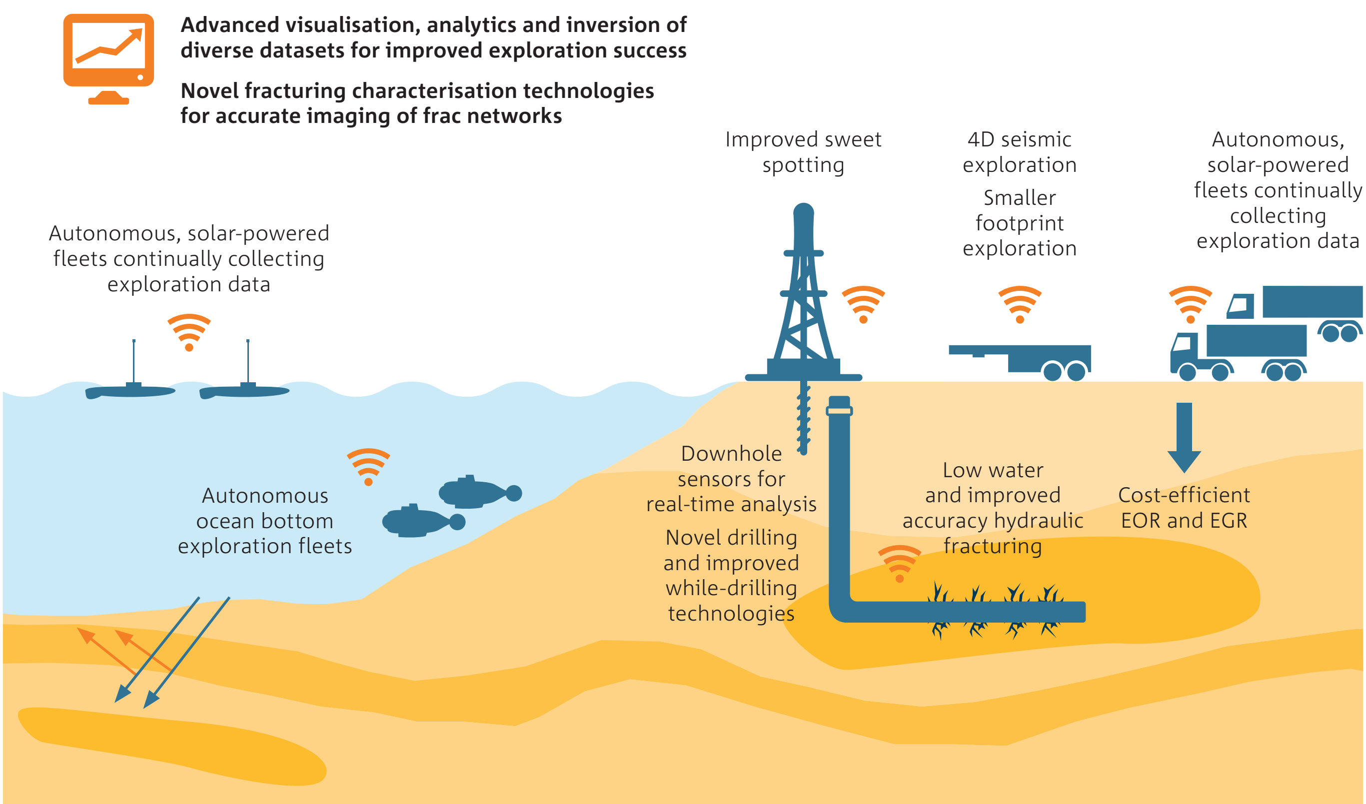
4.1 Enhanced basin productivity

The cost of exploration and production of Australian oil and gas resources has been steadily increasing for a number of years. Globally, it is estimated that the costs of finding and developing new reserves have increased on average six-fold between 2000 and 2013.[132] Technologies that enable relevant cost efficiencies, especially offshore and in unconventional plays, represent a large target for investment for the sector.

This section focuses on three potential targets for cost-efficiency and productivity improvement in this area.

- Increasing exploration success – exploration is becoming increasingly complex as companies move into more remote locations and deeper waters, leading to increased time and costs, as well as the greater geological uncertainty related to being further away from pre-existing wells. Sub-surface geophysical and geological characterisation needs to improve, both to avoid dry wells and to reduce the costs associated with poor geomechanical prediction leading to non-commercial discoveries (e.g. unconventional wells which cannot be effectively, and economically, stimulated).
- Advances to drilling and well completions – proving and producing reserves requires costly well drilling and completion. Opportunities exist to reduce these costs and improve performance by using new technologies.
- Improving recovery factors – opportunities exist to increase the efficiency of hydrocarbon extraction by using strategies to manage assets for improved oil recovery, or secondary/enhanced recovery methods suitable for the particular accumulation type.

FIGURE 12: A SAMPLE FUTURE VISION FOR ENHANCED BASIN PRODUCTIVITY



132 U.S. Energy Information Administration (2016). *Trends in U.S. Oil and Natural Gas Upstream Costs,* US Department of Energy, Washington.

4.1.1 POTENTIAL APPLICATIONS

Increasing exploration success

An accurate understanding of the subsurface is critical to locating resources and making Australian basins more productive. Locating oil and gas using existing methods, such as 2D or 3D seismic reflection technology, can be time-consuming, high-cost and high-risk. New methods and technologies need to be found to drive down exploration costs, improve the accuracy of exploration data and increase the quality of imaging at the basin level.

Seismic surveys are costly,[133] time consuming and may have adverse effects on the environment. New methods of acquisition should focus on acquiring data in a fashion that is quicker, cheaper, and more accurate, while minimising the impacts on sea life. For example, recent modelling shows that vibrating sources could potentially provide an environmentally safer alternative to conventional airguns without compromising effectiveness.[134] Furthermore, autonomous exploration vehicles[135], and robotically-enabled autonomous seismic acquisition,[136] are increasingly likely to be used to discover offshore hydrocarbons in remote areas.

Onshore seismic acquisition can also be problematic in remote areas where vehicles carrying the seismic wave generator face logistical challenges. Most of Australia's onshore resources are located in very remote areas. For example, the Beetaloo sub-basin – a shale resource currently in the exploration phase – is located 500km south-east of Darwin in the Northern Territory and covers an area of 18,500km^2.[137]

Ways of addressing these challenges range from better management of pre-competitive data to using AI and new modes of acquisition.

Firstly, improvements in the management of pre-competitive data could significantly increase exploration efficiency. These datasets may at present be incomplete, non-standardised or be held in different databases depending on jurisdiction. Onshore pre-competitive data is separately administered by each state or territory government, while Geoscience Australia (GA) curates data for Australia's offshore regions. GA receives newly collected exploration data within the statutory submission period and makes data publicly available after the statutory timeframes. This framework may lead to exploration inefficiencies, with opportunities to apply big data analytics being missed due to very limited standardised national datasets. Subsurface geophysical, petrophysical and available production data should be centrally available to facilitate geological understanding of entire basins and corresponding reservoir dynamics. This would improve exploration efficiency by providing pre-competitive data necessary for basin-wide models that help to identify potential locations for drilling and production.

Secondly, new technologies for interrogating and interpreting seismic data represent another opportunity to improve exploration success. One approach is to use AI to improve seismic inversion and interpretation. Neural networks, fuzzy logic, and genetic algorithms have already been shown to improve seismic inversion.[138] Even greater potential may lie in the sophisticated inversion of other data types, such as those from wireline and electromagnetic surveys, to provide greater resolution and accuracy in subsurface imaging.

133 To collect offshore seismic data, large ships outfitted with air gun sound sources and hydrophone streamers sweep wide swathes of the ocean, for weeks or months at a time.

134 Weilgart, L. (2016). *Alternative Quieting Technology to Seismic Airguns for Oil & Gas Exploration and Geophysical Research,* Brief for GSDR – 2016 Update, [Online] Available from: https://sustainabledevelopment.un.org/content/documents/973534_Weilgart_Alternative%20Quieting%20Technology%20to%20Seismic%20Airguns%20for%20Oil%20&%20Gas%20Exploration%20and%20Geophysical%20Research.pdf Accessed 8/06/2017

135 Technavio (2017). *Global underwater exploration robots market 2017–2021,* Infiniti Research Limited.

136 Moldoveanu, N., et al (2016). *Marine seismic acquisition with 3D sensor arrays towed by wave gliders*. SEG Technical Program Expanded Abstracts 2016, pp. 168–172.

137 ICN Gateway (n.d.). *Beetaloo Basin Project - Exploration Phase*, [Online] Available from: https://gateway.icn.org.au/project/2615/beetaloo-basin-project-exploration-phase Accessed 27/06/2017

138 Holdaway, K, (2014). *Harness Oil and Gas Big Data with Analytics: Optimize Exploration and Production with Data Driven Models,* Wiley.

Thirdly, it is unclear whether computational improvements for conventional exploration data alone will be sufficient to overcome the problem of imaging thin reservoir horizons that require sub 10-metre resolution – those which characterise many unconventional resources. Although continued refinements in seismic acquisition, including multi-frequency seismic source technology and multi-azimuth acquisition, can provide the raw materials to create a truer image from the data, the seismic paradigm may be reaching its theoretical limits. Emerging alternative technologies, such as quantum gravity sensors, may improve the ability to precisely locate and image resources.[139] However, it remains unclear exactly what the next subsurface acquisition paradigm that could outperform seismic will be.

Advances to drilling and well completions

A significant opportunity exists to drive down the costs of drilling and completing wells through advanced technologies, new designs and processes. These costs are high and are increasing due to many factors. Onshore, these include the remoteness of Australia's basins, poor infrastructure and supply chains, and lack of benefits that would accrue from economies of scale from a more active exploration and production landscape. These factors will become even more pronounced in future unconventional gas developments. This is because they will require thousands of wells to be drilled, and the scale of these endeavours will magnify cost inefficiencies in drilling, completions and in supply chain operations.

FIGURE 13: KEY PROSPECTIVE TECHNOLOGY OUTPUTS AND SOLUTIONS

SHORT TERM (0 – 3 YEARS)	MEDIUM TERM (3 – 10 YEARS)	LONG TERM (10+ YEARS)
Increasing exploration success		
• All Australian geophysical (2D and 3D seismic, potential field), environmental, meteorologic, oceanographic, etc. data digitised, stored and made publicly accessible after standard 'holding periods' • Improved satellite/airborne exploration systems that collect more detailed imagery and subsurface data over the whole basin suitable for identifying potential new onshore and offshore exploration targets • Train AI (neural networks, support vector machines, genetic algorithms, etc.) on available geophysical, remote sensing and well data • Advanced visualisation and interpretation tools for exploration data • Joint inversion of diverse geophysical datasets • Trial of marine seismic sources with reduced environmental impact and improved resolution using lower frequencies • Smaller footprint exploration tools and equipment for more efficient transport and logistics	• Subsurface imaging at twice the currently available spatial resolution (approaching ~10m at 3km depth) through improved broadband acquisition, potentially incorporating seabed node receivers, and combined with full waveform imaging • Bayesian seismic inversion rock properties and geological structures • Real-time collection, transmission and AI-enabled analysis of seismic survey data, to enable quick look prospectively screening • Machine learning systems fully trained to automatically interpret and locate probable oil and gas deposits in 3D geophysical data • Subsurface imaging technologies with reduced environmental impact used both onshore and offshore, including: passive seismic, lower noise sources, high fidelity multicomponent, broadband node receivers	• 1-metre vertical resolution imaging capability • Autonomous onshore, offshore and ocean bottom exploration fleets • Accurate characterisation of the subsurface negating the need for exploration wells to be drilled • Gravimeters based on quantum sensing, offering a step change in sensitivity over mechanical systems • Fully integrated pore to basin scale geological-mathematical models • Improved CSG resource productivity predictions based on multi-variate analysis linking production data to palynology and biological characteristics in the reservoir

139 The Economist (2017). *Technology Quarterly, Quantum technology is beginning to come into its own*, [Online] Available from: http://www.economist.com/technology-quarterly/2017-03-09/quantum-devices Accessed 2/06/2017

Offshore, costs have been increasing due to a range of issues that are not likely to subside. They include long travel distances from major transport hubs, relatively high Australian labour costs, a trend towards drilling further offshore in deeper waters and in areas with less favourable metocean conditions, such as geomechanical instability in areas of high stresses and pressures.

To address these cost pressures – onshore and offshore – digital solutions, including automation, IoT, AI, and robotics, as well as new well designs and stimulation technologies, have the potential to drive down the costs of wells and completions, improve insights derived from exploration wells, and improve long-term performance of production wells. Several examples follow.

Offshore, seismic inversion and machine learning could be combined to automate and standardise the process of identifying and mitigating the risks of high stress/pressure conditions in Australian basins, for instance by integrating seismic data with previous well instability events. Collaboration between operators is necessary to support this approach.

Real-time data from 'logging while drilling' systems is being used to 'geosteer' wells to their intended positions and avoid hazards such as faults. Greater use of drilling data and logging information, including gas logs, rapid determination of stratigraphic age with microfossils (so-called 'biosteering'[140]), pressure while drilling and rock property information from returned cuttings could, with better integration, enable more rapid updates of geological models in real time. This would ensure the well and completions are implemented to maximum effect, achieved more rapidly and safely, and at lower cost.

Using the noise from drilling itself as a seismic source is now possible, offering the possibility of creating a vertical seismic profile of the region close to the wellbore. These data could be used to update the full 3D seismic image and 'ground truth' depth and rock information. The time required to do this could be shortened by improved algorithms and higher computational speeds. Ultimately, this could result in a constantly recalibrated seismic image, available in near-real time, essentially closing the loop in the geosteering process.

Unconventional resources such as shale and some tighter coal seams require stimulation techniques like hydraulic fracturing to induce the flow of hydrocarbons. Continued advances in fracture characterisation techniques, such as advanced modelling and simulation, microseismic and tiltmeter monitoring, and tracers, will help to more accurately depict the location and growth patterns of induced fractures and support optimum productivity.[141] Furthermore, greater understanding of the propagation of fractures and their interaction with natural faults will facilitate environmental stewardship.[142]

Future Australian shale developments will require substantial water inputs to support the required hydraulic fracture stimulation. This will necessitate sustainable water sources, methods of recovery, and treatment regimes to be viable in Australia's water-scarce areas and to assuage social concerns. The development of less water-intensive stimulation techniques together with technologies able to utilise lower quality water could deliver significant economic and environmental benefits for unconventional resource developments.

140 O'Neill, M., Denos, M. (2017). *Automating biostratigraphy in oil and gas exploration: Introducing GeoDAISY,* Journal of Petroleum Science and Engineering, Vol 149, pp 851-859.

141 Le Calvez, J., et al (2016). *Hydraulic Fracturing Insights from Microseismic Monitoring*, Oilfield Review 28, Schlumberger.

142 CSIRO (2015). *What is hydraulic fracturing?* [Online] Available from: https://www.csiro.au/en/Research/Energy/Hydraulic-fracturing/a-What-is-hydraulic-fracturing Accessed 2/06/2017

Technology spotlight

Ikon Science

Ikon Science's RokDoc Ji-Fi software system, developed in collaboration with CSIRO, integrates seismic and well data to derive quantitative predictions of rock, fluid and reservoir properties. These inversions are generated through sophisticated rock physics modelling and risk analysis.

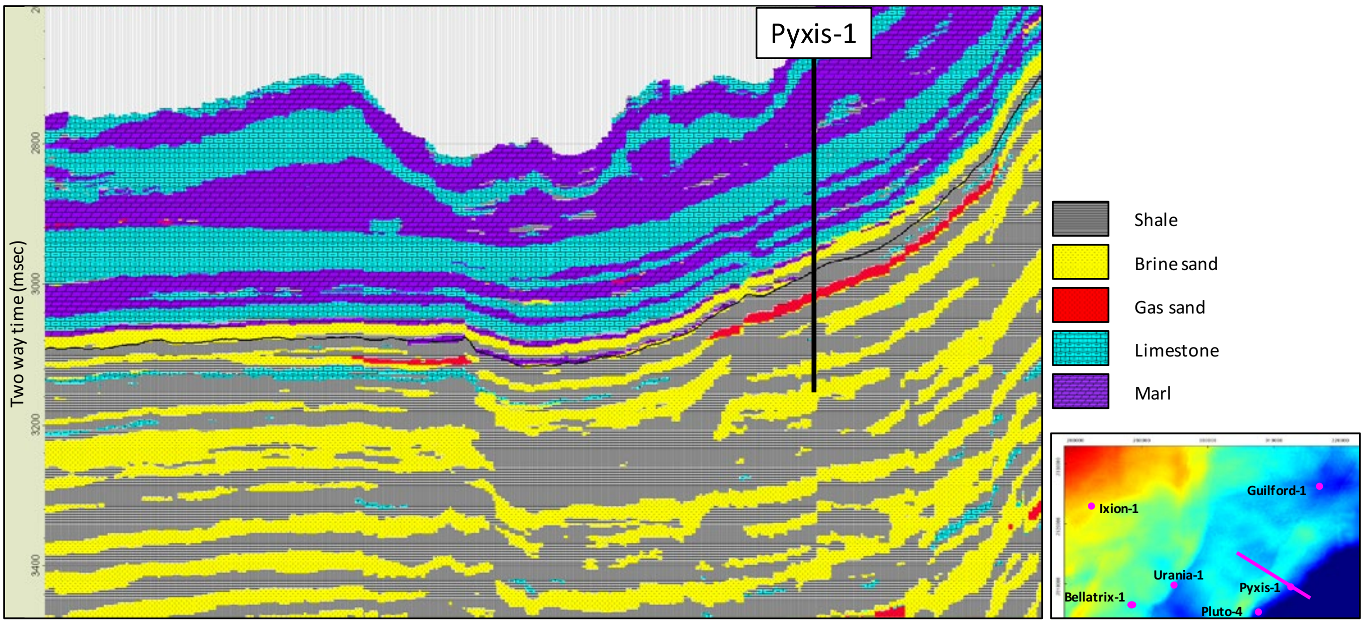
Rokdoc can provide decision support for exploration, production and drilling activities and has been used to generate high-fidelity production predictions for numerous late-stage oil and gas fields around the world.[143]

Figure 14 shows the results of facies prediction from seismic inversion of a North West Shelf data cube using the Ji-Fi toolbox. The position of the 2D vertical section is shown on the inset time slice amplitude map at Upper Triassic level. The inversion correctly identifies gas sands in red, penetrated by the Pyxis-1 exploration well. Several undrilled targets are also identified in the seismic data cube.

