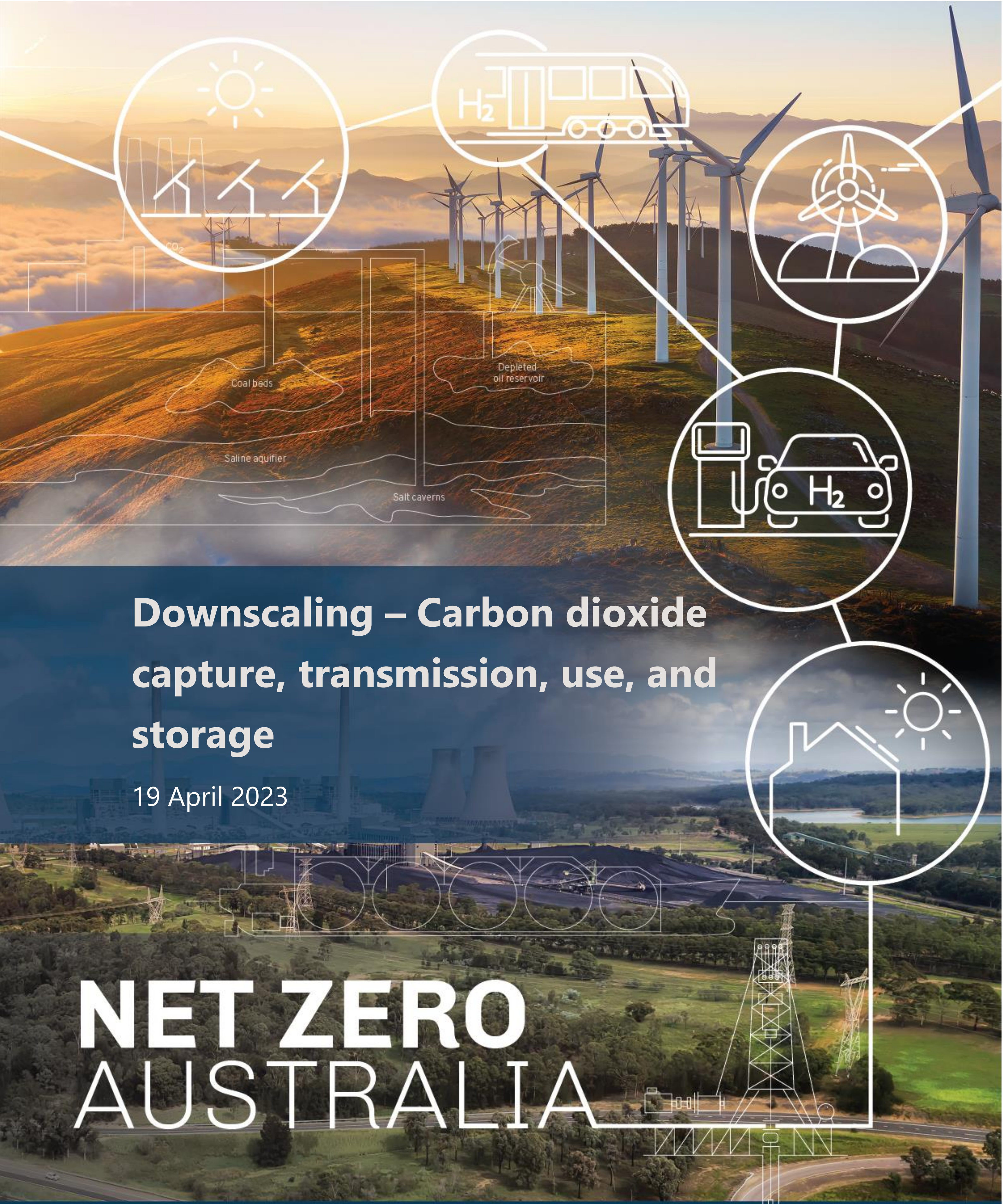

Downscaling – Carbon dioxide capture, transmission, use, and storage

19 April 2023

NET ZERO AUSTRALIA

THE UNIVERSITY OF MELBOURNE

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The Net Zero Australia (NZAu) project is a collaborative partnership between the University of Melbourne, The University of Queensland, Princeton University and management consultancy Nous Group. The study examines pathways and detailed infrastructure requirements by which Australia can transition to net zero emissions, and be a major exporter of low emission energy and products.

Net Zero Australia

Downscaling – Carbon dioxide capture, transmission, use, and storage

19 April 2023

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Contents

1 Introduction

Carbon capture, utilisation and storage (CCUS) refers to a suite of techniques which either capture CO2 from stationary point sources or engineer direct carbon dioxide removal (CDR) from the atmosphere, before then either recycling this CO2 into products such as low-carbon fuels and building materials (utilisation), or permanently sequestering it in deep underground geologic formations (storage) [1]. Ultimately, CCUS achieves mitigation via reducing CO2 emissions to the atmosphere or withdrawing it from the atmosphere. The Net-Zero Australia study has adopted a similar analytical framework as the Net-zero America study (NZA), in which CCUS was one of the six pillars of decarbonization [2].

To align with the NZA study, NZAu developed supply curves defining the location of prospective basins to host geological storage of CO2 in Australia, the associated unit costs of storage, and the relationship between CO2 transportation costs, flowrate and distance between CO2 emissions point sources and geologic sinks [1]. These supply curves are used in NZAu optimisation models.

Most of the technologies employing carbon capture (w/cc) and use technology are discussed in more detail in other downscaling documents or in the Methods, Assumptions, Scenarios & Sensitivities (MASS) [1] document for the steel and cement industries. This document will focus on CO2 after it is captured and the conveyance of the captured CO2 to use and storage locations. A discussion of the onshore CO2 pipeline networks used for NZAu is included in the MASS [1], with a section later in this document noting the adjustments and additions to this network made during downscaling and estimating difference between the capital costs of the main model and the downscaled network.

Table 1 lists the CCUS technologies allowed in modelling, the reference document where the technology is covered in downscaling documentation, and the scenarios in which the technology is used to process an annual national CO2 flow of greater than 1 million tonnes per annum (Mtpa) in any of the five-year model steps. The NZAu scenarios listed in Table 1 include the high electrification (E+), slow electrification (E–), 100% renewables (RE+), renewables constrained (RE–), and the onshoring (ONS) scenarios. A detailed description of each of these scenarios can be found in the MASS document [1].

Table 1 | CCUS technologies allowed in modelling, location of documentation, type of CCUS technology, the scenarios in which the technology reports an annual national CO_2 flow of greater than 1 Mtpa in any of the five-year model steps

Technology	Ref document(s)	Site	Scenarios used
Autothermal reforming w/cc	H2 and Alt fuels	Capture	E+, RE–, E– ONS
Biofuels w/cc	Biomass	Capture	E+, RE+, RE–, E–, ONS
Cement w/cc	MASS, CCUS	Capture	E+, RE+, RE–, E–, ONS
Power w/cc	Thermal generation	Capture	RE–
Conventional gas extraction w/cc retrofit	Fossil Fuels/CCUS	Capture	E+, RE+, RE–, E–, ONS
Direct air capture	CCUS	Capture	E+, RE+, RE–, E–, ONS
Fisher-Tropsch liquids	H2 and Alt fuels	Use	E+, RE+, RE–, E–, ONS
Geologic sequestration	CCUS	Storage	E+, RE+, RE–, E–, ONS

Table 1 indicates that sited carbon capture technologies selected by the model include autothermal reforming (ATR) with carbon capture (w/cc) in four of five core scenarios; power w/cc in a single scenario; and biofuel technologies w/cc, cement w/cc, conventional gas extraction w/cc, and direct air capture (DAC). The only carbon utilisation technology employed by the model is Fischer-Tropsch liquids (FTL), which appears in all scenarios. Geological sequestration also appears in all scenarios to account for the CO_2 not used by FTL.

This document focuses on CO_2 flows from all the technologies listed in Table 1, after capture. Technical information on the CO_2 balances of each technology is covered in the MASS [1]. Further detail on the downscaling of each technology not found in this report (CCUS) can be found in the companion reports indicated in Table 1:

- Downscaling – Hydrogen and Synthetic Fuels;
- Downscaling – Biomass;
- Downscaling – Thermal generation; and
- Downscaling - Fossil Fuels.

2 CCUS by scenario and year (national)

Figure 1 presents national CO_2 capture in Mtpa by technology, scenario, and year.

Figure 1 | National CO_2 capture in Mtpa by technology, scenario, and year

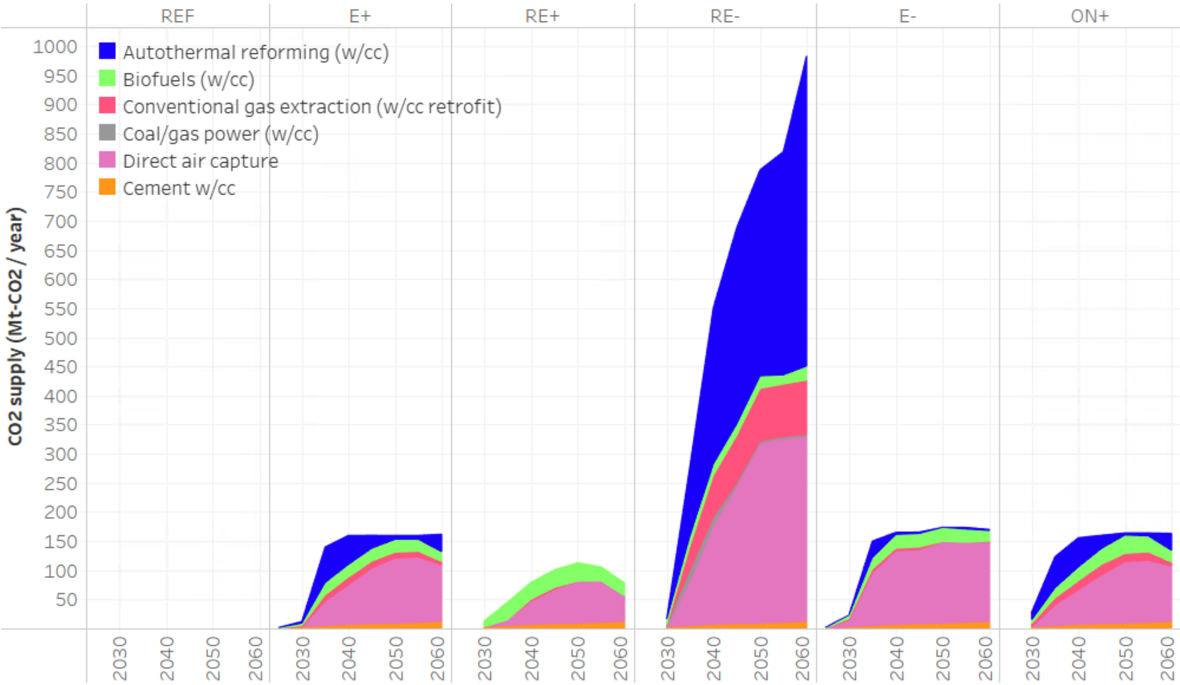


Figure 1 indicates that direct air capture is the main capture technology employed in all scenarios except for the RE– scenario which captures a greater amount of CO_2 from autothermal reforming in all years of the transition. Figure 1 and Table 1 indicate that technologies paired with carbon capture in all scenarios include direct air capture, biofuels production, cement manufacturing, and conventional gas extraction. Autothermal reforming is used in all scenarios but the RE+ scenario. Power generation from natural gas w/cc is only observed in Figure 1 in the RE– scenario. Larger carbon flows in the RE– scenario in Figure 1 arise from the allowance of upside carbon geological sequestration rates [1], which can be observed in Figure 2, which presents national CO_2 use and storage in Mtpa by technology, scenario, and year.

