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# Bayu-Undan: A test bed for carbon trading or a distraction?

Key details of Santos's massive carbon capture project remain a mystery three years after it was unveiled

Kevin Morrison, Energy Finance Analyst, Australian Gas
John Robert, IEEFA Guest Contributor

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# Key Findings

**Greater transparency is needed about Santos's proposed Bayu-Undan CCS project, including the costs and quantity of $CO_2$ likely to be sequestered, and whether Santos will need to buy additional carbon credits to offset emissions from its Barossa gas project.**

**Santos should provide a decommissioning plan for existing infrastructure at Bayu-Undan, including the costs and the timeline.**

**Santos must demonstrate how it will meet its targets given CCS's history of underperformance, including at Chevron's Gorgon project, and provide the cost implications of any underperformance of the Bayu-Undan CCS project.**

**Investors will require transparency on the liability issues associated with any potential $CO_2$ leaks from the Bayu-Undan CCS project. Australia and Timor-Leste will need to reach an agreement on liability provisions given the project is in Timor-Leste waters.**

# Executive Summary

In September 2021, Australian gas producer Santos unveiled ambitious plans to turn the near depleted Bayu-Undan gas field in the Timor Sea into a carbon capture and storage (CCS) facility. In the three years since, however, Santos has yet to disclose the costs or provide technical details on the world's largest CCS venture proposal. The project also presents many legal and regulatory risks.

The Bayu-Undan announcement followed Santos reaching final investment decision (FID) on its Barossa gas project, also located in the Timor Sea. The company plans to start producing gas from Barossa in 2025, and it claims the project will have net zero emissions from day one. This is a bold claim given Barossa will be the most carbon-intensive gas field to supply feedstock to an Australian LNG project, with carbon dioxide ($CO_2$) content of 18%.

Santos's net zero claim on Barossa is contingent on burying some of the $CO_2$ it produces at Bayu-Undan. Santos plans to develop the world's largest CCS facility, and one of the most complex, with $CO_2$ moving through almost 800km of pipelines and across maritime boundaries.

To date, Santos has not published an offshore project proposal (OPP) or environmental impact statement (EIS) on Bayu-Undan CCS, as would be expected for a venture of this scale. Instead, Santos says only that it intends to sanction Bayu-Undan CCS in 2025 and start injecting $CO_2$ into it from 2028, buying carbon credits in the interim. Santos still requires regulatory approval for some of the CCS infrastructure, and it has no permits in place to allow it to send $CO_2$ to Timor-Leste.

The total emissions from the two locations – the floating production, storage and offloading (FPSO) facility and the Darwin LNG plant – would be 5.4 million tonnes of $CO_2$ equivalent ($MtCO_2e$) a year, which exceeds forecast LNG production by more than 50%; in other words, it would be a $CO_2$ emissions factory with an LNG byproduct. This has clear financial implications for Santos given the requirement for it to fully offset all reservoir emissions under Australia's revised Safeguard Mechanism.

It will also make Australia's commitment to cut greenhouse gas (GHG) emissions by 43% by 2030 more challenging unless Santos is able to successfully sequester most of the $CO_2$ from Barossa.

At its 2022 annual meeting, 37% of Santos shareholders voted against its climate strategy, which hinges on using CCS to achieve its net zero emissions goal by 2040. Since then, Santos has widened its CCS ambitions. Bayu-Undan is part of the company's three-hub CCS strategy in Australia, along with the Moomba CCS project in South Australia and the Reindeer CCS hub in the Carnarvon Basin offshore Western Australia (WA). Santos aims to expand its CCS footprint beyond these three projects, with successful bids for other offshore CCS permits around Australia.

Santos aims to sequester up to 10 million tonnes of $CO_2$ ($MtCO_2$) a year in Bayu-Undan, with the $CO_2$ coming from Barossa and other $CO_2$-laden gas fields offshore northern Australia, as well as $CO_2$ shipped from Japan and South Korea. This as-yet-untested undertaking could make Bayu-Undan

integral to an Asia-Pacific $CO_2$ trading hub that could also sequester waste $CO_2$ from Japan in CCS projects in Malaysia and Indonesia.

Despite Santos's lofty ambitions for Bayu-Undan, the economics of the project are unknown, and the multiple legislative and regulatory approvals required add uncertainty to the project timing.

The costs of the project are likely to be large given it is intended to be more than twice the size of Chevron's beleaguered Gorgon CCS facility on Barrow Island in WA, and will involve more complex engineering. At Gorgon CCS, $CO_2$ is injected into a reservoir known as the Dupuy formation, 2km below the island; the injection pipeline is just 7km long. However, despite Gorgon CCS's onshore location (which is less costly) and smaller scale, Chevron and its partners Exxon and Shell have spent more than A$3.2 billion on the project, which still only operates at about one-third of its design capacity. While Gorgon CCS was designed to store up to 4Mt$CO_2$ a year, it has grossly underperformed since it started operating in 2019.

As part of the Bayu-Undan CCS project, Santos intends to pipe $CO_2$ over a distance more than 100 times greater than the Gorgon CCS project, despite the fact the existing subsea pipelines were designed for a very different purpose, and Santos has no approval to pump $CO_2$ to Bayu-Undan.

Santos has stated its CCS plan for Bayu-Undan is an opportunity to avoid hundreds of millions of dollars in decommissioning costs for the declining gas field's platforms and facilities. However, investors should still factor in those decommissioning costs, as Santos will still face this obligation either at the end of the life of Bayu-Undan CCS or should the project not go ahead.

IEEFA believes investors do not have sufficient information to understand the economics and the legal and regulatory risks associated with both the Bayu-Undan CCS and Barossa gas projects. In our view, Santos should release provisional estimates so the true cost of the CCS project and producing gas from Barossa can be assessed, along with the net emissions savings from $CO_2$ injections into the Bayu-Undan field. It should also provide technical evidence that Bayu-Undan is geologically suitable to store $CO_2$, given the many technical issues offshore CCS ventures face. In addition, Santos should clarify what the CCS project means for its decommissioning obligations.

# Introduction

The Bayu-Undan CCS project would be the largest of its kind in the world. It is designed to bury carbon dioxide ($CO_2$) from one of the most carbon-intensive gas fields in Australia, as well as to store $CO_2$ from Japan and possibly South Korea. Aside from significant technical challenges, it faces possible international obstacles as the waste $CO_2$ would need to cross multiple maritime boundaries to reach the waters of Timor-Leste.

## Second life for near depleted Bayu-Undan gas field?

Santos announced plans to turn the near depleted Bayu-Undan gas field in the Timor Sea into a CCS facility in September 2021, six months after it reached final investment decision (FID) on the Barossa gas project in March 2021.[1] This gave Bayu-Undan a new lease of life as Santos had filed plans to decommission it in August 2020.[2,3]

If developed, the Bayu-Undan facility will have a target injection rate of 10Mt$CO_2$ a year, more than double the size of the world's largest CCS project – the 4Mtpa Gorgon CCS plant in Western Australia (WA).[4] Alongside Bayu-Undan, Santos is progressing two other CCS projects: at Moomba (1.7Mtpa) in South Australia's onshore Cooper Basin; and at the now depleted Reindeer gas field (5Mtpa) offshore WA. Santos plans to sanction the latter in 2025 and start injecting $CO_2$ by 2028.[5]

One of Santos's key motivations for developing Bayu-Undan is to sequester $CO_2$ from the Barossa gas reservoir, which has a high $CO_2$ content at 18%.

However, the project has many additional layers of complexity compared with other CCS facilities. It will be one of the first CCS projects to transport $CO_2$ across international maritime boundaries. This plan triggered a legislative change in Australia to allow the movement of $CO_2$ across international borders so Australia could export $CO_2$ for storage.[6] But before any $CO_2$ can be buried in Bayu-Undan, Santos will have to seek further regulatory and legislative changes and approvals from both the Australian and Timor-Leste governments. Timor-Leste has not ratified any agreement for Bayu-Undan to be used as a depository for $CO_2$ from other countries. A key question is which country will be responsible for any $CO_2$ emissions that are leaked, and whether either Australia or Timor-Leste can earn carbon credits from the planned $CO_2$ injections.

[1] Santos. Santos announces FID on the Barossa gas project for Darwin LNG. 30 March 2021.
[2] Santos. Bayu-Undan Gas Export Pipeline Environment Plan. 27 October 2023. Pages 1-2.
[3] Santos. Bayu-Undan Suspension of Operations. Supplier Information Session, Dili, Timor-Leste. May 2022. Pages 5-7.
[4] Chevron. The Gorgon Project.
[5] Santos. Barossa Gas Project.
[6] Parliament of Australia. Environment Protection (Sea Dumping) Amendment (Using New Technologies to Fight Climate Change) Bill 2023.

While Santos's plan to send $CO_2$ from Australia to Timor-Leste could expand to include waste $CO_2$ from Japan and South Korea, the specialised shipping vessels required are not yet in use.[7]

After three years, Santos has yet to provide any freight, injection and storage cost estimates for importing $CO_2$ and the associated infrastructure so investors can assess the feasibility of the project, and whether it will allow Santos to achieve its emissions reduction targets and at an economic cost. Crucially, this includes how Santos intends to manage the novel engineering challenges and technical risks associated with the project, given $CO_2$ has never travelled such distances through pipelines or by ship, and whether the Bayu-Undan gas field is suitable for injecting $CO_2$ on this scale.[8] Santos also has not published the results of any studies on the seismic impacts from injecting $CO_2$ into the Bayu-Undan field nor on whether the surrounding caprock can withstand the pressure of storing an estimated total capacity exceeding 250Mt$CO_2$.[9] (For more, see Technical challenges, doubts and financial risks.)

