Carbon Dioxide Removal and Usage in Aotearoa New Zealand

A summary of carbon capture, utilisation and storage and its possible application in supporting New Zealand's climate goals

Ara Ake
Future Energy Development

Contents

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Glossary

BECCS	Bioenergy carbon capture and storage
CCS	Carbon capture and storage
CCUS	Carbon capture, utilisation and storage
CO_2	Carbon dioxide
CO_2e	CO_2 equivalent (allows matching of different gases' greenhouse potential)
DAC	Direct air capture
EECA	Energy Efficiency and Conservation Authority
ETS	Emissions Trading Scheme
GHG	Greenhouse gases
GIDI	Government investment into industry decarbonisation
GNS	Geological and Nuclear Sciences
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial processes and products use
kt	Kilotonne (1,000 tonnes)
LULUCF	Land use, land-use change forestry
MBIE	Ministry of Business Innovation and Employment
Mt	Megatonne (1,000,000 tonnes)
NCG	Non condensable gas
NZU	New Zealand Unit

Acknowledgements

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Arup
Auckland University of Technology
Beach Energy
Contact Energy
Elemental Group
Energy Resources Aotearoa
Enerlytica
Ernst and Young
Gas Industry Company
Genesis Energy
Geothermal Association of New Zealand
Golden Bay Cement
Mercury Energy
Methanex
NZ Oil and Gas
NZ Steel
OMV NZ
Otago Innovation Ltd
Otago University
Refining NZ
Todd Energy
Top Energy
University of Canterbury
Venture Taranaki
Waikato University
Worley

Executive summary

The Intergovernmental Panel on Climate Change (IPCC) reported in April 2022, that policies in place to reduce emissions as of December 2020 would lead the planet to 3.2 degrees Celsius of warming, more than double the 1.5 degrees limit that scientists say is essential for avoiding the worst impacts of climate change.

The runway to abate emissions is shortening, as the effects of climate and weather extremes are accelerating.

Recently, New Zealand increased its target to reduce greenhouse gas (GHG) emissions from 30 percent below 2005 levels by 2030, to 50 percent below 2005 levels by 2030 as part of our first Nationally Determined Contribution (NDC). NDCs embody efforts by each country to reduce national emissions and adapt to the impacts of climate change. [1]

Overwhelming Parliamentary support was received for the Zero Carbon Act in November 2019, and more recently, the Carbon Budgets through to 2035 have set the pathway for Aotearoa New Zealand to reach net zero emissions by 2050.

The first budget sets the limit of:

- Emissions Budget 1 (2022-2025) 72.4 mt a year
- Emissions Budget 2 (2026-2030) 61 mt a year (in principle)
- Emissions Budget 3 (2031-2035) 48 Mt a year (in principle)

Capturing carbon and removing it from the atmosphere, or using it as a valuable commodity, is being increasingly explored around the world as countries seek to mitigate climate change and meet their international obligations. Reducing emissions is always the priority, but according to the IPCC "the deployment of carbon dioxide removal to counterbalance hard-to-abate residual emissions is 'unavoidable' if net-zero CO_2 or GHG emissions are to be achieved." [2]

So, while various methods for atmospheric carbon dioxide removal are increasingly available – the Intergovernmental panel on climate change (IPCC) says that "carbon dioxide removal cannot serve as a substitute for deep emissions reductions but can fulfil multiple complementary roles: (1) further reduce net CO_2 or GHG emission levels in the near-term; (2) counterbalance residual emissions from 'hard-to-transition' sectors."

The imperatives of personal and corporate effort to reduce our energy demand, and adopt technology for low or zero emissions energy, are first and foremost. Added to these, carbon dioxide removal from the atmosphere and its permanent and stable storage or utilisation, could be an important third step in working to ensure catastrophic climate change does not become the legacy future generations inherit from today's emitters and decision-makers.

In Aotearoa New Zealand, the Climate Change Commission has stated that "Investigating the potential of other options to remove emissions from hard-to-abate industries, such as CCUS or bioenergy combined with CCUS, could be worthwhile." [3]

There is currently limited information about CCUS and its options for Aotearoa New Zealand. The Ministry of Business, Innovation and Employment (MBIE) state on their website, that "the rationale to adopt carbon capture and storage (CCS) technology in New Zealand is different from other countries.

1 Nationally Determined Contributions (NDCs) I UNFCC

2 https://report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_SummaryForPolicymakers.pdf (SPM-47, C.11)

3 Ināia tonu nei: a low emissions future for Aotearoa – Page 290, para 129

Compared to other countries, New Zealand has relatively few point sources of CO_2 emissions and a far higher renewable contribution to electricity generation. This means that CCS has limited potential to help New Zealand mitigate climate change. New Zealand's international approach has been to support the uptake of CCS, in particular by countries that emit large amounts of CO_2. New Zealand's support for the international development of CCS does not prejudge any decision on whether or when CCS might be undertaken in New Zealand." [4]

While the above is true regarding relatively few point sources of CO_2 emissions in New Zealand, there are emerging technologies, such as bioenergy, which could start to play a bigger part in our primary energy. And with that comes the opportunity for capturing and storing the CO_2 to create negative emissions to take us more quickly to net zero in Aotearoa New Zealand.

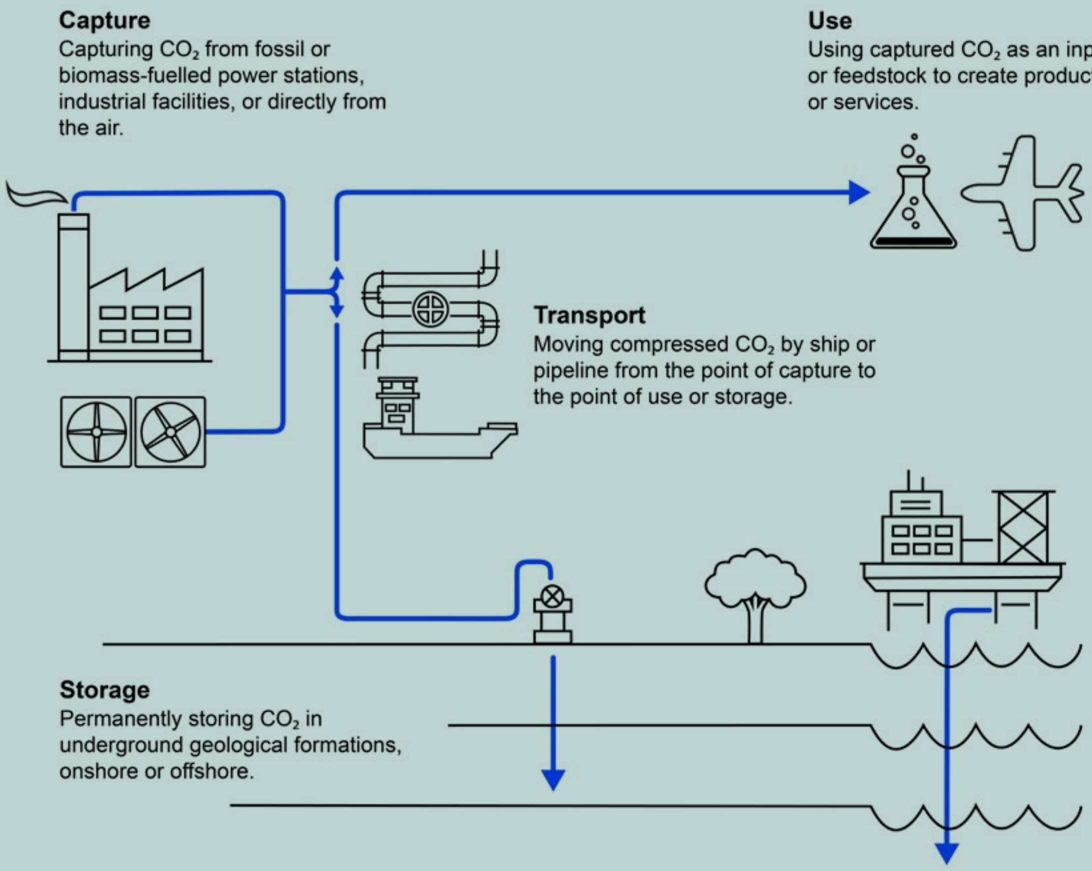
Added to that, technologies such as direct air capture and storage, CO_2 mineralisation, and carbon sequestration through soils and oceans are gaining wider interest and in many cases support.