Improving hydrocarbon recoveries

Although the global average recovery factor[144] for oil is 35%,[145] many Australian oil reservoirs consistently achieve recovery rates of above 50%, without the use of enhanced recovery techniques.[146] Enhanced Oil Recovery (EOR) technologies have been limited in their use in Australia. However, improved oil and gas recovery strategies – through optimal well positioning and whole of life field management enabled by well surveillance and time lapse sensing – have the potential to yield further improvements in ultimate recovery factors for Australia's reservoirs.

FIGURE 14: BAYESIAN INVERSION OF 3D SEISMIC DATA



Source: CSIRO, 2017

143 Ikon Science (2016). *The "Double Triple": Ikon Science's RokDoc Ji-Fi gains three Supermajor sales and three prestigious awards,* [Online] Available from: https://www.ikonscience.com/about/news/2016/11/30/the-double-triple-ikon-sciences-rokdoc-ji-fi-gains-three-supermajor-sales-and-three-prestigious-awards Accessed 2/06/2017

144 The recoverable amount of original or residual oil in place in a reservoir, expressed as a percentage of total oil in place. The recoverable amount includes produced oil plus the volume of proven reserves

145 International Energy Agency (2013), *Resources to Reserves 2013*, OECD/IEA, Paris.

146 Geoscience Australia (2014). *Australian Energy Resource Assessment, Second Edition*, pp 47, Canberra.

FIGURE 15: KEY PROSPECTIVE TECHNOLOGY OUTPUTS AND SOLUTIONS

<table>
<tr><th>SHORT TERM
(0 – 3 YEARS)</th><th>MEDIUM TERM
(3 – 10 YEARS)</th><th>LONG TERM
(10+ YEARS)</th></tr>
<tr><td colspan="3">Advances to drilling and well completion</td></tr>
<tr><td>• Robust down-hole sensors for real-time analysis of rock properties and hydrocarbon content
• Improved while-drilling technologies (for example, full integration of sensor data) to support real-time drill-steering operations
• Linking fracturing models with dynamic reservoir models to produce comprehensive understanding of interactions
• Process technology to convert local resources to fracturing proppant
• Improved accuracy, modelling and simulation of hydraulic fracturing growth patterns and proppant distribution through integration of multiple sensing modes
• Novel drilling technologies and techniques, for example multilateral horizontals and slim wells</td><td colspan="2">• Novel fracturing characterisation technologies for accurate imaging of fracture networks
• Miniaturisation of bore holes and downhole equipment and sensors, resulting in reduced logistics and completion costs
• AI applied to developing mechanical configurations and operating parameters for new resource plays, effectively determining appropriate configurations that maximise NPV
• More adaptable and tailorable unconventional well and flowline designs, and smarter, leaner and quicker workover technologies and practices
• Low quality water and low/no water fracturing techniques
• Real-time fully integrated basin/reservoir models</td></tr>
</table>

Improving gas recovery rates and extending the life of existing reservoirs to feed the growing LNG industry represents a significant opportunity. One potential technology is microbially enhanced coal bed methane,[147] also known as Reservoir Rejuvenation Technology (R2T).[148] This involves enhancing the activity of microorganisms in coal seams to stimulate new methane production. Another approach is enhanced gas recovery (EGR), using CO_2 to displace hydrocarbon gas into wells.[149] Preliminary studies find this approach feasible in coal seams, but more research is needed to understand its potential across a range of coal types. Subsurface CO_2 injection for aquifer pressure support could also assist in maintaining production and extending the life of offshore, high CO_2 gas fields while at the same time disposing of a significant waste gas stream.

Other improvements to recovery factors over the medium to long term will come from a range of technologies. For example, data provided by shapeshifting autonomous down-hole robots may help optimise recovery factors and prolong field life, and could potentially be directly integrated into automated production management systems. Advanced reservoir characterisation technologies will allow for more efficient and informed 'sweet spotting' or targeting of hydrocarbons. Improved identification of sweet spots minimises the required number of hydraulic fractures, improving the overall economics.[150]

147 CSIRO Energy (2015). *Enhanced oil recovery,* [Online] Available from: http://research.csiro.au/oilandgas/wp-content/uploads/sites/49/2015/10/Enhanced-oil-recovery-2015.pdf Accessed 2/06/2017

148 CSIRO (2017). Reservoir rejuvenation technology (R2T), [Online] Available from: https://www.csiro.au/en/Research/EF/Areas/Oil-gas-and-fuels/Onshore-gas/Microbes Accessed 17/07/2017

149 International Energy Agency (2013). *Resources to Reserves 2013*, OECD/IEA, Paris.

150 Speight, J (2016). *Handbook of Hydraulic Fracturing*, John Wiley & Sons.

FIGURE 16: KEY PROSPECTIVE TECHNOLOGY OUTPUTS AND SOLUTIONS

SHORT TERM (0 – 3 YEARS)	MEDIUM TERM (3 – 10 YEARS)	LONG TERM (10+ YEARS)
Improving recovery rates		
• Cost-efficient enhanced gas recovery using waste CO_2 • Low cost microbially enhanced EOR • Low cost chemical additives that change the rock surface properties and flow characteristics of reservoirs allowing for selective production of hydrocarbons and limit production of water and impurities • AI engine for reservoir production optimisation and sweet spot identification		• Autonomous, shapeshifting downhole surveillance robots to provide information that can help optimise production • Advanced nanotechnology-enabled EOR • Designer oilfield chemicals for improved performance and productivity

Technology spotlight

Reservoir Rejuvenation Technology (R2T)

CSIRO is conducting research to enhance gas production by using cultured indigenous microbes which are active in coal seam gas reservoirs and produce secondary biogenic methane.

A long-term field trial will be undertaken where microbes and nutrients will be injected into the reservoir to optimise gas generation. If successful, this research will lead to the development of a technology to increase methane content of CSG reservoirs and enhance production.[151]

151 CSIRO (2016). *Reservoir rejuvenation technology (R2T),* [Online] Available from: https://www.csiro.au/en/Research/EF/Areas/Oil-gas-and-fuels/Onshore-gas/Microbes Accessed 2/06/2017

4.1.2 ENABLING SCIENCE AND TECHNOLOGY

A variety of technologies and research programs will be required to make Australian basins more productive. Research priorities to enable these developments are detailed below.

RESEARCH PRIORITIES

Digital technologies

- More robust and less costly sensors, power supplies and data communication systems for monitoring in harsh environments, such as at the drill bit.
- Increased application of Distributed Temperature Sensing (DTS) and Distributed Acoustic Sensing (DAS) for hydraulic fracturing and production monitoring.
- Improved downhole technologies to provide production data, such as pressures and temperatures.
- Improved AI for applications across the sector, such as analysing large amounts of geoscience data to proactively locate probable deposits and collecting large amounts of sensor data using machine learning algorithms to automatically manage and optimise reservoir production.
- High data-transfer-rate communication technology and/or data compression techniques to transmit large amounts of exploration and downhole data to the cloud.
- Improved computing power, communications technology (e.g. swarm intelligence), sensing and dexterity for exploration robots.

Hydraulic fracturing

- Precision hydraulic fracturing (modelling and methods) that will enable a step-change reduction in the power and equipment footprint requirements, and dramatically reduce costs.
- Enhanced geomechanical models to facilitate prediction of induced seismicity.
- Increased water recovery and reuse technology.
- Technology to produce effective proppants from local materials in remote areas.
- Research into alternatives to radioactive fracking water tracers that can be monitored remotely and left in place.
- Improved fracturing techniques that use less water or lower quality water, and corresponding proppants.

Subsurface imaging

- Faster and stronger algorithms for improved sub-surface exploration and imaging.
- Research into alternatives to seismic acquisition.
- More accurate microseismic and tiltmeter technology, and supporting analytic software.

Enhanced recovery

- Enhance recovery techniques based on nanotechnology, biotechnology, and *in-situ* surface chemistry manipulation.
- Basin-specific absorption-desorption characteristics for CO_2 Enhanced CBM.

4.1.3 BUSINESS ECOSYSTEM CHANGES

In order to unlock this opportunity, several suggestions for improving the business ecosystem are presented for consideration.

PROCESSES, STANDARDS AND REGULATIONS

- Increase the pace and quality of proactive pre-competitive data collection from underexplored and frontier basins to encourage exploration.
- Cloud-based, open access storage of all standardised Australian pre-competitive data to encourage interrogation using AI such as machine learning.
- Consider the impact potential water regulations may have on hydraulic fracturing and begin actively pursuing alternative approaches.
- Investigate adoption of international design and construction standards and codes for equipment as opposed to Australian based standards.

PEOPLE, SKILLS AND COLLABORATION

- Improve multidisciplinary collaboration, and collaboration between companies and among research groups, to arrive at new ways of de-risking exploration, enhancing operational efficiency along the entire value chain, and improving production of oil and gas on a per-well and whole-of-asset basis.
- Invest in transdisciplinary skill development that transcends traditional roles by moving toward a more integrated perspective.
- Consider using open innovation challenges (crowdsourcing) designed to mine pre-competitive data.

Digital operations and maintenance

Rapidly evolving digital technologies provide opportunities for safer and more efficient O&M of oil and gas assets.

RELATED MEGATRENDS

- Digitally enabled
- More complex and costly

KEY STATISTICS

- Globally, it is estimated that digital transformation may create as much as $1 trillion in value for oil and gas firms, gained in part by transforming the way companies manage their assets and operations, and by enabling a more collaborative ecosystem for innovation.[152]
- Robots and UAVs may help reduce inspection and maintenance costs by 25%.[153]
- Increased oil and gas automation could bring CO_2 emissions down by 20 million tonnes between 2016 and 2025.[154]
- In a recent survey by Accenture, 80% of firms indicated that they intend on maintaining or increasing their digital investments in the coming years.[155]
- More than 80% of Australia's conventional oil and gas resources exist in remote, offshore areas.[156]

(Note: digital technologies for exploration and field development are discussed in Section 4.1)

152 World Economic Forum (2017). *Digital Transformation Initiative: Oil and Gas Industry*, Geneva.

153 World Economic Forum (n.d.). *Robots and drones: automation on the rise,* [Online] Available from: http://reports.weforum.org/digital-transformation/robots-and-drones-automation-on-the-rise/ Accessed 1/06/2017

154 World Economic Forum (n.d.). *Robots and drones: automation on the rise,* [Online] Available from: http://reports.weforum.org/digital-transformation/robots-and-drones-automation-on-the-rise/ Accessed 1/06/2017

155 Accenture, Microsoft (2016). *2016 Upstream Oil and Gas Digital Trends Survey,* [Online] Available from: https://www.accenture.com/_acnmedia/PDF-6/Accenture-Upstream-Oil-Gas-Companies-Spend-Smarter-Digital-Technologies-Drive-Value-Reduce-Costs#zoom=50

156 The Australian Trade Commission (2014). *Resources research and development.*

4.2 Digital operations and maintenance

The potential to capitalise on digital technologies in the Australian oil and gas sector is significant, given looming operational expenditures, which are important targets for cost reductions. For example, the annual expenditure on Australian LNG operations and maintenance is expected to increase from $1.3 billion in 2014 to $4.9 billion by 2020.[157] Australian operators should continue to investigate the potential of digital technologies to decrease costs by streamlining operations and maintenance activities. These technologies include the Industrial Internet of Things (IoT), advanced sensors and analytics, machine learning, artificial intelligence (AI), automation, and integration of other digitally enabled technologies.

With Australia's comparatively high labour costs and the remoteness of both offshore and onshore resources posing logistical and health and safety challenges, automation is a key opportunity. Digital solutions that enable the remote operation of facilities, such as Remote Operation Centres (ROCs), robotics and unmanned vehicles are all well-suited to address these problems. Moreover, autonomous and digital technologies may actually be *required,* in order to comply with harsher future inspection regimes that may call for continuous monitoring capability.[158] For example, to ensure plant integrity, digital imaging may emerge as a requirement for independent structural validation of as-built drawings.

With Australia's mining sector also looking to pursue greater automation and integration of digital solutions,[159] Australia's oil and gas sector may be in a position to parlay its digital expertise to create new technologies with the mining sector.

Digital advances are expected to assist the sector in gaining cost efficiencies through improved productivity of operations, alongside protecting its workforce. Through consultation with the industry, two key applications have been identified:

- Robotics, automation and remote operations – including more efficient and autonomous subsea operations and processing.
- Optimising operations and supply chains – using advanced analytics, artificial intelligence and other digital solutions.

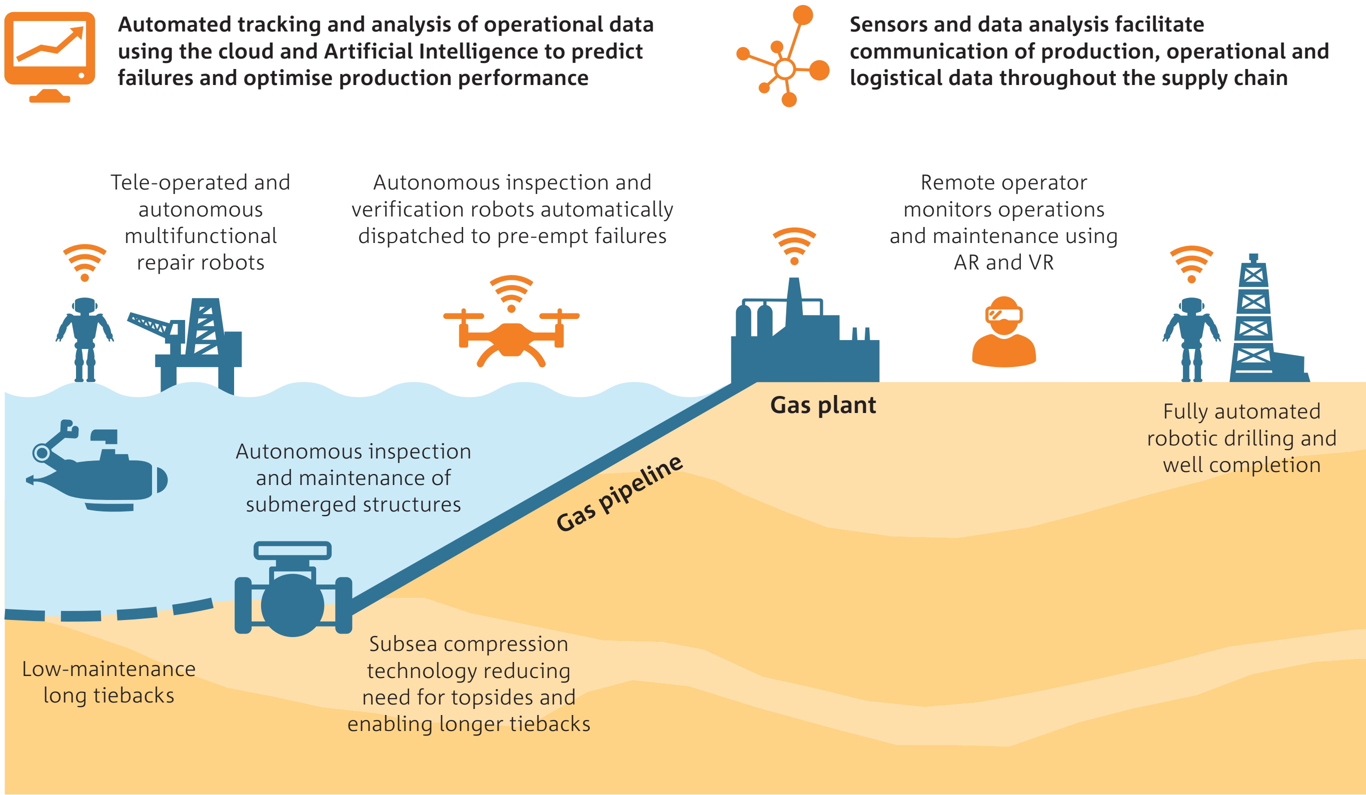
4.2.1 POTENTIAL APPLICATIONS

Robotics, automation and remote operations

Digital technologies have broad appeal and are poised to transform exploration, production, inspection and maintenance activities across onshore and offshore developments. In exploration, future developments may see autonomous vehicles powered by solar, wind and wave energy, outfitted with seismic acquisition technology with the potential to transform how resources are found.[160] In drilling, recent advancements in robotics could soon allow nearly complete automation of drilling and construction offshore well bores.[161] In operations, unstaffed offshore platforms (similar to those currently used in the Gulf of Mexico) will be used to exploit smaller reserves[162] using tele-operated robotics supported by human operators in consolidated remote operations centres.[163]

157 Accenture (2015). *Ready or Not? Creating a world-leading oil and gas industry in Australia.*
158 Shukla, A., Hamad, K., (2016). *Application of robotics in onshore oil and gas industry – A review Part I*, Robotics and Autonomous Systems Vol 75, Part B, pp 490–507.
159 CSIRO (2017). *Mining equipment, technology and services roadmap,* Canberra.
160 Moldoveanu, N., et al (2016). *Marine seismic acquisition with 3D sensor arrays towed by wave gliders*. SEG Technical Program Expanded Abstracts 2016, pp. 168-172.
161 Minyaeva, E., (2015). *Automated drilling gains momentum in offshore operations.* Offshore. [Online] Available from: http://www.offshore-mag.com/articles/print/volume-75/issue-10/drilling-and-completion/automated-drilling-gains-momentum-in-offshore-operations.html Accessed 1/06/2017
162 Andrews, J., Fecarotti, C., (2017). *System design and maintenance modelling for safety in extended life operation*, Reliability Engineering & System Safety, Vol 163, pp. 95–108.
163 Shukla, A., Hamad, K., (2016). *Application of robotics in offshore oil and gas industry—A review Part II*, Robotics and Autonomous Systems Vol 75, pp 508490–507.

FIGURE 17: A SAMPLE FUTURE VISION FOR DIGITAL OPERATIONS AND MAINTENANCE



Definitions

Artificial Intelligence (AI) – A branch of computer science involving the replication of intelligent human behaviour using computer algorithms.

