CLIMATE COUNCIL

POLLUTION AND PRICE: THE COST OF INVESTING IN GAS

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info@climatecouncil.org.au

climatecouncil.org.au

Andrew Stock
Climate Councillor

Petra Stock
Energy and Climate Solutions Analyst, Climate Council

Professor Will Steffen,
Climate Councillor

Dr Martin Rice
Head of Research, Climate Council

Greg Bourne
Climate Councillor

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Key Findings

1

Australia's electricity system is ageing, inefficient and polluting.

- As coal fired generators close new power plants must be built to provide clean, affordable, secure power.
- Tackling climate change and protecting Australians from worsening extreme weather requires our electricity system to produce zero emissions before 2050.
- Fossil fuels: coal, oil and gas all produce greenhouse gas emissions driving climate change. Limiting global temperature rise requires that they are all phased out.

2

Gas is not sufficiently less polluting than coal to garner any climate benefit.

- Greenhouse gas emissions are produced both from gas power stations and gas production (for instance, methane from gas leaks). Methane is 86 times more potent as a greenhouse gas than carbon dioxide over a 20-year period.
- Old gas plants in Australia, such as Torrens Island, are as polluting as coal fired power stations.
- New gas power plants are less polluting than coal, however, when the entire supply chain of gas production is considered, gas is not significantly less polluting than coal.
- Current levels of reliance on gas power in Australia must be reduced to play our role in limiting global temperature below 2°C. Expanding gas usage is inconsistent with tackling climate change as it locks in emissions for decades into the future.

3

Greater reliance on gas will drive higher power prices.

- Australia's Liquefied Natural Gas (LNG) exports are pushing up the price of gas power as domestic gas prices are now inextricably linked to world market prices for oil. This will continue into the foreseeable future.
- The most economic and accessible reserves are now being exported. Further gas expansion will drive increased reliance on unconventional gas, which is expensive.
- Reliance on gas power is also driving power price spikes particularly in South Australia, Queensland and increasingly in New South Wales, due to lack of competition among gas power companies.

4

Investment in new gas plants is financially risky.

- The large increases in future gas prices and volatility resulting from LNG exports together with domestic gas prices controlled by relatively few producers, make investments in new power plants using gas very risky.
- New gas power plants would rely on ageing gas infrastructure (e.g. processing plants and high pressure pipelines) that is increasingly vulnerable to failure. Costs of updating this infrastructure and accounting for methane leakage must be factored into policy and investment decisions.
- New gas infrastructure locks in carbon emissions for decades. Future regulations may impose higher costs or stricter limits on emissions in the future, impacting on the economic viability of gas production and electricity generation, stranding investments.

5

Significant development of new gas plants is unfeasible without a massive expansion of unconventional gas, including thousands of new unconventional gas wells.

- The sheer volume of gas required, the cost, the lock in of long-term emissions, and community concerns makes this unrealistic.
- Currently the emissions from unconventional gas in Australia are unknown due to a lack of measurement and data. This presents a long-term carbon risk to investors as high emissions fossil fuel infrastructure faces the possibility of future regulation due to climate change.
- Development of new unconventional gas is entirely out of step with meeting the Federal Government's climate change goals.

6

Renewable energy can provide a secure, affordable alternative to new fossil fuels.

- New renewable energy is cost competitive with new gas. The cost of renewable power and storage, particularly solar, wind and batteries, continues to fall and has no associated fuel costs. This contrasts with rising and volatile gas prices.
- Technologies such as solar thermal, hydro and biomass plants can meet demand for electricity at all times of the day as well as meeting technical requirements for grid stability. Combining these technologies with wind, solar PV, and large-scale energy storage, can meet electricity demand round-the-clock.
- Using existing gas-fired generators and supply infrastructure prudentially to complement wind and solar power while scaling up a range of renewable energy technologies, energy storage, and energy efficiency measures could deliver a limited benefit, provided the end goal is phasing out the use of all fossil fuels as quickly as possible.

Recommendations for Policy Makers

UNDERSTAND EMISSIONS FROM GAS PRODUCTION AND POWER PLANTS.

1. Require independent field measurements of methane emissions (baseline before development is approved, after development, throughout operations and after abandonment) at every current and proposed unconventional gas project in Australia to determine accurate emissions factors for gas production and generation and national greenhouse gas reporting.

ROLE OF GAS IN AUSTRALIA'S ENERGY SYSTEM

2. Do not provide policy support for new gas power plants or gas supply infrastructure. New gas infrastructure risks "locking in" expanded gas use and exploration for decades into the future, and carries risks associated with emissions, electricity costs and asset stranding.

3. Design any new policy, for example an Emissions Intensity Scheme, taking into account the full emissions profile of gas (including supply chain emissions), as well as the full cost implications. This is critical for affordability and emissions.

4. Existing gas plants should be thought of as a short-term, expensive, emergency backup as renewable energy and storage is rapidly scaled up.

A NATIONAL PLAN FOR AUSTRALIA'S ELECTRICITY SYSTEM

5. Introduce a national transition plan for Australia's electricity system that:

a. ramps up a diverse range of renewable energy, energy efficiency and storage technologies to enable the phase out of fossil fuelled electricity generation over the next 2-3 decades;

b. is secure and robust, particularly in light of worsening extreme weather events; and

c. reaches net zero emissions before 2050 at the latest.

6. Incentivise greater interconnection between states by transmission lines to provide more diverse, distributed, and secure electricity supply and increase competition in the electricity market.

7. Incentivise a more distributed system (with power generation spread geographically rather than large, concentrated power plants) involving a wider variety of supplies - wind, solar, biomass, hydro, and energy storage – to ensure more resilience to disruption from increasing extreme weather events due to climate change.

1. Introduction

Australia is at a critical juncture on energy and climate policy.

Australia's energy infrastructure is ageing, inefficient and polluting, and must be replaced over the next few decades. Already nine coal fired power stations have shut down in the last five years (McConnell 2016; ABC 2017a). Meanwhile, over the last 20 years, 1.6 million households have invested in solar panels for their homes, and the cost of renewable energy, particularly solar photovoltaic and wind power, has rapidly decreased. The Australian energy system is experiencing a transition, which is similarly being experienced around the world as the cost of renewable power drops and countries seek to tackle climate change.

Meanwhile, it is now clear that climate change is already worsening extreme weather events. The 2016/2017 summer has been described as the "Angry Summer" highlighting the significant number of weather records broken. This follows a long-term trend of global warming over a number of decades. Climate change is driven by emissions of greenhouse gases from the burning of fossil fuels (coal, oil and gas). Tackling climate change requires transitioning away from fossil fuels for electricity to renewable energy generation, storage and improvements in energy efficiency. The regulatory and investment decisions made in the next decade will either lock in more emissions intensive infrastructure, or accelerate the transition to zero emissions electricity generation before 2050.

At the same time community concerns about high and climbing electricity prices, as well as discussion about the reliability of our electricity system are issues dominating the news media.

This report investigates the role of gas as Australia transitions its electricity sector to net zero emissions before 2050. Gas has been commonly referred to and promoted by the gas industry as playing a 'pivotal role … in the transition to a low-carbon economy' (APPEA 2016). This report looks at how gas-fuelled electricity generation measures up against the principal policy criteria for Australia's electricity system: affordability, reliability and emissions reduction (Finkel 2016). While focusing chiefly on gas-powered electricity generation, this report considers other relevant factors where necessary, such as Australia's Liquefied Natural Gas (LNG) export market and methane emissions associated with unconventional gas production.

The report finds limiting global temperature rise means moving away from gas as well as coal for power generation. Greater reliance on gas will also drive higher power prices. The report shows that a secure, dependable, cost effective power system can be achieved without gas.

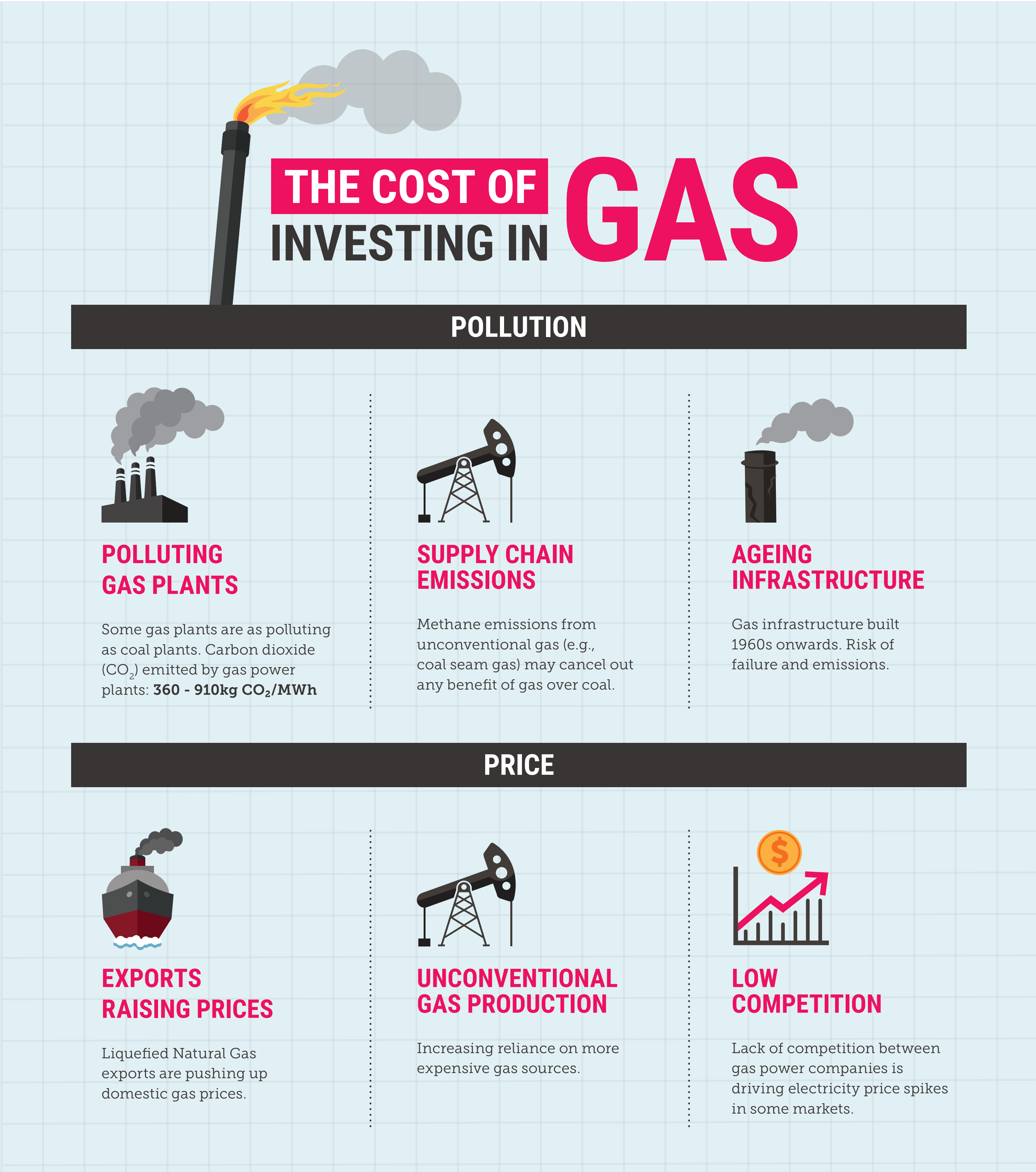


Figure 1: Gas - polluting, ageing and expensive.