The purpose of this report is to:

- Promote fresh discussion about the role of carbon capture, utilisation and storage (CCUS) as a tool that Aotearoa New Zealand could utilise as we face the challenge of reducing the detrimental effects of greenhouse gas (GHG) emissions in our atmosphere.
- Highlight emerging technologies that could enable opportunities for "negative emissions" using CCUS which could accelerate the journey to net zero, and potentially beyond.
- Acknowledge carbon dioxide is also a valuable feedstock for low-emission fuels, such as sustainable aviation fuel, and that capturing and utilising waste carbon dioxide can create an economic value chain.
- Emphasise information gaps, such as a thorough geological knowledge of carbon storage opportunities in New Zealand, and an absence of a current assessment (or case studies) on the economic viability of CCUS opportunities.
- Investigate the effectiveness of the Emissions Trading Scheme to support the extraction of carbon dioxide from the atmosphere.

What is carbon capture, utilisation, and storage?

CCUS refers to a suite of technologies that cover the capture of CO_2 from large point sources, including power generation or industrial facilities using fossil fuels or biomass for fuel. It also includes the capture of CO_2 directly from the atmosphere. If not being used on-site, the captured CO_2 is compressed and transported by pipeline, ship, rail, or truck to be used in a range of applications or injected into deep geological formations (including depleted oil and gas reservoirs, saline formations, or potentially ultramafic rock formations) which trap the CO_2 for permanent storage. [5] There are a range of existing and emerging technologies this report will reference.



Reference IEA - About CCUS (2021) https://www.iea.org/reports/about-ccus

Net zero emissions and negative emissions.

There are two main avenues CCUS technologies can help reduce CO_2 emissions (based on the balance between the amount of CO_2 produced and the amount removed from the atmosphere.)

Firstly, net zero emission processes mean the volume of greenhouse gases captured is the same as the volume emitted. For example, a thermal plant can be net zero if all the

5 About CCUS – Analysis - IEA

greenhouse gases produced are captured and permanently stored in the process of generating electricity.

Secondly, negative emission processes are those that remove CO_2 from the atmosphere. Two emerging approaches are gaining momentum, being direct air capture and storage (DACS) and bioenergy with carbon capture and storage (BECCS).

CCUS is often viewed through the lens of large point-source emissions where we may yet see reduction of emissions through technology improvements (NZAS, Tiwai Point Aluminium Smelter),[6] cessation of activity (Refining NZ no longer operates as a refinery at Marsden Point),[7] or fuel switching (Genesis, Huntly power station). [8]

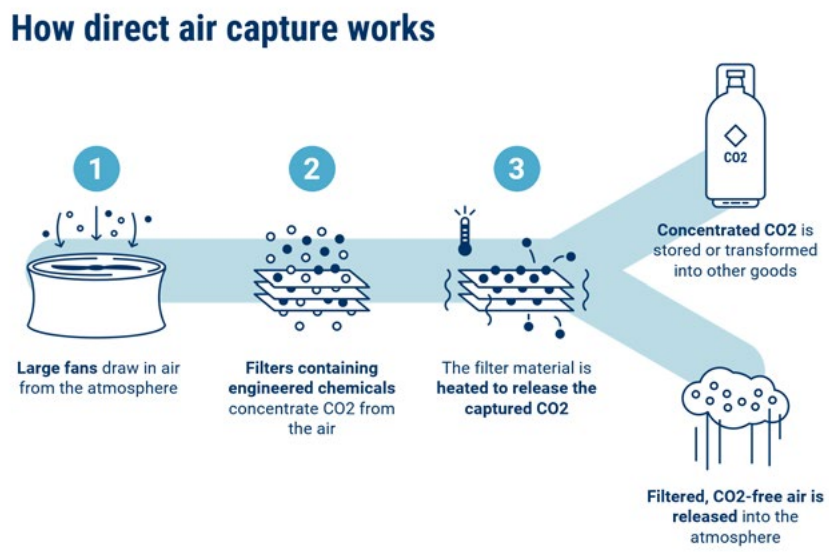
Several geothermal power generators are investigating adopting GHG reinjection technology to eliminate releasing their emissions to the atmosphere.

The Government's GIDI Fund, administered by EECA, has recently invested $5 million to install a biomass boiler and CO_2 recovery unit, understood to be a New Zealand first, at a capsicum growing facility. Emerging technologies and fuel-switching options will reduce emissions in cement making, steel making and dairy processing. Each of those sectors are already applying carbon reduction technologies within their industries.

However, the challenge of abatement should not be over-estimated. The Climate Change Commission has stated that hard-to-abate industries are likely to still be creating significant emissions in 2050.

Read more under "Hard-to-abate industries."

Two emerging approaches are gaining momentum, being direct air capture and storage (DACS) and bioenergy with carbon capture and storage (BECCS).



6 Carbon free aluminium smelting a step closer: ELYSIS advances commercial demonstration and operates at industrial scale
7 Shareholders Vote to Close Marsden Point Refinery, Cutting 1Mt CO2 Emissions From NZ Books | Newsroom
8 Forestry Waste Trial Offers Lifeline to Huntly Power Plant | Newsroom

Existing technologies

For successful carbon capture using existing technologies, large point-source emissions including thermal power stations, cement works, steel making, aluminium manufacture, oil refining and/or large chemical manufacturers (methanol or fertilisers) are preferable; rather than dispersed emissions from smaller point-sources such as cars, small industrial boilers, or home-heating systems. This is because existing carbon capture technologies are capital intensive, expensive and best used at scale.

However, due to New Zealand's limited number of point-source emissions and their geographic dispersal, the advantages of scale and proximity are weakened.

CO_2 could be stored in depleted petroleum, geothermal or saline reservoirs deep underground. Todd Energy cited that subsurface storage is the most mature of carbon storage technologies available to New Zealand, and their Kapuni gas field is the single best example and opportunity for CO_2 storage in New Zealand. The Kapuni field has a long history of reinjecting gas for the purpose of advanced oil (condensate) recovery.

OMV say research is needed to confirm that compatibility exists if CO_2 were to be stored in a subsurface reservoir which has not previously held CO_2. It would also be better to start using depleted reservoirs which previously had a high CO_2 content. The Kapuni field has delivered gas with high CO_2 content in the past.

However, any consideration of a permanent subsurface storage site would first need legislative enablement and then would be subject to a stringent testing and monitoring regime. GNS, the Crown Research Institute, has a long history of investigating subsurface reservoirs in New Zealand.

Emerging technologies

New capture technologies such as bioenergy carbon capture, direct air capture and CO_2 mineralisation are gaining momentum. Other emerging technologies include carbon (biochar) sequestration in soils, advance weathering and ocean fertilisation.

Direct Air Capture and storage (DACS)

Direct Air Capture (DAC) technology coupled with geological sequestration offers an opportunity to draw down atmospheric CO_2 with minimal land use impact compared to afforestation. Dr. Rajat Panwar of Appalachian State University in Boone, North Carolina says, "It's worth pointing out that a single Carbon Engineering DAC plant sequesters about 100 times more atmospheric carbon dioxide than a forest occupying the same land area, and that the land under a DAC plant does not need to be arable." [9]

However, the technology required to implement DAC on a scale large enough to significantly impact global CO_2 levels is still in its infancy with plants operating worldwide on a small scale. Direct air capture offers the potential that carbon capture will be able to include more distributed CO_2 sources.

Today, two technology approaches are being used to capture CO_2 from the air: liquid and solid DAC. Liquid systems pass air through chemical solutions (e.g., a hydroxide solution), which removes the CO_2. The system reintegrates the chemicals back into the process by applying

9 Expert: Beware Of Simple Solutions - Tree Planting Won't Solve Climate Change

high-temperature heat while returning the rest of the air to the environment.

Solid DAC technology makes use of solid sorbent filters that chemically bind with CO_2. When the filters are heated and placed under a vacuum, they release the concentrated CO_2, which is then captured for storage or use. [10]

Currently the DAC market is dominated by three companies; the Swiss based Climeworks, Canada Based Carbon Engineering, and the United States based Global Thermostat. Each has adopted a different approach and technology, from Climeworks who have opted for a modular system which can be scaled to suit the desired level of CO_2 drawdown, to Global Thermostat who have developed a suite of DAC solutions ranging from hybrid point source DAC to pure DAC.

