Institute for Energy Economics and Financial Analysis

The Good, the Bad, and the Ugly reality about CCS (Carbon Capture and Storage)

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Key points

- **Good** - CCS is a way of burying CO_2 from oil and gas reservoirs in production (scope 1 emissions)
- **Bad** – It has a poor track record of capturing this scope 1 emissions, most CCS projects do not capture at forecast rates
- **Ugly** – Scope 1 represents less than 10% of total emissions from oil and gas projects. So far what is captured is also costly and capture at >85% is not proven

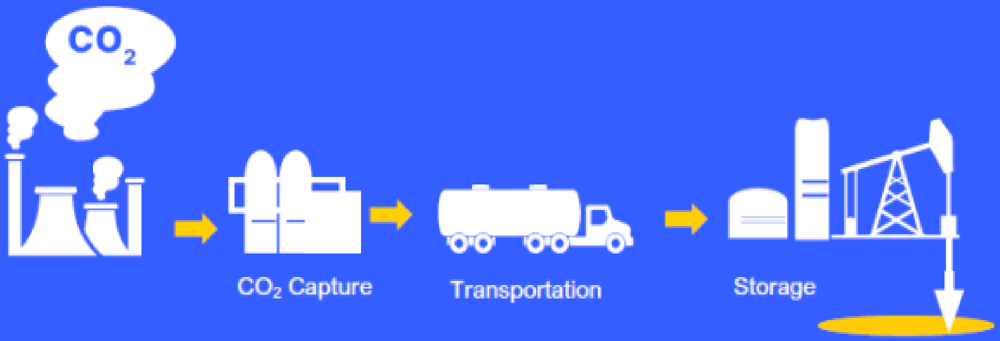
Carbon Capture and Storage: The results so far

Carbon capture and storage (CCS) is a 50-year-old technology with variable results in capturing and storing carbon dioxide. Most projects have used CCS for enhanced oil recovery (EOR), producing more oil and gas and more emissions.

Snapshot of Carbon Capture

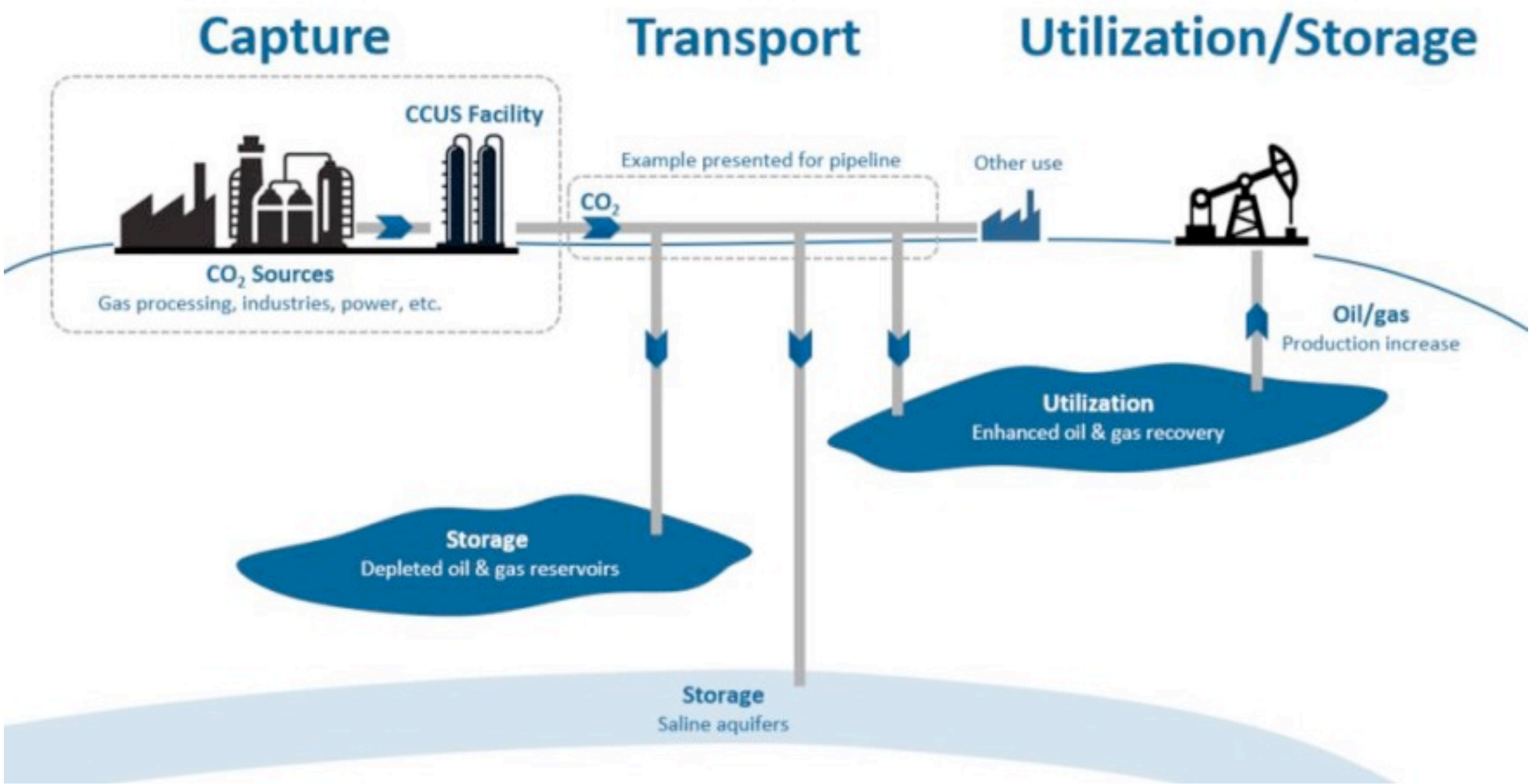
Carbon Capture and Storage (CCS)

Carbon Capture and Storage (CCS): Carbon is captured from a stationary source, such as power generation plants, and is transported to sites and stored in saline aquifers or other underground deposits – and is not used for enhanced oil recovery (EOR).



