Sensitivity: General

# Review of CCUS/CCS Potential in New Zealand

Written in support of the Gas Transition Plan

Prepared for Gas Industry Company
Prepared by Wood Beca Limited

**28 March 2023**

global expertise local understanding

## Contents



## Figures

# Table of Tables



# Appendices

## Revision History

| Revision Nº | Prepared By | Description | Date |
|---|---|---|---|
| A | Wood Beca Ltd | Draft for Operator review | 25/01/2023 |
| B | Wood Beca Ltd | Draft for client review (revised based on comments from Operators) | 13/03/2023 |
| C | Wood Beca Ltd | Issued as final | 28/03/2023 |
| | | | |
| | | | |

## Document Acceptance

| Action | Name | Signed | Date |
|---|---|---|---|
| Prepared by | Elizabeth Timings | | 28/03/2023 |
| Reviewed by | Nick Cozens | NWJC | 28/03/2023 |
| Approved by | *Phil Robson* | | 28/03/2023 |
| on behalf of | Wood Beca Limited | | |

# List of Abbreviations

2C – Proven and probable reserves

2P – Best estimate of contingent resources

APAC – Asia Pacific And China

BCF – Billion Cubic Feet of Gas. For context:

1) Maui GIIP ~ 4000BCF, or
2) Calendar year 2021 New Zealand total gas production was 139BCF

CAPEX – Capital Expenditure

$CO_2$ – Carbon Dioxide

CCS – Carbon Capture and Storage

CCUS – Carbon Capture, Utilisation and Storage

EOR - Enhanced Oil Recovery

ERB – Emission Reduction Budget

ETS – Emission Trading Scheme

FEED – Front End Engineering Design

GIIP – Gas Initially In Place

LTS – Low Temperature Separation

Mtpa – Million Tonnes per Annum

OOM – Order of Magnitude

OPEX – Operating Expenditure Costs

RKM – Rimu/Kauri/Manutahi

TAWN – Tariki/Ahuroa/Waihapa/Ngaere

TCF – Trillion Cubic Feet

TIC – Total Installed Costs. For context this includes:

1) $CO_2$ Capture (NZD/tonne)
2) $CO_2$ Transportation (NZD/tonne/km)
3) $CO_2$ Injection (NZD/tonne)

# Executive Summary

Globally, emission reduction targets are being pursued through various decarbonising initiatives; displacement of fossil fuel with renewable alternatives being both significant and challenging. However, energy transition will be gradual, occurring over many decades and only, when affordable and reliable alternatives are sourced, and developed. Demand for oil and natural gas continue, not only in New Zealand, but globally, as demand growth persists (McKinsey & Company, 2022).

In the context of New Zealand, objectives set out under the Gas Transition Plan seek a series of recommendations, which relate to the possible role CCUS and CCS could play to meet emission reduction targets, specifically:

- Whether the technology is technically and economically viable in New Zealand
- What contribution sequestration can make to emissions reductions, security of supply and energy affordability
- How a pathway that includes sequestration compares to alternative scenarios
- The requirement for a legislative framework to enable CCS and CCUS

Wood Beca have reviewed CCUS/CCS opportunities and report on two potential CCS candidates reviewing the technical and economic aspects of these projects only - The Maui and Kapuni gas fields in Taranaki. These are late life assets now reaching depletion which, alternatively serve as technically feasible candidates, to store decadal scale volumes of $CO_2$ and potentially contributing towards emission reduction objectives. While CCS and CCUS initiatives are cited in this report, they remain subject to technology advancement, consenting processes, economic, environmental assessments and supportive legislation.

Emissions associated with natural gas production currently (2021) account for ~ 0.715 Mtpa $CO_2$ – across all production in Taranaki. The Operators are targeting a 2027 implementation, subject to normal project lifecycle process (business case, regulatory environment, consenting), application of CCS at Maui East (step out discovery from the Maui A platform) and Kapuni, has the potential effect on ERB 2 and 3 as described below:

- ERB 2 (2026 – 2030) target annual average is 61Mt. This is an 11.5 Mt reduction from ERB 1 (target annual average of 72.5 Mt $CO_2$ during 2022 – 2025).
    - Kapuni follows forecast 2P production profiles; natural gas supply declining steadily out to 2048. This would produce 0.75 Mt of $CO_2$ during the 2027–2030 period. Should Maui East commence operations by 2027, up to 1.36 Mt $CO_2$ would be produced during the 2027-2030 period. Together, 2.1 Mt $CO_2$ could be sequestered from Maui East and Kapuni.
- ERB 3 (2031 – 2035) target annual average is 48 Mt. This is an 13Mt reduction from ERB 2.
    - Kapuni follows forecast 2P production profiles; natural gas supply declining steadily out to 2048. This would produce 0.56 Mt $CO_2$ would be produced during the 2031–2035 period. Should Maui East commence operations by 2027, up to 1.7 Mt of $CO_2$ could be produced during the 2031-2035 period. Together, 2.3 Mt $CO_2$ could be sequestered from Maui East and Kapuni.

Between 2027 and 2035, a sum total of 4.4 Mt of emissions associated with natural gas production could be sequestered through CCS activity.

Class 5 (-50%/+100%) cost estimates, based on international norms for onshore application of CCS at natural gas production facilities in New Zealand range in the order of \$30 – 110 NZD/tonne $CO_2$. While actual values are highly dependent on site specifics, this range provides alternatives to current ETS forecasts facing natural gas producers.

Considering the wider concepts of CCUS, $CO_2$ is a commodity growing in global importance. In the Taranaki region, $CO_2$ is an important chemical building block in the production of urea and methanol – two large industrial outputs in the region. These industries are highly reliant on $CO_2$ rich natural gas (consuming over 50% of produced natural gas in New Zealand). The Kapuni – Methanex low temperate separation pipeline will be an important asset to consider as a transport vector for $CO_2$ producers, $CO_2$ off takers and those proximal to potential $CO_2$ sinks (e.g. the RKM, and Pohokura fields). Further, as emerging CCS technologies mature, additional emission reduction initiatives such as direct air carbon capture may benefit from lower barriers to commercialisation.

# 1 Context

The purpose of this study is to provide inputs to the Gas Transition Plan on how CCS and CCUS may contribute to emissions reduction for New Zealand. The scope of this report was to focus on the technical and economic feasibility of CCS and CCUS. This report does not cover the significant legislative or consenting aspects of the pathway to implementation for CCS or CCUS and recognition of it as a viable carbon sequestration mechanism in New Zealand.


Figure 1-1. Flow diagram of ERP and CCUS/CCS applicability

Pillar I of the Gas Transition Plan focuses on articulating transition pathways for the fossil fuel sector whereas Pillar II focuses on potential decarbonisation solutions, including renewable gases and CCS/CCUS. This review therefore focusses on Pillar II.

Gas Industry Company seeks:

- Whether the technology is technically and economically viable in New Zealand
- The potential volume of $CO_2$ that may be sequestered
- How a pathway that includes sequestration compares to alternative scenarios

## 1.1 Wood Beca – Gas Industry Company agreed SoW

Agreed terms of non-disclosure restrict the level of detail this report can publish. As Wood Beca hold confidentiality agreements with the Operators – and not Gas Industry Company. The primary role of Wood Beca is to act as the technical intermediary between Gas Industry Company and – in this instance Operators, OMV and Todd. Specifically, Wood Beca will seek to:

- Determine the contribution CCS *could* provide to ongoing security of supply and energy affordability.
- Review Maui and Kapuni technical considerations as possible CCS candidates.
- Provide Class 5 (-50% / + 100%) cost considerations for successful CCS implication.
- Quantify the role CCS could make on an annual basis utilising the operator data
- Describe how a pathway that includes CCS compares to alternative scenarios that do not.

  To note – Wood Beca have not conducted a subsurface review of reservoir candidates. This remains the preserve of the Operators.

Wood Beca do note the following steps have been taken to ensure integrity of our review:

- November 23rd – Wood Beca / OMV technical workshop.
- December 14th – Wood Beca / Todd technical workshop.

Consequently, Wood Beca have generated three technical review reports titled:

Appendices 1. Not included in this report – Wood Beca OMV CCUS Technical Review

Appendices 2. Not included in this report – Wood Beca Todd CCUS Technical Review

Appendices 3. Provided separately – Cost Analysis

Should Gas Industry Company wish to access these outputs, this will occur under separate confidentiality arrangements between the Operators and Gas Industry Company.

## 1.2 Overview of CCUS and CCS

CCUS and CCS refer to the process of capturing $CO_2$ and either storing it permanently (CCS) or utilising it by converting it into valuable products, such as fuels and chemicals (CCUS). Both CCUS and CCS are based on carbon capture, the difference between the two lies in what happens after the capture step (Figure 1-2).

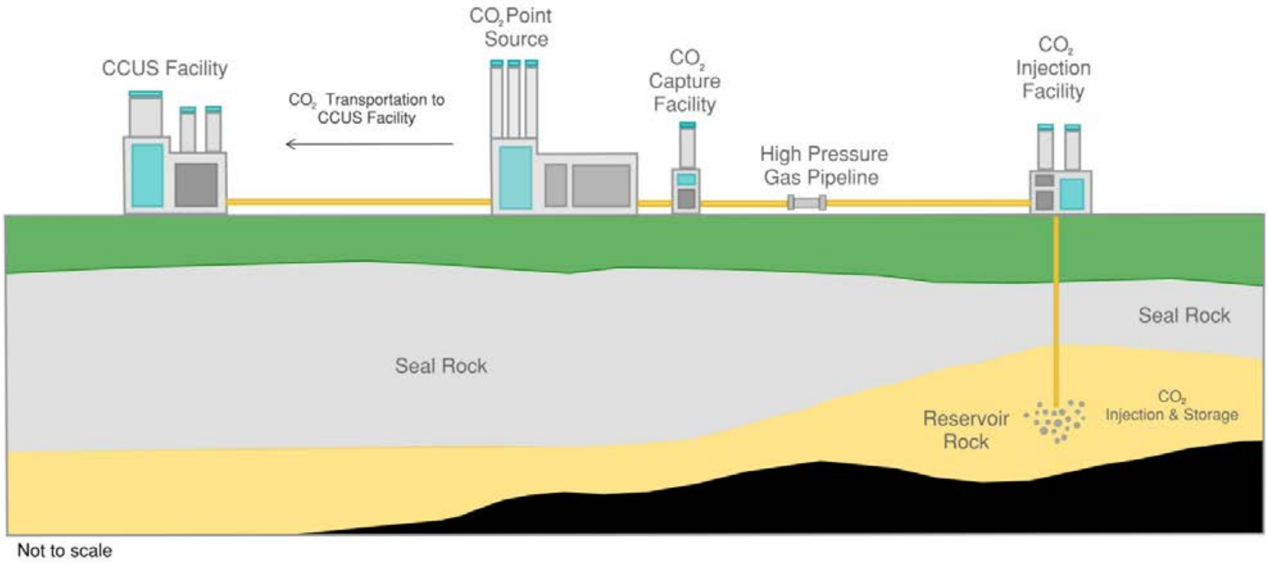



Figure 1-2. Diagram of CCUS / CCS

Candidates in the carbon capture economy, known to be investigating CCUS and CCS initiatives in New Zealand are upstream oil and gas and midstream chemical companies. Oil and gas companies, OMV and Todd, are currently investigating CCS research, while chemical manufacturing companies Ballance Agri-Nutrients Ltd (Ballance) and Methanex New Zealand Ltd (Methanex) are potential CCUS candidates subject to the right legislative framework, product demand requirements and commercial frameworks, therefore considered agnostic now (Figure 1-3).

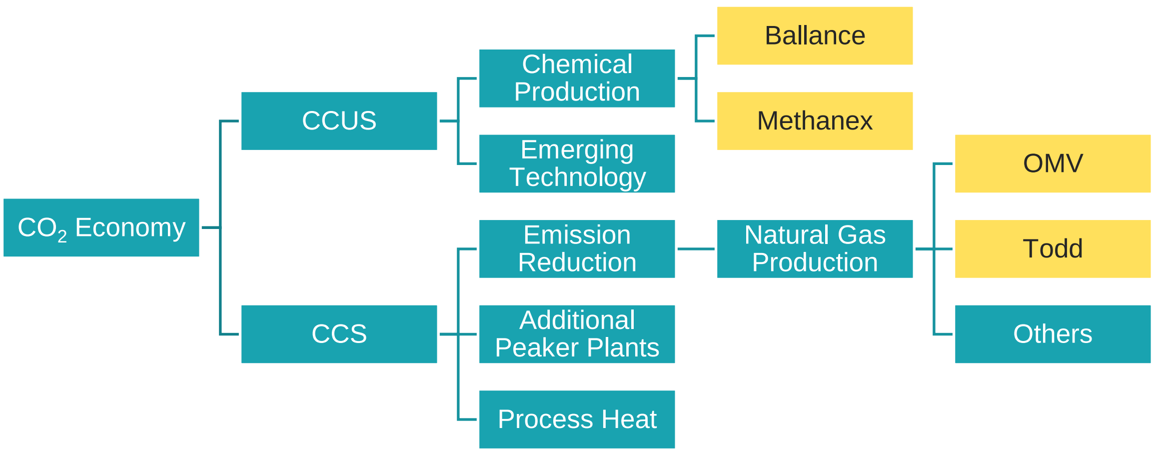



Figure 1-3. Taranaki region CCUS/CCS possible participants

## 1.3 Carbon capture and storage

According to the Global CCS Institute 2022 Status Report (Global CCS Institute, 2022), over 40 $MtCO_2$ is captured annually and a further 200 $MtCO_2$ capture is in development (Figure 1-4).

