Exploring the race to hydrogen production viability

The role of hydrogen in Australia’s net zero future

NET ZERO
AUSTRALIA

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nous

About Net Zero Australia

The Net Zero Australia project (NZAu) is analysing net zero pathways that reflect the boundaries of the Australian debate, for both our domestic and export emissions

The study is:

- **Rigorous** and **granular**
- **Scenario-based** and **evidence-driven**
- **Technology-neutral** and **non-political**

Net Zero Australia is a partnership between the **University of Melbourne**, the **University of Queensland, Princeton University,** and management consultancy **Nous Group.**

NZAu uses the modelling method developed by Princeton University and Evolved Energy Research for its 2020 ***Net-Zero America study.***

NZAu is funded by gifts and grants, and engages broadly

SPONSORS

Generous financial support has enabled this study

Gift and grant agreements protect the project's independence

ADVISORY GROUP

Crucial input is being provided by diverse advisers

INDEPENDENT MEMBERS

SPONSOR NOMINEES

ENGAGEMENT

Numerous briefings have been provided to:

COMMONWEALTH MINISTERS AND DEPARTMENTS

STATE MINISTERS AND DEPARTMENTS

NON-GOVERNMENT ORGANISATIONS

RESEARCH BODIES

A website has also been established netzeroaustralia.net.au

NZAu has consulted widely with the project's sponsors, Advisory Group members and many stakeholders, but is independent of all of them. NZAu does not purport to represent their positions or imply that they have agreed to our methodologies or results.

We have modelled six Core Scenarios

REF

REFERENCE

- Projects historical trends, does not model cost impacts of fossil fuel supply constraints
- No new greenhouse gas emission constraints imposed domestically *or* on exports
- Policy settings frozen from 2020 onwards.

E+

RAPID ELECTRIFICATION

- Nearly full electrification of transport and buildings by 2050
- Renewable rollout rate almost unconstrained
- Lower cap on underground carbon storage rate.

E-

SLOWER ELECTRIFICATION

- Slower electrification of transport and buildings compared to E+
- Renewable rollout rate almost unconstrained
- Lower cap on underground carbon storage rate.

E+ RE+

FULL RENEWABLES ROLLOUT

- No fossil fuel use allowed by 2050
- Renewable rollout rate almost unconstrained
- Lower cap on underground carbon storage rate, which is only used for non-fossil fuel sources post 2050 (e.g. cement production).

E+ RE-

CONSTRAINED RENEWABLES ROLLOUT

- Renewable rollout rate limited to several times historical levels (to examine supply chain and social licence constraints)
- Much higher cap on underground carbon storage (to make net zero achievable).

E+ ONS

ONSHORING

- Domestic production of iron and aluminum using clean energy
- Progressively displaces exports of iron ore, bauxite, alumina and fossil fuels.

The Reference Scenario has *no emissions objective*. All other Scenarios are 'net zero' for both the domestic and exported emissions separately, and start from current emissions, and track in a line to net zero emissions by 2050 (domestic) and 2060 (export). None of the Scenarios are forecasts.

Key insights from Net Zero Australia modelling

WHAT IT WOULD TAKE TO REACH NET ZERO

1. Grow **renewables** as our main domestic and export energy source
2. Establish a large fleet of **batteries**, **pumped hydro** and **gas-fired firming**
3. Greatly increase **electrification** and **energy efficiency**
4. Develop a large **carbon capture, utilisation and storage** industry
5. Greatly expand our **energy transmission and distribution networks**
6. Attract and invest $7-9 trillion of **capital** to 2060
7. No role for **nuclear** unless costs fall sharply and renewables are constrained
8. Transition to **clean energy** and **clean minerals exports**
9. **Locate** these **new export industries** in the north; possibly also in the south
10. Expand a **skilled workforce** from about 100,000 today to 7-800,000 by 2060
11. Move the **land sector** towards net zero and potentially to net negative
12. Carefully manage major **land use changes**, including the Indigenous Estate, ecosystems and agriculture

WHAT AUSTRALIA MUST DO

Deliver an energy transformation
unprecedented in scale and pace

Transform our exports
an essential contribution to global decarbonisation

Invest in our people and land
to reduce impacts and share benefits

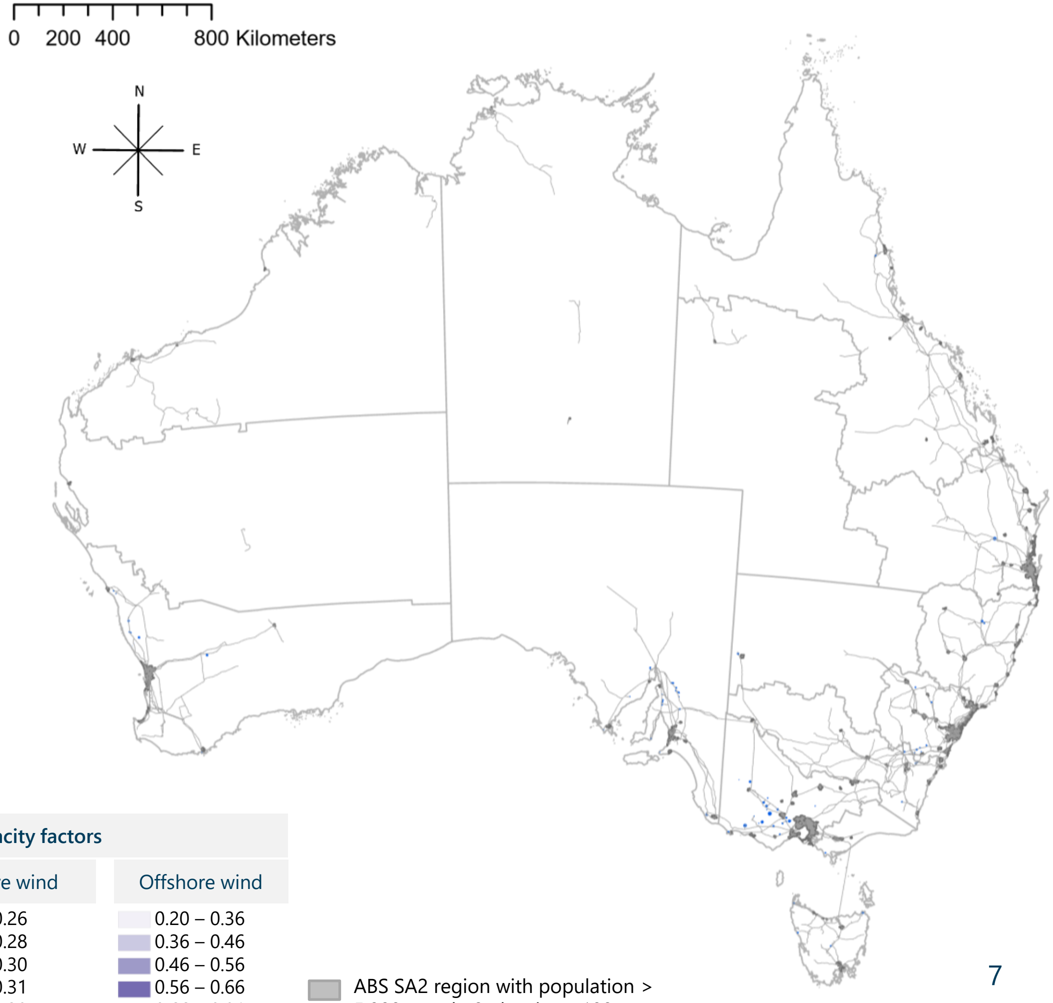
Today's presentation will focus on a sub-set of these key findings. See *netzeroaustralia.net.au* for the full results.

1 Grow renewables as our main domestic and export energy source

5 Greatly expand our energy networks

INDICATIVE ONLY

2020 (for context)



Transmission (MW)

- <1,000
- 6,600
- 13,000
- 20,000

VRE project capacity factors

Solar PV	Onshore wind	Offshore wind
0.14 – 0.20	0.21 – 0.26	0.20 – 0.36
0.20 – 0.21	0.26 – 0.28	0.36 – 0.46
0.21 – 0.22	0.28 – 0.30	0.46 – 0.56
0.22 – 0.23	0.30 – 0.31	0.56 – 0.66
0.23 – 0.29	0.31 – 0.38	0.66 – 0.81

ABS SA2 region with population > 5,000 people & density > 100 people/km^2

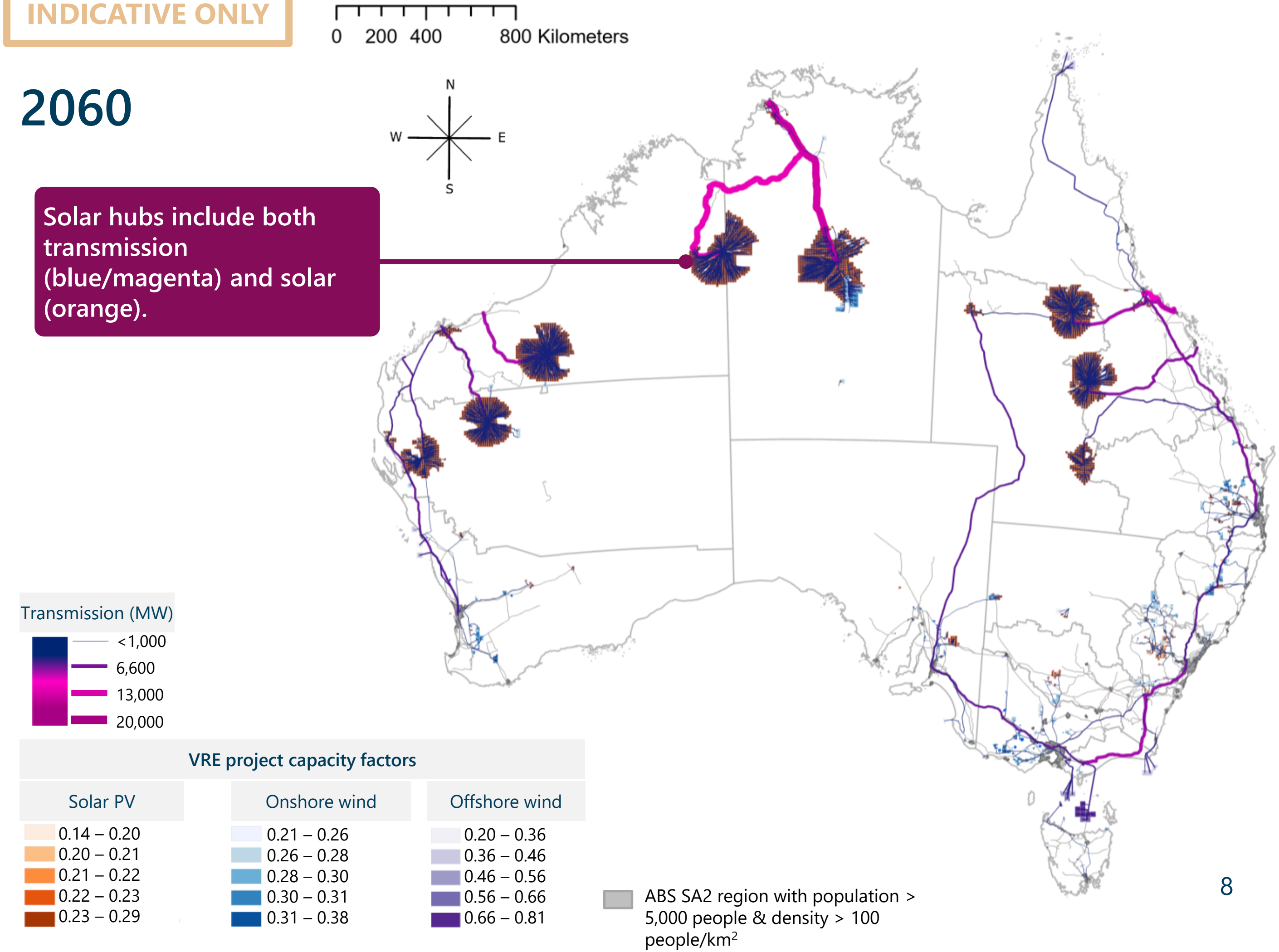
1 Grow renewables as our main domestic and export energy source