The most recent economic assessment of DAC suggests it costs between US$94 and $232 per tonne of CO_2 removed from the atmosphere, depending on the design of the DAC plant and other economic assumptions (e.g., country or region specific OPEX variations). [11]

It is likely DAC will require financial support to realise rapid efficiency gains and drive down the cost per tonne of recovered CO_2. However, the price of carbon credits is increasing and is already within that cost range in the European market.

A significant economic opportunity exists in adopting DAC coupled with permanent geological sequestration through the sale of carbon credits. DAC requires no land-use change with a very small surface footprint compared to a forest sink and can potentially be co-located with a geological sink. New Zealand would have the added benefit of powering DAC with near 100% renewable electricity.

The International Energy Agency reports that the “Momentum for direct air capture is growing. DAC plants currently operate at a small scale, but with plans to grow. Currently 19 DAC facilities are operating in Canada, Europe, and the United States. All but two of these facilities sell their CO_2 for use, and the largest such plant – commissioned in Iceland in September 2021 – is capturing 4,000 t CO_2/year for storage (via mineralisation). The first large-scale DAC plant of up to 1 Mt CO_2/year is in advanced development and is expected to be operating in the United States by the mid-2020s.” [12]

Bioenergy with carbon capture and storage (BECCS)

Bioenergy with carbon capture and storage – known as BECCS – is regarded as one of the most viable and cost-effective negative emissions technologies.

The concept of BECCS is growing biomass for energy purposes. As it grows, the biomass absorbs atmospheric CO_2 through photosynthesis. The biomass is then processed into a fuel form, often pellets. As the fuel combusts, the carbon it is made of forms biogenic CO_2. Biogenic CO_2 is typically counted as a net-zero emission in most Greenhouse Gas accounting schemes.

The New Zealand Government’s publication ‘Measuring Emissions: A Guide for Organisations’, states that “The carbon dioxide emitted from the combustion of biofuels and biomass (including wood) is biogenic, meaning it equates to the carbon dioxide absorbed by the feedstock during its lifespan. This means we treat the carbon dioxide portion of the combustion emissions of biofuels as carbon neutral.” [13]

10 Direct Air Capture – Analysis - IEA
11 A Process for Capturing CO2 from the Atmosphere - ScienceDirect
12 Direct Air Capture 2022 – Analysis - IEA
13 Measuring Emissions Detailed Guide 2020 – Page 26

The IPCC states that “Bioenergy has significant potential to mitigate GHGs if resources are sustainably developed, and efficient technologies are applied. Certain current systems and key future options including perennial crops, forest products and biomass residues and wastes, and advanced conversion technologies, can deliver significant GHG mitigation performance - an 80 to 90% reduction compared to the fossil energy baseline.” [14]

Genesis Energy has indicated it is planning a trial which may lead to converting the Huntly power station from coal-fired generation to biomass-fired generation. As biogenic CO_2 is counted as a neutral emission, this would bring a significant reduction in the accounting of CO_2 emissions in the energy sector. Marc England, Chief Executive of Genesis Energy, is enthusiastic on the potential to replace fossil fuels with advanced fuel pellets and to provide a dry-year solution that is renewable. He says the pellets are energy-dense, low moisture, and can be stored outdoors, making them a near drop-in replacement for coal. [15]

Biomass pellets

The advantage of using biomass in the form of a pellet is its energy density. This refers to the amount of energy that can be stored in a given amount of a material.

On their own the wood and residues like wood chips and sawdust that make up biomass do not have a high energy density. A kilogram of wood, for example, stores little energy, compared to fuels like coal or diesel.

However, by compressing forest industry residues into a pellet, biomass becomes significantly more energy dense. Wood pellets can also have very low moisture content, giving them a high combustion efficiency – an important feature in power generation.

The wood is chipped, screened for quality, heated to reduce its moisture content to below 12% and then converted into a fine powder. This is then pressed through a grate at high pressure to form the solid, short, dense biomass pellet.

Biomass pellets can be used to generate power in a similar way to coal, allowing existing coal power stations to be transformed to use renewable bioenergy instead. A conveyor system takes pellets from storage through to pulverising mills, where they are crushed into a fine powder that is then blown into the power station’s boiler. Here the biomass is combusted as fuel, the heat from this combustion is used to make steam which powers the generators that produce electricity.

14 Bioenergy — IPCC – Page 306
15 Genesis imports US wood pellets to fuel Huntly renewable energy trial | Newsroom

The Ministry for Primary Industries recently reported in their Wood Fibre Futures report on the viability of wood-based alternatives to high carbon emitting products such as transport fuel, concrete, steel, and coal. [16]

Scion earlier reported that the potential for GHG reductions at a national level from substituting wood for coal is estimated to be around 900,000 to 1,000,000 tonnes of CO_2e per annum. [17]

Bioenergy is still a nascent technology in New Zealand and is proving its commercial viability. Challenges to be worked through include developing and strengthening a biomass supply chain as well as ensuring regulations cover BECCS to enable the negative emissions it produces, to be counted.

The Energy Efficiency and Conservation Authority (EECA) recently stated in their report 'Accelerating the Decarbonisation of Process Heat' that "The market sounding has revealed that even when economic incentives align to support fuel switching, there are significant capacity constraints across the fuel supply chain (depth and liquidity) both locally and internationally, which may result in process heat users paying more for heat for an extended period." [18]

As part of their consideration of converting the Huntly coalfired rankines to biomass, Genesis is concerned that the biomass supply chain is not yet sufficiently developed to support their requirements. Their hope is that if several large energy users can create a consortium of sorts, this could create enough demand certainty for the market to be established to deliver the right product every time.

Carbon dioxide mineralisation

Carbon mineralisation was proposed 30 years ago as a strategy for CO_2 removal from the atmosphere. [19]

Carbon mineralisation is the process by which carbon dioxide becomes a solid mineral, such as a carbonate. It is a chemical reaction that happens when certain rocks are exposed to carbon dioxide. The biggest advantage of carbon mineralization is that the carbon cannot escape back to the atmosphere.

It happens naturally, but the process can be sped up artificially. Most of the rocks that have the potential for carbon mineralisation are igneous or metamorphic, as opposed to porous sedimentary reservoirs. [20]

A scientific investigations report produced by the U.S. Department of the Interior and the U.S. Geological Survey in 2019 refers to the reaction rates for CO_2 mineralisation. Ordinarily this takes thousands of years, yet they describe two pilot projects using basalts that have shown nearly complete mineralisation of injected CO_2 in less than 2 years. [21]

Carbon mineralisation can be divided into three approaches:

- ex situ, where the material is transported to the site and reacted with CO_2 typically at elevated temperatures and pressures,
- surficial, using dilute or concentrated CO_2, and
- in situ, where the CO_2 is transported to the site with suitable geological formations, typically containing serpentine or olivine-bearing basalts. [22]

Several materials have been proposed for carbon mineralisation, including serpentine, olivine, wollastonite, magnesium oxide, and magnesium hydroxide.

New Zealand's geography provides rocks suitable for mineral sequestration. These rocks, collectively known as 'ultra-mafic rocks', extend along the length of the South Island, under the North Island, and exist in isolated pockets throughout the country (e.g., near Bluff).

16 Accelerating New Zealand's investment into biofuels | NZ Government
17 Scion - Biomass for industrial heat
18 Accelerating-the-decarbonisation-of-Process-Heat.pdf – Page vii
19 Frontiers | An Overview of the Status and Challenges of CO2 Storage in Minerals and Geological Formations | Climate
20 Making Minerals-How Growing Rocks Can Help Reduce Carbon Emissions | U.S. Geological Survey
21 sir20185079.pdf - Carbon Dioxide Mineralization Feasibility in the United States – Page 4
22 Transformation of abundant magnesium silicate minerals for enhanced CO2 sequestration | Communications Earth & Environment (Dr. Allan Scott, University of Canterbury)

The carbonation reaction consists of an induced exothermic alteration of metal-rich minerals (i.e., olivine, serpentine) to carbonate minerals (i.e., magnesite). The resulting carbonate minerals are thermodynamically stable and therefore will not release CO_2 back into the atmosphere.

