Modelling Future Fuel Options for Australia

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AusIndustry
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"Our goal is to reach net-zero emissions as soon as possible, and preferably by 2050."

Scott Morrison, National Press Club, 1st February 2021

Achieving zero emissions "will be the hardest thing humanity has ever done because the physical economy - cement, steel, transportation, agriculture - all of these sectors will have to make changes."

Bill Gates, ABC Radio National, 16 Feb 2021

"Updated projections confirm Australia is on track to meet and beat its 2030 Paris target."

Australian Minister for Energy and Emissions Reductions, 10th December 2020

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This work is funded by the Future Fuels CRC, supported through the Australian Governments' Cooperative Research Centres Program. The cash and in-kind support from the industry participants is gratefully acknowledged.

We acknowledge the value of peer review comments provided by Andrew Robertson, David Norman, Klaas van Alphen, Fariba Ramezani and Liam Wagner.

The results reported here were obtained using the GEMPACK economic modelling software – see Horridge et al. (2018).

Abbreviations

AEMO	Australian Energy Market Operator
ABS	Australian Bureau of Statistics
CCS	Carbon Capture and Storage
CGE	Computable General Equilibrium
CO_2	Carbon Dioxide
CH_4	Methane
CO_2-e	Carbon dioxide equivalents
CoAG	Council of Australian Governments
CoPS	Centre of Policy Studies, Victoria University
HFCs	Hydrofluorocarbons
PFCs	Perfluorocarbons
SF_6	Sulfur hexafluoride
FFCRC	Future Fuels CRC
Future fuel	Any source of liquid or gaseous energy that can be produced and used without the emission of a greenhouse gas
GDP	Gross Domestic Product
GSP	Gross State Product
H_2	Hydrogen
IEA	International Energy Agency
kg	Kilogram
LNG	Liquid natural gas
MJ	Megajoule
Mt	million tonnes
NEM	National Electricity Market (Qld + NSW + ACT + Vic + Tas + SA)
NFRC	National Federation Reform Council
PJ	Petajoule
VURM	Victoria University Regional Model
Qld	Queensland
N_2O	Nitrous Oxide
NSW	New South Wales
ACT	Australian Capital Territory
Vic	Victoria
Tas	Tasmania
SA	South Australia
UNFCCC	United Nations Framework Convention on Climate Change

EXECUTIVE SUMMARY

Measured against a 2005 benchmark, the Australian Government is projecting that, by 2030, it will have reduced greenhouse gas emissions to 511 Mt CO_2-e. The government has been adopting a "Technologies, not taxes" approach to reducing emissions and released a Technology Investment Roadmap that seeks to position Australia as a global leader in low-emission technology development.

Coupling these expectations with the IEA's integrated assessment of demand for energy products if the rest of the world follows a stated-policy development pathway, this report assesses the regional and national implications of the introduction of hydrogen to Australia's energy mix in scenarios achieving a 60% and a 100% reduction in greenhouse gas emissions by 2050.

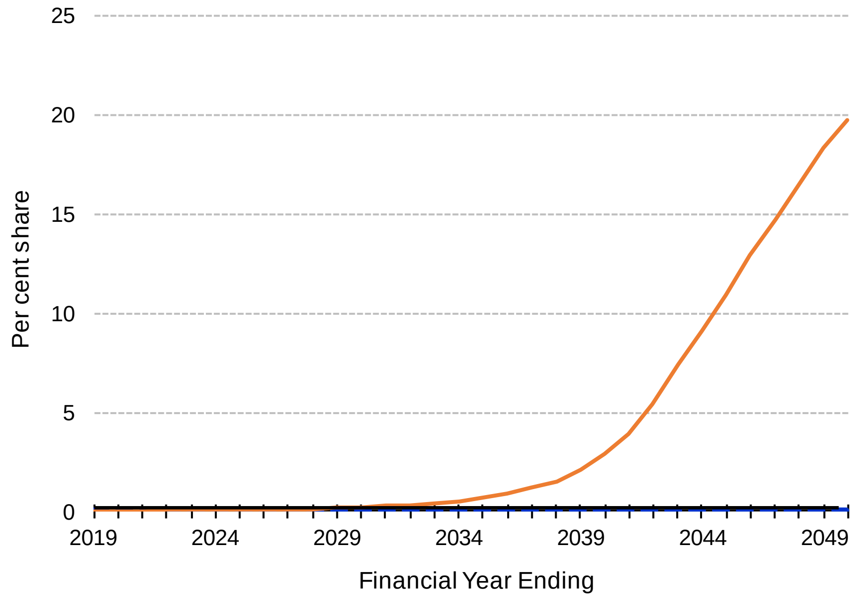
Our most striking finding is that, without change to current policy and/or major technological improvements, attainment of net-zero emissions in Australia by 2050 requires the extraction of massive amounts of CO_2 from the air.

Although some offsets from agricultural and other land management (bio-sequestration) are possible, by 2050, this action becomes prohibitively expensive and direct CO_2 extraction from the air becomes necessary.

Extending current policy settings to reach net-zero by 2050 – using either hydrogen or electrification - will require the Government to pay for the extraction of about 160 million tonnes of CO_2 from the air. Using optimistic assumptions, we estimate that this will end up costing in the vicinity of $15.5 to $16.4 billion per annum.

Surprisingly, if Australia succeeds in reducing the cost of producing hydrogen for local users to $2 per kilogram and for bulk export to $1 per kilogram, the estimated direct extraction offset requirement in 2050 is reduced by only 9 million tonnes per annum.

Growth of the hydrogen industry's share of the energy market, as modelled in our net-zero by 2050 with hydrogen scenario, is shown in the figure below. Intuitively, we had expected a greater contribution.



Hydrogen industry's share of final fuel sales by value assuming green hydrogen production costs fall to $2 per kg and emissions are net-zero emissions are achieved by 2050

The reasons for the limited role that hydrogen and its derivatives play can be explained, in part, by

1. The fact that a significant proportion of emissions do not involve energy consumption and therefore can neither be reduced using a renewable source of electricity nor a future fuel;
2. The lack of a carbon price or equivalent market signal for activities other than renewable electricity production that would bring forward investment in zero-emission technologies at scale;
3. The difficulty in reducing emissions in the extremely-hard-to-abate and hard-to-abate sectors;
4. The slow rate of emission reduction between now and 2030; and
5. The assumed Government willingness and commitment to purchase the offsets necessary for Australia to remain on target.

These observations, coupled with the results from our model lead us to three conclusions.

Our first conclusion is the observation that if Australia continues with its current suite of policies and continues to rely on the development of technology without introducing any form of market-based signal for greenhouse gas emissions Australia will only be able to meet its 2050 targets, whether they be for 60% reduction or net-zero, by establishing a massive greenhouse gas emission offset program. Moreover, this cannot be affordably achieved via bio-sequestration.

Our second conclusion is that the development of the future fuel industry at scale risks being delayed until the late 2030s and only becomes a substantial part of the economy in the 2040s. This lack of progress is due largely to the current focus on the development of technology coupled with an approach that delays investment until these technologies become cost-competitive. From a FFCRC perspective, there is merit in carefully examining and, if found appropriate, assessing the case for a different approach – as many in the industry are already arguing for.

Our third, much more tentative, conclusion – better stated as a hypothesis to be tested – is that the current stated policy framework favours the development of electrification as a decarbonisation pathway at the expense of future fuels, potentially precluding the substantial role that more timely large-scale deployment could play.

Given these observations, we recommend that the FFCRC use our model to explore the implications of scenarios that involve

- A global transition to net-zero emissions and an Australian response consistent with the IEA's recent net-zero report and Treasury's recent 2021 *Intergenerational Report*;
- The inclusion of a greenhouse gas emission price signals in the Australian economy;
- Revisions and adjustments that explore the nature of regional impacts of alternative strategies for the development of future fuels in Australia; and
- Examination of detailed transition pathways for the economy as a whole; for transport; for heavy industry; for international trade, for energy use; and for households.

Long-term scenarios necessarily involve the exercise of judgement and simplifying technical assumptions. This underscores the importance of viewing the scenarios as one possible picture of the future based on expected structural pressures and existing policy settings. In other words, this report presents a world that could be, rather than will be. In doing so, it helps all members of society including businesses, households and governments to prepare for future challenges, take advantage of future opportunities and decide to modify existing strategies.[1]

The Australian Treasury, 2021

[1] Adapted from the Australian Treasury's 2021 Intergenerational report https://treasury.gov.au/sites/default/files/2021-06/p2021_182464.pdf, page xvii.

Contents

MODELLING FUTURE FUEL OPTIONS FOR AUSTRALIA

CHAPTER 1. INTRODUCTION

Developed for the Future Fuels Cooperative Research Centre (FFCRC), this report aims to demonstrate the capacity of a regionalised Computable General Equilibrium (CGE) model to inform questions about the role of hydrogen in greenhouse gas emission-reduction strategies.

In this report, future fuels are defined as any source of liquid or gaseous energy that can be produced and used without the emission of a greenhouse gas.[2] The main one explored in this report is hydrogen. With some modification, however, our modelling system could easily be expanded to include consideration of other future fuels such as ammonia and biogas.

Nearly every country in the world is debating how fast to reduce greenhouse gas emissions and how best to do it.

- How fast should Australia seek to reduce its greenhouse gas emissions?
- How does the emission-reduction pathway chosen affect investment opportunities and prospects for the nation as a whole?
- Which regions and which sectors stand to gain the most under different strategies?
- What role can hydrogen and other types of future fuel play in delivering the emission reduction pathway chosen?
- What strategies can be chosen to influence decisions about which sources of energy to invest in and which sources of energy to use?

1.1 Structure and a caveat

This report provides an overview of our initial findings and the capacity of the modelling system we have developed.

It is stressed that our initial findings are high level in nature and presented cautiously. More work is planned. Overall, we consider that many of the assumptions about the cost reductions of producing hydrogen and progress in other sectors are optimistic—and highly optimistic in the net-zero scenarios.