5 Greatly expand our energy networks

E+ 2060

INDICATIVE ONLY

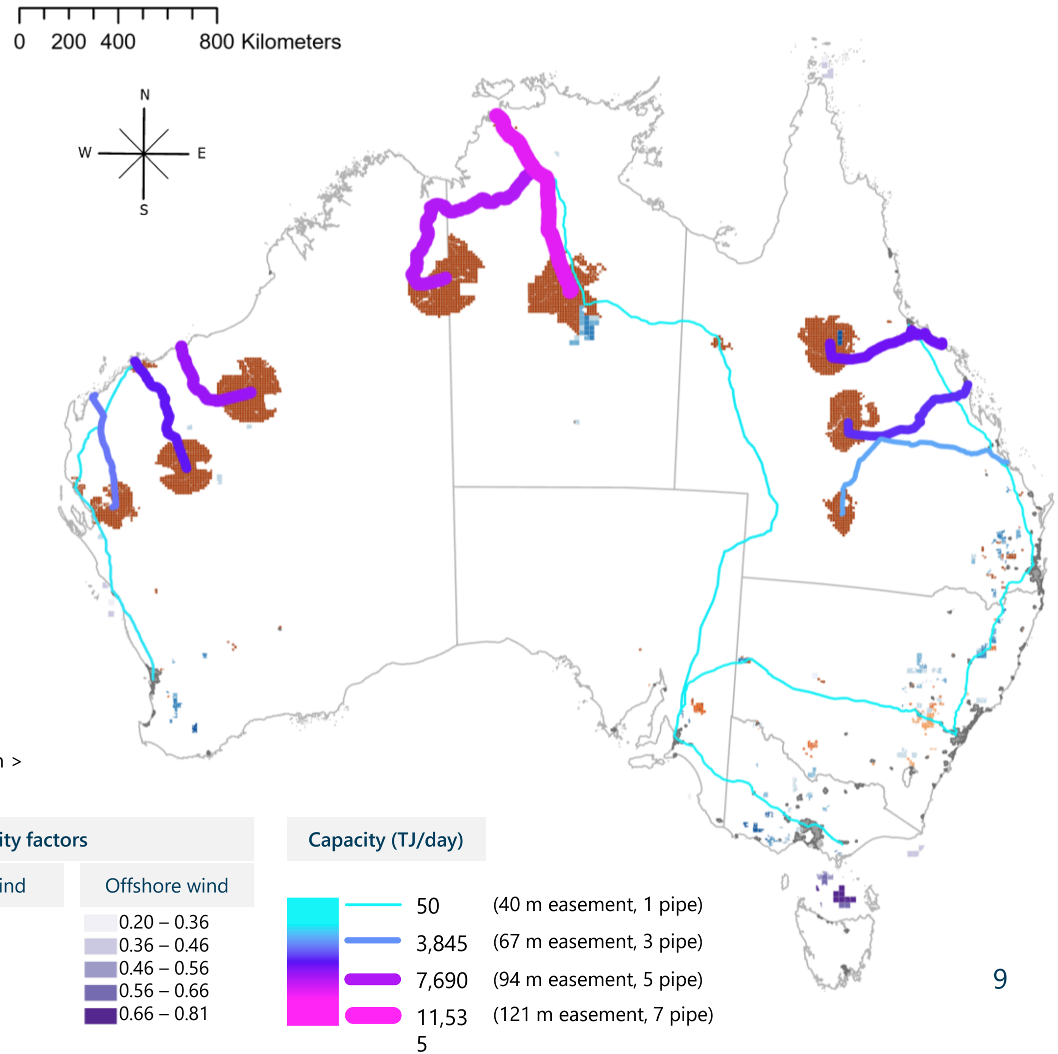
2060



5 Greatly expand our energy and ancillary networks: including pipelines carrying hydrogen

INDICATIVE ONLY

2060



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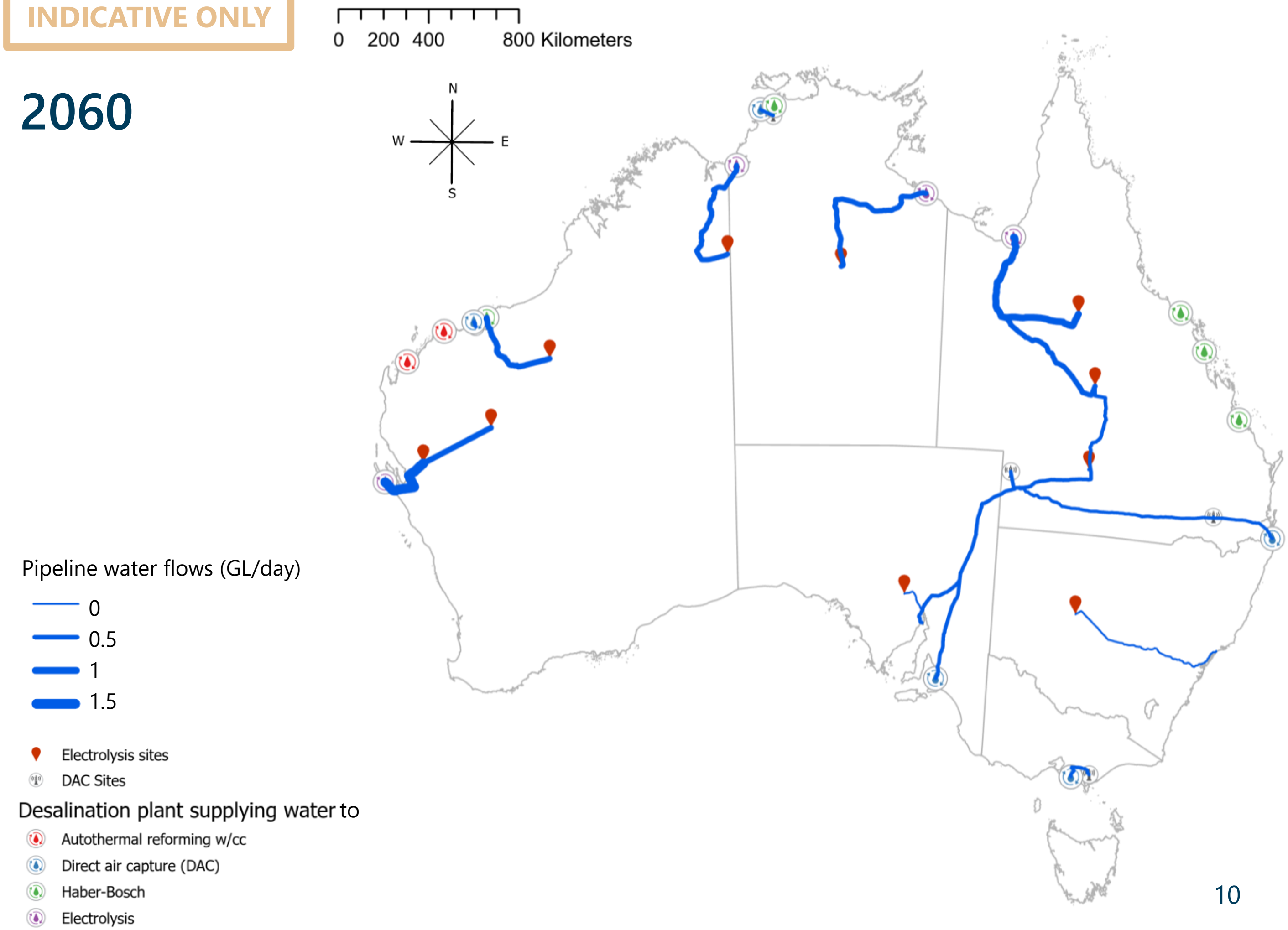
E+ 2060

5 Greatly expand our energy and ancillary networks: including pipelines carrying desalinated water

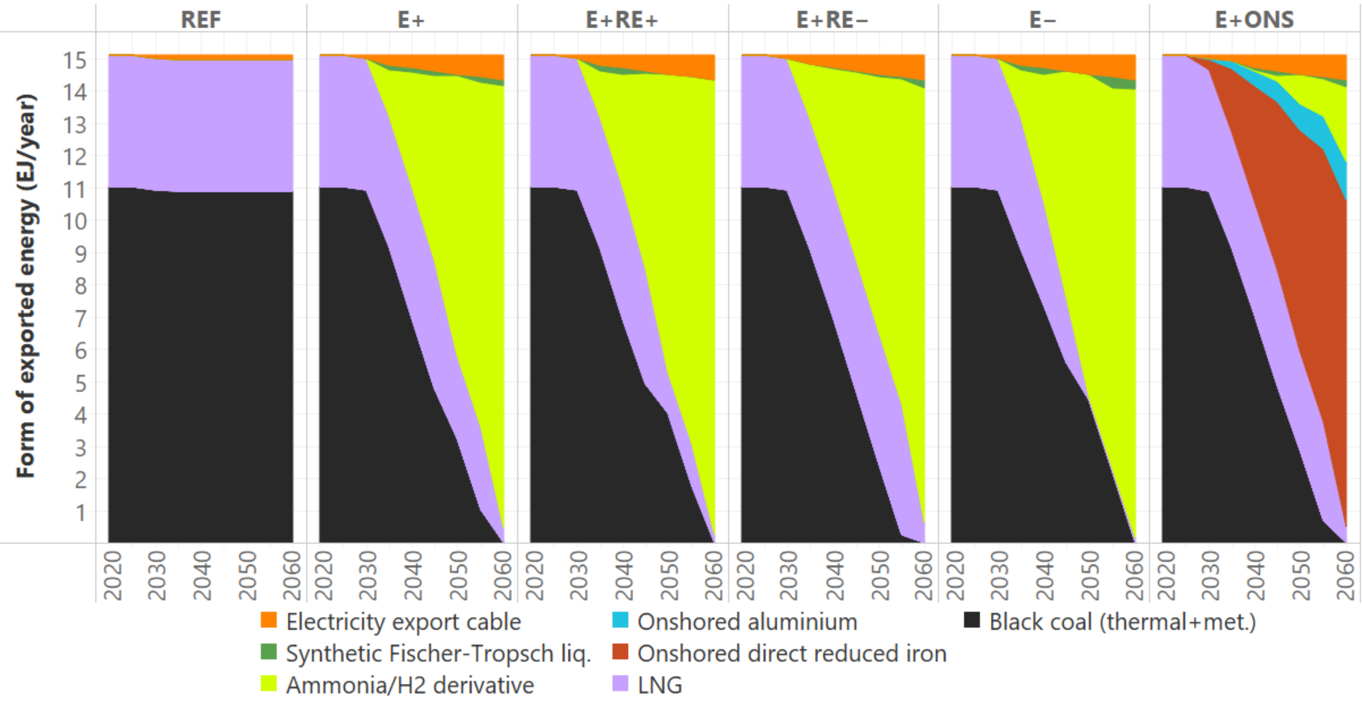
INDICATIVE ONLY

2060



Fossil energy exports are replaced by low-emissions energy carriers

Projected form of exported energy (EJ/year)



KEY TAKEAWAYS

- Ammonia/Hydrogen derivative dominates energy exports except in E+ONS, where onshored processing of Australian iron and alumina ores (E+ONS) displaces the majority of current energy exports.
- Coal and LNG exports drop rapidly from 2030.
- Undersea electricity cable link to Singapore is a modest share of export energy. (NZAu modelling was conducted prior to recent developments in AUS>SGN energy projects)

Modelling note

- **Energy export demand is held constant at 15 EJ/year** – about 3× 2050 domestic demand.