Shipping $CO_2$ over thousands of kilometres will involve burning heavy fuel oil. Once the associated emissions are considered, the net volume of $CO_2$ sequestered in Bayu-Undan may be significantly reduced, and this may need to be factored into the economics of the project. As noted previously by IEEFA: "Santos needs to detail how much energy will be used to transport the $CO_2$ from Darwin to Bayu-Undan, given that $CO_2$ is almost three times denser than methane, and what sources of energy will be used to move the $CO_2$ over vast distances?"[10]

Japanese trading house Mitsubishi and oil distributor Eneos Corp are also studying plans to liquefy $CO_2$ emitted by thermal power plants and oil refineries to be shipped to Malaysia for storage. Shipping $CO_2$ from Japan to Indonesia is also being investigated.[11] This makes Bayu-Undan one of multiple potential CCS hubs for Japanese companies to export waste $CO_2$.

Santos said initial engineering studies on the Bayu-Undan CCS project were 90% complete as of 21 August 2024 and were expected to be finished during the December 2024 quarter.[12] Santos has not said if it will disclose the costs and technical challenges of the project once these studies are complete.

Santos sees Bayu-Undan as a key part of its strategy to meet its emissions reduction targets under the Safeguard Mechanism, which requires Australia's highest greenhouse gas (GHG) emitters to reduce their emissions in line with the federal government's target of 43% below 2005 levels by 2030 and net zero by 2050.

[7] Santos. Bayu-Undan joint venture and Timor Gap sign MOU to cooperate on carbon capture and storage. 7 August 2023.
[8] OnePetro. Design of Carbon Capture and Sequestration CCS wells. March 2022. *Ceyhan,I; Pilisi, N; Suryanarayana, PV; and Krishnamurthy, RM*.
[9] ANPM. Carbon Capture and Storage (CCS) presentation. January 2023. Page 11.
[10] IEEFA. Darwin Pipeline Duplication Project. Submission to the Northern Territory Environmental Protection Authority. June 2023. Page 5.
[11] The Financial District. Japan firms' plans for CO2 export, storage in southeast Asia rise. 12 April 2024.
[12] Santos. 2024 Half-year results video. 21 August 2024.

Under the Safeguard Mechanism, Santos is required to have net zero reservoir emissions from the Barossa gas project. However, there are many sources of emissions in the Barossa to Darwin LNG project (Table 1). Further, emissions from the use of fuel gas on the floating production storage and offloading (FPSO) unit to extract gas from the Barossa reservoir must decline by 4.9% a year to 2030 and to net zero by 2050.

Emissions from the Barossa gas reservoir are estimated at 3.4Mt$CO_2$ a year (Table 1). The licensed cap on emissions from the Darwin LNG liquefaction plant is 2.05Mt$CO_2$ a year.[13] Total emissions from Barossa gas/Darwin LNG plant translate to an emissions intensity, or specific emissions in production (SEP), of 1.47t$CO_2$ per tonne of LNG. This figure is more than double the average SEP for the Australian LNG industry as a whole,[14] and in turn makes it more challenging for the sector to reduce its emissions under the Safeguard Mechanism (Figure 1).

Emissions at the LNG plant are associated with the separation of $CO_2$ from the Barossa gas and the production of the LNG itself. Total emissions from the Barossa gas field and Darwin LNG plant are anticipated to be about 5.4Mt$CO_2$ a year, or about 3.9% of Australia's total emissions of 138.7Mt$CO_2$ a year under the Safeguard Mechanism in the 2022-23 fiscal year.[15] In theory, these emissions should fall by 4.9% to 138.03Mt$CO_2$ during FY2023-24. This creates a challenge for the federal government as it tries to meet the opposing objectives to increase or maintain Australia's LNG exports while reducing GHG emissions.

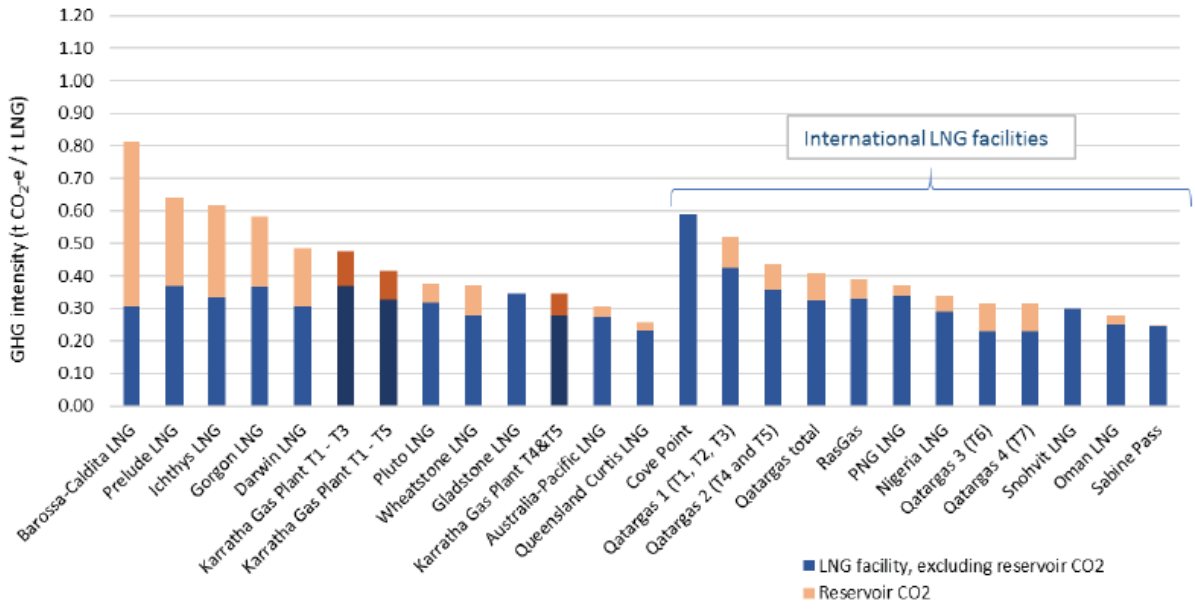
**Table 1: Main sources of emissions from Barossa offshore gas project**

| Million tonnes $CO_2$ pa ($MtCO_2$) | Vent | Combustion | Total |
|---|---|---|---|
| Offshore (FPSO) | 1.82 | 1.56 | 3.38 |
| Onshore (Darwin LNG) | 0.51e | 1.54e | 2.05 |
| **Total** | **2.33** | **3.1** | **5.43** |

*Source IEEFA estimates.[16] Calculations based on information from Barossa Development Plan March 2018.[17] Note: The gas industry promotes gas as a transition fuel to a less emissions-intensive energy system, but the evidence seems to point to the contrary, with Australia's GHG emissions intensity set to rise when Barossa comes online to provide feedstock to the 3.7Mtpa Darwin LNG plant.*

[13] ConocoPhillips Australia. Barossa area development offshore project proposal. March 2018. Page 128.
[14] IEEFA. Should Santos' proposed Barossa gas 'backfill' for the Darwin LNG facility proceed to development? 1 March 2021.
[15] Clean Energy Regulator. Safeguard facility reported emissions data. 16 May 2024.
[16] IEEFA. How To Save the Barossa Project From Itself. 1 October 2021.
[17] ConocoPhillips Australia. Barossa area development offshore project proposal. March 2018.

**Figure 1: GHG intensity of Australian vs international LNG facilities**




*Source: Woodside. Appendix F North West Shelf Project Extension Greenhouse Gas Benchmarking Report*

Bayu-Undan is earmarked to start in 2028, three years after the Barossa gas field begins production. Santos said it bought carbon credits to offset the Barossa emissions to meet its obligations under the Safeguard Mechanism, but did not disclose the price.[18] Under existing rules, to offset its emissions Santos can only buy Australian Carbon Credit Units (ACCUs), which were trading at A$36.25/t $CO_2$ on 9 October 2024. Santos says it "will meet its obligations under the Safeguard Mechanism and, subject to a future investment decision, may offset emissions through CCS at Bayu-Undan".[19]

Based on prevailing carbon credit prices, it could cost Santos more than A$600 million over three years to cover its Scope 1 and 2 emissions from Barossa and Darwin LNG by the time the Bayu-Undan CCS facility opens.[20] Increased demand for credits under the Safeguard Mechanism, including from Barossa, is likely to increase credit prices.

Given Barossa's high $CO_2$ content, the costs of operating a CCS facility to abate its emissions may command a significant share of total costs of the combined Barossa, Darwin LNG plant and Bayu-Undan CCS. S&P Global estimates Bayu-Undan CCS represents 34% (or US$3.26 per million British thermal units/mmBtu) of Barossa gas field's total upstream costs of US$9.6/mmBtu and more than the Darwin LNG plant's operating costs of US$2.4/mmBtu.[21]

[18] The Australian. Santos locks in carbon credits for $5.7bn Barossa LNG project. 17 June 2024.
[19] Parliament of Australia. Middle Arm Inquiry. Santos, answers to questions on notice. Page 3. 15 July 2024.
[20] Clean Energy Regulator (CER). Emissions and energy types. 8 April 2024. Scope 1 or direct emissions are a result of the activities at a facility. Scope 2 or indirect emissions are those released outside the facility to produce electricity consumed at the facility.
[21] S&P Global Commodity Insights. The future of Australia's LNG exports in a changing global market. 8 August 2024. Page 8.