Figure 2 | National CO_2 use and storage in Mtpa by technology, scenario, and year

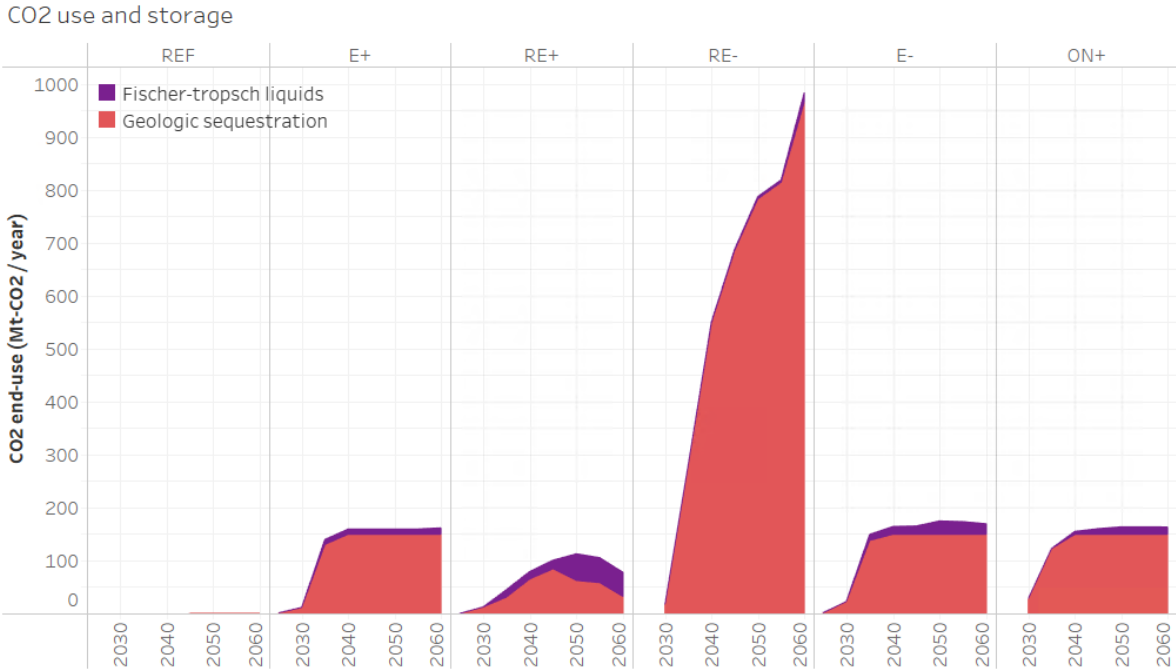


Figure 2 indicates that geological sequestration of carbon is the main use and storage technology employed in all scenarios. Figure 2 and Table 1 indicate that captured CO_2 is used in Fischer-Tropsch liquids (FTL) manufacturing in all scenarios. Table 2 provides a national CO_2 balance (in Mtpa) between sources and sinks for the E+ scenario.

Table 2 | National CO_2 balance between sources and sinks (in Mtpa) for E+ scenario

Technology (with CCUS)	2020	2025	2030	2035	2040	2045	2050	2055	2060
Autothermal reforming	0	0	3	61	50	22	7	7	30
Biofuels	0	2	4	21	22	22	22	21	17
Cement	0	0	3	5	7	8	9	11	12
Coal gas power	0	0	0	0	0	0	0	0	0
Conventional gas	0	0	2	11	13	12	10	10	6
Direct air capture	0	0	0	42	68	95	112	112	97
Fischer-Tropsch liquids	0	0	0	-9	-10	-10	-10	-10	-12
Geologic sequestration	0	-2	-12	-131	-150	-150	-150	-150	-150
Balance (sources – sinks)	0	0	0	0	0	0	0	0	0

Table 2 shows national CO_2 source and sink quantities balancing in each model year for the E+ scenario. National balances for all other scenarios can be found in the Appendix.

3 CO_2 by scenario, year, and state/territory

Figure 3 plots CO_2 captured in Mtpa by scenario, year, and state/territory.

Figure 3 | CO_2 captured in Mtpa by scenario, year, and state/territory

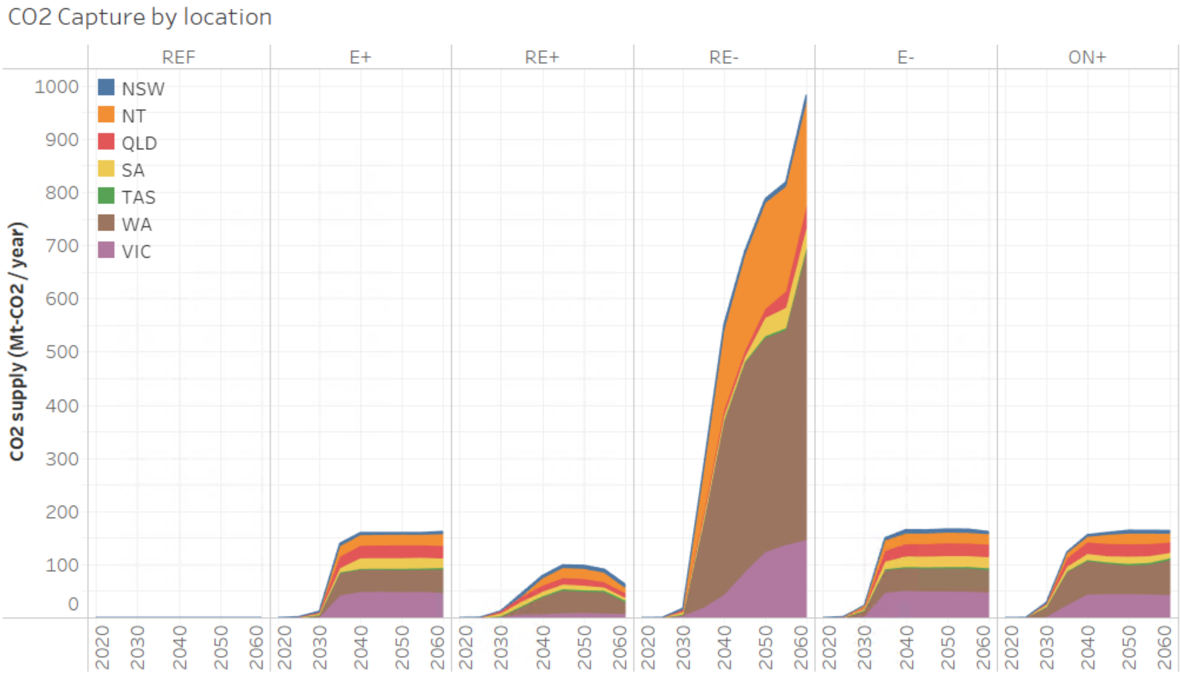


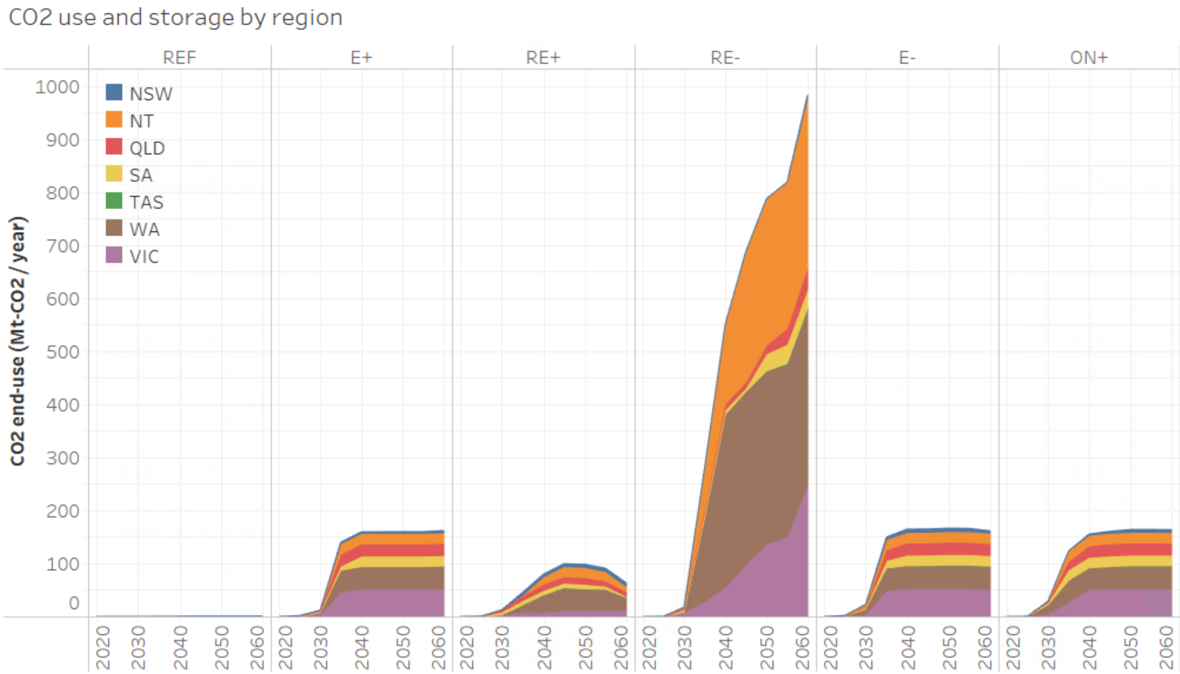
Figure 3 indicates an increase in CO_2 capture in all regions of Australia from 2030, with the largest capture flows occurring in states/territories with access to storage basins (NT, QLD, SA, WA, VIC). In the RE– scenario, CO_2 capture in WA in 2060 is nearly 3x larger than the amount captured in the NT in the same year and is over 12x the amount captured in WA in the E+ scenario in the same year. Table 3 provides the CO_2 flows by state/territory for the E+ scenario.