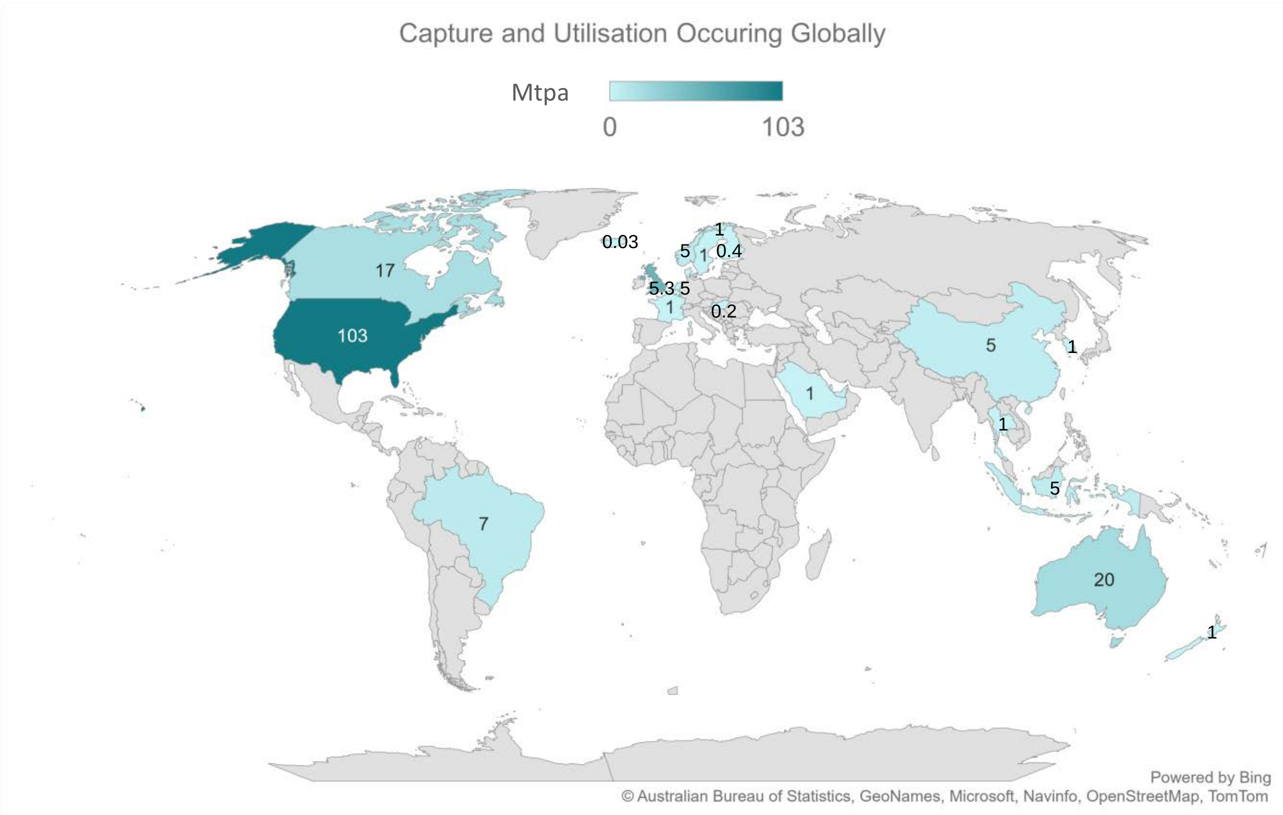



Figure 1-4. Global CCUS/CCS projects as of 2022 (Global CCS Institute, 2022)

Further review of this data (Figure 1-5) reveals a number of insights:

- The mean value of CCS/CCUS projects in the APAC region is 2 Mtpa, which is significantly larger than the global mean. Over 90% of APAC projects are >1 Mtpa, with 4 projects >4 Mtpa. The size of these projects indicates the shift towards large CCUS hubs rather than smaller individual facilities in the APAC region, servicing industrial clusters with multiple emitters accessing a common storage site.
- Globally, both EOR and permanent CCS projects have successfully been deployed in a number of jurisdictions, mostly onshore with a small number occurring offshore. Of the ~ 200 projects cited:
  - 58% are permanent ***CCS*** projects,
  - 16% are EOR projects,
  - 26% of projects are various use or undefined.
- The mean size of global CCS projects is 0.5 Mtpa, slightly lower than the average size of global EOR projects (0.8 Mtpa).

  OMV and Todd represent potential candidates for CCS in New Zealand. Emissions associated with OMV's potential Maui East development (>0.34 Mtpa) represent a capacity lower than the global mean of permanent CCS projects. If Todd's existing Kapuni gas field operates at current capacity, Kapuni's associated emissions would represent a capacity similar to the global mean of permanent CCS projects (Figure 1-5).

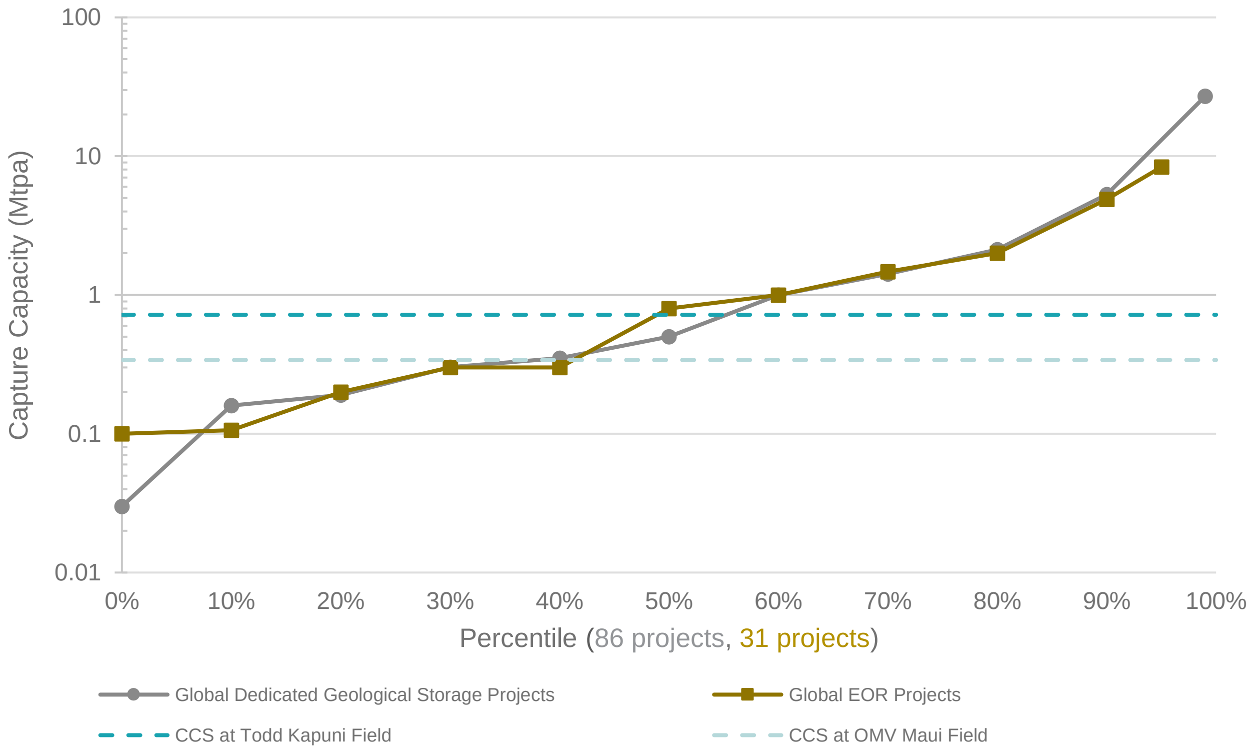



Figure 1-5. Statistical distribution of global CCS projects (Global CCS Institute, 2022)

## 1.4 Carbon capture, utilisation and storage – Taranaki concepts

There is currently a shortage of industrial grade $CO_2$ in New Zealand. In Taranaki, there are two large chemical production facilities which rely on a $CO_2$ feedstock provided through a reliable supply of natural gas.

### 1.4.1 Methanex

Methanex, which is a major industrial participant in the Taranaki region, is also an active CCUS participant in North America. The chemical reactions involved in making methanol lead to the production of excess $H_2$ (Figure 1-6). By injecting additional $CO_2$ to combine with the excess hydrogen, higher methanol yields and increased production efficiency can be expected than the current natural gas (pre combustion) feed.

Conceivably, the current Kapuni LTS 070 pipeline infrastructure, which runs from Kapuni to Methanex can carry 22TJ/day, transporting in the order of 0.1Mtpa $CO_2$. It is conceivable that this pipeline could transport concentrated $CO_2$, this would need to be confirmed by an engineering assessment. A successful example of CCUS at Methanex is, in 2013 Methanex modified its North American Medicine Hat plant and began to introduce $CO_2$ sourced from an industrial neighbour into its production process, utilising approximately 0.08 Mtpa $CO_2$ in 2021 (Methanex, 2021).

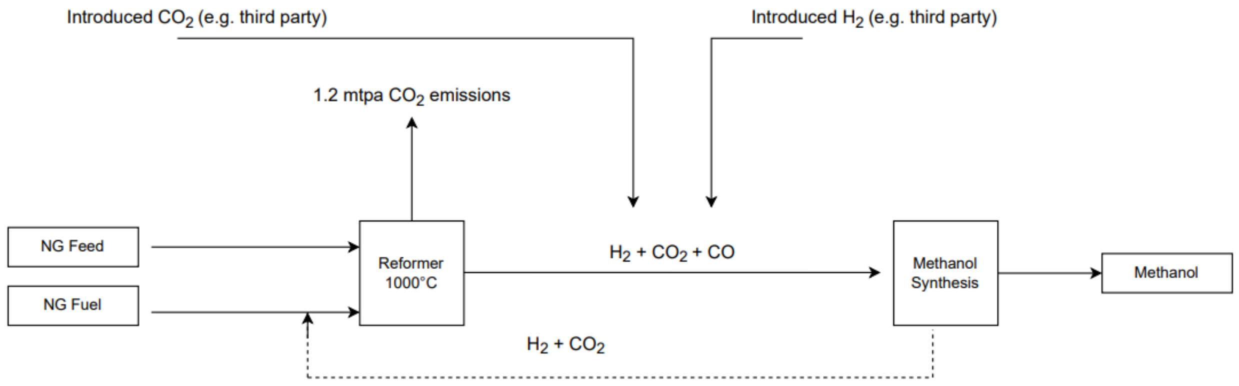



Figure 1-6. Methanol block flow diagram

### 1.4.2 Ballance Agri - Nutrients Ltd, Kapuni site

The Ballance Agri-Nutrients (Ballance) ammonia-urea manufacturing plant is also located near the Kapuni – Methanex LTS pipeline and the Kapuni gas field. Production of ammonia-urea at this site contributes approx. total annual emissions of 0.22 Mt. Close to 0.18 Mt of which, are from the reforming process, this varies based on annual production (Beca, 2023).

### 1.4.3 Other concepts

Other CCS concepts, albeit at much lower technical readiness levels than methanol or urea chemical production, include Direct Air Carbon Capture (DACC) and chemical leaching of olivine. Two such initiatives are under consideration in New Zealand by private start-ups.

Aspiring Materials. https://www.aspiringmaterials.com/

- Acid is used to dissolve olivine, a mineral found in serpentine group minerals, pyroxenes, and amphiboles. These minerals are abundantly found in the earth's crust.
- A solution rich in dissolved silica, iron and magnesium is yielded.
  - The magnesium component being particularity attractive and useful for atmospheric $CO_2$ absorption, producing magnesium hydroxide (Scott et al., 2021).

Capture6. https://capture6.org/

- Capture6 claims - at a cost of less than \$100 USD per tonne of $CO_2$ (Capture6, 2022), successful application of its proprietary technology could lead to gigaton scale removal goals.
- Capture6 claims a novel re-organization of existing chemical elements and available technology, its DACC process converts $CO_2$ to calcium carbonate (lime).

While $CO_2$ is ultimately utilised, it is the by-products of these processes that carry additional value and opportunity.

## 1.5 Research rationale

Directly supporting Pillar II objectives, this review focusses *primarily* on CCS (and not CCUS) application in the Taranaki region for the following salient reasons:

- CCS technology is available and commercially in use in several countries.
- Commencing in 2022 and concluding in 2035, the sum total of the three required ERB's amount to ~ 31 Mt of total $CO_2$ reduction (Ministry for the Environment, 2022a). Should natural gas production levels be maintained at current contracted rates over the same period of time, then emissions from Kapuni (~8.5 Mt) and possibly Maui East (~4.5 Mt) will equate to ~12 Mt. The role CCS could therefore play in emission reductions associated with natural gas production is significant.

- Global examples provide evidence of successful CCS application at natural gas production facilities.
- Reservoir void space, no longer hydrocarbon bearing, at late life assets Maui and Kapuni, represent depleted theoretical volume in the order of 5 TCF – a volume sufficient to accommodate several decades of introduced $CO_2$.
- In the fullness of time, adopted CCS practise may support a wider CCUS carbon economy concept. Fuel and chemical production, horticulture, or food and beverage utilisation, may all be benefactors of a $CO_2$ contribution and withdrawal network (Section 8.1).

## 1.6 Agreed terms of confidentiality

Wood Beca has, under mutually agreed terms of confidentiality, received data from OMV and Todd. The nature of this data transfer relates to CCS candidates Maui (OMV) and Kapuni (Todd).