2. Emissions Reduction: Limiting Global Temperature Rise Means Moving Away From Gas as Well as Coal

Climate change (fuelled by the burning of coal, oil and gas) is already influencing extreme weather events across Australia.

Australia has agreed with world leaders to limit global temperature rise to well below 2°C, which means Australia's electricity system needs to reach zero emissions before 2050. Gas power generates greenhouse gas emissions at the power plant and along the gas supply chain. Greater reliance on gas for power generation is inconsistent with action on climate change.

2.1. Delivering Australia's Emission Reduction Commitments

2016 was the hottest year on record globally for the third year in a row. The record global warmth of 2016 is part of a long-term trend. All of the world's 10 warmest years have occurred since 1998. 2016 was the 40th consecutive year with above-average global temperatures (NOAA 2017). Human activities, such as the burning of coal, oil and gas for electricity, are driving up greenhouse gas emissions and fuelling this long term warming trend.

In 2016, Australia sweltered through its warmest autumn on record. Highest temperatures on record were experienced throughout much of eastern and northern Australia including Queensland, New South Wales, Victoria and the Northern Territory. From late February through to March 2016, the sea surface temperatures over the northern, pristine part of the Great Barrier Reef were around 1 to 1.5°C above the recent long-term average (2002-2011). Warm waters caused devastating bleaching and the death of 67% of coral in the northern section. Western Australian and other reefs throughout the world were also badly affected by this mass global bleaching event, the worst in recorded history, driven by climate change and a recent El Niño event.

During the "Angry Summer" of 2016/17, over 205 records were broken around Australia. For example, Brisbane, Canberra and Sydney experienced their hottest summer on record. The extreme summer heat in New South Wales was made at least 50 times more likely to occur due to climate change (King et al. 2017). The "Angry Summer" of 2016/17 follows hot on the heels of previous Angry Summers in 2012/13 and 2013/14, with Australians facing record-breaking extreme weather events driven by climate change, yet again (Climate Council 2017a).

Climate change is influencing all extreme weather events in Australia and around the globe (Trenberth 2012). Heatwaves are becoming hotter, lasting longer and occurring more often (Perkins and Alexander 2013; e.g., Figure 2). Marine heatwaves that cause severe coral bleaching and mortality are becoming more intense and occurring more often (e.g., Moore et al 2012). Extreme fire weather and the length of the fire season are increasing, particularly in the south and east of the continent, leading to an increase in bushfire risk (Clarke et al 2013). Sea level has already risen and continues to rise, driving more devastating coastal flooding during storm surges (IPCC 2012). The impacts of extreme weather events are likely to worsen unless global greenhouse gas emissions are reduced rapidly and deeply (Climate Council 2017b). Australia is the 16th largest emitter of carbon dioxide in the world, larger than 180 other countries (Global Carbon Project 2016). Australia must do its fair share in reducing emissions.

As global temperatures continue to rise, there are serious consequences for human health and wellbeing, as well as the natural systems that support us, like land, air and water. The burning of fossil fuels (coal, oil and gas) produce greenhouse gas emissions, these gases trap heat in the atmosphere causing global warming. The additional heat in land, ocean and atmospheric systems is driving worsening extreme weather. If we do not rapidly reduce greenhouse gas emissions, then even more harmful and potentially catastrophic consequences for humanity will occur.

Under the Paris Agreement, world leaders including Australia agreed to limit global temperature rise to well below 2°C above pre-industrial levels, and to pursue efforts to limit temperature rise to only 1.5°C. This near universal agreement - signed by 196 nations, ratified by 139 nations and accounting for 97% of global emissions - entered into force on 4 November 2016. Australia ratified the Paris Agreement on 9 November 2016 (UNFCCC 2017).

Figure 2: Heatwaves are now hotter, longer and more often due to climate change (Perkins and Alexander 2013).

While 2°C may not sound like much, this level of temperature rise will have serious impacts on the lives and livelihoods of people all over the world. Already at only about 1°C temperature increase from pre-industrial levels, climate change is intensifying extreme weather events. In order to achieve the 1.5-2°C target, the Paris Agreement sets a goal to reach net zero greenhouse gas emissions globally in the second half of this century (UNFCCC 2017) - specifically, carbon dioxide emissions have to drop to net zero between 2060 and 2075, while total greenhouse gas emissions need to decline to net zero between 2080 and 2090 (WRI 2015).

In ratifying the Paris Agreement, Australia has committed to both a 2030 emissions reduction target, and to rapidly reduce our carbon emissions (including electricity sector emissions), in line with a pathway to zero emissions by 2050 (The Climate Institute 2015).

The Federal Government has set a 2030 emissions reduction target of 26 - 28% below 2005 emissions levels (Australian Government 2015a). Yet in 2015, leading up to the Paris climate talks, the Climate Change Authority recommended - based on climate science, international actors and economic factors - that Australia should reduce its emissions 40 - 60% below 2000 levels by 2030 (or a range of approximately 45-65% below 2005 levels). It is important to note that these Climate Change Authority recommendations are based on only a two-thirds chance of avoiding 2°C warming. For a stronger chance, the emissions reduction target should be higher. Therefore, if global average temperature is to stay below 1.5 - 2°C then the Climate Change Authority recommendations should be seen as a bare minimum for Australia's contribution to tackling climate change in concert with the rest of the world. To stay below 2°C, Australia's electricity system needs to reach zero emissions before 2050 (ClimateWorks 2014).

Australia's electricity system needs to reach zero emissions before 2050.

2.2. Australia's Electricity Sector, Our Largest Source of Emissions

Today, Australia's electricity sector is the nation's single largest source of greenhouse gas emissions - accounting for 35% (189 $MtCO_2$¬e in 2016) of total emissions (Australian Government 2016a). The electricity sector has seen the largest total growth in emissions, increasing 46% (59.5 $MtCO_2$¬e) between 1990 and 2016 (Australian Government 2016a). When emissions from extraction, processing and transporting coal, gas and diesel are added, electricity generation is clearly the dominant contributor to Australia's emissions (Climate Council 2014).

Australia's electricity generation is dominated by high emissions fossil fuels (black coal 43%, brown coal 20%, gas 21% and oil 3%) with renewable energy making up 14% (Australian Government 2016b; note: numbers have been rounded).

If the electricity generation sector is to meet its proportionate share of the 2030 target, it needs to reduce its emissions by 48 $MtCO_2$ per year by then. As power stations are large single point sources of emissions, whereas emissions from many other sectors of the economy are widely dispersed, arguably the electricity sector should bear a higher proportion of the emissions reduction effort (Climate Council 2016a).

Electricity emissions must drop 50 million tonnes per year by 2030.

2.3. Emissions Associated with Gas Powered Electricity Generation

Using gas for power generation releases both carbon dioxide (directly from power plants and gas processing plants) and methane emissions (due to a multitude of gas leaks, venting, equipment purging, incomplete combustion, potential migratory emissions and other sources associated with the gas supply chain). There is an additional risk of large methane releases due to the failure risk from ageing infrastructure, e.g., see Section 2.6.

Methane (CH_4), the main component of natural gas, can be directly released to the atmosphere at each stage of gas production and transport either intentionally (via flaring or venting, equipment purging, or incomplete combustion) or unintentionally (e.g., leaks and failures). Methane is a particularly potent greenhouse gas, which later oxidises in the atmosphere (after 10-12 years) to form carbon dioxide. The global warming potential of methane is 86 times greater than carbon dioxide over a 20-year timeframe (Lafleur et al 2016) and 28 times greater over a hundred years (Schwietzke et al 2016).

Methane released in the gas supply chain is a potent greenhouse gas.

BOX 1: GAS JARGON

CARBON RISK

Due to high emissions associated with fossil fuel infrastructure, companies and investors face the possibility of future regulation due to climate change.

NATURAL GAS

Natural gas is a fossil fuel primarily consisting of methane (CH_4) and small amounts of other gases (less than 10%, such as ethane, propane, butane and carbon dioxide – which can vary up to as much as 50% of the raw gas stream before it is processed) (Parliament of Victoria 2013).

LNG

Liquefied Natural Gas (LNG) refers to natural gas converted into liquid form under very low temperatures (-161°C) in order to be more easily transported internationally and stored (APPEA 2016).

LNG TRAIN

An LNG Train is a facility that liquefies and purifies natural gas to reduce its volume, enabling the gas to be exported.

PETAJOULE (PJ)

The basic unit of measurement for energy is a "joule". A petajoule (PJ) is 1,000,000,000,000,000 joules or 10^{15} joules. The energy in 1PJ is roughly equivalent to the annual electricity use of 30,000 households (Parliament of Australia 2011).

MTPA

An mpta, or million tonnes per annum, is a measure of LNG exports. Producing 1mtpa of LNG requires approximately 60PJ of gas (Queensland Government 2009).

Carbon dioxide (CO_2) is emitted when natural gas is burned, for example when gas is used to generate electricity, heat, or steam. Carbon dioxide is also vented, sometimes in large quantities, in the natural gas production process when raw natural gas produced from underground is treated and carbon dioxide removed to ensure the gas meets pipeline specifications. When gas is used to generate electricity, the CO_2 emissions per unit of electricity depend on the particular gas power plant age, technology, and gas supply chain emissions (see Section 2.4).

Reliance on gas power in Australia poses significant, unaccounted for emissions risks associated with:

- Under-reporting of methane emissions due to lack of field studies and direct measurement by Australia's coal seam gas industry (Lafleur et al 2016, see Section 2.5). Most reporting of methane emissions uses factors derived from out-dated United States (US) industry metrics which have been shown to significantly under-report emissions, particularly from the coal seam gas industry (Kort et al 2014). There were no baseline studies undertaken of methane emissions before development of large coal seam gas deposits took place in the Bowen and Surat Basins (CSIRO Energy Technology 2012). Minimal studies have been done since of actual emissions over this now very large developed area. These factors mean that Australia's actual methane emissions from coal seam gas developments are largely unknown.
- Catastrophic infrastructure failure (e.g., ageing pipelines or gas storage wells) with the potential to release sizeable amounts of methane (see Section 2.6). Much of Australia's gas infrastructure – pipelines, storage facilities and wells were built in the 1970's and are now over 40 years old (The Australian Pipeliner 2016), potentially suffering from corrosion which brings associated catastrophic failure risk. Over the lifetime of any newly built gas power plants (2030 to 2060), this gas infrastructure will reach 60 to 80 years old. For example, the blowout of an underground gas storage well in the US released 100,000 tonnes of methane (equivalent to over 8 million tonnes of CO_2), before it was plugged (Conley et al 2016). There are numerous examples of failures of gas wells, pipelines and production plants in Australia.

These risks adversely impact Australia's ability to meet emissions targets for 2030 and beyond, and our ability to stay within our carbon budget (see Section 2.7).

Actual methane emissions from Australia's coal seam gas developments are largely unknown.