Research on rock formations shows that natural reactions have taken place at depth with total carbonation of rocks in some cases. In some regions there is evidence that reactions are occurring today. [23]

New Zealand has an abundance (several thousand cubic kilometres) of CO_2-reactive rocks. The current scientific consensus indicates that if only a fraction (0.15 percent) of this rock volume is converted to carbonate, multiple gigatonnes of carbon could be sequestered. [24]

Several solutions exist for ex situ mineralisation that provide valuable products such as building materials, which can be alternatives to existing products such as adhesives, sealants, paints, coatings, paper, cement, construction materials, food, and pharmaceutical products (while also storing CO_2). [25]

Ex situ mineralisation offers the opportunity to sequester distributed CO_2 emissions, especially if the source of reactive rock is close to the source of emissions.

Currently in New Zealand significant research is underway at Otago University and University of Canterbury regarding carbon mineralisation. The next step for this research is to be demonstrated in the field.

Olivine sand can absorb its own weight in CO_2

23 Dr. Christian Ohneiser, Department of Geology, University of Otago. Dr. Luke Taylor, Otago Innovation Ltd.

24 Ibid

25 Frontiers | Calcium Carbonate Precipitation for CO2 Storage and Utilization: A Review of the Carbonate Crystallization and Polymorphism | Energy Research

Storing carbon in agricultural soils

Massachusetts Institute of Technology Scientists have estimated that soils - mostly, agricultural ones - could sequester over a billion additional tonnes of carbon each year. This has led policymakers to increasingly look to soil-based carbon sequestration as a "negative emissions" technology – that is, one that removes CO_2 from the air and stores it somewhere it can't easily escape.

Cropland, which takes up 10% of the Earth's land, is a major target for soil-based carbon sequestration. Farmers can add more carbon to agricultural soils by planting certain kinds of crops. For example, perennial crops, which do not die off every year, grow deep roots that help soils store more carbon. "Cover crops" like clover, beans and peas, planted after the main crop is harvested, help soils take in carbon year-round, and can be plowed under the ground as "green manure" that adds more carbon to the soil. Farmers can also do less intensive tilling.

By breaking up the soil, tilling prepares land for new crops and helps control weeds, but also releases a lot of stored carbon. [26]

Storing carbon in agricultural soils through biochar is an emerging technology which offers promise is returning carbon to the soil with claims of enhancing both forest health and soil health. The term biochar has been around for about 10 years although using charcoal in soil has been around for several thousand years. [27]

Enhanced weathering and Ocean Fertilisation

Less developed approaches include enhanced weathering to accelerate natural processes that absorb CO_2 (for example, by adding very fine mineral silicate rocks to soils) or ocean fertilisation in which nutrients are added to the ocean to increase its capacity to absorb CO_2. Enhanced weathering and ocean fertilisation approaches require further research to understand their potential for carbon removal as well as their costs, risks and trade-offs. [28]

26 Soil-Based Carbon Sequestration | MIT Climate Portal
27 A Definition of Biochar - Pacific Biochar Benefit Corporation
28 Going carbon negative: What are the technology options? – Analysis - IEA

Capturing CO_2

There are a number of technologies being used to capture CO_2.

- Pre-combustion: Fuel is decarbonised prior to its use.
- Post-combustion: carbon dioxide is removed from the flue gas created from an industrial process.
- Oxyfuel: Fuel is combusted in pure oxygen rather than air to produce flue gas that is rich in carbon dioxide without any nitrogen.
- Bioenergy carbon capture and storage: carbon dioxide from the atmosphere is absorbed via photosynthesis into the biomass of plants, which is then combusted in power plants.
- Direct air capture: Uses chemical or thermo-electric processes to capture and separate carbon dioxide directly from ambient air.
- Carbon mineralisation: uses naturally occurring minerals to chemically capture CO_2 either in-situ or ex-situ.

Transporting CO_2

If subsurface reservoirs are used to permanently store captured carbon dioxide, suitable locations for these facilities may be some distance from the point of emissions. Therefore, transportation (including road, rail, ship, and pipeline options) will be required to enable that storage.

New Zealand has experience in the handling and transportation of CO_2. Liquid CO_2 has been trucked from Kapuni Gas Treatment Plant in specialty vehicles to points of use. In the past, Taranaki has also transported CO_2 rich gas via pipeline to the methanol production facilities in north Taranaki.

The shipping of CO_2 is another alternative to trucking or piping CO_2 to points of permanent storage. Liquefied CO_2 is loaded onto ships using conventional cryogenic loading arms. CO_2 shipping has been carried out globally for more than 30 years with most demand coming from the food and beverage industry. All existing CO_2 carriers are small vessels, with capacities up to 2,500t.

Storage of CO_2 in New Zealand

The largest CO_2 storage potential is geological storage. In this process the captured CO_2 is injected into a deep reservoir and stored within rock pores or fractures.

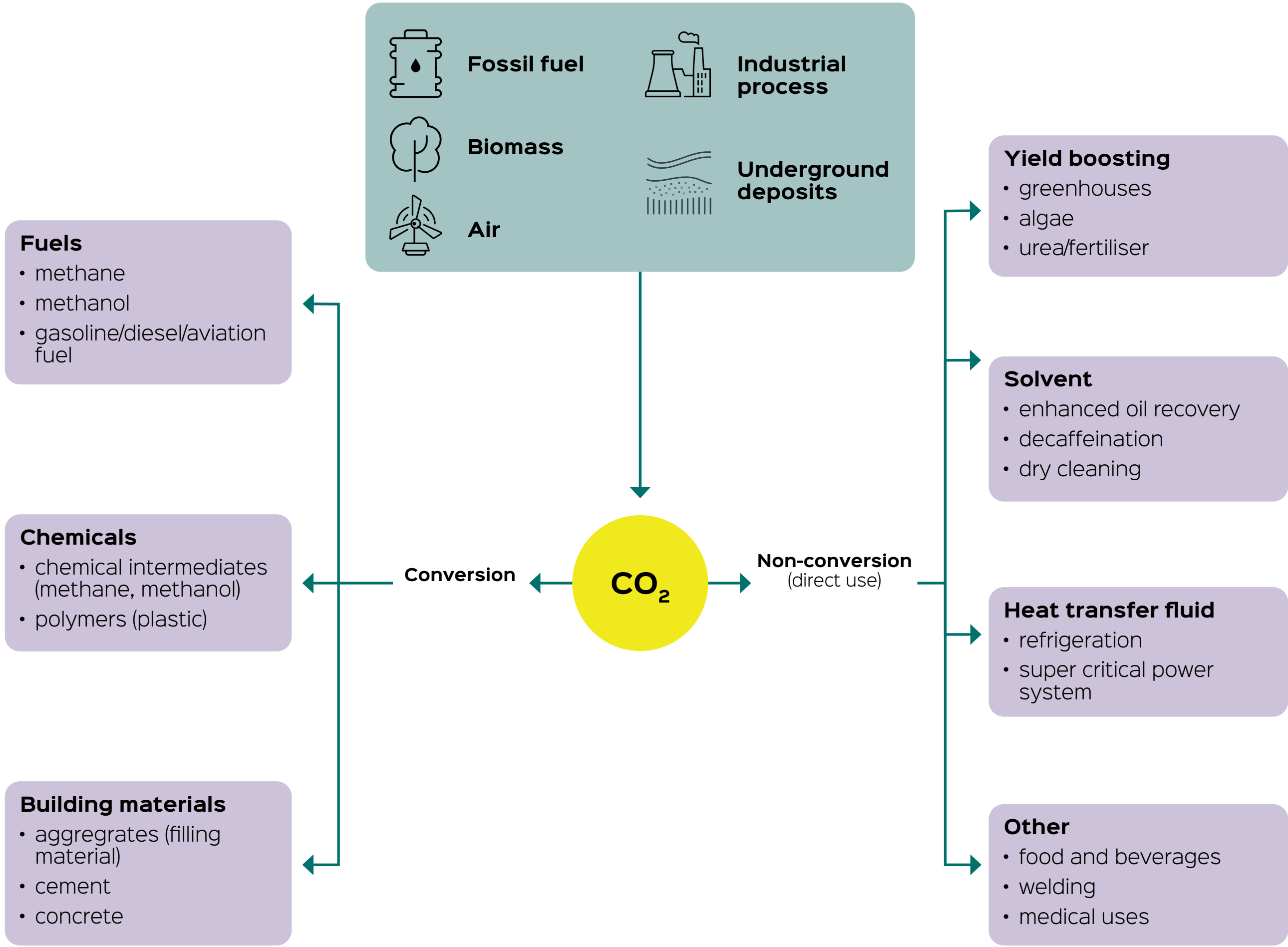
Four geological storage types identified in New Zealand are depleted petroleum fields, geothermal reservoirs, deep saline aquifers and ultramafic rock formations:

Depleted petroleum fields

For years, the Kapuni field reinjected gas. This was an enhanced oil recovery process and proved that reinjection is possible into a petroleum reservoir in Taranaki.