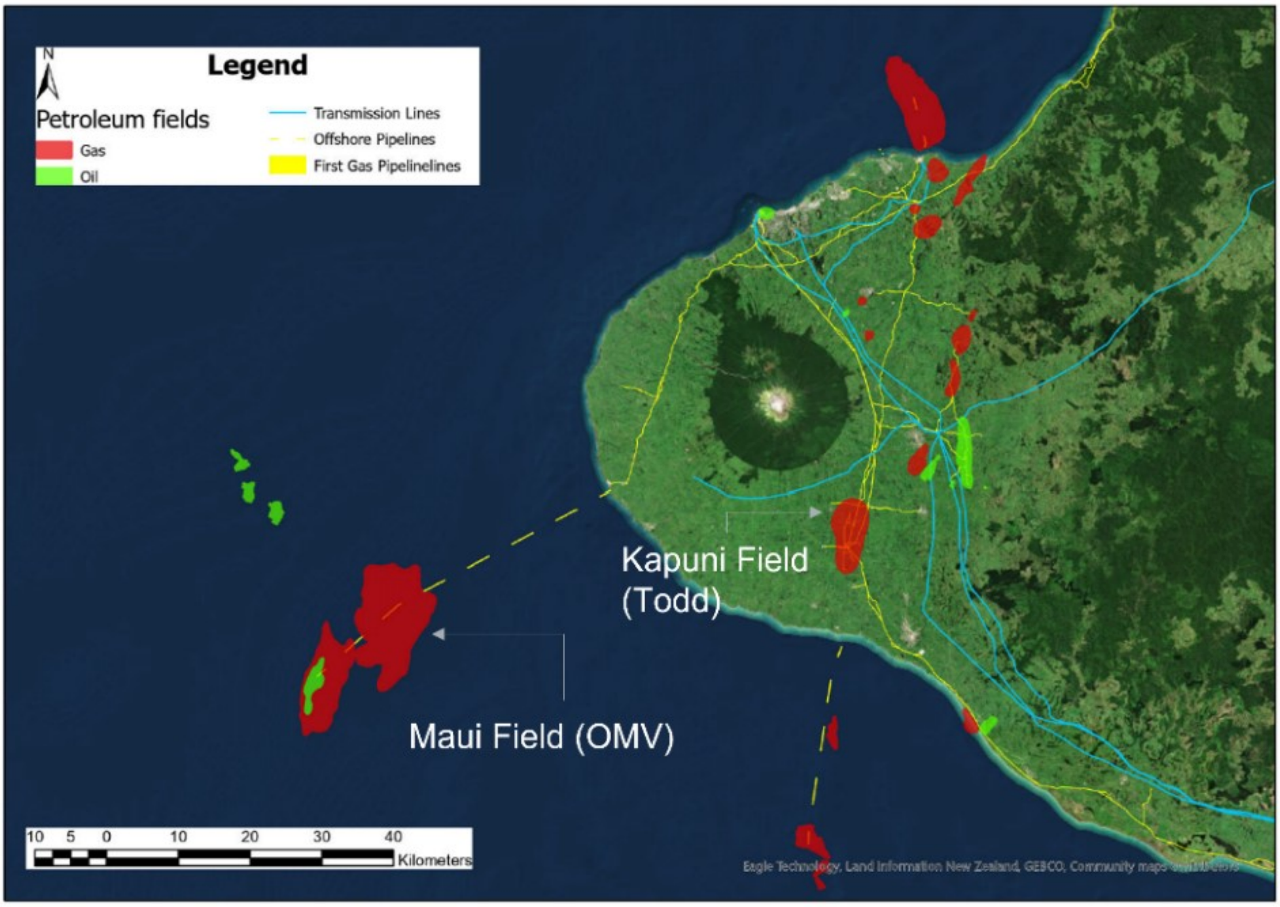



Figure 1-7. Maui & Kapuni locations

In the broadest terms, data transferred to Wood Beca relates to the following:

- Means to determine processing emissions associated with the current and possible operations at both Maui and Kapuni.
- Concept assessment for potential CCS development scenarios. Only base case scenarios will be referenced in this report.
- Targeted sequestration volumes at both Maui and Kapuni fields.

# 2 Security of Natural Gas Supply

Presently, circa 53% of New Zealand's *primary* energy comes from natural gas (21%) and oil (32%) (MBIE, 2021a).. While projections indicate (a steady decline in natural gas usage out to 2050 (Concept Consulting, 2022), the effect higher carbon prices will have on this supply and therefore demand remains unclear.

Meeting current demand, operators are actively researching technical and commercial merits of CCS activities in Taranaki, in part to 1) relieve their ETS liabilities, 2) meet their stated carbon reduction measures, and 3) provide additional production options to ensure affordable supply is met.

Close to ~70% of natural gas demand is being met by aging fields (**OMV** – Maui, Pohokura, **Todd** – Kapuni, Mangahewa, McKee) (MBIE, 2021b). Cumulative deliverability from these assets, in recent years is plateauing (Figure 2-1), placing upward pressure on natural gas price and assurance of continued supply.

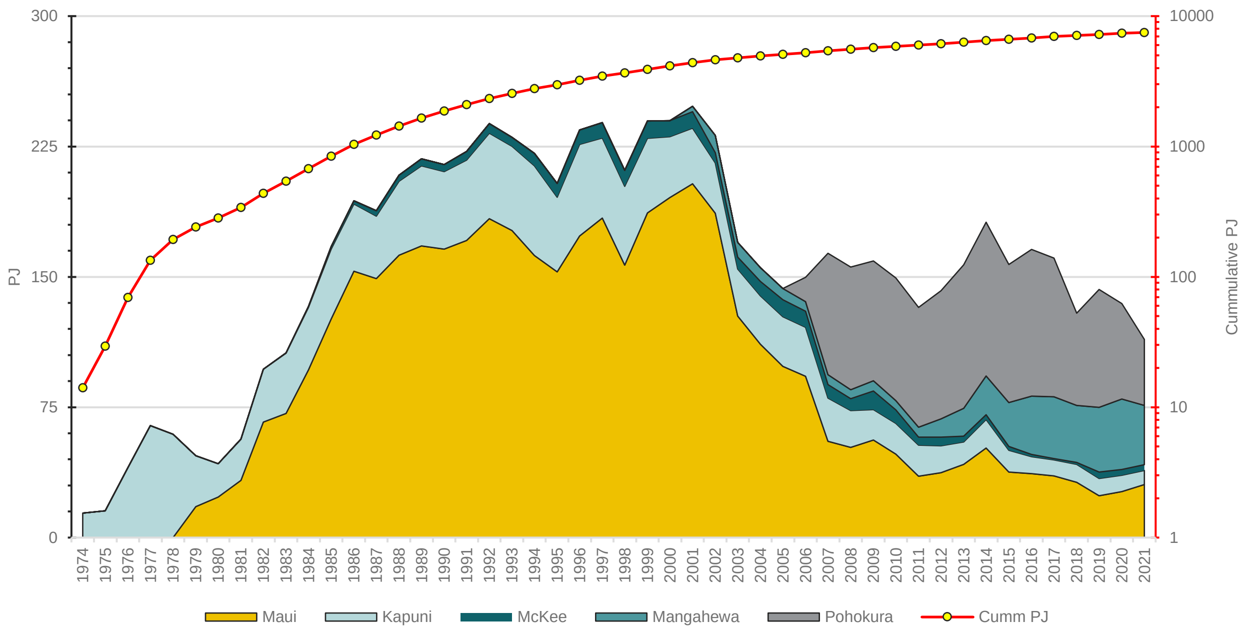



Figure 2-1. Historical production (MBIE data) across currently operated OMV and Todd assets (Data sourced from MBIE, 2021b).

Analysing statutory reporting and reviewing recent exploratory drilling results (shared under NDA between OMV and Wood Beca), several important insights are revealed:

**Statutory reporting and corresponding observations:**

- Maui and Kapuni natural gas delivery, has for the past 10 years, been reasonably steady, albeit down from 2003. Pohokura and Mangahewa fields continue to be large producers alongside the older Maui and Kapuni volumes.
- End of field life forecasts at Maui and Kapuni, *currently* occur before large scale electrification alternatives conceivably take effect e.g. Transpower electricity supply/demand forecasts (Transpower, 2022), which may present primary energy supply issues.
- Remaining (2P) reserves at Maui and Kapuni respectively indicate 7% and 14% of ultimate reserve remains (Figure 2-1). The inference being, produced volumes represent a theoretical void space of >5 TCF, where introduced $CO_2$ could be re-injected.

- Notwithstanding (2C) contingent resource values may increase remaining available natural gas volumes still to be produced, this data remains confidential to the Operators and has not been pursued in this report.
    - It should be noted, (2C) resource interpretations range from 0.8 to > 1.2 TCF at Kapuni, and 250 – 300 BCF at Maui (MBIE, 2021b).

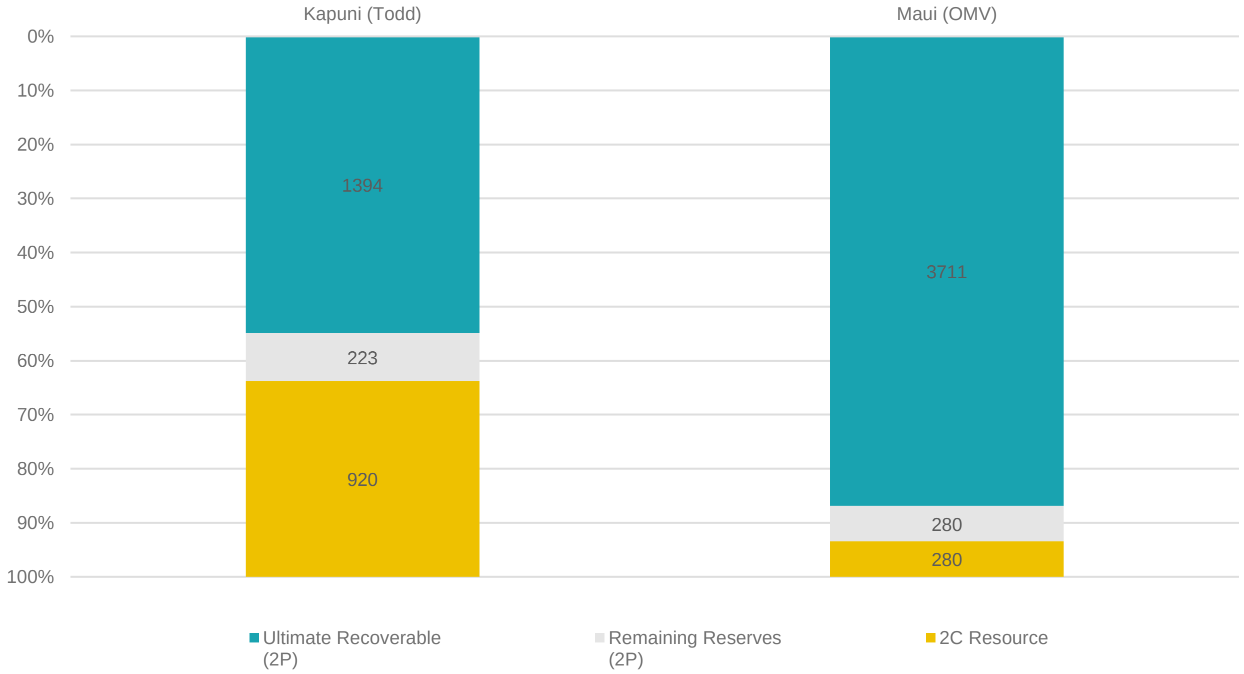



Figure 2-2. Maui and Kapuni non-hydrocarbon bearing void space referenced in Billion Cubic Feet (BCF). Data sourced from MBIE, 2021b.

**Confidential data and corresponding observations:**

- During Q4 2021, Maui East-1 was successfully drilled at the end of the Maui-A Crestal Infill drilling campaign. Discovered was a resource estimate 180 – 280 BCF (MBIE, 2021b) comprising elevated in place $CO_2$ volumes. Commencing in Q4 2022 – Q1 2023, this discovery will be appraised to confirm volumes and $CO_2$ disposal solutions.
- Should this discovery confirm a reserves upgrade, current and possible Maui East production forecast to 2039 is a foreseeable scenario, subject to factors highlighted in the Executive Summary. However, securing access to this natural gas volume will also attract up to 90 BCF (~4.5 Mt) $CO_2$ over its production life.
- Data supplied by Todd (confidential) has allowed Wood Beca to conclude the Kapuni field exhibits all necessary components to support a functioning CCS facility.

# 3 Carbon Capture Quantities

An output of this report is to provide commentary on the role CCUS and CCS may have on emissions reductions.

Emissions associated with natural gas production, predominately flaring and venting activities, currently account for 0.715 Mtpa (Ministry for the Environment, 2022b). Significantly:

- Kapuni operations contribute most of these emissions (currently 2 production trains, which emit >0.5 Mtpa $CO_2$ at capacity). At full plant capacity with 3 trains operating, Kapuni could contribute up to ~0.72 Mtpa of $CO_2$. For every PJ of natural gas extracted from the Kapuni field, ~13 kt of $CO_2$ is currently produced.
- Potential emissions from a Maui East development are expected to add at least 0.34 Mtpa. Every PJ of natural gas from the Maui East is expected to have an associated ~10 kt $CO_2$.

Combined $CO_2$ capacity of storage at Maui East (>0.34 Mtpa) and Kapuni (0.72 Mtpa) future operations equate to anecdotal values in the order of 1.06Mtpa. However, correlating future emissions at Kapuni to publicly available 2P production profiles, which steadily decline out to 2048, emissions are expected to decline (Figure 3-1). Based on the Operators expected project development timeframes, subject to suitable $CO_2$ disposal solutions being identified and sanctioned, CCS activities at both Maui East and Kapuni are being targeted to commence in 2027 by the operators. If CCS is initiated from 2027, then the following scenarios should be considered:

Scenario 1. Kapuni follows forecast 2P production profiles; natural gas supply declining steadily out to 2048. This would produce 0.75 Mt of $CO_2$ during the 2027–2030 period, and 0.56 Mt of $CO_2$ during the 2031–2035 period. Should Maui East commence operations by 2027, up to 1.36 Mt of $CO_2$ would be produced during the 2027-2030 period and 1.7 Mt of $CO_2$ produced during the 2031-2035 period.

Scenario 2. Maui East does not come online at all. Consequently, no uplift in natural gas production and associated emissions occur at Maui East. Kapuni follows forecast 2P production profiles; natural gas supply declining steadily out to 2048. This would produce 0.75 Mt of $CO_2$ during the 2027–2030 period, and 0.56 Mt of $CO_2$ during the 2031–2035 period.

Scenario 3. Wider industrial activity, albeit less mature than initiatives at Kapuni and Maui East, could investigate additional depleted reservoirs in the onshore Taranaki Basin (e.g. TAWN, RKM, Pohokura fields) for complementary CCS / CCUS initiatives.

Between 2027 and 2035, a total of 4.4 Mt of emissions associated with natural gas production could possibly be sequestered through CCS activity if there was a legislative framework that permits this and it was considered economically feasible.