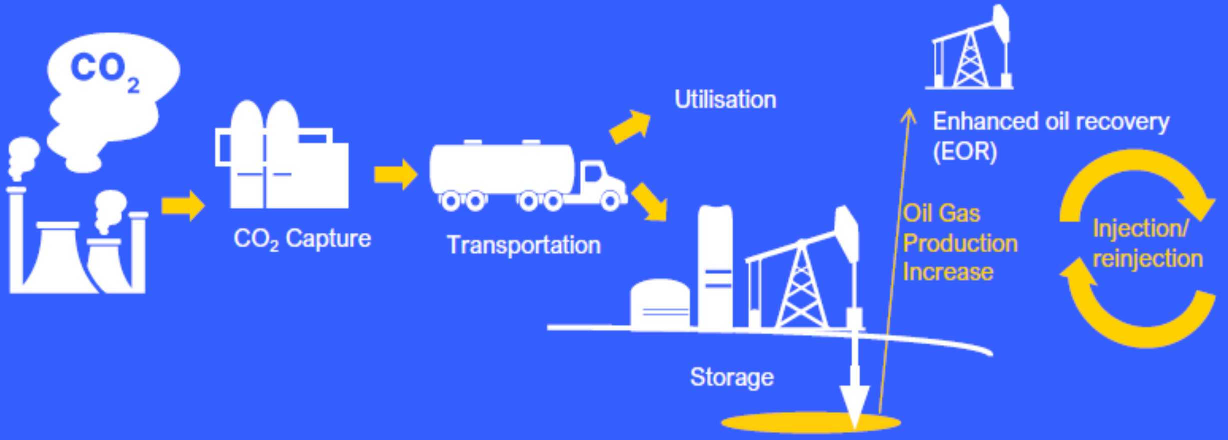
=27%
of the total current capture capacity

How does CCUS work?



Carbon Capture Utilisation and Storage (CCUS)

Carbon Capture Utilisation and Storage (CCUS): Captured carbon is sold and utilised for enhanced oil recovery (EOR) – where it is pumped into depleted fields to push more oil and gas out of wells - and then stored underground. Selling captured CO2 enhances the economic viability of gas development projects. Enhancing oil production increases carbon emissions, negating CO2-EOR as a climate solution.



=73%

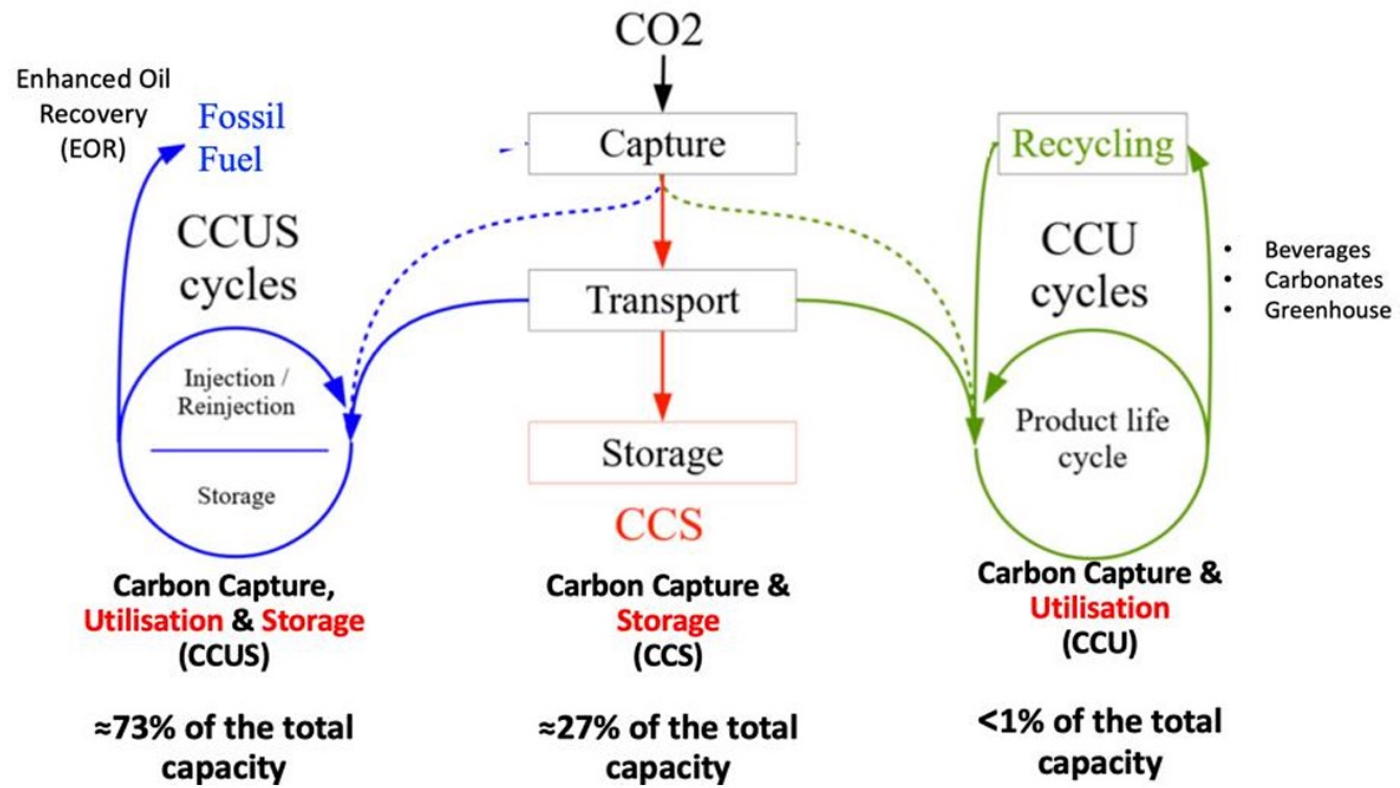
of the total current capture capacity

Carbon Capture

Other carbon dioxide removal technologies (CDR) includes Bioenergy with Carbon Capture and Storage (BECCS) and

Direct Air Carbon Capture and Storage (DACCS) which are not well advanced technically and commercially.

CCUS vs CCS vs CCU



Source: Sustainability Journal, MDPI, 2019.