Due to the chemical properties of CO_2, it is recommended that it is stored at depths greater than 800 metres. Over the last century 1,209 wells having been drilled across the Taranaki region, therefore potential carbon storage sites are well understood with an estimated capacity for 572 Mt of carbon dioxide (nine years of New Zealand's net carbon dioxide emissions). [29]

However, a thorough technical assessment is essential to ensure the reservoir conditions are suitable to permanently hold the CO_2 and ensure the risk of leakage is extremely low.



Simple classification of pathways for CO_2 use - Source IEA

29 Opportunities for underground geological storage of CO2 in New Zealand - Report CCS-08/5 - Onshore Taranaki Basin overview December 2009

Geothermal reservoirs

Geothermal reservoirs may also be suitable for returning CO_2 to the reservoir it came from. It is likely at least 568,000 tonnes a year (the volume of emissions from geothermal power generation) can be sequestered. This is mainly around the central plateau between Taupo and Rotorua. [30]

Currently several geothermal generation plants are preparing trials for CO_2 reinjection. Contact Energy have stated they will soon be commencing trials to reinject non condensable gas (NCG). [31]

Saline Aquifers

GNS estimates that 16,000 Mt CO_2 could be stored in deep saline aquifers across New Zealand. They say that aquifers at depths greater than about 800 meters below ground level in the Taranaki Peninsula contain saline water (defined as >10,000 ppm total dissolved solids). Saline water-bearing reservoirs occur at virtually all stratigraphic levels within the Taranaki Basin. There appears to be plenty of potential to store CO_2 in such reservoirs, safely beneath any potentially usable potable groundwater aquifers and many of the petroleum exploration wells drilled onshore could provide suitable locations for injecting CO_2 into the subsurface. [32]

Ultramafic rock formations

See the section on carbon mineralisation.

It is likely at least 568,000 tonnes a year (the volume of emissions from geothermal power generation) can be sequestered.

30 New-Zealand-Greenhouse-Gas-Inventory-1990-2020-Chapters-1-15 – Page 106
31 Contact Energy – Emission Reduction Opportunities – Slide 7
32 Opportunities for underground geological storage of CO2 in New Zealand -Report CCS -08/5 -Onshore Taranaki Basin overview – Page 103

Stability of geological storage

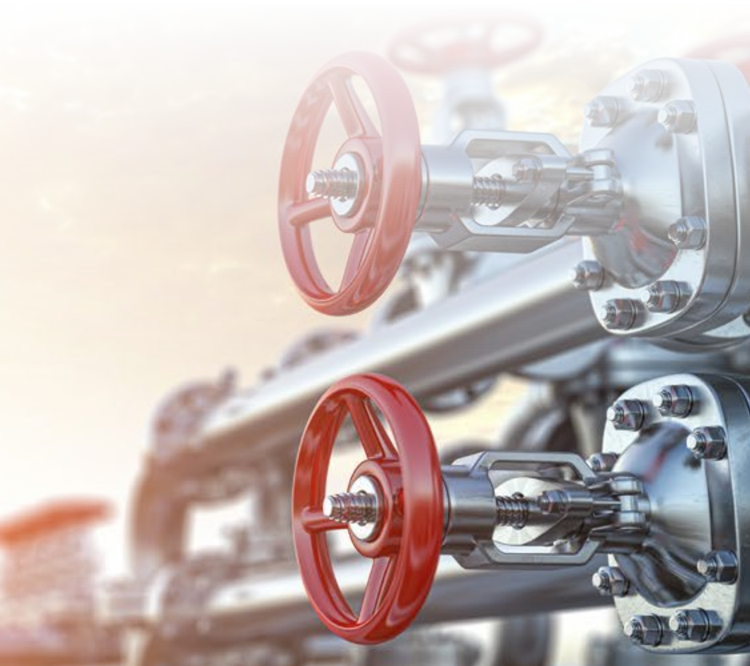
A 2019 scientific investigation report by the U.S. Department of the Interior and the U.S. Geological Survey talks about the stability of mineralisation in storing CO_2 with CO_2 mineralisation being the best process for permanent storage.

A 2018 report by Dr Juan Alcalde from the School of Geosciences, Kings College, University of Aberdeen, highlights the importance of regulating and monitoring subsurface reservoirs regarding their stability for storing CO_2. It states that "CO_2 retention in storage reservoirs was recently assessed as 98 percent over 10,000 years for well-managed reservoirs, and 78 percent for poorly regulated ones." [33]

OMV have suggested research is needed to confirm that compatibility exists if CO_2 were to be stored in a reservoir where it was not held previously. It would also be better to start using depleted reservoirs which previously had a high CO_2 content such as the Kapuni field.

Further investigation would be required to be assured of long-term integrity of the cap rock with seismic coverage of the reservoir, so any potential leakage points would be known.

The Ahuroa underground gas storage facility, opened in Taranaki in May 2011, demonstrated gas can be injected and stored in a reservoir and remains an example for the stability of geological storage.[34] The reservoir is located 3km underground in the Tariki sandstone formation. It was studied and deemed excellent for storage due to its high reservoir quality and integrity.



33 Estimating geological CO2 storage security to deliver on climate mitigation | Nature Communications
34 Ahuroa Underground Gas Storage Facility - Hydrocarbons Technology

Carbon Dioxide Trapping

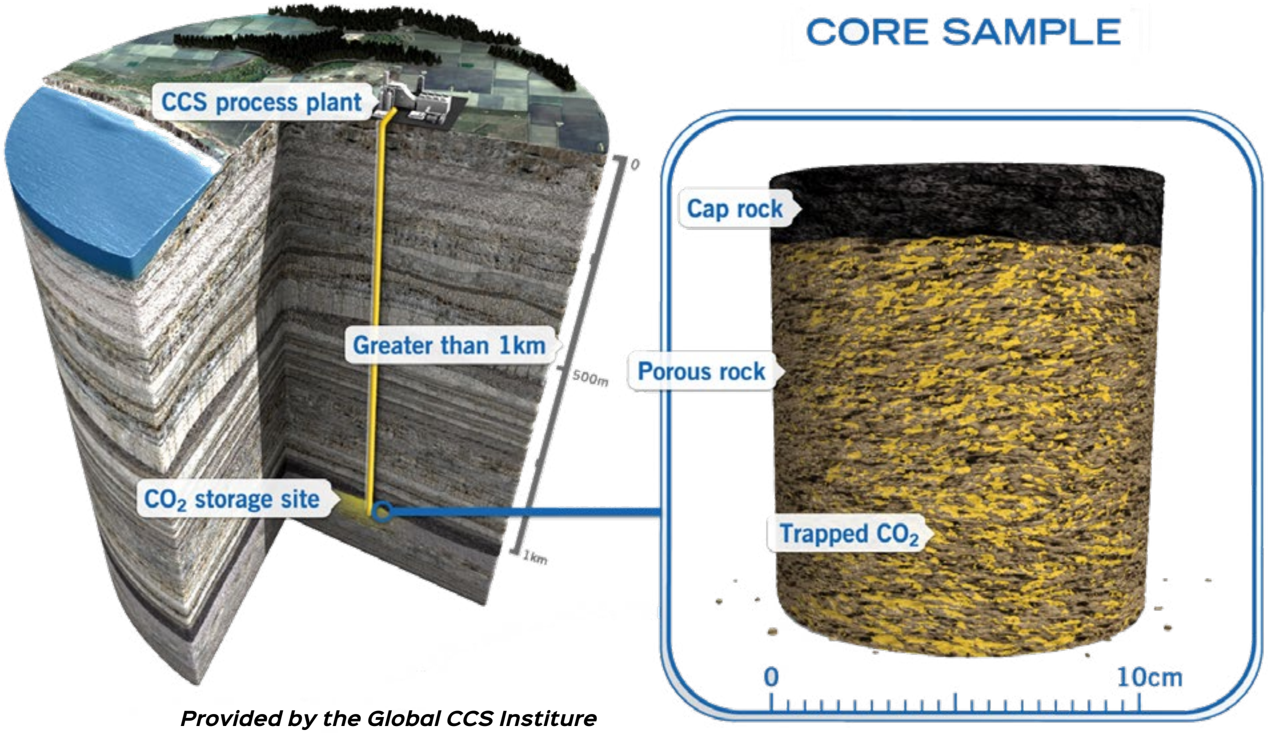
The Global CCS Institute provide a factsheet on different aspects of CO_2 trapping in geological storage.