CCS has a long history of failure and underperformance.[22] It is possible therefore that the Bayu-Undan CCS project could fail to meet its target $CO_2$ injection rates. This poses a financial risk for Santos as it could be subject to fines from Australian regulators for not meeting its Safeguard Mechanism obligations.

## Santos bets on CCS to reach emissions goals

CCS is central to Santos's strategy to reduce GHG emissions, and the company has signed multiple non-binding agreements with international partners as part of a growing network of CCS projects across Southeast Asia and Australasia.

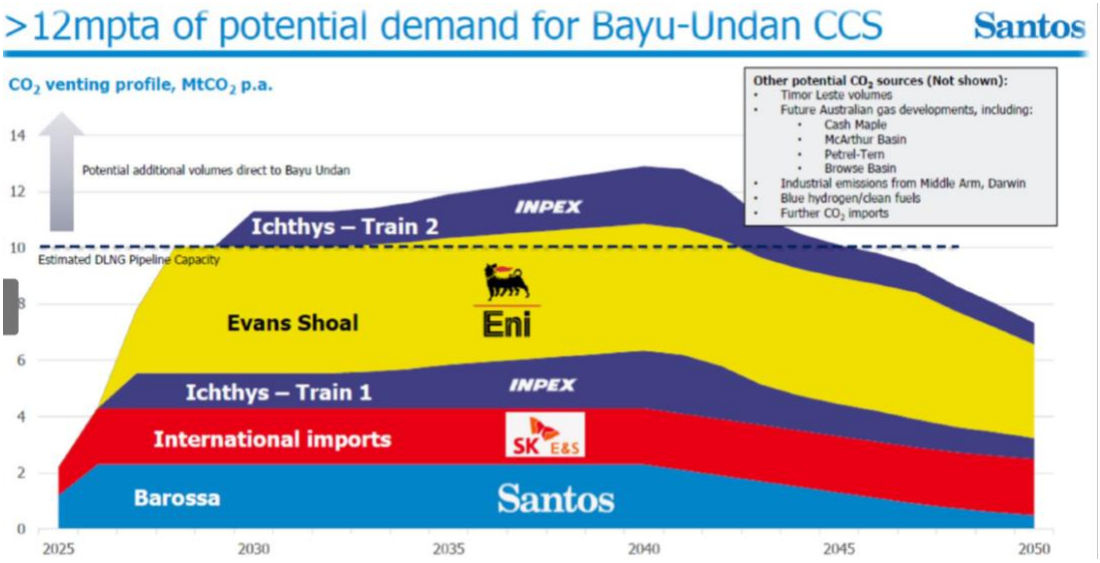
As part of their energy solutions strategy, Santos and its partners plan to export and import $CO_2$ across maritime boundaries. The passage of Australia's Sea Dumping Bill in 2023 led to several alliances and informal agreements to use Bayu-Undan as a regional hub for storing $CO_2$. Santos has also signed agreements to import $CO_2$ from Japan and South Korea to store it in depleted offshore gas/oil fields. Japanese companies INPEX and JERA own a combined 17.3% stake in Bayu-Undan while South Korea's SK E&S owns 21%. Santos owns 36.5% of Bayu-Undan.

Santos is factoring in imports of $CO_2$ being injected into Bayu-Undan CCS from day one of the Barossa gas field's operation, despite the fact the CCS facility will not be ready for at least three years after Barossa starts production (Figure 2). In addition, the 12Mt$CO_2$ annual storage estimate quoted by the Timor-Leste government is 20% higher than Santos's nameplate capacity of 10Mtpa. Santos signed a memorandum of understanding (MOU) with South Korean energy company and Bayu-Undan co-owner SK E&S to collaborate on securing additional $CO_2$ storage at Bayu-Undan as well as developing a "low-carbon hub" at Darwin.[23] The Santos and SK agreement was struck on the same day the Australian Senate passed the Sea Dumping Bill.

However, SK E&S's carbon strategy may change following its merger with affiliate SK Innovation, owner of electric vehicle battery maker SK On.[24] Santos has also reached an agreement with Timor-Leste's national oil company, Timor Gap, to collaborate on Bayu-Undan CCS.[25] Timor Gap was awarded a 16% stake in the Bayu-Undan on 17 September 2024 so it could still receive an income to reflect the prevailing gas sales to the Northern Territory (NT) market.[26]

[22] IEEFA. Blue hydrogen: Not clean, not low carbon, not a solution, making hydrogen from natural gas makes no sense. 12 September 2023. Page 18.
[23] Santos. Santos and SK E&S to collaborate on cross-border carbon capture and storage. 13 November 2023.
[24] Energy Connects. SK Group to merge energy units to help ailing battery business. 17 July 2024.
[25] Santos. Bayu-Undan joint venture and Timor Gap sign MOU to cooperate on carbon capture and storage. 7 August 2023.
[26] Santos. Santos and Timor Gap execute sale and purchase deed for the Bayu-Undan upstream project. 17 September 2024.

**Figure 2: Sources of $CO_2$ for Bayu-Undan CCS project**




*Source: National Authority for Petroleum and Minerals (ANPM)*[27]

A significant share of the potential $CO_2$ to be stored in Bayu-Undan is from the Evans Shoal gas field in the Timor Sea, west of the Barossa field. Evans Shoal, renamed the Verus gas field, has a $CO_2$ content of about 27% or about 50% higher than Barossa.[28] Italian oil major Eni had planned to sanction the Verus gas project by 30 June 2024.[29] In March 2024, Eni said it was reviewing development plans for Verus.[30] Eni also owns 9.2% of Bayu-Undan.

$CO_2$ to be injected in Bayu-Undan from INPEX's Ichthys gas field in the Browse Basin offshore WA is piped with the gas almost 890km to Darwin (Figure 3). There, INPEX has the downstream liquefaction plant for Ichthys gas, and owns 11.4% of the permit that hosts Bayu-Undan.[31] It plans to pursue CCS as a way to decarbonise the Ichthys gas field, which comprises two fields: Brewster, with an average $CO_2$ content of 8%; and Plover (17%).[32]

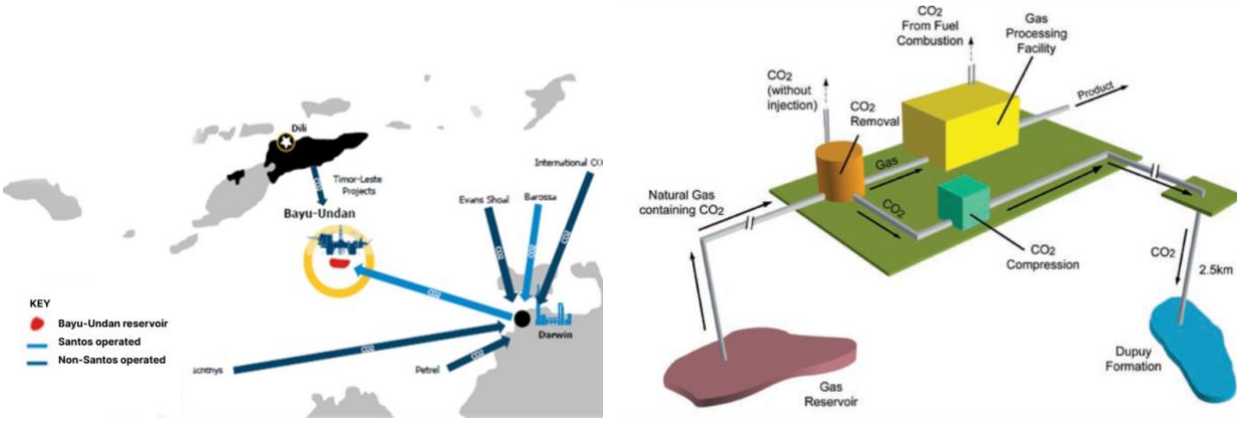
The large difference in the $CO_2$ content of each field for the Ichthys LNG means the average GHG emissions from the gas reservoir, also known as Scope 1 emissions, of the venture will change over the planned 40-year life of the project.[33,34] INPEX and fellow Japanese energy company JERA have signed an agreement to undertake a joint study to assess the feasibility of a CCS value chain from Japan to Australia, which includes the capture of $CO_2$ in Japan to transport to Australia for storage.[35]

[27] ANPM. Carbon Capture and Storage (CCS) presentation. January 2023.
[28] IEEFA. Eni's Verus Not So True on Net Zero. 8 May 2023. Page 4.
[29] Ibid. Page 5.
[30] ABC. Eni to review plans for carbon-intensive Verus gas field to minimise 'environmental footprint'. 27 March 2024.
[31] Santos. Santos completes Bayu-Undan and Darwin LNG sell-down to SK. 30 April 2021.
[32] INPEX. Draft Environmental Impact Statement. Chapter 9: Greenhouse Gas Management. Page 420.
[33] INPEX. Draft Environmental Impact Statement. Chapter 9: Greenhouse Gas Management. Page 420.
[34] LNGPrime. Inpex: Ichthys LNG plant hits record in 2023. 13 February 2024.
[35] Offshore Energy. INPEX and JERA evaluating feasibility of Japan-Australia CCS value chain. 10 May 2024.