Share of CCUS vs CCS in capturing carbon; 50-years cumulative and 2021

Carbon Capture Type	Accumulated Captured CO_2 (Million Tonnes)	Share of Current 39MTPA Capture Capacity (%)
Enhanced Oil Recovery (EOR) - CCUS	>240 MT (80-90%)	~73%
Dedicated Geological Storage - CCS	<60 MT (10-20%)	~27%
Total	~300	100

What is Carbon Capture and Sequestration (CCS) and why is it now such a big issue?

- *CCS is touted as key part of reducing emissions of CO_2 from fossil-fired power plants, hydrogen production facilities, and certain large industries that that would otherwise be emitted into the atmosphere.*
- ***All, or very nearly all, of the CO_2 produced by any of these facilities will have to be captured and promoters claim CCS technology is proven.***

Key questions:

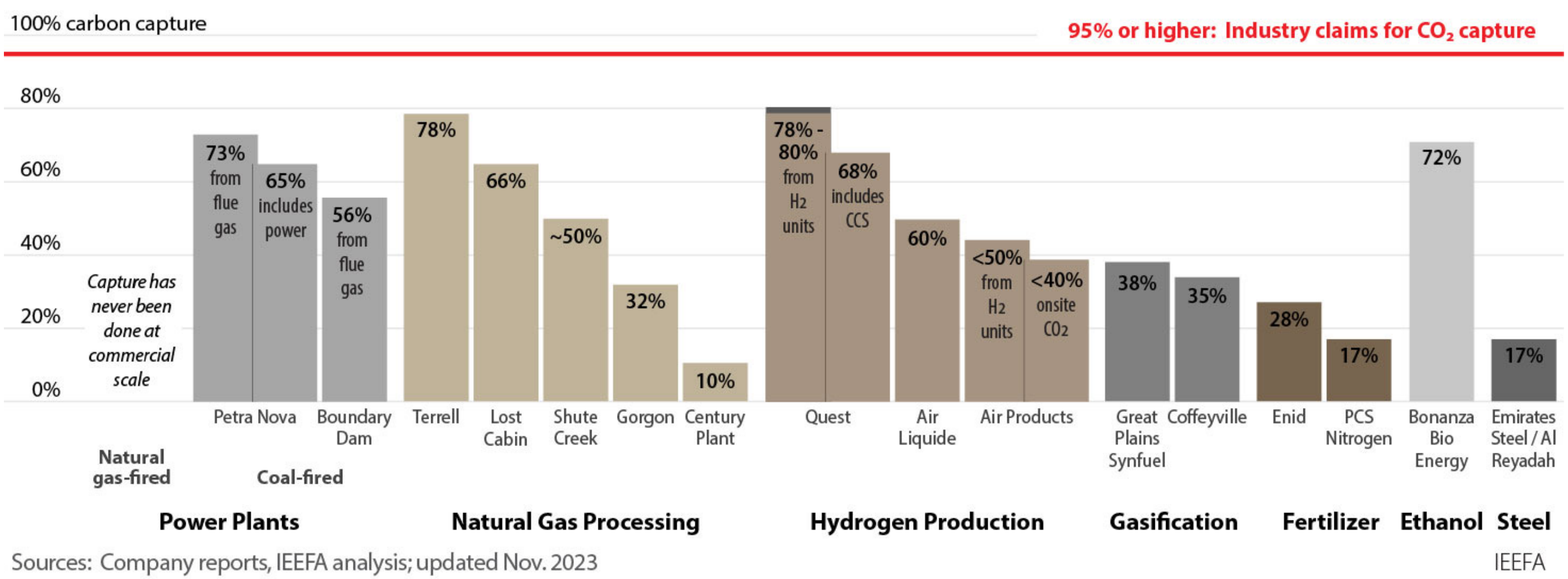
1. Can CCS reliably capture >90% of the CO_2 produced by a plant?
2. Will CCS be financially viable without massive, permanent government subsidies?
3. Can we be certain CO_2 stored "permanently" underground actually will stay there?
4. Are there cheaper, more reliable, and faster options for decarbonizing the economy?

Carbon Capture and Storage (CCS) projects' poor report card

Project	Capacity (MtCO2 p.a.)	Performance
Natural Gas processing		
1986 Shute Creek	7	Lifetime under-performance of 36%
1996 Sleipner	0.9	Performing close to the capture capacity
2004 In Salah	1.1	Failed after 7 years of operation
2007 Snøhvit	0.7	Performing close to the capture capacity
2019 Gorgon	4	Lifetime under-performance of ~50%
Industrial sector		
2000 Great Plains	3	Lifetime under-performance of 20–30%
2013 Coffeyville	0.9	No public data was found on the lifetime performance.
2015 Quest	1.1	Performing close to the capture capacity
2016 Abu Dhabi	0.8	No public data was found on the lifetime performance.
2017 Illinois Industrial (IL-CCS)	1	Lifetime under-performance of 45–50%
Power sector		
2014 Kemper	3	Failed to be started
2014 Boundary Dam	1	Lifetime under-performance of ~50%
2017 Petra Nova	1.4	Suspended after 4 years of operation

https://ieefa.org/resources/carbon-capture-crux-lessons-learned

Real World CO_2 Capture



Last updated December 5, 2023. Originally appear in IEEFA report Blue Hydrogen: Not clean, not low carbon, not a solution