There is structural trapping, solution trapping, residual trapping, and mineral trapping – all ways in which the CO_2 is trapped in the host reservoir.

Once captured, the CO_2 is compressed into a fluid almost as dense as water and pumped down through a well into a porous geological formation. The pores in underground formations are initially filled with a fluid – either oil, gas, or salty water.

Because injected CO_2 is slightly more buoyant than the salty water that co-exists within the storage formation, a portion of the CO_2 will migrate to the top of the formation and become structurally trapped beneath the impermeable cap rock that acts as a seal. In most natural systems, there are numerous barriers between the reservoir and the surface.

Some of the trapped CO_2 will slowly start to dissolve into the saline water and become trapped indefinitely, called solution trapping; another portion may become trapped in tiny pore spaces referred to as residual trapping. The ultimate trapping process involves dissolved CO_2 reacting with the reservoir rocks to form a new mineral. This process, called mineral trapping, may be relatively quick or very slow, but it effectively locks the CO_2 into a solid mineral permanently.



Provided by the Global CCS Institute

https://www.globalccsinstitute.com/resources/ccs-image-library/

Utilisation of CO_2

Even though CO_2 contributes to climate change, it also has a number of uses in our society including food and beverage production, iron and steel production, hydrogen production, methanol production, ethanol production, natural gas processing, fertiliser production, oil refining, synthetic natural gas and chemical production. Sustainable aviation fuels also require CO_2.

In New Zealand, CO_2 is most commonly utilised in the horticulture and food / beverage industry and is transported from some oil and gas sites in New Zealand to the point of use.

Methanol production in Taranaki also benefits from a CO_2 rich gas, which in the past came from the Kapuni gas production site. To a lesser extent CO_2 is used for refrigeration and medical uses.

CO_2 is a valuable feedstock for industry. For instance, the New Zealand market will be deficient of approximately 100,000 tonnes of industrial CO_2 a year (mostly for the food and beverage sector) due to the Marsden Point refinery closure. New Zealand will need to import CO_2 as the remaining domestic production of industrial quality CO_2 is currently insufficient to meet market needs.

Imported CO_2 will cost significantly more than domestically produced CO_2 and come with added transportation emissions from Asia to New Zealand.

Eventually bioenergy carbon capture and direct air capture may offer opportunities to supply CO_2 for industrial purposes or low emission fuels. Other current CO_2 emitters may also be able to capture, purify, store, and deliver their CO_2 to the New Zealand market.

While the focus should be on removing emissions, a holistic approach in a low carbon economy could see captured CO_2 produce low carbon fuels and chemicals. An example of this approach is Methanex and their partners world's first pilot renewable methanol plant in Iceland, which utilises emissions-to-liquids technology, converting renewable energy and captured CO_2 emissions into renewable methanol.[35] An increasing use of methanol is for low emission shipping fuel.

As CO_2 is an essential component for developing low carbon fuels, it could have a part to play in the energy transition for future fuels as they become economic to use. It has been suggested that CO_2 could be temporarily stored in geological reservoirs, similarly to natural gas being temporarily stored in the Ahuroa gas storage facility, and then extracted and utilised as needed.

CO_2 can also be used in the construction industry to replace water in concrete, called CO_2 curing or carbon curing, or as a raw material in cement and/or construction aggregates. The CO_2 is reacted with minerals or waste streams, such as iron slag, to form carbonates, the form of carbon that makes up concrete. This conversion pathway is typically less energy intensive than standard pathways for fuels and chemicals, plus CO_2 is permanently stored in the materials. [36]

However, despite the opportunities to utilise CO_2, it is important to be aware that CO_2 emissions are significantly larger in magnitude than the amount that can be utilised.

35 Methanex and Carbon Recycling International Sign Landmark Investment Agreement for Advanced Renewable Fuel Production | Methanex Corporation
36 Carbon-negative roads could save planet - Asia Pacific Infrastructure

Hard-to-Abate Industries

The New Zealand Climate Change Commission in its Advice to the Government (2021) said hard-to-abate industries are likely to still create significant emissions in 2050, but provide products that are fundamental to the economy, like cement, steel, and iron and that New Zealand has a choice as to whether it is critical to keep these industries and manufacturing plants based in this country. [37]

Across New Zealand's industrial sector, there are commitments to CO_2 reduction and this to be continually encouraged and expected.

The question the Climate Change Commission asks is whether carbon removal and storage could support atmospheric CO_2 reduction for these hard-to-abate industries. There are economic and social questions to consider, but there is also the issue of "emissions leakage" to consider if a domestic solution is not found.

The Ministry for the Environment's public discussion document on the emissions reduction plan, refers to emissions leakage. [38]

Emissions leakage

With New Zealand's grid being 80 percent renewable, our electricity is much cleaner than many other countries in the world where replacement products would need to be sourced. Global transportation is also likely to increase the carbon emissions component in sourcing these commodities.

37 Ināia tonu nei: a low emissions future for Aotearoa – Page 306
38 Emissions-reduction-plan-discussion-document.pdf – Page 39

MBIE's Departmental Report to the Environment Select Committee on the amendments to the Crown Minerals (Petroleum) Amendment Bill in 2019 stated that "in the case of steel, if New Zealand were to start to import more steel to offset a drop in local production it is likely, based on historical import trends, to come from Australia and Indonesia. Both countries have average emissions intensity in electricity which is 5 – 6 times more than New Zealand. The implication is that importing steel from overseas rather than making it in New Zealand will result in an increase to global emissions. A similar comparison can be made for importing more urea compared with urea produced in New Zealand." [39]

The Commission stated if New Zealand keeps existing emitting plants, it may be possible to use forests to offset the emissions associated with some of these processes and that investigating the potential of CCS or bioenergy combined with CCS, could be worthwhile.

The tradeoff should not be that hard-to-abate industries can continue with historic levels of emissions. The rising carbon price and reducing level of free NZU (units) to trade exposed industries, means their business models are being challenged as the ETS is designed to do. Progress in their decarbonisation journey must continue at pace.

The Drax power station in North Yorkshire, UK, is being modified from coal-fired into a biomass-fired power station. Carbon capture technology is being installed on two of the four biomass-fired generation units. BECCS will enable up to 95 percent of CO_2 emitted during electricity generation to be captured, delivering up to 8 $MtCO_2$ of negative emissions per year. Storage will be in the North Sea. This project is part of a larger programme to eventually use CCS on all four of its bioenergy units by the mid 2030's.

39 Ministry of Business Innovation and Employment, Departmental Report – Page 37

Scale of the CCUS opportunity in New Zealand

The drivers for CCUS in New Zealand are different to other countries, as most greenhouse gas (GHG) emissions come from sectors where CCUS is not viable, such as agriculture (40 Mt CO_2 a year) and transport (17 Mt CO_2 a year) due to lack of point-source capture opportunities.

The main sectors where CCUS could potentially be deployed include energy (22 Mt CO_2 a year), industrial (5 Mt CO_2 a year) and waste (3 Mt CO_2 a year), which make up approximately 36 percent of the country's gross emissions.

Land use, land use change, and forestry (LULUCF) tracks GHG removals through forestry, crops, and pasture. It is the only sector where CO_2 is removed from the atmosphere (23.4 Mt CO_2 a year).

Electricity generation is responsible for 5 percent of our GHG emissions.