We are of the view that the initial scenarios we have developed would benefit from a series of refinements designed to explore sensitivities and examine regional differences. In this initial report, for example, we have not adjusted for the regional differences in opportunities to expand solar and wind energy production. Instead, we assume that growth is in proportion to existing investments. In addition, this report is limited to our interpretation of the nature of “stated government policies”—which we interpret to mean that emitters remain free to emit greenhouse gases without penalty and that the Australian Government remains willing to pay for the offset those emissions as required to meet emission targets. This is similar to the Australian Government’s current approach in the Emissions Reduction Fund, where it enters into contracts to purchase carbon reductions[3].

[2] The use of biomethane produces carbon dioxide but as this has been absorbed from the atmosphere, these emissions do not contribute towards greenhouse gas emissions associated with global warming.

[3] http://www.cleanenergyregulator.gov.au/ERF/About-the-Emissions-Reduction-Fund/How-does-it-work

1.2 Four scenarios

The scenarios modelled in this report were developed in consultation with industry representatives involved in the FFCRC and seek to explore the extremes of plausible policy and technological outcomes. We consider them to be exploratory and the assumptions that underpin them as illustrative.

The four scenarios examined in this report are

- **60E** – A 60 per cent emission reduction on 2005 levels with the more widespread use of renewable electricity as a final fuel (“60 per cent with electrification”) but no significant role for hydrogen;
- **60H** – A 60 per cent emission reduction on 2005 levels with the widespread use of renewable electricity and the emergence of hydrogen—both green and blue—as a substantial part of the final energy mix;
- **100E** – A 100 per cent emission reduction on 2005 levels that relies almost entirely on electrification to reduce energy emissions and little use of hydrogen;
- **100H** – A 100 per cent emission reduction on 2005 levels with the more widespread use of renewable electricity and the emergence of hydrogen as a substantial part of the final energy mix.

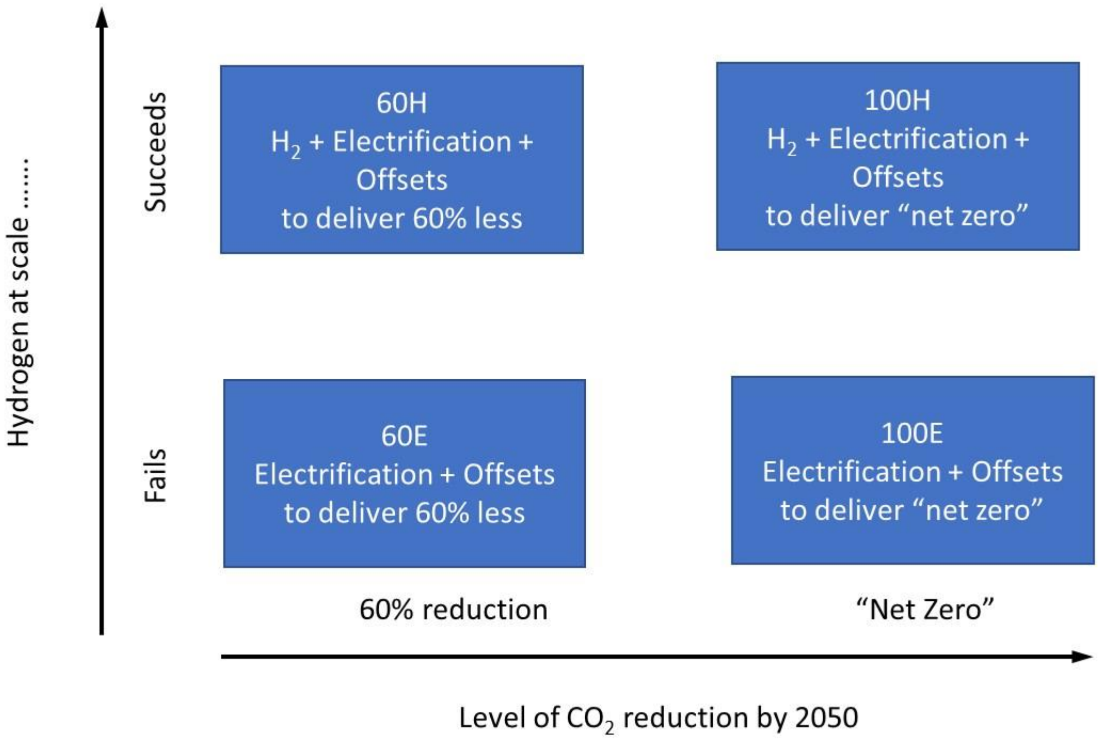


Figure 1 Overview of scenarios

Rather than developing a set of alternative policy choices, in this report, our scenarios examine “stated policy” options. That is, while our model has the capacity to allow each sector to be exposed to a carbon-price signal or an emissions trading regime, in each of the above scenarios no such mechanism is used.

Instead, we have tried to specify each of the scenarios in a manner that is broadly consistent with estimates and policy commitments made in

- The Australian Government's Emission Reduction Fund;
- The Australian Government's greenhouse gas emission projections to 2030;
- Australian Energy Market Operator's (AEMO) demand forecasts;
- Australian Government's Technology Investment Roadmap; and
- International Energy Agency energy demand projections to 2040; and
- CoAG's National Hydrogen Strategy.[4]

Each of the scenarios assumes that Australia's emission reduction pathway between now and 2030 is consistent with the Australian Government's stated expectation that Australia's emissions will be reduced to 511 Mt CO_2-e in 2030 which is 16 per cent below 2005 levels (Department of the Environment and Energy 2019).[5] After 2030 and as shown in Figure 2, the chosen emission reduction pathway depends upon whether the goal is to reduce emissions only by 60% which is seen as a very conservative outcome or, as States and Territory Governments have stated to achieve net-zero by 2050.

4 "On 29 May 2020, National Cabinet agreed to the formation of the National Federation Reform Council (NFRC) and the cessation of the Council of Australian Governments (COAG)." See National Federation Reform Council | Department of the Prime Minister and Cabinet (pmc.gov.au).

5 In the 2019 Australian Government update of its emissions projections, at page 6, it is stated that "Emissions are projected to decline to 511 Mt CO_2-e in 2030 which is 16 per cent below 2005 levels."
The difference between this statement and the Australian Government statement that it expects to over achieve Australia's 2030 target of 26 to 28 per cent below 2005 levels, is due to the Australian Governments' decision to include carry forward 411 Mt CO_2-e of savings from previous targets. For more information, see https://www.industry.gov.au/data-and-publications/australias-emissions-projections-2019.

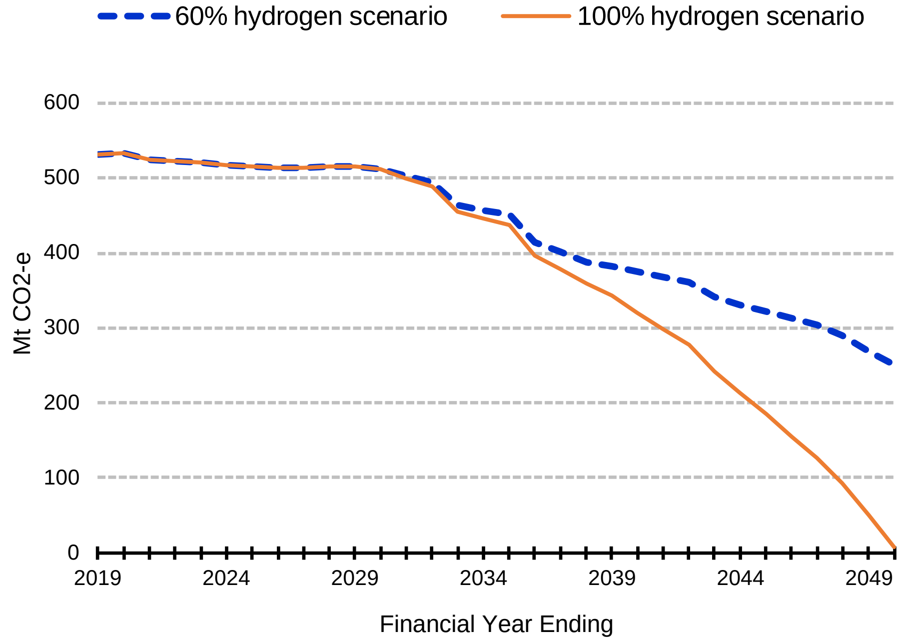


Figure 2 Greenhouse gas emission pathway followed for the Hydrogen Scenarios which is the same as that followed for the two electrification scenarios

CHAPTER 2. ASSUMPTIONS AND MODEL

2.1 The economy as a whole

As is the case with any CGE model, our model makes many assumptions about the nature of business and household responses to changes in costs, prices and other influences on economic activity. All scenarios assume that Australia continues to retain its relative place in the world trading system; that GDP per capita continues to grow; and that there is a net flow of capital into the economy.

We assume, also, that the recovery from COVID 19 is rapid and, hence, in this report, we make no attempt to adjust for the impact of COVID 19 on the economy. That is, we use a pre-COVID baseline and, for now, implicitly assume that the impact of COVID on each scenario will be similar and does not induce a change in government policy that would have a differential impact on one or more of the scenarios examined.

Implicitly, our model also assumes that Australia will continue to be a major importer of capital as it has been for more than two centuries.

2.2 Population and immigration policy

One of the most important assumptions made in this report is the assumption that GDP per capita continues to increase and, of critical importance for this report, the Australian population continues to grow.

All scenarios adopt the Australian Bureau of Statistics (ABS) series B projection. In 2019, Australia's total fertility rate was 1.66 babies per woman and, as the rate necessary to achieve population replacement is considered to be in the vicinity of 2.1 babies per woman, we assume, as the ABS does for Series B, that the immigration rates seen prior to COVID-19 restrictions on immigration will continue. The result is a projection, common to all scenarios, that by 2050 there will be 37.5 million people living in Australia.[6]

[6] As a result of COVID 19 and several other considerations, the Australian Government's Population Centre has just estimated that "Australia's population will be around 4 per cent smaller (1.1 million fewer people) by 30 June 2031 than it would have been in the absence of COVID-19." See https://population.gov.au/docs/population_statement_2020.pdf. These updated projections were released after the analysis reported in this report was completed.