INPEX has so far not committed to sending $CO_2$ to Bayu-Undan, and has instead focused on a CCS venture in the Bonaparte Basin offshore NT, based on a GHG permit in which it has a 53% stake, with TotalEnergies holding 26% and Woodside Energy 21%.[36]

**Figure 3: $CO_2$ storage and travel, Bayu-Undan vs Barossa**

***Bayu-Undan and its potential sources of $CO_2$*** ***Gorgon Gas and CCS development***




*Sources: ANPM,[37] WA Department of Energy, Mines, Industry Regulation and Safety. Note: Right-hand side shows the proximity of the $CO_2$ storage area (Dupuy formation) to the Gorgon project; Left-hand side shows the vast distance $CO_2$ will travel from Barossa to Darwin and then onto Bayu-Undan.*

As part of its international CCS strategy to bury its own $CO_2$ from gas reservoirs as well as those from third parties, Santos signed MOUs with Japanese energy firms JX Nippon Oil & Gas Exploration Corporation (JX) and Eneos Corporation for a "joint feasibility study that will evaluate the potential to capture, transport and sequester emissions from Japan, supporting expansion of the Moomba CCS project"[38] in the onshore Cooper Basin in South Australia. This is one of several Japanese-backed CCS projects in or near Australia to dump $CO_2$.

Santos also signed an MOU with ADNOC, the state-owned oil company of the United Arab Emirates to "collaborate on the development of CCS technologies; joint participation in global CCS projects and the provision of CCS solutions to emitting companies across Asia including the development of shipping and transport infrastructure".[39] No CCS projects have been identified in this MOU.

[36] INPEX. Bonaparte Carbon Capture and Storage.
[37] ANPM. Carbon Capture and Storage (CCS) presentation. January 2023.
[38] Santos. Santos, JX and Eneos to collaborate on carbon capture and storage to support Moomba CCS phase 2 and help Japan decarbonise. 18 December 2023.
[39] Santos. Santos establishes strategic collaboration on CCS with ADNOC. 22 November 2023.

## Santos has a long history with CCS but is yet to store $CO_2$

Santos has long held plans to develop a CCS project and is on the cusp of starting one at Moomba in South Australia in late 2024, despite more than a third of its investors rejecting the company's emissions reduction plans. Santos also sees CCS as a way to generate revenue by storing $CO_2$ waste from other companies and countries.

At its 2022 annual meeting, 37% of shareholders voted against Santos's climate strategy, which hinges on CCS to achieve its net zero emissions plan by 2040.[40] Santos's CCS ambitions have had a long gestation. It unveiled plans for the A$700 million Moomba CCS project in 2007, targeting initial $CO_2$ injections in 2010,[41] which did not occur.

Back in 2007, Santos planned to scale up the Moomba CCS project to store 20Mt$CO_2$ a year.[42] The project was shelved in 2009 only to be revived in 2018 when Santos planned to assess "incremental improvements in oil recovery from oil reservoirs in the Cooper Basin using captured $CO_2$".[43] Santos had already been injecting $CO_2$ into Cooper Basin reservoirs at Fly Lake in South Australia since 2008 for enhanced oil recovery (EOR).[44] Santos has since removed any reference to EOR at Moomba. The latest incarnation of the Moomba CCS project was sanctioned in November 2021 with estimated development costs of US$165 million,[45] after Santos received a A$15 million grant from the Australian government's Carbon Capture Use and Storage Development Fund.[46] The Moomba FID coincided with CCS being accepted to receive carbon credits under Australia's Emissions Reduction Fund.[47]

Granting credits for $CO_2$ buried at Moomba could be contentious as Santos has said the project could be used for EOR,[48] which is excluded from the Emissions Reduction Fund.[49] There has been no suggestion that enhanced oil or gas recovery will be used at Bayu-Undan.

## CCS a favoured solution by gas companies

CCS has been assertively promoted by the global oil and gas industry despite its underwhelming history in terms of the volume of $CO_2$ it can store, which represents for many oil and gas projects less than 10% of the total GHG created by the combustion of the fossil fuels produced. The industry has successfully lobbied governments to accept CCS as part of their GHG reduction policies.

[40] Australian Financial Review. Why investors want more control over companies climate plans. 27 April 2023.
[41] Santos. Funding commitment for Moomba Carbon Storage. 20 November 2007.
[42] Ibid.
[43] Santos. Climate Change Report 2019. Page 23. February 2019.
[44] Santos. Santos Energy Solutions – Moomba CCS Project. 2020 Roundtable for Oil and Gas. 30 November 2020. Page 4.
[45] Santos. Santos announces FID on Moomba carbon capture and storage project. 1 November 2021.
[46] Santos. Moomba CCS project boosted by A$15 million grant from carbon capture use and storage development fund. 8 June 2021.
[47] Santos. Santos welcomes CCS method for emissions reduction fund, clearing way for Moomba CCS project to apply for registration. 1 October 2021.
[48] Santos. Santos CCUS – Cooper/Eromanga basin CO2-EOR. Global CCS Institute Asia Pacific Forum 31 May 2019. Pages 1-9.
[49] Australian Government, Clean Energy Regulator. Carbon capture and storage method 2021 – simple method guide. January 2024. Page 5.

Whether a system that does little to reduce overall emissions warrants further investment is worthy of further scrutiny.

Most of the projects categorised as CCS around the world are used primarily for enhanced oil or gas recovery, according to the Global CCS Institute (GCCSI).[50] The EOR process pumps $CO_2$ into a depleted oil or gas field to extract any remaining hydrocarbons. Instead of a climate solution, CCS is boosting oil and gas production, and in turn increasing GHG emissions (See Appendix).

$CO_2$ injected into suitable, depleted oil reservoirs can enhance oil recovery by 10-15%.[51] The International Energy Agency (IEA) estimates that EOR projects produce about 500,000 barrels of oil equivalent (boe) a day globally.[52]

However, there are more CCS projects under development focused on permanently storing $CO_2$, according to the GCCSI. The only $CO_2$ captured from the Barossa/Darwin LNG and Bayu-Undan CCS venture is the $CO_2$ from the Barossa gas reservoir, known as Scope 1 emissions. It will not capture the emissions from the fuel gas at the FPSO nor those generated at the Darwin LNG plant (Scope 2 emissions). Nor will it capture most of the emissions associated with the Barossa gas project, which are created when the gas is combusted by users (Scope 3 emissions).

In addition, existing CCS projects rarely, if ever, reach their emissions capture targets. The Gorgon CCS venture on Barrow Island in WA, has underperformed since it started in 2019. In FY2022-23, for example, 1.72Mt$CO_2$ was injected into storage at Gorgon, or 43% of its targeted annual volume.[53] Gorgon's underperformance is reflective of CCS projects around the world. Not one has been able to capture 100% of $CO_2$ emissions.[54]

In 2023, global energy-related $CO_2$ emissions rose by 410Mt to a new high of 37.4 billion tonnes. By comparison, CCS, which has been in operation for 50 years, has a total global storage capacity of 11.33Mt $CO_2$ a year or 0.03%.[55] The actual amount of $CO_2$ stored is well below this level.

This mismatch between global energy-related emissions and the actual amount of $CO_2$ stored in CCS projects was highlighted by the IEA, which urged the industry to let go of "the illusion that implausibly large amounts of carbon capture are the solution" to the world's climate goals.[56]

Many CCS projects fail to get off the ground as their near-term projections fall short of integrated assessment models. Globally, 70% of the 149 CCS projects planned to be operational by 2020,

[50] Global CCS Institute. Global status of CCS 2023, Scaling up through 2030. Pages 77-78.
[51] IEA Greenhouse Gas R&D Programme. Putting Carbon Back into the Ground. Page 14. February 2001.
[52] IEA. Can CO2-EOR really provide carbon-negative oil? 11 April 2019.
[53] Chevron. Gorgon Gas Development and Jansz Feed Gas Pipeline. Environmental Performance Report 2023. 7 November 2023. Page 64.
[54] IEEFA. Blue Hydrogen: Not Clean, Not Low Carbon, Not a Solution. September 2023. Page 18.
[55] Global CCS Institute. Global status of CCS 2023, Scaling up through 2030. Pages 77-78.
[56] IEA. Oil and gas industry faces moment of truth – and opportunity to adapt – as clean energy transitions advance. 23 November 2023.

representing 130Mt$CO_2$ annual storage, were not implemented.[57] The main factors include cost, technological challenges and lack of revenue streams.[58] Among existing operational CCS projects, only about 9Mt$CO_2$ or 20% of the total annual capture capacity of 45Mt$CO_2$ is injected for storage. The rest is used for enhanced oil recovery.[59]

# CCS a costly delay to decommissioning?

The Bayu-Undan gas field had long been earmarked for decommissioning[60] before Santos changed tack with its CCS plan. This could create risks for investors and taxpayers if plans to decommission other depleted oil and gas fields are suddenly shelved to make way for CCS projects.

Santos took over operations at Bayu-Undan and Barossa in May 2020 when it acquired the northern Australia assets of ConocoPhillips for US$1.465 billion.[61] At the time, Bayu-Undan was already in the twilight of its production life.