Most of New Zealand's geothermal electricity generators are centred around the Taupo Volcanic Zone. About 550,000 tonnes of carbon emissions are produced a year when geothermal fluid is extracted from the ground and dissolved CO_2 is released. As power stations are located above geothermal reservoirs, CCUS for geothermal plants, including using CO_2 in horticulture, is likely to be easier and cheaper than for other emission sources such as coal or gas-fired power plants. Each of the geothermal generators have indicated they are investigating CO_2 reinjection in their operations.

In 2019, emissions in the Industrial Processes and Product Use (IPPU) sector contributed 6.2 percent of New Zealand's gross GHG emissions. The largest category is the metal industry, with substantial CO_2 emissions from iron, steel, and aluminium production. The mineral and chemical industry categories also contribute significant CO_2 emissions. These emission sources may be suitable targets for CCUS application.

International examples of carbon capture and storage

Carbon capture and storage investment has recently increased, driven by renewed focus on decarbonising historically high emission sectors.

As of November 2021, CCUS technology is currently deployed in 27 localities globally with the combined capacity to capture around 40 million tonnes per annum (Mtpa) of CO_2. In addition to the 27 commercially operating carbon capture and storage facilities globally, another four are being constructed, 58 are in advanced development and 44 are in early development.[40] This compares with the 37 projects identified in 2017. The IEA add that recent announcements lifts this to nearly 200 projects.[41] The capture capacity of all these projects is 149.3 Mtpa.

Norway

When it starts operations in 2024, Northern Lights will be the first ever cross-border CO_2 transport and storage infrastructure network. It will offer companies across Europe the opportunity to store their CO_2 safely and permanently deep under the seabed in Norway. The company is building two dedicated CO_2 carriers and will ship captured CO_2 to an onshore terminal on the Norwegian west coast and, from there, transport it by pipeline to an offshore subsurface storage location in the North Sea. Phase one of the project will be completed mid-2024 with a capacity of up to 1.5 million tonnes of CO_2 per year. The ambition is to expand capacity by an additional 3.5 million tonnes to a total of 5 million tonnes, dependent on market demand. The receiving terminal, offshore pipeline, and the umbilical to the offshore terminal will be built to accommodate the additional volumes. Both phases will offer flexibility to receive CO_2 from European sources. The Norwegian Government believes CCUS will be important for Europe to achieve its carbon neutrality targets, however its overall success relies on other European countries participating and contributing financially to the project as well. [42]

Northern Lights is a partnership between Equinor, Shell and Total, and is a key component of Longship, the Norwegian Government's full-scale carbon capture and storage project. This project aims to capture and store approximately 0.8 Mtpa of CO_2 by 2024 from a cement factory in Brevik and Fortum Oslo Varme, a waste-to-energy facility located in Oslo. [43]

40 Global Status Report 2021 - Global CCS Institute – Page 10
41 Carbon capture, utilisation and storage - Fuels & Technologies - IEA
42 Norway to launch $2.7 billion Longship carbon capture and storage project
43 Northern Lights – CCUS around the world – Analysis - IEA

The United Kingdom

The UK Government's CCUS roadmap outlines joint government and industry commitments to the deployment of CCUS in the UK and sets out the approach to delivering four CCUS low carbon industrial clusters, capturing 20-30 $MtCO_2$ per year across the economy by 2030 to help meet the UK's 2050 net zero target. [44]

It has estimated that the United Kingdom alone has 70 billion tonnes of potential CO_2 storage space in sandstone rock formations under the North Sea. [45] The UK's biggest project is converting the Drax coal-fired power station to a biomass power station, capturing and permanently storing the CO_2.

United States

When it begins operations in 2024, DAC 1 is set to become the world's largest DAC facility. It will be the world's first million-tonne DAC plant.

This landmark project is an important development that can help demonstrate the valuable and unique role of DAC for meeting net zero goals. DAC 1 is being financed and developed by 1PointFive, a development company created by Oxy Low Carbon Ventures (OLCV). It will be located in the Permian Basin of the United States.

The project will use DAC technology from Canada's Carbon Engineering. It features a scalable setup consisting of air contactors that pull in atmospheric air, which reacts with a potassium hydroxide solution to bind and separate the CO_2. Through a series of chemical reactions this process yields a pure, compressed stream of CO_2 that will be sent to geologic storage sites to permanently remove this carbon from the atmosphere. [46]

44 Carbon capture, usage and storage (CCUS): investor roadmap
45 Can carbon capture take the UK beyond net zero? - Drax Global, Chapter 5
46 DAC 1 – CCUS around the world – Analysis - IEA

Economics of CCUS

As the price of a tonne of carbon increases, high point-source emission industries will have their business models challenged. This the purpose of the Emissions Trading Scheme, to drive innovation and mitigation. Staying in business will require investment in one form or another, either to adopt cleaner technology, fuel-switch, and if needful and possible, to invest in permanent carbon sequestration.

Many emitters are adopting new technology or fuel switching to reduce their emissions in response to climate change and rising carbon prices.

Worley Reports – 2010 and 2022

In a 2010 Transfield Worley Report, a case-study of a natural gas combined cycle power plant retrofitted with carbon capture capability, estimated that capturing one million tonnes of CO_2 a year including transportation and storage, would have an abatement cost of \$73/t CO_2 over 30 years of operation. [47]

Using the same assessment tools as in 2010, Worley have updated these estimates.

The costs of capturing one million tonnes of CO_2 a year would create a loss of performance cost on the power plant of \$67.5 million a year, a CAPEX cost of \$865 million and an OPEX cost of \$28 million a year for capture, transport, and storage. This equates to approximately \$124/t CO_2 abatement cost over 30 years.

Please note that these cost estimates are for comparative purposes only. They do not include discount rates to calculate a net present value or an estimated capacity factor for the plants operation.

"Hubbing" to reduce costs for CCUS technology

The IEA addresses the economic challenge of a CCUS supply chain by proposing collection hubs be developed around CCUS transport and infrastructure to assist in reducing costs.

The principal benefit of a hub approach to CCUS deployment is the possibility of sharing CO_2 transport and storage infrastructure. This can support economies of scale and reduce unit costs, including greater efficiencies and reduced duplication in the infrastructure planning and development phases. The initial oversizing of infrastructure increases the capital costs and so can make it harder to raise financing, but it can reduce unit transport and storage costs substantially in the longer term. [48]

However, within the New Zealand context where point-source emitters are not clustered, hubbing does not appear to offer an economic advantage.

A compromise between a paucity of clustered point-sources emissions in New Zealand, and increasing distributed emission sources, might appear in the form of a network of locally hubbed DAC units mirroring the distributed emissions map. This might provide 'hubbing' benefits, as well as reduce current constraints on the widespread implementation of DAC itself.

47 CCS in New Zealand: Can carbon capture and storage deliver value to New Zealand as we head towards a low carbon future? Summary report September 2011

48 Understanding-Industrial-CCS-hubs-and-clusters.pdf

Te Ao Māori and CCUS

The Māori World View is that everything is related. i.e., living, inanimate and even the metaphysical are all connected through whakapapa (genealogy). Māori have for centuries been the kaitiaki (Guardians) of things around them.

Having been dispossessed of most of their lands during the period 1860-1930, there are just over 110 iwi in New Zealand who are recognised by the Crown and most of them have been through, or are engaging in, a treaty settlement process. Regardless of what land they still have, all iwi still seek to exercise kaitiakitanga (guardianship) across their rohe (traditional tribal area). Furthermore, they are partners with the Crown as provided for under Te Tiriti o Waitangi (the Treaty of Waitangi).

It is challenging to capture a single view from Te Ao Māori, (The Maori World) on CCUS. Like other parts of New Zealand society, Māori society is dynamic and evolving with a diverse range of opinions and positions. What, however, can be captured are opinions of key decision makers, identified through discussion.

Our enquiries as part of this study were predominantly personal and informal. To elucidate a broader and deeper Māori review on CCUS would require numerous hui and korero over a period of time. Significant thought and reflection at both iwi and hapū level as to what may be acceptable in one rohe may not be in another. No individual we talked to would be prepared to, or feel they had the right to offer a view on CCUS for all of Māoridom.

Some of the people we spoke with were comfortable with the concept that we are returning CO_2 from where it has come and restoring the balance between Ranginui and Papatūānuku. Others however found the concept of transferring pollution from one atua (demi god) to another as offensive. CO_2 injection for enhanced oil recovery (EOR), for example, was generally not favoured by those spoken to, as this would be seen as exacerbating emissions and perpetuating the oil and gas industry. Perhaps the best example of where CCUS could be acceptable to Māori is where CO_2 is extracted and then returned to the original reservoir, such as would be the case for geothermal reservoirs and the Kapuni gas reservoir.