There is only very limited experience with carbon capture

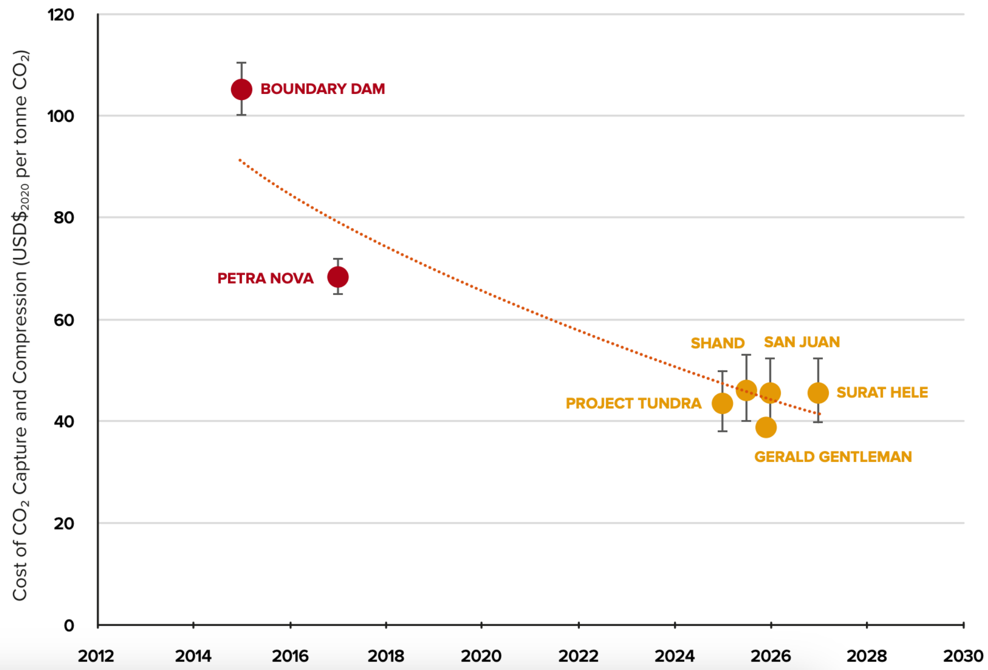
- CCS has been around for decades, but there are **only about 30 active carbon capture projects in the world.** Numerous projects had been cancelled or have failed.
- Coal-fired power plants: There are **only two** in the world capturing any of their CO_2
- Gas-fired power plants: **No CO_2 has been captured** at a commercial-size plant
- Steel plants: **CO_2 has been captured at one plant** in Dubai
- Concrete plants: **No plant** has captured any CO_2
- Hydrogen plants: **None of the 3 plants** that have captured CO_2 has captured more than 68% of the total it has produced

Proponents of CCS claim capture costs are going down

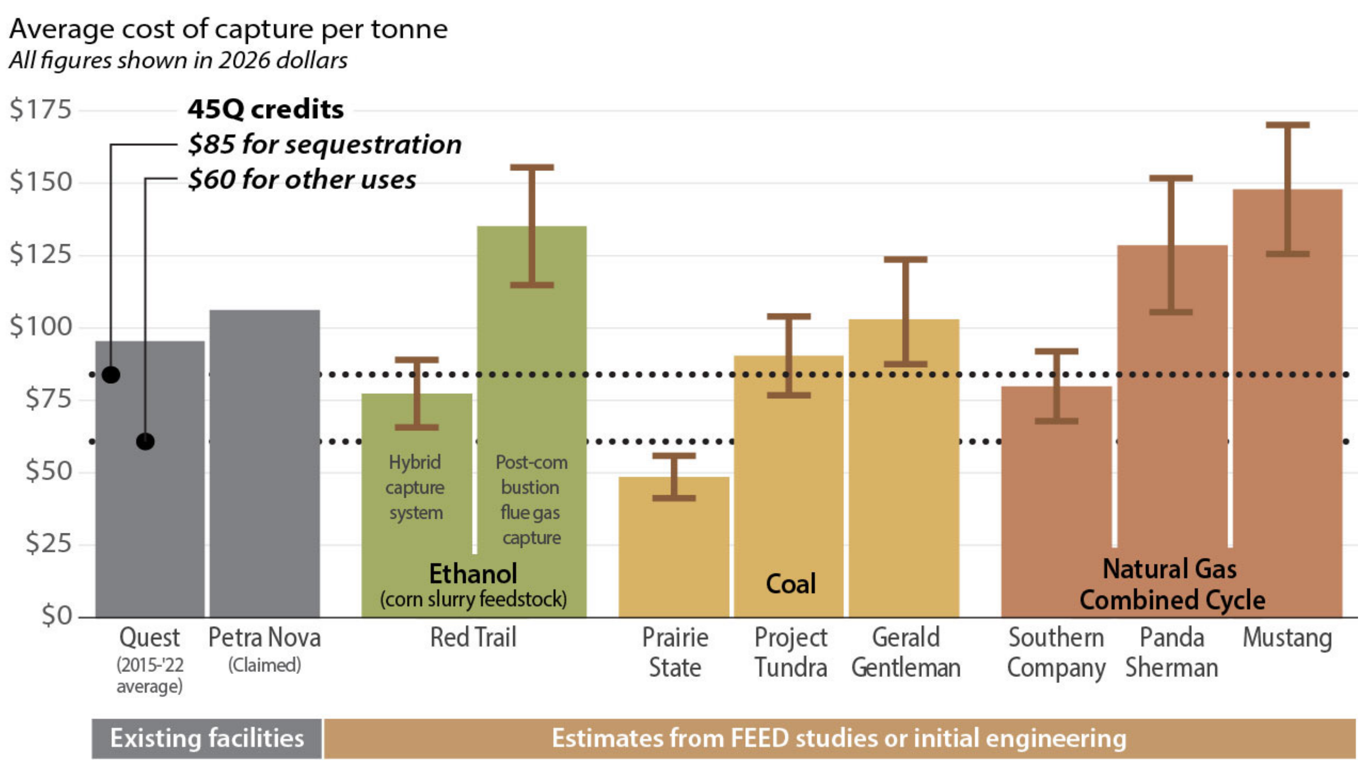
***According to CCS proponents**, future costs (shown in gold) will be much lower than current actuals (shown in red)*

The chart shows the cost of CO_2 capture and compression (in USD per tonne CO_2) for commercial post-combustion CO_2 capture facilities at coal-fired power plants

Includes plants in operation or in advanced development Front End Engineering Design stages (FEED)