Machine learning – A class of AI algorithms that use large amounts of input-output data to learn patterns which are then used make decisions without requiring direct human intervention.

Artificial neural networks – Machine learning models based on emulating neurophysiology of the human brain to establish multidimensional, nonlinear, and complex models.

Cognitive computing – A high-level computing system that composes multiple hypotheses to make decisions based on modelling in context and learning from data. The system provides a series of alternative answers along with an explanation of the rationale or evidence supporting each answer.[164]

Augmented and virtual reality – Augmented Reality (AR) is representation technology that superimposes computer-generated content over a live view of the physical world to a user using either a conventional display screen or head mounted display.

Unmanned vehicles – A broad range of mobility platforms having different levels of vehicle control from manual, supervised or autonomous. Examples include:[165]

- Sea: Remotely Operated Vehicles (ROV) and Autonomous Underwater Vehicles (AUV).
- Land: Unmanned Surface Vehicles (USV) and Autonomous Surface Vehicles (ASV).
- Air: Unmanned Aerial Vehicle (UAV) and Autonomous Air Vehicle (AAV).

164 Hurwitz, J., Kaufman, M., Bowles, A., (2015). *Cognitive computing and big data analytics,* Wiley.

165 Oil and Gas Facilities (2017). *Unmanned Vehicles and Robotics Gain Momentum*, [Online] Available from: https://www.spe.org/en/ogf/ogf-article-detail/?art=2677 Accessed 2/06/2017

The future of maintenance activities for the sector will increasingly see routine monitoring and inspection conducted remotely or autonomously to capitalise on considerable cost efficiencies and health and safety benefits that can be gained by de-staffing these activities. Active maintenance will also be increasingly conducted remotely, as robotic technologies become more agile and reliable. For example, UAVs (already being deployed in CSG gas fields) will soon be regularly used to check valve positions, read gauges, detect leaks and perform surface condition monitoring. Low-cost sensor networks will be capable of monitoring production data, corrosion and fatigue. Queensland's geographically dispersed and remote CSG industry, with its numerous wells, may be an ideal test-bed for this remote monitoring technology. Remotely operated undersea welding equipment may remove the need for diving welders to enter dangerous environments. ROVs will be used to operate subsea infrastructure, and AUVs will be used for subsea inspection and survey. Similarly, robots may be used to perform confined space inspections of pipelines and tanks, as well as gas and fire detector testing, sampling, pigging, cleaning, and refilling.[166]

Moreover, there is considerable potential to drive down the costs of non-routine inspection and maintenance with digital technologies such as Virtual Reality (VR), Augmented Virtuality (AV) and Augmented Reality (AR). Non-experts can be trained by VR, can visualise complex information more efficiently with AV, and perform interventions with the aid of remote expertise via AR. In the longer term, it is anticipated that remote-controlled or even autonomous robots will be used to conduct the majority of non-routine inspection and maintenance tasks.

Remote operations in the offshore environment are already occurring with some smaller platforms already unmanned. These 'Not Normally Manned' or 'Nominally Unmanned Installation' production facilities are controlled and monitored remotely through ROCs. Remote operations will be further enabled by developments in reliable electrically-driven subsea production and processing, reducing the need for expensive offshore platforms and associated onshore infrastructure. For example, subsea compression equipment can extend the feasible length of long tie-backs to bring new fields into existing processing facilities. Automation is a critical aspect of subsea processing as the equipment is required to run autonomously for many years in order to fully realise potential capital savings. Robotics, either remotely operated or autonomous, are needed to perform inspection and maintenance interventions. The Australian industry could take the lead in the development and testing of subsea technologies, including lightweight and efficient processing equipment such as boosters, compressors and separators. Advances in these technologies are critical to the further economic development of Australia's remote offshore resources.

166 Stavinoha, S., et al (2014). *Challenges of Robotics and Automation in Offshore Oil & Gas Industry*, the 4th Annual IEEE International Conference on Cyber Technology in Automation, Control and Intelligent.

FIGURE 18: KEY PROSPECTIVE TECHNOLOGY OUTPUTS AND SOLUTIONS

SHORT TERM (0 – 3 YEARS)	MEDIUM TERM (3 – 10 YEARS)	LONG TERM (10+ YEARS)
Robotics, automation and remote operations		
• Remote, real time drill steering • Tele-operated robotics for remote and assistive automation of manual tasks • Shared remote operations centres to centrally monitor production • Remote UAV-based inspection of linear assets (e.g. pipelines) and equipment at height (e.g. flare stacks, ducting, pipe racks, vents) • Continuous monitoring for leaks and spills • AR technologies for remote assistance, collaboration and supervision • VR and AV simulation training • In-pipe inspection robots (IPIRs) and tank inspection robots (TIRs) • Advanced ROVs for monitoring of offshore, underwater structures • Long tiebacks to existing infrastructure to connect increasingly remote offshore resources • Standardised functional requirements and components for subsea pumping • 'Retrofittable' IoT devices (sensors) for monitoring on key plant assets	• Advanced diagnostic tools to detect sensor failures and false positives • Fully automated robotic drilling and well completion • Rapid and reliable 3D printing of complex parts • Autonomous inspection and maintenance of submerged structures and onshore processing facilities • Automated internal non-destructive pipeline inspection • Robotic amphibious vehicles (RAVs) (i.e. a combination of autonomous air, land and sea unmanned vehicles[167]) used for remote inspection across onshore and offshore applications • Self-powering, robust wireless sensor network technology for low cost monitoring of pipelines, rigs, wells, tanks and process equipment. • Smaller footprint centrifugal subsea compression • Long-life and self-healing pipeline structures • Collaborative AR and VR platforms that promote rapid communication and decision-making	• Fully autonomous inspection robots, including self-powered downhole robots that can operate during production to track temperature, pressure and flow regimes • Autonomous vehicles for consumable provision transport • Robotic maintenance intervention which is remotely monitored and autonomous • Autonomous shapeshifting robots for confined space inspections • Natural User Interfaces moving away from keyboard/mouse/screen • Unmanned floating LNG[168] • Platform-free offshore fields enabled by ultra-long tie-backs[169] • Subsea and downhole wireless monitoring systems • 4D printing using advanced materials

167 Shukla, A., Hamad, K., (2016). *Application of robotics in offshore oil and gas industry – A review Part II*, Robotics and Autonomous Systems Vol 75, pp 508490–507.
168 DNV GL (n.d.). *Solitude - Unmanned FLNG concept,* [Online] Available from: https://www.dnvgl.com/technology-innovation/flng/ Accessed 2/06/2017
169 CSIRO (n.d.). *Subsea Pipeline Collaboration Cluster – final report*, [Online] Available from: http://www.cofs.uwa.edu.au/__data/assets/pdf_file/0018/2343510/FINAL-Subsea-Pipeline-Cluster-Report-56pp.pdf Accessed 2/06/2017

Optimising operations and supply chains

Although digital technologies are not new to the oil and gas sector the full potential of these technologies has not yet being realised. Some estimates show that operators are using less than 1% of the data being captured at the well.[170] Improving operational and maintenance efficiencies represents a huge opportunity that digital technology can unlock. By using data from sensor networks and cloud-based analytics, companies can reliably predict the probability of equipment and process failures in order to reduce or eliminate unplanned maintenance and costly down-time.[171] The economic benefits of this are significant. For example, GE estimates that unplanned outages cost the LNG industry approximately US$11 million per day.[172] Furthermore, unplanned downtime is estimated to cost offshore oil and gas organisations US$49 million annually.[173]

Cognitive computing platforms (for example, IBM's Watson and Google's Deepmind) can digest reams of historical data and documents, and be trained to interact with human operators to provide insights used to inform decisions. These technologies apply reasoning and learning to very large data sets and can help to rapidly retrieve information and find answers to complex operational problems. Cognitive computing can use both structured and unstructured data, including documents, diagrams, and even weather reports, to build a knowledge base.

Supply chain optimisation is another application for digital technologies; helping to seamlessly communicate production, operational and logistical data throughout the supply chain in order to optimise operations for the many different businesses involved. Big data analytics and AI can be applied to more efficiently match supply with demand,[174] while Blockchain technology may be employed to streamline contracts and payments to gain further efficiencies.[175]

170 Womack, D., et al (2016). *Exploring the power of cognitive IoT,* IBM Corporation.

171 Pearce, R., (2016). *How the IoT and cloud are paying off for Woodside,* Computerworld, [Online] Available from: http://www.computerworld.com.au/article/598875/how-iot-cloud-paying-off-woodside/ Accessed 01/06/2017

172 Thomas, K (2016). *Digitisation decisive in cutting LNG project costs, says GE's Simonelli,* LNG World Shipping, [Online] Available from: http://www.lngworldshipping.com/news/view,digitisation-decisive-in-cutting-lng-project-costs-says-ges-simonelli_42573.htm Accessed 26/06/2017

173 GE (2016). *The impact of digital on unplanned downtime – an offshore oil and gas perspective.*

174 Booth, A., Mohr, N., Peters, P., (2016). *The digital utility: new opportunities and challenges*, McKinsey&Company, [Online] Available from: http://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/the-digital-utility-new-opportunities-and-challenges

175 World Economic Forum (2017). *Digital Transformation Initiative: Oil and Gas Industry*, Geneva.

FIGURE 19: KEY PROSPECTIVE TECHNOLOGY OUTPUTS AND SOLUTIONS

SHORT TERM (0 – 3 YEARS)	MEDIUM TERM (3 – 10 YEARS)	LONG TERM (10+ YEARS)
Optimising operations and supply chains		
• Leveraging historical data and advanced analytics to minimise downtime by predicting failures and process disruptions, and to proactively schedule maintenance actions • Integrated, cross-company scheduling and logistics platforms to support maintenance activities to minimise downtime • Platform-as-a-service integrating multiple data sources allowing for broader insights and easier operation • Machine learning-based analytics algorithms aimed at optimising maintenance operations • Integration of Robotics Process Automation technologies to exploit efficiencies in current generation software systems • Digital Twins that represent virtual and physical infrastructure and processes for improved simulation, analysis and control	• AI (e.g. machine learning algorithms) embedded into operations, maintenance and process controls, thereby eliminating unplanned maintenance • Conversant cognitive computing platforms to support operations and pre-emptive maintenance • AI develops all maintenance schedules and activities, including route planning and logistics operations	• End-to-end digitalisation of operations and maintenance, linking everything from predictive maintenance to the dispatch and payment of vendors • AI embedded in production control systems, effectively linking digital operations directly to the relevant supply chains and to market data, using real-time data to shift production levels and optimise Net Present Value (NPV) of assets[176]

Technology spotlight

Woodside – the Internet of Things, advanced analytics and cognitive computing drives operational efficiencies and cost reductions

Woodside has invested in advanced digital technologies to help improve operations – outfitting its Pluto LNG plant with over 200,000 sensors. Data from these sensors are stored in the Cloud and managed by third party services. Data are fed into over 6,000 statistical modules, where machine learning algorithms predict operational problems and maintenance issues, providing Woodside with days, and sometime weeks, of advanced warning of potential process upsets.[177]

Woodside is also investing heavily in cognitive computing; for instance, using IBM's Watson cognitive capability to become an expert in the company's operational history. Woodside has provided Watson with 30 years of operational detail, including nearly 30,000 historical documents, with the view to recognising patterns and generating new insights from them. Engineers can converse with Watson in natural language and obtain answers to their queries in seconds – a process which drives operational efficiencies and cost savings.

176 World Economic Forum (2017). *Digital Transformation Initiative: Oil and Gas Industry*, Geneva.

177 Pearce, R., (2016). *How the IoT and cloud are paying off for Woodside,* Computerworld, [Online] Available from: http://www.computerworld.com.au/article/598875/how-iot-cloud-paying-off-woodside/ Accessed 01/06/2017

4.2.2 ENABLING SCIENCE AND TECHNOLOGY

Many digital technologies are still in their infancy, requiring further development prior to meaningful integration and adoption. For example, robots are largely constrained to single tasks, and currently lack the robustness and dependability to enable completely autonomous operations. Integration of components into a systems-level framework or platform will be critical in enabling the future development of digital oil and gas solutions.

Research priorities to enable these technical developments are detailed below.

RESEARCH PRIORITIES

Sensors, networks and analytics

- Architecture platform frameworks for integrating component technologies.
- Miniaturisation of sensors, imaging and mapping technologies, such as light-weight LIDAR (Light Detection and Ranging remote sensing), advanced photogrammetry technologies, and thermal imaging technologies for non-destructive monitoring and inspection of enclosed structures (e.g. tanks).
- Improved durability, connectivity, accuracy and application of sensors for real-time monitoring across production infrastructure.
- Intrinsically safe networks and communications, and robust cybersecurity solutions that act in anticipation to prevent unauthorised and malicious access to digital infrastructure.
- Interoperability of software and systems and common standards to ensure plug-and-play solutions for networking of equipment.
- Intelligent/smart sensors able to process system and resource data on board, allowing real-time, highly accurate decisions and corrective action.

Robotics and unmanned vehicles

- Advanced, more dexterous end-of-arm tooling such as intelligent grippers, vacuum grippers and others that are application specific.
- Robots with improved computational ability, navigation, and situational awareness, allowing autonomous movement, repair, self-calibration and the ability to change behaviours in variable environments.
- Improved machine-to-machine communication, interoperability, positioning and signal processing between different types of autonomous robots and unmanned vehicles.
- Improved robustness and durability of robotic units, associated electronics and drive systems to allow 'all-terrain' operation for environments typical of offshore platforms, subsea operations or onshore facilities.
- Machine vision to allow robots to develop perception and situational awareness to safely interact with humans and their environments, particularly on offshore platforms.
- Increased energy density and miniaturisation of batteries for autonomous robots, and software to optimise the use of on-board power.
- Improved human–machine interface, including tele-operation and tele-supervision.

Virtual and Augmented Reality

- Advanced software and hardware for virtual and augmented reality, such as motion-tracking and haptic-feedback to support Natural User Interface (NUI).
- Advanced mobile and wearable technologies that make use of AR interfaces to improve training and operation efficiency, by providing contextual, *in-situ* information.

Integrating advanced materials

- Advanced materials and additive manufacturing (3D printing) developments focusing on light weighting, energy harvesting, strength and functionality.
- Advanced materials with pervasive sensing that can be applied to equipment and infrastructure, and can monitor a range of environmental and process indicators.
- Corrosion resistant and maintenance-free composite materials for subsea production applications and long-lifespan pipelines, including materials and technologies to prevent the formation of hydrates in long tie-backs.

4.2.3 BUSINESS ECOSYSTEM CHANGES

In order to unlock this opportunity several suggestions for improving the business ecosystem are presented for consideration.

PROCESSES, STANDARDS AND REGULATIONS

- Support the development of common industry standards like data sharing protocols and open systems architectures to enable process automation and help to ensure interoperability and security, leading to faster innovation cycles around IoT integration.
- Ensure regulatory frameworks clearly enable seamless integration of disparate digital technologies.
- Embed cyber security into all digital development initiatives.
- Improve digital infrastructure and enable high-speed remote internet connectivity.

PEOPLE, SKILLS AND COLLABORATION

Companies will need to prioritise and actively support digital transformation and integration efforts.

- Address the existing divide between information technology (IT) and operational technology (OT) staff to increase the chances of efficiency gains.
- Operators and the supply chain may need to share and integrate scheduling data in order to coordinate O&M activities, and to maximise efficiency and minimise operational down time.
- Build a collaborative culture to facilitate rapid development and adoption of innovative digital technologies.
- Identify workforce skills gaps in the application, operations and maintenance of digital technologies, including: specialist IT skills required for future site technicians, upskilling for remote operators that do not have hands-on operational experience, and digital literacy skills to help manage autonomous and robotic equipment.
- Work with industry associations to establish collaborative agreements to maximise use of national High Performance Computing infrastructure to improve the modelling of large datasets.
- Improve collaboration and exchange learnings with other industries, such as manufacturing, automotive and airline industries.

Advanced environmental solutions and processes

Developing technologies and processes that reduce the environmental and social impacts of field developments and processing plants may also provide financial benefits to the Australian oil and gas sector.

RELATED MEGATRENDS

- Carbon constrained
- Socially concerned
- More complex and costly

KEY STATISTICS

- Globally, it is estimated that 30% of gas reserves have a CO_2 content of between 15% and 80%.[178]
- In Queensland, CSG water production in 2015–16 was 60,499ML from 5,127 wells (enough to fill over 24,000 Olympic-sized swimming pools).[179]
- Australia's nine major LNG projects[180] could contribute at least 50 million tonnes of CO_2 emissions per annum, based on the projected amount of vented CO_2 gas separated from the methane streams and from the energy used to run the liquefaction process.[181]
- Increasing interest in decommissioning technology: 350 patents filed globally between 2010 and 2015 in the category of plugging and abandonment techniques.[182]

178 Baccanelli, M., et al (2016). *Low temperature techniques for natural gas purification and LNG production: An energy and exergy analysis*, Applied Energy Vol 180.

179 Queensland Department of Natural Resources and Mines (2017). *Petroleum and gas production and reserve statistics,* [Online] Available from: https://data.qld.gov.au/dataset/petroleum-gas-production-and-reserve-statistics Accessed 13/06/2017

180 APLNG, Browse, GLNG, Gorgon, Icthys, Pluto, Prelude, QCLNG, and Wheatstone

181 Reuters (2011). *Green Business News, Factbox: Projected CO2 emissions from top Australia LNG projects,* [Online] Available from: http://www.reuters.com/article/us-australia-lng-carbon-fb-idUSTRE7491FU20110510 Accessed 12/07/2017

182 Frost & Sullivan (2016). *Oil and Gas Technology (TechVision)*, Mountain View.

4.3 Advanced environmental solutions and processes

The oil and gas sector faces several environmental and social challenges.

Firstly, the sector is energy intensive, consuming about 20% of its output for its own needs.[183] Becoming more efficient would reduce the sector's energy intensity and would help the sector reduce its emissions intensity, thereby supporting Australia's global commitments made to meet the COP21 goals.