PILLAR 3: **Zero-carbon fuels and feedstocks (including bioenergy)**

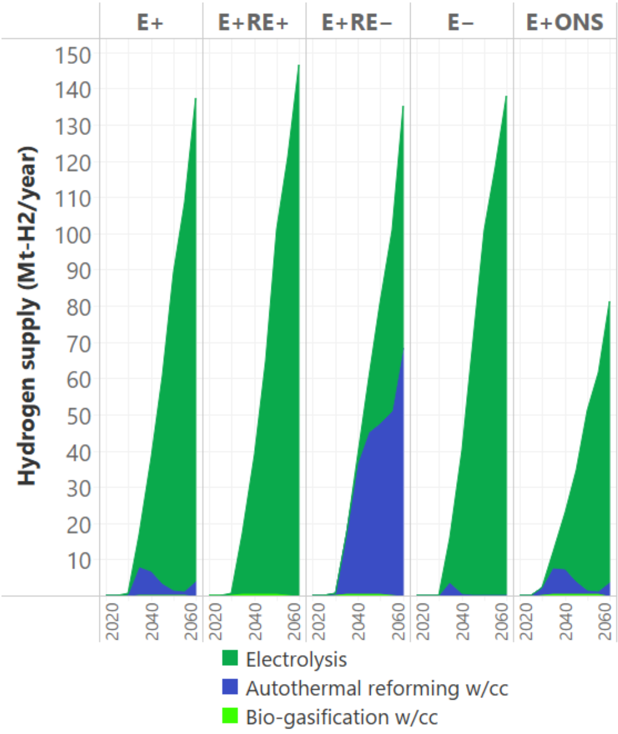
KEY FINDINGS

Clean fuel production will use 25-50% of domestic electricity – but 90% of all electricity, given export demand

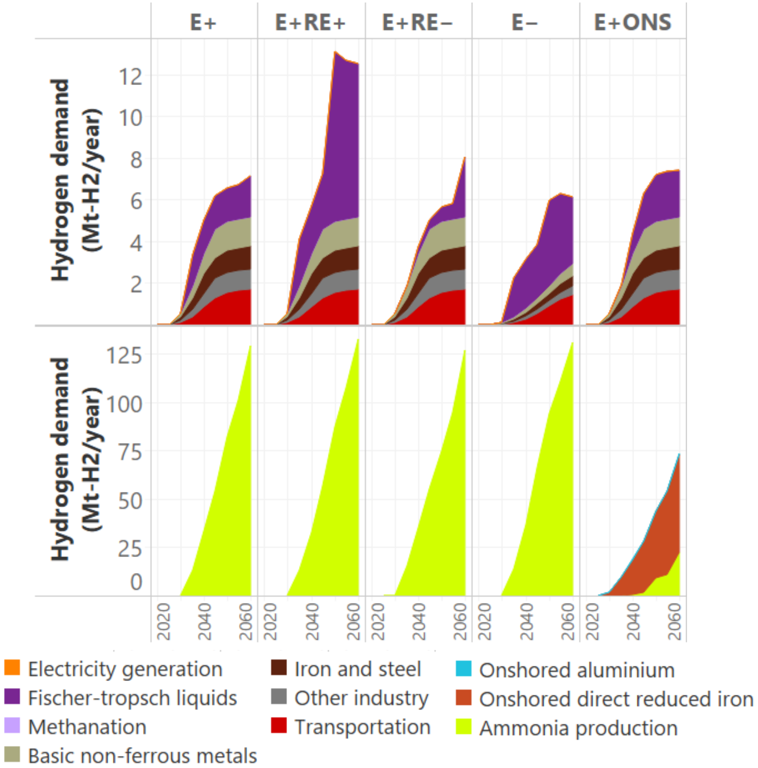
- Most Australian hydrogen will be produced through electrolysis and exported (as clean energy or clean minerals)
- Major underground hydrogen storage capacity is needed for the domestic system, and multiples more for exports
- Significant build of hydrogen transmission infrastructure is largely associated with export projects
- Most Scenarios significantly reduce production and use of pipeline methane gas by 2060, except for E+RE−, where production expands for H_2 production with CCS
- Bioenergy potential is limited by sustainable supply of biomass, but still expands by 8.5× to ~1,100 PJ/year
- Bioenergy facilities are rapidly installed from 2030, and are regionally distributed based on location of distributed biomass resources
- Aviation remains fully dependent on fossil fuels, except in E+RE+, which prohibits fossil fuel use

Most Australian hydrogen will be produced through electrolysis and exported (as clean energy or clean minerals)

Projected hydrogen supply, by technology (Mt-H_2/year)



Projected hydrogen use, by sector/technology (Mt-H_2/year). Note 10× difference in y-axis scale

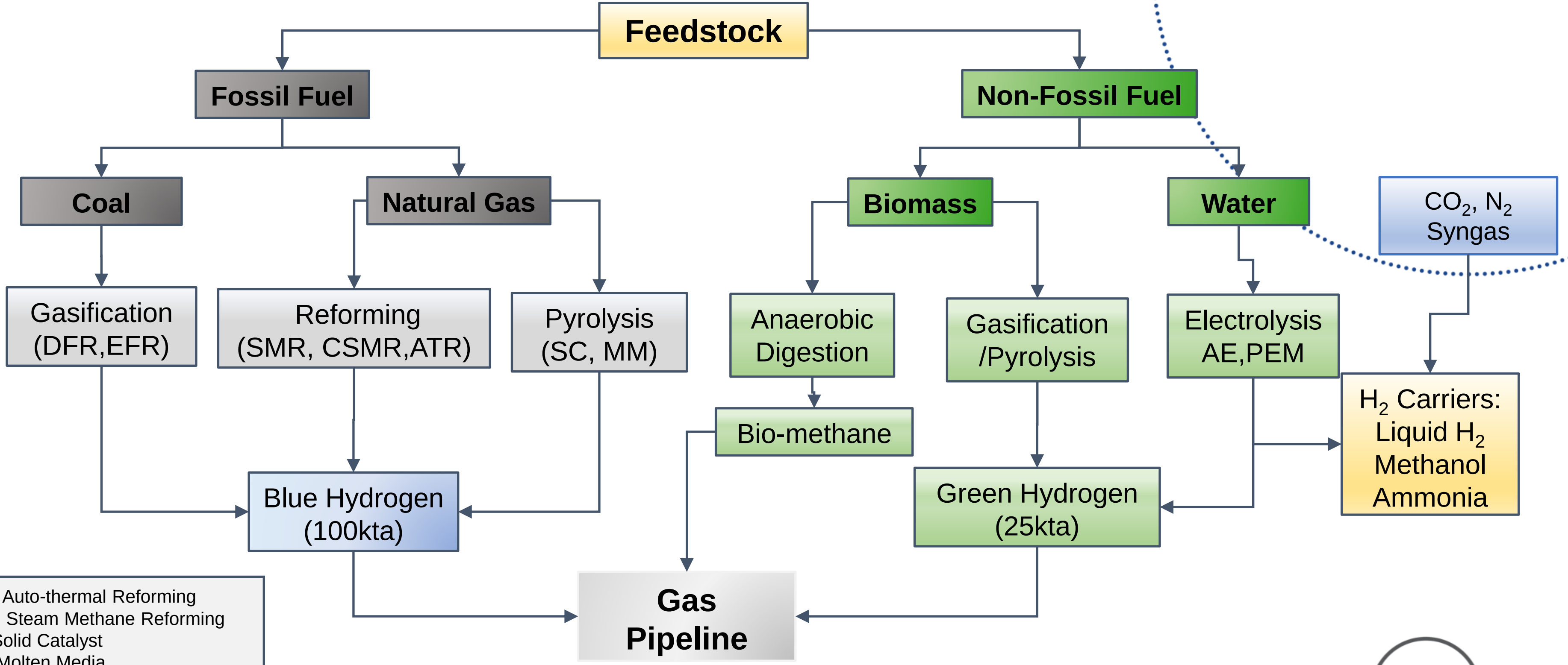


KEY TAKEAWAYS

- Haber-Bosch ammonia production is assumed for exports. Other hydrogen forms/derivatives (LH_2, methanol, etc.) may be more prospective.
- Around 140 Mt/year of hydrogen produced to substitute current fossil energy exports with clean carriers, except for ONS where only 80 Mt/year is produced
- Electrolysis dominates hydrogen production capacity in most scenarios.
- Blue hydrogen supplies a small early share in E+ and E−, none in E+RE+, and substantial share in E+RE−, due to increase in maximum CCUS capacity and renewable rollout constraints.
- Domestic role for hydrogen is small, relative to that produced for export.

Hydrogen Production Technologies

Future Fuels production technologies



ATR: Auto-thermal Reforming
SMR: Steam Methane Reforming
SC: Solid Catalyst
MM: Molten Media,
DFR: Dual Fluidized bed Reactor
EFR: Entrained Flow Reactor
AE: Alkaline Electrolyser
PEM: Proton Exchange Membrane

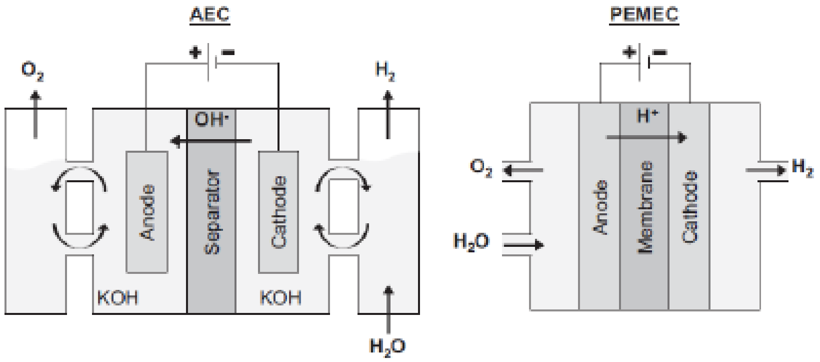
Green Hydrogen

Electrolysis

Electrolysis

- Alkaline Electrolysers (AE)
  - Commercially mature
  - Do not respond well to power fluctuations
  - Efficiencies of ~54-58 kWh/kg-H_2

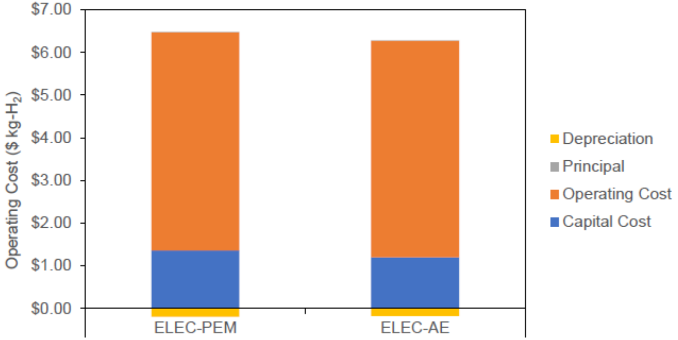
- Proton Exchange Membrane (PEM) Electrolysers
  - Rapidly becoming commercially viable
  - Wide operating range and ramping ability
  - Stack efficiencies of ~59-62 kWh/kg-H_2



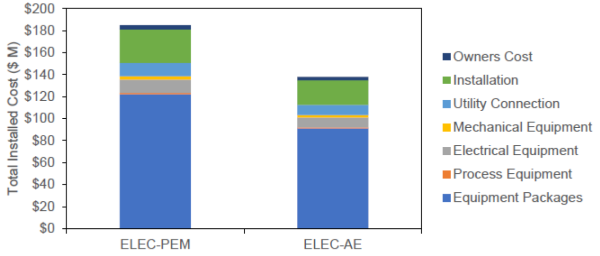
Electrolysis

Financial Analysis

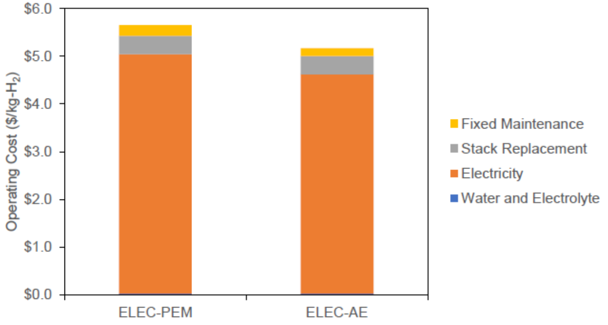
Levelised Cost ($/kg-$H_2$)



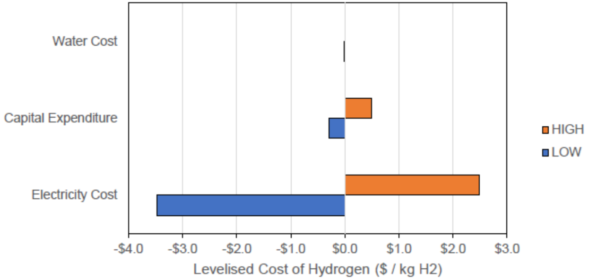
Capital Expenditure



Operational Expenditure



Sensitivity Analysis



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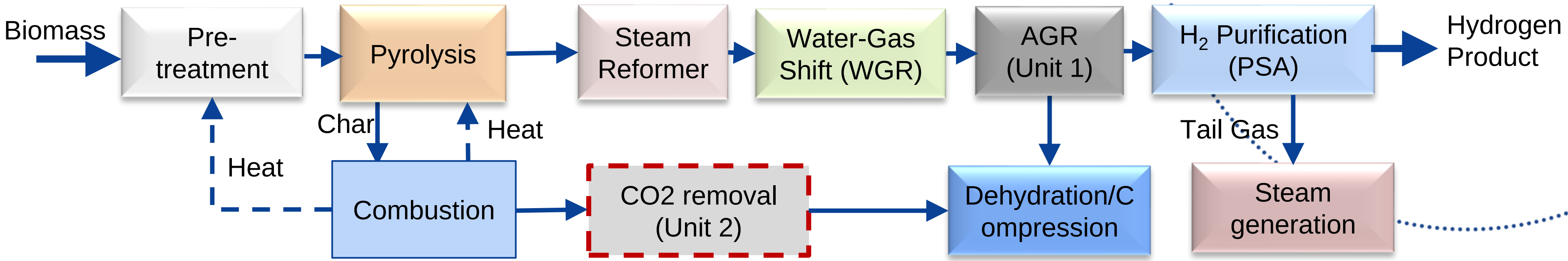
Green Hydrogen