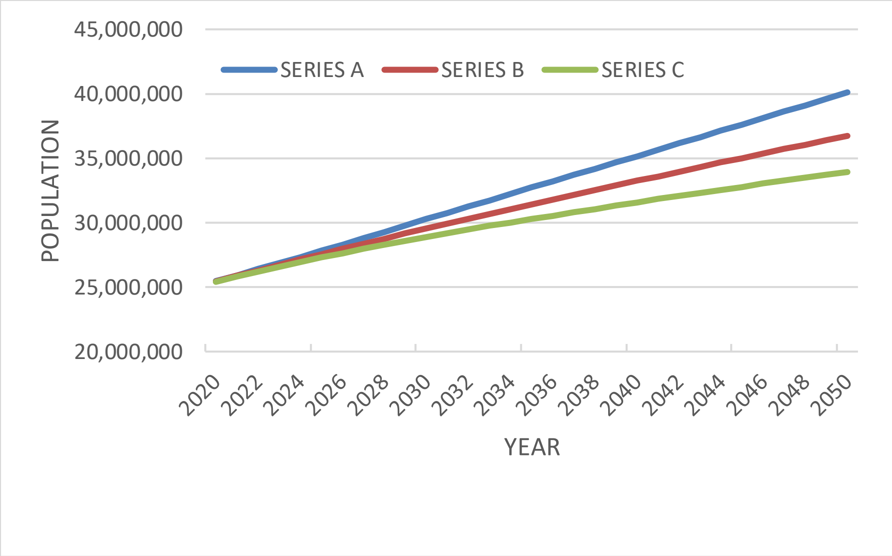


Figure 3 Australian Bureau of Statistics Population Projections to 2050
Source: *https://www.abs.gov.au/AUSSTATS/abs@.nsf/mf/3222.0*

From a greenhouse gas emission perspective, this population increase means that, in order to achieve a 60% reduction in emissions when measured against a 2005 baseline, per capita emissions have to be reduced by 80%.[7] As these considerations are important, our model tracks and reports on both

- the intensity of emissions per unit of production; and
- the extent of aggregate reductions in emissions.

A surprising observation, common to all scenarios is the observation that neither GDP per capita nor GDP decline in any Australian State or Territory nor in any of 11 regions examined. That is, under all scenarios, no region experiences economic decline defined as an absolute decline in regional income.

The reason that no region suffers an economic decline is that, while there is considerable adjustment, the regions in the Australian economy are integrated and growth at the national level flows down to all of the regions albeit with varying strength. As shown in Figure 4, under the scenarios we run, every region experiences some employment and population growth. In other words, while some regions benefit more than others, there is no region where the aggregate impact of a 60% reduction in emissions or the elimination of emissions (net-zero) is negative. As a result, we conclude that further work on the relationship between greenhouse gas reduction pathways, population and immigration policy options could be justified – if for no other reason than the fact that Australia's energy industries have a major influence on decisions about where to locate infrastructure and how large such investments should be.

[7] The Australian Governments 2021 Intergenerational report states that 'To date, Australia has reduced greenhouse gas emissions by 20.1 per cent compared to 2005 levels. Emissions per person are 46.7 per cent lower than 1990 levels, while the emissions intensity of the economy is 66.1 per cent lower." See https://treasury.gov.au/sites/default/files/2021-06/p2021_182464.pdf

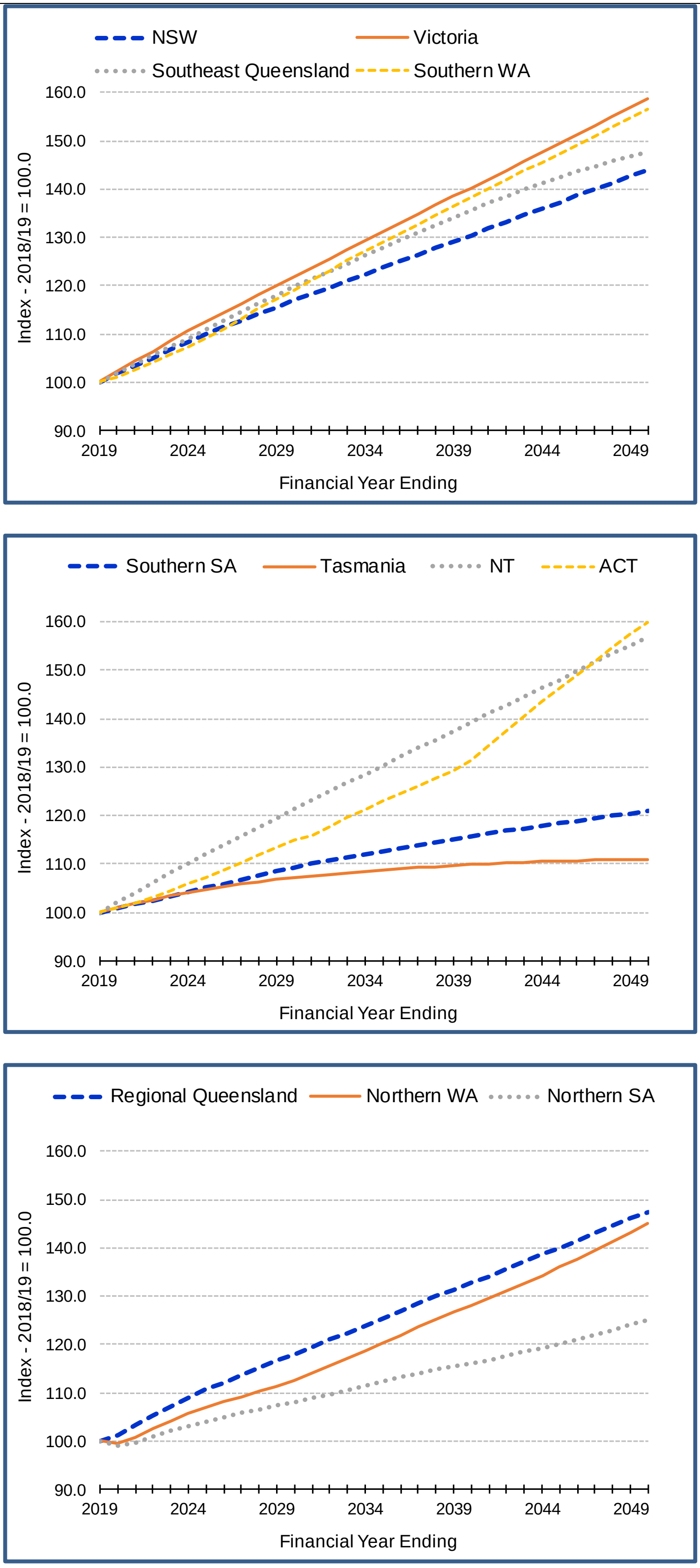


Figure 4 Changes in regional employment by year for "net-zero by 2050 with Hydrogen" (100H) scenario

2.3 Infrastructure and internal migration

One of the strengths of the CGE modelling approach is the way supply chain interdependencies are modelled. Sectors are forced to compete with one another for access to scarce goods and services. Each can and, to the extent necessary, draws upon and uses the products produced by all other sectors, each household and each government in a manner that takes into account the extent of the available infrastructure (capital) and its influence on costs and prices.

In particular, care is taken to allow for the time it takes to build new infrastructure and the cost of accessing the capital necessary to build this infrastructure. Similarly, care is taken to adjust for the willingness of people to move from one region to another and to change the sector they work in.

2.4 Stated policy assumptions

The Australian Government has stated that it prefers a greenhouse gas emission reduction strategy that gives priority to the development of low-emission technologies and envisages that the emission reductions will occur when and as it becomes more profitable to adopt low emission technologies and phase out current high emission technologies. This implies that switching technologies to reduce emissions will only occur when that technology becomes lower cost than the incumbent, and when financing permits.

In addition and consistent with stated Australian government policy, all scenarios assume that the Australian Government continues to purchase whatever offsets are necessary to achieve the necessary reduction in net greenhouse gas emissions. Initially and during the development of our model, we considered a scenario in which offsets were purchased only through the expansion of investments in bio-sequestration, but the cost of this eventually became prohibitively expensive. The scale of the offset task becomes massive, as it requires that more and then still more land be dedicated to offsets year after year.

As a result, we circled back and added a new direct CO_2 extraction sector to the economy. This sector does not yet exist in the economy and it relies on the development of a technology that can extract at feasible cost. There are a number of research projects in progress, around the world, seeking to find a way to do this, but there is considerable uncertainty about what can be achieved. Consistent with the currently stated Australian Government policy of paying for greenhouse gas offsets, in the current version of VURM-FF all forms of direct CO_2 extraction from the air are paid for by the Australian Government. Optimistically, we assume that by 2040 the cost of doing this will be around $100 per tonne.[8] Rather than arguing whether or not this cost is appropriate for direct carbon capture on its own, we suggest that this payment is better seen as an indication of what could be done if research and development outcomes are positive. **As the role of offsets is so critical, we recommend that the implementation of a substantial offset program be subject to further investigation.**

In addition to these “stated policies,” we add AEMO projections for the closure of coal and gas-fired power stations with extensions to Western Australia as a surrogate for the suite of renewable energy targets that have been developed by the Clean Energy Regulator and, also, by State and Territory governments.

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8 For more information on this assumption see https://www.sciencemag.org/news/2018/06/cost-plunges-capturing-carbon-dioxide-air .