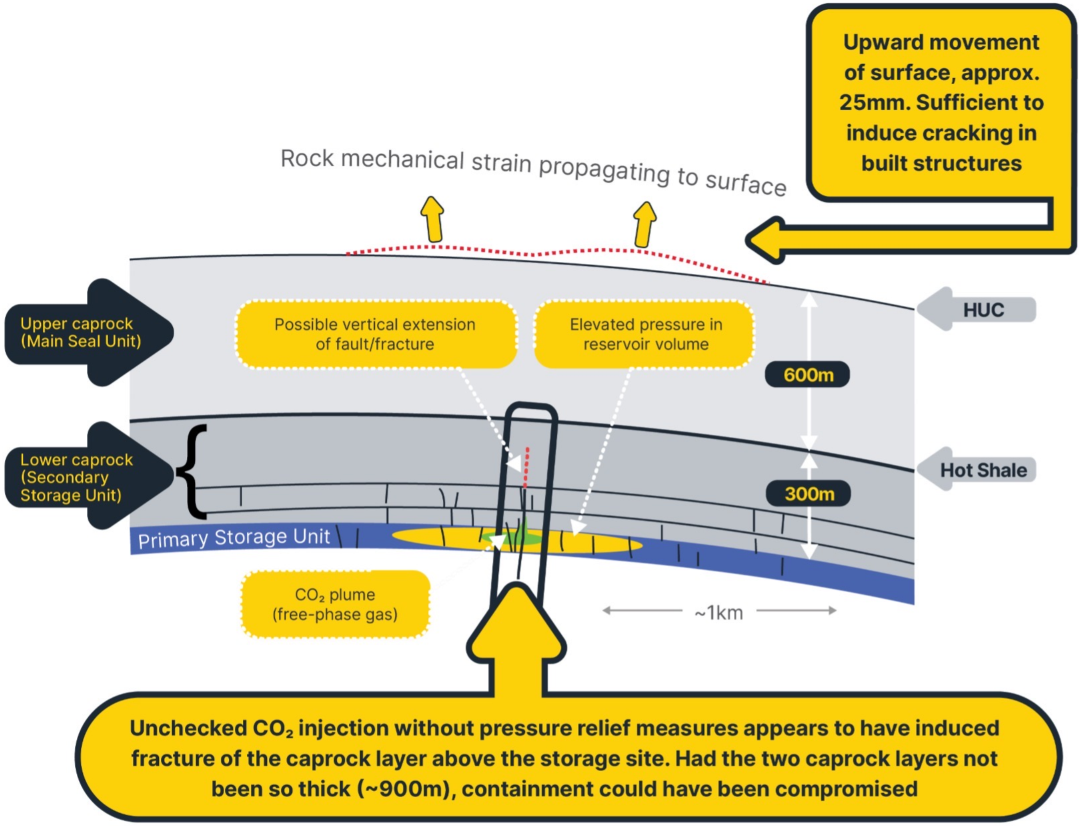
But recent CO_2 capture cost estimates shown no such decline



Important points about CO_2 capture costs

- Most of the costs associated are fixed that must be paid regardless of how little CO_2 is captured
  - These fixed costs include capital cost and fixed operating & maintenance costs
- This means the average cost of capture shown in the previous slide will be higher if projects don't capture as much CO_2 as proponents claim
- Further increases in estimated construction costs can be expected as project design and actual construction are completed
  - This is another reason to expect actual capture costs will be higher
- Costs of transporting and sequestering captured CO_2 very uncertain

In Salah CO_2 storage site failure mode



Sketch illustrates main geomechanical observations around injection well KB-502

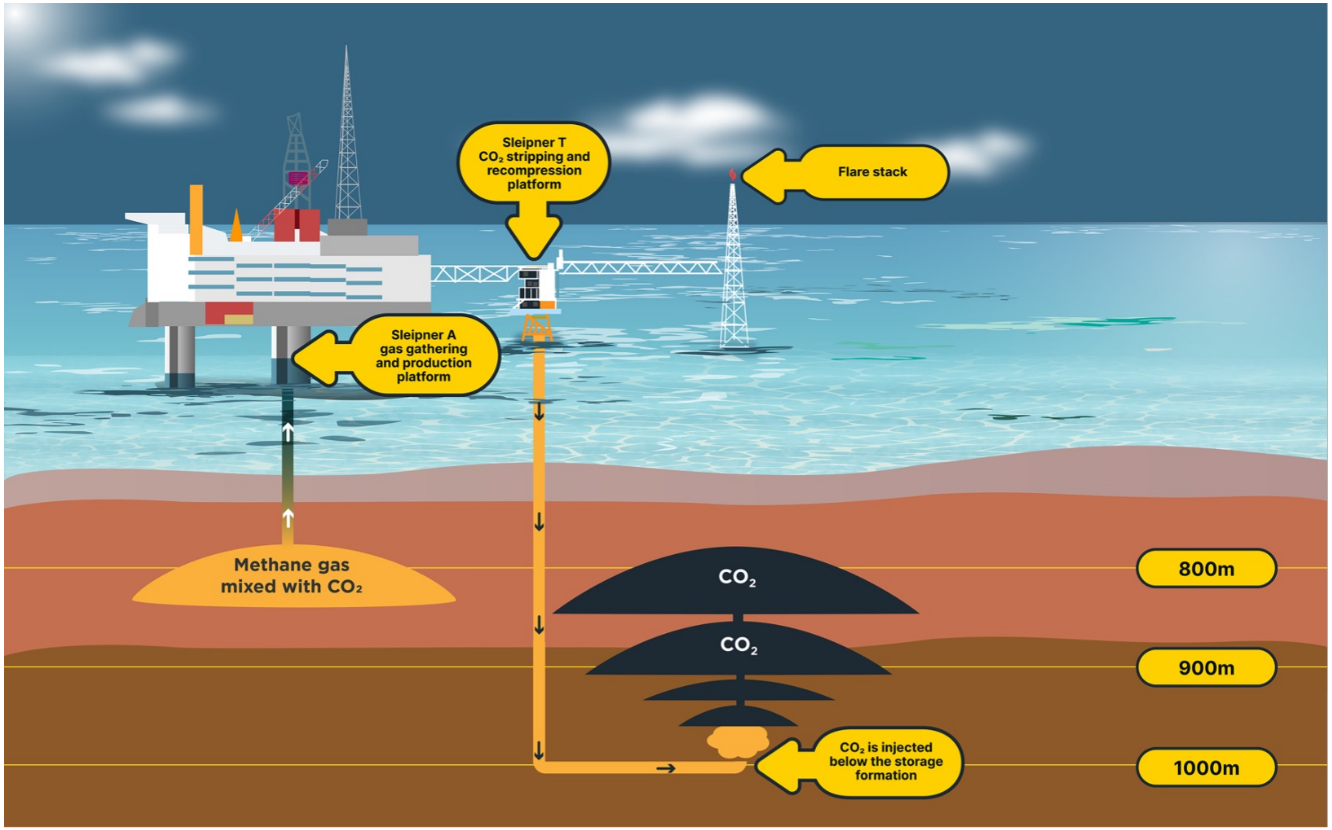
IEEFA

Source: Energy Procedia. The In Salah CO_2 storage project: lessons learned and knowledge transfer. Ringrose et al. No 37, 2013, p. 6226-6236.