Secondly, there are growing stakeholder concerns and opposition to the oil and gas industry. This has been particularly evident in onshore unconventional developments, and in development of new basins and infrastructure offshore. There is also growing opposition to the continued focus on non-renewable energy sources. Onshore, key concerns relate to land access, threats to water and air quality, and effects on native flora and fauna. Offshore, stakeholder concerns are largely focused on the potential impacts of oil spills. However, other issues, such as impacts of sound on marine life, are also generating wider stakeholder interest.[184]

Lastly, due to the number of ageing facilities in Australia, the decommissioning of wells and infrastructure will become a growing focus of both industry and government, and is also likely to generate interest from stakeholders and other users of the marine and terrestrial environments.

Given these and other pressures, there is considerable opportunity for Australian research organisations and oil and gas companies to develop a range of new solutions, ranging from technologies to improve environmental outcomes to new methods for decommissioning infrastructure. New technologies can improve water and air quality and help to mitigate environmental concerns.

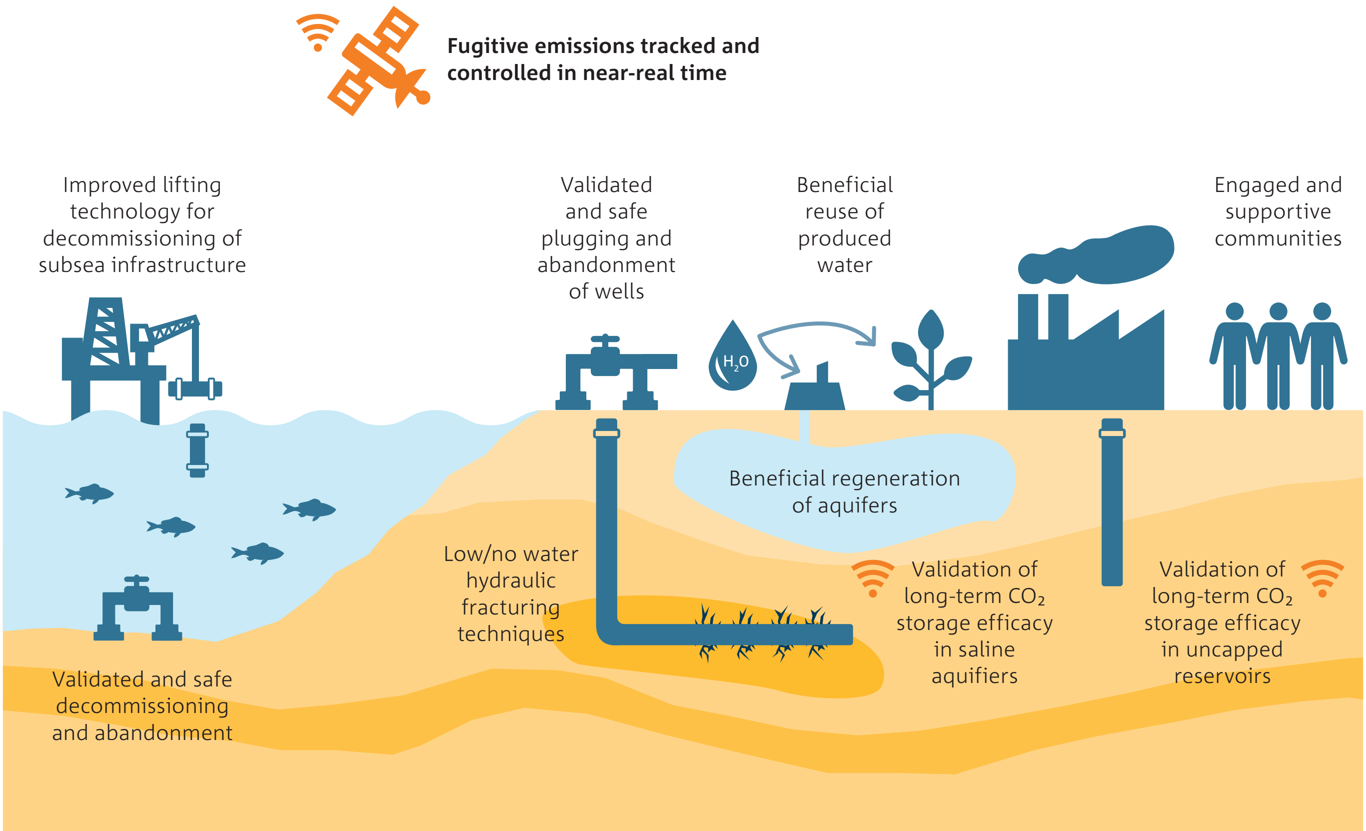
This section focuses on just three potential applications for advanced environmental solutions, noting that there are many more pathways that could be pursued:

- Water quality and reuse – technologies to combat contamination of water and to manage the largest waste stream from the oil and gas sector.
- Mitigating greenhouse gas emissions – solutions to minimise, utilise, or effectively store CO_2 and other emissions.
- Efficient and environmentally-responsible decommissioning – solutions and processes to ensure Australia plans for and conducts decommissioning in ways that provide the best social, economic and environmental outcomes.

183 World Energy Council (2013). *Energy Efficiency Technologies: Overview Report,* London.

184 Tollefson, J. (2017). *Air guns used in offshore oil exploration can kill tiny marine life,* Nature News, [Online] Available from: https://www.nature.com/news/air-guns-used-in-offshore-oil-exploration-can-kill-tiny-marine-life-1.22167 Accessed 5/07/2017

FIGURE 20: A SAMPLE FUTURE VISION FOR ADVANCED ENVIRONMENTAL SOLUTIONS AND PROCESSES



4.3.1 POTENTIAL APPLICATIONS

Water quality and reuse

Better technologies are needed to allay water concerns on multiple fronts.

Firstly, some CSG and (future) shale developments may require drilling through water aquifers. This will require robust water treatment processes and technologies to prevent contamination of groundwater, and affordable sensor network technologies to monitor and verify it. This is a primary concern of stakeholders, especially landholders, farmers and remote communities, who rely on groundwater for their livelihood. Technologies that monitor and prevent groundwater contamination and treatment technologies are vitally important to the sector, and are expected to undergo rapid development and improvement. Developments such as advanced bio and nano-sensors, affordable sensor networks, and *in situ* remediation technologies, are needed.

Secondly, improved technologies are needed to manage water, both onshore and offshore. For example, an onshore CSG well in Queensland averages 30,000 litres of produced water per day.[185] This produced water is usually high in salt and contains contaminants that must be separated before disposal or reuse. Currently, this water is either placed in large holding ponds or piped great distances to centralised processing facilities. Centralised processing does not afford any opportunity for the water to be reused where it was produced, opening up an opportunity to develop low-cost, distributed water treatment technology to be located near the well head.

185 APPEA (n.d.). *Water volume FAQ*, [Online] Available from: https://www.appea.com.au/industry-in-depth/technical-information/water/water-volume/water-volume-faq/ Accessed 30/06/2017

A related problem is the large amount of salt by-product contained in CSG produced water.[186] The high likelihood of increasingly stringent environmental regulations related to production effluent[187] will translate into higher production costs, unless cost-effective treatment, re-use, monitoring and verification technologies can be developed. In the marine environment, baseline measurement and operational monitoring is needed to enable, among other things, cost-effective and robust spill preparedness and response.

Offshore, there is ongoing debate regarding best practice management of produced water, largely in relation to the fate and effects of various chemicals within the produced water. The global produced water to oil ratio is approximately 3:1, and the produced water ratio for gas is even higher.[188] This remains an area of focus for regulators, and continues to be an ongoing area of uncertainty and expense for offshore operators. New technologies and solutions that help to improve water treatment processes, while, at the same time, accommodating the space and weight limitations and motion on offshore platforms, will be increasingly important.

Thirdly, where possible, beneficial reuse of produced water is an attractive solution for the sector, especially in water-scarce regions of Australia where competition for water may be an issue. Reuse applications include aquaculture, agriculture, coal washing, construction, landscaping and revegetation, industrial and manufacturing operations, research and development, incidental land management, and recharging of aquifers. The Chinchilla Beneficial Use Scheme highlights the potential for reusing CSG produced water. High-quality treated CSG water is piped to the Chinchilla Weir, where it supplements the water available for use by irrigators in the area.[189]

Fourthly, many future unconventional plays will require water to support hydraulic fracturing of the source rocks. Shale and other tight gas resources will require high-pressure water to introduce fissures into the rock to stimulate gas flow from the highly compact source rock material.[190] Finding source water may be problematic in water-scarce areas of Australia, prompting the need to find low or no-water fracturing technologies (also refer to Section 4.2.2). Locally sourced low-quality (e.g. brackish) water, or produced water from other operations (if transport distance is feasible), should be researched as viable alternatives.

Overall, in terms of managing all of these water inputs, best practices will need to be employed to reduce the perceived risks of spills, avoid subsurface contamination, and to appropriately manage the use of surface waters.

186 Arrow Energy (n.d.). *Coal seam gas water and salt management strategy.*

187 Society of Petroleum Engineers (n.d.). *Challenges in Reusing Produced Water*, [Online] Available from: http://www.spe.org/industry/challenges-in-reusing-produced-water.php Accessed: 2/06/2017

188 Zheng, J., et al (2016). *Offshore produced water management: A review of current practice and challenges in harsh/Arctic environments,* Marine Pollution Bulletin, Vol 104, Iss 1–2, pg 7–19.

189 SunWater (n.d.). *Chinchilla Weir,* [Online] Available from: http://www.sunwater.com.au/schemes/chinchilla-weir Accessed 30/06/2017

190 Cook, P., et al (2013). *Engineering energy: unconventional gas production.* Report for the Australian Council of Learned Academies.

FIGURE 21: KEY PROSPECTIVE TECHNOLOGY OUTPUTS AND SOLUTIONS

SHORT TERM (0 – 3 YEARS)	MEDIUM TERM (3 – 10 YEARS)	LONG TERM (10+ YEARS)
Water quality and reuse		
• Impact modelling tools and studies for application specific beneficial reuse of produced water • More energy efficient distillation, membranes, adsorption, capacitive deionisation, electrodialysis, ion exchange, hydrocyclone, and media filtration technologies • More energy efficient dehydration and water treatment technologies • Cost effective tools for conducting baseline characterisation operational monitoring in the marine environment, including spill detection technologies	• Miniaturised separations and processing equipment for select downhole uses • Routine aquifer injection of purified CSG water • Conversion to beneficial products, or safe disposal techniques for salt by-product from CSG produced water • Biotechnology-based treatment solutions for produced water • Cost-efficient desalination techniques, including forward osmosis, and humidification-dehumidification technologies • Validated fate and transport models and adsorption/decomposition models for hydraulic fracturing and drilling mud chemicals • Distributed, small-scale, produced water processing plants at the wellhead to support CSG operations and provide clean water for local use	• All separations and pre-processing are conducted in the well bore in the subsurface • CSG brine water left downhole • Low quality water and low/no water fracturing techniques

Reducing greenhouse gas emissions

With the energy sector under pressure to reduce its carbon footprint, increasing focus will be placed on the energy intensity of operations, as well as venting and flaring practices. Although energy efficiency measures, integration of renewable energy and processes to convert waste gases instead of flaring (see Section 4.4, for instance) have the potential to reduce the sector's emissions intensity, the high CO_2 content of many gas reserves make this task difficult. Globally, it is estimated that 30% of gas reserves have a CO_2 content of between 15% and 80%.[191] If and when these reserves are produced, the sector will be pressured to either treat or avoid producing the CO_2 altogether (for example, by leaving it in the reservoir). Development of technologies that directly help the sector to reduce such emissions should be a priority.

Carbon Capture, Utilisation and Storage (CCUS)

CCUS refers to the set of technologies used to capture, transport, and store or utilise CO_2 emissions, preventing them from otherwise being released into the atmosphere. Despite its potential value in decarbonising the energy sector, global deployment of CCUS has been limited. For example, there are only 17 large-scale Carbon Capture and Storage (CCS) projects operational globally.[192] Of these, only four are dedicated geological storage. The Global CCS Institute ranks Australia highly in its CCS Readiness Index.[193] However, there are only a few active projects and only one commercial scale plant application – Chevron's Gorgon Carbon Dioxide Injection Project, which is expected to become operational in 2017, sequestering between 3.4 and 4 MTPA of CO_2.[194]

191 Baccanelli, M., et al (2016). *Low temperature techniques for natural gas purification and LNG production: An energy and exergy analysis*, Applied Energy Vol 180.

192 Global CCS Institute (2017). *Large-scale CCS facilities,* [Online] Available from: https://www.globalccsinstitute.com/projects/large-scale-ccs-projects Accessed 04/09/2017

193 Consoli, C., Havercroft, I., Irlam, L., (2016). *Carbon capture and storage readiness index,* Global CCS Institute.

194 Global CCS Institute (2017). *Gorgon Carbon Dioxide Injection – Projects Database, [Online] Available from: https://www.globalccsinstitute.com/projects/gorgon-carbon-dioxide-injection-project Accessed 10/7/2017*

As the costs of capture and sequestration decrease, the oil and gas sector may be able to deploy the technology to assist in lowering the carbon intensity of its own operations. For example, LNG plants already employ CO_2 separations technologies, so a portion of the costs are already covered and sequestering it remains. New offshore gas fields with higher CO_2 content are also logical targets for capture and sequestration, particularly if this gas could be captured and reinjected offshore before being brought to shore. Using waste CO_2 for enhanced oil recovery (EOR) is a possibility; however, due to the distance between the high-CO_2 gas fields (usually located offshore) and applicable oilfields, dramatic cost reductions in transport methods would be needed.

There may be an opportunity for the sector to store CO_2 in novel geologic formations. Currently only capped reservoirs – both relatively unconfined aquifers and depleted oil or gas fields – are used for CO_2 storage projects. However, these fields are limited in number in Australia which, in turn, constrains the potential locations for sequestration. If more ubiquitous saline aquifers and uncapped formations could be utilised to store CO_2, this would improve the chances that suitable sequestration locations could be found for new gas projects. These novel geologies, of course, need validation, but this can be accomplished using advanced computer modelling and through pilot studies leveraging the latest advances in monitoring, measurement and verification (MMV) technologies. Of course, the economics of such endeavours will be driven by a price on carbon emissions.

Proving that storage can work in many types of geologic formations would directly support efforts to decarbonise coal-fired power generation. It will open up opportunities for injection much closer to existing coal fired power plants, thereby improving the economics of capture and storage, and helping the electricity generation sector to meet its regulatory requirements. If coal is to remain a large part of the electric power generation capacity of Australia and other parts of the world, capture and storage will almost certainly be required in the coming decades.

Taken together, this could present an opportunity for oil and gas firms to expand into new markets (if a cost on carbon is levied) by leveraging the sectors geologic expertise and applying it to the downstream power sector.

CO_2 utilisation (i.e. the beneficial use or conversion of CO_2) is a potential long term opportunity for the oil and gas sector to move into chemicals and higher-value fuels, and to establish new revenue streams. Already CO_2 and other feedstocks can be converted into chemical intermediates like methanol and formic acid, and in some cases CO_2 is being used for more novel applications like microalgae production for fish feed. However, the cost of conversion is currently high, and smaller-scale efficient conversion systems are needed. Furthermore, it is important to note that CO_2 conversion technologies are not emission reduction pathways because no market for any chemical product is large enough to deal with the amount of CO_2 needing abatement globally.

Fugitive emissions, flaring and venting

Fugitive emissions associated with this sector are those emissions released during the extraction, processing and delivery of oil and gas. In 2015, fugitive emissions from oil and gas were estimated to be 14 Mt CO_2e – accounting for 2.7% of Australia's total emissions. By 2030, these emissions are projected to increase by 25% on 2015 levels, with emissions from LNG production expected to more than double.[195] Fugitive emissions have a direct impact on profit margins, so there is an explicit commercial incentive to reduce them but only if those methods are cost-effective.

There is an opportunity for the sector to build upon Australian experience and expertise, and lead the way in developing novel methods to cost-efficiently monitor and minimise fugitive emissions from the sector; in particular, in unconventional gas, due to the high global warming potential of methane. For example, efforts are underway to remotely identify, track and measure the volume of methane emissions from thousands of wellheads, and hundreds of kilometres of pipeline infrastructure, using lasers and space-based hyperspectral imaging.

195 Department of Environment and Energy (2016). *Australia's emissions projections 2016,* Commonwealth of Australia.

Flaring is the controlled burning of waste gas streams, while venting is the practice of releasing gas streams to the atmosphere. Both practices lead to the release of emissions and need to be minimised through improved operational practices and by technological solutions such as advanced process control.[196] Flared gas represents 4% of the total gas produced globally, prompting the World Bank Group to lead an effort to reduce it through the 'Zero Routine Flaring by 2030' initiative.[197] Improved methods to cost-effectively capture and use or convert gases that are typically flared will directly improve process economics in oil and gas fields. For example, the LNG production plants in Australia provide an excellent opportunity to embed best practice and reduce venting and flaring, and to test and incorporate novel technologies for capture and abatement.

A solution for flaring offshore, where space and weight on the platform are at a premium, is particularly attractive. However, this would require significant improvements in process miniaturisation (to separate and convert gases), together with novel storage and/or transport solutions. One potential solution here may be the refuelling of seafaring vessels with traditionally flared gases that are captured and repurposed.

FIGURE 22: KEY PROSPECTIVE TECHNOLOGY OUTPUTS AND SOLUTIONS

SHORT TERM (0 – 3 YEARS)	MEDIUM TERM (3 – 10 YEARS)	LONG TERM (10+ YEARS)
Reducing greenhouse gas emissions		
• Compact, low-cost energy efficient waste gas separation equipment • More robust amine compounds with greater longevity and higher operating temperatures • Optimised hybrid gas treatment processes (e.g. membranes and cryogenic separations) • Advanced process control to reduce LNG flaring and venting	• Validation of long-term storage efficacy of CO_2 in saline aquifers • Cheap and efficient long-term passive measuring, monitoring, and verification of CCS • Low-cost UAV-based or remote sensing and monitoring of fugitive emissions • On-site reuse of traditionally flared or vented gas • Reduced CO_2 storage field development costs	• Validation of long-term storage efficacy of CCS in uncapped reservoirs • Cost-effective direct conversion of CO_2 to beneficial products via novel catalysts • Near-zero energy CO_2 capture technology • Nanomaterial based photo-electochemical cells for CO_2 conversion

196 Campey, T., et al (2017). *Low Emissions Technology Roadmap.* CSIRO, Australia.

197 The World Bank (2017). *Zero Routine Flaring by 2030*, [Online] Available from: http://www.worldbank.org/en/programs/zero-routine-flaring-by-2030#1 Accessed 6/06/2017

Efficient and environmentally-sound decommissioning

Planning for the entire lifecycle of resource development projects provides significant opportunity to minimise the future cost liabilities to the sector. This is particularly true with decommissioning activities, which occur when oil and gas facilities reach the end of their productive life.