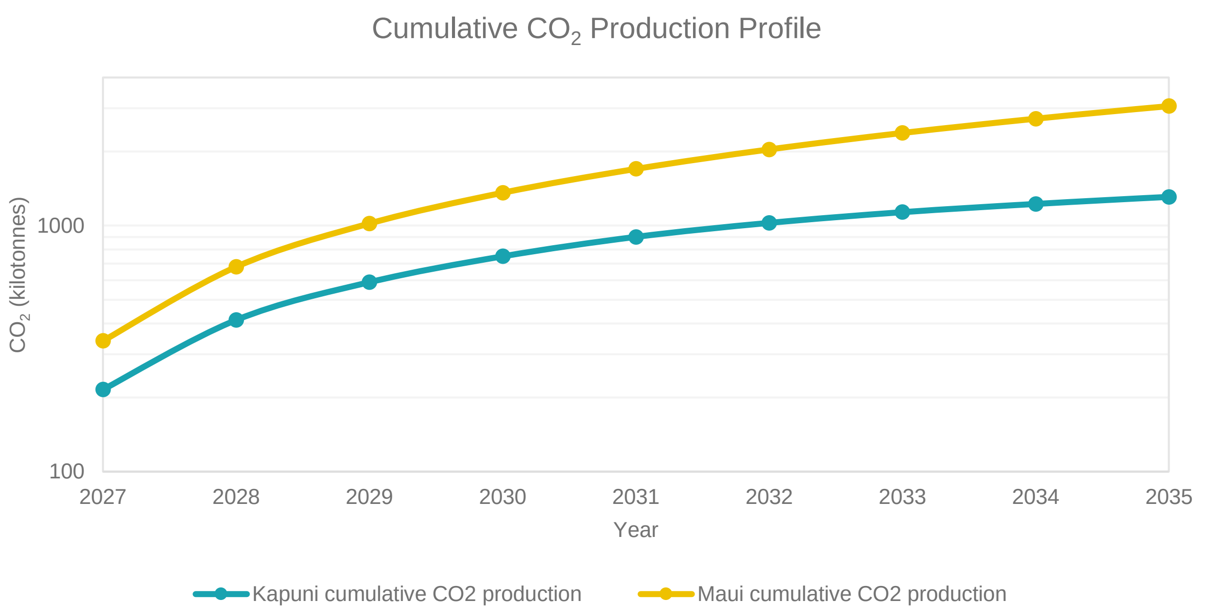
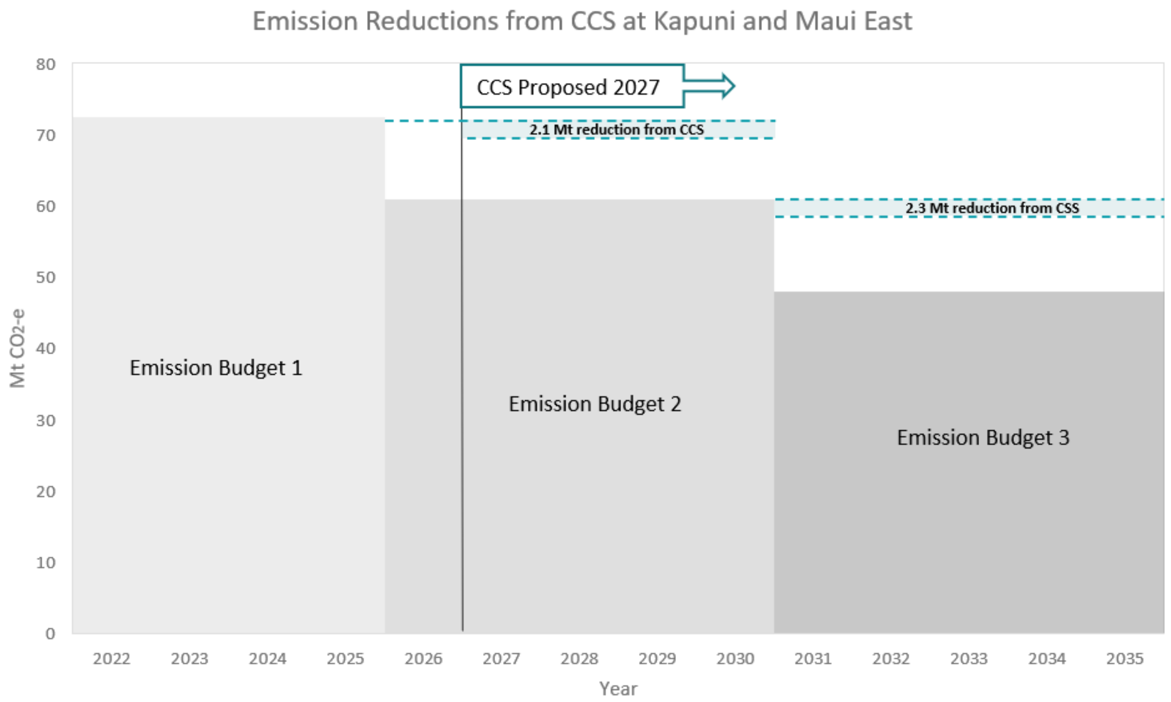



Figure 3-1. Cumulative $CO_2$ production profile for Maui East and Kapuni fields




| CCS facility | Operator CCS commencement target date | (Mt) (4 years of capture) | (Mt) (5 years of capture) |
|---|---|---|---|
| Todd | 2027 | 0.75 | 0.56 |
| OMV | 2027 | 1.36 | 1.70 |
| *Total* | | *2.11* | *2.26* |

Figure 3-2. Emission reduction budgets – pathway with and without CCS

# 4 OMV (NZ) Ltd

OMV carry several development scenarios for CCS application. Bounded by terms of confidentiality, Wood Beca are only permitted to give reference to the base case scenario – noting a series of scenario's are currently under consideration.

## 4.1 Base Case – offshore $CO_2$ stripping and injection

The base case for CCS at Maui involves separation of $CO_2$ from gas extracted within the Maui East field. Extracted gas will be directed to a purpose-built separation and compression facility located on Maui A platform. Separated $CO_2$ will be transported to an injection well and injected into a depleted reservoir offshore within the Maui Field.

## 4.2 Technical considerations

The Wood Beca technical review conclusion is:

- The offshore CCS project at Maui East is technically feasible but reliant on membrane $CO_2$ capture technology, due to real estate constraints on the Maui A platform. The practical limitation is approximately 55 MMscfd hydrocarbon inflow which relates to ~ 0.34 Mtpa $CO_2$ injection. Note that

OMV have not yet carried out Maui East well flow rate tests. As such the planned capacity of the CCS project is currently an uncertainty. Should the well flow rate test prove higher Maui East rates, then OMV will need to constrain Maui East hydrocarbon production based on the $CO_2$ plant capacity. This will introduce a commercial risk (deferred revenue), however could be mitigated somewhat by planning for a longer Maui East late life production phase.

- The Maui East offshore $CO_2$ management strategy requires resolution of key technical risks relating to asset integrity, well re-use, $CO_2$ release dispersion and evacuation procedures.
- The risks for the base case CCS development appear smaller than alternative CCS development strategies at Maui East.
- The Maui East offshore $CO_2$ management strategy is 'stand-alone' (e.g. an isolated development catering only for Maui East gas). There is currently no CCS hub opportunity to increase the development capacity by enabling 3$^{rd}$ parties to access the Maui reservoir.

# 5 Todd Energy

## 5.1 Base Case – Kapuni CCS

The base case $CO_2$ management strategy is to capture the $CO_2$ associated with 100 MMscfd raw Kapuni gas feed using the existing Benfield trains (some upgrades may be required) and reinject the $CO_2$ with a single reinjection well into the existing K3E reservoir.

## 5.2 Technical considerations

Information shared by Todd has allowed Wood Beca to make the following assessment:

- The Kapuni $CO_2$ management strategy requires resolution of key HSSE risks relating to $CO_2$ release dispersion, plant evacuation procedures and pipeline approval. All other technical risks identified are considered 'business as usual' to be worked through the project engineering phases.
- The Kapuni $CO_2$ management strategy is currently 'stand-alone' e.g. an isolated development catering only for Kapuni gas. As such, the project is currently effective in reducing emissions from a major hydrocarbon contributor. A key opportunity exists to accommodate simple design changes early in the project to allow for future expansion and 3$^{rd}$ party emitter access to the K3E reservoir for $CO_2$ storage. Examples include adequate tie-in points, custody transfer metering / allocation considerations, a pipeline diameter review and development of a fluid specification for engagement of regional industry.

# 6 Class 5 Cost Estimations

## 6.1 Overall cost of CCS in New Zealand (onshore and offshore)

### 6.1.1 Summary table: type scenario (e.g. onshore New Zealand)

Table 6-1 shows the estimated Class 5 lifecycle cost (-50% / +100%) for an onshore New Zealand CCS facility of 1 Mtpa capacity, 1 km pipeline and 20 year field life **scenario**. Note that costs are highly dependent on site specifics and don't include a range of ancillary project costs including the costs for, re use of existing equipment and consenting or any legislative processes as noted in detail in section 6.1.3. The values presented in Table 6-1 below are designed assuming a new membrane or amine-based capture system is required. The detailed analysis of these costs can be found in Appendix 3.

| | Capture (in millions) | Compression (in millions) | Transportation (in millions) | Storage (in millions) | Continency (in millions) | Price per tonne ($NZD/tonne $CO_2$) |
|---|---|---|---|---|---|---|
| Capex | $190 | $66 | $2 | $36 | $88 | $30 |
| Annual Opex | $6 | $2 | $0 | $1 | | |

Table 6-1 Summary table for onshore CCS *scenario* - 1 Mtpa capacity, 1 km pipeline, 20 year field life

### 6.1.2 Approach to cost estimate

There is insufficient data received from the Operators to enable an independent cost estimate (greater than Class 5) of specific CCS projects. Such a review will entail detailed analysis and enhanced access to proprietary data. A generic approach has been taken to generate cost information to illustrate the future issue for the whole of New Zealand industry and not just a particular or select industry.

Wood Beca has provided OOM CAPEX information either in the form of costed scenarios or cost metrics (dollar per unit).

A cost estimate accuracy is not provided for OOM CAPEX estimates. The information relies heavily on industry benchmarks, analogues and judgment with capacity factoring which aligns to the outer bounds of an AACE Class 5 (-50% / +100%), however this is not guaranteed. The OOM estimate is appropriate for strategic business planning, market studies and assessment of initial viability.

A simple building block approach is taken to allow development of case studies:

- Building block 1: cost of carbon capture
- Building block 2: cost of carbon compression
- Building block 3: cost of carbon transportation (pipelines)
- Building block 4: cost of carbon injection

### 6.1.3 Common basis of estimate

Costs have been developed by Wood Beca based on adjustment of equipment sizes from previous Wood studies/projects. Thereafter, design & PMT, bulks, fabrication, construction, commissioning, and owner's costs have been factored against the equipment procurement to obtain TIC. This factoring method is known as the Lang factor. The Lang Factor used is 3.0.

- The OOM estimates reflect industry experience of productivity and labour rates in the identified locations.
- The OOM estimates assume onshore site locations do not require significant groundwork prior to construction.
- The OOM estimates assume that all services, such as power, water and drainage are available at the site location.

The reference datasets are based on costs/estimates from 2017-21. An inflation factor is included at 15% for 2022. All costs are provided for 4$^{th}$ quarter 2022. Costs exclude forward escalation.

Growth and contingency are not factored into the individual building blocks.

This estimate has been prepared in New Zealand Dollars. The following foreign exchange conversions have been used where necessary: Although in New Zealand Dollars estimates are based on internal costs with no factor applied for specific new Zealand or site conditions.

| Currency | Conversion |
|---|---|
| GBP to NZD | 1.95 |
| AUD to NZD | 1.08 |
| USD to NZD | 1.66 |

Table 6-2 Q4 2022 average exchange rates (OFX, 2022)

The OOM estimates exclude:

- Infrastructure upgrades, demolition, or decommissioning
- Land costs, permits, consenting costs, surveys
- Sparing, commissioning, delays due to abnormal weather
- Past and current owners' costs, duty & Tax, royalties, and license fees
- Buildings, civil and utility works

All OOM cost look-up plots are provided only to support viability assessment and are not to be relied upon for project specific cost estimation. Every project is bespoke, and hence caution is required applying a generic approach.

#### 6.1.4 Building block 1a: Cost of carbon capture from natural gas processing

Membrane based capture plant

The Operators engaged for the project are both considering CCS projects for natural gas process plants i.e., to capture and sequester the $CO_2$ arising from production of hydrocarbons.

Feedback from the Operators engaged is a preference for membrane $CO_2$ removal plant either due to offshore real estate constraints, or as a technology test challenge to exiting solvent-based $CO_2$ removal plants. On this basis, Wood Beca have estimated the OOM TIC for a membrane $CO_2$ capture plant.

Amine based capture plant

Amine solvent-based $CO_2$ capture has a wider track record for acid gas removal from natural gas processing plants. To give a direct comparison with the membrane technology, the OOM CAPEX has been estimated from an analogue FEED project (confidential).

Assumptions for the cost analysis of membrane and amine capture technologies are detailed in Appendix 3.