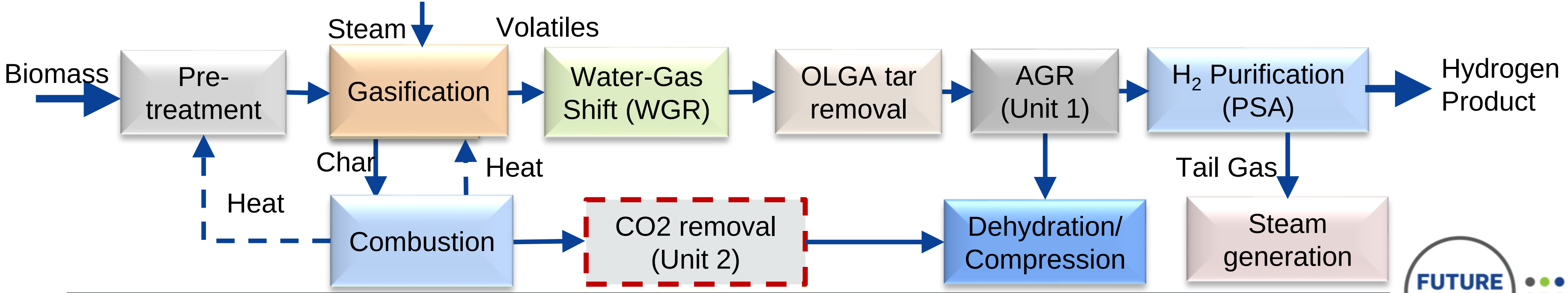
Biomass

Green hydrogen from biomass (Pyrolysis)

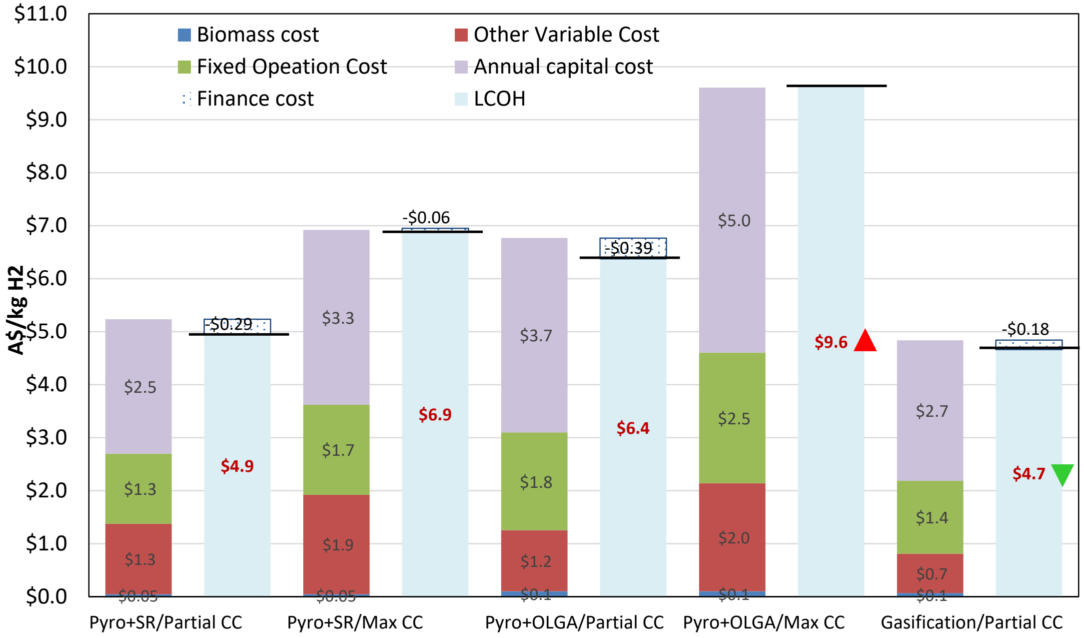
Biomass pyrolysis with Steam reforming

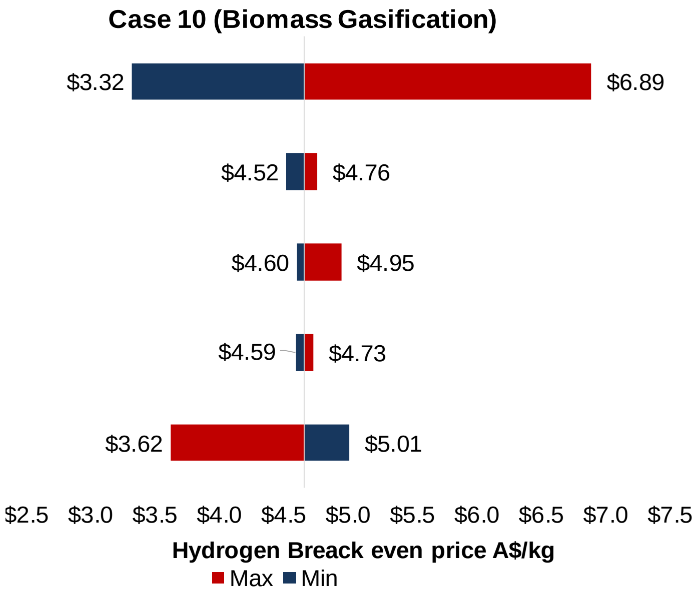


Biomass pyrolysis/Gasification with OLGA tar treatment



Green hydrogen from biomass





- LCOH is mostly sensitive to Capital cost and carbon credit
- The LCOH could further drops if the carbon credit increases from $25/t (base case) to $100/t of captured CO_2.

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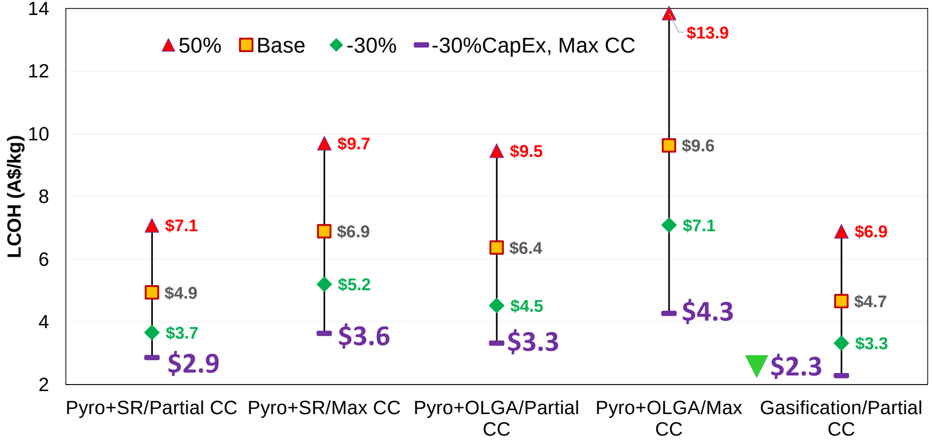
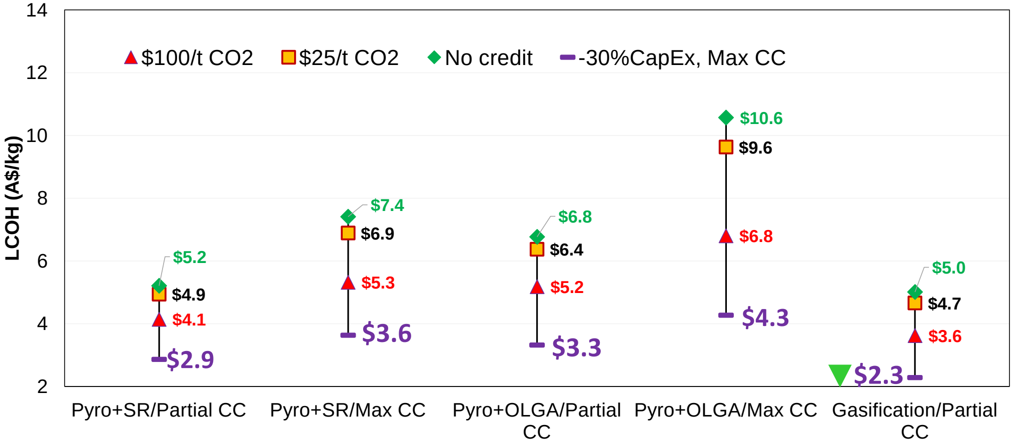
Sensitivity Analyses

- The LCOH shows highest sensitivity to the CAPEX variation
- The lowest LCOH ($3.3) is achievable upon 30% reduction of CapEx for biomass gasification

Effect of CAPEX on Biomass pyrolysis/gasification



Effect of Carbon Credit on Biomass pyrolysis/gasification



- Carbon credit, also has a significant impact on the LCOH
- With the simultaneous reduction of CapEx by 30% and carbon credit to $100/t of CO2, LCOH would drop to $2.2 for biomass gasification

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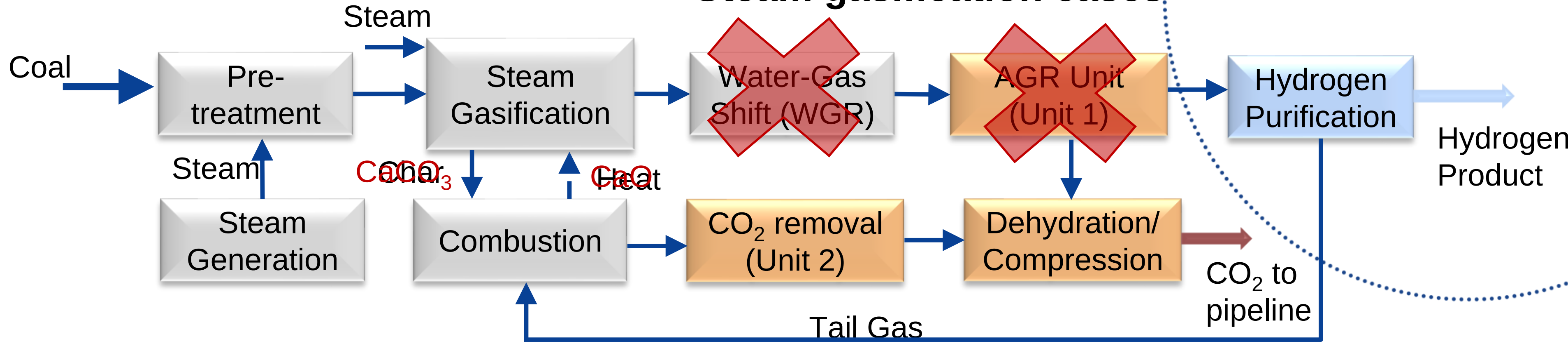
Blue Hydrogen