It is estimated that Australia's future decommissioning liability is US$21 billion over the next 50 years.[198] By 2040, it is estimated that over 100 offshore installations in Australian waters will require decommissioning.[199] This liability stems largely from offshore petroleum infrastructure installed in the Bass Strait from the 1960s, and the North West Shelf in the 1980s. Onshore liability could also be very significant over the longer term, considering the large number of wells in the CSG industry, and the similar geographic span of future unconventional developments like shale.

There is a significant opportunity to minimise the economic impact by developing new best-practices and advanced technologies for decommissioning, alongside new uses for infrastructure prior to decommissioning. Better understanding of the decommissioning process could enable the tailoring of new infrastructure in ways that reduce end-of project liabilities, optimise environmental and safety outcomes, and minimise legacy costs.

For example, new technologies that more cost-effectively plug and abandon wells could result in significant savings. Another opportunity – which may present the optimal environmental, social and economic outcome in some circumstances – may be to leave offshore infrastructure in place or transition it for other uses, such as offshore wind farms or the development of tidal energy. Leaving subsea offshore infrastructure in place is predicated on the notion that its removal might cause more damage than leaving it in place. For example, transforming the infrastructure into artificial reefs may be a better option.[200] This option may also eliminate the need to put divers in high-risk situations to remove infrastructure embedded in or on the sea floor, or eliminate the need for costly robotics to do the same. However, more research is required by industry, government and stakeholders to provide the scientific evidence necessary to enable comprehensive assessment of all decommissioning alternatives.[201]

198 Accenture (2016). *Oil & Gas Industry Competitiveness Assessment*, NERA.

199 DecomWorld (2016). *DecomWorld: Decommissioning and Ageing Asset Market Map 2016*.

200 Chandler, J., White, D., Techera, E., (2017). *Engineering and legal considerations for decommissioning of offshore oil and gas infrastructure in Australia*, Ocean Engineering, Vol 131.

201 Western Australian Marine Science Institution (n.d.). *Decommissioning offshore infrastructure: a review of stakeholder views and science priorities - Draft Report*, [Online] Available from: http://www.marinescienceblueprint.org.au/sites/default/files/Decommissioning%20offshore%20infrastructure%20a%20review%20of%20stakeholder%20views%20and%20science%20priorities.pdf Accessed 6/07/2017

FIGURE 23: KEY PROSPECTIVE TECHNOLOGY OUTPUTS AND SOLUTIONS

SHORT TERM (0 – 3 YEARS)	MEDIUM TERM (3 – 10 YEARS)	LONG TERM (10+ YEARS)
Efficient and environmentally-sound decommissioning		
• Forecasting model to generate reliable estimates of decommissioning costs • Improved lifting and cutting technology for decommissioning of subsea infrastructure • Improved land remediation technologies • Integrate improved decommissioning planning into upfront infrastructure planning	• Cost efficient long-term passive monitoring of decommissioned infrastructure, especially in subsea environments • Sophisticated modelling tools for environmental impact of various decommissioning options • Clear regulations enabling assessment and approval of all decommissioning approaches, and detailed guidelines to support decision-making • Cost efficient and smaller footprint technologies/methodologies for plugging and abandoning wells • New waste management technologies for decommissioned infrastructure, including treatment and recycling solutions	

Technology spotlight
LanzaTech

Founded in 2005, LanzaTech has commercialised a carbon capture and reuse technology that captures CO_2-rich waste gases and converts them to high value fuels and chemical intermediates. This company has received over US$150 million in investment from companies including Kohsla Ventures, Siemens and PETRONAS, and the technology has been successfully deployed in a number of sectors, including steelmaking and oil and gas.

The technology is based on a gas fermentation process. LanzaTech's proprietary microbes have the capability to produce 20 different compounds, including ethanol, 1,2-Butadiene and 2,3-Butanediol; the latter being important chemical intermediates used in the production of nylon and rubber products. In collaboration with PETRONAS, the company is working on acetic acid-to-lipids pathways to produce jet fuel, diesel and gasoline.[202]

202 LanzaTech (2017). [Online] Available from: http://www.lanzatech.com/ Accessed: 25/07/2017

4.3.2 ENABLING SCIENCE AND TECHNOLOGY

A variety of technologies and research programs are needed to facilitate these advanced environmental technology and process outcomes. They range from advanced separations technology and new materials to more nuanced understanding of marine ecosystems. Research priorities to enable these technical developments are detailed below.

RESEARCH PRIORITIES

Separations

- Downhole separation of water and contaminants.
- Advanced designer amines that rejuvenate at higher temperatures and last longer.
- Less-energy intensive solvent regenerative systems.
- Alternative gas-capture mechanisms like Metal-Organic Frameworks.
- Nanomaterial separation technologies such as carbon nanotubes and/or graphene.

Sensors

- Space-based hyperspectral imaging of chemical signatures from fugitive emission.
- Next-generation low-cost technologies for MMV of CO_2 storage such as Distributed Acoustic Sensing (DAS) fibre-optics.
- Robust long-lasting sensors for biological system health monitoring.
- Sensors to ensure integrity of plugged and abandoned wells.

Studies and modelling

- All Australian capped reservoirs suitable for CCS fully identified and studied.
- Advanced characterisation of CO_2 storage sites, including exploration and appraisal of alternative basins such as saline aquifers and uncapped geological horizons.
- Detailed and accurate modelling of hydraulic fracturing, including induced seismicity, and accurate fate and transport models for input materials.
- Monitoring of impacts of offshore sound generation on marine life.
- Research to provide clear evidence of the environmental acceptability of different decommissioning options, such as the environmental and biological impacts of leaving decommissioned infrastructure *in situ*.

Materials

- Identify novel pipeline materials, sealing, and joining technologies to reduce fugitive and CO_2 emissions.
- Fracturing proppants that are mobilised in non-aqueous fracturing solutions.
- Self-healing materials and structures to ensure well integrity and materials to expand lifespan of pipelines.
- Low-cost and long-lasting well-plugging material alternatives to cement.

Processes and equipment

- Advanced catalysts and micro-channel reactors to facilitate conversions of waste products like CO_2 that improve selectivity, reduce side reactions and increase catalyst life.
- Improved procedures and more modular tools with smaller footprint for decommissioning.
- Modelling, monitoring and treatment improvements for produced water.
- Integrated processes and equipment for CO_2 capture, conversion and utilisation from high CO_2 content gas fields.

4.3.3 BUSINESS ECOSYSTEM CHANGES

In order to unlock this opportunity, several suggestions for improving the business ecosystem are presented for consideration.

PROCESSES, STANDARDS AND REGULATIONS

- Consider the impact of a potential future cost on carbon, or similar regulatory framework, which would provide the economic impetus for capture and storage, particularly for fields with small percentages of CO_2.
- Support the development of standards and practices for tracking of fugitive emissions in all aspects of onshore gas operations, not just wellheads.
- Adoption of fit-for-purpose water design codes for produced water and brine systems.
- Assess the impacts of all decommissioning options, as well as jointly investing in technologies and processes that help to minimise adverse effects of decommissioning oil and gas infrastructure.
- Development of CCS standards and protocols for novel formation types.
- Development of industry-wide spill operational response and scientific monitoring protocols.

PEOPLE, SKILLS AND COLLABORATION

- Increase collaboration around new developments at the basin-scale. Companies, as well as local, federal and state agencies should coordinate more effectively in the planning stages to ensure that environmental, social and economic benefits are fully realised in the long-term.
- Align and collaborate to share the costs of common infrastructure, and minimise the impact on the environment of new large-scale projects.
- Increase collaboration to share the costs of environmental surveys and monitoring.

High-value diversification

Businesses should consider adapting their business models and diversifying into higher-value product and service offerings to gain competitive advantage and hedge against an uncertain future energy mix.

RELATED MEGATRENDS

- Carbon constrained
- Socially concerned
- More complex and costly
- Energy hungry

KEY STATISTICS

- 40% of upstream companies are likely to invest or diversify away from oil and gas in 2017, according to a recent global benchmark study.[203]
- Forecasts show that solar PV could achieve cumulative cost reductions of 84% between 2009—2025.[204]
- Costs of grid-scale solar PV are quickly becoming cheaper than fossil fuel-based electricity generation, reaching a Levelised Cost of Electricity (LCOE) of $75–95/MWH by the end the decade and dropping to between $55–70 by 2030.[205]
- Gas currently accounts for less than 1% of all transport fuel in Australia.[206]
- Global demand for LNG for transport is expected to grow four-fold to 100MTPA by 2030.[207]
- Estimates of the small-scale LNG market are around US$50 billion by 2021.[208]

203 DNV GL (2017). *Short-term agility, long-term resilience – The outlook for the oil and gas industry in 2017.*

204 Shankleman, J., (2017). *Solar Could Beat Coal to Become the Cheapest Power on Earth*, Bloomberg, [Online] Available from: https://www.bloomberg.com/news/articles/2017-01-03/for-cheapest-power-on-earth-look-skyward-as-coal-falls-to-solar Accessed 12/07/2017

205 Campey, T., et al (2017). *Low Emissions Technology Roadmap.* CSIRO, Australia.

206 Core Energy Group (2016). *Commercial Assessment of CNG and LNG as Transport Fuels.*

207 Madconald-Smith, A., (2016). *Shipping to become 'major new sector' for LNG: Shell, Australian Financial Review,* [Online] Available from: http://www.afr.com/business/energy/gas/shipping-to-become-major-new-sector-for-lng-shell-20161101-gsfw74 Accessed 2/06/2017

208 TechSci Research (2016). *Global Small Scale LNG (SSLNG) Market By Application, By Mode of Supply, Competition Forecast & Opportunities, 2011 – 2021*, Abstract [Online] Available from: https://www.bharatbook.com/oil-gas-market-research-reports-801973/small-scale-lng-global.html

4.4 High-value diversification

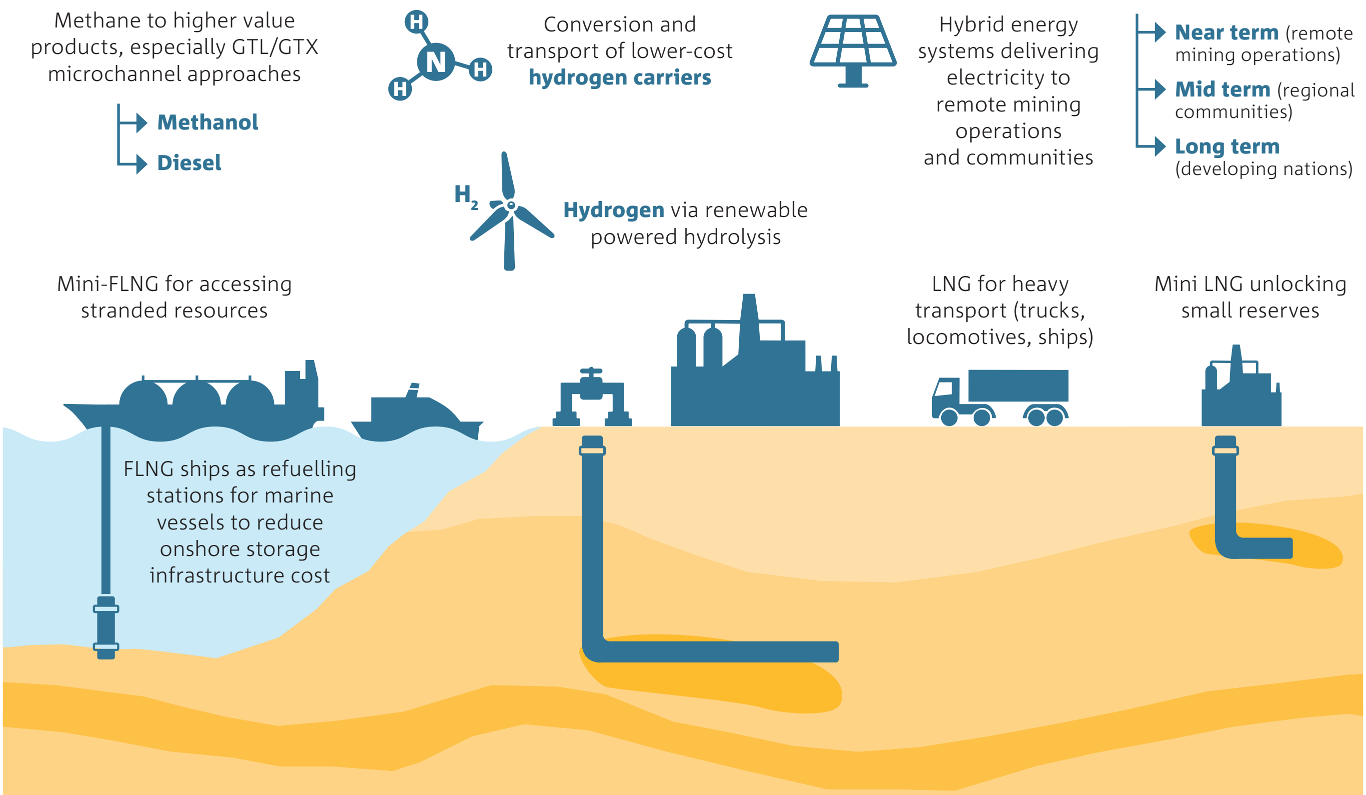
The industry faces a series of market, regulatory, and technological uncertainties that make projecting oil and gas demand and energy mix difficult, particularly in the long term. As pressure increases on the energy sector to lower its carbon intensity, oil and gas companies will need to adapt.

Many companies are already diversifying their offerings and repositioning themselves as 'energy providers' as a result of these changes. For example, some companies are moving into or expanding their gas resources, while other companies are moving into renewables. The biggest firms are exploring higher-value energy products, as demonstrated by Shell's and Total SA's investment in the Hydrogen Council. It is expected that together with large automakers they will invest US$10.7 billion in the hydrogen industry over the next five years.[209]

Within this realm, there are tremendous opportunities for operators and service firms. Industry interviews and desktop analysis highlight four examples of diversification, each of which are identified and explored in further detail within this chapter. These include:

- Integrated energy services – Finding new ways to get energy to market, including by providing hybrid and renewable energy solutions to remote communities and resources operations
- Mini LNG and small floating LNG – Providing economical means to develop small and marginal fields and bring them to market
- LNG as fuel for heavy transport – Delivering LNG into transport markets, including trucks, trains and ships
- Alternative energy products and intermediates – Exploring alternative energy products such as GTL fuels, feedstocks such as methanol, specialty chemicals, and hydrogen.

FIGURE 24: A SAMPLE FUTURE VISION FOR HIGH-VALUE DIVERSIFICATION



209 Abbott, J., (2017). *How to get from here to there: building the future of transport together,* Speech, [Online] Available from: http://www.shell.com/media/speeches-and-articles/2017/building-the-future-of-transport-together.html Accessed 2/06/2017

4.4.1 POTENTIAL APPLICATIONS

Integrated energy services

In remote locations, electricity from the grid is often not an option, and diesel is used to power local communities and mine sites which, in turn, poses economic and logistical challenges. Oil and gas companies operating in remote locations usually burn valuable product to operate their equipment. None of these solutions are ideal. There are three examples described below, each one increasing in terms of their level of sophistication.

Firstly, an immediate win would be to develop small local gas fields to provide gas directly to nearby mine sites and communities to reduce the use of diesel. Diesel generators can be retrofitted to accept natural gas as fuel, or high efficiency gas turbine technology can be employed to supply the local microgrid.

Secondly, oil and gas companies can integrate renewable energy into their operations. This may include solar and wind for onshore and offshore, or tidal and wave power for offshore. Rapid cost reductions and continuing efficiency improvements in solar and wind power are making these options attractive alternatives to the burning of oil or gas or trucked-in diesel. These renewable technologies can be integrated into production and operations to power on-site equipment, such as artificial lift and compression. Gas powered hybrid systems can provide rapid respond base-load to even out intermittency of renewable energy.

Thirdly, to provide power for larger operations, some businesses in the sector are pursuing hybrid energy solutions to power microgrids and provide energy for oil, gas and mining operations. These solutions reduce reliance on costly diesel and other fuels by making better use of abundant renewable energy. Skills and capabilities developed in the creation of such systems for regional Australia can be parlayed into export markets for developing nations.

FIGURE 25: KEY PROSPECTIVE TECHNOLOGY OUTPUTS AND SOLUTIONS

SHORT TERM (0 – 3 YEARS)	MEDIUM TERM (3 – 10 YEARS)	LONG TERM (10+ YEARS)
Integrated energy services		
• Conversion and retrofit technology to enable diesel electricity generation to run LNG • Solar, wind, tidal and/or wave energy integrated into remote oil and gas operations • Small gas fields developed and supplying remote mine sites and communities	• Solar Photovoltaic (PV) at high enough efficiency to power offshore platforms • Hybrid energy systems providing power to Australian remote communities	• Flexible and transparent PV technologies integrated into building and pipeline materials[210] • Hybrid energy systems exported to developing nations

210 ARENA (2017). *Innovating Energy ARENAs 2017 investment plan*, Canberra.

Technology spotlight

Laing O'Rourke: Sunshift re-deployable hybrid diesel-solar plant[211]

SunShift technology is a re-deployable modular solar PV-diesel hybrid power plant for off-grid use. A recent pilot demonstration project funded by the Australian Renewable Energy Agency (ARENA) saw a reduction of 36% in diesel use per kWh. Over the 81 day trial, an estimated 166 tCO_2e was avoided.

The system consists of five different modules that can be integrated in multiple configurations depending on the end user's needs. They include diesel generators, tanks, an integrator, solar sub-arrays and an optional lithium ion battery and inverters. The system is scalable, using component 50kW arrays.

Small and mini-LNG and small floating LNG for small and marginal fields

Mini-LNG – up to 0.2MTPA	**Small LNG** – up to 1MTPA	**Small floating LNG** – 1 to 2MTPA

Following the LNG construction boom of the last decade, companies are now delaying investment decisions regarding new plants. Changing market conditions have left operators searching for new ways to deliver gas with the least amount of capital and operating expenses.