Table 3 | Regional CO_2 from within-region capture in Mtpa for the E+ scenario

Region	2020	2025	2030	2035	2040	2045	2050	2055	2060
NSW	0	0	1	5	4	4	3	3	4
NT	0	0	0	20	20	20	20	20	22
QLD	0	1	2	21	24	24	24	23	24
SA	0	1	3	8	20	20	20	20	18
TAS	0	0	1	2	2	2	2	2	3
VIC	0	0	1	42	49	49	49	49	47
WA	0	0	3	42	41	41	42	41	44
ALL	**0**	**2**	**12**	**140**	**160**	**160**	**160**	**160**	**162**

Table 3 indicates that CO_2 capture in regions is correlated to the amount of available CO_2 storage potential that exists in the region, with NSW and TAS seeing very little capture and regions with storage potential (NT, QLD, SA, VIC, and WA) reflecting annual capture rates in proportion to the annual storage potential. This arises as a result of a modelling choice to locate DAC assets near storage basins to minimise CO_2 transport costs. Regional CO_2 capture tables for additional scenarios are provided in the [Appendix](#). Figure 4 plots CO_2 use and storage in Mtpa by scenario, year, and state/territory.

Figure 4 | CO_2 use and storage in Mtpa by scenario, year, and state/territory



At the resolution presented, Figure 4 looks almost identical to Figure 3. The CO_2 use and storage flows by state/territory listed for the E+ scenario in Table 4 provide the higher resolution needed to differentiate Figure 3 and Figure 4. Regional CO_2 use and storage tables for additional scenarios are provided in the [Appendix](#).

Table 4 | Regional CO_2 use and storage flows in Mtpa for the E+ scenario

Region	2020	2025	2030	2035	2040	2045	2050	2055	2060
NSW	0	0	0	3	3	3	3	3	4
NT	0	0	0	20	20	20	20	20	20
QLD	0	1	2	22	23	23	23	23	23
SA	0	1	3	8	20	20	20	20	20
TAS	0	0	0	0	0	0	0	0	0
VIC	0	0	4	46	52	52	52	52	52
WA	0	0	3	42	41	42	42	42	43
ALL	**0**	**2**	**12**	**140**	**160**	**160**	**160**	**160**	**162**

Although the regional CO_2 use and storage quantities in Table 4 appear similar to the regional capture quantities in Table 3, they exhibit a difference in values where regional transfers are occurring. Regional transfers are accomplished using a CO_2 pipeline network.

4 CCUS network mapping

We map a notional CCUS network consisting of trunk pipelines, notional storage, use and capture locations in the subsequent sections. Alternate configurations are possible and depend much on the siting decisions made for the industrial, hydrogen, alternate fuels and bioenergy sectors. These are discussed in companion downscaling reports:

- Downscaling – Hydrogen and Synthetic Fuels;
- Downscaling – Biomass;
- Downscaling – Thermal generation; and
- Downscaling - Fossil Fuels.

4.1 Storage

Figure 5 shows the geologic storage basins used in modelling, along with notional [and upside] capacities [1] for each basin. Storage connection locations are shown at the geometric centroid of basins (as points in Figure 5) rather than in scoped locations like EPQ10 [3], [4] and Pelican [5], or at pilot sites like Gorgon [6], as there is still uncertainty around viable injection/storage locations. Note also that although storage locations are shown as a single point on the map, wells might be added at any suitable site in the basin.

A keen observer of the MASS [1] will note that the NZAu downscaling team has added the Perth basin to the map to reduce small CO_2 flows over long pipelines to/from southern WA. The maximum storage by state (basin) in Mtpa in any model year is shown in Table 5.

Table 5 shows storage flows nearing maximums for all basins in the E+, E– and ONS scenarios. The RE+ scenario sees reduced storage flows for all basins but the WA basin. In the RE– scenario, full upside potentials are approached for the basins in WA and NT.

Figure 5 | Storage basins and connection locations, with notional [and upside] basin storage in Mtpa

Table 5 | Maximum storage by state (basin) in Mtpa in any model year

State (basin)	REF	E+	RE+	RE–	E–	ONS
WA (Carnarvon, Browse, Perth)	0	40	40	325	40	40
NT (Bonaparte)	0	20	19	322	20	20
QLD/SA (Cooper)	0	20	9	36	20	20
QLD (Surat)	0	20	9	38	20	20
VIC (Gippsland)	1	50	9	246	50	50
All	**1**	**150**	**86**	**967**	**150**	**150**

4.2 Capture

The total CO_2 captured in each scenario is provided in Mtpa by facility type in Table 6.

Table 6 | Maximum CO_2 captured in any model year of a scenario in Mtpa, by facility type

Facility type	REF	E+	RE+	RE–	E–	ONS
Autothermal reforming w/cc	0	61	0	533	28	53
Biofuels w/cc	0	22	32	24	24	32
Cement w/cc	0	12	12	12	12	12
Power w/cc	0	0	0	18	0	0
Conventional gas extraction w/cc retrofit	0	13	3	93	6	18
Direct air capture	0	112	72	318	140	106

Table 6 indicates that direct air capture facilities are responsible for the most CO_2 capture in all but the RE– scenario, in which direct air capture is responsible for the second largest quantity of CO_2 captured. In the RE– scenario, Table 6 indicates that autothermal reforming w/cc plays the largest role in the capture of CO_2, rather than playing the second largest role as it does in all scenarios but the RE+ scenario in which no autothermal reforming is built. Constructed capacities for the four technologies connection with the production or generation of energy carriers – autothermal reforming, biofuels, power, conventional gas extraction – are discussed in other downscaling documents, as are the details used to turn those capacities into facilities with locations. The maximum number of facilities employing carbon capture is provided by facility type and scenario in Table 7.

Table 7 | Maximum number of facilities employing carbon capture in a scenario by technology

Facility Type (document discussing)	REF	E+	RE+	RE–	E–	ONS
Autothermal reforming w/cc (H_2 and Alt Fuels)	0	32	0	237	14	27
Biofuels w/cc (Biomass)	0	58	81	83	74	73
Cement w/cc^ (MASS)	0	4	4	4	4	4
Power w/cc (Thermal generation)	0	0	0	5	0	0
Conventional gas extraction w/cc retrofit^^ (Fossil Fuels)	0	4	4	4	4	4
Direct air capture^^^	0	112	72	318	140	106
Scenario Maximum	0	206	161	651	236	214

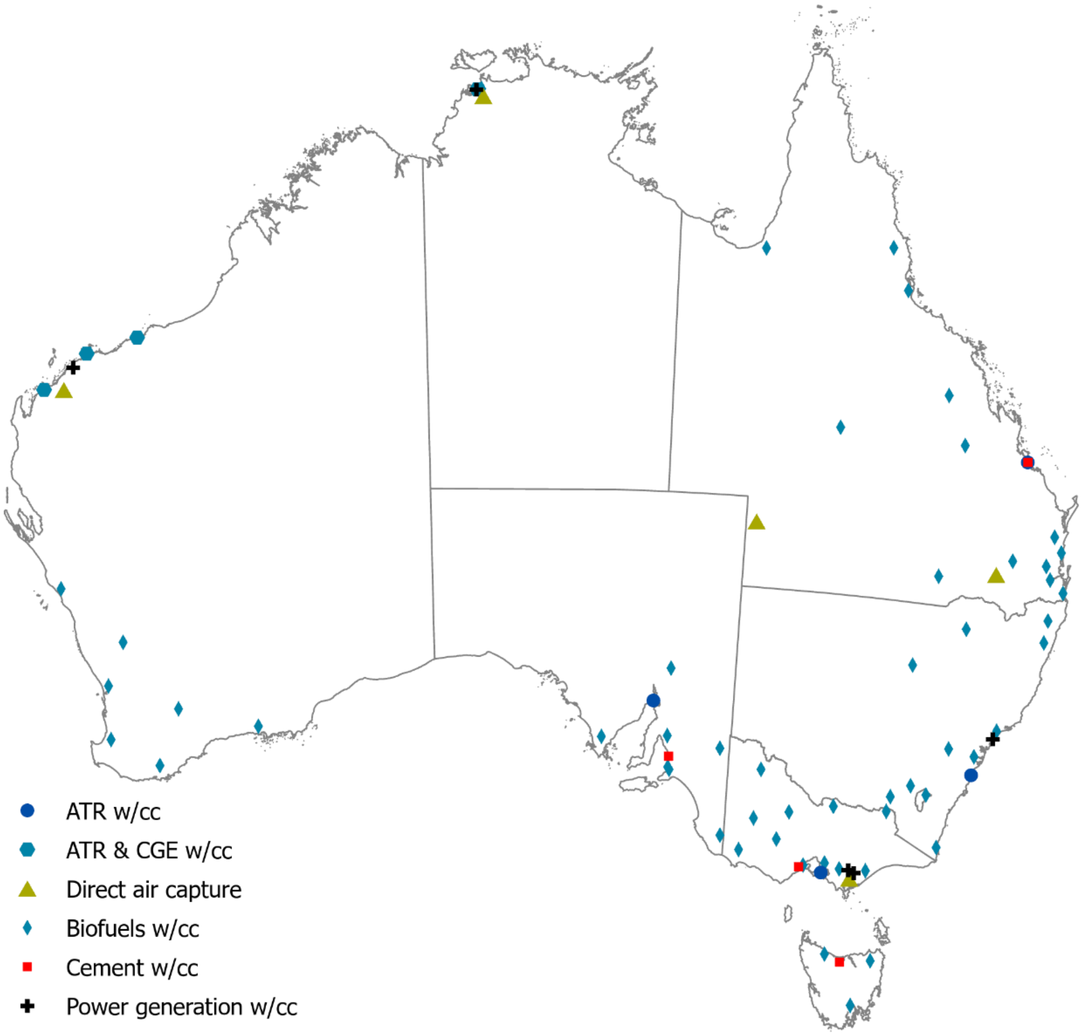
^ Cement downscaling is covered in the MASS [1] and follows a similar process to the one used in the Net-Zero America project [2]. Notional maps for the cement industry transition can be found in the Appendix

^^ Carbon capture facilities are notionally co-located with gas processing facilities already in operation in the four export ports in WA and the NT

^^ A modular direct air capture facility is allocated for every 1 Mtpa of CO_2 captured by the technology [7]

As expected from earlier Figures and Tables, Table 6 and Table 7 indicate that the RE– scenario has the largest amount of CO_2 captured and the greatest number of capture facilities of any core scenario. All potential capture locations considered in NZAu scenarios are shown in Figure 6.