In short, if "net-zero" truly means "net-zero", our results suggest that the economic case for the development of technologies that extract CO_2 from the air is persuasive. As the IPCC Special Report on 1.5°C observes, significant investment in sinks will be required as

- The point at which net-zero emissions will be required can be expected to occur well before all emission creating technologies have been completely phased out; and
- By the time net-zero is reached and if global warming is to be kept within 1.5°C, the load on the atmosphere will need to be reduced at a faster rate than natural decline.[9]

2.5 Emission reduction pathways

Our scenarios are consistent with the Australian government projection that Australia will achieve a 16% reduction in annual emissions by 2030 when benchmarked against the 2005 emissions. That is, all scenarios assume the same rate of emission reduction between now and 2030 and occurs at a rate of 2.2 million tonnes CO_2-e per annum.

Beyond 2030, emission reductions need to be reduced much more rapidly to achieve either a 60% reduction by 2050 or net-zero emissions by 2050. That is, all four scenarios assume a rapid post-2030 shift in national strategy in a manner that is consistent with the current Australian Government strategy of avoiding the use of any direct price, any market-based signal or regulatory controls that discourage emissions other than those associated with the pursuit of renewable energy targets. After 2030, the assumed rate of emission reduction for

- the 60% emission-reduction scenarios, increases to around 13 Mt CO_2-e per annum; and
- the 100% emission-reduction scenarios, increases to around 24 Mt CO_2-e per annum.

To achieve emission reductions on this scale is a substantial task and, in the absence of supporting government interventions, there is a need for very favourable developments in the costs of clean technologies. We ask: What pace of energy and emissions efficiency improvements will be needed to abate current emissions? And, what role will the Australian Government have in the purchase of offsets to take Australia to aggregate emission targets?

The economic efficiency of a slow then extremely rapid trajectory, in our view, is an issue worthy of further research. There may, for example, be considerable merit in setting a much more aggressive 2030 target. Amongst other things, this could result in the development and adoption of different technologies including those that make great use of future fuels.

In summary, all scenarios can be described as a plan for a slow (preparatory) decade that is followed by two decades of rapid adjustment with a bias towards the development of renewable forms of electricity production forced by state regulations. We stress also that, as a result of the assumed population and GDP increase, the rate of reduction in emission intensity per unit of output is faster than the required rate of reduction in aggregate emissions.

2.6 Stated emission-pricing policies

It is our understanding that it is the Australian Government's current policy to not impose any economic penalty on greenhouse gas emissions. That is, the government has stated that it intends to adopt a "*Technologies, not taxes*" approach to emission reduction and has released a Technology

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[9] See https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf.

Investment Roadmap that seeks to position Australia as a global leader in low-emission technology development.

There are, however, a suite of state and territory government policies that, in effect, require a proportion of electricity to be produced using renewable energy. Rather than modelling these renewable energy targets explicitly, however, we use AEMO's schedule for the closure of coal-fired power stations, with extensions to cover Western Australia. As summarised in

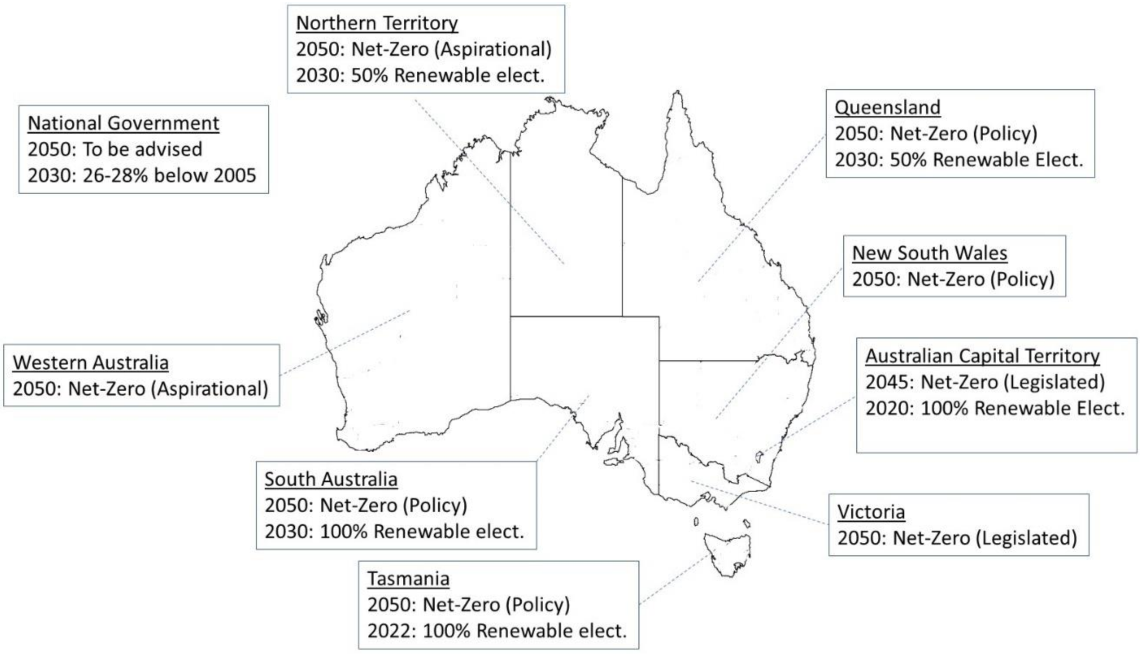

Figure 5 Overview of Australian State and Territory emission reduction targets[10]

All states and territories also have stated an ambition to be net-zero by 2050 or earlier.

In addition, we add a capacity for the Australian Government to purchase greenhouse gas offsets in the form of payments for the planting of trees, increases in soil carbon and other forms of bio-sequestration. Essentially, this is an extension of the Government's current policy of purchasing offsets through its Emissions Reduction Fund.

All other emission reductions are market-driven and achieved via a combination of falls in the cost of low emission technology and budget-funded offset efforts. Taxpayers at large, rather than emitters, carry the cost of emission reductions.

While we have confined our attention to no-economic penalty emission policies, this does not imply that we regard this as the best policy approach. In our view, the role of "carbon pricing" and other market-like mechanisms as a means to expedite the development of future fuels could be a much more cost-effective approach – especially if this reform is undertaken at the same time as the rate of emission reduction between now and 2030 is increased.

10 Adapted from https://onestepoffthegrid.com.au/more-than-half-australias-local-governments-have-zero-emissions-targets/

Consistent with current government policy, and although our model has a structure and rules that allow the evaluation of carbon tax and emission trading options, all scenarios assume that no comprehensive emissions tax or emissions trading permit system is used to influence business and household interest in using low emission technologies. It is of course possible that various regulatory mechanisms could be used to steer the economy towards cleaner technologies, especially in the energy mix. As a result, in our scenarios, the rate of emission reduction is determined by

a) Declines in the cost of low-carbon technology relative to the cost of technologies in current use; and

b) Australian government purchases of emission offsets.

We leave others to assess whether or not the rates of improvement in technology and, hence, the assumed extent of the assumed reduction in the cost of low emission technology is achievable.

We consider that the assumptions we have used in the 100% scenario to be extremely optimistic. In our view, further assessment of them is warranted. Clearly, **the examination of options for the reduction of greenhouse gas emissions in the hard to abate and extremely hard to abate sectors from a future fuel perspective is an area worthy of further research.**

2.7 International demand for Australian goods and services

The extent of international demand for hydrogen, ammonia and all other future fuels is an issue of particular interest to the FFCRC. As a first step towards the development of more detailed assessments, all scenarios are aligned with the IEA *Stated Policies Scenario,* in which growth in international demand for traditional Australian energy exports – the bulk of which is coal and LNG – declines.

In our hydrogen scenarios (60H and 100H), these data project a pronounced downturn in demand for LNG. Growth in demand for blue hydrogen—possibly shipped as ammonia—takes its place.

Many people are of the view that the IEA *Stated Policies Scenario projections* are conservative as many governments are in the process of developing more aggressive emission-reduction policies.[11] If they are right, then the potential of hydrogen to contribute to the Australian economy may be greater than our 60H and 100H scenarios suggest. Once again, **changes in international demand is an issue that can be examined using a variety of international demand scenarios that could and perhaps should take account of regional opportunities such as the development of an iron pellet and/or green steel industry in the Pilbara that using various mixes of locally produced green and blue hydrogen.**

[11] If this is correct, then it is likely that the IEA Stated Policy Scenario may significantly over estimate international demands for coal, LNG and petroleum.

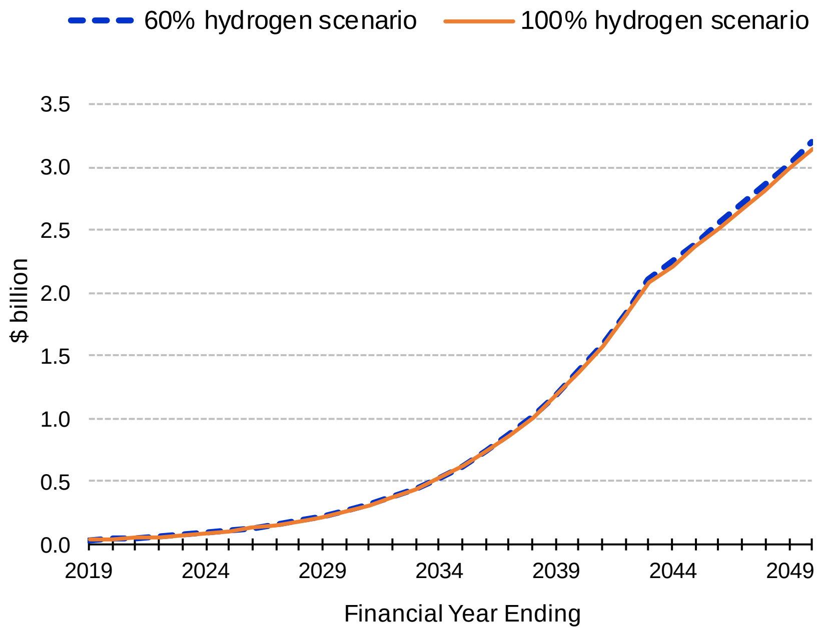

Figure 6 Annual value of hydrogen exports

2.8 The VURM-FF model

The Victoria University's Centre of Policy Studies Regional Model known as VURM is the base model for our analysis. VURM is an 81-sector model of the Australian economy incorporating a carbon emissions model. It produces results for the eight States and Territories with and also allocates the State total results to regions within the States. We have expanded VURM in a number of ways to meet the needs of modelling future fuels and refer to this modified version of the model as VURM-FF. In VURM-FF, outputs are reported with sub-state detail for Queensland, South Australia and Western Australia so that implications for "the Pilbara", South Australia's "Iron Triangle" and "Regional Queensland" can be separated from the rest of the relevant state. This structure, for example, enables detailed examination of opportunities to develop green pellet and green steel export industries in the Pilbara and the Iron Triangle, export blue hydrogen from Gladstone and pursue other similar regional future fuel orientated initiatives.

