Crosthwaite comments on Gas Infrastructure 2050

Jim Crosthwaite B.Ag.Eco. (UNE), M.Comm and PhD. (U.Melb)

After a career in the Australian Bureau of Statistics, Jim worked over 34 years for the Victorian Government and national research programs on the economic and social dimensions of environmental management, focusing on biodiversity, water, forestry and agriculture.

Summary of key points [1]

In introducing my comments, I wish to highlight three critical and related points

- importance of cumulative emissions,
- scope of scenarios being tested, and
- views of business and economists

These are crucial considerations that should weigh heavily in choosing between the scenarios for the future of Victoria's Gas Infrastructure. They are even more critical given the recent IEA Roadmap report [2], the IPCC sixth assessment report [3]and the forthcoming Glasgow summit – in order to avoid the worst of climate change, time is running out for drastic action.

Cumulative emissions over the next 30 years really count. Emissions over the past 30 years equal all emissions since the start of the Industrial Revolution in 1751.[4] Different pathways to Net Zero 2050 will result in greatly different emissions and impacts, as graphically illustrated by Ketan Joshi.[5] He shows massively higher emissions if a slow path is taken.

Multiple scenarios that can realistically deliver net zero emissions by 2050 and low cumulative emissions over the next 30 years must be under consideration. As will be shown, AEMO scenarios are moving in this direction; the Doris Engineering scenarios commissioned by Infrastructure Victoria are too weak; and the faults in the Frontier Economics study commissioned by the gas industry make their scenario analysis altogether implausible.

Business leaders and economists are calling for drastic and immediate action on climate change. These people read the IPCC reports, see the devastation already happening, and know the tipping points very well. They have high expectations of the Glasgow summit. The Alliance of CEO Climate Leaders [6], under the umbrella of the World Economic Forum, has called for strong action.

In my profession, **economists globally** are overwhelmingly calling for drastic and immediate action on climate change as found in research[7] highlighted by the World Economic Forum.[8] In a 2021 global poll of 738 economists, 75% strongly agreed with drastic action compared with just 50% surveyed in

[1] All references have been accessed over July and August 2021.
[2] https://www.iea.org/reports/net-zero-by-2050
[3] https://www.ipcc.ch/report/sr15/summary-for-policymakers/
[4] https://ieep.eu/news/more-than-half-of-all-co2-emissions-since-1751-emitted-in-the-last-30-years
[5] https://medium.com/lobbywatch/the-gas-war-part-2-the-australian-gas-industry-and-their-anti-electrification-campaign-5b8702d8d6a1
[6] https://www.weforum.org/projects/alliance-of-ceo-climate-leaders
[7] https://policyintegrity.org/publications/detail/gauging-economic-consensus-on-climate-change-issue-brief
[8] https://www.weforum.org/agenda/2021/04/economists-global-action-climate-change-natural-disasters/

2015, most commonly because of "escalation in recent extreme weather events, which have included climate-linked wildfires and heat waves".

Business leaders have a mandate to deliver returns to shareholders. This should not be an excuse to bow to the pressure of some corporations to slow the transition and choose a path to Net Zero 2050 that allows high levels of emissions to continue largely unchecked. Strong short-term targets are critical.

Multiple scenarios that can realistically deliver net zero emissions by 2050 and low cumulative emissions over the next 30 years must be under consideration.

The scenario analysis of Doris Engineering points to the central role of demand reduction, energy efficiency and electrification

Demand reduction is critical, and targets are needed for reducing total energy consumption in Victoria, going well beyond what closure of coal-fired power stations will deliver.

There may be a **marginal role for biofuels, carbon capture and other technologies** – but public money should be limited to R&D purposes.

The gas distribution and transmission network is ageing and over time **should be decommissioned in a planned and regulated way**, while ensuring that it provides a reliable service while in operation. Supporting further investment will only lead to pressures to delay from investors seeking to recoup their capital.