Figure 6 | All potential carbon capture locations considered in NZAu scenarios



Biofuel, cement, and power facilities w/cc are shown as individual point sources in Figure 6. Figure 6 shows conventional gas extraction facilities – which capture the CO_2 instead of venting it – at the ports already containing existing facilities in WA and the NT. Autothermal reforming w/cc facilities are shown in aggregate in the downscaled NZAu ports shown in Figure 6.

Notional direct air capture locations are shown in aggregate and are placed as close as possible to storage areas, while avoiding the same economic, national interest, or environmental exclusion zones used in the siting of variable renewables. To ensure that aggregate direct air capture facilities have enough land area, we have increased an estimate of 0.4 km^2 per 1 Mt-CO_2/year facility [7] to a conservative 0.5 km^2 of land area per 1 Mt-CO_2/year facility; and also located a land parcel large enough to fit DAC facilities in all scenarios allowing upside storage capacities.

4.3 Use

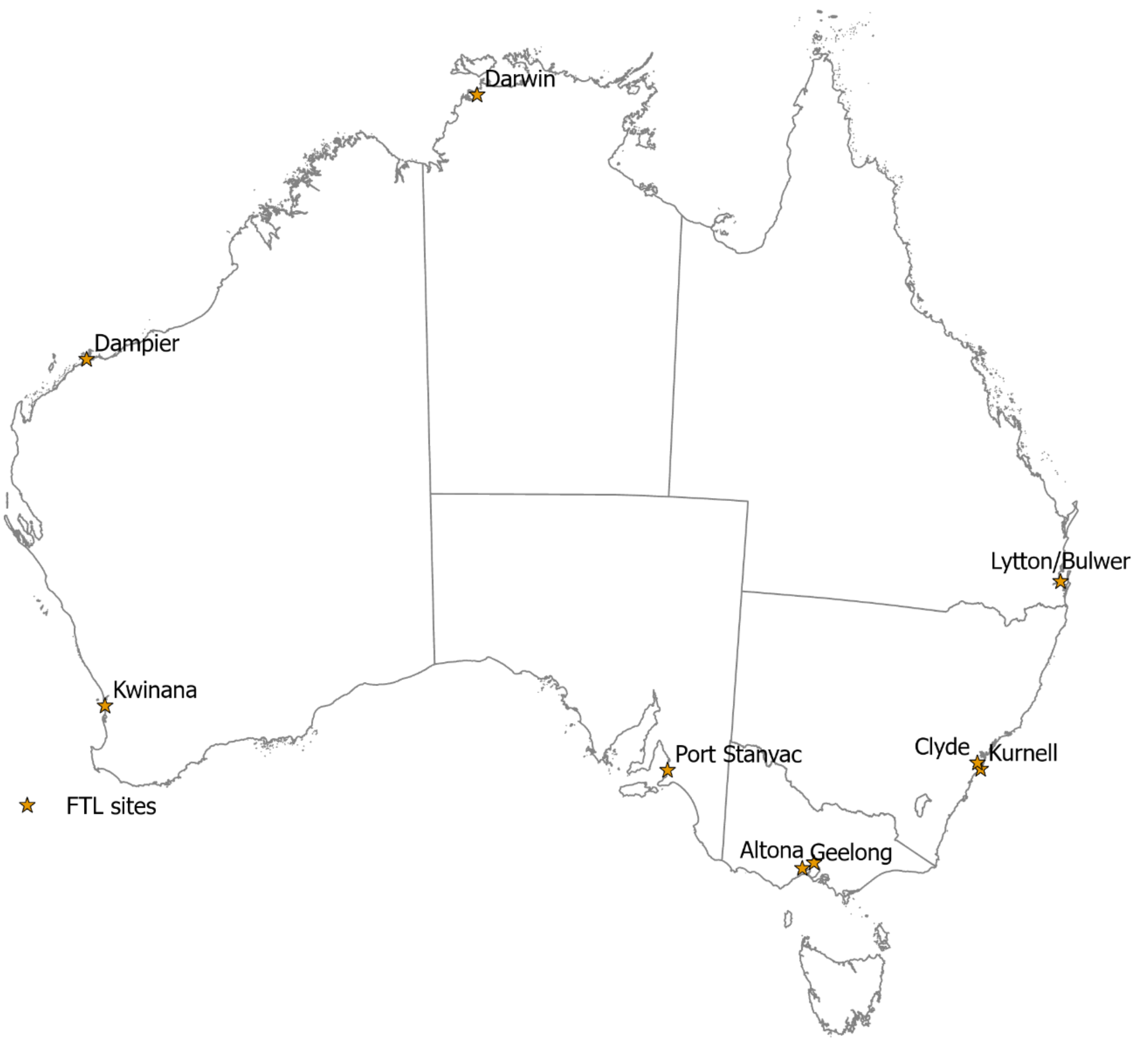
There are no special carbon technologies employed in the use of CO_2 in the industrial Fischer-Tropsch liquids processes modelled in NZAu. Carbon dioxide enters industrial facilities as a process stream transported via pipelines. The maximum CO_2 captured in each scenario (in Mtpa) is provided along with the estimated number of Fisher-Tropsch liquids facilities using captured CO_2 in 2060 in Table 8.

Table 8 |Maximum CO_2 captured in each scenario (in Mtpa), along with the estimated number of Fisher-Tropsch liquids facilities using captured CO_2 in 2060

Fischer-Tropsch liquids	REF	E+	RE+	RE–	E–	ONS
Maximum CO2 used (Mtpa)	0	12	50	18	25	14
Modular facilities (114.7 MW each)	0	100	338	121	195	109
Aggregate facilities (capacity depends on locations used)	0	7	10	6	9	7

All potential Fisher-Tropsch liquid production locations considered in NZAu scenarios are shown in Figure 7. Fisher-Tropsch are either shown as aggregate "Synthetic Fuel" locations near prior/current sites of related industries, or as an aggregate facility at the port locations of existing LNG facilities in WA and the NT.

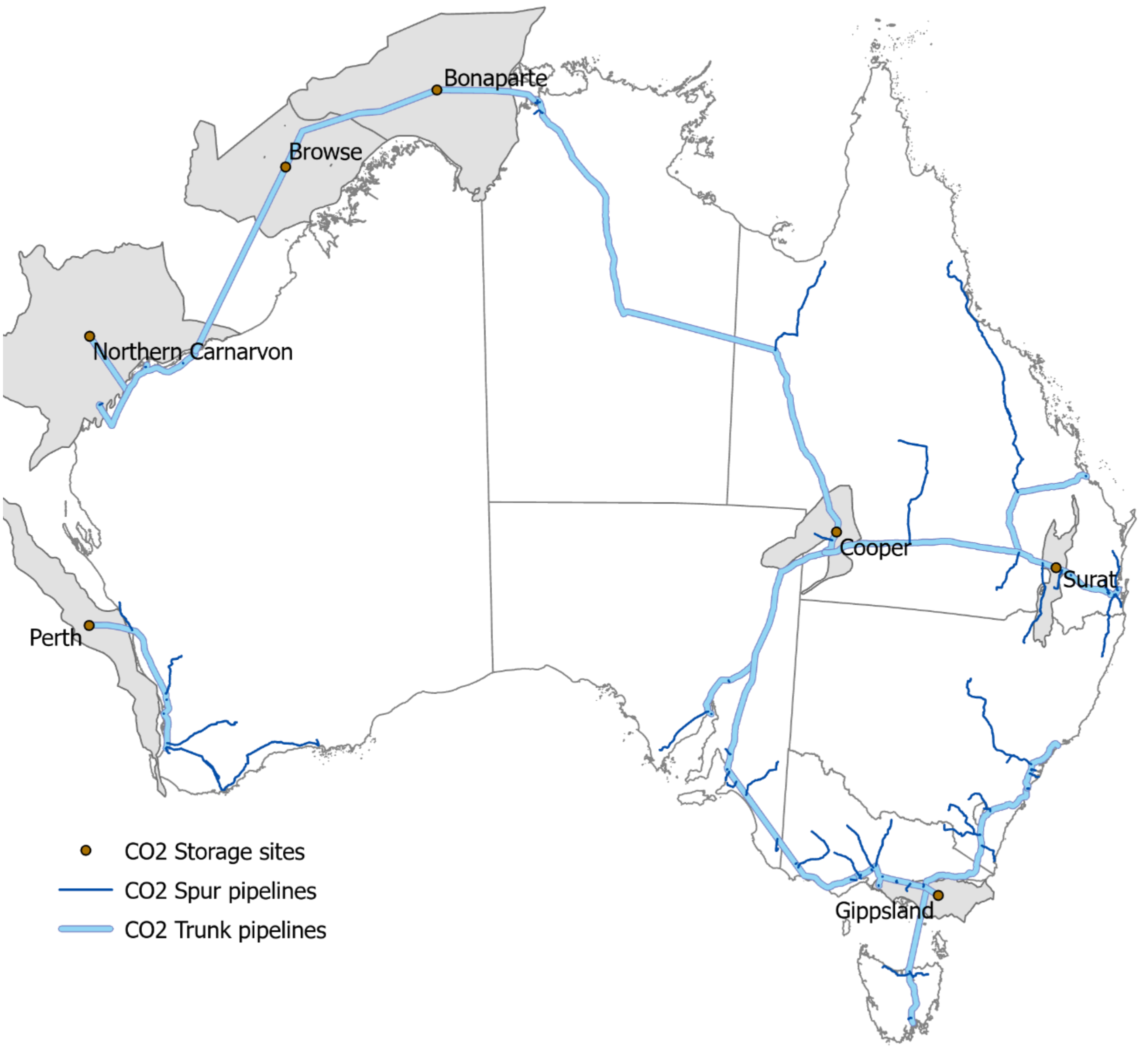
Figure 7 | Set of all potential CO_2 use locations used in NZAu scenarios



4.4 Pipelines

Figure 8 shows the set of all potential CO_2 trunk and spur pipelines used in NZAu scenarios. CO_2 trunk pipelines have been mapped in existing pipeline corridors when available [8]. Spur pipelines from each carbon capture and use site are routed to the trunk network (or storage site if closer) using the same least-cost pathway method (and exclusions) used when siting spur electricity transmission lines for wind and solar PV sites.