Santos filed a plan in August 2020 to decommission the production infrastructure for the Bayu-Undan gas and liquids project. This included removing pipelines and capping wells, with work to start between early 2021 and late 2023.[62] More than a year after the plan was filed, Santos identified CCS as a way to defer its Bayu-Undan decommissioning liabilities. “Our access to depleted gas reservoirs in a number of our core assets not only provides the opportunity to develop CCS at scale, but also provides the opportunity to defer decommissioning expenditure at mature assets,” Santos chairman Keith Spence said.[63]

Spence’s opinion was also noted by corporate advisory firm Grant Samuel & Associates in its independent expert report on the Santos-Oil Search merger in 2021: “Santos’ investigation of a potential CCS project that would repurpose the Bayu-Undan reservoirs for the storage of $CO_2$ from Barossa and, potentially, third parties is a potential risk mitigant. Given the very early stage of this potential project and the issues (including jurisdictional issues) still to be addressed, Grant Samuel has not attributed any explicit value to this project. In addition to mitigating some or all of the direct $CO_2$ costs and broader $CO_2$ risks, a CCS project would result in the deferral of material Bayu-Undan abandonment expenditures, resulting in a reduction in the present value of abandonment expenditures, indicatively in the range US$350-400 million.”[64]

[57] Environmental Research Letters. Explaining successful and failed investments in U.S. carbon capture and storage using empirical and expert assessments. 29 December 2020. Page 2.
[58] Gas Science and Engineering. Risks and uncertainties in carbon capture, transport, and storage projects: A comprehensive review. 20 September 2023. Page 119.
[59] Nature Communications. The feasibility of reaching gigatonne scale CO2 storage by mid-century. 28 August 2024. Page 1.
[60] ConocoPhillips Australia. Bayu-Undan gas export pipeline production cessation. March 2019.
[61] Santos. Santos completes ConocoPhillips northern Australia acquisition. 28 May 2020.
[62] NOPSEMA. Bayu-Undan to Darwin Gas Export Pipeline Decommissioning & Preservation. 10 August 2020.
[63] Santos. Oil Search and Santos merger update: Court approves distribution of Scheme Booklet and convening of Scheme Meeting. 11 November 2021. Page 10.
[64] Ibid. Page 229.

Nonetheless, investors should still factor in potential decommissioning costs for Bayu-Undan should the CCS project not proceed. Even if it does, Santos would still have to decommission the associated infrastructure, such as the pipelines and FPSO, once the reservoir is filled with $CO_2$ and capped. Santos has said decommissioning could start as early as 2028 and no later than Q3 of 2030[65] if the CCS project does not go ahead.

In July 2024, Santos was granted a five-year extension for the Bayu-Undan gas pipeline environmental plan by the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA).[66,67] The ruling allows Santos to keep the pipeline, which is near the end of its operational life, in place while it assesses the feasibility of using it to carry $CO_2$ more than 500km for at least two decades, which is unprecedented globally.

"If CCS does not proceed, offshore decommissioning execution shall occur," NOPSEMA says. Santos and other oil and gas operators with offshore activities are required under the Offshore Petroleum and Greenhouse Gas Storage Act to maintain all structures, equipment and property, and remove all the structures, equipment and property once it is not used.[68]

## Timor-Leste yet to legislate on Bayu-Undan CCS

Timor-Leste is a key participant in the development of the Bayu-Undan CCS project. The Bayu-Undan reservoir is within its maritime border, and the project comes under the legal jurisdiction of Dili. Timor-Leste will be looking for a payment to store the $CO_2$, which will add to the overall cost of the project. Santos's plan to convert Bayu-Undan into a $CO_2$ depository relies on consent from Timor-Leste, which has so far embraced the concept, but has not provided any formal approvals wor entered into any agreements on fiscal arrangements for the project.

The Bayu-Undan gas and condensate field had been an important contributor to the Timor-Leste economy, but there has so far been no financial detail to assess what fiscal impact the Bayu-Undan CCS project could have on Dili's finances. Timor-Leste has tried to use some of its leverage over the project by threatening Santos that it could lose control of Bayu-Undan unless Dili is given an equity share in the project.[69]

Bayu-Undan is about 250km south-west of Timor-Leste, or about half the distance from Darwin to the gas field. It came under Timorese jurisdiction in 2018 following the renegotiation of the maritime boundaries between Dili and Canberra.[70,71] Taxes and royalties from gas and condensate production

[65] Santos. Bayu Undan to Darwin Gas Export Pipeline Environmental Plan. Page 39.
[66] Ibid.
[67] Australian Senate Environment and Communications References Committee. Middle Arm Industrial Precinct hearing, Canberra. 17 June 2024. Page 18.
[68] NOPSEMA. Section 572 Maintenance and removal of property. 20 November 2020. Page 6.
[69] The Sydney Morning Herald. Timor-Leste lays down ultimatum to Santos on gas project negotiations. 26 August 2024.
[70] Australian Government, Department of Foreign Affairs and Trade. Australia and Timor-Leste maritime boundaries. 6 March 2018. Page 1.
[71] Ibid. Page 3.

at the field have been a vital source of income for the Southeast Asian nation. Most of the royalty revenues flow into the country's petroleum fund, which totalled US$18.45 billion at 31 March 2024.[72]

Dili's Petroleum Fund finances more than 80% of government spending. The country's dependence on the oil and gas sector is a concern for the International Monetary Fund (IMF), as well as other organisations such as La'o Hamutuk that monitor and analyse Timor-Leste. The IMF said: "With oil and gas production (Bayu-Undan) having recently come to a halt, progress on diversifying the economy and developing the private sector is urgently needed. Fiscal deficits are financed by the country's considerable Petroleum Fund savings, but regular large withdrawals are expected to lead to its full depletion by the end of the 2030s." The Dili government has also acknowledged the issue, warning that the fund may be depleted by 2036.[73] Hence, Dili's reliance on the oil and gas sector has left it open to becoming a host of other countries' $CO_2$ dumping.[74]

Financial details of the Bayu-Undan CCS project have not been disclosed, but Timor-Leste's National Authority for Petroleum and Minerals (ANPM) said, "Bayu-Undan CCS will continue to generate revenue for the country for at least 25 years from the largest CCS in the world and generating revenue and carbon credits."[75] Revenue for Timor Leste is a cost to the Bayu-Undan CCS partners. (ANPM has since split into the National Authority of Petroleum (ANP) and the National Authority of Minerals (ANM).)

Despite this, CCS does not appear to be high on the Timor-Leste government's agenda.[76] Indeed, it may conflict with Dili's plan to develop a "blue economy" through ocean-based economic activities such as fishing, tourism (diving) and renewable energy.[77,78,79] The Timor-Leste government has sought advice from the World Bank's International Finance Corporation (IFC) about the legal frameworks to operate its first CCS project at Bayu-Undan and host $CO_2$ from other countries. The IFC will conduct "assessments on legal and regulatory issues and best practices, and potential fiscal benefit sharing and local participation opportunities".[80]

Timor-Leste and the IFC reached an agreement on technical assistance to develop the legal and regulatory frameworks for CCS,[81] which is ongoing. However, Dili has yet to sign any bilateral agreement with Canberra on the importation of $CO_2$ from Australia.

[72] Banco Central de Timor-Leste. Petroleum Fund of Timor-Leste Quarterly Report. 31 March 2024. Page 8.
[73] Timor-Leste government. Ministry of Finance presentation. 4 July 2024. Page 55.
[74] International Monetary Fund (IMF). Democratic Republic of Timor-Leste. IMF Country Report No. 24/56. 27 February 2024. Page 1.
[75] ANPM. Carbon Capture and Storage (CCS) presentation. January 2023. Page 31.
[76] Government of Timor-Leste. Programme of the 9th Constitutional Government. 2023. Page 86.
[77] Timor-Leste Prime Minister. Speech of Prime Minister Xanana Gusmao on the occasion of the presentation of the programme of the 9th constitutional government to the national parliament. 18 July 2023. Page 12.
[78] The London School of Economics and Political Science (LSE). What is the blue economy? 16 May 2023.
[79] OECD. The Ocean Economy in 2030. 27 April 2016.
[80] International Finance Corporation (IFC). IFC Project Information & Data Portal. Timor Leste Carbon Capture and Storage. Accessed 5 July 2024.
[81] Government of Timor-Leste. Government Signs Cooperation Agreement with IFC for Carbon Capture and Storage Project. 22 March 2024.

# Many legal hurdles for Bayu-Undan CCS

Santos's ambitions of sanctioning Bayu-Undan CCS will only be achieved once it navigates the maze of regulatory approvals, respective government legislation in Australia and Timor-Leste, as well as bilateral arrangements between the two countries to allow this novel $CO_2$ trade to occur.

Santos will need approval from upstream regulator NOPSEMA to use the Darwin to Bayu-Undan pipeline for $CO_2$, as its permit only covers transporting gas and associated liquids from Bayu-Undan to Darwin. Santos will have to submit operation environmental plans for the pipeline with NOPSEMA and its counterpart in Dili, ANP. It will also have to submit a Bayu-Undan carbon sequestration environmental plan with ANP. Repurposing the pipeline will also have to be approved under Australia's Environment Protection and Biodiversity Conservation (EPBC) Act.

Santos faces multiple hurdles before it can export $CO_2$ to Timor-Leste. In November 2023, Australia passed the Sea Dumping Bill, allowing the export of $CO_2$, but the bill still needs to be ratified by Australia's Federal Executive Council.[82]

The Sea Dumping Bill implements Australia's obligations under the London Convention, an international protocol that controls marine pollution and dumping of waste and other matter in the sea, adopted in 1996.[83] Santos wrote to federal ministers urging them to pass the bill so Santos and its partners could reach FID on the Bayu-Undan CCS project.[84] Previously, Australian law only allowed the sequestration of domestically sourced $CO_2$ in Australian waters.[85] IEEFA raised serious issues to be considered before the Sea Dumping Bill was passed.[86]

While Santos can apply for a permit to export $CO_2$ to Bayu-Undan, Timor-Leste is not a party to the London Convention. It would need to pass compatible legislation for the CCS project to proceed. This is in addition to any necessary bilateral agreements to import $CO_2$ from convention signatories such as Australia, Japan and South Korea. Furthermore, the Sunrise oil and gas project in the Timor Sea appears to be a much higher priority for Dili than CCS.