Targeting **efficiency measures by gas users** is very important, as outlined by Alan Pears (Senior Industry Fellow at RMIT) in his submission to this inquiry and to DELWP's Gas Substitution inquiry. He also highlights the importance of **monitoring and smart technology** in improving efficiency.

Gas use in industrial processes should have priority ahead of commercial and residential use, where there are clear alternatives. Over time, hydrogen produced onsite or delivered through dedicated pipelines is likely.

Costs of electrification will be low by comparison with the story portrayed by Frontier Economics in their analysis for the gas industry associations, and cited in *Gas Vision 2050* [9] and in their submissions to the inquiry into Victoria's 30 Year Infrastructure Strategy.[10]

Keeping the gas network open so that **hydrogen can be added would be a gross waste of resources**. A more direct route should be pursued for Victoria to develop a hydrogen economy with onsite production and a dedicated small number of pipelines. 80-90% of the fuel mix would be methane for a long time to come, defeating the aims of Victoria's climate ambitions. The network would need a total makeover if it were ever to take 100% hydrogen.

I fully support the submission from Alan Pears AM, which includes his submission to the Roadmap inquiry. It is based on his long experience and expertise across these issues. I also cite the Lighter Footprints submission, and the United Workers Union submission to the DELWP Roadmap inquiry. All three emphasise the great benefits for Victoria on jobs and industry more than I do.

[9] https://www.energynetworks.com.au/projects/gas-vision-2050/
[10] https://www.infrastructurevictoria.com.au/victorias-draft-30-year-infrastructure-strategy-submissions/

Response to questions

1. Do you have any further information, evidence or concerns that you wish to raise in relation to the scenario design and analysis?

The scenario design by Doris Engineering appears to be robust, although limited. Their scenario analysis points to the central role of:

a) demand reduction, energy efficiency and electrification.
b) factors affecting cost and availability of gas and its alternatives

In the further work that Doris Engineering are being commissioned to undertake [11] for the Infrastructure Victoria investigation, the following points should be addressed:

- The potential for **reducing gas demand** in Victoria as highlighted by **Northmore Gordon** [12] should be tested in the scenario analysis.
- The effects of a **shadow carbon price** should be tested, as explained by the Australian Institute of Company Directors [13], and adopted by companies like Wesfarmers [14] into their investment decision making.
- Test scenarios for **cumulative emissions** over the next 30 years.
- Key assumptions should be **made explicit** in the final report to Government, including those adopted from AEMO. Policy makers need to be aware of them, their origin and rationale. Such assumptions include total energy use, population growth and per capita energy use. We need to ask: what are the barriers to reduction in energy use, and what are the links to gas use? Attachment A lists some assumptions from the Doris Engineering and Frontier Economics reports that bear closer scrutiny. See the points below about AEMO assumptions.
- Doris Engineering should be encouraged to **test stronger scenarios** than those already considered. They are currently based on meeting net zero 2050 targets, but not reducing cumulative ambitions and reaching ambitious 2030 targets – the need for which is graphically illustrated by Ketan Joshi.[15] In their current study, indexes (cost and other) are used to compare scenarios – scenario 1 is the baseline. The environmental component involves a) getting to net zero quicker than 2050, and b) environmental risk / opportunity balance (p.229).
- Also review scenarios in light of a) **AEMO plans** for its 2022 Integrated System Plan (ISP) [16], and b) **arguments for bolder scenarios** made in submissions to AEMO during the ISP process by the Australian Conservation Foundation. The intent of AEMO to change its scenarios is highly significant. One is explicitly for 'Net Zero 2050', while there is also a

[11] Their report states "The goal of the study was to identify the strongest scenario(s) to carry forward for more detailed analysis" p.48. The Doris Engineering website also refers to the ongoing work.
[12] http://environmentvictoria.org.au/wp-content/uploads/2020/06/Vic-Gas-Market-Demand-Side-Study-Final-Report-1.pdf
[13] https://aicd.companydirectors.com.au/membership/company-director-magazine/2021-back-editions/july/zero-tolerance
[14] https://www.wesfarmers.com.au/sustainability/our-principles/climate-change-resilience/shadow-carbon-price
[15] https://medium.com/lobbywatch/the-gas-war-part-2-the-australian-gas-industry-and-their-anti-electrification-campaign-5b8702d8d6a1
[16] https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2022-integrated-system-plan-isp/current-inputs-assumptions-and-scenarios

'Hydrogen Superpower' scenario and one for 'Step Change' scenario that recognises dynamic change in the climate and energy responses of business and household sector.