	Region
RQld	= Regional Queensland
SEQld	= South East Queensland
NSW	= New South Wales
ACT	= Australian Capital Territory
Vic	= Victoria
Tas	= Tasmania
SSA	= Southern South Australia
NSA	= Northern South Australia
SWA	= Southern Western Australia
NWA	= Northern Western Australia
NT	= Northern Territory

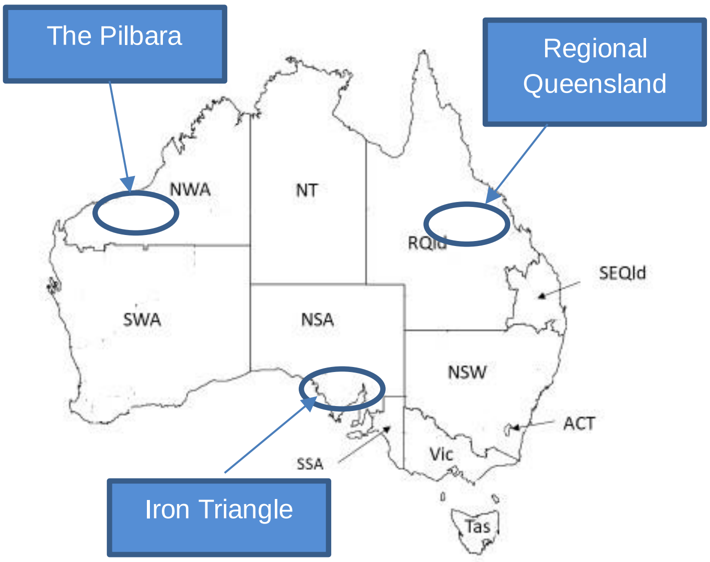

Figure 7 Location of regions in our CGE model of the Australian economy

In VURM-FF, five "new" industries are added to VURM

1. Production of blue hydrogen from natural gas with full capture and storage of the CO_2;
2. Production of green hydrogen from renewable sources of electricity;
3. Production of biogas;
4. Bio-sequestration – processes that increase the amount of carbon on agricultural land; and
5. Direct extraction of CO_2 from the air using renewable sources of energy to convert it to a form of carbon that can either be stored or kept without further emissions.[12]

One of the strengths of CGE models is that they force consideration of interactions among all sectors of an economy. We draw attention to the last industry added – the direct extraction of CO_2 from the air. This last industry was added when it became clear that, without such an industry, the costs of bio-sequestration would rise to hundreds of dollars per tonne of carbon sequestered and force a considerable reduction in agricultural production.

2.9 Abatement difficulty

One of the most difficult questions to explore is the rate of emission reduction in the non-energy sectors. To date, much less research has been undertaken on likely rates of technological innovation in these non-energy sources of emission – even though when it comes to assessing prospects for greenhouse gas emission reduction or elimination this matters a lot.

In order to enable us to make progress, all sources of greenhouse gas emissions in Australia were classified as being "very easy", "easy", "moderately hard," "very hard" or "extremely hard" to abate. The result was an estimate that 52% of current emissions are either "very easy" or "easy" to abate by 2050. The "hard" sectors included industries such as aviation, agriculture, and chemical processes.

[12] We have modelled this as the cost of running a machine that extracts CO2 from the air as described by Keith et al.(2018)). See https://www.cell.com/action/showPdf?pii=S2542-4351%2818%2930225-3 https://doi.org/10.1016/j.joule.2

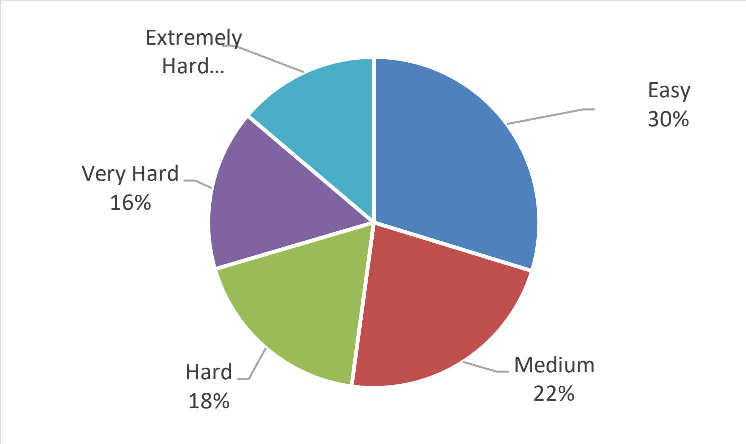

Figure 8 Assessed difficulty in abating greenhouse gas emissions from Australia using the methodologies defined in our technical report

2.10 Tracking progress in the development of low-emission technologies

In order, to estimate greenhouse gas emissions, each of the 86 economic activities included in VURM-FF tracks emission intensity per unit of output as well as total emissions. Changes in energy intensity per unit of output directly reduce emissions and changes in the energy mix from dirty fuels to clean fuels reduce emissions further. VURM-FF also tracks the use of energy type per unit of output in a manner, for example, that differentiates between the proportion of renewable, gas and coal-fired power that is sourced. By means of these energy and emission intensity factors, the "emissions intensity" of each of VURM-FF's 86 activities can be varied through time.

In the two 60% scenarios, there is only a modest improvement in direct-emission intensities that do not involve the use of energy. Instead, reductions in emissions come mainly from a change in the energy mix towards cleaner fuels. Coal and gas are displaced largely by renewable electricity generation. Use of petrol and diesel in transport declines as can be seen in Figure 9 below. In the 60H scenario, "hydrogen" displaces electricity and to a lesser extent petroleum and natural gas.

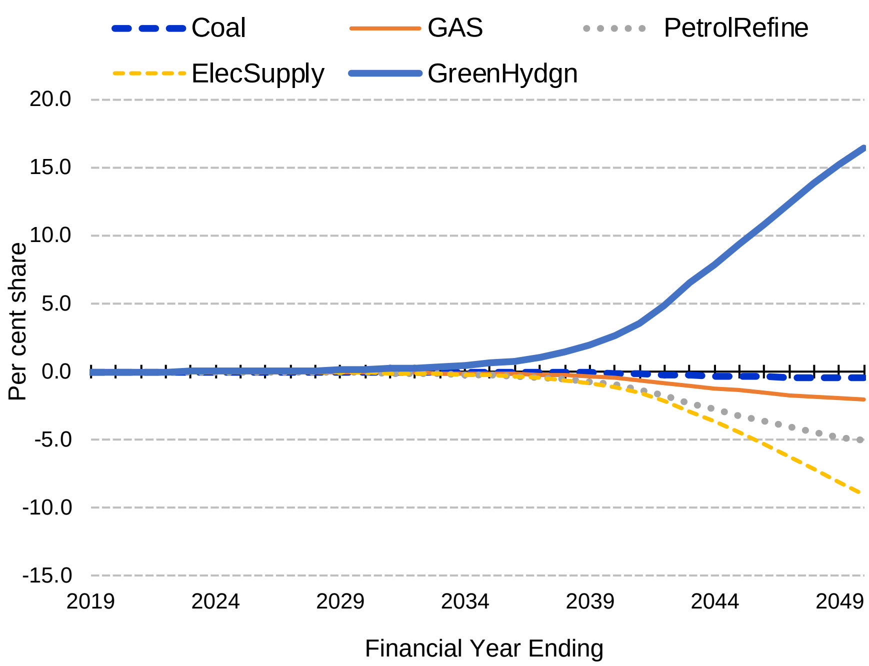

Figure 9 Final fuels – differences in share of the value of all final fuels – 60% Scenarios 60H relative to 60E

The main driver of the change in the energy mix is the progressive replacement of coal and gas generation with renewable generation, culminating in a zero-emissions electricity generation sector by 2050. This results from an assumed fall in the relative costs of zero-emission electricity production technologies and also the technologies necessary to ensure the continuous supply of electricity to users. **VURM-FF is constructed in a manner, for example, that could be used to assess the impacts of injecting hydrogen into natural gas pipelines and hence reducing the emission intensity of gas-fired power generation in any region that has access to natural gas.**

Critically, our 60% scenarios assume that the reduction of greenhouse gas emissions in the hard and extremely hard to abate sectors is minimal. Reducing emissions is difficult and new clean technologies will be adopted only when they become cheaper than existing production processes. As there is no penalty on emissions that will provide an economic incentive for these industries to adopt new clean technologies in the absence of cost incentives or regulations, the rate of adjustment is determined by decreases in the cost of production of clean technology—whether delivered through inherent productivity improvements or subsidies and regulatory incentives to support the take-up of cleaner processes.

In the net-zero or 100% scenarios, we assume that in addition to the phase-out of coal-fired and gas-fired electricity generation, between 2030 and 2050 Australia is lucky and able to costlessly achieve

- an additional 60 percentage points reduction in stationary non-generation emissions; and
- an additional 47 percentage point reduction in transport emissions

In addition, the extent of non-combustive emissions falls

- in agriculture by 15%;
- in energy production—fugitive emissions from gas flaring, methane from coal mines, etc.—by 25%;
- in industry and manufacturing by 25%; and
- in urban and industrial waste management including sewage by 50%.