2.4. Power Plant Emissions

Different power plants emit different levels of greenhouse gases. While on average new gas-fired power plants emit less than new coal (Finkel 2016; Table 1), emission levels depend on power plant age and technology (Climate Council 2014), as well as the emissions associated with extracting, processing and transporting the fossil fuel to the power station. For example, some subcritical gas plants in Australia (such as Torrens A and Torrens B in South Australia; Figure 3) emit a similar amount of greenhouse gases per unit of electricity (840-910 kgCO_2-e/MWh) as subcritical black coal plants (Climate Council 2014).

Combined and open cycle gas power plants are less polluting than new coal, but not as substantially as one might expect. While, combined cycle gas turbines are around 50% less emitting than ultra-supercritical black coal plants, open cycle gas power plants (often used to meet peak demand) are around 10% less emitting than ultra-supercritical black coal plants. Most Australian gas power plants are emissions intensive open cycle plants. If run for peaking only, the amount of emissions would be contained, but if run more often, emissions will be little better than coal plants.

Table 1: Estimated emissions from new power stations (and Torrens Island power plants).

Generation type	Estimated operating emissions as generated (kg CO_2-e/MWh)
Coal	
Subcritical brown coal	1,140
Supercritical brown coal	960
Subcritical black coal	940
Supercritical black coal	860
Ultra-supercritical brown coal	845
Ultra-supercritical black coal	700
Gas	
Torren Island power plants*	840 - 910*
Open cycle gas turbine	620
Combined cycle gas turbine	370
Renewable energy	
Wind	0
Hydro	0
Solar PV	0

Source: Finkel 2016; Climate Council 2014*.

Figure 3: Torrens Island Power Plant, South Australia.

Some gas plants in Australia are as polluting as subcritical black coal plants.

BOX 2: SOURCES OF GAS

There are two main sources of gas produced for economic use globally, so called "conventional" and "unconventional" gas. The main sources and attributes of each are:

- **Conventional Gas** – typically sourced from deep underground, rocks 1,000 metres or much more below ground level, either onshore or offshore. The gas is usually produced at very high pressures requiring a relatively small number of wells to extract it. Sometimes, if rates of production are naturally low, the rocks may be fractured using injected fluids, to increase output. Conventional gas may be produced in association with oil, light oil (called condensate), or with small amounts of water. It has varying levels of impurities – such as carbon dioxide – that are removed to meet pipeline specifications. The carbon dioxide is usually vented (released to the air).
- **Unconventional Gas** – typically sourced from shallower levels, from a few hundred metres to less than 1,000 metres, and only onshore. The gas is usually produced at lower pressures, requiring tens to hundreds of wells to achieve the same output as a single conventional gas well. Low natural production rates may be increased through fracturing the coals or shale rock that the gas comes from. There are two main source rocks – coals (coal seam gas) and shales (shale gas and shale oil). Coal seam gas typically contains no oil or condensate, may have some carbon dioxide, and considerable produced water. Shale gas often is produced along with shale oil, or contains light oil.

Further details of gas industry terms and an introduction to gas in Australia can be found in the appendix near the back of this report.

Source: Parliament of Victoria 2013.

2.5. Methane Emissions

When considering emissions from gas power, methane emissions from the gas supply chain also need to be considered to determine whether gas is indeed a lower emissions source of electricity generation compared to coal. To determine the actual emissions intensity of using gas for electricity, emissions from gas production are added to the emissions generated from burning gas.

In national greenhouse gas accounts, the Australian Government applies default emissions factors for methane emissions largely based on figures sourced from the US gas production industry for gas production, rather than direct measurement. Emissions from all gas produced in Australia is reported as 0.5% of gas production (Lafleur et al 2016).

Published emissions data based on field studies and direct measurement from Australia's unconventional gas industry are extremely limited (GISERA 2015). Generally, no baseline emissions surveys were done prior to widespread exploration and development drilling of unconventional coal seam gas in basins like the Bowen, making reliable estimates of increased methane emissions difficult to determine (CSIRO 2012).

However, satellite and aircraft-based measurements of methane emissions from unconventional gas production in the US have demonstrated that the US industry is under-reporting emissions in the San Juan Basin coal seam gas province by between 1.8 to 3.5 times. Viewed from space, the San Juan Basin shows up as a remarkable methane "hot spot" (Kort et al 2014; see Figure 4). These US conclusions indicate that actual methane emissions from coal seam gas extraction in Australia may be substantially higher than the default factors applied to reporting here.

US measurements show methane emissions from unconventional gas production are significantly under-reported.

Figure 4: San Juan Basin methane emissions.

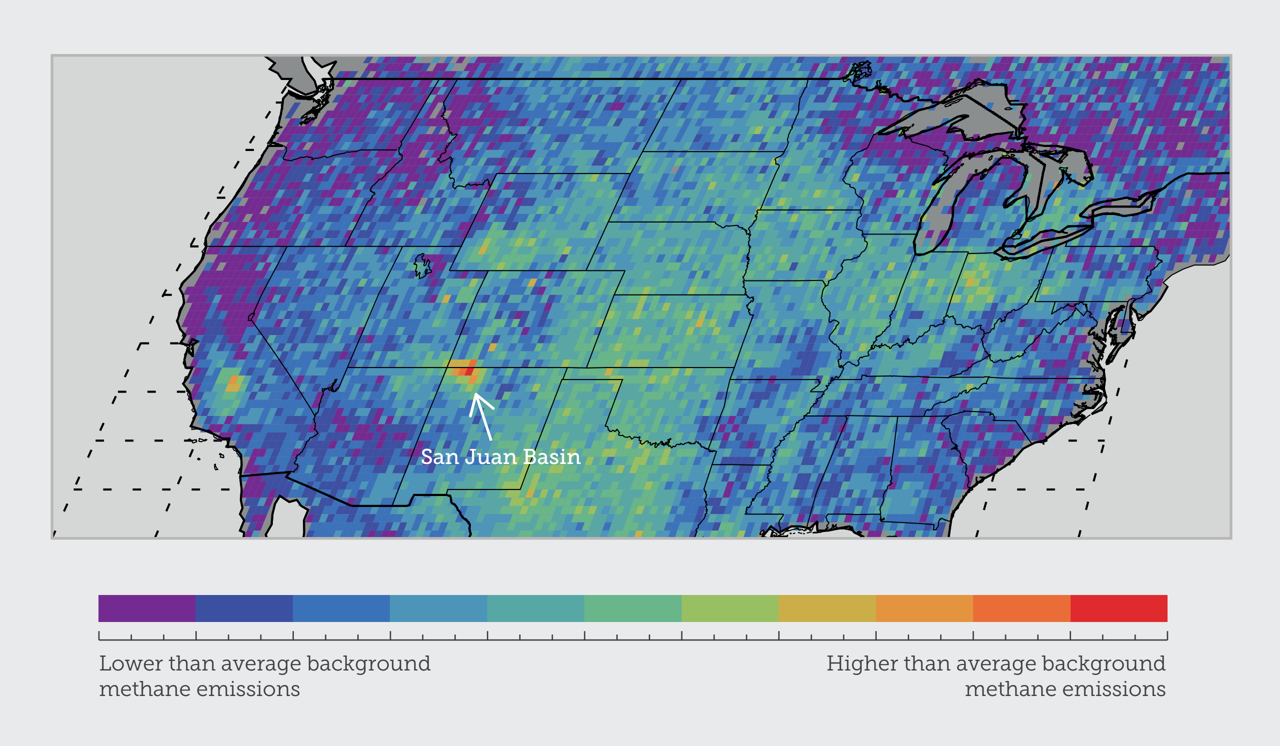


Image: Courtesy NASA/JPL-Caltech/University of Michigan.

Note: The San Juan Basin (located by the arrow and shown in red on Figure 4 above) is the major US hot spot for methane emissions in this map showing how much methane emissions varied from average background concentrations from 2003-2009 (dark colours are lower than average; lighter colours are higher).

If gas power is to have a net climate benefit compared to coal power, methane emissions must be less than 3 to 4% of production (Alvarez et al 2012; Hardisty et al 2012; NAS 2012). When methane emissions from the gas supply chain reach these levels and are added to the carbon dioxide emissions generated from burning gas in a power plant, the greenhouse gas pollution associated with generating electricity from gas is similar to coal. Field measurements in the US have found methane emissions from unconventional gas production are much higher, with some methane emissions recorded in some studies ranging from 2 to 17% of production (US Department of Energy 2010; Pétron et al 2012; Karion et al 2013; Caulton et al 2014; Pétron et al 2014; Schneising et al 2014; Howarth 2015; Lafleur et al 2016).

The lack of measurements and data on methane emissions from unconventional gas in Australia presents a significant carbon risk (facing the possibility of future regulation due to greenhouse gas emissions) for both Australia's LNG export industry and gas power generation. This is particularly concerning given the potency of methane as a greenhouse gas, the rapid and continuing scale-up of unconventional gas exploration and production associated with LNG exports and the growing proportion of coal seam gas in domestic supplies.

Given increased scrutiny by regulators and the investment community of investments at risk of stranding, or to potential damages actions, due to climate change impacts (APRA 2017), it would arguably be reckless to base a national transition strategy to lower emissions in the electricity generation sector around widespread expansion of unconventional gas production in the absence of sound emissions measurements of:

- Baseline methane emissions (i.e., before exploration and development commences)
- The impact of existing unconventional and conventional gas developments on methane emissions levels, particularly around ageing gas infrastructure and unconventional coal seam gas field developments.

Lack of Australian fugitive methane emission measurement and data is a serious unaccounted for risk.

2.6. Ageing Infrastructure

Many of Australia's gas production and storage wells, processing plants and high pressure transmission pipelines are already many decades old (The Australian Pipeliner 2016). Failures of such infrastructure through age or poor operating practices can release substantial volumes of methane, a potent greenhouse gas as described above. Consequently, relying on gas power and infrastructure can pose significant carbon risk (because high emissions fossil fuel infrastructure faces the possibility of future regulation due to climate change). Resulting economic costs and social consequences on society of failures (e.g., injuries or lives lost as a result of explosions) can also be severe.

A recent example (and the largest methane leak in US history) occurred in 2015 when a natural gas storage well in Aliso Canyon, California "blew out" releasing over 100,000 tonnes of methane in less than four months before the well was sealed. The well blowout led to a state of emergency being declared and more than 5,000 families being evacuated (Conley et al 2016).

Australia is not immune to environmental disasters resulting from infrastructure failure from oil and gas exploration and production. Events like the Aliso Canyon well blowout have happened here.

In Australia, there have been a number of major offshore and onshore gas well blowouts, some of which have taken months to stop. In addition, gas pipelines and gas processing plants have suffered major failures leading to significant methane emissions and, in some cases, major economic disruption (Table 2).

Failure of ageing gas infrastructure can cause emissions, economic and social risks.

Table 2: Australian gas-related infrastructure failures and well blowouts.

Offshore Well Blowouts	Year	
Barracouta 1	1965	Gas
Marlin B-1	1966	Gas
Marlin A7	1968	Gas
Petrel 1	1969	Gas
Marlin A4	1971	Gas
Flounder A1	1984	Oil
Montara H1	2009	Gas, Condensate, Oil

Onshore Well Blowouts	Year	
Della 1	1987	Gas Storage
Myall Creek 8	2003	Gas
Habanero 3	2009	Geothermal
Arrow	2011	Gas
AGL	2011	Gas

Gas Plant Explosions	Year	
Longford	1998	Gas
Moomba	2004	Gas
Varanus Island	2008	Gas

Gas Pipeline Ruptures	Year	
Moomba to Sydney	1982	Gas
Varanus Island	2008	Gas
Pt Pirie/Whyalla Lateral	2015	Gas

A major gas escape at a pipeline or processing plant may ignite, potentially increasing the damage caused and time to repair.