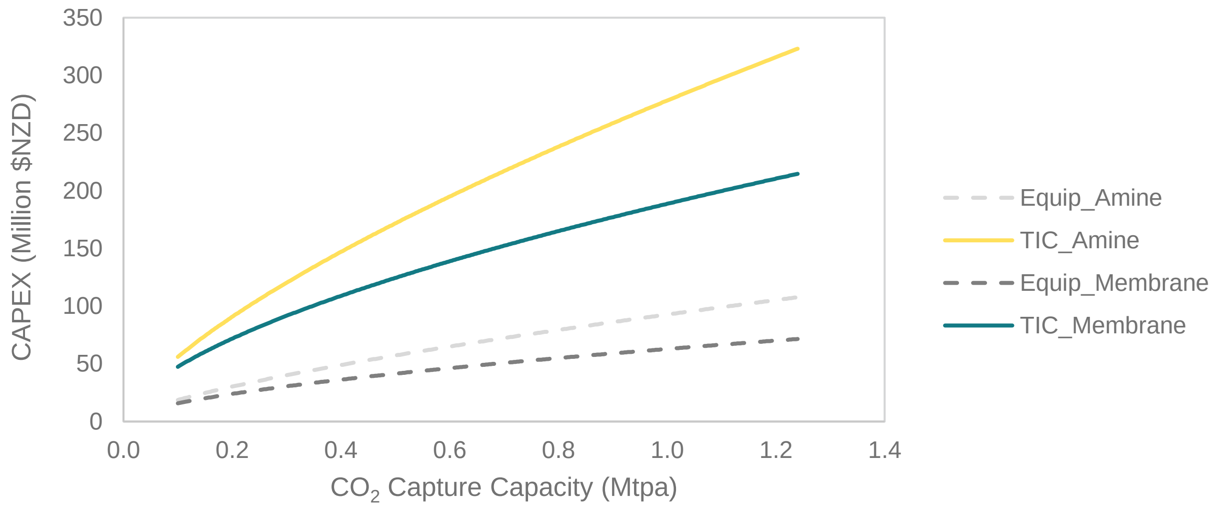



Figure 6-1. Scaled $CO_2$ capture cost (OOM), 2022 basis

### 6.1.5 Building block 1b: Cost of carbon capture from industrial emitters

Wood Beca have elected to exclude estimation of $CO_2$ capture from industrial emitters. $CO_2$ capture for local industry is highly bespoke to the specific characteristics of the emitted stream, with different processes and treatment systems required for pre-combustion, post-combustion, and oxy-combustion sources. It must be noted though, that additional to natural gas production facilities, industrial emitters of $CO_2$ (though not modelled in this review) represent potential sources that could support the wider concept of a $CO_2$ economy.

### 6.1.6 Building block 2: Cost of carbon compression

An internal cost estimate tool developed for $CO_2$ compression equipment has been used for calculation purposes. Refer to Appendix 3 for further information.

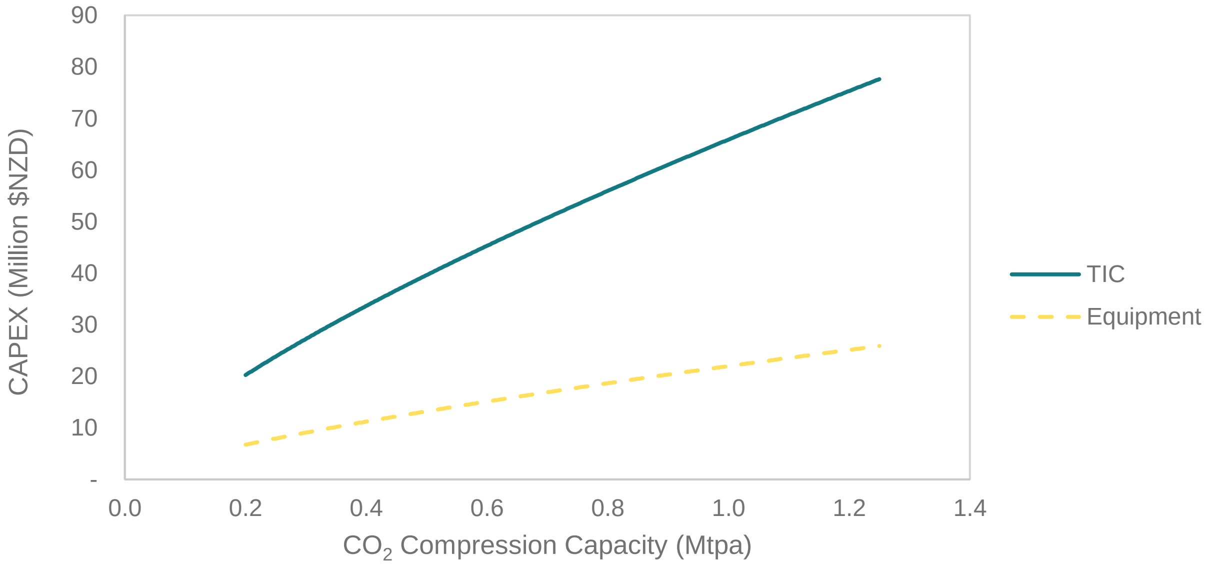
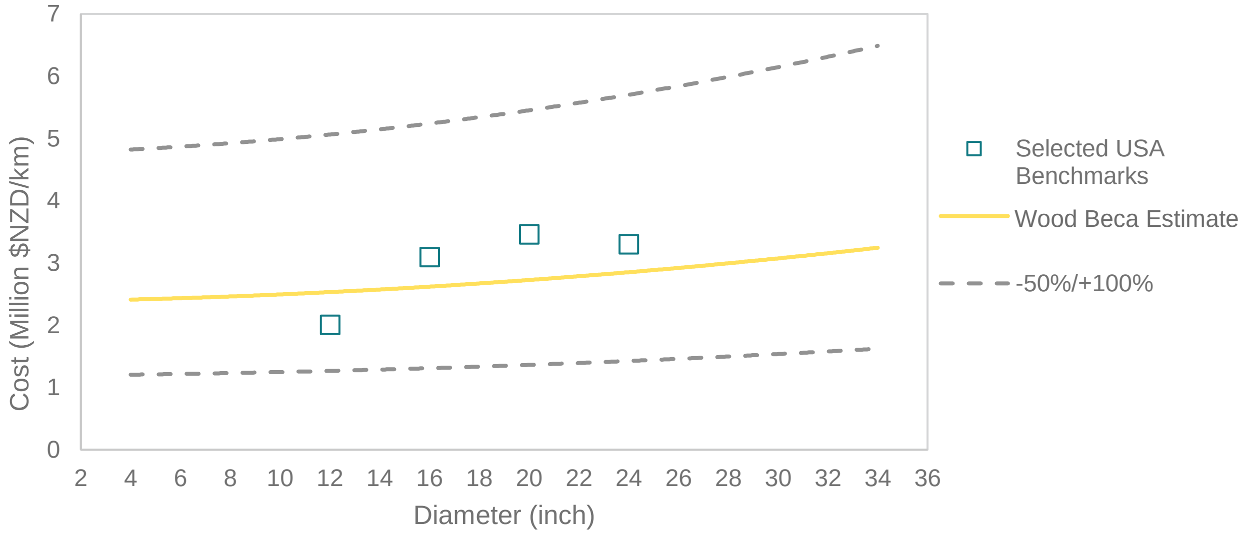



Figure 6-2. Scaled $CO_2$ compression cost (OOM), 2022 basis

### 6.1.7 Cost of transportation (pipelines) - onshore

An internal cost estimate tool developed for $CO_2$ pipeline transportation has been used. More information on the tool and basis of calculation is available in Appendix 3.

Selected USA $CO_2$ pipeline installation costs are provided which show a reasonable match to the Wood Beca order of magnitude estimate.




| Rate (Mtpa) | 0.2 | 0.4 | 0.6 | 0.8 | 1 | 1.2 | 1.5 | 2 | 5 |
|---|---|---|---|---|---|---|---|---|---|
| **Size (inch)** | 4 | 6 | 6 | 8 | 8 | 8 | 10 | 10 | 16 |
| **Pressure Drop (bar)** | 20.2 | 10.4 | 23.3 | 10.4 | 16.1 | 23.2 | 11.4 | 20.2 | 15.8 |
| **Velocity (m/s)** | 0.9 | 0.9 | 1.3 | 1.0 | 1.3 | 1.5 | 1.2 | 1.6 | 1.8 |

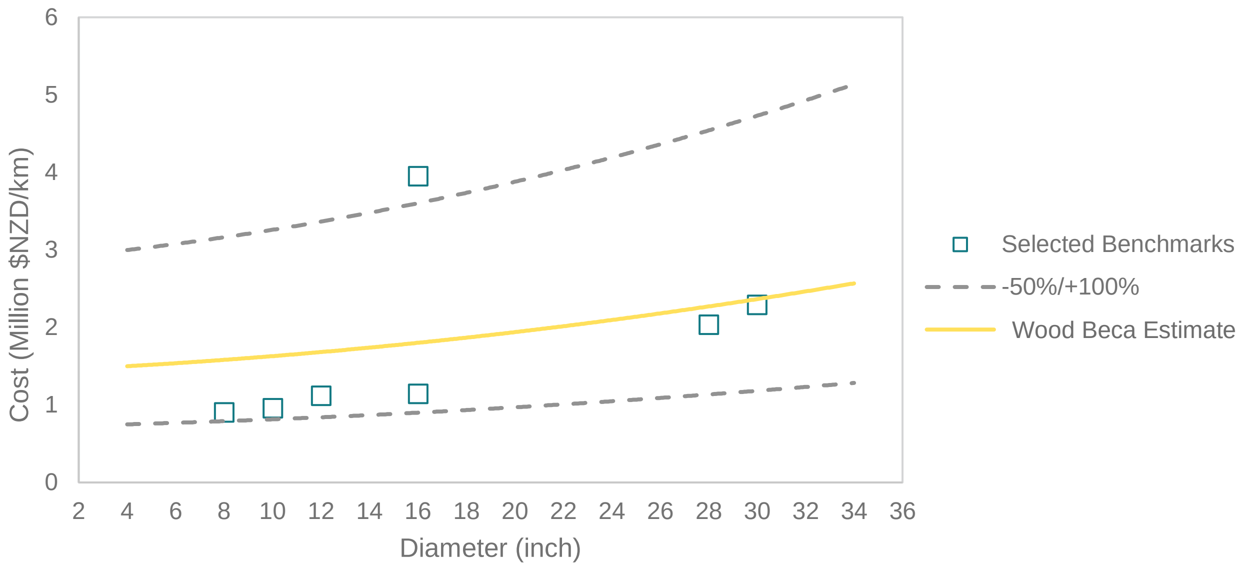
Figure 6-3. Onshore pipeline cost (OOM), 132 bar design pressure, dense phase pipeline graph and line size guidance (40km 120 bar dense phase pipeline)

The pipeline cost metric is very high at low flowrates, with the cost metric decreasing significantly with increasing flow. For example, a pipeline for *0.25 Mtpa*, 40 km (4 inch), 20 year field life has a CAPEX of $59 NZD / tonne $CO_2$ stored where as a pipeline for *1.0 Mtpa*, 40 km (8 inch), 20-year field life has a CAPEX of $25 NZD / tonne $CO_2$ stored.

### 6.1.8 Cost of transportation (pipelines) - offshore

As per the onshore pipeline estimate, an internal cost estimate tool developed for $CO_2$ pipeline transportation has been used (refer to Appendix 3).

Total installed costs (per km) estimate is provided in Figure 6-4 as a function of pipeline diameter, based on a 120 bar working pressure (144 bar design pressure) dense phase pipeline. This transportation condition is considered representative of the majority of use cases for offshore NZ CCS.




| Rate (Mtpa) | 0.2 | 0.4 | 0.6 | 0.8 | 1 | 1.2 | 1.5 | 2 | 5 |
|---|---|---|---|---|---|---|---|---|---|
| **Size (inch)** | 4 | 6 | 6 | 8 | 8 | 8 | 10 | 10 | 16 |
| **Pressure Drop (bar)** | 20.2 | 10.4 | 23.3 | 10.4 | 16.1 | 23.2 | 11.4 | 20.2 | 15.8 |
| **Velocity (m/s)** | 0.9 | 0.9 | 1.3 | 1.0 | 1.3 | 1.5 | 1.2 | 1.6 | 1.8 |

Figure 6-4. Offshore pipeline cost (OOM), 144 bar design pressure, dense phase pipeline graph and line size guidance (40km 120 bar dense phase pipeline)

### 6.1.9 Cost of injection

Costs for injection have been estimated by Wood Beca based on previous New Zealand studies/projects. A cost of $12M NZD has been assumed for drilling an onshore well of 0.5 Mtpa maximum capacity. N+1 well philosophy should be assumed. Cost of injection is much higher for offshore drilling.

### 6.1.10 All in cost per tonne (onshore)

The Class 5 cost for an onshore CCS facility in New Zealand ranges from $30 - $110/tonne $CO_2$ (Table 6-3). This cost estimate is based on a capacity of 0.25 – 1 Mtpa, with a pipeline length of 1 – 80km, assuming a 20 year facility life. The Kapuni – Methanex LTS line fits within this range of pipeline lengths. This cost includes 3% of CAPEX for annual operation and maintenance costs for capture, compression and injection equipment and 1% of CAPEX for annual operation and maintenance costs for onshore pipeline. A contingency factor of 30% CAPEX has been applied. Wood Beca have elected not to provide a Class 5 cost estimate for offshore CCS due to a lack of suitable data, however, note that the cost of executing an offshore CCS project is expected to be much higher than onshore. These costs are generated for $CO_2$ arising from natural gas processing (concentrated $CO_2$) rather than dilute $CO_2$ flue gas sources (e.g. power station), which have a higher cost of capture as well as having cost penalties due to inefficiencies (energy diversion away from the product). Therefore, these cost metrics are only appropriate for CCS from natural gas processing and cannot be used for other industrial $CO_2$ sources.

Our conclusions show there is a large range in the cost of CCS. These conclusions are consistent with the Global CCS Institute 'Technology Readiness and Costs of CCS' report. Global CCS Institute conclude that large scale natural gas processing is a low-cost opportunity and CCS may be less than $33 NZD/ tonne $CO_2$ (assuming an exchange rate of 1.66 NZD to USD).

Below parametric shows cost change for natural gas CCS systems as a function of capacity and pipeline distance. The capacity of the system has first order impact on cost, pipeline length is second order.

| 20 years | Mtpa | | | |
|---|---|---|---|---|
| | 0.25 | 0.5 | 1 | |
| 1km | 50 | 36 | 28 | \$ NZD / tonne $CO_2$ stored |
| 10km | 57 | 40 | 30 | \$ NZD / tonne $CO_2$ stored |
| 20 km | 64 | 43 | 31 | \$ NZD / tonne $CO_2$ stored |
| 40 km | 78 | 50 | 35 | \$ NZD / tonne $CO_2$ stored |
| 60 km | 93 | 58 | 39 | \$ NZD / tonne $CO_2$ stored |
| 80 km | 107 | 65 | 42 | \$ NZD / tonne $CO_2$ stored |

Table 6-3 Onshore CCS Class 5 cost estimates: variation and impact on cost (+30% contingency applied on overall whole scope TIC n+1 well philosophy, 0.5 Mtpa capacity per well assumption)

## 6.2 Implication with ETS

There are a number of forecasts and shadow price models for ETS price and benchmark values. Figure 6-5 presents the historic NZ ETS price alongside two forecasts, Tūī and Kea from the New Zealand Business Energy Council (ASEAN Climate Change and Energy Project, 2008), and a shadow emissions price from the Ināia Tonu Nei demonstration path (Business NZ Energy Council, 2021).