Sleipner, near Norway's maritime border, potential problems if it starts to leak

Source: Zhu Laboratory, Indiana University Bloomington. IEEFA

Sleipner's self-contained offshore CO_2 processing platform



Source: Geological storage of CO_2: project design and global scale-up. Ringrose. March 29, 2021. IEEFA

Sleipner and Snøhvit - comparison

Project	Sleipner[62]	Snøhvit[63]
Configuration	Strips out, compresses and injects CO_2 atop remote offshore platform built solely for this purpose. Shoreside facilities for stripped natural gas connect directly to piped gas network.	Pumps raw gas to onshore processing facility, which strips out, compresses and pipes CO_2 back to gas extraction site for injection and storage. Part of the larger, remote Hammerfest LNG export project.
Start of commercial operations	August 1996	April 2008
Gas CO_2% content	4%-9%	5%-8%
CO_2 production	0.85mtpa-1mtpa	0.7mtpa
CO_2 processing location	Offshore, on-platform	Onshore
CO_2 transportation distance	12.5km	143km
Pipeline	Unknown material	World's first offshore CO_2 pipeline. Uses special high-chromium steel alloy to avoid corrosion from CO_2* in supercritical state.
Injection depth	800m-1,000m	2,600m initial; well plugged and abandoned 800m current
Subsequent well intervention / investment	Not applicable	2011 – made additional perforations at 2,600m, then new perforation at 800m. 2016 – drilled new CO_2 well for third storage formation access.
Capital cost (US$)	$92m in 1996 [$181m in 2022 dollars]	$191m in 2008 [$311m in 2022 dollars] $225m in 2016 for new CO_2 well plus 2 new production wells
Operating cost (US$)	$7m/year in 1996 [~$13.2m/year in 2022 dollars]	Not disclosed
Estimated CO_2 sequestration cost (US$ per tonne)	~$17-$20	Not disclosed
Norway carbon tax: At final investment decision (2022 US$-equivalent per tonne)	$41 ($78)	~$45 ($65)
Projected field closure	Not disclosed	2035

* Snøhvit uses gas-drying processes and pipes with high chromium to avoid long-term corrosion from CO_2 transport.

Norwegian ‘success stories’ demonstrate material ongoing risks

Sleipner

- CO_2 migrated up faster than expected
- Moved into a previously unidentified shallow layer in unexpectedly large quantities
- Had layer not been geologically bounded, CO_2 may have escaped

Snøhvit

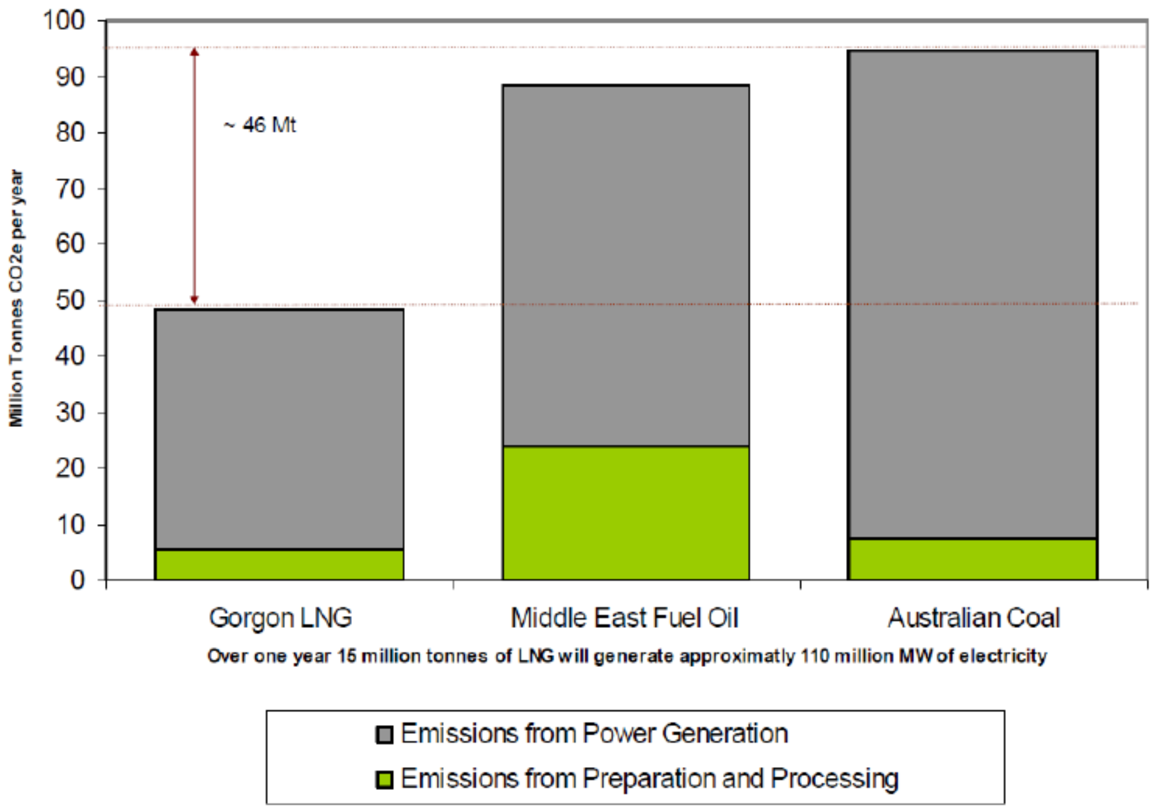
- Targeted formation was meant to have 18 years capacity
- Only 18 months into operations, pressure rose precipitously, risking geologic failure
- Storage needed to be suspended
- Had to conduct remedial actions & identify alternative storage at great cost

https://ieefa.org/resources/norways-sleipner-and-snohvit-ccs-industry-models-or-cautionary-tales