If power generation infrastructure were to become increasingly dependent on gas supplies, as the gas supply infrastructure ages further, the risk of failures may increase due to factors such as corrosion, failure of cements, metal fatigue and poor operating practices. The economic impacts of gas infrastructure failures can be major if a city's power supplies, or its industry, is heavily dependent on gas as a major energy source. The Longford Gas Plant explosion in 1998 is estimated to have had an economic cost to Victoria of $1.3 billion (The Age 2002), while the Varanus Island Explosion in 2008 cost the Western Australian economy an estimated $2.4 billion (Parliament of Australia 2008).

One recent major upstream gas release occurred at the Montara Wellhead Platform. In 2009, a well control barrier failed, causing a major oil and gas leak in the Timor Sea which took over 70 days to stop. While numerous reports into this incident made estimates of the amount of oil released (between 4,750 and 23,630 tonnes), no estimates appear to have been made of the volumes of gas released before the platform eventually caught fire and burned after 70 days of raw gas and oil release (AMSA 2010; Borthwick 2010; Australian Government 2016d; Crikey 2016). The gas release was substantial, as images of the rig and platform show (Figure 5).

Figure 5: Montana gas and oil blowout shows the huge cloud of escaping vented gas and oil slick - the platform is not on fire at this stage.

2.7. Gas and the Global Carbon Budget

The carbon budget (cumulative emissions) approach provides a conceptually simple yet scientifically robust way to translate climate policy targets into global carbon emissions budgets and to track progress towards meeting those targets (IPCC 2013). For example, the carbon budget provides a guide to how much carbon can be “spent” to meet the Paris target of limiting global temperature rise to 2°C or less. At any point in time, the carbon budget allows the calculation of a remaining emissions budget. This provides a critical reality check on the effectiveness of climate policies and the required depth and speed of emission reductions into the future.

The scientific basis for the carbon budget approach is the approximately linear relationship between the total amount of human emissions of carbon dioxide (CO_2) since the beginning of the industrial revolution and the resulting rise in global average temperature (Figure 6). As shown in the figure, there is a range of uncertainty around the linear relationship, represented by the coloured band, which allows a probability analysis of meeting specific temperature targets.

Figure 6 is based on projections by a number of different climate models of the rise in global temperature as cumulative global CO_2 emissions increase. The black line on the graph shows the actual cumulative CO_2 emissions since 1870 and the observed rise in global temperature. The figure shows the proportional (approximately linear) relationship between emissions and temperature rise; the more CO_2 we emit, the warmer the climate gets.

The carbon budget is a guide to how much carbon can be “spent” while keeping global temperature rise below 2°C.

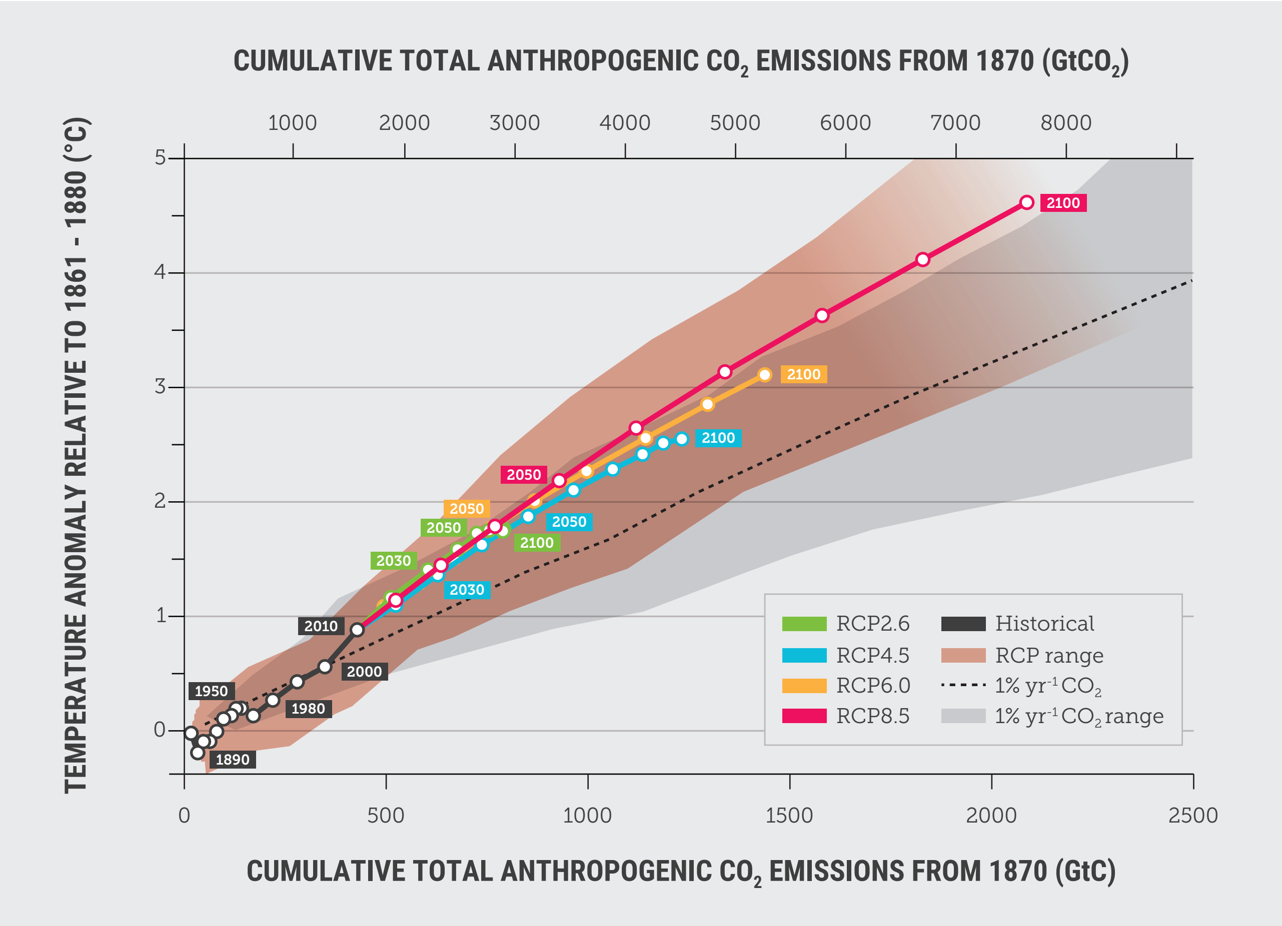


Figure 6: Global mean surface temperature increase as a function of cumulative total global CO_2 emissions from various lines of evidence.

Note: Results from a hierarchy of climate-carbon cycle models for each RCP (emission scenario) until 2100 are shown with coloured lines and decadal means (dots). Some decadal means are labelled for clarity (e.g.,2050 indicating the decade 2040-2049). Model results over the historical period (1860 to 2010) are indicated in black. The coloured plume illustrates the multi-model spread over the four RCP scenarios and fades with the decreasing number of available models in RCP8.5. The multi-model mean and range simulated by CMIP5 models, forced by a CO_2 increase of 1% per year (1% yr-1 CO_2 simulations), is given by the thin black line and grey area. For a specific amount of cumulative CO_2 emissions, the 1% per year CO_2 simulations exhibit lower warming than those driven by RCPs, which include additional non-CO_2 forcings. Temperature values are given relative to the 1861-1880 base period, emissions relative to 1870. Decadal averages are connected by straight lines. **Source:** Adapted from IPCC (2013).

Because 90% of the CO_2 that we emit comes from the burning of fossil fuels, to meet the carbon budget for the 2°C Paris target, most of the world's fossil fuel reserves must be left in the ground, unburned. "Reserves" refers to the fraction of fossil fuel resources that are exploitable under current economic conditions and have a specific probability of being produced.

McGlade and Ekins (2015) analysed the unburnable fossil fuels globally and for the OECD Pacific group (which consists mainly of Australian reserves, see Table 3).

To have a better than 75% chance of staying below the 2°C warming limit, more than 70% of Australia's existing, conventional reserves of gas are unburnable.

Table 3: Percentage of existing fossil fuel reserves that can be burned, based on a carbon budget approach for the OECD Pacific group (largely Australian reserves) for emissions from 2011 through 2050.

Probability of meeting 2°C target	75%
Oil	32
Gas	29
Coal	3

Source: Meinshausen et al. 2009; IPCC 2013; McGlade and Ekins 2015.

This analysis is based on a carbon budget from 2011 to 2050. Thus, results from this analysis will need to be reduced even more to account for the emissions from fossil fuels burned over the 2011-2016 period, which have consumed part of the 2011-2050 budget.

The analysis by McGlade and Ekins (2015) also finds that no amount of unconventional gas reserves (e.g., coal seam gas and shale gas) can be burned (unless they are cheaper than, and thus displace, production from existing conventional gas reserves, which is highly unlikely).

Some in the gas industry have argued that additional gas resource development (conventional and unconventional) is essential to transition to a low carbon electricity generation system. However, this will not be possible within the 2°C carbon budget because tackling climate change requires that most of the world's (including Australia's) existing fossil fuel reserves be left in the ground, unburned. There is no room in the carbon budget for any new fossil fuel development.

For more details on fossil fuels and the carbon budget, see the Climate Council's (2015) report, "Unburnable Carbon: Why we need to leave fossil fuels in the ground".

To have a 75% chance of meeting the 2°C target, over 70% of Australia's existing conventional gas reserves must remain in the ground, unburned.

2.8. Has Australia Already Over-Spent its Gas Carbon Budget on LNG Exports?

On Australia's east coast, substantial unconventional gas reserves and resources (in excess of 25,000PJ – more than 40 times annual domestic gas use) have already been committed to export LNG contracts. However, any further development of unconventional gas will exceed the carbon budget (see section 2.7).

Various estimates have been made of the reserves and resources of unconventional gas on Australia's east coast. Most of the current proven and probable (2P) developed and undeveloped unconventional gas reserves are already committed to Gladstone LNG export contracts (AEMO 2016). The Australian Energy Market Operator (AEMO) determined that additional development of undeveloped 2P Reserves, and less economic Possible or Contingent resources will be needed to meet LNG export obligations to 2035 and beyond, as well as meet existing domestic demand beyond 2019. Other experts (e.g., see Energyquest 2016) form the view that AEMO's estimates of gas reserves and deliverability adequacy are overly optimistic. Energyquest determined gas supply would fall short of existing domestic demand over the period 2016 to 2025 by around 1,500PJ, that existing unconventional gas into LNG exports had been overcommitted, and domestic markets were left short of supplies and increasingly dependent on unconventional gas as traditional conventional supplies reduced (Energyquest 2017).