- **Review and test key assumptions** underpinning AEMO's analysis for the ISP. Arguably, many of the AEMO assumptions relating to future supply of alternatives to gas and demand for both gas and alternatives are too conservative. I note that the AEMO 2020 assumptions for its middle scenarios underpin the Doris Engineering report (pp.29-30) [17] for this inquiry while 2019 assumptions underpin the Frontier Economics report for the gas industry (pp.55-56.[18] I understand that these are out of date, given the latest ISP is for 2021 and bigger changes are planned for ISP 2022.

AEMOs **explanation of scenario planning and sensitivity testing** should be born in mind, especially when considering submissions from the gas industry. In my judgement, the analysis by Frontier Economics fails to adequately deal with either. AEMO states in the 2021 Inputs, Assumptions and Scenarios Report [19] (p.7) that:

- The use of scenario planning is an effective practice to manage investment and business risks when planning in highly uncertain environments, particularly through disruptive transitions. Scenarios are a critical aspect of forecasting, enabling the assessment of future risks, opportunities, and development needs in the energy industry. It is vital that the dimensions of scenarios chosen cover the potential breadth of plausible futures impacting the energy sector and capture the key uncertainties and material drivers of these possible futures in an internally consistent way.
- Sensitivities serve a different purpose; they are designed to test the materiality of uncertainty associated with individual input parameters or assumptions. They aim to increase confidence in investment decisions, by testing the sensitivity of outcomes to various input uncertainties.

There is huge potential for change in both **energy efficiency** (see Alan Pears submission) and **energy habits** (some of which can be triggered with behind-the-meter monitoring). Here are two other considerations:

- **Per capita use of energy** is far higher in Australia than in most other countries. Other developed countries also face this challenge, but countries like Germany, France, Denmark, Italy and Israel use far less than Australia on a per capita basis. The World Bank data (from the IEA) show per capita energy demand in Europe in 2010 at 137.3GJ falling to 115.1GJ in 2030 by comparison to Oceania at 183.4 GJ in 2010 falling to 172.9 GJ in 2030.[20]
- Moreover, **comparisons with 70 years ago** suggest great potential for reductions with the right policy settings – an average 136GJ per year was used in the five years to 1965-66 compared to well over 200Gj annually in recent years (calculated from Australian Energy Statistics 2020 Table B).[21] Fortunately, use has been falling from its peak around the year 2000.

[17] https://www.infrastructurevictoria.com.au/document/net-zero-emission-scenario-analysis-study-report-doris-engineering/

[18] https://www.energynetworks.com.au/resources/reports/2020-reports-and-publications/the-benefits-of-gas-infrastructure-to-decarbonise-australia-frontier-economics/. They state in the report: "The objectives of this study are to determine and document an estimate of the value of gas infrastructure in 2050, accounting for Australia's carbon-emission commitments."

[19] https://aemo.com.au/consultations/current-and-closed-consultations/2021-planning-and-forecasting-consultation-on-inputs-assumptions-and-scenarios

[20] https://documents1.worldbank.org/curated/en/603241469672143906/pdf/778890GTF0full0report.pdf

[21] https://www.energy.gov.au/sites/default/files/Australian%20Energy%20Statistics%202020%20Energy%20Update%20Report_0.pdf

2. Do you have any further information or evidence that can help identify an optimum scenario for a net zero emissions gas sector in 2050?

There is likely to be a hydrogen sector of significance in 2050 producing onsite energy for industry, delivering it through dedicated pipelines to specialised users, and exporting it. This could be based in Renewable Energy Zones, near specific Industrial precincts and near shipping ports. However, it is unlikely to be based on the current gas network. As shown in the Doris Engineering report, most of the current gas network is over 40 years old, larger pipes are needed for hydrogen, and the overall costs of conversion would be very high. Resources are better placed elsewhere.