As noted above, we consider these assumptions to be extremely optimistic and unlikely to be realised without substantial policy interventions. In practice, we see this as another area that is worthy of further analysis.

2.11 Energy sector detail

At present, the energy sector accounts for around 80% of Australian emissions and 35% of its emissions come from electricity generation.

We have sought at a high level, as far as possible, to use predictions that are broadly accepted by industry. In all scenarios and, as set out below, the stock of coal-fired power generators shrinks in line with AEMO projections of capacity, which foreshadow significant retirements in the 2030s. Most gas-fired generation is retired later – in the 2040s.

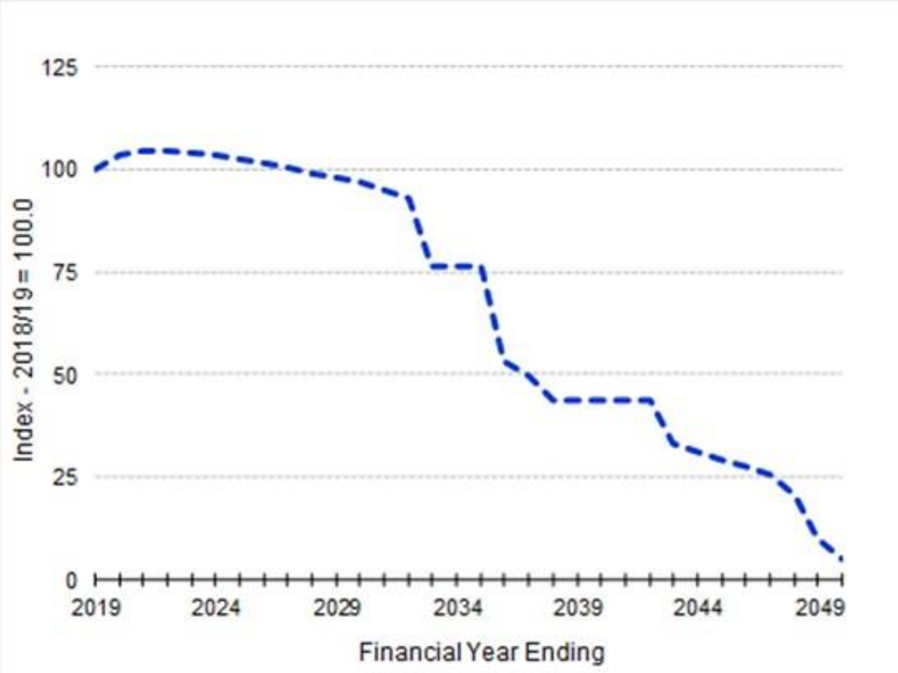

Figure 10 Exogenously imposed limit on national coal-fired power-station capacity Adapted from AEMO data as described in our technical report

2.12 The hydrogen sector

As described above, we have added green and blue hydrogen sectors to VURM. In VURM-FF, blue hydrogen is produced by the conversion of natural gas into hydrogen coupled with the capture and the return of most of the resultant CO_2 to the wells from which the gas was extracted. Blue hydrogen production is limited to regions where natural gas is being produced. Moreover, as without access to the data necessary to assume otherwise, our model assumes that the efficiency of the technology used to produce blue hydrogen is the same in each region and that each uses the same array of inputs. This, however, does not mean that each region faces exactly the same costs. The cost of purchasing the goods and services used to produce blue hydrogen varies by region.

In a similar, manner our model assumes that no region has a technological advantage in the production of green hydrogen. We assume also that each region is equally interested in and able to produce green hydrogen and does it in a manner that is not constrained by the presence or otherwise of supply infrastructure.

As shown in Figure 11, we assume that there are significant reductions in the cost of producing both blue and green hydrogen. Obviously, it remains to be seen whether these cost reductions can be achieved. We acknowledge as well that some claims made from time to time regarding the future of these technologies are contested. Our modelling assumptions should not be construed as an endorsement of any particular view; they are chosen for the purpose of illustration and other assumptions could also reasonably have been considered. **We stress that the assumed fall in the costs of producing blue and green hydrogen are illustrative.**

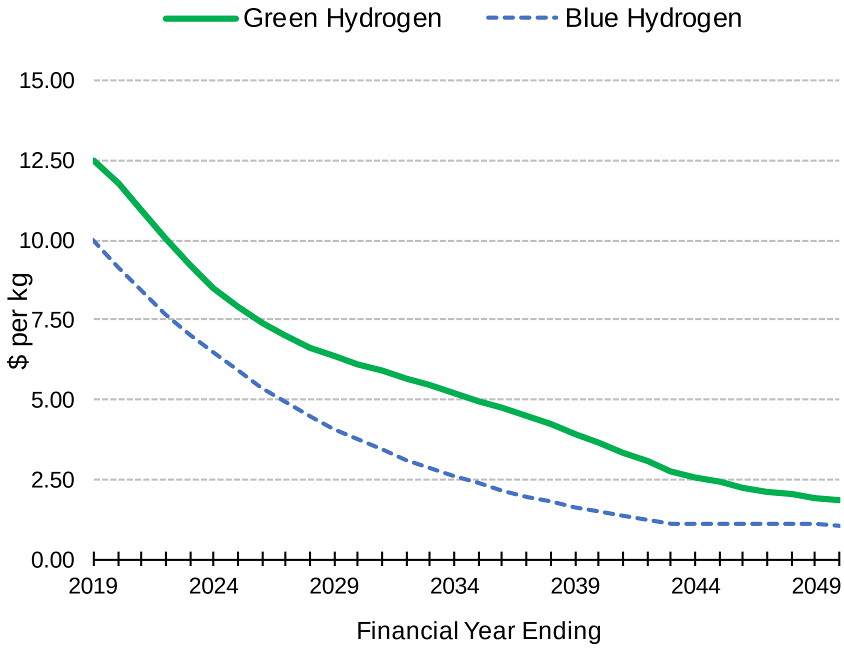

Figure 11 Modelled producer prices for hydrogen under 60H scenario[13]

2.13 Overview of assumptions

We stress that our scenarios emerged from a consultative process. Our emissions trajectories are based on FFCRC stakeholder views about how hard it will be to reduce different sources of emissions. The cost trajectories for green and blue hydrogen have been based on assessments in the literature about what might be feasible. They have, however, not been underpinned by detailed techno-economic modelling. We regard them as exploratory.

Each of the electrification scenarios is constrained to produce the same GDP but different quantities of emissions reduction reflecting differing degrees of technological improvement and government expenditure on emission offsets and CO_2 extraction. In the hydrogen scenarios, GDP is determined within the model, taking into account reductions in the costs of producing hydrogen and changes in export demand.

Under all scenarios, Australia remains a prosperous economy characterised by economic growth. The 100% scenarios require more technological progress than the 60% scenarios in that they assume costless low-emission-technology improvements in the hard-to-abate and extremely-hard-to-abate sectors of the economy.

All scenarios reveal the extent of economic and social changes that Australia will need to accommodate in the years through to 2050. As the Australian population is no longer replacing itself, immigration policy assumptions are critical.[14] While they need to be adjusted for the reduction in immigration during the COVID pandemic, the anticipated population increase from 25 million to 37 million - based on central case ABS projections - means that none of the 11 regions we model experience population decline. Nationwide the size of the economy more than doubles in real terms.

13 Producer prices under the 100H scenario are slightly different as the cost of inputs are slightly different.

14 In 2019, Australia's total fertility rate was 1.66 babies per woman in 2019. The rate necessary to achieve population replacement is considered to be in the vicinity of 2.1 babies per woman. See Births, Australia, 2019 | Australian Bureau of Statistics (abs.gov.au)

Table 1 and Table 2 summarise, firstly, the nature of the economic assumptions used to shape each scenario and, secondly, the nature of the emission assumptions used to define the pathway used to reduce emissions between now and 2050.

Table 1 Overview of economic assumptions used to specify each scenario

Scenario	**60E**	**60H**	**100E**	**100H**
Economic regions	11 Regions	Same	Same	Same
Population projection	ABS Series B	Same nationwide, regional deviations	Same nationwide, regional deviations	Same nationwide, regional deviations
Economic growth	Mainly AEMO "Fast Change"	Determined by model	Mainly AEMO "Fast Change	Determined by model
New industries	Blue & Green H_2, Bio-sequestration, Direct Extraction All blue hydrogen is exported. All green hydrogen is used within Australia	Same	Same	Same
Consistency with AEMO outlook	AEMO "Fast change"	AMEO Fast change" with hydrogen added	AEMO "Fast change"	AMEO "Fast change" with hydrogen added
Greenhouse gas price signal	No greenhouse gas emission price signal. All necessary offsets paid by Government	Same	Same	Same

Table 2 Overview of emission assumptions used to specify each scenario

Scenario	60E	60H	100E	100H
Level of net emission reduction ambition	60% reduction from 2005 baseline => (only 11% from 2020 to 2030 or 16% from 2005)	Same as 60E	Net-zero by 2050	Same as 100E
Electricity sector emissions	Zero emissions by 2050. Follows AEMO projections for closures to 2042	Same as 60E	Same as 60E	Same as 60E
Shift in demand for exports (non-fuel)	Energy demand grows with global GDP as per IEA Stated Policies Scenario	IEA Stated Policies with an increase in H_2 but reduction in LNG production	Demand grows as per IEA Stated Policies Scenario	IEA Stated Policies with an increase in H_2 but reduction in LNG production
Fuel exports - LNG	Export demand grows in line with East Asian fuel demand as per IEA Stated Policies Scenario	Export demand grows more slowly as blue hydrogen takes market share	Export demand grows in line with East Asian fuel demand as per IEA Stated Policies Scenario	Export demand grows more slowly as blue hydrogen takes market share
Fuel exports - Hydrogen	Hydrogen exports < $100m in 2050	Hydrogen exports grow to $3.2bn in 2050	Hydrogen exports < $100m in 2050	H_2 exports grow to $3.2bn in 2050
Fuel exports - Coal, Oil	Export demand grows in line with IEA's Stated Policies East Asian fuel demand Scenario	Same	Same	Same
Stationary non-generation emissions	25% reduction between 2030 and 2050	Determined by model	85% reduction between 2030 and 2050	Determined by model
Transport emissions	47% reduction between 2030 and 2050	Determined by model	94% reduction between 2030 and 2050	Determined by model
Agricultural emissions	No change between 2030 and 2050	Determined by model	15% reduction between 2030 and 2050	Determined by model
Fugitive emissions	No change between 2030 and 2050	Determined by model	25% reduction between 2030 and 2050	Determined by model
Industrial and manufacturing emissions	No change between 2030 and 2050	Determined by model	25% reduction between 2030 and 2050	Determined by model
Urban & industrial waste emissions	No change between 2030 and 2050	Determined by model	50% reduction between 2030 and 2050	Determined by model

CHAPTER 3. RESULTS

3.1 Electrification scenarios

Our two electrification scenarios enable consideration of the effects of different emission reduction pathways in a setting where technology developments in the production and utilisation of hydrogen are insufficient to bring about its widespread use.