The shadow price value of $140 (in 2019 dollars) is from the demonstration path from the Climate Change Commission's Ināia Tonu Nei advice which forms part of the draft advice to government. The Climate Change Commission's recommended emission budgets were based on this demonstration path, which should be interpreted as a shadow emissions price, rather than necessarily an explicit price in the NZ ETS (Climate Change Commission, 2022).

**ETS shadow pricing and corresponding observations**:

- CCS stand-alone costs would appear to provide options to mitigate ETS liability and emission reduction for large scale natural gas producers such as Todd and OMV
- The price of ETS in Kea and Tūī forecasts increase steadily over the next decade, this would make CCS more economic

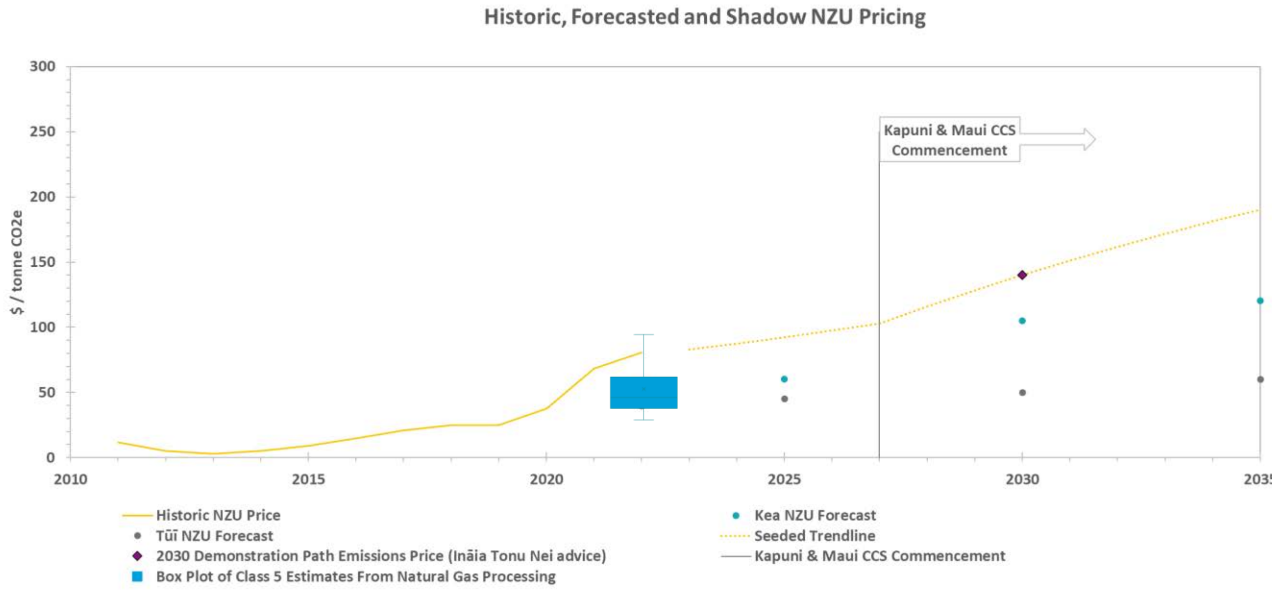



Figure 6-5. ETS historic, forecasted and shadow pricing (box plot represents Class 5 cost estimates for CCS facilities of 0.2 – 1.2 Mtpa capacity, 0.5 – 40 km pipeline length and 20 year field life)

# 7 Additional Considerations

## 7.1 A $CO_2$ economy

$CO_2$ is a valuable resource. Management of this, in a collective sense, will allow for known and suspected surplus *and* shortage of $CO_2$ to be balanced under the broader concept of a $CO_2$ economy. On one hand, as current emitters seek to limit their emission liability, other large scale $CO_2$ consumers seek enduring business certainty. The role of CCUS and CCS should be treated as complementary elements to managing this valuable resource. Wood Beca make the following comments:

- By establishing a network, initially in the Taranaki region, a phased approach may support the case to recommission the Kapuni – Methanex LTS pipeline. Connected by way of a shared pipeline:
  - Current chemical production of urea and methanol in Taranaki rely on $CO_2$ feedstock provided through affordable and reliable supply of natural gas.
  - Future chemical production of urea, methanol, hydrogen, and ammonia utilising Green Hydrogen will require large volumes of introduced electricity, and in the case of urea and methanol production – access to $CO_2$. Large scale offshore wind derived electricity could integrate into the concept of a $CO_2$ economy.
  - Note that the success of a CCUS hub in Taranaki depends on whether local chemical manufacturers will accept fossil-based $CO_2$ rather than biogenic $CO_2$.
- Surplus to CCUS requirements, non-utilised $CO_2$ - derivatives of emissions and/or post combustion process from industrial emitters, become immediate CCS (both permanent and temporary storage) candidates.

# 8 Concluding Remarks and Recommendations

Since 2019, global carbon capture capacity (concept, under construction and operating), has increased by a factor of four up to 320Mt from 80Mt.

This review, consistent with global increases in CCUS / CCS research, has under conditions of limited time and breadth of data made available, allowed Wood Beca to reach the following perspectives, subject to final decisions to be made by private asset owning organisations operating in the constraints at the time. Noting work is required to confirm the assumptions made prior to any investment decision:

## 8.1 Is CCS technically and economically viable in New Zealand?

- CCS reflects known technology capable of successful application at both Maui and Kapuni late life fields.
- Sufficient reservoir void space exists to receive injected $CO_2$ at the Maui and Kapuni fields.
- Wood Beca has provided Class 5 cost estimates for CCS application in New Zealand. Arriving at a potential value of $30 NZD for a simplified onshore Taranaki *type scenario*. It must be noted though, a range of CCS costs in Taranaki ($30 - $110) exist, highly dependent on location, reservoir depth and quality of $CO_2$. When compared against current and forecast ETS cost, ranges of CCS cost provide compelling grounds for favourable consideration.
- A consequence of any sanctioned CCS application at:

  Maui East may:

  - Support future $CO_2$ economy considerations, which could include all Maui associated infrastructure.

  Kapuni may:

  - Support broader concepts of a $CO_2$ economy by utilising, amongst options, the Kapuni to Methanex 070 pipeline infrastructure.

  Other:

- Complementary source / sink pairs within the Taranaki region or further afield create a broader portfolio of optionality.

## 8.2 What contribution can sequestration make to emissions reductions, security of supply and energy affordability?

Combined CCS programmes envisaged for Maui and Kapuni have the potential to reduce emissions after 2027, when operating.

- Significant emissions reductions could be made with CCS (provided this is enabled by legislation).
- Production of natural gas in New Zealand can continue to provide security of supply to energy users well into the late 2030's. Natural gas is likely to be required but CCS enables it to occur with lower emissions.
- End of field life forecasts at Maui and Kapuni, *currently* occur before majority electrification replacement (e.g. large-scale offshore wind) conceivably takes effect. Extension of field life through remaining 2P reserves and 2C resource upgrades using capture of $CO_2$ will provide energy security during the transition to electrification.

- Noting the Maui and Kapuni fields respectively contribute ~ 18% and 5% of New Zealand's daily natural gas consumption (MBIE, 2021b); prolonged production profiles could mitigate natural gas price increase in an otherwise shortening market.

## 8.3 How does a pathway that includes sequestration compares to alternative scenarios that do not?

A path that does not include methods of sequestration will leave potential options for $CO_2$ emissions reduction off the table. As demonstrated above there are large numbers of CCS and CCUS projects being implemented globally as the world transitions to net zero.

A path including sequestration allows for a transition to renewables by prolonging the end of field life. Thus, supporting energy security, affordability, and sustainability.

In the context of CCUS, growing demand for e-chemical production, including urea and methanol will require access not only to electricity, but $CO_2$.

- Opportunity for a $CO_2$ economy exists within the Taranaki region to service the requirements of current and future CCUS initiatives, while supporting both permanent and temporary CCS requirements.

# 9 References

ASEAN Climate Change and Energy Project. (2008). *Renewable Energy and Energy Efficiency*. *February*, 41–58. https://doi.org/10.14217/smalst-2008-4-en

Beca. (2023). *Internal Ballance presentation*.

Business NZ Energy Council. (2021). *Draft first package of advice to the Government to the Climate Change Commission*.

Capture6. (2022). *DAC and Storage*. https://capture6.org/

Climate Change Commission. (2022). *Advice on NZ ETS unit limits and price control settings for 2023-2027 (July 2022)*. *July 2022*, 1–98. https://www.climatecommission.govt.nz/our-work/advice-to-government-topic/nz-ets/our-advice-on-the-nz-ets/nz-ets-unit-limits-and-price-control-settings-for-2023-2027/full-report/

Concept Consulting. (2022). *Gas Supply and Demand Projections*.

Global CCS Institute. (2022). *Status Report*. https://status22.globalccsinstitute.com/2022-status-report/introduction/

MBIE. (2021a). *Energy in New Zealand*. https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-publications-and-technical-papers/energy-in-new-zealand/

MBIE. (2021b). *Petroleum Reserves Data*. https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/petroleum-reserves-data/

McKinsey & Company. (2022). *Global Energy Perspective*. https://www.mckinsey.com/industries/oil-and-gas/our-insights/global-energy-perspective-2022

Methanex. (2021). *Methanex Sustainability Report*. https://www.methanex.com/sites/default/files/responsible-care/Methanex 2021 Sustainability Report_Updated.pdf

Ministry for the Environment. (2022a). *Emission budgets and the emission reduction plan*. https://environment.govt.nz/what-government-is-doing/areas-of-work/climate-change/emissions-budgets-and-the-emissions-reduction-plan/

Ministry for the Environment. (2022b). *New Zealand's Interactive Emissions Tracker*. https://emissionstracker.environment.govt.nz/#NrAMBoEYF12TwCIByBTALo2wBM4eiQAc2RSWcAnO dNEA

OFX. (2022). *Exchange Rates*. ofx.com

Scott, A., Oze, C., Shah, V., Yang, N., Shanks, B., Cheeseman, C., Marshall, A., & Watson, M. (2021). Transformation of abundant magnesium silicate minerals for enhanced CO2 sequestration. *Communications Earth and Environment*, *2*(1), 1–6. https://doi.org/10.1038/s43247-021-00099-6

Transpower. (2022). *Transpower seeks investment to power New Zealand's energy transition*. https://www.transpower.co.nz/news/transpower-seeks-investment-power-new-zealands-energy-transition#:~:text=Industry forecasts%2C including our own,achieving net zero carbon emissions."

global expertise local understanding

# Cost of CCS in New Zealand

## In support of the Gas Transition Plan

# Approach to cost estimate

Because of the confidentiality agreements signed, there is insufficient data received from NZ Operators to enable an independent cost estimate of specific CCS projects. A generic approach is therefore taken to generate cost information to help illustrates future issue for the whole of New Zealand industry and not just a particular or select industry.

Wood Beca has elected to provide Order of Magnitude (OOM) CAPEX information either in the form of costed scenarios or cost metrics (dollar per unit). A detailed breakdown of the working behind these costs is not provided or considered relevant to the objective of this high-level study.

A cost estimate accuracy is not provided for OOM CAPEX estimates. The information relies heavily on industry benchmarks, analogues and judgment with capacity factoring which aligns to the outer bounds of an AACE Class 5 (-50% / +100%), however this is not guaranteed. The OOM estimate is appropriate for strategic business planning, market studies and assessment of initial viability.

A simple building block approach is taken to allow development of case studies:

- Building block 1: cost of carbon capture – *generalised cost for both onshore and offshore*
- Building block 2: cost of carbon compression – *generalised cost for both onshore and offshore*
- Building block 3: cost of carbon transportation (pipelines) – *onshore and offshore costs presented separately*
- Building block 4: cost of carbon injection – *onshore costs presented only*

# Common basis of estimate

Costs have been developed by Wood Beca based on adjustment of equipment sizes from previous Wood studies/projects. Thereafter, design & PMT, bulks, fabrication, construction, commissioning, and owner's costs have been factored against the equipment procurement to obtain Total installed Cost (TIC). This factoring method is known as the Lang factor. The Lang Factor used is 3.0.

The OOM estimates reflect industry experience of productivity and labour rates in the identified locations.

The OOM estimates assume onshore site locations do not require significant groundwork prior to construction.

The OOM estimates assume that all services, such as power, water and drainage are available at the site location.

The reference datasets are based on costs/estimates from 2017-21. An inflation factor is included at 15% for 2022. All costs are provided for 4th quarter 2022. Costs exclude forward escalation.

Growth and contingency are not factored into the individual building blocks.

This estimate has been prepared in New Zealand Dollars. Although in New Zealand Dollars, estimates are based on internal costs with no factor applied for specific New Zealand or site conditions.

The foreign exchange conversions used are shown in Table 1.

***Table 1 Currency conversions***

| Currency | Conversion |
| --- | --- |
| GBP to NZD | 1.95 |
| AUD to NZD | 1.08 |
| USD to NZD | 1.66 |

*Ref. ofx.com, Q4 2022 average taken on Dec 18th 2022*

# Common basis of estimate

The OOM estimates exclude:

- Infrastructure upgrades, demolition, or decommissioning
- Land costs, permits, consenting costs, surveys
- Sparing, commissioning, delays due to abnormal weather
- Past and current owners' costs, duty & Tax, royalties, and license fees
- Buildings, civil and utility works

All OOM cost look-up plots are provided only to support viability assessment and are not to be relied upon for project specific cost estimation. Every project is bespoke, and hence caution is required applying a generic approach.