See also my response to other questions, especially Questions 1, 3 and 6.

Be alert to **possible flaws** in arguments for such a gas sector in 2050 that are made by Frontier Economics, and used in *Gas Vision 2050*, and other documents of the gas industry. This research has been cited in industry submissions to the inquiry into Victoria's 30 year Infrastructure Strategy and to other inquiries. The research is used to claim that hydrogen into our pipelines is a clear winner, based on great infrastructure savings and huge electrification costs of alternative solutions. I have reviewed the objectives, method, evidence, findings and recommendations in that research. Flaws include:

- Lack of sensitivity testing of results to changes in assumptions
- Inadequately dealing with uncertainty; this is particularly important given that uncertainty about the future is basic to AEMOs rationale for scenario testing. AEMOs scenarios are to 2040, whereas Frontier Economics extrapolates AEMO results beyond this to 2050. Frontier scenarios are snapshot out to 2050 based on estimating annual costs in that year; scenarios are compared for 'net cost' (pp.47-50).
- Key factors are omitted or downplayed in this research and in a recent summary of points by Dennis Van Puyvelde head of gas at ENA, who was lead for developing Gas Vision 2050.[22] Important rebuttals have been made by Alan Pears [23]and Ketan Joshi [24].

3. What policies and/or regulations, if any, are needed to support the development of low carbon pathways such as biogas, green hydrogen, and carbon capture and storage?

It will be a misdirection of the resources required to build a green hydrogen industry in Victoria if policy was directed towards injecting hydrogen into the current gas pipeline network.

- Strategy for hydrogen should centre on onsite production and possibly targeted pipelines to key industry. The gas industry's vision for hydrogen into the whole network should be rejected. I note that the UK plan is for selective pipelines for (blue) hydrogen, not all pipelines. Hydrogen into the network will require major upgrades to the pipelines. As Alan Pears states: "... investments in additional gas production for which a

[22] https://www.energynetworks.com.au/news/energy-insider/2021-energy-insider/playing-with-gas-victoria-should-substitute-with-its-star-performer/
[23] https://reneweconomy.com.au/hydrogen-vs-electrification-why-enas-gas-vision-is-a-house-of-cards-96820/
[24] https://medium.com/lobbywatch/the-gas-war-part-2-the-australian-gas-industry-and-their-anti-electrification-campaign-5b8702d8d6a1

need to repay capital costs adds to pressures to maintain gas consumption and associated emissions, risks and costs." (his Roadmap submission)

- Emissions will continue as high by following a pathway of including green hydrogen into the gas network because in the short and medium-term it will depend on a) 80% methane in the mix and b) hydrogen produced with fossil fuels. Alan Pears states in his Roadmap submission that "Even if ambitious targets for cost reduction of renewable hydrogen are met, timing is uncertain and likely to be more than a decade away."
- New research shows that hydrogen produced with fossil fuels and using carbon capture and storage to capture emissions will potentially have a higher greenhouse effect than burning natural gas. The researchers accounted for lifecycle emissions of both carbon dioxide and unburned fugitive methane.[25]
- There is an additional problem with using the existing gas network as part of the transition to green hydrogen, as pointed out by Alan Pears. The emissions intensity of gas depends on its source – this will almost certainly increase when using gas from imports and from new local fields. Note that BHP and Esso recently invested billions into a plant to 'clean up' the remaining gas from the Longford fields.

Biogas can play a role, but limited, because of limited production potential. Its role should be explored in particular regional locations.

Carbon capture and storage is a false hope that could drain public resources and achieve very little by way of net carbon storage. Some experiments may succeed, but commercial success is very difficult given the high costs and technical uncertainties, whether dealing with emissions when generating power, when liquefying gas or when producing blue hydrogen.[26]

Secondly, gas leaks will occur. As a 2007 House of Representatives report [27] found: "The greatest environmental risk associated with CCS concerns the potential for CO2 leakage" – either abruptly or slowly and undetected.