Santos still needs to obtain approvals to extract gas from the Barossa field. It must submit separate operations environmental plans for both Barossa's FPSO and the Darwin to Bayu-Undan pipeline to NOPSEMA. In addition, Santos must submit environmental plans for the pipeline and carbon sequestration at Bayu-Undan to Timor-Leste's regulator, ANP.

[82] Parliament of Australia. Environment Protection (Sea Dumping) Amendment (Using new technologies to fight climate change) Bill 2023. 27 November 2023.
[83] Australian Senate, Environment and Communications Legislation Committee. Environment Protection (Sea Dumping) Amendment (Using New Technologies to Fight Climate Change) Bill 2023 [Provisions]. Page 1.
[84] Santos. Letter to Chris Bowen, minister for climate change and energy. 6 June 2023.
[85] Ibid. Page 2.
[86] IEEFA. Submission to the Senate Standing Committees on Environment and Communications re the Inquiry into the Environment Protection (Sea Dumping) Amendment (Using New Technologies to Fight Climate Change) Bill 2023 [Provisions]. July 2023.

The timing of government legislation and planning approvals may significantly delay both the Barossa gas and the Bayu-Undan CCS projects, adding to the costs.

# Technical challenges, doubts and financial risks

Technical challenges persist across the entire CCS process, from whether the depleted gas or oil reservoirs are suitable to hold $CO_2$, to maintaining suitable pressure and temperature levels to ensure the safety and integrity of the pipeline network. In addition, injecting $CO_2$ into a reservoir from an FSPO, as is the case at Bayu-Undan, adds another layer of technical complexity.

## The challenges of $CO_2$ storage

The concept for storing $CO_2$ in depleted oil and gas reservoirs is based on the premise that the "hydrogeological conditions that allowed the hydrocarbons to accumulate in the first place will also permit the accumulation and trappings of $CO_2$ in the space vacated by the production of hydrocarbons".[87] The hydrocarbons are held in place over time by caprock, relatively impermeable layers of rock that seal the top of reservoirs and other geological formations.[88]

In theory, this caprock should retain the sequestered $CO_2$ for thousands of years, as long as it is not damaged from overpressuring during the $CO_2$ injection or by undetected fault lines, unsealed, incomplete or abandoned wells and seismic activity.[89] Caprock is not foolproof for $CO_2$ storage; if wells have been drilled in it previously, they may compromise any $CO_2$ storage, causing leaks.[90]

Old wells are risky as they were designed for hydrocarbon extraction, not for injection of $CO_2$. Casing metallurgy, sealants and grouts, and rock interfaces can all be compromised over time.[91] Fields with older wells not designed to tolerate $CO_2$ may need to be reopened, relined and plugged again with $CO_2$-appropriate materials. In some cases, wells may be so compromised that effective plugging for $CO_2$ is not possible.[92] Petroleum engineers have raised concerns that a different approach is required for developing CCS wells. One issue is the use of concrete as its "integrity is essential to prevent undetected migration of stored $CO_2$ out of the storage zones".[93]

It is important to note that unlike oil and gas production, where some losses of product are expected, permanent $CO_2$ disposal demands that there are no leaks. A leak of 0.1% a year equates to a total

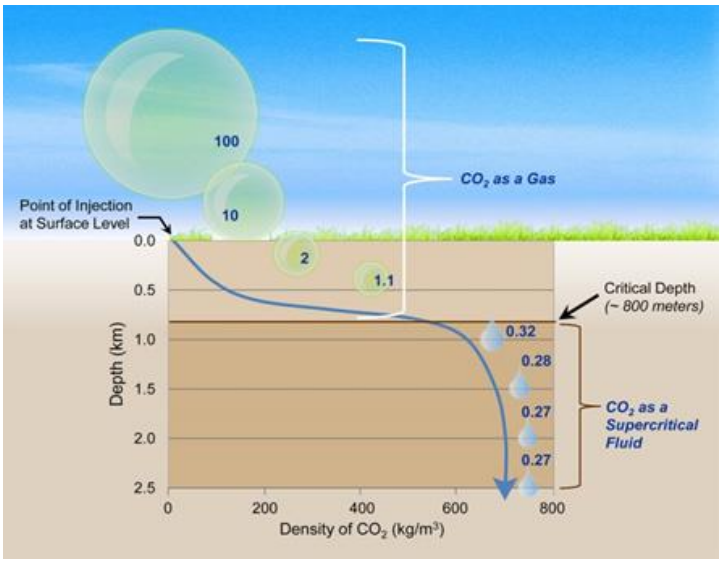
[87] Geological Fieldwork 2002, Paper 2003-1. Geological and Mineral CO2 Sequestration Options: A Technical Review. Page 267.
[88] University of Calgary, Energy Education. Cap Rock.
[89] Geological Fieldwork 2002, Paper 2003-1. Geological and Mineral CO2 Sequestration Options: A Technical Review. Page 267.
[90] Water Resources Research. Status of CO2 storage in deep saline aquifers with emphasis on modelling approaches and practical simulations. 17 July 2024. Page 6849.
[91] Journal of Marine Science and Application. Application of Feature, Event, and Process Methods to Leakage Scenario Development for Offshore CO2 Geological Storage. 3 March 2024. Page 7.
[92] OnePetro. Design of Carbon Capture and Sequestration CCS wells. March 2022.
[93] Ibid.

loss of 9.5% over a 100-year period.[94] Therefore, a leakage rate of 0.5% of the injected volume per year means that almost half, or 47.5%, of the total volume of stored $CO_2$ will escape in that time.

About 80% of the world's hydrocarbon fields are at depths greater than 800 metres.[95] The Bayu gas and condensate discovery was made at a depth of almost 900m, including water depths of about 80m around the entire Bayu-Undan production complex.[96] Pressure, temperature and density variations play important roles in storing $CO_2$. For instance, the density of $CO_2$ increases with depth, and this enhances storage capacity.[97] At normal atmospheric conditions, $CO_2$ is a gas but changes form as it is injected underground, allowing it to travel deeper from the injection point.[98]

The low levels of $CO_2$ stored permanently via CCS underscore these technical challenges, and demonstrate that repurposing oil and gas wells for CCS is not a straight swap. As reported in Offshore, "CCS wells are different in that they are expected to have much longer regulatory lifetimes; increasing pressure over well lifetimes; inherently corrosive environments; intermittent operation; and large variation of $CO_2$ injection stream properties depending on its impurities."[99]

**Figure 4: How $CO_2$ is sequestered**




*Source: The GeoIntegra Group*[100]

[94] Frontiers in Energy Research. Bearing the Cost of Stored Carbon Leakage. 15 May 2018. Page 3.
[95] Geoscience Canada. Geological, Ocean, and Mineral CO2 Sequestration Options: A Technical Review. Volume 31, Number 1. March 2004. Page 13.
[96] Offshore Technology. Bayu-Undan, Timor Sea. 9 February 2016.
[97] Journal of Natural Gas Science and Engineering, Volume 28. A screening criterion for selection of suitable CO2 storage sites. January 2016. Page 320.
[98] The GeoIntegra Group. Why it's super-critical that your underground CO2 is supercritical. 3 April 2023.
[99] Offshore. Drillers see opportunity in CCS market. 13 February 2024.
[100] The GeoIntegra Group. Why it's super-critical that your underground CO2 is supercritical. 3 April 2023.

In a submission to the NT government on the Darwin Pipeline Duplication (DPD) project, IEEFA asked:[101] "How does Santos know that the well-known Bayu-Undan gas reservoir geological structures won't present the same issues as Chevron Gorgon CCS system has found on the also well-known Barrow Island structures? […] Santos asserts that the Bayu-Undan CCS would be able to manage the reservoir $CO_2$ emissions from the Barossa gas field. What tests or evidence are there that Bayu-Undan can host 10 million tonnes a year (Mtpa) of $CO_2$, given that there is no CCS project of this scale in Australia or in neighbouring countries?" In IEEFA's view, Santos has yet to provide sufficient information demonstrating it will work.

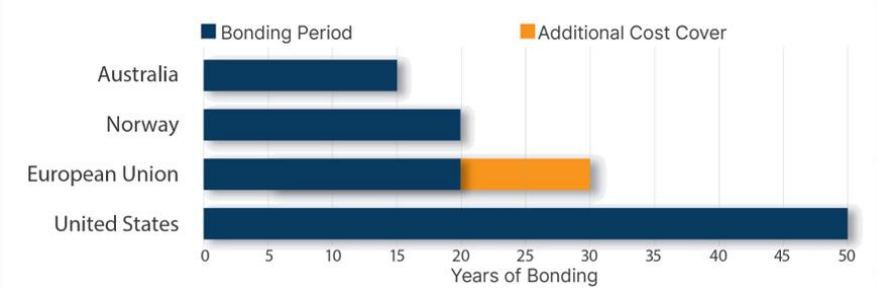
$CO_2$ injection ventures have a vastly different time scale to oil and gas production projects. $CO_2$ is intended to be buried for many centuries as opposed to decades. Investors in a CCS project would need clarity on whether the infrastructure used for extracting oil and gas is suitable for transporting $CO_2$, which has different chemical properties to oil or gas, and reacts differently to steel pipelines than fossil fuels. As argued by *Ringrose et al*, "these requirements for demonstrating long-term storage effectiveness make $CO_2$ storage projects significantly different from hydrocarbon field development studies. More attention is needed on geological, geomechanical and geochemical processes operating over hundreds to thousands of years into the future."[102]

Every storage site has different characteristics in geology and geochemistry. No one site is a predictor for another, meaning every prospective $CO_2$ storage site must be studied extensively and monitored continuously to assure its integrity, all of which adds to the project costs.