# Cost of carbon capture from natural as processing (onshore and offshore)

*Membrane based capture plant*

The Operators engaged for the project are both considering CCS projects for natural gas process plants i.e., to capture and sequester the $CO_2$ arising from production of hydrocarbons.

Feedback from the Operators engaged is a preference for membrane $CO_2$ removal plant either due to offshore real estate constraints, or as a technology test challenge to exiting solvent-based $CO_2$ removal plants. On this basis, Wood Beca have estimated the OOM TIC for a membrane $CO_2$ capture plant.

Capex for a circa. 0.2 Mtpa membrane-based capture plant has been estimated from in-house membrane technology datasets.

- The equipment cost of the membrane, permeate compressor and other associated equipment as shown in the Figure 1 has been estimated by pro-rating on the $CO_2$ loading of Stream B
- The pre-treatment equipment cost has been assumed to be 25% of the membrane cost

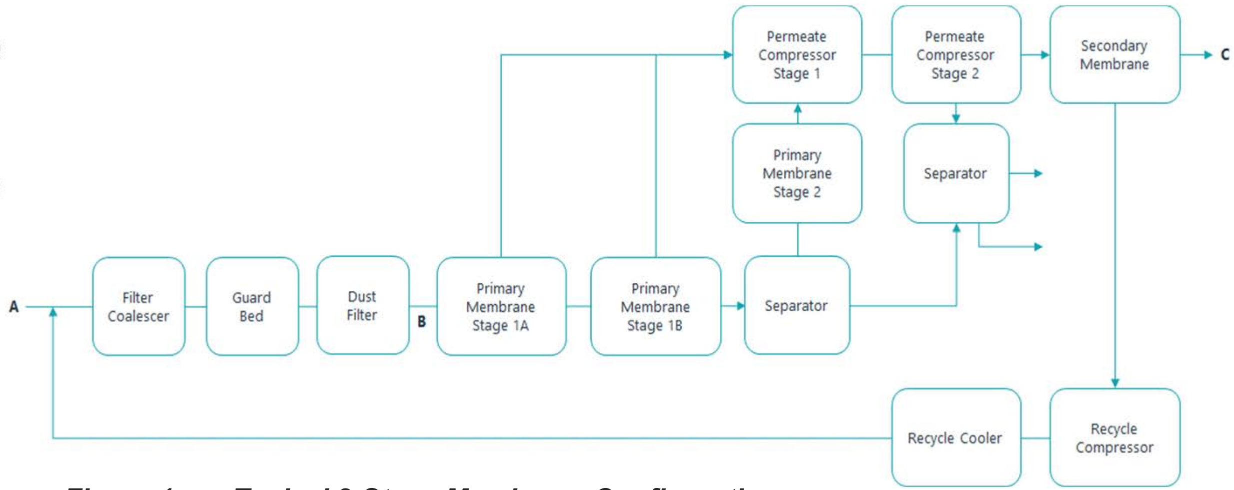



***Figure 1 Typical 2-Stage Membrane Configuration***

# Cost of carbon capture from natural as processing (onshore and offshore)

***Table 2 $CO_2$ Loading Basis***

| Stream | Pressure (barg) | Temperature (°C) | MMscfd | $CO_2$ mol% | mtpa |
|---|---|---|---|---|---|
| A | 55 | 29 | 37 | 32 | 0.23 |
| B | 53 | 34 | 52 | 38 | 0.38 |
| C | 3 | 40 | 12 | 95 | 0.21 |

For the system outlined in Figure 1 and the loading outline in Table 2, the OOM CAPEX is as follows:

***Table 3 Membrane Based Capture Plant - 0.2 MTPA $CO_2$***

| Item | Million USD | Million NZD |
|---|---|---|
| Equipment Cost | 13.0 | 21.6 |
| Equipment Cost, 2022 Basis | 14.9 | 24.8 |
| TIC | 39.0 | 64.7 |
| TIC, 2022 Basis | 44.9 | 74.5 |

The equipment cost is inclusive of the membranes, separators, compressors, coolers and pre-treatment allowance. The membrane cost alone represents approximately 50% of the equipment cost. Vendor data and benchmarks are confidential and cannot be shared, however the Table 3 data is generally aligned.

# Cost of carbon capture from natural as processing (onshore and offshore)

Amine based capture plant

Amine solvent-based $CO_2$ capture has a wider track record for acid gas removal from natural gas processing plants. To give a direct comparison with the membrane technology, the OOM CAPEX for a 0.2 Mtpa has been estimated from an analogue FEED project (confidential). The equipment cost has been estimated based on pro-rating the cost based on the $CO_2$ capture rate (0.55 Mtpa basis pro-rated for 0.2 Mtpa plant).

***Table 4 Amine Based Capture Plant - 0.2 MTPA $CO_2$***

| Item | Million USD | Million NZD |
|---|---|---|
| Equipment Cost | 16.5 | 27.4 |
| Equipment Cost, 2022 Basis | 19.0 | 31.5 |
| TIC | 49.5 | 82.2 |
| TIC, 2022 Basis | 57.0 | 94.6 |

Summary

A capture plant OOM cost look-up plot is provided in Figure 2, based on an industry standard scaling relationship. The plot is provided only to support viability assessment and is not rely upon for project specific cost estimation. Every project is bespoke, and hence caution is required applying a generic approach.

## Cost of carbon capture from natural as processing (onshore and offshore)

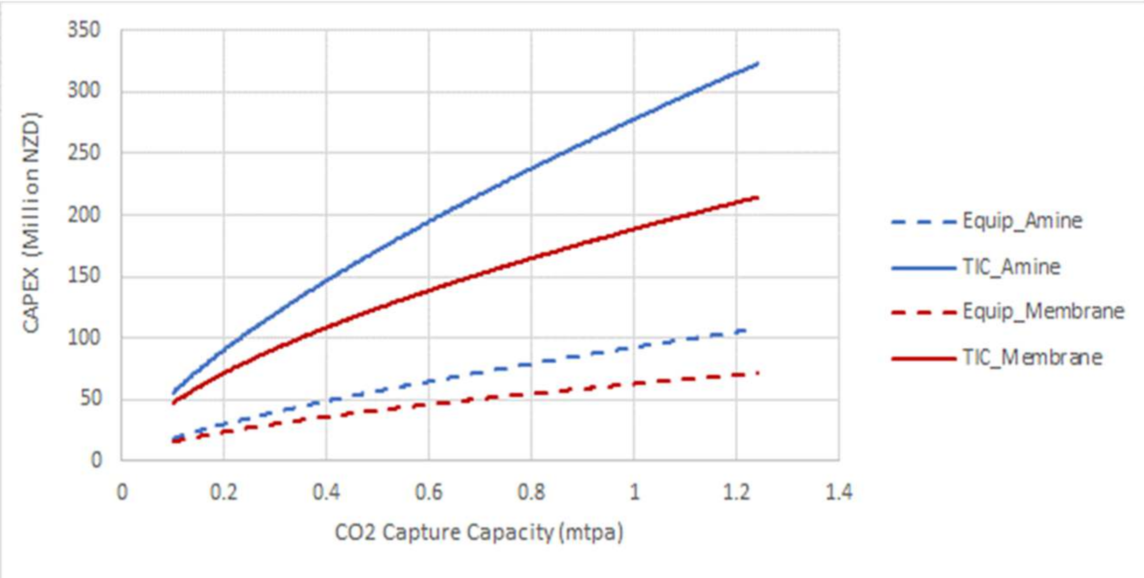



***Figure 2 Scaled $CO_2$ Capture Cost (OOM), 2022 Basis***

## Cost of carbon capture from industrial emitters

Wood Beca have elected to exclude estimation of $CO_2$ capture from industrial emitters. $CO_2$ capture for local industry is highly bespoke to the specific characteristics of the emitted stream, with different processes and treatment systems required for pre-combustion, post-combustion, and oxy-combustion sources.

# Cost of carbon compression (onshore and offshore)

An internal cost estimate tool developed for $CO_2$ compression equipment has been used. This is based on benchmarked vendor and project cost data collected over a period 2017 to 2021. This data is covered under confidentiality and cannot be shared. The following costing premise is considered:

- A range of captured $CO_2$ compression rate from 0.2 to 1.25 Mtpa
- A compressor inlet pressure of 3 bara
- A typical compressor discharge pressure of 120 bara. This is based on dense phase $CO_2$ transport over relatively ’close-coupled’ systems i.e. the compression plant is adjacent (or within <10 km) of the $CO_2$ storage site. A range of 85 to 150 bar is typical to assure dense phase transport. Note:
  - Less than 85 bar risks two-phase conditions in the downstream pipeline and wells.
  - A discharge pressure greater than 150 bar may be required for longer distance $CO_2$ transport and may require a pump stage to provide the additional pressure.
- A multi-stage 1 x 100% compression train is costed. For the pressure increase considered (3 bara to 120 bara), typically 4 stages of compression will be required, with interstage cooling and liquid knock-out (separators) and an aftercooler.

A compression plant OOM cost look-up plot is provided in Figure 3. The plot is provided only to support viability assessment and is not rely upon for project specific cost estimation. Every project is bespoke, and hence caution is required applying a generic approach.

# Cost of carbon compression (onshore and offshore)

As indication of utilities demand for compression from 3 bar to 120 bar, with discharge at 40°C;

- 0.2 Mtpa will require approximately 2.0 MW compression power and 4.9 MW cooling demand
- 1.0 Mtpa will require approximately 9.9 MW compression power and 30.7 MW cooling demand

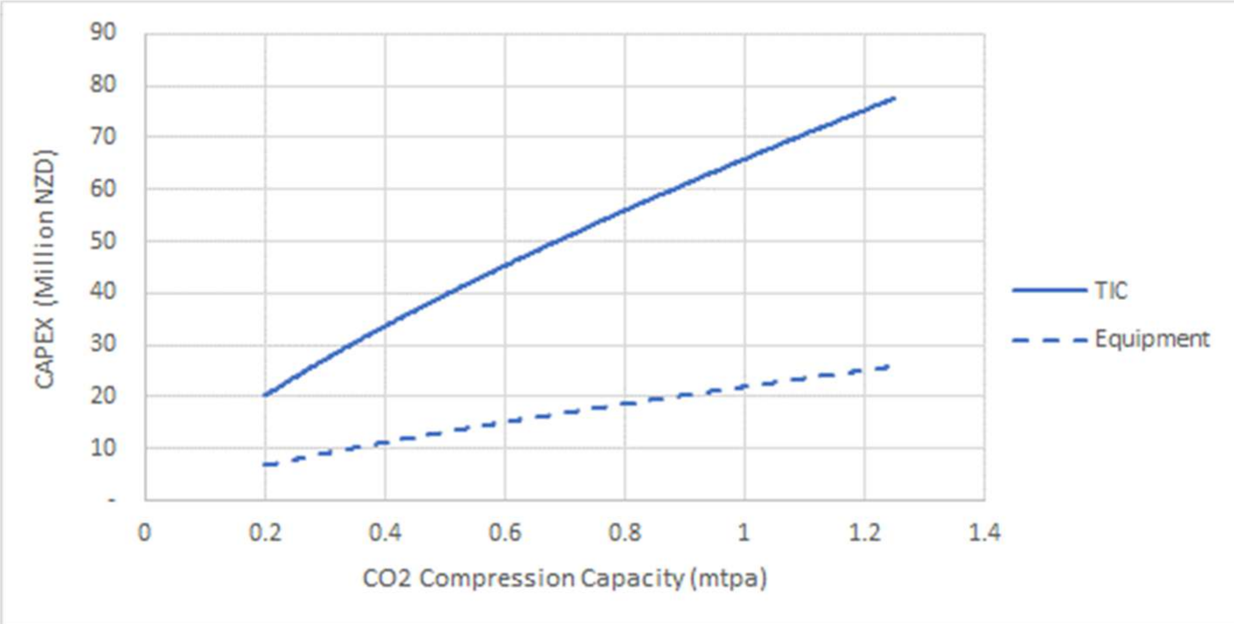



*Figure 3 Scaled $CO_2$ Compression Cost (OOM), 2022 Basis*

# Cost of transportation (onshore) - pipelines

- An internal cost estimate tool developed for $CO_2$ pipeline transportation has been used. The tool determines the pipeline size required based on $CO_2$ rate and the wall thickness required based on the working pressure. The pipeline costing then accounts for the following cost items based on industry benchmarked cost metrics (activity durations, unit costs):

- Geotechnical and topographical route surveys
- Materials: line pipe, internal, external, and concrete weight coating procurement
- Installation: site set-up, right of way preparation and pipeline installation
- Crossings: roads, rail, existing pipelines, and minor rivers
- Miscellaneous activity fixed allowance (approximately 4.9 million NZD)
- Project management and engineering
- Fixed margin (10%) for spurs, offtakes, and pigging facilities

- The TIC OOM cost (per km) estimate is provided in Figure 4 as a function of pipeline diameter, based on a 120 bar working pressure (132 bar design pressure) dense phase pipeline. This transportation condition is considered representative of the majority of use cases for onshore NZ CCS.
- The plot is provided only to support viability assessment and is not rely upon for project specific cost estimation. Every project is bespoke, and hence caution is required applying a generic approach.
- Industry cost analogues are difficult to obtain as the basis can be unclear (e.g., wall thickness / pipe schedule, environment, distance, diameter, installation date etc.). Selected USA $CO_2$ pipeline installation costs are provided which show a reasonable match to the Wood Beca OOM estimate.

# Cost of transportation (onshore) - pipelines

A rough guide to line sizing is provided in Table 5. This is indicative only, specific to a 120 bar working pressure, 40 km dense phase pipeline. Flow assurance analysis is required for specific scenarios.