Take the option of offshore storage in the Gippsland Basin; we simply do not have the tools to monitor for slow leaks through small fractures in rock over long periods of time. I note that some slow leaks are well-known, but controls are not in place or have been abandoned, as found in a recent report by the Australian Conservation Foundation for the Ravensworth mine where Glencore promised to capture methane emissions.[28]

4. What is your view on the best ways to maintain the reliability and affordability of Victoria's gas supply if natural gas use declines?

Take a strong government lead in managing the necessarily rapid transition to renewables. Government can develop mechanisms to ensure reliability and affordability. This will require stronger regulation of the suppliers of gas that have monopolistic or oligopolistic control over parts of the network. It will require support for vulnerable households and possibly small business. Build capability within government so that this can happen.

[25] https://onlinelibrary.wiley.com/doi/10.1002/ese3.956
[26] See for example KPMG https://home.kpmg/xx/en/home/insights/2020/11/the-hydrogen-trajectory.html
[27] https://www.aph.gov.au/binaries/house/committee/scin/geosequestration/report/fullreport.pdf
[28] https://www.acf.org.au/methane_creating_a_stink

Alan Pears has useful proposals in response to this question. I am also impressed with proposals from the United Workers Union to the Roadmap Inquiry.

5. What else can you tell us about the implications of decarbonisation pathways for the electricity generation, transmission and distribution networks?

This is a really important area for government action, as is already happening with Victorian Energy Upgrades. The Lighter Footprints submission to this inquiry outlines many measures available to government that should be pursued vigorously. Alan Pears has valuable comments in answer to this question, and in his comments about electric vehicles, dwellings and 'deep storage' under "Need for an Integrated Approach".

Switching over from gas to electricity as an energy source will benefit households, consumers and small business. Research by RENEW and other organisations shows that their energy bills will be lower in most cases. Where households install solar panels and heat pumps, their capital outlays will be recouped.

Decarbonisation will increase demand for electricity. However, the increase will not be as great as suggested by modelling.

- It is wrong to assume no changes in efficiency of transmission of electricity noting that 15% of electricity is consumed in its own production (at coal power stations) and in transmission. Power stations will be closing, and efficiencies in transmission are feasible (see Alan Pears submission on this)
- It is wrong to assume no significant reduction in energy use, whereas increased energy efficiency and changed habits of consumers can make a major difference. As Alan Pears notes in his Roadmap submission "Timely feedback to operators of appliances, equipment and buildings will support identification of faulty and poorly maintained equipment – a much bigger issue than most realise, and is poorly documented." He goes on "Lack of meaningful, timely feedback on energy use for consumers is a critical problem across all sectors, especially for gas. In order to provide 'efficiency' indicators, data from multiple data streams is needed, along with data analytics."

6. How can the use of Victoria's existing gas infrastructure be optimised during the transition to net zero emissions, over the short (10 years), medium (20 years) and long-term (30+ years)? How can the Victorian Government assist in this?

There is no 'optimal' use of the gas infrastructure in the sense of optimising social welfare or the public good (the goal of economics).

Optimising the reduction in carbon emissions requires a managed wind-down as rapidly as possible. The economics of electrification and energy storage mean that this can be achieved rapidly, with government paying attention to adverse effects on particular consumers of energy as well as energy-sector workers.

In contrast, network expansion should be stopped forthwith, and investment allowed only for maintenance and safety reasons.

A sub-optimal solution would be to manage the system for the shareholders of the monopoly and oligopolistic businesses that manage most of the network. This requires allocation of public resources and customer dollars to maintain and invest more into the network. Alan Pears in his submission highlights the public risk of over-valuing the current network to the benefit of its owners. Does the cited $40 billion of value in the network, much of it 40 years old, 'represent market value, depreciated value or replacement value'?

Other economic analyses may identify optimal uses. As pointed out in response to earlier questions, their approach and underlying assumptions should be scrutinised carefully. I make two additional points.