For iwi that have a commercial interest in the land, there is commonly payment of either easement or lease fees associated with the use of the land. These agreements can vary widely based on when they were entered into.

For geothermal assets, and in a limited number of petroleum assets, iwi are also part owners of the businesses and can also gain royalties. The way in which iwi interact with petroleum and geothermal fields is therefore very diverse, ranging from neighbours, to leaseholders, to royalty holders and owners. This is a common experience for iwi neighbouring geothermal areas of Waikato, Bay of Plenty and Northland and iwi neighbouring petroleum fields in Taranaki.

One of the main businesses of iwi in these areas is agriculture and these interactions are managed as determined by the understandings and arrangements outlined above. For CCUS undertakings, the activities described above would look very similar to those for geothermal and petroleum businesses.

Another opportunity for Māori occurs through employment. The activities outlined above require a skilled workforce and Māori are already well established in both the geothermal and petroleum service sectors. We expect this would be the same for a new CCUS industry.

For example, the Tuaropaki Trust[49] is centred at Wairakei and started as a dairy farming entity. It now has business interests in food and nutraceuticals, telecommunications, geothermal power generation from the Mokai field, temperature-controlled horticulture, hydrogen production and is the owner of MB Century.

MB Century owns drilling rigs and is an energy services and engineering business that services and constructs energy wells and facilities. The business currently employs approximately 130 personnel and based on its existing assets and skillsets it would easily be able to apply itself to CCUS construction and maintenance activities.

In summary, as with all sectors of society, Māoridom encapsulate a diverse range of opinions on the utilisation of CCUS. If CCUS proceeds, local iwi and hapū should be engaged, consulted and included from the onset.

49 Tuaropaki Trust

Legislative and Regulatory Barriers

New Zealand does not have an enabling legislative framework for CCUS. In comparison, the Australian Government recently supported the Moomba CCS project, led by Santos, by permitting the project to qualify for carbon credits.

Santos stated in a 2021 press release that it "has successfully registered the Moomba CCS project with the Clean Energy Regulator. The Clean Energy Regulator's CCS method provides a crediting period of 25 years, over which period the project will qualify for Australian Carbon Credit Units for emissions reduction from Moomba CCS." [50]

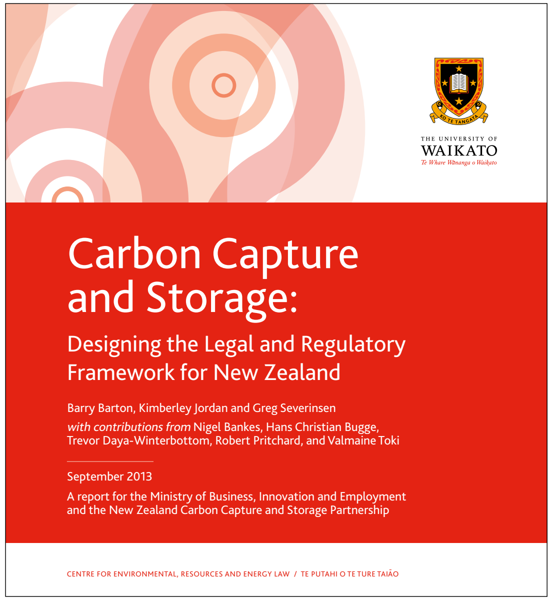
The New Zealand Productivity Commission in their 2018 report Low Emissions Economy stated that when and whether CCS will be viable in New Zealand remains unclear. They said that existing legislation is not adequate to manage the risks of CCS recommending that the Ministry for the Environment should carry out policy work on new legislation to appropriately regulate CCS activities." [51]

They went on to say that the ETS should also be amended, saying carbon capture and storage is currently treated as a 'removal activity' under the NZ ETS, and that though ETS participants conducting carbon capture and storage could claim credits for CO_2 removed from the atmosphere; it also meant that CCUS activities not directly linked to NZ ETS participants that sought to remove general carbon from the atmosphere would not qualify for NZ ETS credits.

Their concern was that this disadvantages CCS against other carbon removal activities such as forestry. The Commission agreed with Barton, Jordan and Severinsen (2013) that the NZ ETS should be amended, so that CCS is "a removal activity whether or not the CO_2 is from an activity that is required to surrender units. [52]

A regime for CCS activities is different than revising ETS regulations, as it will facilitate and regulate the permanent geological sequestration of CO_2.

Professor Barry Barton of Waikato University who supervised an extensive analysis of the legislative regime for CCUS in 2013, has said in the Executive Summary of his report that "a [new] CCS Act will provide a permitting regime for CCS activities in New Zealand both



onshore and offshore, with regulation that is site-specific and performance-based. The purpose of such a CCS Act will be to facilitate and to regulate the permanent geological sequestration of CO_2, as part of efforts to reduce the emission of greenhouse gases, in such a way as to protect the environment and human health and safety." [53]

50 Santos announces FID on Moomba carbon capture and storage project | Santos
51 Productivity-Commission_Low-emissions-economy_Final-Report.pdf – Page 420
52 Productivity-Commission_Low-emissions-economy_Final-Report.pdf – Page 449
53 University-of-Waikato-CCS-Report-2013-web.pdf

Conclusion

Reinjection technologies have already been deployed in New Zealand at Kapuni (for the purpose of enhanced oil recovery) and Ahuroa (for gas storage). Similar technologies are being implemented around the world for CCUS purposes.

CCUS technologies are advancing, and the IPCC says they are 'unavoidable' if the currently held time trajectories to limit anthropogenic global warming to 1.5°C and no more than 2°C by the end of the century, are to be met.

There are barriers to overcome, including high capital investment, emerging technologies that need testing in a New Zealand context, and review of regulations to enable the benefits of carbon capture from biomass, direct air capture or CO_2 mineralisation to be recognised.

There are significant opportunities to be considered as emerging technologies that capture and store CO_2 from non-fossil fuel sources have the potential to reduce New Zealand's carbon footprint by creating negative emissions. The replacement of fossil fuelled process heat and power generation by biomass is expected to ramp up over the next decade and a half, to enable this opportunity.

Opportunities will undoubtedly arise for negative carbon emissions via the aggregating of more, smaller emission sources through distributed direct air capture, particularly in densified industrial zones and high traffic zones. Such CCUS synergies could offset hard-to-abate industrial sectors to enable Aotearoa New Zealand to close the gap on becoming net zero, while also enabling manufacturing and other industrial sector jobs stay in New Zealand, as part of the energy transition.

The imperatives of personal and corporate effort to reduce our energy demand, and adopt technology for low or zero emissions energy, are first and foremost. Added to these, carbon dioxide removal from the atmosphere and its permanent and stable storage, is a possible supporting step in ensuring catastrophic climate change does not become the legacy future generations inherit from today's emitters and decision-makers.

Recommendations

- Engage with iwi and Māori groups, to gain their perspective on the value and application of CCUS and ensure iwi and Māori groups are supported to engage with relevant parties to explore mutually beneficial socio-economic outcomes.
- Support a public discussion and submission process on whether CCUS can be of use to Aotearoa New Zealand in reducing its emissions to fulfil our international obligations.
- If CCUS is considered a potential technology to assist Aotearoa New Zealand in reducing its emissions, review legislation and regulations to identify barriers and review the ETS to test whether companies who sought to remove carbon dioxide from the atmosphere would qualify (or not) for NZ ETS credits
- If CCUS is considered a potential technology to assist Aotearoa New Zealand, then support a trial at a bioenergy plant, a Direct Air Capture site, and a CO_2 Mineralisation site, to test technology and develop the knowledge, skill base and supply chain necessary for CO_2 capture, and utilisation/storage. This could potentially lead to the development of a replicable working demonstration for creating neutral/negative emissions within Aotearoa New Zealand.
- Stock-take the need for CO_2 in Aotearoa New Zealand's industries; where that CO_2 can be sourced, purified, stored and transported to meet the industrial and sustainable fuels demand for CO_2 in the economy. This may be able to happen as part of the National Energy Strategy that the Government will lead.