Figure 8 | Set of all potential trunk pipelines used in NZAu scenarios



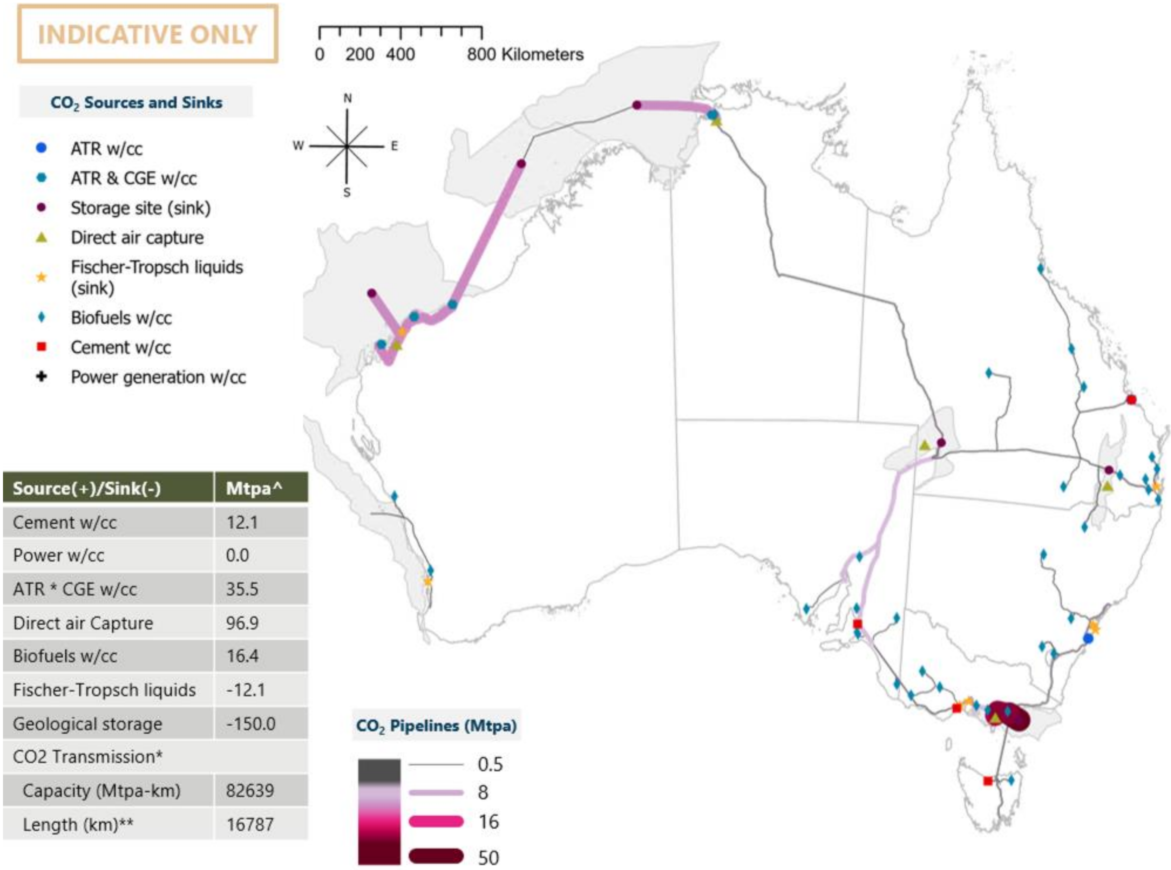
Note that not all trunk pipelines shown in Figure 8 are built in all scenarios – with the north-south pipeline between the Bonaparte basin and the Cooper Basin only being built in two core scenarios (RE–, ONS). Similarly, not all spur pipelines shown in Figure 8 will be built – especially if the length of the pipeline exceeds a reasonable distance when considering the maximum annual CO_2 flow in the pipeline.

5 Network analysis

5.1 CCUS map examples for E+ and RE– in 2060

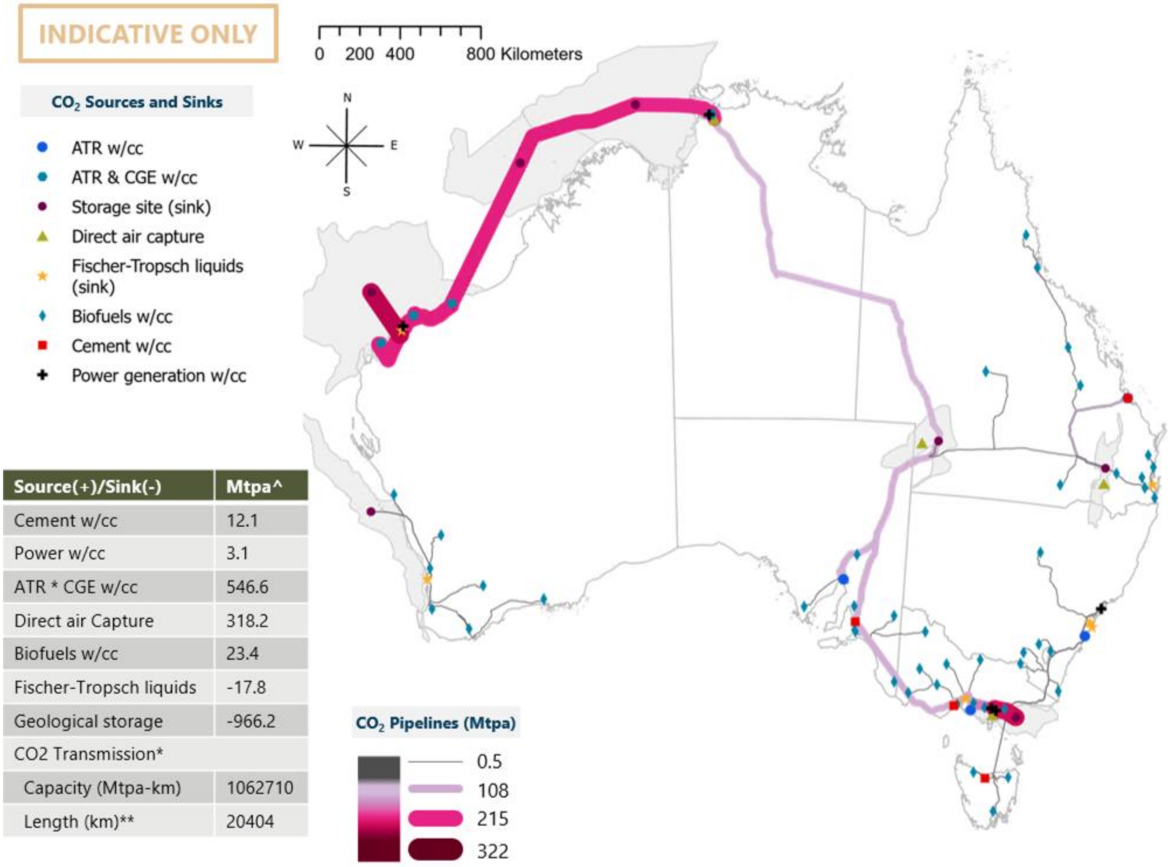
Combined CCUS map showing notional CCS capture sites, storage locations and CO2 pipeline network is shown for 2060 in the E+ scenario in Figure 9 and for 2060 in the RE– scenario in Figure 10. E+ and RE– are chosen to represent the most common CCUS narrative (E+) and the most extreme narrative (RE–) in NZAu and therefore illustrate the bounds of the CCUS debate in the core scenarios. CCUS map progressions for all scenarios are in the Appendix.

Figure 9 | Combined CCUS map for the E+ scenario in 2060



Source(+)/Sink(-)	Mtpa^
Cement w/cc	12.1
Power w/cc	0.0
ATR * CGE w/cc	35.5
Direct air Capture	96.9
Biofuels w/cc	16.4
Fischer-Tropsch liquids	-12.1
Geological storage	-150.0
CO2 Transmission*	
Capacity (Mtpa-km)	82639
Length (km)**	16787

Figure 10 | Combined CCUS map for the RE– scenario in 2060



Source(+)/Sink(-)	Mtpa^
Cement w/cc	12.1
Power w/cc	3.1
ATR * CGE w/cc	546.6
Direct air Capture	318.2
Biofuels w/cc	23.4
Fischer-Tropsch liquids	-17.8
Geological storage	-966.2
CO2 Transmission*	
Capacity (Mtpa-km)	1062710
Length (km)**	20404

Map notes for Figure 9 and Figure 10:

- (^) The minimum threshold for mapping point sources and spur lines is 100Ktpa. Implementation of this minimum threshold leads to many biomass point sources with small capture flows being left off maps (especially in SW Australia). This also results in the sum of the CO_2 sources value being a fair bit less than the CO_2 storage value in all scenarios where biofuels are used. It is expected that either small biofuel point sources would be aggregated with other flows to improve CCUS economics (or DAC might also be added to offset expected capture from biofuels).
- (*) Transmission expansion is mapped to follow existing rights of way for existing TX > 132kV, national roads, railroads, pipelines; paths are indicative not definitive. Inter-regional and storage transmission expansions of below 0.100 Mtpa are not mapped. All transmission expansions are built five years before the full CO_2 flows they are intended to allow. Transmission figures include: CO_2 trunks and spurs.
- (^^) Currently reported lengths cover the length of corridor added, and not total pipeline distance (e.g. a 100 km corridor with two pipelines reports 100km, not 200km)."

Figure 9 and Figure 10 show strikingly different scales in the flows represented, with the RE– scenario shown in Figure 10 seeing flows of up to 322 Mtpa in a single corridor (Darwin to the Bonaparte storage site), while the E+ scenario's maximum flow in 2060 is 50 Mtpa to the Gippsland storage site. Both scenarios also see a connection between the NT and SE Australia by 2060, supporting the North to South transfer of overflow CO_2 from autothermal reforming and conventional gas extraction w/cc from the NT and WA. The overflow of CO_2 from WA to the larger Bonaparte storage site (in RE–) and then on to SE Australia is also facilitated by a Browse storage site to Bonaparte storage site connection in both scenarios.

The RE– scenario (Figure 10) indicates that southwestern Western Australia has greater CO_2 capture from greater biofuel production, which is complimented by increased production of Fischer-Tropsch liquids (FTL) in the region. Notably in Figure 9, southwestern Western Australia does not see storage in 2060 as CO_2 flows are actually moving in the opposite direction from storage to the Kwinana FTL production site – where the CO_2 flow is combined with CO_2 flows from biofuels production sites.

NZAu CO_2 pipeline networks and point sources have locations that are for the most part highly notional and can be reconsidered any number of ways.