- It is not enough to simply try to understand the end-point of 2050, as done by Frontier Economics. The pathway to 2050 is equally important, not least because the cumulative emissions (and likely carbon costs) over that time period will vary greatly between scenarios. As the graphic prepared by Ketan Joshi shows, emissions from a rapid scenario will be just 1/3 of a business-as-usual case to 2045 and then a very-rapid-reduction to 2050.[29]
- A cost-benefit analysis is the appropriate method for comparing the scenarios. This must involve discounting cash flows over a given period back to the present day. This is not done by Frontier Economics; their analysis can best be described as partial budgeting (albeit using sophisticated modelling) which at best can test if a given scenario is worthy of further investigation.

7. What principles should apply or what measures will be needed to manage the impacts of gas decarbonisation on households and businesses?

I argue as follows:

- Look after low-income households, and facilitate their rapid transition off gas a.s.a.p. so as to ensure that they don't carry the burden of paying for maintenance of gas infrastructure.
- Strongly regulating the charges for gas especially transmission and distribution

See also the submissions by Lighter Footprints and Alan Pears, including his case study of a household's cumulative emissions when primarily using gas or electricity.

In their Roadmap submission to DELWP, the United Workers Union gives valuable insights based on the needs of their lower paid members. This includes a proposal for Managed Energy Services Agreements under which households don't have to pay upfront for energy efficiency upgrades or electrification.(pp4-5).

8. What policies, programs and/or regulations should the Victorian Government consider or expand to encourage households, commercial buildings and small businesses to reduce their gas use?

- Major programs are required to target three separate areas - energy habits, energy efficiency and electrification – for each of households, commercial buildings and small

[29] https://medium.com/lobbywatch/the-gas-war-part-2-the-australian-gas-industry-and-their-anti-electrification-campaign-5b8702d8d6a1

businesses. We can also add institutions such as hospitals, schools and universities and potential users like warehouses.

- More research to identify energy use and energy efficiency, especially in the commercial sector. Relevant research has begun, and the gaps identified.[30]
- Build capacity and capability within government, recruiting people with industry experience, to drive major programs
- An early focus on the larger users and potential users of gas, including companies like Mirvac that are leading other businesses on setting sustainability targets.[31]
- Targeted incentives to encourage firms to replace and avoid gas
- Tighter regulation/standards around equipment, as well as gas leaks and emissions
- Strong education and training programs for business owners and workers, and for dwelling owners, landlords and tenants. Build these programs with the idea that government can and should play a leading role in mobilising community as a key means of building understanding and action.
- Continue to strengthen the Victorian Energy Upgrades program
- Targeted programs via retailer obligations at "the highest 5% of consumers use around 15% of total energy." (Alan Pears, Infrastructure & Roadmap submissions). Incentives and regulation may be necessary. A survey on uptake of solar panels found that the wealthy were less likely to have installed them than low and middle income groups.[32] Some wealthy households may also be cash poor, or perceive themselves as cash poor given other expenditure priorities. Policies can be developed that do not favour them over low-income households (see extended discussion by Alan Pears in his submissions).

- Important recommendations by Alan Pears should be addressed. Based on his experience with residential, commercial and industrial users of gas, Alan Pears finds that the current efficiencies are over-stated – they are incorporated into modelling as good when in fact they are poor. (Alan Pears, Infrastructure & Roadmap submissions).

9. What policies, regulations or other support, if any, do you think are needed to support industrial users to switch from natural gas to lower emissions energy sources or chemical feedstocks?