CCS in Australia - Gorgon

Global Carbon Capture and Storage performance				
Year	**Volume of CO2 removed**	**Volume of CO2 injected**	**Target 80% of CO2 removed**	**Shortfall from target**
2016-17	1	0	0.8	0.8
2017-18	3.5	0	2.8	2.8
2018-19	3.7	0	3	3
2019-20	3.9	2.7	3.1	0.4
2020-21	3.2	2.2	2.5	0.4
2021-22	5	1.6	4	2.4
2022-23	5.05	1.72	4.04	2.32
Total	**25.35**	**8.5**	**20.24**	**12.12**
Summary	**16.85mt pumped into atmosphere**	**(33% of total)**	**(42% of target)**	**(58% of target)**

Gorgon CCS, the world's biggest

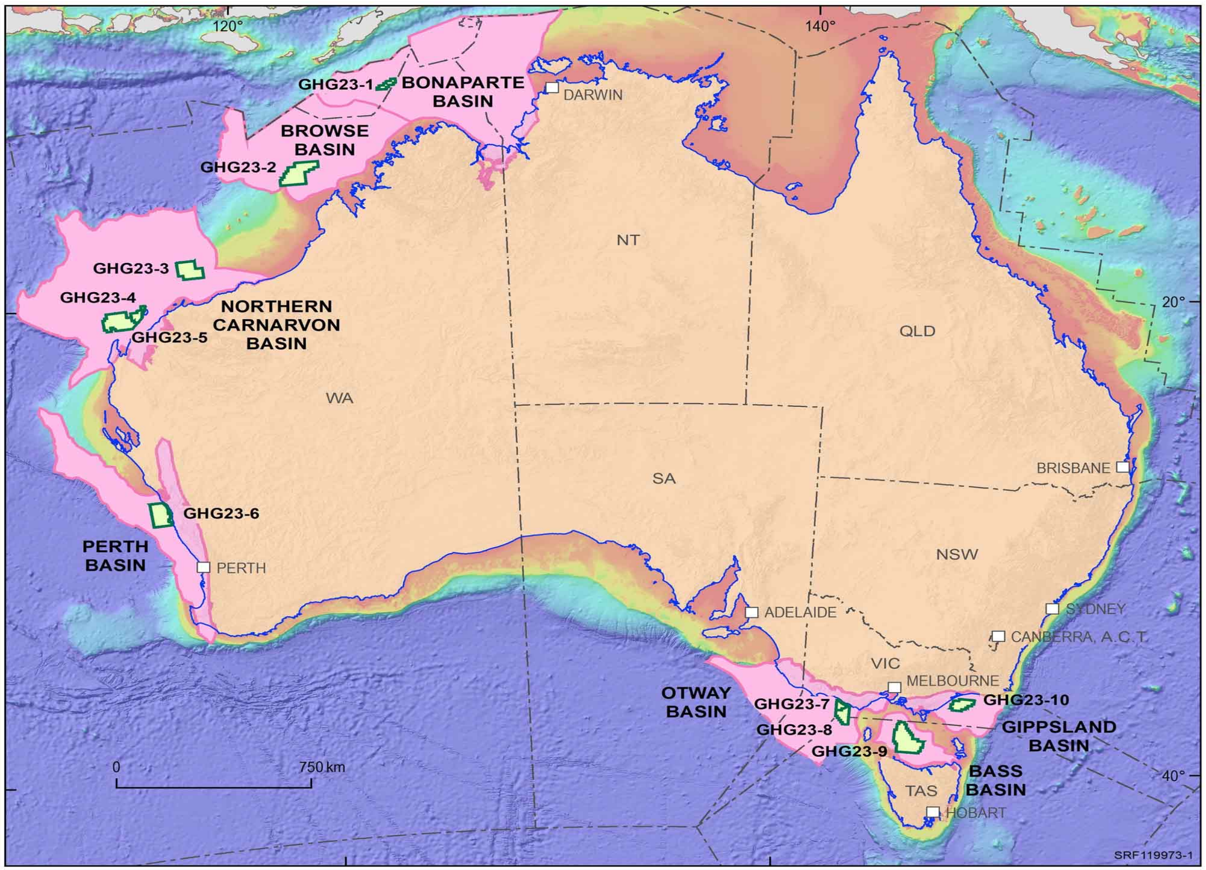


Source: [Chevron]