As more gas is exported overseas as LNG, domestic gas is expected to get even more expensive than it has been of late. AEMO (2107a) notes that new gas supplies to meet LNG export demands and domestic gas needs will rely on unconventional gas resources that are uneconomic at current prices and much more costly to develop and produce. Some gas companies have impaired their LNG investments as they are unable to economically develop sufficient unconventional gas at current prices (e.g., Santos 2016). Energyquest (2017) estimates that gas to Sydney will cost around $14 per gigajoule by 2024. States heavily dependent on gas for peaking power have seen prices for summer 2017 more than double in one year (The Age 2017). These predicted high costs mean that gas power will become more expensive. Forecasts of higher gas costs in future mean that new gas power, will become less attractive, while the cost of electricity from renewable energy technologies continues to fall.

There is a general lack of understanding of just how much additional unconventional gas development would be required if Australia's emissions reduction targets for the electricity sector were to be delivered through new gas power stations replacing coal. Various estimates of the amount of new gas generation have been made, but two recent studies provide indications of the impact. By 2030, between 70,000 GWh/yr (Frontier Economics 2016) and 110,000 GWh/yr (Jacobs 2016) of additional gas fuelled power production (by more than an extra 8,000MW of new power plant by 2030) would be needed to displace coal to achieve the 26-28% reduction in power emissions.

To put this in context, this would require the development of gas reserves and production equivalent to that needed to supply between 2 to 4 additional LNG trains like those at Gladstone (potentially more gas than the entire east coast of Australia currently uses each year). Experienced industry consultants are already anticipating a shortfall against existing east coast domestic demand, and companies like Santos are already impairing their results because they are unable to economically develop sufficient gas to fill out their existing GLNG plant. In these circumstances, it would be economically (as well as environmentally) questionable to base future emission reduction policy for the power generation sector around any policy measure which would require a dramatic expansion of gas exploration and development. Furthermore, while a massive investment in gas development and new power stations might achieve 2030 emissions targets, it would also lock in substantial emissions from the gas power plants and supply chain for the following two decades, a time when the power generation sector needs to achieve zero emissions.

Transitioning to more gas power would use enormous volumes of gas.

2.9. Australia Needs to Transition Rapidly to a Zero Emissions Electricity System

In addition to carbon budget analysis requiring the majority of Australia's gas reserves to stay in the ground, analysis of Australia's electricity emissions has found that even current levels of reliance on gas power are inconsistent with International Energy Agency (2016) modelling of allowable emissions intensity for electricity generation for limiting global temperature below 1.5 - 2°C. In addition to transitioning away from coal, Australia needs to reduce its current reliance on gas for power by 70% (McConnell 2017).

To help protect Australians from worsening climate impacts (e.g., more destructive storms, intense heatwaves and worsening bushfire conditions) Australia needs pathways to transition as rapidly as possible away from coal, oil and gas to reach net zero emissions before 2050. The more quickly Australia, and other nations, reduce emissions, the more likely it is that we will avoid worsening climate impacts.

Using existing gas-fired generators and supply infrastructure prudentially to complement wind and solar power while scaling up a range of renewable energy technologies, energy storage, and energy efficiency measures could deliver a limited benefit, provided the end goal is phasing out the use of all fossil fuels as quickly as possible.

However, attempting to build new gas power plants and infrastructure based on policy schemes which foster new gas development, risks “locking-in” expanded gas use and the associated emissions of carbon dioxide and methane for decades into the future, increasing reliance on rapidly ageing gas infrastructure, and dramatic expansion of new unconventional gas resource exploration and development. More likely would be that neither equity or debt would be forthcoming, such is the associated carbon risk.

It is critical that new developments do not lock in fossil fuel emissions for decades to come.

3. Affordability: Greater Reliance on Gas Will Drive Higher Power Prices

As Australia's ageing coal fired power stations close, new power plants will need to be built to meet our electricity demand.

Renewable power technologies are cost competitive now with new gas and do not have the associated fuel costs or emissions. LNG exports; increased reliance on more expensive unconventional gas to meet export and domestic demands; and lack of competition are all driving higher gas prices.

3.1. Renewable Energy is Cost Competitive and Without the Associated Fuel Costs of Gas

Technologies such as solar thermal, biomass and hydropower are all capable of providing round-the-clock, or on-demand power. These renewable technologies, complemented by small and large scale storage schemes, can play a similar role to gas peaking plants in the electricity system by meeting peaks in demand and complementing much greater uptake of wind and solar PV generation.

Some renewable power technologies are cost competitive with gas power generation now (Table 4). As shown in Table 4, current gas power prices are already increasing due to increased gas costs. Renewable energy sources such as solar PV and wind are already cost competitive, and prices are falling. A range of other studies reinforce this point (e.g. Lazard 2016; Reputex 2017).

While the cost of renewable energy and storage - particularly solar, wind and batteries - continues to fall and has no associated fuel costs; gas power prices are high, volatile and likely to increase as the cost of fuel (gas) increases and bring associated financial risks (due to carbon emissions).

Table 4: Levelised cost of energy for different power technologies in Australia in 2016.

Power Plant Type	Levelised Cost of Energy /Benchmark (US$/MWh)
Solar PV large-scale	$70-135 / $85
Wind	$55-110 / $70 (**)
Gas combined cycle	$55-70 (*) / $62 [*up to $70 - 85 based on current gas prices * up to $95 - 110 based on future gas prices]

Source: Bloomberg New Energy Finance 2016

(*) – NB The BNEF study reflects 2016 Australian conditions and uses a gas cost of US$6/MMBTU (approx. A$8/GJ). Current Australian gas costs are higher than this, and at peak times can be up to 2-3 times higher. Higher current actual Australian gas costs would increase benchmark combined cycle power costs by around US$15/MWh to US$75-80/MWh, while the sorts of costs projected by Energyquest (Energyquest 2017) for 2024 of A$14/GJ (US$11/GJ) would increase benchmark combined cycle costs by US$35/MW to around US$100/MWh.

(**) Some recent Australian wind contract prices are reportedly as low as US$55/MWh (AFR 2017b).

Some renewable power technologies are cost competitive with gas.

3.2. LNG Exports are Pushing Up the Price of Gas in Australia

The escalating diversion of gas reserves to meet LNG export contracts has already resulted in higher prices for gas used in Australia (Australian Government 2015b; Figure 7). The linkage to international oil prices, has pushed Australian wholesale gas prices up dramatically and increased volatility, which in turn increases gas power prices (Australian Government 2015b; Sandiford 2016; The Age 2017). Local manufacturing businesses, such as Victoria Wool Processors, are now being directly affected with gas quotes doubling (ABC 2016). Recently the Australian Industry Group (2017) reported members being quoted contracts for gas priced at around four times higher than 2015 levels and more than five times the historic gas average. AEMO (2016) forecasts that gas prices \$2/GJ higher may reduce commercial and industrial gas use by 20PJ/year. Higher gas prices feeding into higher electricity prices may cause businesses at risk from higher gas prices to close.

Figure 7: Gladstone LNG plants, Queensland.

International LNG contracts have led to some companies selling gas supplies overseas rather than using the gas for local power generation. This has led to the mothballing of gas power plants such as Pelican Point in South Australia and Swanbank E gas plant in Queensland (RenewEconomy 2016a), and higher gas prices across the National Electricity Market (Saddler 2016). An inability to access local gas supplies means these power plants are unavailable to respond when needed (AFR 2017a).

With Australian gas now mostly exported as LNG, domestic gas prices are inextricably linked to world market prices for oil. At current oil prices (around US$60/bbl), LNG netback prices are equivalent to around A$8-10/GJ (e.g., see ACIL Allen 2014; Climate Change Authority 2014; Lewis Grey Advisory 2016). If oil prices were to reach US$100/bbl or more again, domestic gas prices (already at high levels) would double to around A$20/GJ.

However, gas prices are much higher than this on occasions even now. LNG export supply contracts have dramatically increased the demand for gas to export, and led to much higher prices for gas available for domestic power production in Australia (Sandiford 2016). The market response to the unavailability of cheap gas sees gas prices routinely reach $20/GJ, driving up local gas and power prices greatly. A gas price of $20/GJ gas needs a power price of between $A140 to $200/MWh, just to cover fuel costs.

Reliance on gas power is also driving extreme price spikes and volatility due to lack of competition among gas power companies, particularly in South Australia and Queensland (Climate Council 2016b; RenewEconomy 2017; The Guardian 2017; The Age 2017). For example, gas power companies played a key role in driving price spikes in South Australia by using their bidding power to push up the price of electricity at opportune times, particularly in July 2016 (Climate Council 2016b).

To meet existing LNG export demands, the major gas companies are pushing for increased onshore gas exploration and for the removal of state government moratoriums or bans on onshore gas exploration, and for changes to workplace laws to reduce costs (Offshore Technology; The Australian 2016).

Lack of competition contributed significantly to recent power price spikes in South Australia.

3.3. Gas is an Expensive Transition Fuel Compared to Renewable Technologies

Gas is commonly referred to and promoted by the gas industry as a "transition fuel" in tackling climate change, as gas power plants emit less carbon dioxide than coal. However, this statement doesn't take into account the associated methane emissions from the gas supply chain (as described in Sections 2.3 and 2.5).

In 2016, the Climate Change Authority commissioned modelling (Jacobs 2016) of policy options for achieving Australia's commitment to keeping temperature rise below 2°C. Every modelled scenario requires Australia to move away from coal as a source of power generation, with power from coal declining from providing 63% of Australia's electricity generation today to almost zero by 2050. The picture for gas varies more widely depending on the policy option pursued. For example, carbon pricing sees increasing gas power supply in the medium term (to 41% in 2030) while a range of other policy options see the contribution by gas to electricity generation fall below 10% by 2030 (Jacobs 2016).

Proposed policies that rely on increased gas power as a transition fuel would require significant investment in new power plants, gas supplies and pipeline infrastructure. By 2030, modelling (Jacobs 2016) showed an emissions intensity scheme reliant only on gas would require between 70,000GWh to 100,000GWh of gas power generation each year. This would involve:

- Over 8,000MW of new gas power plant investment costing $8 billion to $11 billion (for example, see Frontier Economics 2016; Jacobs 2016).
- Additional gas supplies of between 450 PJ to 700 PJ per year (to put this gas demand in context, each LNG Train at Gladstone uses between 200 -220 PJ per year of gas), requiring upstream exploration and development investment of many billions of dollars as well as major spending on new pipeline infrastructure.
- Annual fuel costs ranging from $2.5 billion to $7 billion per year, depending on gas and oil prices.

Investing in new gas power generation assets has both economic and carbon risks.

Future gas price increases and volatility due to LNG exports, and domestic prices controlled by relative few producers, make investing in new gas power plants very risky.

This extra gas development would "lock in" over a billion tonnes of additional carbon dioxide emissions over the lifetime of the 8,000MW of new gas power plants, and the operating lives of the plants would extend well beyond 2050, when electricity sector emissions need to drop to zero.

Investing well over $10 billion in new gas power generation assets, and probably the same amount or more in upstream gas development, is very risky economically. With gas costs linked to volatile international oil prices, new open cycle or combined cycle gas power stations would be uncompetitive relative to renewables, as the latter have zero fuel costs. In addition, new gas power stations would be reliant on 60 to 80 year old gas processing and transmission infrastructure. To upgrade this infrastructure involves significantly more costs.