The industry is likely to focus on minimising costs in two ways. Firstly, it will leverage existing LNG plants by optimising production of existing plants, and perhaps building additional trains to them, rather than investing in new greenfield projects. Any new trains that are built will utilise the latest technological advances to drive down costs.

The second approach will be to shift focus towards smaller developments that do not require such significant capital investments. The problem is finding ways to bring these (often stranded) assets to market. This challenge can be overcome using low-cost mini-LNG and small floating LNG (FLNG) technologies.

The appeal of mini, small and floating assets are their shorter development and deployment timelines, relatively low capital and operating costs, and ability to unlock small stranded resources (~0.5 to 1.5tcf fields[212]). In remote areas of Australia, small-scale LNG can enable economic development that would otherwise be limited by a lack of electric supply infrastructure.

211 ARENA (n.d.). *SunShift Demonstration Report,* [Online] Available from: https://arena.gov.au/assets/2016/04/Laing-ORourke-MS-2-ii-Case-Study.pdf Accessed 2/06/2017

212 Piasenti, F., (2015). *Can the SEA FLNG Approach Monetise Small Australian Stranded Gas Resources?* [Online] Available from: http://www.sut.org/wp-content/uploads/2014/09/Francesco-Piasentin-SUT-Is-SEA-FLNG-Approach-suitable-for-Australia-website-approved.pdf Accessed 2/060/2017

Similarly, small FLNG may have many advantages over traditional offshore gas developments. For example, depending on the economics, these vessels (with some reconfigurations depending on field conditions) can be readily redeployed, giving operators market flexibility to maximise profits. They may also be built from older vessels that have been repurposed, potentially offering reductions in capital cost.[213]

The market for small and mini-LNG and small FLNG is potentially significant. Estimates of stranded gas fields (those larger than 48bcf) outside the US amount to 2,612tcf of gas. Australia has an estimated 173tcf of stranded gas assets[214] with total potential market value of $1.8 trillion.[215] Many of these stranded assets are located offshore, in remote or deep locations where large scale LNG plants are not suitable due to the need to install pipelines over long distances, or where there are significant environmental issues related to locally situating plants. These stranded assets make Australia an attractive location for mini-LNG and small FLNG.

LNG for heavy transport

There is a potentially large global market for LNG to power heavy transport vehicles, such as trucks, trains and ships, with demand for these applications expected to exceed 100MTPA by 2030.[216] This is driven by the many advantages associated with the use of LNG as a diesel substitute. These include cost efficiency over diesel per unit of energy, lower emissions profiles, and fewer particulates. LNG also has advantages over liquefied petroleum gas (LPG) as it is considered more environmentally friendly due to lower emissions and lower running costs.

However, there are challenges in implementing this vision. For example, there is the issue of safe and cost-efficient storage of LNG at smaller scales in bunkering applications for ships, and similar infrastructure for regional ground transport hubs. Advanced materials and insulators would be needed to sufficiently lower storage costs. In addition, LNG-powered engines for long-haul applications are currently expensive and the costs of switching from diesel powered drive trains to LNG would take time. In the interim, mini-regasification terminal infrastructure would be required to more easily use LNG in the form of lower-pressure Compressed Natural Gas (CNG). Formerly diesel-powered transport vehicles can be more easily converted to CNG, and it is more applicable for equipment with more intermittent use patterns.

FIGURE 26: KEY PROSPECTIVE TECHNOLOGY OUTPUTS AND SOLUTIONS

SHORT TERM (0 – 3 YEARS)	MEDIUM TERM (3 – 10 YEARS)	LONG TERM (10+ YEARS)
Small and mini-LNG and small FLNG		
• Implementation of small and mini-LNG plants in remote areas to monetise smaller fields and supply local markets for energy and transport	• More economical and smaller-footprint process technologies to enable small FLNG • Means to cost-effectively store LNG to support electricity production in small communities	• Several small FLNG facilities deployed in Australian waters • FLNG ships as refuelling stations for marine vessels to reduce onshore storage infrastructure cost

213 International Gas Union (2017). *IGU 2017 World LNG Report.*

214 Attanasi, E.D., Freeman, P.A., (2013). *Meeting Asia's future gas import demand with stranded natural gas from central Asia, Russia, Southeast Asia, and Australia,* SPE Economics & Management Vol5, Iss2.

215 $10GJ basis for calculation

216 Madconald-Smith, A., (2016). *Shipping to become 'major new sector' for LNG: Shell, Australian Financial Review,* [Online] Available from: http://www.afr.com/business/energy/gas/shipping-to-become-major-new-sector-for-lng-shell-20161101-gsfw74 Accessed 2/06/2017

There is room for growth in the Australian market for LNG-powered ground transport. LNG currently accounts for less than 1% of all transport fuel.[217] Conservative estimates conclude that for Australian trucks, public transit, mining vehicles, ships and rail applications to switch to either CNG or LNG could require 3.7bcm per annum of natural gas (approximately 2.7MTPA LNG equivalent) by 2030.[218]

Rail also provides a market opportunity, albeit smaller. Converting the estimated 1,500 locomotive engines that carry iron ore and coal around the country to LNG would require about 0.3bcf (0.2MTPA LNG) per annum.[219]

Since the 1970s, LNG has been used for marine vessels; however, there has never been a compelling economic or regulatory case for making this standard practice. This scenario is quickly changing, driven by new regulations, such as: sulphur content reductions for marine fuels by 2020;[220] potential broader implementation of Economic Control Areas (ECAs) which result in stricter emissions levels around ports; and industry-led greenhouse gas reduction efforts.

Globally, the potential maritime LNG opportunity is large, with upside estimates of between 30 and 60MTPA by 2030.[221] Domestically, demand could also be robust; conservative estimates of supplying just half of the coastal ship fleet would require only 0.44bcf (0.32MTPA LNG).[222] However, an optimistic scenario could see much higher demand. In 2030, the projected number of calls to Australian ports from container and bulk carrier ships is expected to increase by nearly 60% to a total of 34,300 per year – or potentially around 94 ships per day needing fuel.[223]

Woodside Energy is already moving to capitalise on this market, having recently commissioned Australia's first LNG-fuelled support ship.[224] This is part of a larger plan of working with collaborators to build an LNG supply chain in the Pilbara and the North West Shelf to enable Woodside to change the company's fleet of 16 marine support vessels to LNG over the following five years.[225]

FIGURE 27: KEY PROSPECTIVE TECHNOLOGY OUTPUTS AND SOLUTIONS

SHORT TERM (0 – 3 YEARS)	MEDIUM TERM (3 – 10 YEARS)	LONG TERM (10+ YEARS)
LNG for heavy transport		
• Conversion and retrofit kits for intermittent use applications like heavy trucks to run on CNG	• New lightweight, super-insulated LNG fuel storage tanks for use on heavy road vehicles to expedite conversion of the road fleet	• FLNG ships as re-fuelling stations for marine vessels to reduce onshore storage infrastructure requirement • Substantial portions of Australian locomotion LNG powered • Substantial portions of Australian maritime shipping LNG powered

217 Core Energy Group (2016). *Commercial Assessment of CNG and LNG as Transport Fuels.*
218 Heyning, C., Segorbe, J., (2016). *The role of natural gas in Australia's future energy mix*, McKinsey and Company.
219 Heyning, C., Segorbe, J., (2016). *The role of natural gas in Australia's future energy mix*, McKinsey and Company.
220 Australian Government (2013). *Marine Order 97 (Marine Pollution prevention – air pollution) 2013,* Federal Register of Legislation, [Online] Available from: https://www.legislation.gov.au/Details/F2016C01016 Accessed 10/04/2017
221 Aronietis, R., et al (2016). *Forecasting port-level demand for LNG as a ship fuel: the case of the port of Antwerp.* J. Shipp. Trade.
222 Heyning, C., Segorbe, J., (2016). *The role of natural gas in Australia's future energy mix*, McKinsey and Company.
223 Bureau of Infrastructure Transport and Regional Economics (BITRE) (2010). *Australian Maritime Activity to 2029–2030*, Canberra.
224 Woodside (2017). *Trunkline, The magazine for Woodside people Q1, 2017*, [Online] Available from: http://www.woodside.com.au/About-Us/trunkline/Documents/Trunkline%20Q1%202017.pdf#search=Siem%20Offshore%20Australia Accessed 2/06/2017
225 Wilkinson, R., (2017). *Woodside promotes LNG as a fuel within Western Australia*, Oil&Gas Journal, [Online] Available from: http://www.ogj.com/articles/2017/02/woodside-promotes-lng-as-a-fuel-within-western-australia.html Accessed 2/06/2017

Technology spotlight:
EVOL LNG

In operation since 2001, EVOL LNG is leading Australian efforts to provide LNG as a fuel for remote power stations, industrial facilities, marine bunkering and transportation. EVOL LNG completed Australia's first commercial LNG bunkering in Western Australia early in 2017. With Australia's largest fleet of LNG road tankers (including LNG-fuelled delivery tankers), EVOL LNG is licenced to provide truck-to-ship LNG bunkering by two major Australian port authorities, Fremantle Ports and the Pilbara Port Authority.[226]

Higher-value products

The current level of competition in the global natural gas market may provide an opportunity for oil and gas companies to explore alternative energy products and chemicals, such as converting Gas to Products (GTX), Gas to Liquids (GTL), or reforming methane to create hydrogen.

GTX/GTL can convert natural gas (or even gasified biomass or coal) into syngas, and through subsequent catalytic reactions can lead to fuels like diesel, gasoline, or jet fuel (so called Fischer-Tropsch fuels) and other chemical intermediates like methanol. While there are technical and economic challenges for GTX/GTL – for example, tougher capital markets and low oil and gas prices – the market is expected to experience growth. The global market is projected reach US$15.5 billion by 2022.[227]

Price sensitivity of GTX and GTL

The inherently high costs of GTX and GTL make them hard to compete with traditional refining routes using cheap oil. To make these approaches affordable in Australia, cheaper gas and lower-cost facilities are needed. Perhaps, more gas supply could help drive down costs, which can be accomplished by opening up currently restricted onshore resources. To convert it, small-scale GTX and GTL production facilities can be used, and they should leverage micro-channel processing technologies to enable a reduction in capital expenditure and operating costs.

A key opportunity lies in the miniaturisation of GTX/GTL that could bring about an order of magnitude reduction in required investment, making the technology cost-effective at smaller scales. This could be done via micro-channel technologies that intensify chemical reactions by reducing the dimensions of reactor systems. This means that small-scale systems could be used to more profitably unlock value in stranded gas fields. Estimates indicate that nearly 75% of the world's stranded assets are suitable for GTL (based on a 10 million cubic feet per day (mmcfd) gas need to support a 1kpd GTL facility for 30 years[228]). In Australia – which has limited local refining capacity – GTL to monetise smaller fields would have the additional benefit of helping with liquid fuel energy security.[229] Furthermore, mini GTL and GTX could help developments become more profitable by converting waste gas and associated gas into valuable commodities (particularly in regions where flaring is limited). Their small footprint means they will be deployable even in the constrained offshore environment.

In terms of chemical intermediates, GTX could be used to create a number of products, including Methanol and Di-Methyl Ether (DME). These can easily be derived by transforming methane and other gases into syngas and performing subsequent catalytic conversion.

Methanol is an increasingly important fuel and chemical intermediate that has strong demand growth. The market for methanol was US$29.6 billion in 2015 and is expected to grow to US$54 billion by 2021; largely driven by demand for polyethylene and polypropylene plastics.[230]

226 EVOL LNG (n.d.). *Marine,* [Online] Available from: https://www.evollng.com.au/marine Accessed 2/06/2017

227 Stratistics (2017). *Gas-to-Liquids Processes for Chemicals and Energy - Global Market Outlook (2016-2022).*

228 Clint, O., West, R., (2013). *BERNSTEIN Commodities & Power: What if "Small-Scale Gas to Liquids" Was the Next "Shale Gas"? Are We On the Verge Of Another Energy Revolution?,* [Online] Available from: http://www.velocys.com/resources/Velocys_131211_Bernstein_note.pdf

229 Blackburn, J., (2013). *Australia's Liquid Fuel Security: A Report for NRMA Motoring and Services.*

230 M2 Presswire (2017). *Methanol Market worth 54.16 Billion USD by 2021*, [Online] Available from: https://search.proquest.com/docview/1861650852?accountid=26957 Accessed 2/06/2017

Methanol also has potential use as a fuel. Methanol has lower energy density than other liquid fuels; however, it does have a distinct advantage over hydrogen and natural gas in terms of its transportability. It can be used to supplement gasoline, much like ethanol is today. Furthermore, methanol can be directly converted to diesel and gasoline using many commercially available synthesis routes.[231]

The GTX method can also yield Dimethyl Ether (DME) – a viable alternative to diesel in the trucking industry. With minor adjustments to the engine and fuelling systems, DME can be blended (nearly seamlessly) with LPG as a fuel. The advantages of DME as a fuel are significantly lower NOx emissions and particulate matter.[232]

GTL and GTX are flexible systems offering the potential to shift production toward products that maximise profits based on shifting market demand. Savvy operators could capitalise on global commodity price shifts to produce gas, methanol, diesel, and higher value speciality chemicals and waxes for instance, depending on relevant market signals. As GTL and GTX processing equipment becomes smaller and more efficient, there is an increased likelihood that these solutions could be integrated into LNG facilities both on and off shore.

A final opportunity is the production of hydrogen gas – a fuel with diverse applications and a very high energy density by mass and clean-burning, emitting only water vapour. Hydrogen is expected to support transport and electricity production in the future, with hydrogen-powered vehicles a key target market. Growth in fuel cell electric vehicles is expected to be rapid, with millions on the road globally by 2030.[233]

Key to fully capitalising on hydrogen fuel is finding low or zero-carbon methods of producing it. Australia's vast solar and wind resources could be used to economically produce hydrogen via electrolysis for export, either in pure liquefied form or in a more transport-friendly form, for example ammonia, methanol or LNG. However, cost-efficient conversion technologies will be needed to convert ammonia to hydrogen at the point of use. An alternative approach is to produce hydrogen from natural gas using the current approach (Steam Methane Reforming) and combining this with CCS to mitigate the CO_2 emissions. Once such routes are developed, hydrogen could be an appealing way to store excess renewable energy and to buffer associated intermittency in the domestic energy market. It will also open the doors to industrial scale production.

FIGURE 28: POTENTIAL TECHNOLOGY OUTPUTS AND SOLUTIONS

SHORT TERM (0 – 3 YEARS)	MEDIUM TERM (3 – 10 YEARS)	LONG TERM (10+ YEARS)
Higher value products		
• Small-scale GTL and GTX to produce diesel, methanol, and DME using natural gas feedstocks with improved reforming processes that can handle wider feed variability • Conversion kits developed for trucks to run on methanol and DME	• Large-scale hydrogen production using steam methane reforming combined with CCS • Large-scale production of chemical intermediates such as methanol from methane feedstocks • Efficient large scale PV and wind- powered electrolysis of water to hydrogen and conversion to transportable form (such as ammonia, methanol or LNG) • Cost-effective gasification and syngas conversion (and other second-generation routes) of woody biomass to diesel, gasoline, and hydrogen and higher value products	• Intensified GTL and GTX technology capable of 100+kpbd outputs[234] • Economically viable direct solar-to-hydrogen routes, including photoelectrochemical (PEC) water splitting[235]

231 Abazajian, A., (2016). *'Methanol economy' gains ground with technology, market developments*, Gas Processing. [Online] Available from: http://www.gasprocessingnews.com/features/201604/methanol-economy-gains-ground-with-technology,-market-developments.aspx

232 Wilson, S., (2013), *Into the (dimethyl) ether,* CSIRO, [Online] Available from: https://blog.csiro.au/into-the-dimethyl-ether/

233 Nocera, S., Cavallaro, F., (2016). *The competitiveness of alternative transport fuels for CO2emissions*, J.Transp. Policy Vol 50, pp 1–14.

234 Clint, O., West, R., (2013). *BERNSTEIN Commodities & Power: What if "Small-Scale Gas to Liquids" Was the Next "Shale Gas"? Are We On the Verge Of Another Energy Revolution?,* [Online] Available from: http://www.velocys.com/resources/Velocys_131211_Bernstein_note.pdf

235 Lott, M., (2017). *Scientists Develop a "Better Way" to Produce Renewable Hydrogen,* Scientific American, [Online] Available from: https://blogs.scientificamerican.com/plugged-in/scientists-develop-a-better-way-to-produce-renewable-hydrogen/ Accessed 2/06/2017

4.4.2 ENABLING SCIENCE AND TECHNOLOGY

A variety of technologies and research programs will be required to facilitate both the incremental and substantial technical advancements required for the Australian sector to pursue the various aspects of this opportunity.

In a number of cases, the technology is either already viable or close to being viable; however, market or policy settings do not encourage its adoption or commercialisation. For example, LNG-powered trucks are yet to be widely adopted due mainly to a lack of infrastructure and pilot programs together with high capital costs. Research priorities to enable these technical developments are detailed below.

RESEARCH PRIORITIES

Materials and catalysts

- Robust micro and nano catalysts to support micro-channel (intensified) GTL and GTX processing.
- Low-temperature catalytic conversion processes for ammonia to hydrogen, and methane to methanol.
- High efficiency, compact gas separation technologies, including membranes, sorbent catalysts and other phase change processes to separate natural gas from carbon dioxide, and extract and produce pure hydrogen gas from mixed gas streams.
- Investigate new thermal insulators and composite storage tanks to bring down the costs of LNG storage.
- Low-cost storage and transport solutions for hydrogen gas.
- Higher efficiency solar cells and electrolysers.

Process engineering

- Higher efficiency liquefaction technologies.
- Techno-economic feasibility assessments and modelling for Australian introduction of potential diversification technologies outlined (small LNG, FLNG, GTL, GTX, hydrogen, LNG for transport).
- New approaches to reactor and process design and development which enable less capital intensive plant (e.g. process intensification).
- Investigate hybrid infrastructure and process designs, such as GTL from biomass or biogas.
- Develop and improve GTL and GTX processes to enhance quality and conversion efficiency, and reduce the cost of production, including reforming processes.
- Improve modularity and standardisation of small-scale GTL and GTX and associated gas processing technologies.
- Robust biomass gasifier reactor design, to handle char and tar formation, and material handling processes including reactor bed material, molten salt, feed stocks, etc.
- Improvements to FLNG technologies, in particular to help reduce capital costs, improve efficiency, and reduce power consumption. Modular design and enhancement of the following typical stages of FLNG are required: gas pre-treatment, liquefaction and regasification topsides, hulls, mooring, and transfer systems.