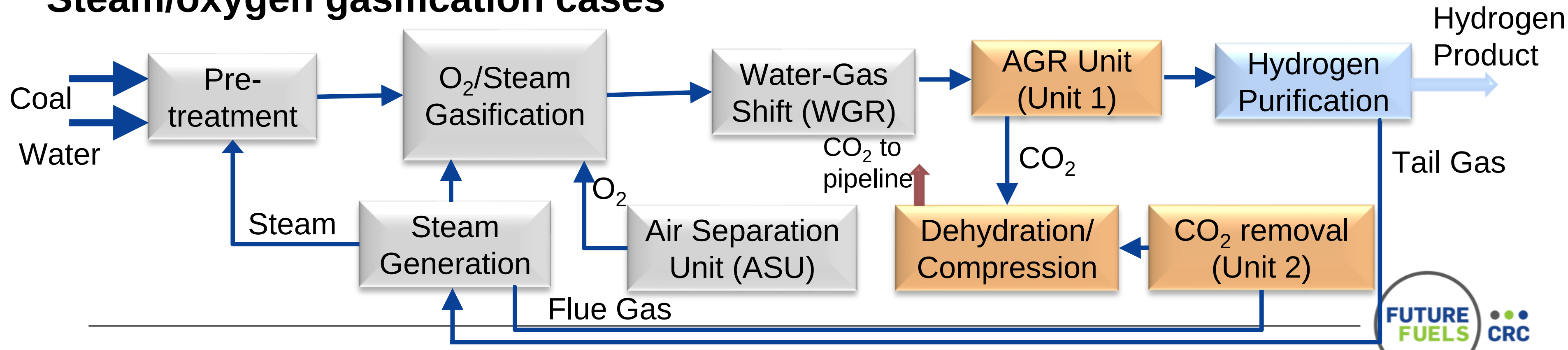
Coal

Blue Hydrogen from Coal

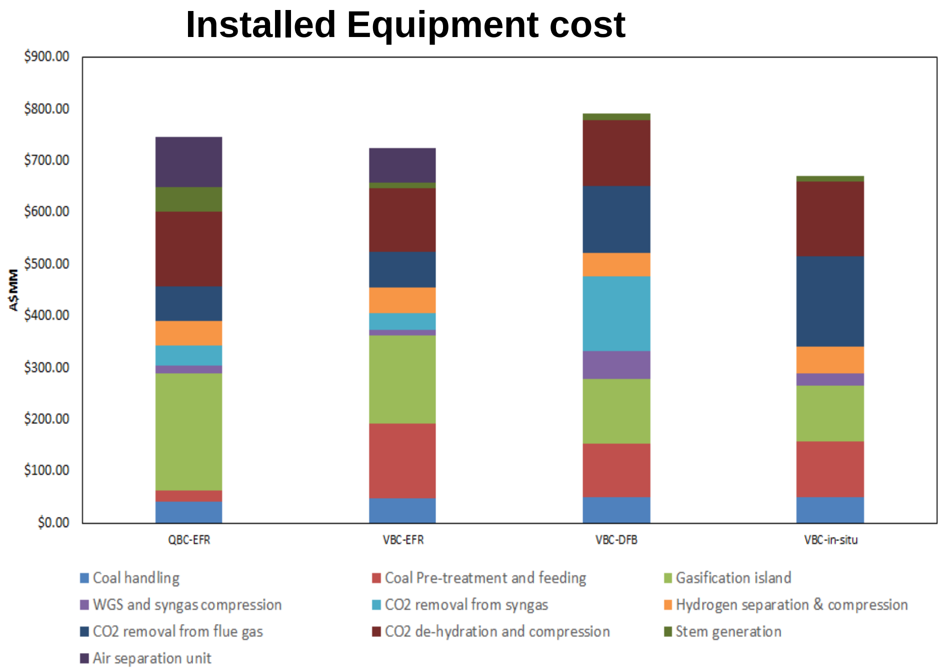
Steam gasification cases

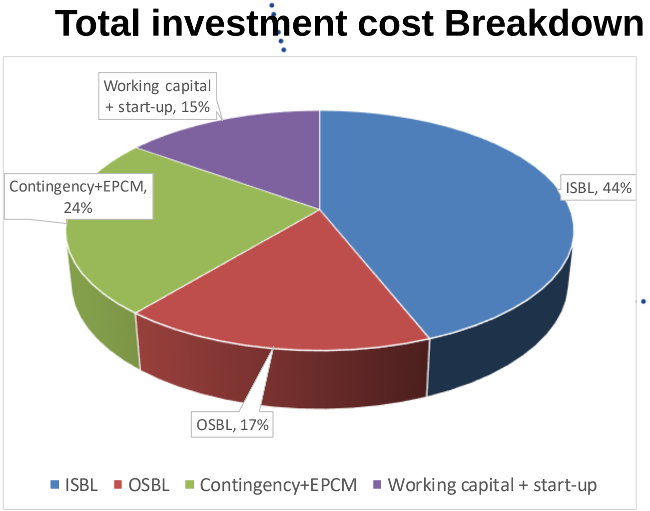


Steam/oxygen gasification cases



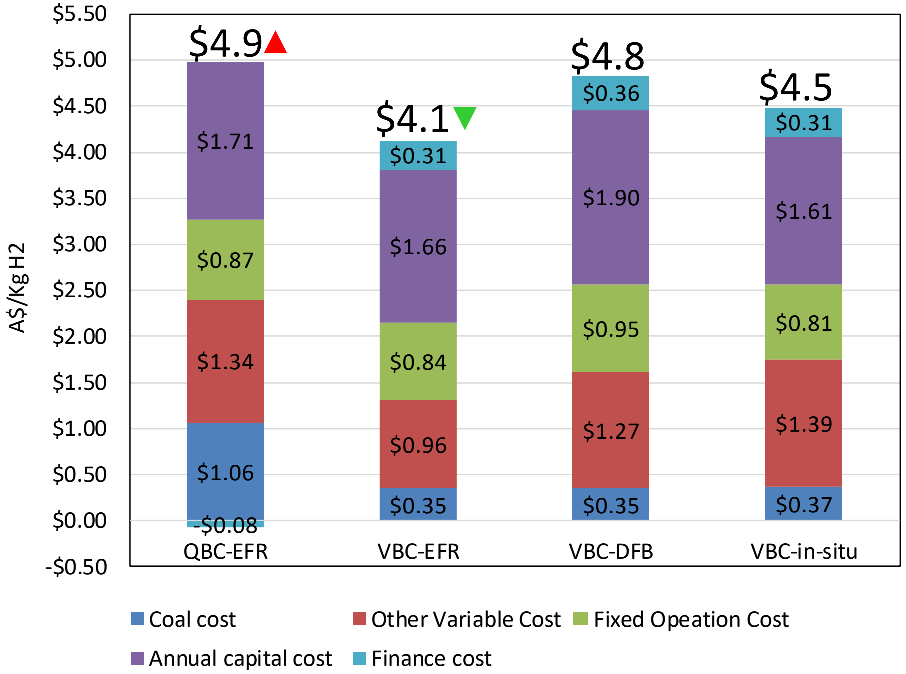
Installed equipment cost and total investment costs



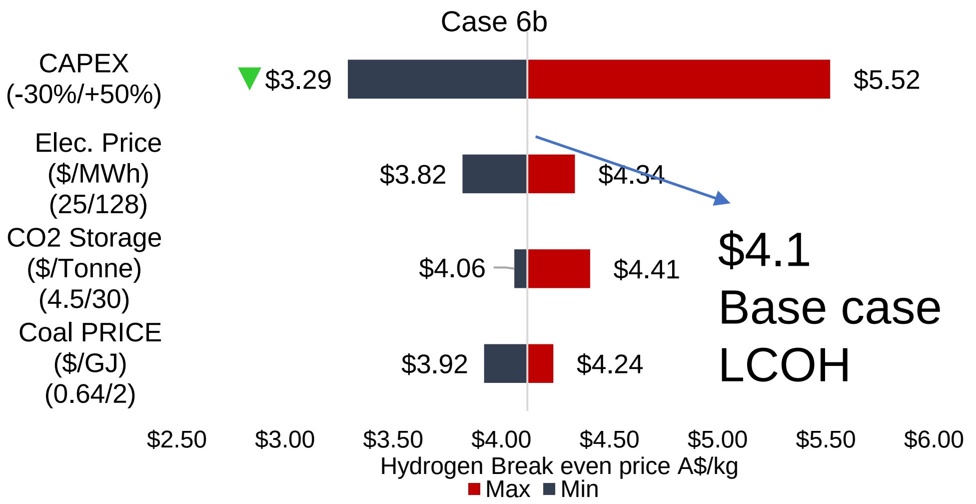


- CO_2 Capture, dehydration and storage makes around half of the installed equipment cost
- The coal gasification in the DFB shows the highest installed equipment and total investment cost
- The Coal gasification with calcium looping process shows lower cost due to needing less units

Levelized Cost of Hydrogen (LCOH)



Sensitivity Analysis for best case



This technology has a highest sensitivity to the capital cost

- QBC gasification using EFR and steam/oxygen gasification shows a highest LCOH ($4.9)
- VBC gasification using EFR and steam/oxygen gasification shows a lowest LCOH ($4.1)

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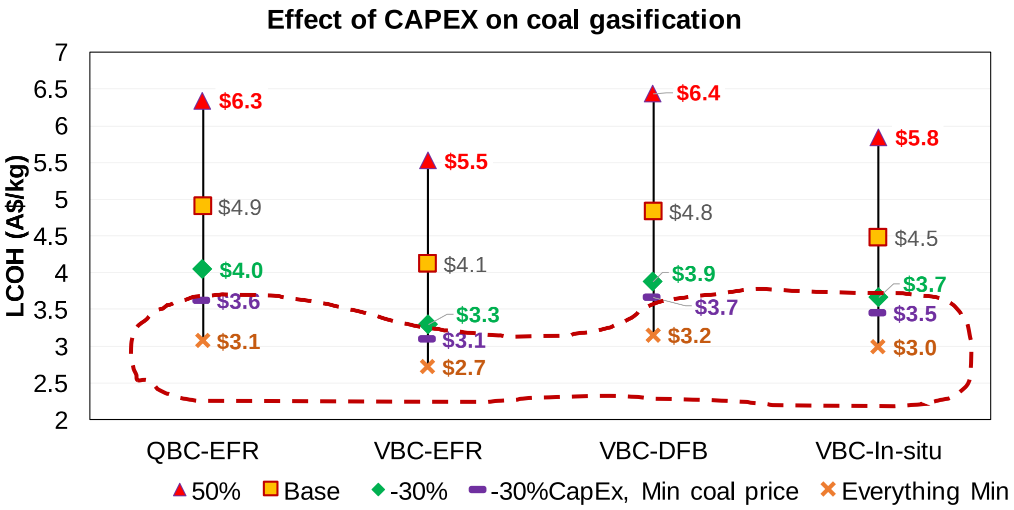
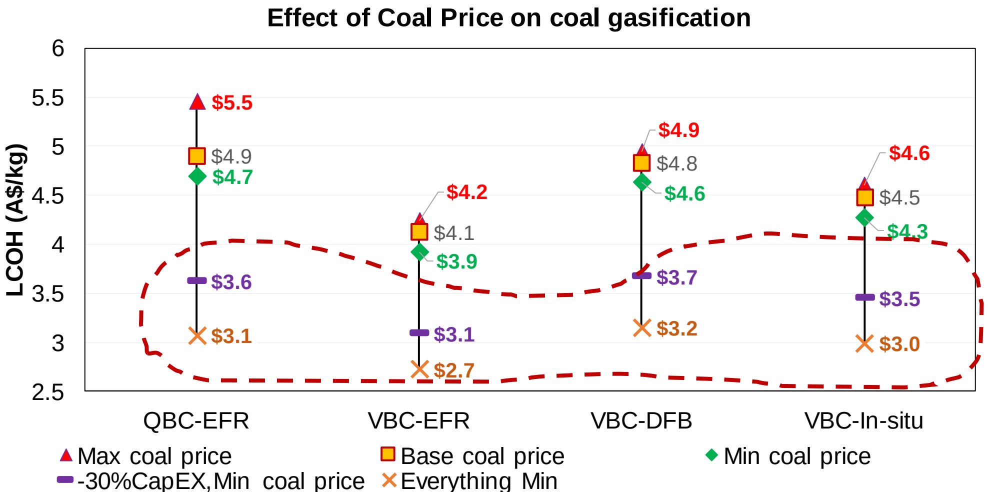
Sensitivity Analyses

- The LCOH shows highest sensitivity to the CAPEX variation
- The lowest LCOH ($3.3) is achievable upon 30% reduction for the VBC in an entrained flow gasifier



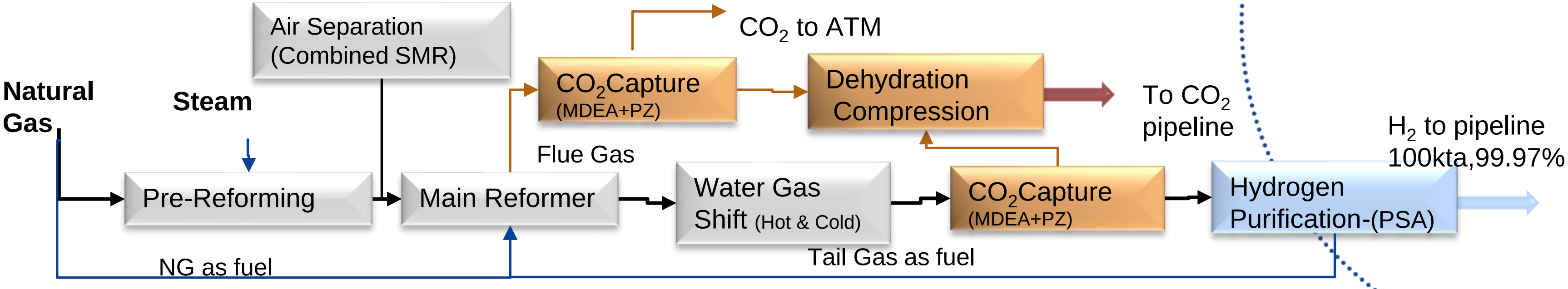


The coal cost variation has a noticeable impact on LCOH for QBC case
The impact of coal cost variation for the VBC is not very significant