- NZAu pipeline networks made use of existing pipeline corridors in moving CO_2 from WA and NT basins to basins in SE Australia, rather than striking out in a more east to west fashion as happens with electricity transmission lines in the RE– scenario.
- DAC for instance might be sited anywhere that storage is possible on land. If the DAC site in Victoria (or anywhere else in Australia for that matter) was able to reach storage from a land location rather than running a pipeline to an offshore location first – as is shown in both Figure 9 and Figure 10 – then the large pipeline running offshore from eastern Victoria might be replaced by a much smaller pipeline.
- Biofuel production sites were not chosen for proximity to the CCUS network (see discussion in the *Downscaling – Biomass* companion report), which may challenge the economic viability of such sites if spur lines are long, CO_2 flows are small, or there is a temporal mismatch between sites selected for use and trunk line construction. Some of these challenges are apparent in the map progressions shown in the Appendix.
- More robust CO_2 storage networks might include additional reinforcing of connections between storage sites, allowing for full storage flows to be routed to other basins should future development of each basin proceed in a manner different from illustrated in NZAu (i.e. with the injectivity of basins either higher or lower than the maximums listed in the MASS document).

5.2 Downscaling cost analysis

The NZAu team considered the potential for differences between model costs, and the costs of the 2060 networks generated during downscaling and shown in Figure 9, Figure 10 and the Appendix. Changes to CO_2 networks that occurred in downscaling include:

- addition of all offshore pipelines including those connecting onshore trunks and storage locations;
- altering the WA and NT pipeline connection to take advantage of extensive offshore infrastructure rather than breaking new ground onshore;
- addition of Perth Basin to storage locations and removal of connection between northern and southern WA to avoid small pipelines that run long distances and to take advantage of storage options in Perth Basin;
- forcing of all NT to SA pipelines through outback QLD to take advantage of existing natural gas pipeline corridors;
- forcing all southern QLD to Gippsland storage connections through the Cooper and Surat basins to take advantage of closer storage options there while re-routing some CO_2 flows from SA to the Gippsland Basin rather than the Cooper Basin.

Table 9 provides a comparison of the capital costs estimated by the model and the capital costs of the notional networks generated during downscaling. This analysis found that downscaled networks are more costly for all but the RE– scenario, which was slightly less costly in its downscaled form. Note that the RE– scenario differs with other scenarios in having CCUS capital costs that were at least 10x greater than the costs of all but the ONS scenario, which was only 1/5th as costly.

Table 9 | A comparison of model estimated capital costs and the capital costs of the notional networks generated during downscaling

CCUS Capital cost ratio	E+	RE+	RE–	E–	ONS
Downscaled costs to model costs	1.82	5.37	0.94	2.31	1.37
Scenario's downscaled CCUS capital costs to E+ capital costs	1	0.88	10.7	0.85	1.85

The downscaled costs in E+, RE+, E–, and ONS, which were 1.37 (ONS) to 5.37 (RE+) times greater than modelled costs, are all a small fraction of the total capital costs in any scenario (see the *Downscaling – Capital Mobilization* companion report). The NZAu team does not expect that the energy mix in any scenario would change significantly if the model's costs were to be updated with downscaled costs — even given the somewhat flat optimization space across many modelled CO_2 reduction technologies. The functionally divergent and necessary role CCUS plays in scenarios is readily apparent from its utilization in even the NZAu scenario which specifies 100% renewable energy (similar finding from NZA [2]).

With the exception of RE–, the only expected impact of higher CCUS capital costs on each scenario is a slightly more costly transition total — a difference that is well within the total uncertainty of the modelling (see discussions in CCUS annex from NZA [2]). In general, downscaled CCUS network capital costs were higher than modelled costs due to the remoteness of most storage sites when compared to the final locations of CO_2 sources and the inter-regional transmission network, as well as the design of more robust CO_2 networks than was possible in modelling.

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Appendices

Appendix A

National CO2 source and sink balances

Table 10 | National CO_2 balance between sources and sinks (in Mtpa) for RE+ scenario

Technology (with CCUS)	2020	2025	2030	2035	2040	2045	2050	2055	2060
Autothermal reforming	0	0	0	0	0	0	0	0	0
Biofuels	0	0	10	30	29	30	32	24	22
Cement	0	0	3	5	7	8	9	11	12
Coal gas power	0	0	0	0	0	0	0	0	0
Conventional gas	0	0	0	0	3	3	0	0	0
Direct air capture	0	0	0	10	40	59	72	71	44
Fischer-Tropsch liquids	0	0	0	-14	-14	-16	-50	-47	-46
Geologic sequestration	0	0	-13	-31	-65	-84	-63	-59	-32
Balance (sources – sinks)	0	0	0	0	0	0	0	0	0

Table 11 | National CO_2 balance between sources and sinks (in Mtpa) for RE– scenario

Technology (with CCUS)	2020	2025	2030	2035	2040	2045	2050	2055	2060
Autothermal reforming	0	0	1	121	269	337	354	383	533
Biofuels	0	0	9	17	20	20	22	16	24
Cement	0	0	3	5	7	8	9	11	12
Coal gas power	0	0	4	18	13	5	3	3	3
Conventional gas	0	0	0	42	72	82	91	91	93
Direct air capture	0	0	0	78	171	237	310	315	318
Fischer-Tropsch liquids	0	0	0	0	-2	-2	-4	-4	-18
Geologic sequestration	0	0	-17	-281	-549	-686	-783	-815	-966
Balance (sources – sinks)	0	0	0	0	0	0	0	0	0

Table 12 | National CO_2 balance between sources and sinks (in Mtpa) for E– scenario

Technology (with CCUS)	2020	2025	2030	2035	2040	2045	2050	2055	2060
Autothermal reforming	0	0	0	28	4	2	1	3	2
Biofuels	0	2	6	20	24	23	24	22	18
Cement	0	0	3	5	7	8	9	11	12
Coal gas power	0	0	0	0	0	0	0	0	0

Conventional gas	0	0	3	6	4	4	1	1	1
Direct air capture	0	0	11	91	127	127	140	137	136
Fischer-Tropsch liquids	0	0	0	-11	-15	-16	-25	-24	-20
Geologic sequestration	0	-2	-23	-138	-150	-150	-150	-150	-150
Balance (sources – sinks)	0	0	0	0	0	0	0	0	0

Table 13 National CO_2 balance between sources and sinks (in Mtpa) for ONS scenario

Technology (with CCUS)	2020	2025	2030	2035	2040	2045	2050	2055	2060
Autothermal reforming	0	0	14	53	50	22	4	5	29
Biofuels	0	0	7	18	24	28	32	27	20
Cement	0	0	3	5	7	8	9	11	12
Coal gas power	0	0	0	0	0	0	0	0	0
Conventional gas	0	0	6	12	16	18	14	15	6
Direct air capture	0	0		36	60	84	106	106	96
Fischer-Tropsch liquids	0	0	0	0	-6	-11	-14	-14	-14
Geologic sequestration	0	0	-29	-123	-150	-150	-150	-150	-150
Balance (sources – sinks)	0	0	0	0	0	0	0	0	0

Regional CO2 capture

Table 14 | CO_2 from within-region capture in Mtpa for the RE+ scenario, by state/territory

Region	2020	2025	2030	2035	2040	2045	2050	2055	2060
NSW	0	0	0	6	5	5	6	6	6
NT	0	0	0	1	14	19	19	18	10
QLD	0	0	4	9	11	12	13	10	9
SA	0	0	5	8	8	9	9	6	5
TAS	0	0	1	2	2	3	3	3	4
VIC	0	0	2	7	7	9	10	8	8
WA	0	0	0	13	31	42	40	40	22
ALL	0	0	13	46	79	99	98	91	63

Table 15 | CO_2 from within-region capture in Mtpa for the RE– scenario, by state/territory

Region	2020	2025	2030	2035	2040	2045	2050	2055	2060
NSW	0	0	2	7	10	8	8	8	13
NT	0	0	0	78	150	180	199	197	196
QLD	0	0	4	8	11	11	17	30	41
SA	0	0	5	9	9	9	35	39	38

TAS	0	0	1	2	2	2	3	4	6
VIC	0	0	4	19	43	86	124	137	147
WA	0	0	1	158	326	392	402	404	543
ALL	0	0	17	281	551	688	788	819	984

Table 16 | CO_2 from within-region capture in Mtpa for the E– scenario, by state/territory

Region	2020	2025	2030	2035	2040	2045	2050	2055	2060
NSW	0	0	0	4	6	6	6	6	4
NT	0	0	4	20	20	20	20	20	20
QLD	0	1	2	20	23	23	24	24	24
SA	0	1	3	14	20	20	21	20	21
TAS	0	0	1	2	2	3	3	3	4
VIC	0	0	3	47	51	50	50	50	48
WA	0	0	10	42	42	43	43	43	42
ALL	0	2	23	150	165	165	167	166	162

Table 17 | CO_2 from within-region capture in Mtpa for the ONS scenario, by state/territory

Region	2020	2025	2030	2035	2040	2045	2050	2055	2060
NSW	0	0	1	2	3	4	6	5	5
NT	0	0	0	10	11	17	20	20	16
QLD	0	0	2	15	22	23	23	23	20
SA	0	0	4	9	11	12	14	13	10
TAS	0	0	1	2	2	3	3	3	4
VIC	0	0	2	24	44	45	45	44	43
WA	0	0	17	62	63	57	54	56	65
ALL	0	0	29	123	156	160	164	164	164

Regional CO2 use and storage

Table 18 | Regional CO_2 use and storage flows in Mtpa for the RE+ scenario

Region	2020	2025	2030	2035	2040	2045	2050	2055	2060
NSW	0	0	0	5	5	5	6	6	6
NT	0	0	0	1	14	19	19	18	10
QLD	0	0	4	9	11	12	13	10	9
SA	0	0	5	8	8	9	9	6	2
TAS	0	0	0	1	1	1	1	1	1
VIC	0	0	3	8	8	11	11	11	13

WA	0	0	0	13	32	43	40	40	22
ALL	0	0	13	45	80	99	98	91	63

Table 19 | Regional CO_2 use and storage flows in Mtpa for the RE– scenario

Region	2020	2025	2030	2035	2040	2045	2050	2055	2060
NSW	0	0	0	0	0	0	0	0	4
NT	0	0	0	78	150	247	276	276	322
QLD	0	0	4	8	11	10	16	30	40
SA	0	0	5	9	9	7	32	36	35
TAS	0	0	0	0	0	0	1	1	3
VIC	0	0	7	28	55	98	136	150	249
WA	0	0	1	158	325	325	325	325	330
ALL	0	0	17	281	551	688	788	819	984