4.4.3 BUSINESS ECOSYSTEM CHANGES

Collaboration is important to unlocking these diversification opportunities. For example, developing new markets for LNG, such as using LNG in heavy transport, will require action across converging industries (e.g. manufacturing and transport) and will also need encouragement via policy.

In order to unlock this opportunity, several suggestions for improving the business ecosystem are presented for consideration.

PROCESSES, STANDARDS AND REGULATIONS

- Consider incentives and/or offsets to spur the development of small GTL production facilities for domestic diesel production.
- Support the development of common standards for processing technologies underpinning hydrogen, GTL, and small and mini-LNG, as well as associated supply and distribution systems.
- Prepare for tighter air emissions regulations which will open the door for alternatives to diesel and bunker fuel.

PEOPLE, SKILLS AND COLLABORATION

- Explore new business and collaboration models for diversification opportunities.
- Look beyond the existing business network connections to identify unique technology investments and develop concurrent strategies to transform existing business models
- Begin forging research and partnership collaborations around new process technology to enable higher-value chemicals and alternative energy products.
- Work with academia to develop curricula to upskill staff with regards to renewable energy, hybrid energy systems, micro-grids and micro-reactors.

Creating the right business ecosystem

5 Creating the right business ecosystem

There are a number of changes that need to occur in the Australian oil and gas sector to enable it to unlock the strategic growth opportunities identified in the last chapter, address its national challenges, and remain globally competitive. The enablers identified in this chapter echo the consistent themes that arose from industry consultation. They focus on the cross-cutting issues in the business ecosystem that will require coordinated effort between oil and gas companies, suppliers, governments, researchers and community stakeholders.

5.1 Pursuing diverse collaborations for innovation

The sector can improve on its approach to collaboration in order to drive better innovation outcomes. Many operators report their prime motivation for collaborating is to reduce costs, whereas accessing new markets is ranked lowest.[236] This preference for cost reduction may result in only incremental changes to technology and focus on existing collaborators. As buyers of technology, operators' collaborative preferences help to explain the sector's persistent reputation for incremental innovation.

To unlock the new opportunities outlined in this report, companies must collaborate in new ways to build competencies that are new to the business, to break into new markets, or to do both. Research sector collaborations will help to create completely new technological paradigms. Partnerships with other sectors may be needed to move into adjacent markets. Both are needed to create completely new businesses.

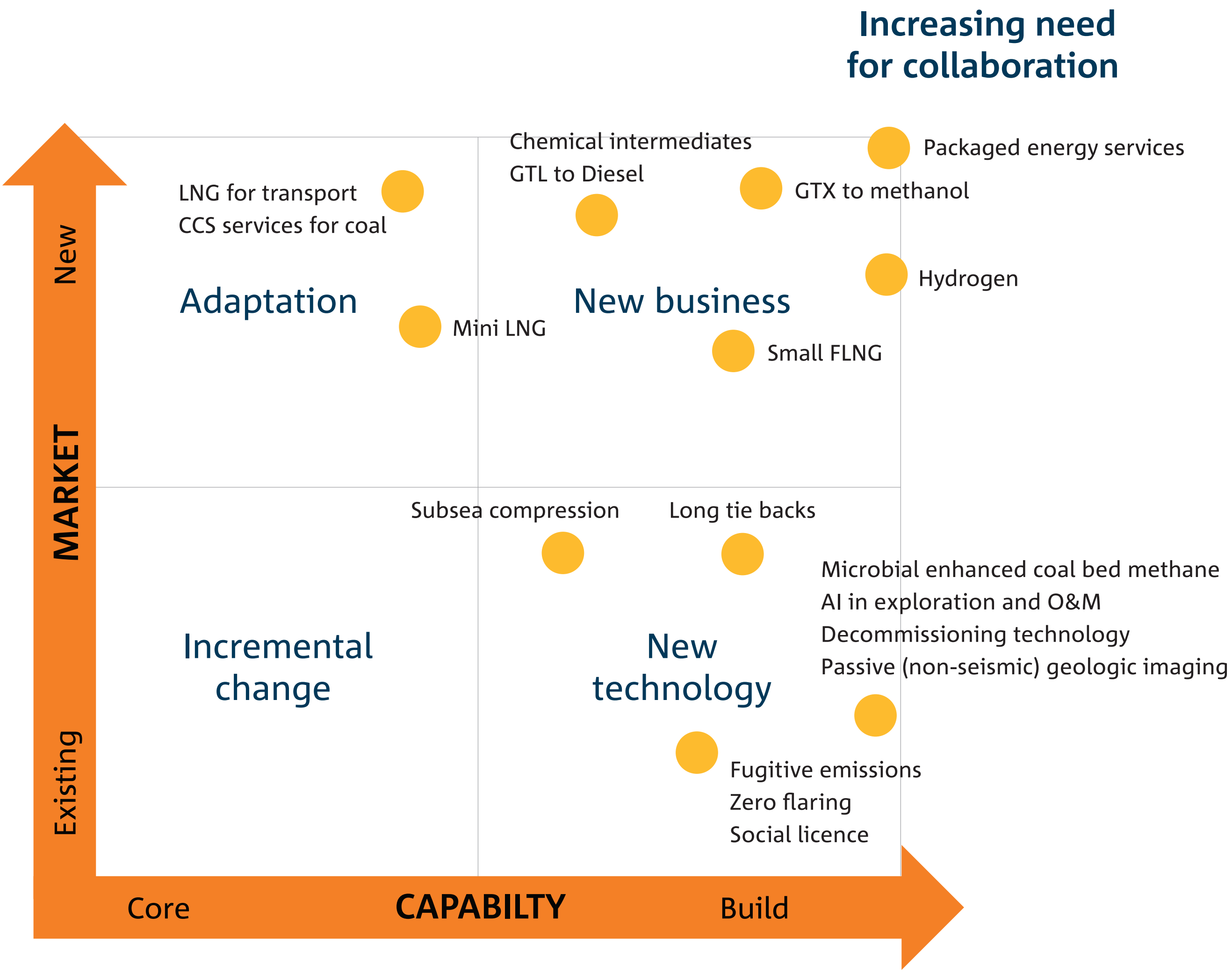
To exemplify these different types of collaborations, Figure 29 uses the measures of capability (core versus build) and markets (existing versus new) to create four notional categories of innovation.

- **Adaptation** – Leveraging existing capabilities into new markets, through variant products or services, may require market channel partnerships to unlock.
- **New business** – Opening up completely new markets using new technology and business models may require outside research perspectives to recognise them, and new market partners in order to execute successfully.
- **Innovation** – New products, processes and systems requiring capability not currently found in the organisation may require science and R&D collaborators outside of the current network.
- **Incremental change** – Slight changes to existing products and services for existing customers, or advancements in process technologies and business systems, that might not require any new collaborations outside of the current network.

This matrix highlights the fact that different collaborators may be needed to bring about each type of innovation.

236 Cullinane, B., Harrison, P., (2017). *A hive mentality: collaboration lessons for Australian oil and gas,* Deloitte.

FIGURE 29: COLLABORATION/INNOVATION MATRIX FOR AUSTRALIAN OIL AND GAS OPPORTUNITIES



5.2 Reducing the cost of doing business

Australia has a growing reputation for having a high-cost business environment, which may deter future industry investment. With many recent projects suffering budget blowouts,[237] together with the emergence of low-cost LNG providers in East Africa, pressure is increasing on the Australian sector to improve. Furthermore, with the depletion of low-cost conventional supplies, exploration and production costs are set to be substantially higher in the future than they have been in the past.[238] The sector (government and industry) needs to focus its attention on ways to reduce costs in order to ensure that Australia remains a competitive and attractive destination for investment.

- **Invest in digital infrastructure** – The common thread running through many of the opportunities outlined in this report is that digital technology can be leveraged to improve the cost-competitiveness of oil and gas operations and supply chains. For example, operational efficiency can be improved by moving toward automated systems. However, this requires industry and government to come together to improve the digital infrastructure needed to enable activities such as remote operations, and the uploading and manipulation of massive amounts of subsurface data.
- **Reduce the costs of physical infrastructure** – In the near term, sharing brownfield infrastructure, such as pipelines and processing facilities, will be an effective way for companies to achieve economies of scale, reduce capital expenditure and avoid replicating infrastructure.[239] Companies, services providers and regulators could work together to encourage shared infrastructure where appropriate. This scenario will also help to improve cost competitiveness. To facilitate the next wave of longer-term investment, advancements in modular construction and advanced materials are needed to enable improved costs.
- **Standardising and streamlining regulation** – see Section 5.4 – *Reducing regulatory uncertainty.*
- **Coordinated environmental planning** – see Section 5.5 – *Improving the sector's public image.*

237 Ellis, M., Heyning, C., Legrand, O., (2013). *Extending the LNG boom: Improving Australian LNG productivity and competitiveness*, McKinsey&Company.
238 Segorbe, J., Lambert, P., (2017). *Meeting east Australia's gas supply challenge*, McKinsey&Company.
239 Ellis, M., Heyning, C., Legrand, O., (2013). *Extending the LNG boom: Improving Australian LNG productivity and competitiveness*, McKinsey&Company.

5.3 Improving Australia's energy security

Despite Australia's significant oil and gas resources, there are potential challenges to ensuring continued adequate, reliable and competitive delivery of energy in Australia's liquid fuel and natural gas sectors.

One prevalent example is the potential shortage of gas in Australia's east coast market, limiting Australia's ability to meet domestic demand while at the same time fulfilling export contracts. At present, growth in exports and constrained supply has led to increasing prices that may have damaging effects on Australian manufacturers. The response to this – the Australian Domestic Gas Security Mechanism (ADGSM)[240] – means that gas earmarked for export could be blocked if a domestic gas shortfall is likely.[241] If successful in reducing wholesale gas prices, the mechanism also reduces State Government royalties, leading to further consequences in those producing States. At the same time, there are concerns that LNG contractual commitments will struggle to be met in coming years, as unproven CSG resources without production history will soon be required to fill the plants, introducing a significant longer-term supply risk.[242]

Another challenge to Australia's energy security is its heavy dependence on imports of crude oil and refined fuels. Australia is a net importer of refined fuels. Australia relies heavily on international trade hubs for imports, particularly Singapore, which itself is reliant on the Middle East. If this port were to close for 30 days due to extenuating circumstances, it has been estimated that the subsequent four months would result in Australian GDP losses of nearly $1.4 billion and real income losses of $2.1 billion.[243]

Domestic energy security concerns could be addressed in part by opening up exploration and production of Australia's onshore gas, which has more than enough capacity to deliver Australia's domestic needs and also support the export markets. Other opportunities lie in developing new technologies (i.e. micro-channel GTL to convert gas to refined fuels), as highlighted in Chapter 4. The following points detail a number of ways the ecosystem may be improved.

- **Analysis of the entire energy market from an energy security perspective** – The plans for Australia's energy system would benefit from a holistic energy security analysis and perspective. For example, with respect to refined fuels, future planning would not simply be based on the historical presumption of low costs and steady supply from Asia and the Middle East. Rather, it would be based on assumptions that such supply could easily be disrupted at any time. This would cause great economic damage in Australia due to the country's low levels of reserves and lack of infrastructure to refine domestic crudes. An energy security perspective would identify alternative pathways to liquid fuels and consider subsidies where necessary to stimulate adequate investment from industry. These alternative pathways may include developing GTL systems (mentioned in Section 4.4) to convert abundant natural gas and even biomass to liquid fuels like diesel. This analysis may be undertaken by the new Energy Security Board recommended in the Chief Scientist's Independent Review.[244]

240 Department of Industry, Innovation and Science (2017). *The Australian Domestic Gas Security Mechanism,* [Online] Available from: https://industry.gov.au/resource/UpstreamPetroleum/AustralianLiquefiedNaturalGas/Pages/Australian-Domestic-Gas-Security-Mechanism.aspx Accessed 4/07/2017

241 Australian Energy Market Operator Limited (2017). *Gas statement of opportunities for eastern and south-eastern Australia.*

242 Energy Quest (2017). *Energy Quarterly – March 2017 Report*.

243 ACIL Tasman (2011). *Liquid fuels vulnerability assessment,* Department of Resources Energy and Tourism, [Online] Available from: http://www.environment.gov.au/system/files/energy/files/liquid-fuels-vulnerability-assessment.pdf Accessed 1/06/2017

244 Finkel A. et al (2017). *Independent Review into the Future Security of the National Electricity Market: Blueprint for the Future*, pg 88 Commonwealth of Australia.

- **Research to unlock onshore gas** – Regulatory restrictions that are not evidence-based can have long-term detrimental impacts on gas exploration and development.[245] A comprehensive, national-level scientific study of the benefits and impacts of onshore gas may help inform a more cohesive national-level policy for onshore gas, especially if conducted by an independent entity like the Gas Industry Social and Environmental Research Alliance (GISERA). Such a study would build on existing sate and territory studies and comprehensively assess the impacts and benefits (i.e. environmental, social and economic) of various plays across the country, and establish the efficacy of the various technologies needed to unlock them and establish the best practices for operating them. Such a study would become the foundation for the development of common policy guidelines across the states, thereby helping to usher in the future of the onshore gas industry. Such a study would become the foundation for the development of common policy guidelines across all states, with the intention of addressing the current moratoria, bans and restrictions in place in the Northern Territory, New South Wales, Victoria, and Tasmania, which represent a sovereign risk and could endanger energy security.
- **Technology to unlock new supply** – Investment in advanced technology will help to unlock new supply to improve Australia's energy security. For example, advanced hydraulic fracturing processes with improved accuracy or lower water requirements, advanced materials for improved equipment and infrastructure, and precise modelling tools will be required to develop future shale gas resources. Furthermore, Australia's reliance on imported refined fuels could be relieved by pursuing GTL projects (see Section 4.4). These developments have the potential to improve Australia's energy security and resilience in the case of a disruption in supply over the long term. However, they would require significant investment in technology and infrastructure, and a substantial increase in Australia's production of natural gas.[246] The economics of supplying liquid refined fuels into the market depends on the policy conditions and market commodity prices.

245 Finkel A. et al (2017). *Independent Review into the Future Security of the National Electricity Market: Blueprint for the Future*, pg 116, Commonwealth of Australia.
246 Clark, R., Thomson, M., (2014). *Transport Fuels from Australia's Gas Resources*, UNSW Press, Sydney.

5.4 Reducing regulatory uncertainty

A stable investment environment helps to ensure that Government and industry are consistently working towards common goals in the development of Australia's vast energy wealth. In the interviews that were conducted with this report we found several areas for improvement.

One of the major issues raised during consultation relates to GHG policy. Over the past decade, several policies and regulations aimed at managing climate change have been introduced and repealed in Australia.[247] It remains unclear how Australia will meet its Paris Accord commitment to reduce emissions to 26%–28% on 2005 levels by 2030. The uncertainty about carbon policy and regulation has delayed investment decisions across many sectors.[248] The lack of an explicit decarbonisation goal is creating significant uncertainty in the oil and gas sector, and represents a significant investment risk.[249]

Enact an enduring carbon policy framework – Investors require clarity regarding the future of Australia's emissions reduction policy in order to bring forward the investments that will deliver a secure and reliable energy supply. Long-term emissions reduction policy is needed to provide stability to the energy sector and guide the necessary investments to meet Australia's Paris Agreement pledges.[250] An enduring carbon policy that has bipartisan political support and is agreed at state and federal levels is needed. Such a stable policy would create the market conditions for achieving certain technology pathways. However, depending on the approach used, these pathways could look very different, ranging from those that focus on natural gas as a bridging fuel, to those that more fully embrace solar and wind.[251] The impact on the oil and gas sector will depend on the mix of policy and incentives that Government chooses, including if and when a price on carbon is enacted.

Other areas of action include:

- **Develop common standards** – The industry must develop a pathway to reach common standards for technologies and equipment – such as electrical and interoperability standards that are suitable for Australia – and to meet the most common standards across the globe. With assistance from the Commonwealth Government, Australian oil and gas companies and the supply chain should be empowered to create such standards in an effort to reduce the costs of equipment and infrastructure.
- **Improve approval processes** – APPEA reports that: '*inefficient and costly approvals processes and regulation form a major hurdle to the growth of the Australian oil and gas industry and its ability to contribute to national prosperity*'.[252] With more than 50 agencies regulating the Australian oil and gas industry, regulatory framework optimisation is also recognised as a key priority by NERA.[253] One of their key initiatives is to work with government and industry to identify opportunities to streamline existing regulation and identify potential reforms. Importantly, reforms should not impose any unnecessary costs, while at the same time ensuring that companies engage in transparent and responsible activities with regards to environment, heritage, land access, and occupational health and safety.

247 Talberg, A., Hui, S., Loynes K., (2016). *Australian climate change policy to 2015: a chronology,* Parliament of Australia, [Online] Available from: http://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/rp1516/Climate2015 Accessed 14/07/2017

248 Herd, E. (2017). *Submission to: Independent review into the future security of the national electricity market,* Investor Group on Climate Change, [Online] Available from: http://www.igcc.org.au/resources/Pictures/IGCC%20Submission%20Finkel%20FINAL%203March2017.pdf Accessed 6/6/2017

249 CSIRO (2013). *Change and choice*, [Online] Available from: https://publications.csiro.au/rpr/download?pid=csiro:EP1312486&dsid=DS13 Accessed 2/06/2017

250 Finkel A. et al (2017). *Independent Review into the Future Security of the National Electricity Market: Blueprint for the Future*, pg 88 Commonwealth of Australia.