An emissions intensity scheme is only one of many possible policy mechanisms to transition to a lower emissions power sector. Other schemes, such as a price on carbon, absolute baselines (where emissions limits for power plants are set and reduced over time) or renewable energy reverse auctions supported by contracts for difference can achieve similar emissions objectives (Jacobs 2016). While the estimates of economic transition costs for each of these alternatives, as modelled, do vary, these are critically dependent on modelling assumptions on aspects like the costs of technology alternatives and the costs (and availability) of fuels like gas. Small changes in assumptions can easily lead one to reaching differing conclusions. Rather than rely solely on economic modelling where outcomes are subjectively based on input assumptions, it is important, therefore, that fundamentals such as emissions lock in, and price volatility from ramped up gas power generation beyond the 2030 time horizon are considered in framing policy choices.

At current development costs, there appear to be insufficient economic gas reserves available from current unconventional gas developments in Queensland to run Australia's existing six LNG trains at capacity. Various reports forecast that while more gas resources may be available, there will need to be much higher gas prices to justify production. Already, domestic industrial and household users of gas have seen higher gas and power prices, threatening industry, household budgets and making power more expensive (e.g., see Energy Quest 2016; AEMO 2017b). The large increases in future gas prices, the volatility linking prices to oil, and domestic gas prices controlled by relative few producers, make investments in new power plants using gas very risky.

Investors would be unlikely to make the major power plant investments required by emissions reduction policy with increased reliance on gas power without first securing substantial gas supply and transport contracts covering at least the first 10 years of new power station demand. To meet the power sector emissions reductions necessary by 2030 by increased gas power alone would require some 5,000 to 10,000 PJ of new gas reserves to be proven up (determined to be technically and economically recoverable) by the mid 2020s at the latest. This is because it takes some 3 to 5 years at a minimum to permit and build new large scale gas power plants. On the eastern seaboard of Australia, such gas is much more likely to be proven up from unconventional sources as existing conventional basins have been well explored over the past 60 years.

The development of such unconventional gas would involve drilling thousands more gas wells, much of it likely to be on prime agricultural land (e.g., Figure 8). It is questionable whether the unconventional gas industry would be able to re-establish an acceptable social licence to secure the necessary acreage to explore for and develop such large amounts of gas.

Pursuing more gas power as an emissions reduction policy is fraught with all manner of risks. Over the next decades as the 2°C carbon budget becomes tighter, gas assets run the risk of stranding as a price on carbon is introduced or regulation becomes more stringent. Other policy options which encourage zero emission technologies (including renewables and storage) are likely to be more robust and lower risk to the unknowable variabilities of future fuel and emissions costs.

Policy options which encourage renewables and storage are likely to be more robust and lower risk.

Figure 8: Coal seam gas, Queensland, Australia.

3.4. Will Greater Reliance on Gas Power Make Electricity More Affordable?

Now that Australian gas power prices are linked to export LNG markets (and oil prices), more gas generation will serve to underpin continuing higher power costs and higher volatility.

New, efficient combined cycle gas plants are unlikely to offer competitive power prices given high gas export prices. Two of the most efficient combined cycle plants in South Australia and Queensland have been mothballed and owners have sold their gas into LNG export markets. This demonstrates that making gas plants profitable in Australia requires Australian consumers to compete with global gas prices.

Further, the parties in the best commercial position to plan for new gas power stations are the existing major players in the power (and gas) retail markets. These incumbent "gentailers" (power retailers who generate electricity as well as selling it on the retail market) in South Australia and New South Wales, already control existing gas power plants and have major gas supply and transportation contracts. A focus on more gas power is likely to reinforce the already strong market power of these companies.

It is also important to note that over half of South Australia's and Victoria's gas generation capacity is over 40 years old. Once generators reach this age, the risk of plant failure increases through reliance on obsolete technology (e.g., in March 2017 three units at Torrens Island Power Station were taken offline due to a voltage transformer exploding) (The Advertiser 2017). One of two major gas pipelines supplying South Australia's gas power stations is also nearly 50 years old, adding to supply risks (Climate Council 2016b), as is one of the two major gas pipelines into New South Wales, and gas pipelines in Victoria.

Increasing the gas supply is unlikely to make domestic gas plants offer more competitive power prices given high gas prices due to LNG exports.

3.5. Policies Transitioning Directly to Renewable Energy are a Lower Cost Alternative to Increased Reliance on Gas

Modelling of Australia's National Electricity Market (e.g., Jacobs 2016) shows that accelerated renewable uptake, paired with storage, a smart grid and energy efficiency, best achieves lowest consumer prices, acceptable reliability and meets Australia's emissions reduction commitments. Importantly this also positions electricity infrastructure for a continued trajectory to zero emissions by 2050, with minimal economic stranding of assets newly built to achieve the 2030 target.

For example, Jacobs (2016) modelled a series of policy options to achieve Australia's 2030 commitment under the Paris Agreement and also to achieve the near zero emissions by 2050, consistent with the longer term 2°C Paris Agreement obligations. Modelled options included:

- a carbon tax
- an emissions intensity scheme
- an extended renewable energy target
- a low emissions target (with wider eligibility than the renewable energy target)
- renewable energy feed-in tariffs with contracts for difference (reverse auctions for renewable energy similar to the Australian Capital Territory's approach for reaching its 100% target)
- regulated coal closures
- absolute emissions baselines.

This modelling (Jacobs 2016) found that a policy of reverse auctions driving investment in new renewable energy (through contracts for difference competitively purchased through reverse auctions) results in by far the lowest costs for all classes of retail consumers; and resulted in the second lowest economic costs overall (after a carbon tax) for meeting Australia's emissions reduction commitments. This approach also resulted in one of the lowest levels of gas generation over the modelling period (2020 - 2050).

The modelling results reflect the fact that new renewable energy power generation, such as wind and solar, is now cost competitive with new gas or coal and avoids the asset-stranding risks inherent in new fossil fuelled generation. There is a range of renewable energy and storage technologies that can provide power on demand to complement variable renewables (at times of low wind or sunshine), such as hydro, pumped storage, solar thermal, large and small scale battery storage, smart grids and demand management.

This direct transition approach avoids the risk of additional emissions, stranded gas and power assets, and high power prices for years to come.

Solar and wind is cost competitive and less financially risky than new gas and coal generation.

4. Reliability: A Secure, Dependable Electricity System Can Be Achieved Without Gas

A secure, reliable electricity system needs to ensure that demand for electricity (from households, business and industry) is instantaneously met with enough supply from power stations, storage and demand reductions (via demand management).

The electricity system needs to meet certain technical requirements (such as frequency control and inertia) for grid stability ensuring that power supply and demand is balanced at all times, and must be able to withstand disturbances to the power system such as severe weather (Finkel 2016). In the longer term, security of power supply relies on planning for infrastructure resilience to withstand increasingly severe weather events associated with climate change.

Each of these challenges can be addressed without increasing reliance on expensive, high emission gas power.

New electricity infrastructure needs to cope with increasing intensity of extreme weather events.

4.1. Reliable Renewable Electricity Can Meet Consumer Demand 24/7 Throughout the Year

There are many renewable energy technologies - solar thermal, sustainable biomass as well as existing hydropower - which are able to provide round-the-clock, or on-demand power. These forms of renewable energy are well placed to complement increasing levels of low cost wind and solar generation (Box 3).

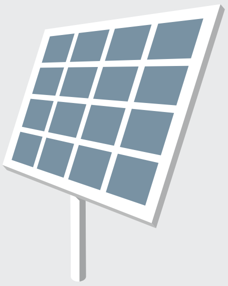
Many renewable energy technologies can provide power on-demand.

BOX 3: RENEWABLE ENERGY TECHNOLOGIES

Renewable Energy Technologies

SOLAR

The sun's energy is converted into heat to drive steam turbines, generating electricity (solar thermal) or converted directly into electricity by solar cells (solar PV).



BIOENERGY

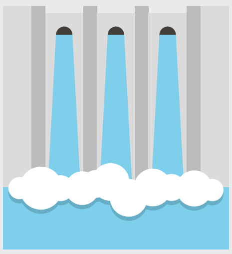
Energy is derived from organic matter (recently living plant or animal material), such as sugarcane waste, landfill gas and algae.

WIND

Wind turns the blades of a wind turbine to generate electricity.

HYDRO

Flowing water turns water turbines to generate electricity.



Source: Climate Council 2015a.

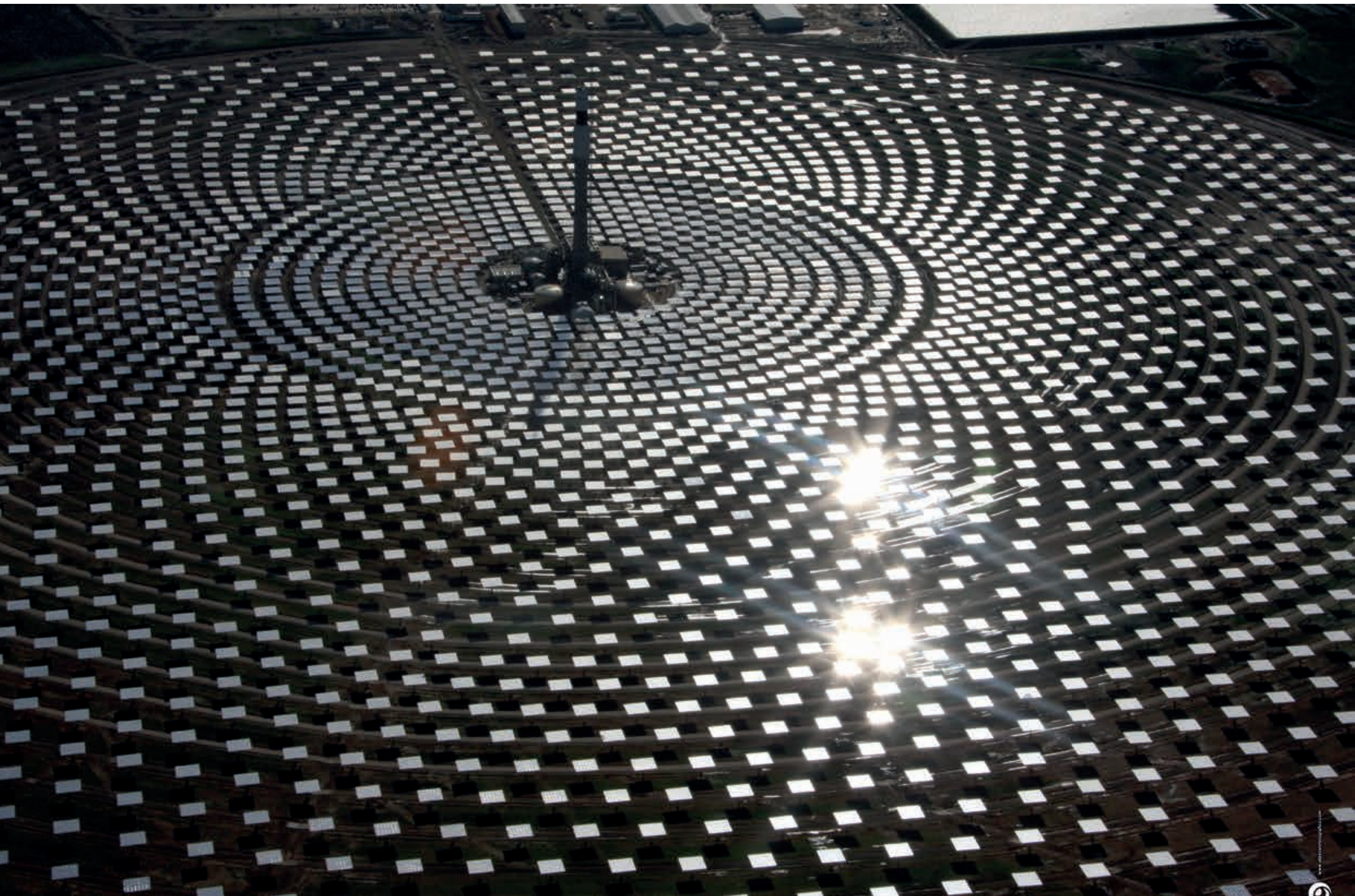
Concentrated solar thermal power plants with storage (e.g., Figure 9) can provide a consistent source of power, or power available on-call to meet periods of high electricity demand such as during heatwaves. These power plants use mirrors to concentrate energy from the sun in order to heat a fluid (such as water, oil or sodium), to produce steam and drive a turbine, generating electricity. Many of these plants also incorporate energy storage. Australian experience to date has been limited, however internationally concentrated solar thermal power plants with storage have proven successful in many countries. The reverse auction process used in Chile (RenewEconomy 2015) stimulated concentrated solar thermal plants with storage, alongside PV and wind projects.