Table 20 | Regional CO_2 use and storage flows in Mtpa for the E– scenario

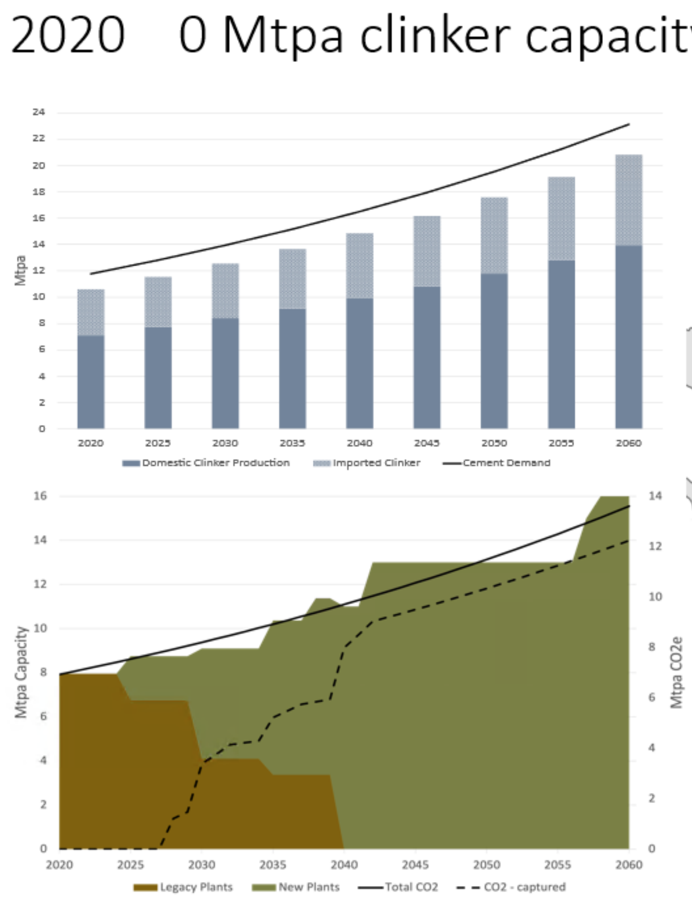
Region	2020	2025	2030	2035	2040	2045	2050	2055	2060
NSW	0	0	0	4	6	6	6	6	4
NT	0	0	4	20	20	20	20	20	20
QLD	0	1	2	20	23	23	23	23	22
SA	0	1	3	14	20	20	20	20	20
TAS	0	0	0	0	1	1	1	1	1
VIC	0	0	4	49	53	53	53	53	52
WA	0	0	10	42	42	42	43	43	42
ALL	0	2	23	150	165	165	166	166	162

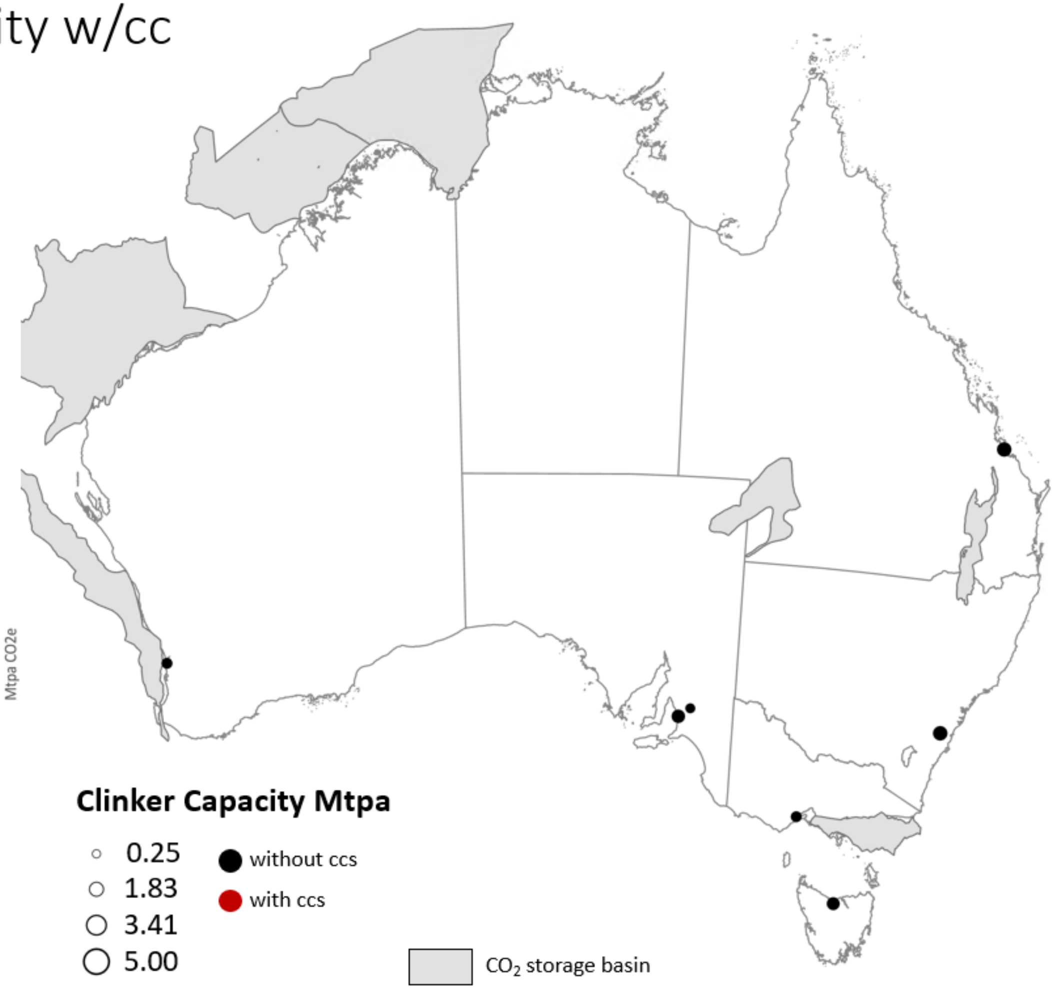
Table 21 | Regional CO_2 use and storage flows in Mtpa for the ONS scenario

Region	2020	2025	2030	2035	2040	2045	2050	2055	2060
NSW	0	0	0	0	2	4	5	5	5
NT	0	0	0	20	20	20	20	20	20
QLD	0	0	2	15	22	23	23	23	23
SA	0	0	4	20	20	20	20	20	20
TAS	0	0	0	0	0	1	1	1	1
VIC	0	0	5	28	51	52	52	52	52
WA	0	0	17	40	40	41	43	43	43
ALL	0	0	29	123	155	161	164	164	164

Notional transition maps for the cement industry in all scenarios

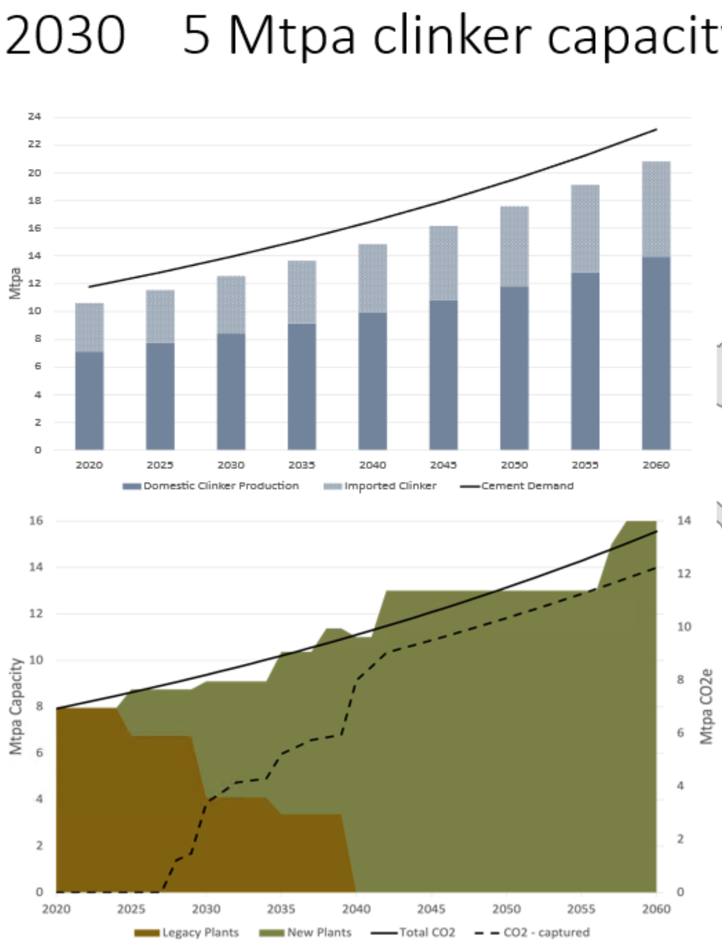
Figure 11 | Cement transition 2020 for all scenarios [1]