251 Campey, T., et al (2017). *Low Emissions Technology Roadmap.* CSIRO, Australia.

252 APPEA (n.d.). *Approvals and Regulation,* [Online] Available from: https://www.appea.com.au/industry-in-depth/policy/approvals-and-regulation/ Accessed 2/06/2017

253 National Energy Resources Australia (2017). *Sector Competitiveness Plan*, Kensington.

5.5 Improving the sector's public image

Improving the sector's social licence to operate through strong and productive, trust-based relationships with local communities, stakeholders and the Australian public is critical to the future success of projects in the sector. While increased stakeholder consultation will go some way toward improving social licence, several changes in terms of the approach for consultation may be required. Social science research (like that being conducted at GISERA) is needed to understand the underlying dynamics of social licence and how it may be maintained in this sector. In addition, more scientific research may help by providing clearer information regarding the potential environmental impacts of oil and gas activities and their mitigation. Likewise, increased outreach by companies might help, as well as social licence related training within the State and Federal Government agencies, where applicable. Several suggested changes to the business ecosystem are detailed below.

- **Increase the level of trust with the communities where projects are conducted** – More can be done by resource companies and government to build trust with local communities. Companies should focus on pursuing a more open dialogue with stakeholders which, in turn, will help to create outcomes that are aligned with community expectations and aspirations.[254] There is often a language gap between the public and industry when it comes to scientific research and energy technology. Improved communication and transparency of science, technology and energy concepts may help to alleviate the concerns of some stakeholders. Similarly, governments must ensure that any decisions that will impact on communities are fair and transparent, and that they demonstrate that stakeholder feedback has been considered in the decision-making process.[255]
- **Conduct more research on social issues related to the sector** – NERA's sector competitiveness plan suggests an industry-wide research initiative that focuses on operational and social licence to operate issues. The usefulness of such work may depend on its perceived independence from both industry and government. The GISERA model is one potential model to consider. GISERA combines the capabilities of CSIRO with an independent governance structure to undertake publically-reported independent research.[256] Although its focus has been on the socio-economic and environmental impacts of Queensland's CSG-LNG industry, GISERA could be expanded nationally, or a similar model enacted, to provide independent research on broader social science issues for all unconventional and conventional resource developments.
- **Strengthen communication of science, technology and energy concepts** – Trust is key to improving scientific comprehension. When levels of trust are low, the use of scientific language is likely to exacerbate existing tensions between community members and industry/government. When levels of trust are high, scientific language becomes less important.[257] While it is worthwhile to keep communicating the activities of the industry in technical terms, the priority should be simply gaining the trust of the public (refer to previous bullet points).

254 Williams, R., Walton, A., (2013). *The Social Licence to Operate and Coal Seam Gas Development*, GISERA.
255 Moffat, K., Zhang, A., (2016). *The paths to social licence to operate: An integrative model explaining community acceptance of mining*, Resources Policy, Vol 39.
256 GISERA (2017), *About us – Factsheet,* [Online] Available from: https://gisera.org.au/wp-content/uploads/2017/04/16-00767_GISERA_AboutUs2ppFactsheet_WEB_170410.pdf Accessed 1/06/2017
257 Gallois, C., et al (2016). *The Language of Science and Social Licence to Operate,* Journal of Language and Social Psychology, Vol 36, Iss 1.

- **Develop integrated basin-wide planning for improved social, environmental and economic outcomes** – There is an opportunity to embed a more integrated and substantial social, environmental and economic planning style into new resource development projects. Operators and regulators should collaborate in order to complete integrated assessment and planning of potential basin developments early in the life-cycle of projects. A first step toward improved planning is the collection of baseline ecological data (water, soil, flora and fauna, etc.) as well as baseline social data, such as detailed information on local business, social norms and structures, including Indigenous perspectives and aspirations. Such datasets could enable basin-scale models of project impacts and inter-basin cumulative impacts. These multifaceted models would not only include competing land uses, water impacts, and support infrastructure planning, but also enable more effective planning decisions in areas such as skills training, education and location of support services.

  Furthermore, integrated planning will help the industry develop more integrated and effective approaches to oil spills. For example, there is a need to develop industry-wide approaches to oil spill preparation and response. This involves both the development of oil spill monitoring plans, as well as development of technologies to detect oil in a response situation.

The road forward

6 The road forward

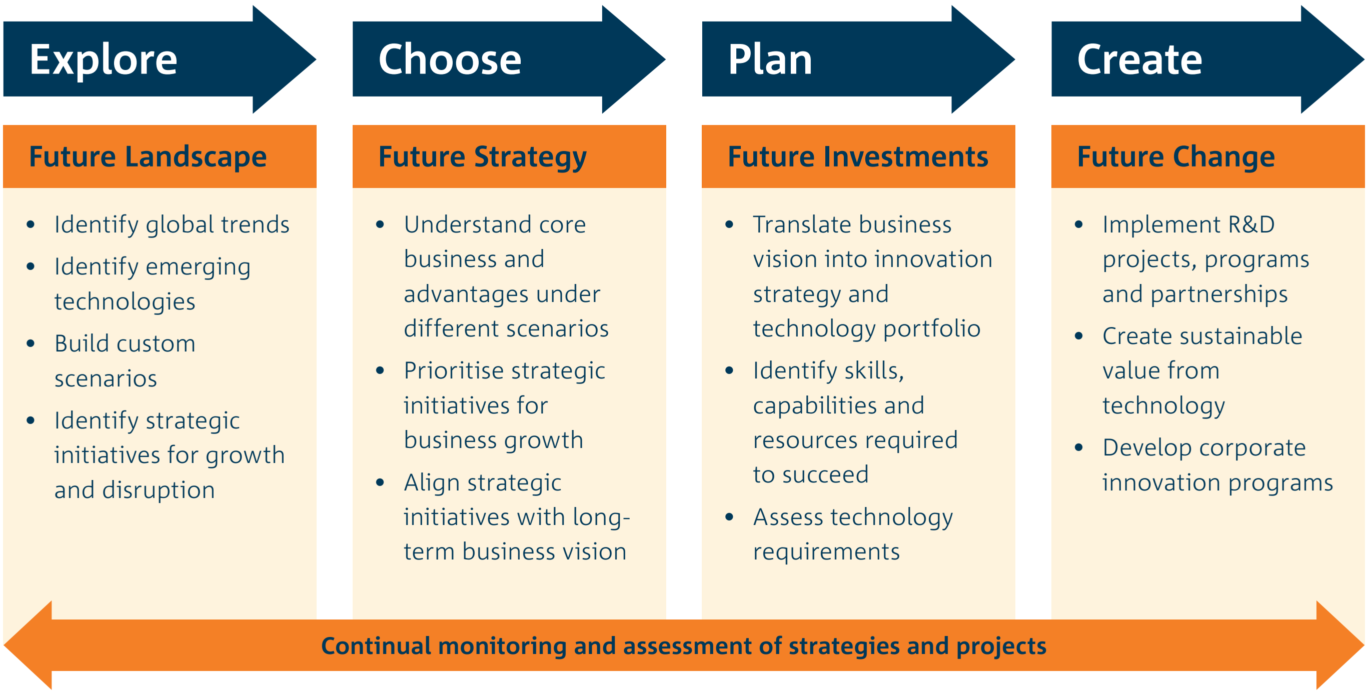
Australia's oil and gas sector will play an important role in Australia's future for decades to come, provided that companies embrace innovation and governments play their part in shaping and providing stability for the regulatory and investment environment. That means proactively identifying and investigating new opportunities for growth and exploring ways that science and technology can help to unlock them. This report offers some high-level guidance, but more work needs to be done.

With substantial market, technological and regulatory uncertainty at present, the most successful oil and gas businesses will be those that constantly reassess the way their businesses are run – ensuring that business decisions are underpinned with strong underlying market and technology assumptions, and that innovation is a central part of their strategy development.

This Roadmap can be used as one tool to inform the strategic decision-making that will be required for business success. Global megatrends, strategic opportunities, enabling technology, and business ecosystem changes are all starting points, but businesses need to create specific innovation strategies that are tailored to their goals and objectives as an organisation.

To develop long-term, technology-enabled strategies for businesses, CSIRO Futures uses a four-step strategic planning framework (see Figure 30). This framework – tailored to individual company requirements – moves from identifying major strategic opportunities using methods such as scenario planning, right through to the detailed planning of research programs and collaboration strategies that are aimed at achieving real commercial milestones.

FIGURE 30: CSIRO FUTURES STRATEGIC PLANNING FRAMEWORK



Appendix

7 Appendix

A.1 NERA Knowledge Priority Areas mapped to document contents

TABLE 1: EXAMPLES OF HOW STRATEGIC OPPORTUNITIES AND BUSINESS ECOSYSTEM CHANGES SUPPORT NERA'S KNOWLEDGE PRIORITY AREAS

NERA KNOWLEDGE PRIORITY AREA	DIGITAL OPERATIONS AND MAINTENANCE (4.1)	ENHANCED BASIN PRODUCTIVITY (4.2)	ADVANCED ENVIRONMENTAL SOLUTIONS AND PROCESSES (4.3)	HIGH-VALUE DIVERSIFICATION (4.4)	BUSINESS ECOSYSTEM CHANGES (5)
Work skills for the future	New skills required for remote operations, robotics and automation, and data and analytics for process optimisation.	Cross-disciplinary skilling of subsurface and data science		Developing new skills to accommodate renewable integration and micro-grid applications, and small-scale gas conversion technology.	
Enabling effective collaboration	Digital platforms to streamline and coordinate supply chains.		Collective planning for environmental and social impacts of resource development projects at basin level.	Collaboration with novel partners will be required to break into new markets and build new capabilities.	See 5.1 *Pursue diverse collaborations for innovation*
Understanding Australia's resource base		Make large volumes of data stored in local, state and federal databases more searchable and consistent.			
Social licence to operate			Increasing energy efficiency of GHG capture, fugitive emissions tracking, etc. to demonstrate the sector's commitment to sustainability.		See 5.5 *Improve the sector's public image*
Unlocking future resources		More accurate subsurface modelling, AI to maximise productivity, advances in hydraulic fracturing and enhanced recovery methods.	Locating affordable locations for CO_2 storage to support resource development projects.	Stranded resources can be unlocked through FLNG and mini-LNG.	
New markets, New technologies, New business models			Beneficial uses of CO_2, new drilling and completion technology.	A key driver of this opportunity is finding new markets, business models and technologies to diversify into.	
Commercialisation of R&D				Development and commercialisation of small scale methane conversion technologies, and lower-cost solar-PV and hybrid energy systems for mini-micro-grid application.	
Efficient operations and maintenance	Using AI to streamline operations and maintenance.				
Regulatory framework optimisation			Understand impacts of different decommissioning options.		See 5.2 *Reduce the costs of doing business and* See 5.3 *Improve Australia's energy security* See 5.4 *Reduce regulatory uncertainty*

A.2 Abbreviations

AAV	Autonomous Air Vehicle
AI	Artificial Intelligence
APPEA	Australian Petroleum Production and Exploration Association
AR	Augmented Reality
ARENA	Australian Renewable Energy Agency
ASV	Autonomous Surface Vehicles
AUV	Autonomous Underwater Vehicles
AV	Augmented Virtuality
bcf	billion cubic feet
bbl	barrels of oil
CBM	Coal Bed Methane
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilisation and Storage
CO_2	Carbon dioxide
COP21	21st Conference of the Parties, United Nations Framework Convention on Climate Change
CSG	Coal Seam Gas
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAS	Distributed Acoustic Sensing
DIIS	Department of Industry, Innovation and Science
DTS	Distributed Temperature Sensing
EGR	Enhanced Gas Recovery
EOR	Enhanced Oil Recovery
FLNG	Floating Liquefied Natural Gas
GAB	Great Australian Bight
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GISERA	Gas Industry Social and Environmental Research Alliance
GLT	Gas-to-Liquids
GTX	Gas-to-Products
IEA	International Energy Agency
IoT	Internet of Things
IT	Information Technology
kW	kilowatt
kWh	kilowatt hour
LIDAR	Light Detection and Ranging
LNG	Liquefied Natural Gas
mmcfd	million cubic feet per day
MMV	Monitoring, Measurement and Verification
Mtoe	Million tonnes of oil equivalent
MTPA	million tonnes per annum
MW	megawatt
NERA	National Energy Resources Australia
NGL	Natural Gas Liquids
NOx	Nitrous oxides
O&M	Operations and Maintenance
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
OT	Operational Technology
RAV	Robotic Amphibious Vehicle
ROC	Remote Operations Centre
ROV	Remotely Operated Vehicles
tcf	Trillion cubic feet
TCO_2e	Tonnes of carbon dioxide equivalent
UAV	Unmanned Aerial Vehicles
UN	United Nations
USV	Unmanned Surface Vehicles
VR	Virtual Reality

A.3 Co-contributing funding schemes for Australian SMEs and start-ups

Many of the activities recommended in this report require investment in R&D. The table below lists national and state-based funding schemes available to Australian SMEs and start-ups that support innovation and commercialisation.[258]

PROGRAM NAME	STATE	FUNDING	PROJECT SME CONTRIBUTION	ELIGIBILITY / NOTES
Innovation Connections	All	< $50k	1:1 cash	$1.5m - $100m turnover, 3+ years in business. Grants available for researcher, business researcher and graduate placements.
CSIRO SIEF STEM+ Business	All	< $105k p.a.	1:1 cash	$1m - $100m turnover. Projects delivered by early-career researchers.
CSIRO Kick-Start	All	$10k-50k	1:1	< $1.5m turnover. Research/development/testing with CSIRO.
Accelerating Commercialisation	All	< $1 mil	1:1	< $20m turnover. Funds commercialisation, not research and development.
ICon Proof of Technology grant	ACT	$5k-30k	1:1 cash and/or in-kind	< $2m turnover.
ICon Accelerating Innovation grant	ACT	$5k-10k	1:1 cash and/or in-kind	< $2m turnover.
TechVouchers	NSW	< $15k	1:1 cash	< $30m turnover, < 20 employees, 1+ years in business. Preference for companies not previously engaged in research.
BISI Innovation Voucher	NT	< $25k	40%	< 100 employees.
Knowledge Transfer Partnerships	QLD	< $50k	1/3 cash	< 200 employees, 2+ years in business. Research performed by KTP eligible graduates.
Innovation Voucher program	SA	$10k -$50k	1:2 or 1:1	< $200m turnover, 1+ years in business. Contribution 1:2 for SMEs below $5m.
Business Transformation Voucher	SA	< $50k	1:1 cash	1+ years in business. Can include developing new business models or R&D.
BioSA Industry Development program	SA	$50k-250k repayable		Early-stage/start-ups. Bioscience and related industry sectors.
SBDF Start-up business grant	SA	< $20k	1:1 cash	To contribute to starting a new business or buying a business.
SBDF Business Expansion grant	SA	$10k-100k	1:1 cash	< 20 employees, 1+ years in business.
Innovation Vouchers	WA	< $20k	At least 20%	< $500k turnover, < 200 employees.

258 For more information on the funding schemes available to Australian SMEs and start-ups see CSIRO's SME Connect Program http://www.csiro.au/SMEConnect

A.4 Further reading

The following reports provide deeper insights into some of the specific trends and concepts covered in this Roadmap:

1. National Energy Resources Australia (2017). *Sector Competitiveness Plan*, Kensington.
2. International Energy Agency (2016), *World Energy Outlook 2016,* OECD/IEA, Paris.
3. Campey, T., et al (2017). *Low Emissions Technology Roadmap.* CSIRO, Australia.
4. CSIRO and Energy Networks Australia (2017). *Electricity Network Transformation Roadmap: Final Report.*
5. International Energy Agency (2013), *Resources to Reserves 2013,* OECD/IEA, Paris.

OTHER ROADMAPS IN THE CSIRO SERIES

This Roadmap is the fifth in a series of roadmaps developed by CSIRO.

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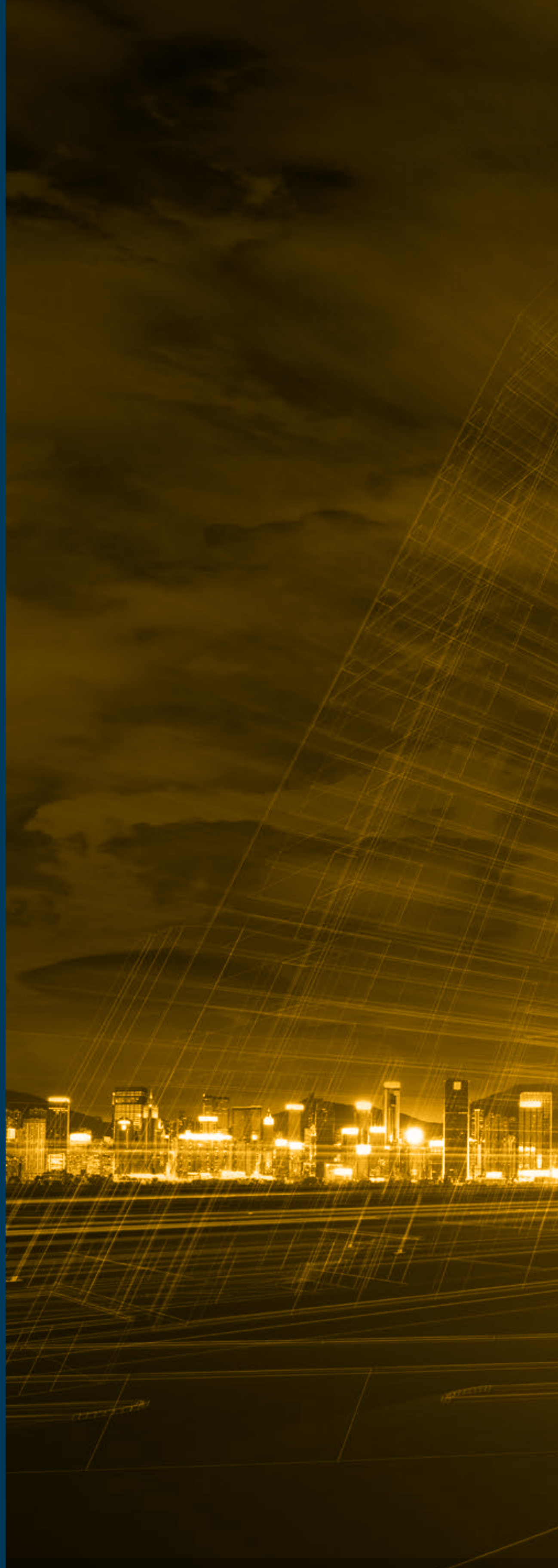

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