The first electrification scenario (60E) requires a 60% reduction in emissions by 2050 and assumes a minimal reduction in the intensity of emissions from all other activities. That is, the focus is on the phase-out of electricity production using coal and natural gas, supported by reductions in emissions from other emitting activities.

The second electrification scenario (100E) delivers net-zero by 2050 and assumes that greater progress is made in the reduction of emissions in all sectors as set out above. In both cases, any remaining emission gap is closed via a government program involving the purchase of offsets and payment for the extraction of CO_2 from the air.

The scale of offset purchases is considerably greater in the net-zero emissions scenario.

Relative to 2019 emission levels, the 60E scenario requires a 53 per cent reduction in emissions or, as the size of the economy grows, a 78 per cent reduction in emissions intensity per unit of GDP.

Key empirical observations that arise from these two electrification scenarios include

- offsets play a significant role in the 60E scenario and account for about a quarter of the reduction in emissions;
- offsets play a major role in the 100E scenario, accounting for nearly a third of the reduction in emissions;
- while both of these scenarios relate to electrification, in the sense that electricity replaces traditional fuel sources such as gas and petroleum products, the electricity intensity per unit of GDP needs to fall by 46 per cent in 60E and by 41 per cent in 100E; and
- because non-offset emission reductions are driven by improvements in the cost of low emission technologies, there is minimal restructuring of the economy outside the electricity generation sector in both 60E and 100E—that is to say, existing high-emitting activities are not subjected to the viability pressures that might be imposed by penalties on emissions.

In both electrification scenarios, GDP is assumed to increase by 116% between 2019 and 2050. However, offset purchases are greater in 100E and household incomes consequently are lower. This impact becomes more pronounced towards the end of the modelling period as offsets ramp up to achieve net-zero in 2050.

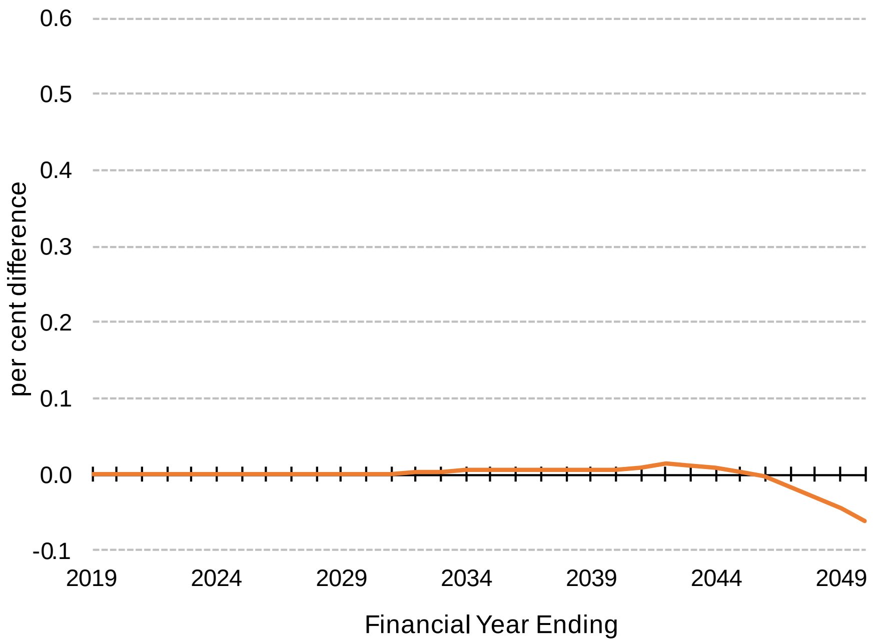

Figure 12 Household disposable income – Australia – Electrification Scenarios 100E relative to 60E scenario

With regard to the transport sector, in the 60E scenario transport emissions fall by 43 per cent between 2019 and 2050. In the 100E electrification scenario, the 94 per cent emissions reduction requires an extremely large reduction in fossil fuel per unit of output, which requires both substantial electrification of the economy and reductions in overall energy intensity. The corresponding reductions in transport emissions intensity per unit of output are 73 per cent and 97 per cent.

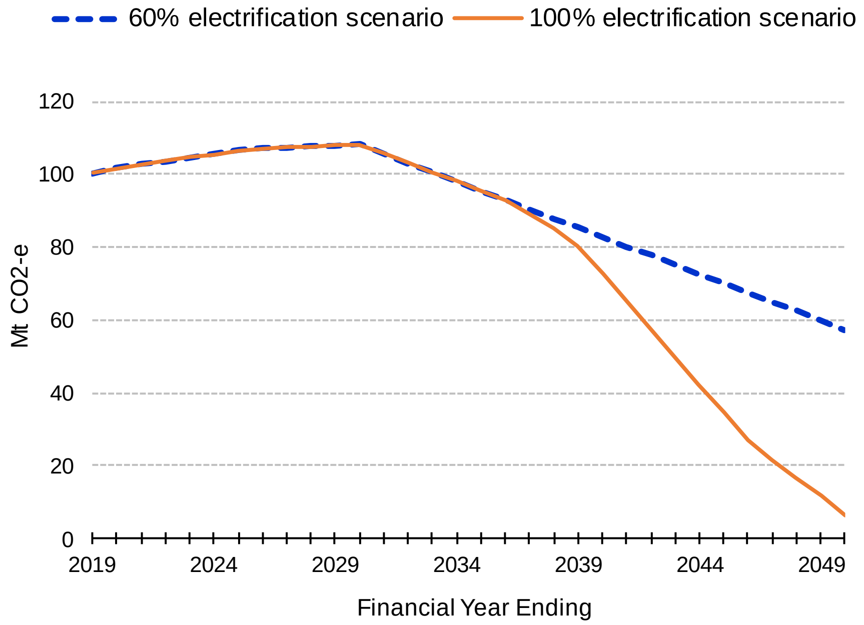

Figure 13 Transport emissions per unit of output - Australia – Electrification Scenarios

Under the 100E scenario, the direct CO_2 extraction industry emission reduction requirement in 2050 is 155 million tonnes of CO_2. Costs of direct extraction are highly speculative but, at a cost of $100 per tonne, the total cost to the budget in 2050 would be of the order of $16 billion. Under the 60E scenario, the direct extraction task is considerably smaller, at 68 million tonnes of CO_2 in 2050, with costs commensurately smaller but still of the order of $7 billion.

3.2 Hydrogen scenarios

COAG has developed a National Hydrogen Strategy and the Australian Government has developed a Technology Roadmap that both place strong emphasis on the use of hydrogen as a means to reduce greenhouse gas emissions.

Our two "hydrogen" scenarios assume success in the development of hydrogen technology. In these scenarios, the opportunity to produce blue and green hydrogen is added and the hydrogen sector begins to compete with all other sources of energy. We regard our cost-reduction trajectories for each form of hydrogen production as optimistic.[15] We assume that blue hydrogen production occurs with the 100% carbon capture and storage of all emissions associated with this process.[16]

Use of hydrogen elsewhere in the economy is assumed to produce zero emissions.

As explained above, in the current version of the model and, as we are not yet in a position to estimate the cost of distributing hydrogen, we assume that all blue hydrogen is exported and all green hydrogen, which we assume costs more to produce, is consumed within Australia. Hence, in this summary report, we differentiate only between locally consumed and exported hydrogen.

Prospects for the hydrogen sector, as with other low emission technology, are constrained by a policy setting that chooses to pay for emission offsets but not penalise other industries for the cost of producing emissions. As a result, hydrogen, for example, only replaces petroleum when it becomes economically competitive to do so. Even so, and as shown in Figure 14 **below, the use of hydrogen when it becomes competitive to do so.**

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15 During the process of model development, we also added in a capacity to significantly increase biogas production but have left this variant out of the scenarios described in this report.

16 While the amount of emissions from green hydrogen is generally assumed to be zero, at present, there is no widely accepted emission standard for blue hydrogen. Some experts are of the view that the processes used to produce blue hydrogen will only succeed in capturing and storing around 90% of the CO_2 produced.