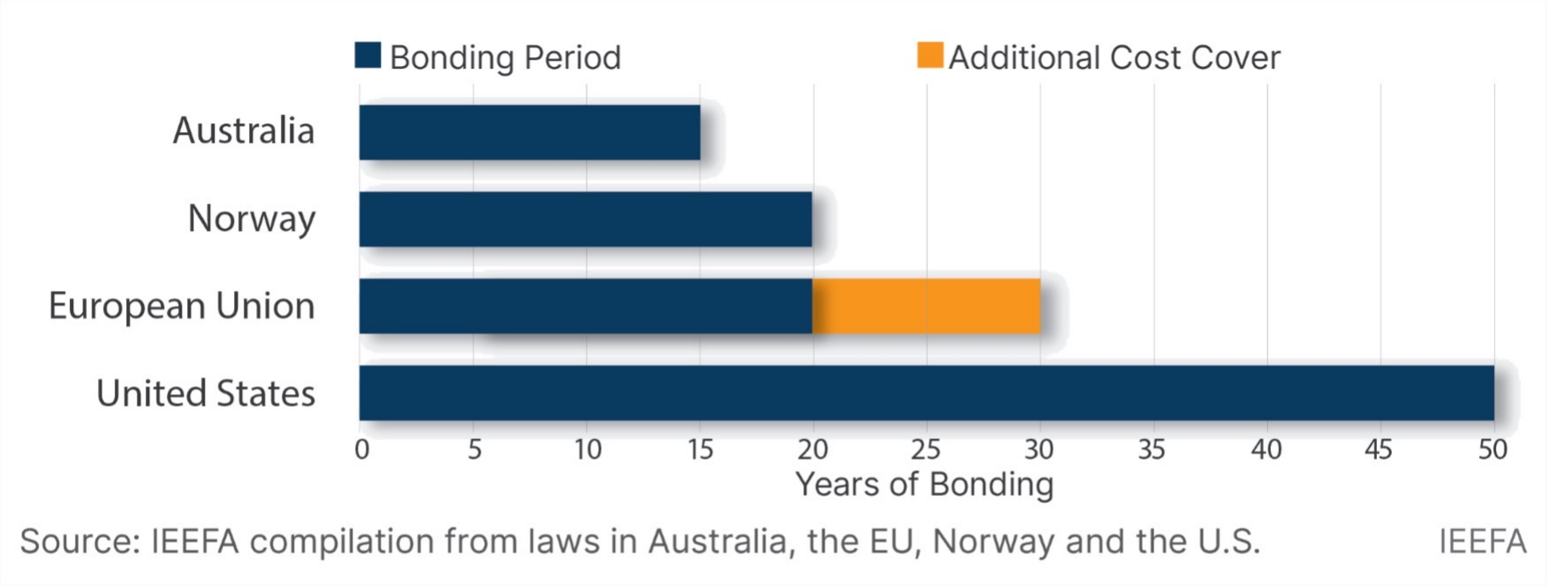
More CCS in Australia

- Moomba CCS in Cooper Basin 1.7mtpa (2024)
- Bayu Undan in Timor Sea 10mtpa (FID 2025)
- Exxon-Woodside plan Bream CCS 0.7mtpa
- Australian govt issued a tender for 10 CCS offshore projects, yet to be finalised
- Sea Dumping bill allows Australia to import CO2, also allows to export Barossa CO2 into Bayu Undan in Timor Leste.

Map of Australia's offshore CCS permits tendered in 2023



Contingency responsibility period after CCS site cover



Selected Asian CCS/CCUS project proposals

Country	Project Name	Sponsor	Capacity	Projected Start of Operation	Notes
Indonesia					
	Rokan	Pertamina Mitsui & Co (Japan)	2mpta	2025	Central Sumatran onshore production block. Considering a CO_2 gathering hub to collect CO_2 from fields spread across central Sumatra using pipelines and trucks. Considering a CO_2 import terminal to add scale and volume to storage
	Sakakemang	Repsol (Spain)	2mpta	To be determined (TBD)	To store up to 30mt of CO_2 stripped from Repsol's Sumatra-based refinery production. Feedstock gas has 28% CO_2 content
	Tangguh LNG (Train 3)	BP (UK) Mitsubishi Inpex CNOOC JX Nippon KG Mitsui LNG Japan	~3.1mtpa	2027	Propose conducting West Papua production and modifying LNG liquefaction facility. Targeting 90% CO_2 reduction from 23% CO_2 content feedstock gas at LNG facility by using 25mt of CO_2 for EGR operations. Final investment decision expected in 2023. About US$3bn investment
	Abadi LNG	Japan Impex 65% Shell 35% (although Shell has been seeking exit for years; Pertamina considering stake)	~2.3mtpa	Early 2030s	To develop greenfield offshore deepwater gas with 9.7% CO_2 content. Abadi LNG targeting 9.5mtpa LNG exports through its US$20bn investment. CCS expected to add US$1.4bn to that cost
	Jatibarang EOR CCUS demonstration	Pertamina JOGMEC (Japan)	Not stated	October 2022 (launched)	Located onshore in West Java, it is Indonesia's first CO_2 injection project for EOR purposes. Extracted gas has 23% CO_2 content. Depending on its success, Pertamina E&P subsidiary Pertamina Hulu Energi is looking to apply CCUS to fields in Sukowati, Gundih, Ramba, Subang, Acacia Bagus and Betung having CO_2 content ranging from 20% to 60%. If applied to all fields, an estimated 15mtpa of CO_2 would be stripped and used for EOR/EGR
	Gundih CCUS /EGR demonstration	Pertamina JGC J-Power Janus Bandung IoT	0.3mtpa	2026-2027	Onshore in Central Java. To strip CO_2 from produced gas and reinject it to enhance further gas production

Selected European CCS project proposals

Country	Project Name	Sponsor	Capacity	Projected Start of Operation	Notes
Norway					
	Northern Lights CCS. "Providing carbon storage as a service." The master project comprises the following four components:				
	Errai (formerly Polaris)	Neptune Energy Horisont Energi Vår Energi	4-8mtpa Phase 1: 1.5mtpa	2024-2026	To make blue ammonia from gas sourced from adjacent Hammerfest LNG site. Integrated with CO_2-receiving terminal that blends received CO_2 with industrial CO_2 captured from sites around Norway
	Smeaheia	Equinor	20mtpa	2027-2028	Slated to become Norway's primary CO_2 storage site
	Luna	Wintershall Dea 60% Cape Omega 40%	5mtpa	Not disclosed	120km offshore from Bergen, awarded by GoN on October 5, 2022
	Langskip (Longship)	Government of Norway (GoN) Norcem AS Fortum Oslo Verme AS	Not applicable		Approved by Parliament on September 21, 2020. GoN operates project through Gassnova SF; and provides state sponsorship for design, construction and testing of CO_2 transport fleet, inclusive of CO_2 gathering and compression facilities. Cost estimate is NOK17.1bn (US$1.59bn) for capital expenditure, and NOK8bn (US$0.75bn) for 10 years of operating expenditure, two-thirds of which would be funded by GoN and one-third from private-sector participants, Fortum and Norcem.
	Trudvang	Sval Energi AS Storegga Geotechnologies Neptune Energy Norge AS	9mtpa	2029	Open-source CO_2 repository with projected total storage capacity of 225mt
United Kingdom					
	Acorn	Storegga 30% Shell 30% Harbour Energy 30% North Sea Midstream Partners 10%	5-10mtpa	2030	Based in Scotland. To develop CO_2 gathering network, both onshore and via ship from other parts of UK, consolidating and compressing, then transporting by repurposed gas pipelines to depleted North Sea gas fields
	Viking CCS	Harbor Energy	10mtpa Phase 1: 2mtpa	Phase 1: 2027	

Conclusion

- Even successful projects show that CCS presents ongoing risks which may negate its benefits
- CCS may have a niche role in the transition, but not in combination with fossil fuels
- Australia needs to improve its regulation to ensure it is not liable for CCS failure

Thank you

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