Blue Hydrogen

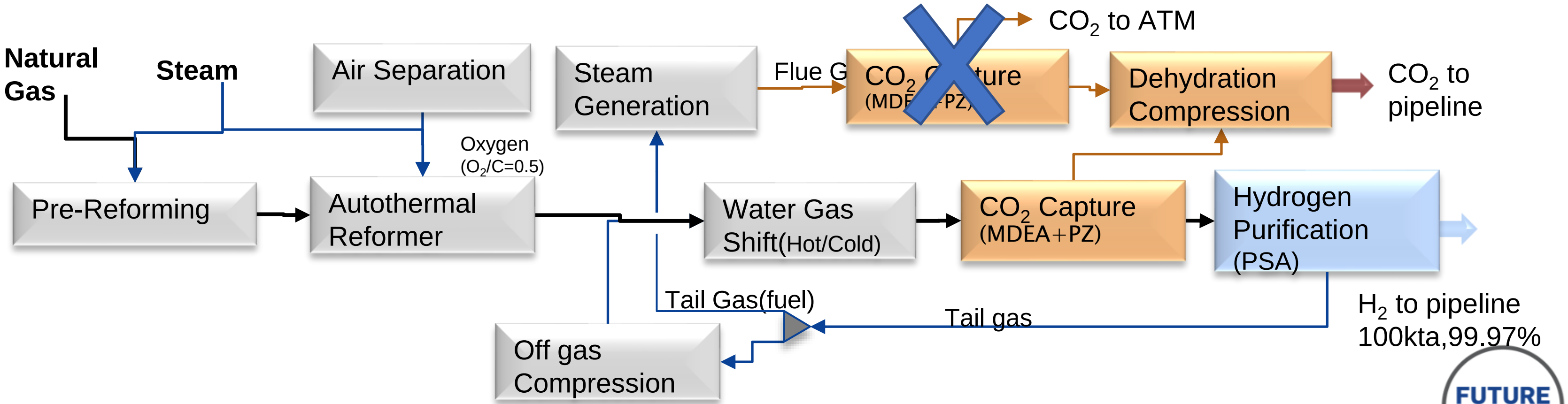
Methane

Steam Methane Reforming(SMR) & Combined SMR Reforming

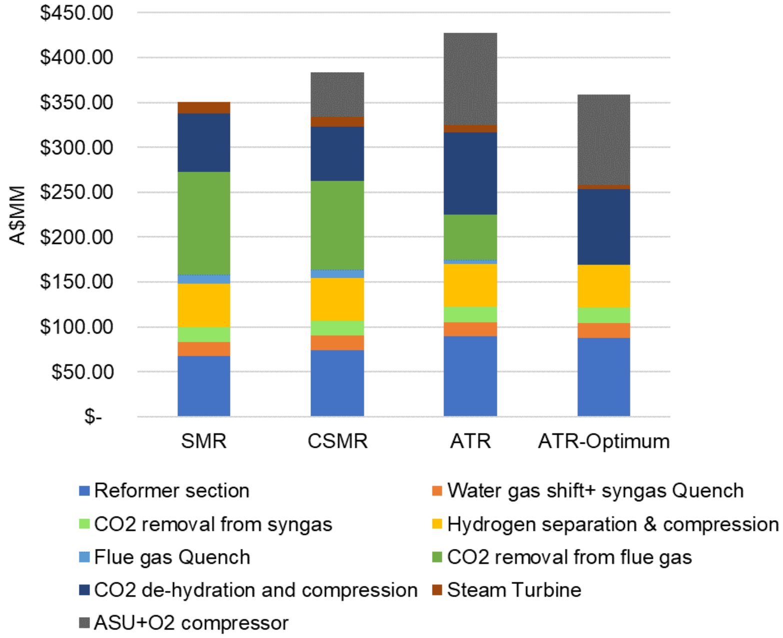


Auto-Thermal Reformer (ATR)

ATR-Optimum Energy Efficency (ATR-OP)-CO_2 Capture from Reformer ONLY

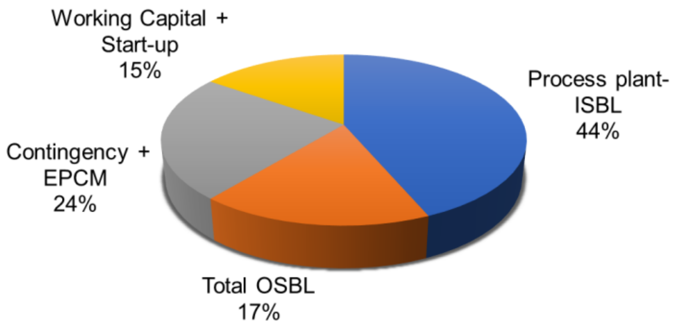


Inside Battery Limit Cost Breakdown*



*)No Contingency and EPCM are included

Total Investment Cost Breakdown for SMR plant



- CapEx significantly increases with high CO_2 capture rate
- ATR technology has the lowest CO_2 capture cost
- ATR at optimum energy efficiency competes with SMR at this scale
- Cost reductions in the air separation unit improve CapEx significantly – by ~25% in ATR processes

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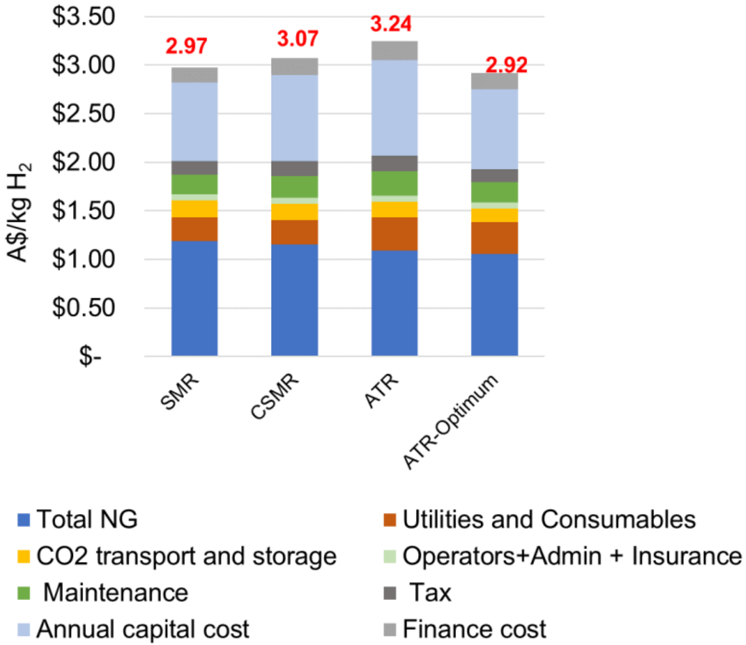
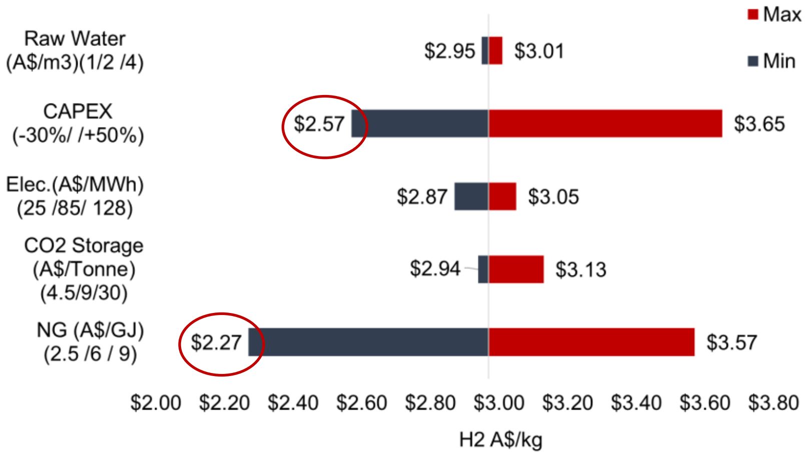
Levelized Cost of Hydrogen(LCOH)



Sensitivity Analysis for the best case SMR



Natural gas has the highest contribution to OpEx, and has the largest impact on SMR process due to the higher feedstock requirement

- $2 H_2/kg is probably achievable at lower natural gas price
- CapEx is the second largest influence on the process economics

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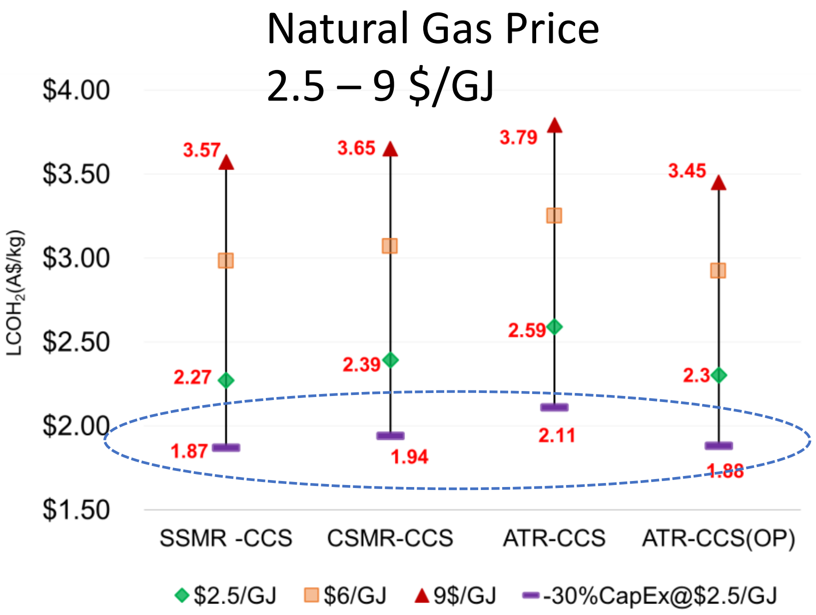
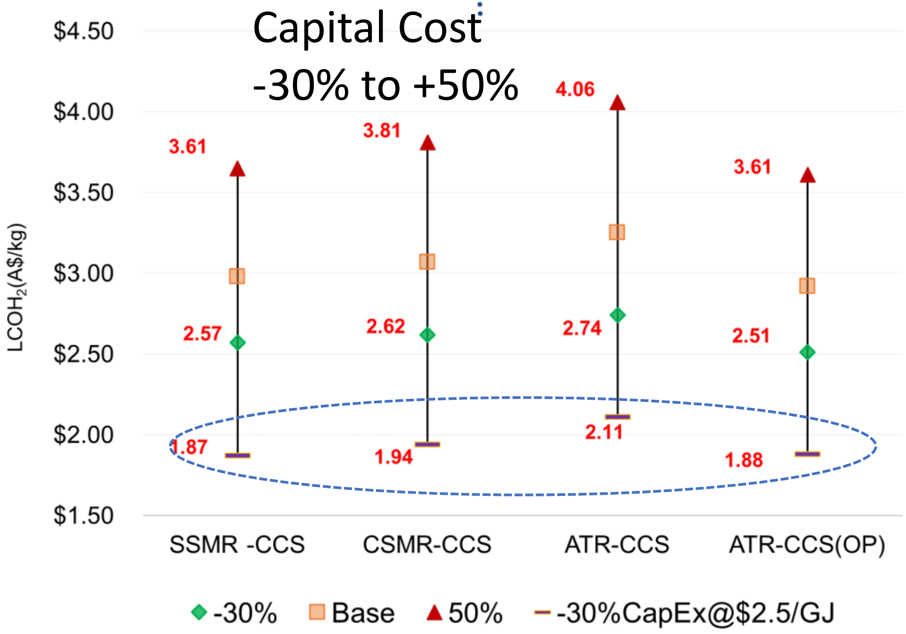
Sensitivity analysis results





To achieve the $2/kg H_2 target both low natural gas prices and substantial CapEx reductions are required

At larger scales we know from experience that ATR(OP) will become more competitive than SMR+CCS