Leaks from CCS projects pose a potential financial risk for both the operator and taxpayers after the CCS facility is capped and closed once the reservoir is full. Regulators across Australia, the EU, Norway and the US recognise that there are still costs incurred for CCS facilities for monitoring activities to detect leakages or movements within the reservoir and any remedial actions. The CCS operator is liable for any expenditure for the first 15 years in Australia after the CCS facility closes. After that, any costs associated with the facility are the responsibility of the Australian government and paid by taxpayers. In contrast, CCS operators are liable for costs for the first 20 years in the EU and Norway after a CCS closure, and up to 50 years in the US. The EU requires financial bonding for 30 years of costs, despite the potential for release of obligation after only 20 years.[103]

[101] IEEFA. Darwin Pipeline Duplication Project. Submission to the Northern Territory Environmental Protection Authority (EPA). June 2023. Page 4.
[102] First Break. Why CCS is not like reverse gas engineering. October 2022. Volume 40. Page 89. *Philip Ringrose, Jamie Andrews, Peter Zweigel, Anne-Kari Furre, Ben Hern and Bamshad Nazarian.*
[103] IEEFA. Norway's Sleipner and Snøhvit CCS: Industry models or cautionary tales? June 2023.

**Figure 5: Contingency responsibility period after CCS site cover**




*Source: IEEFA compilation from laws in Australia, the EU, Norway and the US*

Figure 5 underlines that Australian taxpayers will be liable for CCS projects from 15 years after operations cease, far earlier than other jurisdictions.

## $CO_2$ transportation challenges

There is also the issue of transporting $CO_2$ through offshore pipelines. Pumping $CO_2$ through pipelines is not the same as transporting natural gas through pipelines. $CO_2$ is almost three times denser than methane, which is primarily natural gas.[104,105]

In the CCS process, the $CO_2$ is compressed before it is sent through the pipeline to be injected into storage. For $CO_2$ to remain in its densest, most readily transportable form requires ultra-high-pressure compression as it is not possible to put booster pumping stations along the subsea pipeline.[106] $CO_2$ has never been pumped this far – the 502km Bayu-Undan pipeline – using a single compressor station. This adds to the risk of repurposing a gas pipeline for $CO_2$, which is highly corrosive if it contains any moisture.[107,108] A solution to this corrosion problem has been sought for the past 50 years without a consistent, cost-effective solution. Any possible remedy will come at a significant cost, such as pipe cladded with a metallurgically bonded corrosion-resistant coating.[109]

$CO_2$ under ultra-high pressure turns into a supercritical fluid, which is most suitable and efficient for transport in a subsea pipeline.[110] The US Department of Energy says: "It is likely that the economics of most CCS projects will require that $CO_2$ be transported in its supercritical phase because vapor-phase transport would require considerably larger diameter pipelines for the same mass flow rate

[104] National Library of Medicine. Carbon dioxide.
[105] National Library of Medicine. Methane. When gas is combusted and produces $CO_2$, its weight is three times heavier than during the combustion stage. $CO_2$, has an atomic weight of 44 or 3.67 times the atomic weight of carbon, which is 12.
[106] Intergovernmental Panel on Climate Change. Carbon Dioxide Capture and Storage. 2005. Page 25.
[107] Ibid. Page 30.
[108] Research & Development Resources. Risks and potential impacts from carbon steel pipelines in Louisiana transporting and processing variable produced gases (such as CO2, H2, CH4). 9 October 2022. Page 11.
[109] Ibid. Page 12.
[110] Journal of CO2 Utilization. A review of supercritical CO2 fluid applications for improved oil and gas production and associated carbon storage. April 2023. Pages 1-2.

and would experience high pressure drops. Vapor-phase transport is not used for pipelines that carry significant quantities of $CO_2$ for long distances."[111]

Maintaining pressure as the $CO_2$ travels through the offshore pipelines poses a major challenge. Compressor stations are impractical offshore as they would be difficult to maintain in a marine environment. According to the US Department of Energy, "The pressure of the $CO_2$ within an offshore pipeline must be sufficiently high to maintain single-phase flow over the full length of the pipeline." There is also the concern about the potential pressure change when the $CO_2$ is piped from the seabed to the FSPO on the surface for injection into the reservoir, without a compressor: "Variations in pressure could therefore cause more issues with maintaining single-phase flow in an offshore pipeline than in an onshore pipeline."[112]

## $CO_2$ temperature challenges

Not only does $CO_2$ face pressure changes as it moves through pipelines, but also temperature changes. The US Department of Energy says: "Temperature affects pipeline capacity indirectly as well as directly because the operating temperature affects not only the amount of $CO_2$ that can be compressed to fit the pipeline, but also other factors, such as viscosity."[113] As the $CO_2$ travels deeper into the depleted gas/oil reservoir, its viscosity (the resistance of a fluid to a change in shape) normally increases. As $CO_2$ is less viscous than water in the oil/gas reservoir, this allows it to travel deeper from the point of injection.[114]

Oil-field service companies have launched a joint industry project to research and develop new valve assemblies and safety mechanisms to handle the far wider range of temperatures and pressures $CO_2$ could place on hardware. However, these systems remain at prototype stage, and it could take years of testing before they are ready to be used for $CO_2$ disposal at the scale proposed at Bayu-Undan.[115]

## $CO_2$ injection challenges

$CO_2$ injection operations require precise temperature and pressure conditions, and reliable power and control systems are imperative. A major site-specific issue is seismicity induced by the $CO_2$ injection itself, which can be a serious hazard.[116]

Risks from this induced seismicity include damage to infrastructure and fracturing of the caprock, allowing $CO_2$ to escape to the surface, threatening the integrity of the entire reservoir.[117] A notable example was the In Salah CCS onshore project in Algeria where $CO_2$ injections started in 2004[118] but were suspended indefinitely in 2011 due to seismicity.

[111] US Department of Energy. Subtask 2.19 – Operational flexibility of CO2 transport and storage. December 2014. Page 37.
[112] Ibid. Page 38.
[113] Ibid. Page 39.
[114] The GeoIntegra Group. Why it's super-critical that your underground CO2 is supercritical. 3 April 2023.
[115] Offshore. Researchers assessing measures for safe management of CO2. 11 June 2024.
[116] Earth-Science Reviews. Seismicity induced by geological CO2 storage: A review. February 2023. Page 1.
[117] Ibid. Page 2.
[118] IEEFA. Norway's Sleipner and Snohvit CCS: Industry models or cautionary tales? Pages 26-27.

# Conclusion

The legal and technical challenges of transporting and storing $CO_2$ indefinitely are significant, and investors and regulators need detailed information from Santos on how it will deal with these issues. The technical uncertainties reinforce the perception that Bayu-Undan will underperform like other CCS projects. This may, in turn, affect the revenue promised to Timor-Leste for hosting such an ambitious venture.

These unknowns create uncertainty about how Santos will meet its emissions obligations under the Safeguard Mechanism, at what additional cost, and how the project will affect Australia's 2030 emissions reduction targets.

IEEFA agrees with the IEA's view of CCS that storing implausibly large amounts of carbon is not the solution to reduce GHG emissions. Therefore we believe the Bayu-Undan project should not go ahead. Santos should focus on reducing emissions from its existing operations by implementing methane reduction measures and electrifying as much of its operations as possible. Instead of pursuing its high-risk, high-cost CCS and carbon offsets strategy, it should investigate building renewable energy projects to replace its declining fossil fuel operations.

The poor record of CCS projects globally, coupled with the unique location and scale challenges at Bayu-Undan, may mean the project is not the solution Santos is seeking to reduce its emissions and meet national and company targets.

The legal challenges are considerable. The lengthy list of approvals that Santos must obtain in Australia will be mirrored in Timor-Leste, with the added complication that the small nation has never hosted a project of this type, let alone of this magnitude. Additionally, there is no guarantee that Santos's ambitious timeline for Bayu-Undan aligns with the Timor-Leste government's legislative agenda and priorities.