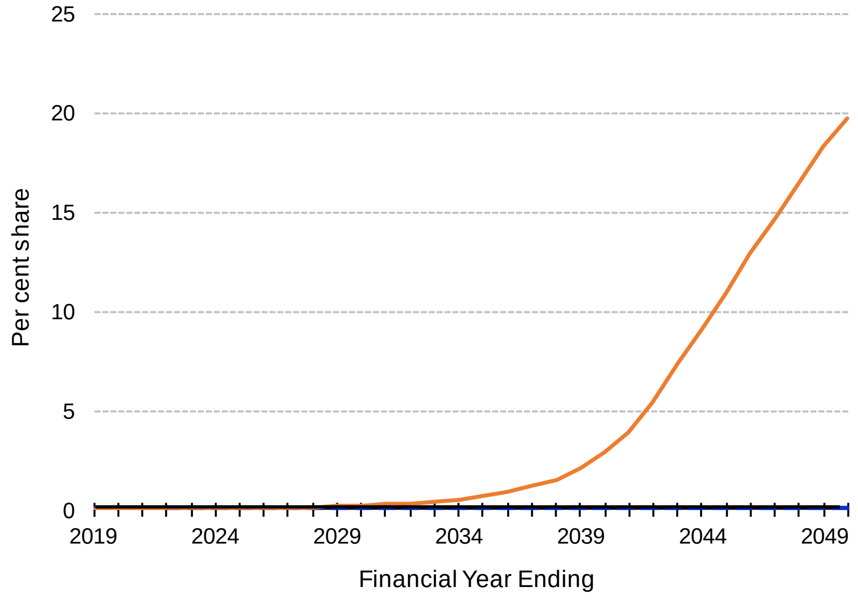

Figure 14 Hydrogen industry's share of final fuel sales by value assuming green hydrogen production costs fall to $2 per kg and attainment of net zero by 2050

As shown in Figure 15, however, once hydrogen becomes competitive the need for direct CO_2 extraction is reduced.

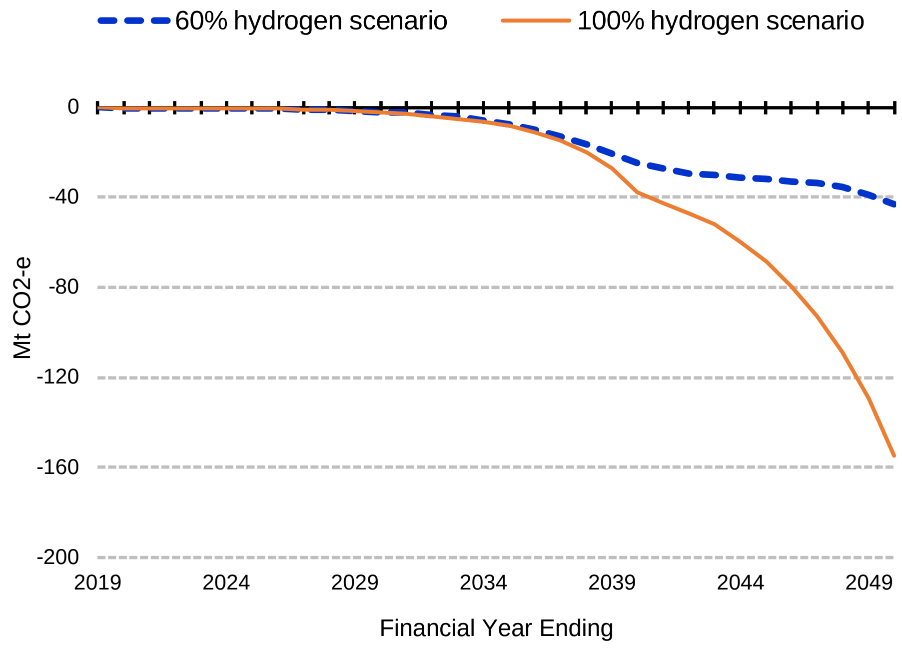

Figure 15 Direct extraction offsets – Hydrogen Scenarios

Both hydrogen scenarios involve major productivity improvements in hydrogen production between 2019 and 2050 — a 94 per cent reduction in input requirements for domestic hydrogen and a 90 per cent reduction for exported hydrogen.

After removing the effects of general price inflation, the cost of hydrogen used within the Australian economy falls to a little under $2 per kg in 2050 from $12.50 in 2019.

Exported hydrogen prices fall to about $1 per kg in 2050 from $10 per kg in 2019. Given these assumptions, the key empirical observations that arise from our two hydrogen scenarios include the observations that

- hydrogen becomes a significant component of the Australian energy mix, such that in 2050 it comprises 17 per cent of domestic energy purchases under the 60H scenario and 20 per cent under the 100H scenario;
- the production and local consumption of hydrogen significantly reduces the role of carbon-emitting fuels in the economy with the result that, in comparison to the 60E scenario, the 60H scenario purchases of petroleum products are 5 per cent lower, gas is down 2 per cent and coal down 0.4 per cent;
- a similar pattern is evident in the 100H scenario, with a greater reduction in domestic market shares for petroleum products, gas and coal;
- electricity's share of domestic energy purchases is also lower in the 60H and 100H scenarios than in 60E and 100E, as hydrogen replaces some electricity consumption, but this fuel switching to hydrogen does not reduce emissions as all electricity production in 2050 is assumed to be emission-free;
- Australian Government offset purchases are 24 Mt CO_2-e (36 per cent) lower in the 60H scenario than in 60E for a gross requirement of 43 Mt;
- in the 100H scenario offset purchases are 9 Mt (5 per cent) less than in 100E but still at a very high level of 155 Mt;
- hydrogen-related savings of offsets in the 100 per cent emission reductions scenarios are quite small because the 100E scenario entails a high degree of electrification, and replacing electricity from renewable generation with hydrogen does not yield any emission reduction.

Critically, from a future fuels' perspective, our model suggests that investment in the production of hydrogen at scale begins only when costs fall to the extent that blue and green hydrogen producers can compete with the already well-developed renewable energy sector which begins to occur in the mid-2030s.

CHAPTER 4. AREAS FOR FUTURE WORK

This report has been prepared with a view to showcasing the potential of the version of the VURM model we have developed. The VURM-FF provides a whole-economy perspective on alternative emissions/energy scenarios for the Australian economy. Future work could consider additional scenarios, refinement of techno-economic assumptions and other improvements to the model.

4.1 Scenario expansion

While we recognise the need for further consultation, the consideration of our initial findings suggests that there is a case for the development of scenarios that consider

- Different international settings including use of the IEA's Sustainable Development rather than its Stated Policies Scenario, and those being developed by the Hydrogen Council[17];

- Emerging Australian low-carbon economy visions including the
    - conversion of all Australian iron ore into iron pellets and green steel products for export using Australian sources of renewable energy;
    - conversion of all or a significant proportion of natural gas into blue hydrogen;
    - increased production and use of biogas;
    - development of a stronger National Electricity Market Grid including significantly improved connectivity between regions;

- Alternative policy settings including
    - Different emission reduction pathways such as an arrangement that would plan to commence substantive adjustment from, say, 2025 rather than 2030
    - The introduction of an emissions trading scheme, a carbon tax or widespread emission-intensity limits;
    - The impact of a carbon-border tax and or adoption of mechanisms that would enable Australia to claim exemption from one;

- A series of sector or industry-specific analyses that, for example, focus on any one of the 86 commodities in VURM-FF.

4.2 Techno-economic refinement

This report is based on broad assumptions around future techno-economic developments. This means that the electrification and hydrogen input assumptions herein have not been underpinned by detailed techno-economic modelling and assume that investments in lumpy infrastructure occur.

More detailed analysis of techno-economic issues could also be expected to give a more informed perspective on locational advantages such as Northern South Australia's access to favourable wind and solar resources and the coincidence of renewable energy and iron ore in both the Pilbara and Northern South Australia.

Similarly, our regional data does not account adequately for opportunities to capture and store CO_2 etc. As a result, we consider that the future development of our VURM-FF would benefit immensely from a suite of Future Fuel CRC techno-economic studies to enable a more informed assessment of options, issues associated with the rollout of (lumpy) infrastructure and, particularly, the vexed question of the best way to supply access to hydrogen. This could also include the development of the

[17] The Hydrogen Council is a global CEO-led initiative of leading companies with a united vision and long-term ambition: for hydrogen to foster the clean energy transition for a better, more resilient future.

data necessary to generate much more detailed estimates of the scale of the physical structure necessary to deliver each scenario.

As a way forward, we suggest that as a bare minimum there is a need for a suite of studies that bring together work on the

- **Industrial and manufacturing sectors** that could decide to use future rather than traditional sources of fuel for energy, heat and the production of goods and services;
- **Household and small business sectors**;
- **Transport sector** with a focus on options for the use of hydrogen and ammonia in heavy transport;
- **Energy supply and distribution sector** including the role of CCS**;**
- **Future fuel production sector** with a focus on both large scale and distributed production opportunities;
- **Production of future fuels for export.**

4.3 Model improvement

To pursue these further lines of inquiry some improvements to the capacity of our version of VURM to examine industry-specific details would be desirable. In particular and as the above work proceeds, there may be a case for

- Creating a separate ammonia production sector;
- Splitting petroleum into petrol and diesel so that it is easier to model implications for heavy and light transport;
- Restructuring the model so that prospects for regional Victoria and New South Wales can be assessed separately from effects on Sydney and Melbourne;
- Finding a way to resolve inconsistencies among ABS economic data, AEMO production data and Australian Government emissions data; and
- Adding a capacity to assess the effects of water supply on hydrogen production.

CHAPTER 5. CONCLUSIONS

The regionalised economic model that we have developed and documented in this report reveals some important insights into the role of future fuels could play in helping Australia to reduce greenhouse gas emissions.

Three high-level conclusions stand out.

Our first conclusion is the observation that if Australia continues with its current suite of policies and continues to rely on the development of technology without introducing any form of market-based signal for greenhouse gas emissions Australia will only be able to meet its 2050 targets, whether they be for 60% reduction or net-zero, by establishing a massive greenhouse gas emission offset program. Moreover, this cannot be affordably achieved via bio-sequestration.

Our second conclusion is that the development of the future fuel industry at scale risks being delayed until the late 2030s and only becomes a substantial part of the economy in the 2040s. This is due largely to the current focus on the development of technology coupled with an approach that delays investment until these technologies become cost-competitive. From a FFCRC perspective, there is merit in carefully examining and, if found appropriate, assisting the case for a different approach – as many in the industry are already arguing for.

Our third, much more tentative, conclusion – better stated as a hypothesis to be tested – is that the current stated policy framework favours the development of electrification as a decarbonisation pathway at the expense of future fuels, potentially precluding the substantial role that more timely large-scale deployment could play.

Future Fuels CRC

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