- Build capacity and capability within government, recruiting people with industry experience, to drive a major program. The proposal of the United Workers Union for an Oil & Gas Industry Transformation Authority in their Roadmap submission (p.8) deserves consideration.
- An early focus on the larger users of gas
- Targeted incentives to encourage firms to replace ageing gas-fired equipment
- Training programs for workers
- Tighter regulation/standards around equipment, as well as gas leaks and emissions

[30] See reports by Strategy. Policy. Research. & AECOM at https://www.vic.gov.au/sites/default/files/2020-02/Appendix_7_Electrification_Commercial.pdf and https://www.sustainability.vic.gov.au/research-data-and-insights/research/energy-efficiency-and-reducing-emissions/commercial-building-sector-research-and-reports

[31] https://www.mirvac.com/sustainability

[32] https://www.pv-magazine-australia.com/2019/02/25/low-middle-income-households-install-solar-more-than-wealthy/

- Strong education programs – but this cannot be relied upon without incentives, regulation and other policies
- Assistance for small businesses that have limited technical or management expertise
- Research into alternative feedstocks, including wood extractives. Victoria should position itself, and assist manufacturers in finding alternatives to replacing gas as a feedstock. For example, there is growing interest in alternatives to plastics, some based on wood derivatives. I understand that almost any plastic product can be made from wood derivatives, and that this was well-known before plastics became cheap and commonplace after 1945.[33]

Attachment A

Assumptions in the reports by Frontier Economics and Doris Engineering

This is an incomplete and partial list. More needs to be done to flesh it out.

ASSUMPTIONS ON DEMAND SIDE

Topic	Frontier Economics	Doris Engineering
Base case demand inputs	"Our Base Case demand inputs are based on the central scenario of AEMO's December 2019 update to its Integrated System Plan report" p.56 "AEMO's demand forecast takes into account the contribution by rooftop PV and non-utility battery to annual consumption and peak demand." P.56	
Energy demand projections	"The difference in outcomes in 2050 between the Base Case and the Zero-carbon Fuels scenario, on one hand, and the other two scenarios, is driven by very large differences in the total amount of electricity demand in 2050 and the timing of this electricity demand." FE S5.1.1	"15% growth in energy demand per decade" – in line with population change" - see their justification p.49. See also p.29 – based on AEMO
Gas demand that has to be replaced	"To estimate the amount of end-use natural gas consumption in the Base Case [and then across all scenarios] we need forecasts of natural gas consumption in Australia in 2050. Because the timing of energy supply affects the costs of energy supply, we need these forecasts to be **daily** forecasts of natural gas consumption. It is also important that the forecasts are split by end use, as this will affect how some of the gas is replaced." . p.10	
	"We use the historical data from	

[33] https://bloom-bioeconomy.eu/2019/11/22/can-wood-replace-plastics/
https://www.bbc.com/future/article/20190125-the-natural-products-that-could-replace-plastic
https://www.sciencedirect.com/topics/engineering/cellulose-nanofibers

	financial year 2016/17, because this is the historical period that we use in our electricity market modelling" p.10 AEMO forecasts and then beyond that by " average annual growth rate over the last five years of AEMO's forecast period " - only for residential, commercial and industrial customers. P.10 "The gas demand from gas-powered generation is accounted for when we undertake separate electricity market modelling. P.10	

ASSUMPTIONS ON SUPPLY SIDE

Topic	Frontier Economics	Doris Engineering
Supply	Assumes in 2050 "that gas will continue to be supplied to end customers (including residential, commercial and industrial customers) and that there will be carbon emissions associated with this end use of gas." Electricity is assumed to be net zero by 2050. P.9	
Base case supply inputs		Comparative cost estimates derived across the scenarios. P.49
Cost breakdown structure		"For the purposes of economic analysis each scenario factor is assessed using cost and quantity metrics developed as part of the study." A summary table is then given. DE pp.52-53 "The cost estimate for the purpose of the study shall be estimated using a combination of bulk rates (where available), and qualitatively scaled or factored costs for the current installed base of infrastructure in Victoria." P.51 "No advantage was taken of the availability of green electricity in the grid, or other potentially interconnected systems such as rooftop solar." P30 – Is this a general point, or part of a point relating to gas scenario?
Capital costs of infrastructure	For hydrogen, expressed in $/unit output (from IEA). For gas and electrification, they use levelised cost of energy (LCOE) sourced from AEMO	Infrastructure & upgrade costs accounted for. See Fig 10 on p.50. Presumably LCOE is used.
Gas production	"… based on the estimated changes in gas consumption" for each scenario	
Cost of gas	"We calculate changes in the costs of gas production by multiplying the	