Australia, through Vast Solar, is leading the way in pioneering the use of sodium as a concentrated solar thermal transfer and storage fluid (Vast Solar 2017).

Solar thermal, biomass and existing hydro power can shore up increased generation from low cost solar PV and wind.

Combining wind and solar together, and/or adding large-scale energy storage, are further options to deliver reliable renewable power to meet demand. There are a number of projects underway across Australia pursuing this approach.

Figure 9: Solar thermal plant in Spain.



The Lakeland integrated solar and battery storage power plant in North Queensland (currently under construction) will be the Southern Hemisphere's first large-scale integrated solar and battery storage facility. The project combines a 13MW solar power station together with 5.3MWh battery storage and will be able to provide reliable power quality and supply (Conergy 2016).

The Kennedy Energy Park in North Queensland combines solar, wind and battery storage (19MW solar PV with 22MW wind and 4MWh of battery storage). There are plans in place for a second stage, scaling up to 600MW of solar PV and 600MW of wind power, once the hybrid approach is tried and tested (ARENA 2017).

The Kidston project in Far North Queensland combines up to 320MW of solar PV (phase one 50MW, phase two 270MW) with pumped hydro storage, utilising a former gold mine. The pumped hydro storage stores energy by pumping water from a lower water storage reservoir to an upper reservoir; the water can later be released (generating electricity) at times of high demand. The project will potentially provide up to 320MW of rapid response power into the National Electricity Market. The Kidston project will commence construction this year (GenexPower 2017). There are many similar renewable energy and storage developments being advanced in South Australia, Victoria, New South Wales and Western Australia.

The Victorian Government is seeking expressions of interest to build a large battery storage facility in Western Victoria to complement nearby current and proposed wind and solar plants and improve grid stability (RenewEconomy 2017a). The South Australian Government has received over 90 expressions of interest from local and international companies to build a 100MW, 100MWh battery by summer 2017 to improve supply reliability (SMH 2017). The South Australian Government has also tendered for proposals to supply "dispatchable" renewable energy to meet 25% of the government's electricity requirements with low carbon power, with successful projects required not to negatively impact on energy security, reliability or wholesale electricity prices (South Australian Government 2016). There are multiple projects around the country (RenewEconomy 2016b) combining large-scale solar and wind with energy storage.

The uptake of energy storage systems is rapidly taking off across Australian households and businesses. Battery storage systems (or other forms of small-scale energy storage) enable households and businesses to maximise their use of rooftop solar panels by storing excess power generated during the day for use later, for example at night time.

These smaller scale, distributed solar and energy storage systems can also benefit the wider electricity grid by smoothing out the electricity demand at peak times, and making more effective local use of solar generation. Distributed energy storage can reduce the need for investment in expanding the network, reducing overall costs for electricity networks and consumers.

In 2016, more than 6,500 households installed a solar and battery system in response to the dramatic cost reductions for solar and storage technology and increasing power bills (Choice 2017).

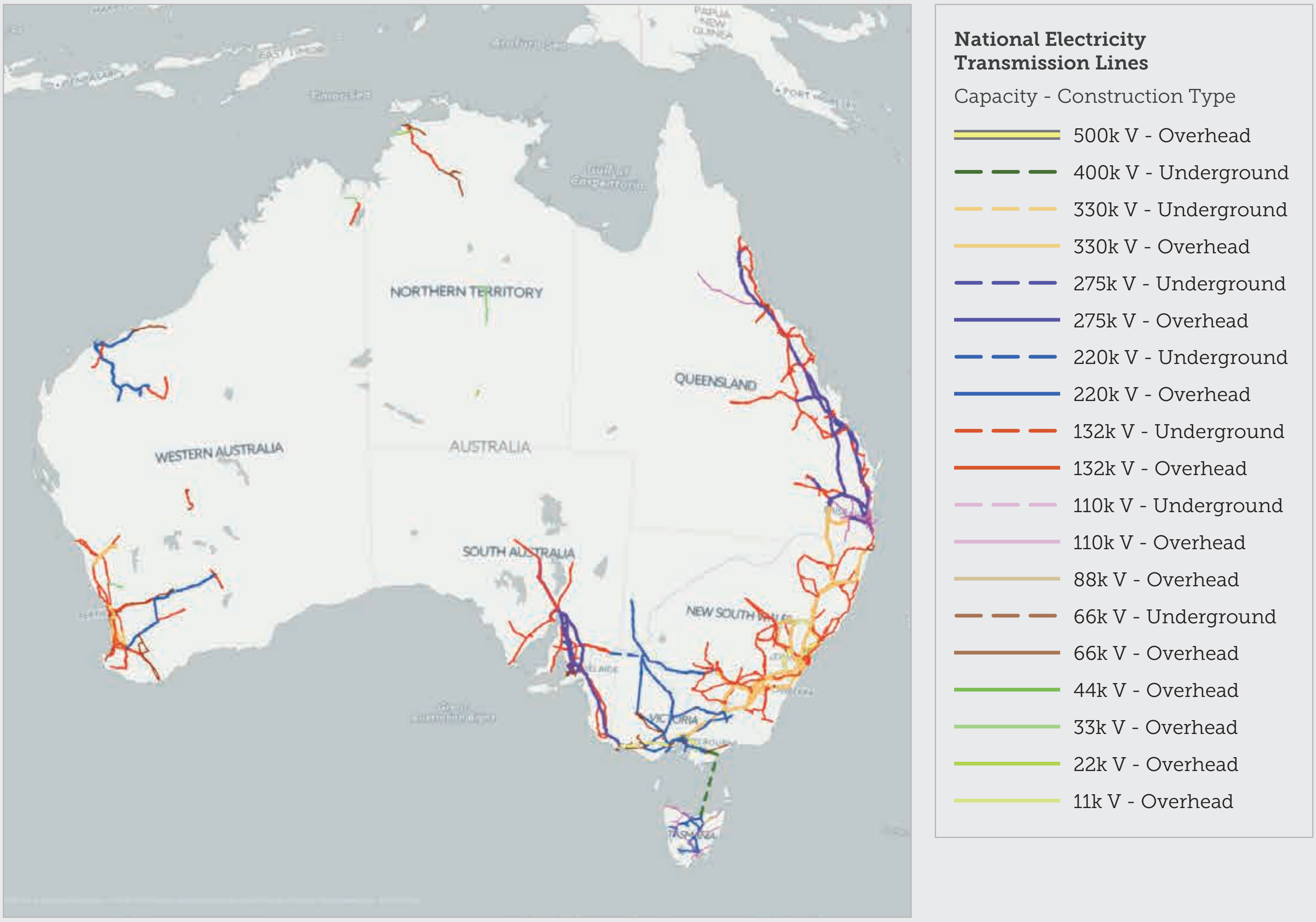
Australia's largest microgrid combining both small and large-scale solar and battery storage is planned for Onslow, Western Australia. The project aims to increase the town's reliance on renewable sources partly in response to cost and reliability issues associated with gas (RenewEconomy 2016c).

4.2. Greater Interconnection Can Improve Security of Power Supply

High voltage transmission lines connect Australia's eastern states and South Australia (referred to as the National Electricity Market, NEM). Some states, like Victoria (which connects to three other states), have higher levels of interconnection than others, such as South Australia and Tasmania.

There are two separate interconnected systems in Western Australia (The North West Interconnected System, NWIS and the South West Interconnected System, SWIS). The Northern Territory has three smaller separate electricity systems (Australian Government 2016c; Figure 10).

Figure 10: Major Australian power transmission lines. **Source:** Australian Government 2017.



While interconnections between states are expensive to build, when available, these interconnections can help to reduce power costs and improve security of supply. They also allow new areas of untapped renewable power to be developed, and enable increased diversity in renewable supplies to several states.

Interconnection can also help prevent blackouts when one state is facing periods of high power demand during a heatwave, exceeding available power generation within the state (Energy Networks Australia 2016).

For example, during February 2017 heatwaves in New South Wales, with near record all-time peak electricity demand, the state narrowly avoided a blackout due to a range of factors. For example, imports of electricity via three interconnections with Victoria and Queensland ran above design limits, contributing 12% to meeting peak demand (AEMO 2017b). Around 3,000MW of fossil fuel plant was not available, including tripping off (400MW), unable to start (760MW), out for maintenance (1,000MW) or output limited due to cooling water limits (600MW). At one stage, the Tomago aluminium smelter shed 580MW of its electricity load. It was these factors, and careful use by consumers (saving 200MW), that allowed New South Wales to avoid widespread blackouts. This heatwave highlights the vulnerability of our energy systems to extreme weather. Climate change will make heatwaves longer, hotter and more frequent (Perkins and Alexander 2013), increasing stresses on Australia's ageing energy infrastructure.

4.3. Renewable Electricity Can Provide Grid Stability

To maintain electricity supply, electricity systems need to keep supply (electricity generation from power plants) closely matched to demand (electricity use by households, businesses and industry). Certain types of power plants provide "inertia" which helps to maintain power when supply and demand become unbalanced, or unequal over short time periods.

Power plants that generate electricity via large rotating steam or water turbines are sometimes called **synchronous generators.** Coal and gas power plants are synchronous generators; so too are solar thermal, hydropower, and biomass power plants (Vithayasrichareon et al 2015).

Figure 11: Quebec wind farm.

Power plants that generate electricity using large rotating steam or water turbines provide **system inertia**, a characteristic that helps to maintain power supply for short periods of time if supply and demand become unbalanced. Inertia provides an initial, immediate response to keep the electricity system working.

Frequency response and operating reserve are needed if supply and demand are not in balance for more than 10 seconds. Frequency response can maintain the system for up to 30 minutes. Frequency response can be provided by technologies such as demand management (where large power users opt to cut their power use for a given time), battery storage systems and large spinning machines called synchronous condensers. For example, the Victorian and South Australian governments have recently called for expressions of interest to build large-scale battery storage in order to improve grid stability (RenewEconomy 2017a; SMH 2017).

Operating reserve is planned spare capacity in the system that can be called upon when there are unexpected variations in electricity demand, or generation or transmission faults.