Turquoise Hydrogen

Methane

Emerging technology - Pyrolysis of Methane

Thermal dehydrogenation of methane produces hydrogen and carbon

$$CH_4 \rightleftarrows C + 2\,H_2$$

CO_2 free hydrogen production from CH_4

- Carbon is a by-product but can also be a problem:
  - Deactivates catalytic surfaces
  - Restricts gas flow through reactors
  - Is removed by combustion, producing CO_2

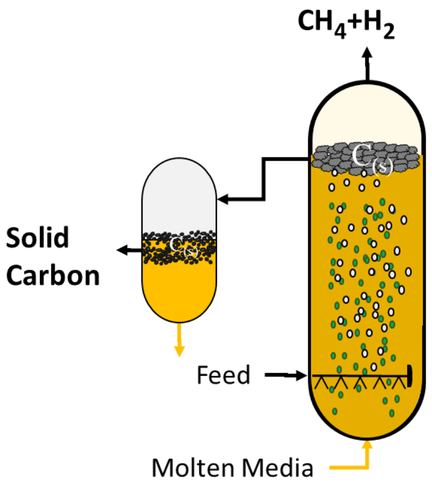
Emerging technology - Pyrolysis of Methane

- Two pyrolysis technologies-with proven concept
  - **Solid Catalyst-** Pilot plant TRL 5
    - Carbon is removed through reaction with catalyst
  - **Molten Media-** Pilot plant under investigation TRL 4
    - Molten Media facilitate to remove the by-product carbon

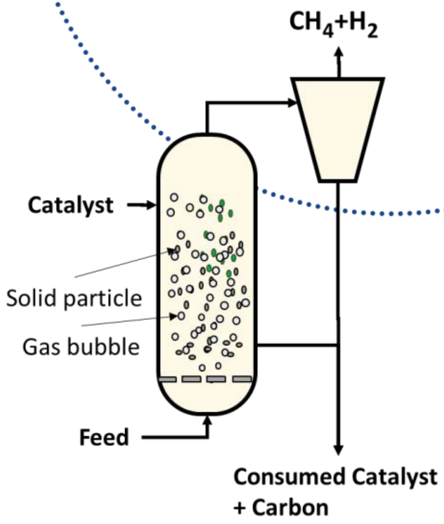
- Plant capacity -100kta H_2

- Feedstock characteristic
  - Australian Pipeline Standard for Natural Gas
  - Coal Seam Gas - 98.68% methane

Selected technologies remove carbon continuously



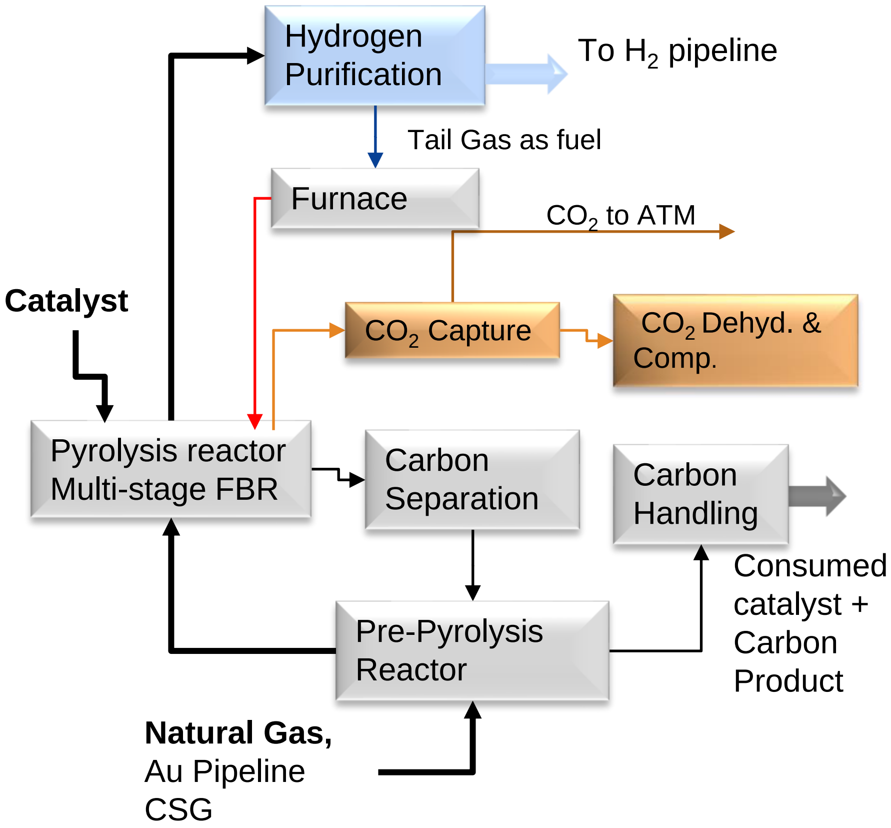
Molten Media
4 cases



Solid Catalyst
3 cases

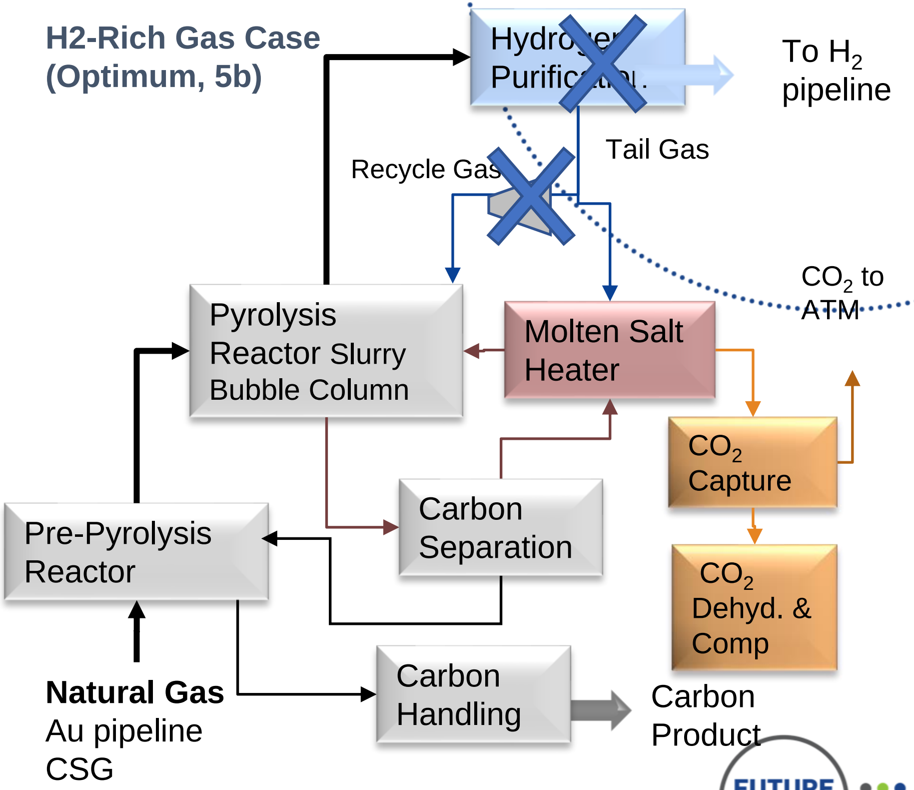
Natural Gas Pyrolysis- Solid Catalyst

Indirect Heating



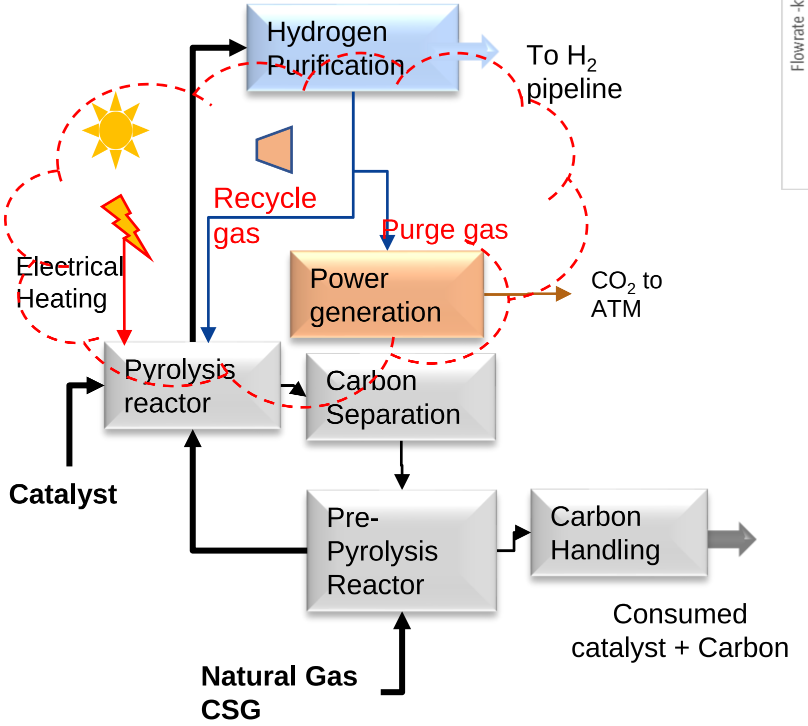
Natural Gas Pyrolysis- Molten Media

Direct Heating via Molten Media

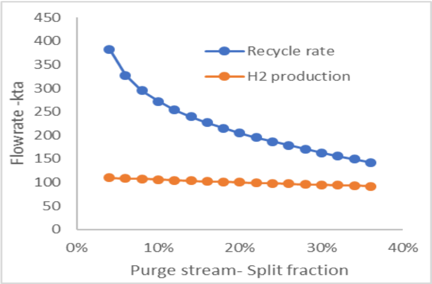


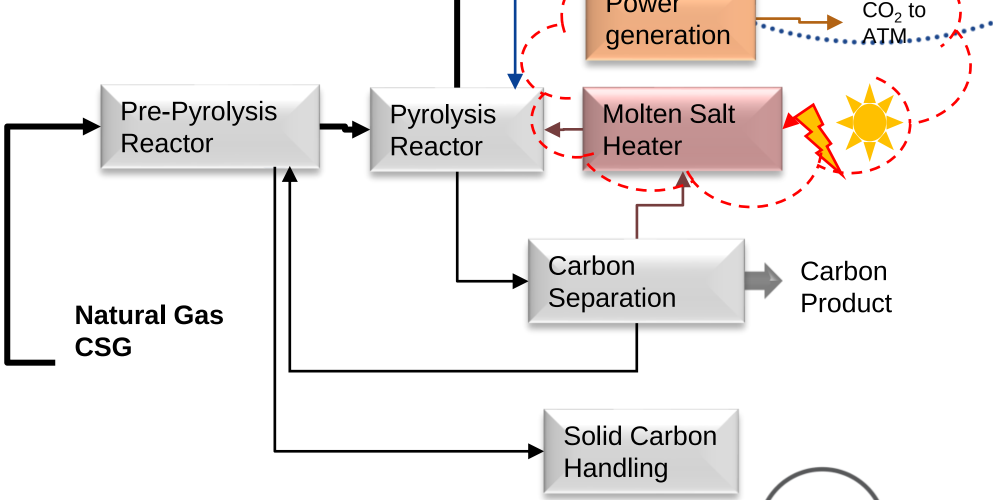
Natural Gas Pyrolysis

Integrated with renewable energy



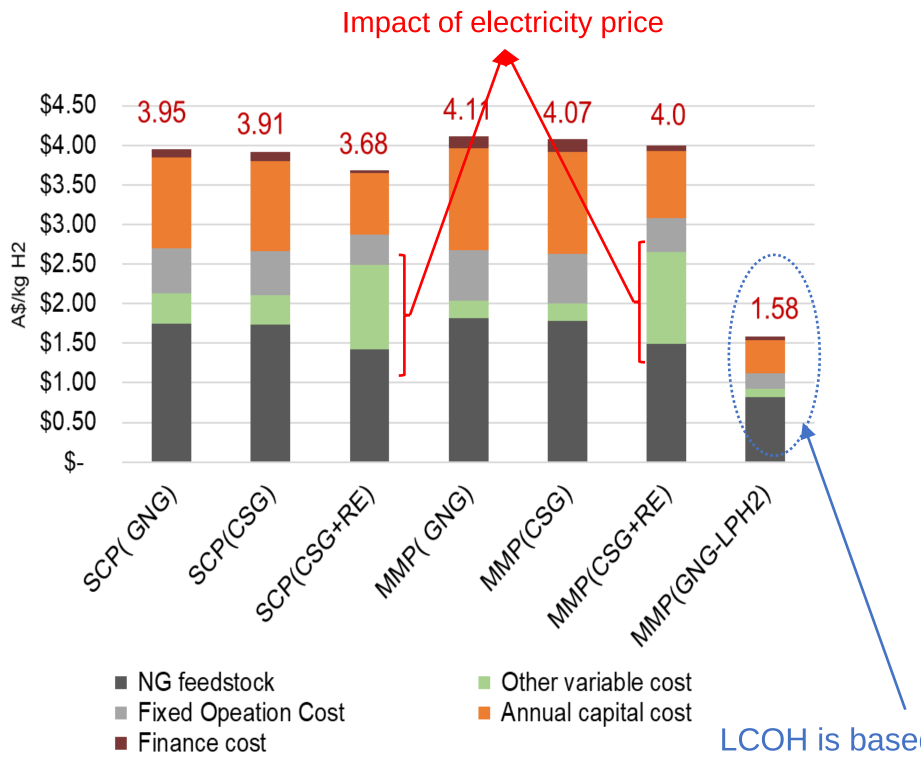
Impact of purge stream on recycle rate





FUTURE FUELS CRC

Levelized Cost of Hydrogen (LCOH)