	change in annual gas production by an estimate of the levelised cost of gas production" " levelised cost of gas production developed as an input into AEMO's 2019 Gas Statement of Opportunities (GSOO) " "we assume that marginal gas supply in 2050 will come from undeveloped 2P or 2C reserves, and not from existing supplies. We base the levelised cost of production on the average of AEMO's estimates of levelised costs for all undeveloped 2P or 2C reserves in eastern Australia." "This levelised cost is $6.62/GJ, which we assume is expressed in $2019. Note that this is the levelised cost of gas commodity only, it does not include costs of delivery through the gas transmission network."	
Gas prices	"… forecasts are sourced from AEMO's Integrated System Plan (ISP) modelling assumptions.	
Power stations (incl. wind and solar)	"… for new entrant power station are based on CSIRO's two-degree scenario in its Electricity Generation Technology Cost Projections report, which is the source of capital costs proposed in AEMO's ISP consultation report." p.58	
Electricity transmission costs	"…based on the current annual allowed revenues for each transmission network, divided by the annual peak demand for the network." FE s4.3 & table 6. Based on "data on annual allowed revenues and peak demand" from AER..	
Electricity distribution	As for transmission. "…substantially higher than [for transmission] … and so form the bulk of the network-related costs. Differences in costs by state reflect different levels of underlying gas consumption and appliance mixes in each region, and difference estimates in the cost of electricity networks (as discussed in Section 4.3). FE s5.1.2	
Electrifying industrial processes	Very high costs still in 2050 – greatly increasing overall costs of ending gas use – AP Technologies are presumed to be the	"… either retain their own source of natural gas on the transmission lines that exist, or that the cost of upgrading the networks to hydrogen will cover connections to their facilities. A behind the meter cost (supply of natural gas) is the most likely

	same. "AEMO also forecasts energy consumption that is "saved" due to improvements in energy efficiency measures. Our Base Case demand forecast reflects the neutral forecast for these components as part of operational demand forecasts." P.56	outcome for industrial gas users." – DE p.42 Scenario B "High industrial efficiency upgrades and decreased energy demand - Upgrades to electric or biogas heating. - Some ongoing industrial use of natural gas where displacement is particularly difficult" DE p.251 In scenario B, efficiency "ground source heat " for heating etc DE p.158
Upgrades to electricity infrastructure req'd	" sufficient renewable generation and storage to ensure electricity demand can be met during periods of solar and wind drought" FE s5.1.1	Scenarios A & B require 5 times the current level, C 3 times and D 2 times p.105. Info about the underlying costs isn't given

GENERAL ISSUES

Topic	**Frontier Economics**	**Doris Engineering**
Geographic scope	National and each state – major conclusions highlight national costs but this is greatly boosted by claimed high costs in Western Australia	Victoria
Period covered	As at 2050	Now till 2050
Comparability of the 4 scenarios	Their snapshot into the scenarios at 2050 is claimed to be a cost benefit analysis. At best, it is a preliminary to one. In the Executive Summary, it is claimed that "we determine the net present value of the difference in annual costs in 2050 between each of the scenarios" p.4	"When applied in the same way to each scenario, use of this (and other) simplifying assumptions and approaches will yield <u>equivalent levels of infrastructure outcomes</u>, albeit non-optimised, which can nevertheless be considered "useful comparative data", but not "useable absolute data"." P.9
Testing of assumptions for robustness	No	Several ways Scale of risk of blowout in cost, including costs of renewables p.47 "A critical implication of this simplified approach is to over-estimate the level of new energy infrastructure required to reach Net Zero."
Limitations acknowledged	Not in the Executive Summary; maybe in the body of the report.	"The structure of the study and the uncertain nature of the scenario factors means that a bottom-up cost estimate based on unit costs, quantities, rates, productivity, and durations cannot be generated." p.49