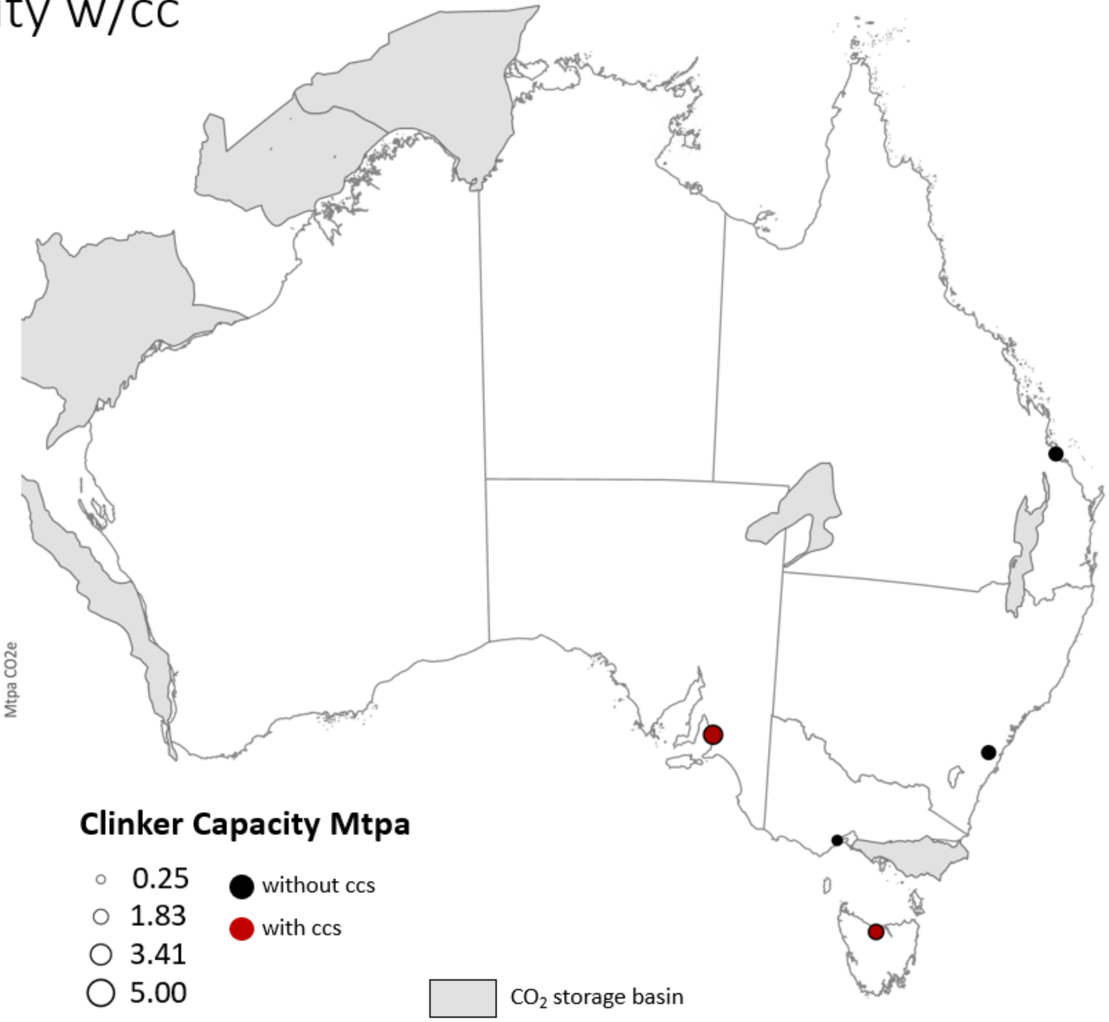




R. Batterham et al., "Methods, Assumptions, Scenarios & Sensitivities." Aug. 25, 2022. Accessed: Oct. 04, 2022. [Online]. Available: https://www.netzeroaustralia.net.au/wp-content/uploads/2022/08/NZAu-Methods-Assumptions-Scenarios-Sensitivities.pdf

Figure 12 | Cement transition 2030 for all scenarios [1]





R. Batterham et al., "Methods, Assumptions, Scenarios & Sensitivities." Aug. 25, 2022. Accessed: Oct. 04, 2022. [Online]. Available: https://www.netzeroaustralia.net.au/wp-content/uploads/2022/08/NZAu-Methods-Assumptions-Scenarios-Sensitivities.pdf

Figure 13 | Cement transition 2040 for all scenarios [1]

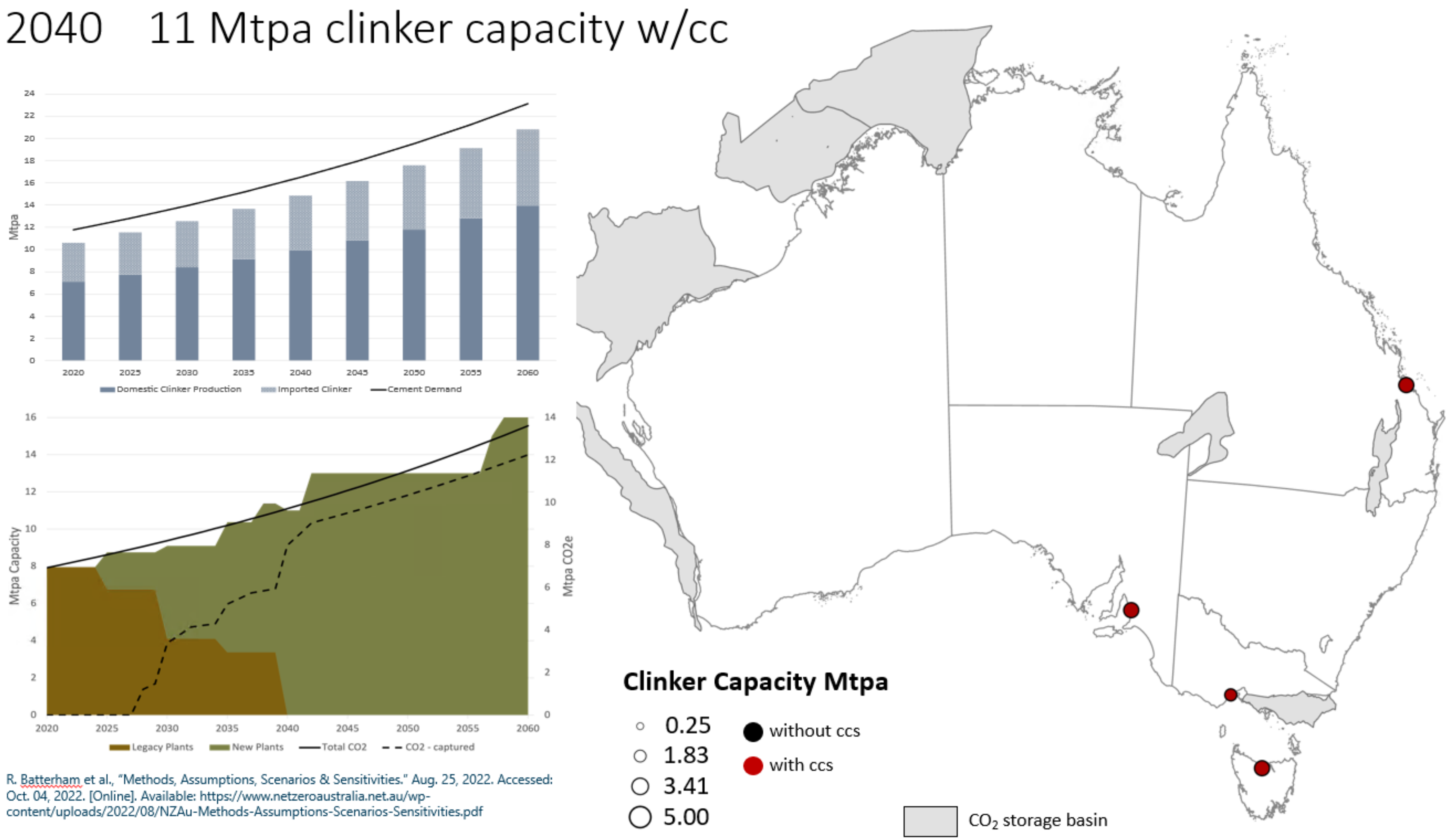


Figure 14 | Cement transition 2050 for all scenarios [1]

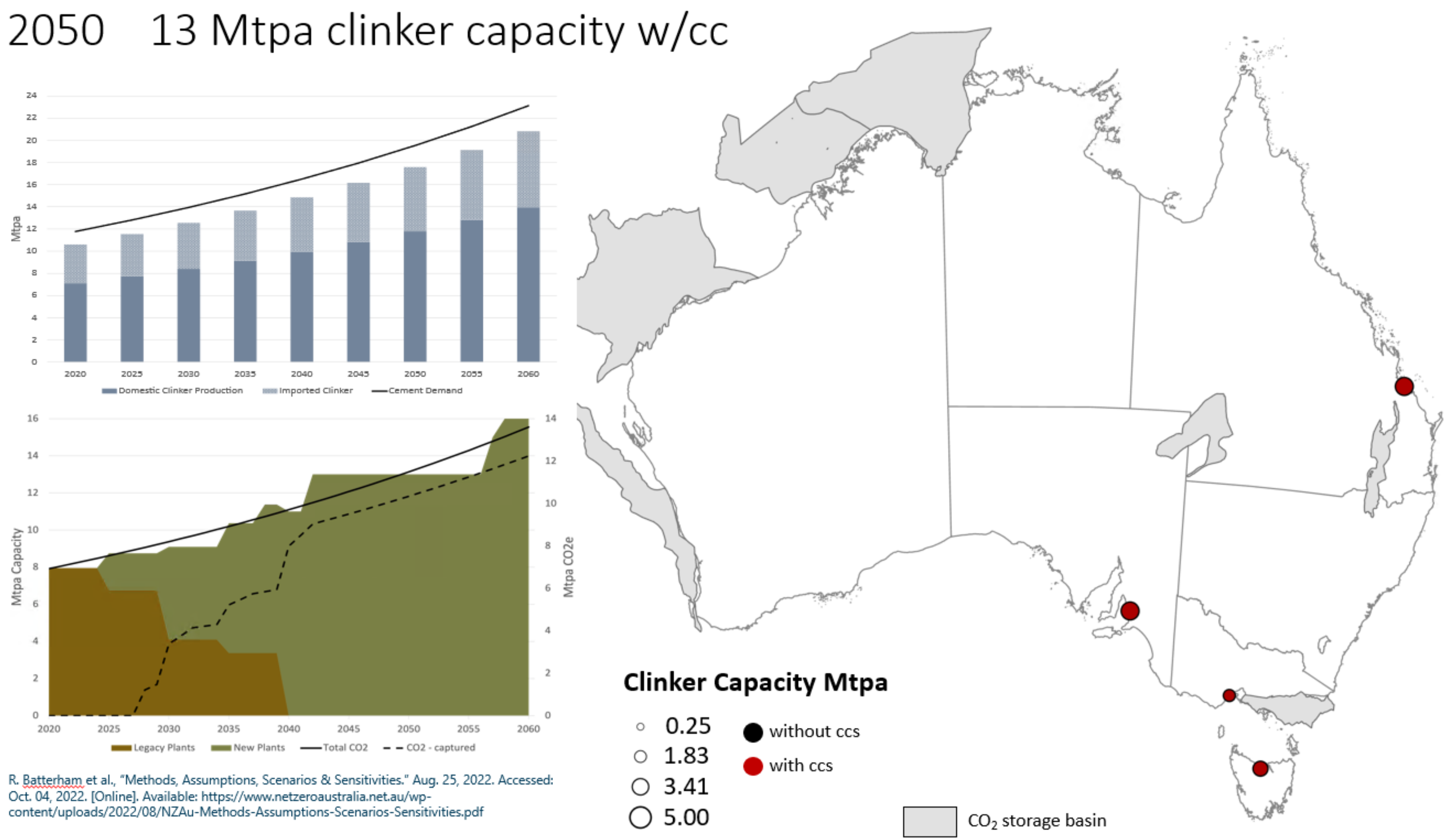


Figure 15 | Cement transition 2060 for all scenarios [1]