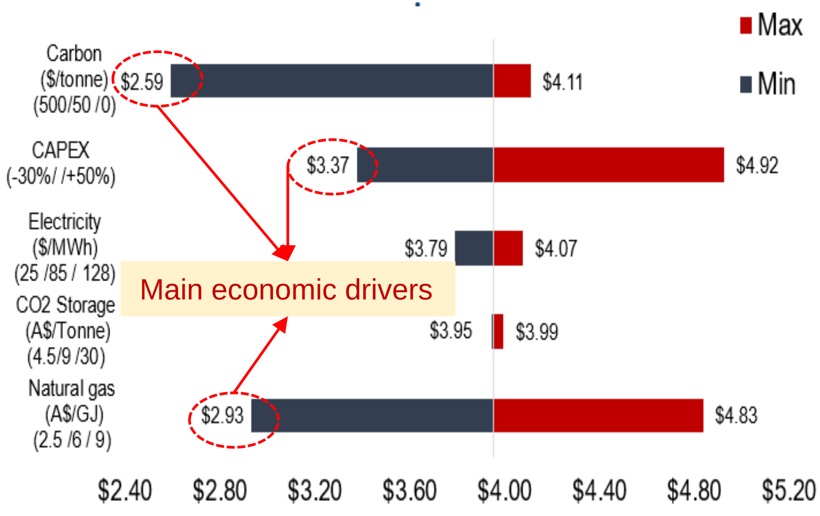


LCOH is based on mixed CH_4+H_2

79 mol% of H_2

Sensitivity Analysis result

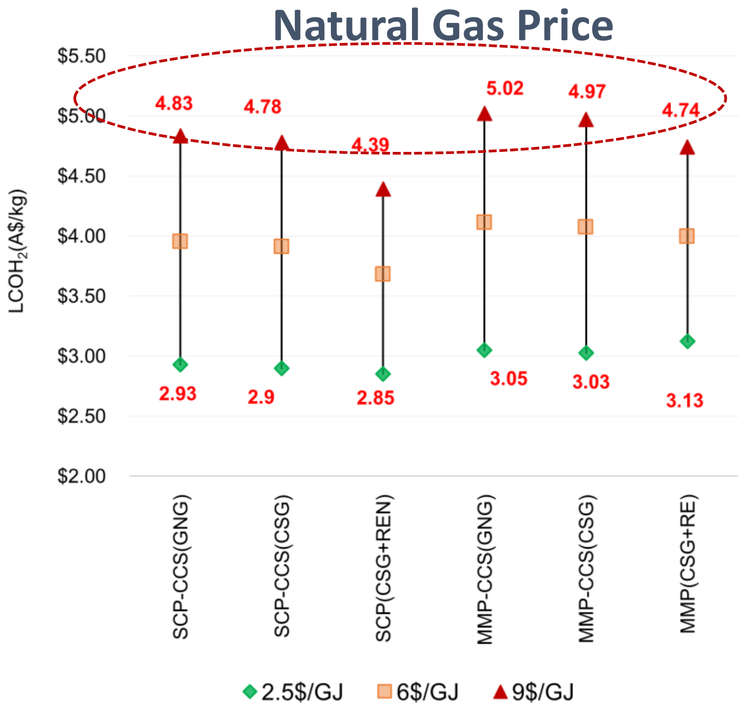
100 kta Solid Catalyst with CCS

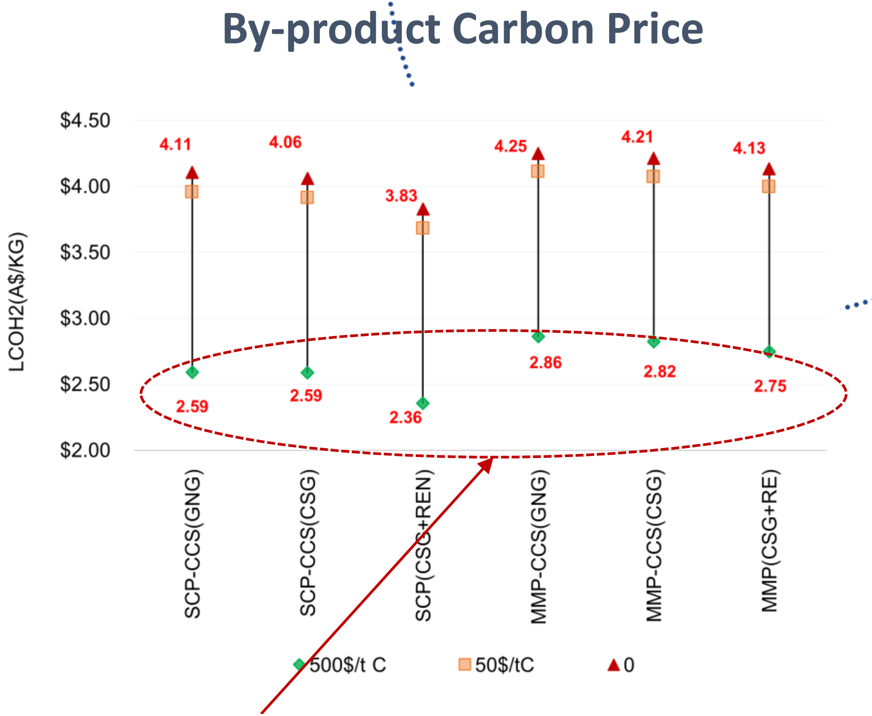


High quality carbon is a game changer

FUTURE FUELS CRC

Sensitivity analysis results





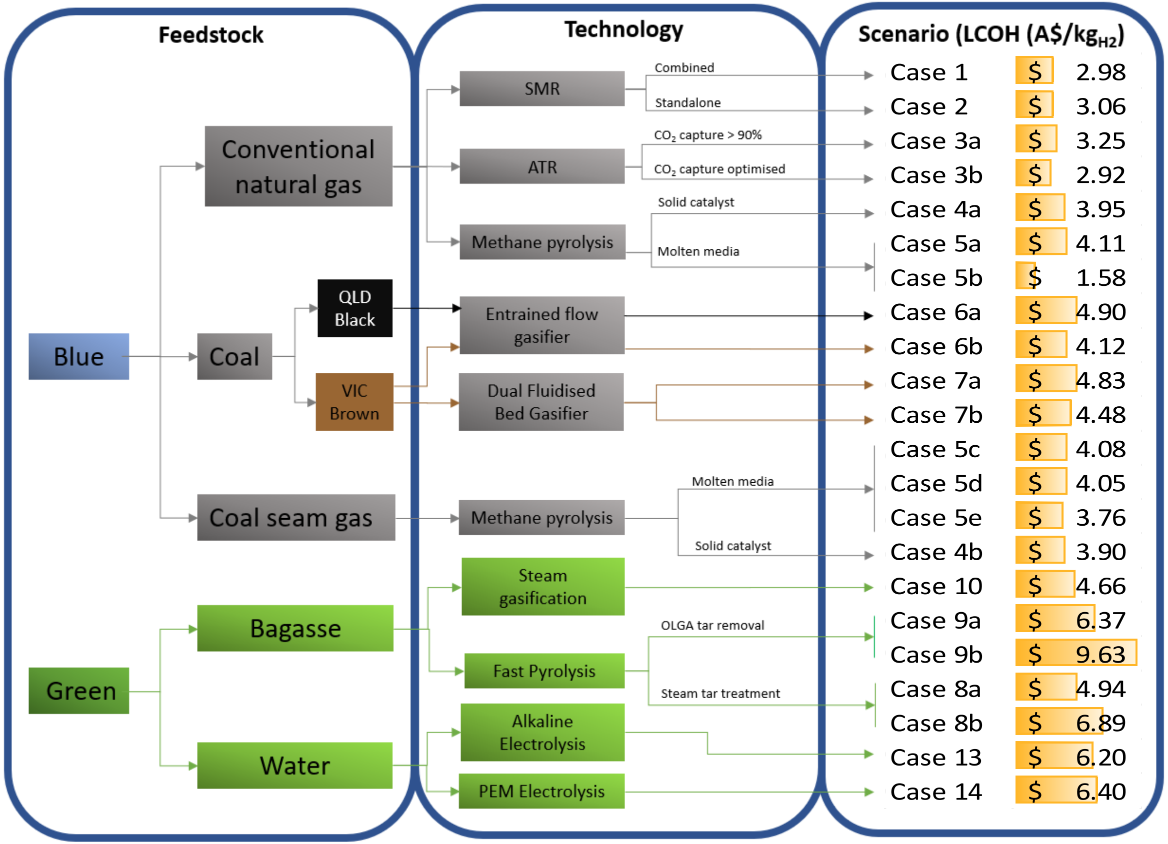
Process economics are less plausible under higher NG price due to higher NG consumption compared to conventional technologies

High quality by-product carbon drives the process economics towards the target price of $2/kg H_2

FUTURE FUELS CRC

Summary

LCOH Comparison



Predicted CapEx Cost Trajectories

Net Zero Australia Project

Green	Capital cost (2020 AU$/kW-e)	
	Alkaline	PEM
2020	1580	1868
2025	1264	1086
2030	1068	738
2040	777	474
2045	739	446
2050	725	436

Blue	ATR + CC	Brown coal gasif. + CC
	$/kg-$H_2$/year	$/kg-$H_2$/year
2020	6.50	11.6
2025	6.37	11.3
2030	6.21	11.0
2035	6.06	10.8
2040	5.91	10.5
2045	5.76	10.3
2050	5.62	10.0

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Technoeconomic modelling of future fuel production pathways

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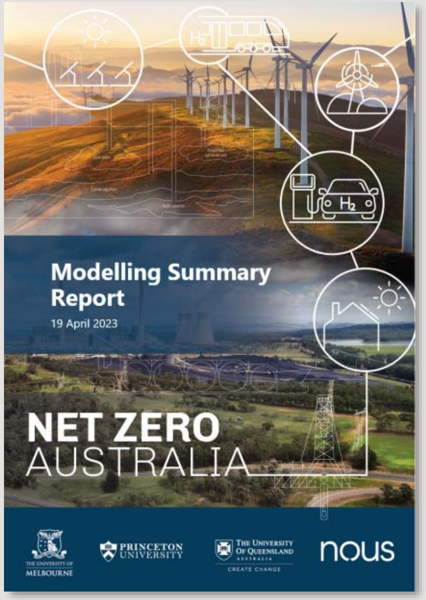
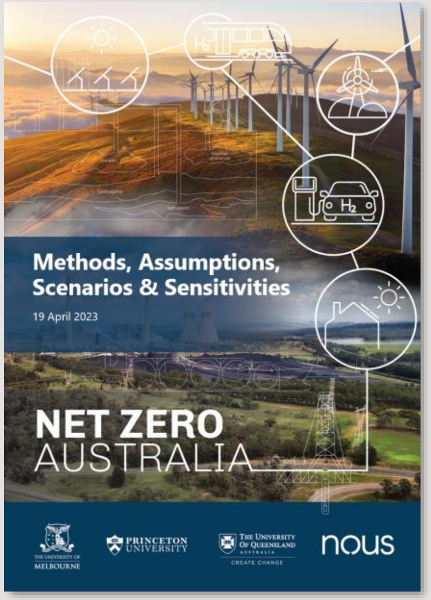
The final summary report and 17 detailed downscaling reports are available on our website

SUMMARY REPORT



DETAILED ASSUMPTIONS (~200pg)



DOWNSCALING REPORTS (17 reports)

netzeroaustralia.net.au

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