# Appendix: LNG, gas and $CO_2$ data

**Table 2: Australian and international LNG export facilities and $CO_2$ content of gas feedstock**

| LNG facility | Location | Year commissioned | LNG production (mtpa)[1] | Reservoir $CO_2$ content (mol%)[1] |
|---|---|---|---|---|
| ***Australian facilities*** | | | | |
| Barossa-Caldita LNG | Offshore Northern Territory (NT) | Design phase. Expected to commence operation in 2023 | 3.6 | 16 - 20 |
| Prelude LNG | Offshore WA | 2018 | 3.6 | 9 |
| Ichthys LNG | Offshore WA, with 890 km pipeline to Darwin, NT | 2016 | 8.4 | Brewster: 8, Plover: 17 |
| Gorgon LNG | WA | 2016 | 15.6 | Gorgon 15, Jansz 0.5 |
| KGP T1 – T3 | WA | 1989-92 | 8.2 | 2.4 |
| Darwin LNG | NT | 2006 | 3.6 | 6 |
| KGP T1 – T5 | WA | 1989-2004 | 18.5 [3]<br>Current operation: 16.6 | 2.4 |
| Wheatstone Project | WA | 2017 | 25 [4]<br>Current capacity: 8.9 | "low" [2] |
| Pluto LNG | WA | 2012 | 4.8 | 2 |
| KGP T4 and T5 | WA | 2004 | 8.4 | 2.4 |
| Gladstone LNG | Queensland | 2015 | 10 | 0.3 |
| Australia-Pacific LNG (APLNG) | Queensland | 2016 | 18 [4]<br>Current capacity: 9.0 | 1 |
| Queensland Curtis LNG | Queensland | 2015 | 11 | < 1 |
| ***International facilities*** | | | | |
| Cove Point | Maryland, USA | 2017 | 5.75 | Not applicable |
| Qatargas 1 (T1 – T3) | Qatar | 1997 | 10 | 2.1 |

| LNG facility | Location | Year commissioned | LNG production (mtpa)[1] | Reservoir $CO_2$ content (mol%)[1] |
|---|---|---|---|---|
| Qatargas 2 (T4 and T5) | Qatar | 2009 | 15.6 | 2.1 |
| Qatargas 3 (T6) | Qatar | 2010 | 7.8 | 2.1 |
| Qatargas 4 (T7) | Qatar | 2011 | 7.8 | 2.1 |
| Qatargas TOTAL | Qatar | 1997 - 2011 | 41.2 | 2.1 |
| RasGas | Qatar | 1999 | 6.4 | 2.3 |
| PNG LNG | Papua New Guinea | 2014 | 6.3 | 0.7 - 2.0 |
| Nigeria LNG | Nigeria | 2000 | 6.1 | 1.8 |
| Snohvit LNG | Norway | 2007 | 4.3 | 8 |
| Oman LNG | Oman | 2001 | 6.9 | 1.0 |
| Sabine Pass | Louisiana, USA | 2016 | 16 | 0.1 - 4.8 |

*Source: Woodside Appendix F North West Shelf Project Extension Greenhouse Gas Benchmarking Report – Revision 1*

## Barossa $CO_2$ content much higher than international plants

Table 3 shows the CCS projects in operation globally, including carbon capture, utilisation and storage (CCUS) facilities, which are used for enhanced oil and gas recovery. These projects by far dominate the carbon capture landscape both in number and capacity. So rather than reduce GHG emissions, most carbon capture projects actually produce more fossil fuels and, in turn, higher levels of $CO_2$ in the atmosphere.

## Table 3: Global CCS and CCUS facilities in operation (2023)

Operational

| Facility | Country | Operational date | Facility industry | Capture, transport and/or storage capacity (Mtpa $CO_2$) | Facility storage code |
|---|---|---|---|---|---|
| Occidental Terrell | USA | 1972 | Natural Gas Processing | 0.5 | Enhanced Oil Recovery |
| Enid Fertilizer | USA | 1982 | Hydrogen / Ammonia / Fertiliser | 0.2 | Enhanced Oil Recovery |
| ExxonMobil Shute Creek Gas | USA | 1986 | Natural Gas Processing | 7 | Enhanced Oil Recovery |
| MOL Szank Field | Hungary | 1992 | Natural Gas Processing | 0.16 | Enhanced Oil Recovery |
| Equinor Sleipner | Norway | 1996 | Natural Gas Processing | 1 | Dedicated Geological Storage |
| Great Plains Synfuels Plant and Weyburn-Midale | USA | 2000 | Hydrogen / Ammonia / Fertiliser | 3 | Enhanced Oil Recovery |
| Core Energy $CO_2$-EOR South Chester plant | USA | 2003 | Natural Gas Processing | 0.35 | Enhanced Oil Recovery |
| Equinor Snohvit | Norway | 2008 | Natural Gas Processing | 0.7 | Dedicated Geological Storage |
| Petrobras Santos Basin Pre-Salt Oil Field | Brazil | 2008 | Natural Gas Processing | 10.6 | Enhanced Oil Recovery |
| Arkalon $CO_2$ Compression Facility | USA | 2009 | Ethanol | 0.5 | Enhanced Oil Recovery |
| Longfellow WTO Century Plant | USA | 2010 | Natural Gas Processing | 5 | Enhanced Oil Recovery |
| Gary Climate Solutions Bonanza BioEnergy | USA | 2012 | Ethanol | 0.1 | Enhanced Oil Recovery |
| Yanchang Integrated Demonstration | China | 2012 | Chemical | 0.05 | Enhanced Oil Recovery |
| Air Products and Chemicals Valero Port Arthur Refinery | USA | 2013 | Hydrogen / Ammonia / Fertiliser | 0.9 | Enhanced Oil Recovery |
| Contango Lost Cabin Gas Plant | USA | 2013 | Natural Gas Processing | 0.9 | Enhanced Oil Recovery |
| Coffeyville Gasification Plant | USA | 2013 | Hydrogen / Ammonia / Fertiliser | 0.9 | Enhanced Oil Recovery |
| PCS Nitrogen Geismar Plant | USA | 2013 | Hydrogen / Ammonia / Fertiliser | 0.3 | Enhanced Oil Recovery |
| SaskPower Boundary Dam | Canada | 2014 | Power Generation and Heat | 1 | Enhanced Oil Recovery |
| Saudi Aramco Uthmaniyah | Saudi Arabia | 2015 | Natural Gas Processing | 0.8 | Enhanced Oil Recovery |
| Shell Quest | Canada | 2015 | Hydrogen / Ammonia / Fertiliser | 1.3 | Dedicated Geological Storage |
| Xinjiang Dunhua Karamay | China | 2015 | Chemical | 0.1 | Enhanced Oil Recovery |
| ADNOC Al-Reyadah | United Arab Emirates | 2016 | Iron and Steel Production | 0.8 | Enhanced Oil Recovery |
| ADM Illinois Industrial | USA | 2017 | Ethanol | 1 | Dedicated Geological Storage |
| CNPC Jilin Oil Field | China | 2018 | Natural Gas Processing | 0.6 | Enhanced Oil Recovery |
| Chevron Gorgon | Australia | 2019 | Natural Gas Processing | 4 | Dedicated Geological Storage |
| Qatargas Qatar LNG | Qatar | 2019 | Natural Gas Processing | 2.2 | Dedicated Geological Storage |
| Enhance Clive Oil Field | Canada | 2020 | $CO_2$ Transport / Storage | 1.12 | Enhanced Oil Recovery |
| NWR Sturgeon Refinery | Canada | 2020 | Oil Refining | 1.6 | Enhanced Oil Recovery |
| WCS Redwater | Canada | 2020 | Hydrogen / Ammonia / Fertiliser | 0.3 | Enhanced Oil Recovery |
| Wolf Alberta Carbon Trunk Line | Canada | 2020 | $CO_2$ Transport / Storage | 14.6 | Enhanced Oil Recovery |
| China National Energy Guohua Jinjie | China | 2021 | Power Generation and Heat | 0.15 | Dedicated Geological Storage |
| Climeworks Orca | Iceland | 2021 | Direct Air Capture | 0.004 | Dedicated Geological Storage |
| Sinopec Nanjing Chemical | China | 2021 | Chemical | 0.2 | Enhanced Oil Recovery |
| Yangchang Yan'an $CO_2$-EOR | China | 2021 | Chemical | 0.1 | Enhanced Oil Recovery |
| Entropy Glacier Gas Plant | Canada | 2022 | Natural Gas Processing | 0.2 | Dedicated Geological Storage |
| Red Trail Energy Richardton Ethanol | USA | 2022 | Ethanol | 0.18 | Dedicated Geological Storage |
| Sinopec Qilu-Shengli | China | 2022 | Chemical | 1 | Enhanced Oil Recovery |
| Yangchang Yulin $CO_2$-EOR | China | 2022 | Chemical | 0.3 | Dedicated Geological Storage |
| China National Energy Taizhou | China | 2023 | Power Generation and Heat | 0.5 | Enhanced Oil Recovery |
| CNOOC Enping | China | 2023 | Natural Gas Processing | 0.3 | Dedicated Geological Storage |
| Sinopec Jinling Petrochemical (Nanjing Refinery) | China | 2023 | Oil Refining | 0.3 | Enhanced Oil Recovery |

*Source: Global Status of CCS 2023. Scaling up through 2030*

# About IEEFA

The Institute for Energy Economics and Financial Analysis (IEEFA) examines issues related to energy markets, trends and policies. The Institute's mission is to accelerate the transition to a diverse, sustainable and profitable energy economy. www.ieefa.org

# About the Authors

**Kevin Morrison**

Kevin is an Energy Finance Analyst, Australian Gas and works closely with the global oil and gas team to examine issues facing the Australian LNG and gas sector. Prior to joining IEEFA, Kevin worked for more than 30 years as a financial journalist for Reuters, The Sydney Morning Herald, The Financial Times and Argus Media, covering the energy and resources sector in Australia and the UK. In 2018, Kevin completed a master's degree in resources taxation with the Institute for Sustainable Futures at the University of Technology Sydney.

**John Robert**

John Robert is a Chemical Engineer and Industrial Economist with more than 40 years' experience, including developing and/or managing estimates for capital and operating costs of LNG plants, along with reviewing the potential impact of emissions trading schemes on LNG and chemicals projects. John has worked for Exxon in the Australian petrochemicals industry and was an Australian Government Trade Commissioner in Europe and the Middle East. Previously, John was a business development manager and technical/economic consultant for 20 years, and then engineering manager with MEO Australia Limited, covering offshore LNG projects in the Timor Sea.



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