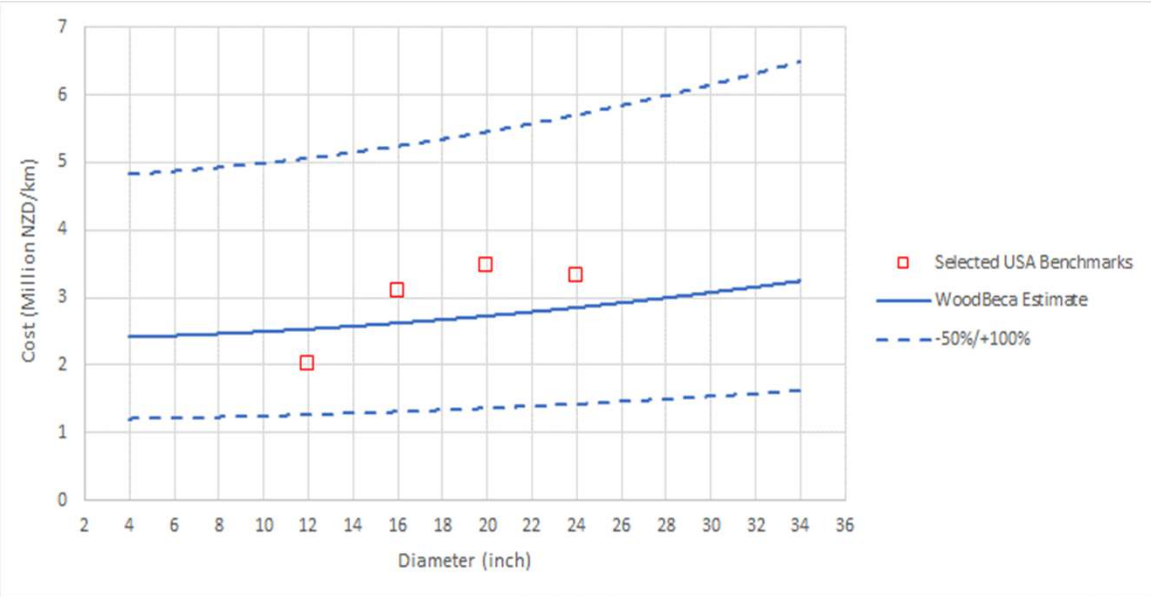



***Figure 4 Onshore Pipeline Cost (OOM), 132 bar design pressure, dense phase pipeline***

***Table 5 Line size guidance, 40 km 120 bar dense phase pipeline***

| Rate | 0.2 | 0.4 | 0.6 | 0.8 | 1 | 1.2 | 1.5 | 2 | 5 |
|---|---|---|---|---|---|---|---|---|---|
| Size (inch) | 4 | 6 | 6 | 8 | 8 | 8 | 10 | 10 | 16 |
| Pressure Drop (bar) | 20.2 | 10.4 | 23.3 | 10.4 | 16.1 | 23.2 | 11.4 | 20.2 | 15.8 |
| Velocity (m/s) | 0.9 | 0.9 | 1.3 | 1.0 | 1.3 | 1.5 | 1.2 | 1.6 | 1.8 |

# Cost of injection (onshore)

Costs for injection have been estimated by Wood Beca based on previous New Zealand studies/projects. A cost of \$12M NZD has been assumed for drilling a well of 1 Mtpa maximum capacity. Cost of injection is higher for drilling offshore.

# All in cost per tonne (onshore)

The Class 5 cost for an onshore CCS facility in New Zealand of 1 Mtpa capacity and 1 km pipeline is $28/tonne, assuming a 20 year facility life. This cost includes 3% of CAPEX for annual operation and maintenance costs for capture, compression and injection equipment and 1% of CAPEX for annual operation and maintenance costs for onshore pipeline. A contingency factor of 30% CAPEX has been applied.

These costs are generated for $CO_2$ arising from natural gas processing (concentrated $CO_2$) rather than dilute $CO_2$ flue gas sources (e.g. power station), which have a higher cost of capture as well as having cost penalties due to inefficiencies (energy diversion away from the product). Therefore, these cost metrics are only appropriate for CCS from natural gas processing and cannot be used for other industrial $CO_2$ sources.

Our conclusions show there is a large range in the cost of CCS. These conclusions are consistent with the Global CCS Institute (GCI) 'Technology Readiness and Costs of CCS' report. GCI conclude that large scale natural gas processing is a low-cost opportunity and CCS may be less than $33 NZD/ tonne $CO_2$ (assuming an exchange rate of 1.66NZD to USD).

## All in cost per tonne (onshore)

Below parametric shows cost change for natural gas CCS systems as a function of capacity and pipeline distance. The capacity of the system has first order impact on cost, pipeline length is second order.

| 20 yrs | Mtpa | | | |
|---|---|---|---|---|
| | 0.25 | 0.5 | 1 | |
| 1 km | 50.1 | 36.1 | 27.8 | NZD/tonne $CO_2$ stored |
| 10 km | 56.6 | 39.4 | 29.5 | NZD/tonne $CO_2$ stored |
| 20 km | 63.8 | 43.0 | 31.3 | NZD/tonne $CO_2$ stored |
| 40 km | 78.3 | 50.3 | 35.0 | NZD/tonne $CO_2$ stored |
| 80 km | 107.1 | 64.9 | 42.4 | NZD/tonne $CO_2$ stored |

***Table 6 Variation and impact on cost (+30% contingency applied on overall whole scope TIC_n+1 well philosophy, 0.5 Mtpa capacity per well assumption)***

# Cost of transportation (offshore) - pipelines

As per the onshore pipeline estimate, an internal cost estimate tool developed for $CO_2$ pipeline transportation has been used. The tool determines the pipeline size required based on $CO_2$ rate and the wall thickness required based on the working pressure. The pipeline costing then accounts for the following cost items based on industry benchmarked cost metrics (activity durations, unit costs):

- Pipeline routing: vessel mob/demob, geotechnical survey
- Materials: line pipe, internal, external, and concrete weight coating procurement
- 1 x shore crossing (typical open cut is assumed)
- Installation: vessel mob/demob (DSV, survey, support and lay vessels), pipeline trenching
- Allowance for crossings

The TIC OOM cost (per km) estimate is provided in Figure 5 as a function of pipeline diameter, based on a 120 bar working pressure (144 bar design pressure) dense phase pipeline. This transportation condition is considered representative of the majority of use cases for offshore NZ CCS.

The plot is provided only to support viability assessment and is not rely upon for project specific cost estimation. Every project is bespoke, and hence caution is required applying a generic approach.

The plot is provided only to support viability assessment and is not rely upon for project specific cost estimation. Every project is bespoke, and hence caution is required applying a generic approach.

# Cost of transportation (offshore) – pipelines

Industry cost analogues are difficult to obtain as the basis can be unclear (e.g., wall thickness / pipe schedule, location, mob/demob durations, distance, diameter, installation date etc.). Selected offshore $CO_2$ pipeline installation costs are provided which show a reasonable match to the Wood Beca OOM estimate, albeit on the lower side. There is one high outlier (16”) noting this is for a short (<30 km) 230 bar design pressure pipeline with high material costs.

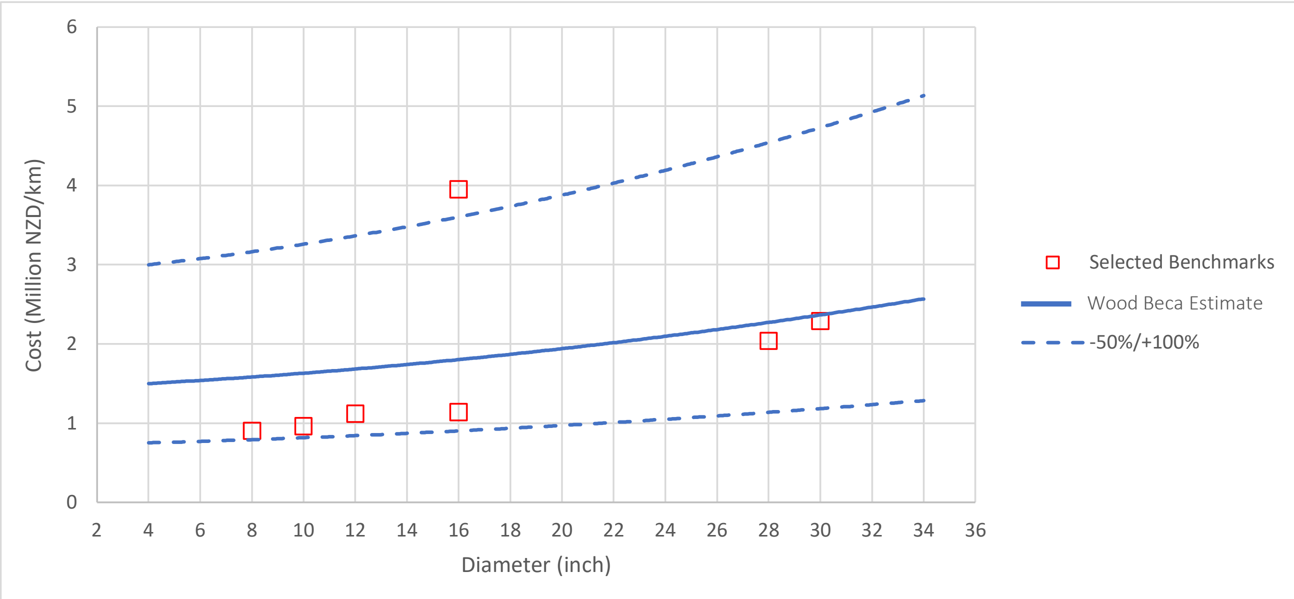



***Figure 5 Offshore Pipeline Cost (OOM), 144 bar design pressure, dense phase pipeline***

# Case 1: Example of Class 5 cost estimate for onshore CCS facility; 0.75 Mtpa and 0.5km pipeline.

**Analysis**

| | | |
|---|---|---|
| Case: | 0.75 | mtpa |
| | 0.5 | km pipeline |
| | 8 | inch |
| | 20 | year project life |
| | n+1 | well philosophy |
| | 30% | contingency |
| | 10% | discount factor |

| | CAPEX (MMNZD) | | | | | Annual OPEX (MMNZD) | | | |
|---|---|---|---|---|---|---|---|---|---|
| mtpa | Cap | Comp | Transp | Inj | Cont | Cap | Comp | Transp | Inj |
| 0.75 | 159 | 53 | 1 | 36 | 75 | 5 | 2 | 0 | 1 |

| | | | |
|---|---|---|---|
| CAPEX | 324 | MMNZD | PV (no CAPEX phasing) |
| OPEX | 7 | MMNZD | per annum |
| OPEX | 149 | MMZD | over field life (not discounted) |
| OPEX | 85.1 | MMZD | discounted |
| CO2 stored | 15 | mTe | |
| Price | 31.6 | NZD/TeCO2 | |
| Price | 27.3 | NZD/TeCO2 | |

woodbeca
global expertise local understanding

# Case 2: Example of Class 5 cost estimate for onshore CCS facility; 1 Mtpa and 20 km pipeline.

**Analysis**

| | | |
|---|---|---|
| Case: | 1 | mtpa |
| | 20 | km pipeline |
| | 8 | inch |
| | 20 | year project life |
| | n+1 | well philosophy |
| | 30% | contingency |
| | 10% | discount factor |

| | CAPEX (MMNZD) | | | | | Annual OPEX (MMNZD) | | | |
|---|---|---|---|---|---|---|---|---|---|
| mtpa | Cap | Comp | Transp | Inj | *Cont* | Cap | Comp | Transp | Inj |
| 1 | 189 | 66 | 49 | 36 | *102* | 6 | 2 | 0 | 1 |

| | | | |
|---|---|---|---|
| CAPEX | 442 | MMNZD | PV (no CAPEX phasing) |
| OPEX | 9 | MMNZD | per annum |
| OPEX | 184 | MMZD | over field life (not discounted) |
| OPEX | 85.1 | MMZD | discounted |
| CO2 stored | 20 | mTe | |
| Price | 31.3 | NZD/TeCO2 | |
| Price | 26.3 | NZD/TeCO2 | |

# Case 3: Example of Class 5 cost estimate for onshore CCS facility; 0.2 Mtpa and 20 km pipeline.

**Analysis**

| | | |
|---|---|---|
| Case: | 0.2 | mtpa |
| | 20 | km pipeline |
| | 4 | inch |
| | 20 | year project life |
| | n+1 | well philosophy |
| | 30% | contingency |
| | 10% | discount factor |

| | CAPEX (MMNZD) | | | | | Annual OPEX (MMNZD) | | | |
|---|---|---|---|---|---|---|---|---|---|
| mtpa | Cap | Comp | Transp | Inj | *Cont* | Cap | Comp | Transp | Inj |
| 0.2 | 72 | 20 | 48 | 24 | *49* | 2 | 1 | 0 | 1 |

| | | | |
|---|---|---|---|
| CAPEX | 213 | MMNZD | PV (no CAPEX phasing) |
| OPEX | 4 | MMNZD | per annum |
| OPEX | 79 | MMZD | over field life (not discounted) |
| OPEX | 85.1 | MMZD | discounted |
| CO2 stored | 4 | mTe | |
| Price | 73.2 | NZD/TeCO2 | |
| Price | 74.6 | NZD/TeCO2 | |

# Case 4: Example of Class 5 cost estimate for onshore CCS facility; 1 Mtpa and 1 km pipeline.

**Analysis**

| | | |
|---|---|---|
| Case: | 1 | mtpa |
| | 1 | km pipeline |
| | 8 | inch |
| | 20 | year project life |
| | n+1 | well philosophy |
| | 30% | contingency |
| | 10% | discount factor |

| | CAPEX (MMNZD) | | | | | Annual OPEX (MMNZD) | | | |
|---|---|---|---|---|---|---|---|---|---|
| mtpa | Cap | Comp | Transp | Inj | Cont | Cap | Comp | Transp | Inj |
| 1 | 189 | 66 | 2 | 36 | 88 | 6 | 2 | 0 | 1 |

| | | | |
|---|---|---|---|
| CAPEX | 381 | MMNZD | PV (no CAPEX phasing) |
| OPEX | 9 | MMNZD | per annum |
| OPEX | 175 | MMZD | over field life (not discounted) |
| OPEX | 85.1 | MMZD | discounted |
| CO2 stored | 20 | mTe | |
| Price | 27.8 | NZD/TeCO2 | |
| Price | 23.3 | NZD/TeCO2 | |