Solar thermal, hydropower and biomass power plants are all synchronous generators capable of providing system inertia and operating reserve. Demand management, pumped storage and battery storage can provide frequency response.

Traditionally wind and solar power have not been considered capable of providing system inertia or frequency control. However, modern wind turbine technology can incorporate **synthetic inertia,** which enables wind farms to provide similar grid stability services to gas plants. Wind farms in Quebec, Canada (e.g., Figure 11) are required to incorporate this technology. Synthetic inertia will soon be trialled at the Hornsdale 3 Wind Farm in South Australia to demonstrate that wind power is capable of providing similar grid stabilising capabilities as gas-fired power (AFR 2017b).

4.4. Energy Security and Climate Change

One of the largest long-term risks to energy security is escalating extreme weather, driven by climate change. Australia has experienced the impact of extreme weather on power systems in the last six months.

On 28 September 2016, South Australia experienced one of its most severe storms in recent decades. The storm drove at least seven tornadoes, wind gusts of 190 - 260 km/h, large hailstones and intense rainfall. The supercell thunderstorms and tornadoes knocked down 23 transmission towers in South Australia triggering a statewide blackout (Burns et al 2016; Figure 12).

Heatwaves place pressure on electricity systems due to both increased demand for electricity (as everyone turns on their air-conditioners) and because coal and gas power plants struggle to operate in the heat. Ageing fossil fuel power stations don't cope well in the heat. Extreme heat reduces output and they suffer mechanical failures right when they are needed most. For example, in February 2017, New South Wales experienced an extreme heatwave and near record demand for electricity. During this time, 3,000MW of gas and coal fired plant wasn't available; it either tripped off (400MW), couldn't start (760MW), couldn't produce at maximum output due to cooling water or other temperatures exceeding limits (600MW), or was otherwise out for maintenance (1000MW) (AEMO 2017a).

Large, concentrated energy assets - like huge coal and gas power stations, are particularly vulnerable to extreme weather, increasing supply risks if one or more fail at times of extreme demand. Backup gas fuelled plants have a poor record of reliability as recent events in New South Wales and South Australia have shown (ABC 2017b; AEMO 2017b). Fossil plant failures also lead to blackouts or load shedding which places significant stress on people and industry.

Electricity systems relying on single massive sources of power transported over long distances, like a large gas power plant with a long grid, are vulnerable to extreme weather such as bushfires, storms and heatwaves.

Coal and gas power stations are vulnerable to extreme weather events.

A more distributed and diverse system with power generation spread geographically rather than large, concentrated power plants from a wider variety of supplies - wind, solar, storage - is far more resilient to disruption.

Cities that have experienced severe damage to their electricity infrastructure from extreme weather, like New York, have diversified the sources and location of power generation. Modern renewable energy means that power can be generated and stored where it is needed. This can reduce risks of grid failure for critical infrastructure.

Figure 12: Severe storms in South Australia brought down transmission towers in 2016.

5. A Secure, Dependable, Cost Effective, Zero Emissions Power System Can Be Achieved Without Gas

The most economic approach to transition away from fossil fuels is to dramatically improve energy efficiency, introduce demand management markets and to move directly to renewable supply, with energy storage, demand management and smart grids.

Existing gas can be considered as a short-term, expensive source of power (while renewable energy and storage technologies are scaled up). However, greater reliance on gas power is not an option, from both an economic and climate standpoint.

Appendix: Gas in Australia Explainer

TYPES OF GAS

There are two types of gas produced in Australia:

1. 'Conventional' gas produced from wells, onshore and offshore, from subsurface porous and permeable reservoir rocks wherein the gas (and sometimes condensate) is trapped by a sealing rock formation.

2. 'Unconventional' gas which is formed in more complex geological systems and requires different methods of extraction. Forms of unconventional gas include coal seam gas (from coal deposits 300-1000m underground), shale gas (from sedimentary rock 1-2km underground) and tight gas (from between tiny pores of rock greater than 1km underground) (Parliament of Victoria 2013).

Both conventional and unconventional gas require several processes to extract and purify the gas to meet specifications for transmission pipelines. Liquid hydrocarbons, carbon dioxide, water (and sometimes mercury and nitrogen) must be removed. The gas must be cooled and compressed. All this uses energy. LNG processing is even more energy intensive as the methane must be liquefied at very cold temperatures, using large refrigeration processes. Around 7-8% of the feed gas is burned to power the LNG process (AEMO 2016).

GAS RESERVES AND RESOURCES

Australia has the 13th largest gas reserves in the world (1.9% of global reserves) of both conventional and unconventional natural gas (BP 2016).

Most of Australia's conventional gas reserves are located off the north-west coast of Western Australia. Unconventional gas resources are located in the coal basins of Queensland and New South Wales and in shales in South Australia, WA and the NT (Australian Government 2015a).

Not all of these potential gas resources are economic to develop or are able to be accessed by existing gas supply infrastructure.

GAS PRODUCTION

The majority of gas produced in Australia is currently exported overseas as LNG, with about a third consumed domestically. The share of gas used domestically is becoming smaller over time due to increasing LNG exports and declining domestic gas consumption (AEMO 2016).

There are three physically separate regional gas markets in Australia:

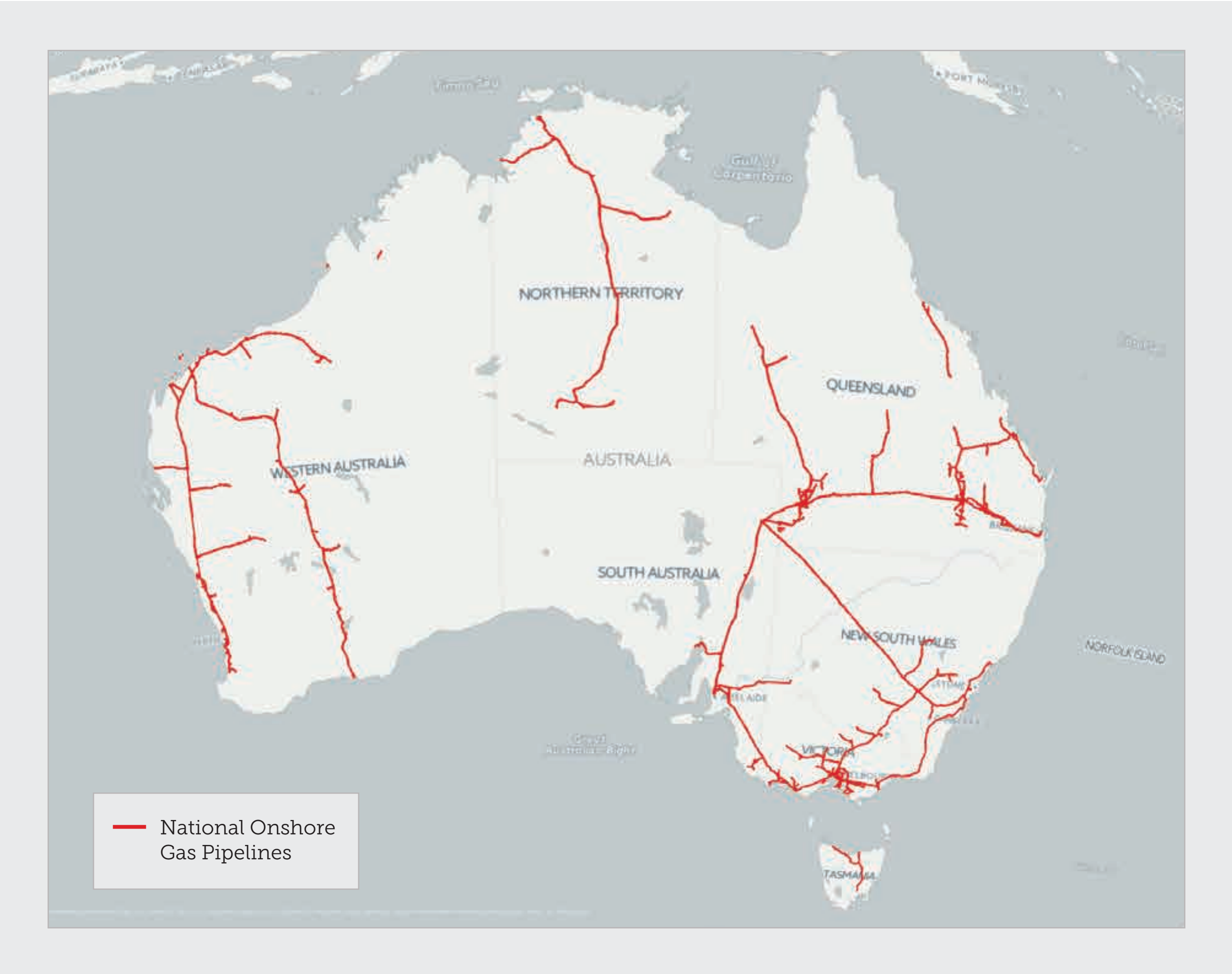
- Western market (WA)
- Eastern market (QLD, NSW, ACT, VIC, TAS and SA)
- Northern market (NT) (Australian Government 2015b).

Currently these markets are not connected. A connection between the northern and eastern markets called the North East Gas Interconnector is likely to be completed by 2018 (Australian Energy Regulator 2015), though this is relatively small in terms of capacity versus demand.

GAS CONSUMPTION

Gas consumed in Australia is mainly used for industrial (46%), residential and commercial uses (32%), and electricity generation (21%) (numbers have been rounded) (AEMO 2016).

Figure A1: Australia's gas markets. **Source:** Australian Government 2017.



LNG EXPORTS

Australia's LNG export industry started in 1989 with gas from the north west coast of Western Australia, followed by gas from Darwin in 2006 (from East Timor's "Joint Petroleum Development Area"), and then by gas from Queensland in 2015.

Australia is currently the third largest exporter of LNG in the world (behind Qatar and Malaysia) and is expected to become the largest producer by 2018 (Reserve Bank of Australia 2015). This is due to an unprecedented expansion of LNG export infrastructure in recent years - with $250 billion spent on LNG infrastructure since 2009 (Forbes 2016).

Three major LNG export projects, each comprising processing facilities and transmission lines - totalling $63.2 billion (Australian Energy Regulator 2015) - have recently been completed in Queensland:

- Queensland Curtis LNG (able to produce up to 8.5 million tonnes of LNG per year, Mtpa)
- Gladstone LNG (7.8 Mtpa)
- Australia Pacific LNG (able to produce up to 9 Mtpa) (AEMO 2016; LGA 2016)
- QCLNG and APLNG are both able to produce at even higher rates (10% above nameplate) (LGA 2016).

A further two projects have also been completed in the Western and Northern market, with still more under construction:

- Gorgon (able to produce up to 15.6mtpa)
- Wheatstone LNG (up to 8.9mtpa).

Australia's LNG export capacity could soon exceed the total imports of our major export market, Japan (LNG imports are expected to continue to fall in Japan as it restarts more nuclear reactors) (Australian Government 2016).

Australia is not alone in increasing LNG exports. The United States, Malaysia, and Russia are also constructing large LNG production and export facilities at a time of slow global demand growth and low prices (IEA 2016). Worldwide, the LNG capacity currently under construction is almost half the global LNG traded annually.

57.4mtpa of LNG has reportedly pre-sold in long-term contracts, totalling more than Australia's entire gas production in 2014-15 (AOG 2015).

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