CIEL

CENTER for INTERNATIONAL ENVIRONMENTAL LAW

Deep Trouble

The Risks of Offshore Carbon Capture and Storage

CENTER for INTERNATIONAL ENVIRONMENTAL LAW

Deep Trouble

The Risks of Offshore Carbon Capture and Storage

About CIEL

Founded in 1989, the Center for International Environmental Law (CIEL) uses the power of law to protect the environment, promote human rights, and ensure a just and sustainable society. CIEL is dedicated to advocacy in the global public interest through legal counsel, policy research, analysis, education, training, and capacity building.

Acknowledgements

This report was authored by Lindsay Fendt, Nikki Reisch, and Steven Feit, with support from Lili Fuhr and Dana Drugmand. It was edited by Lani Furbank and Maria Frausto. Special thanks to Aled Fisher and Tom Swann for their reviews and insights.

Errors and omissions are the sole responsibility of CIEL. This report is for general informational purposes only. It is intended solely as a discussion piece. It is not and should not be relied upon as legal advice. While efforts were made to ensure the accuracy of the information contained in this report is from sources believed reliable, the information is presented "as is" and without warranties, express or implied. If there are material errors within this brief, please advise the authors. Receipt of this report is not intended to and does not create an attorney-client relationship.

Statements in this report and appendix regarding the details of proposed offshore CCS projects are based on publicly available information reflecting project developers' and sponsors' announced or published estimates and projections as of the date of publication. The information is accurate to the best of CIEL's knowledge, but is subject to change, and we make no guarantee as to its completeness or correctness.

Please send comments or questions to info@ciel.org to be sure of a reply.

Design & Layout: Tyler Unger
Cover Photo: An offshore rig in Norway's Sleipner gas field. Sleipner was the world's first CCS project. (NTB / Alamy Stock Photo)

Table of Contents

Acronyms

BBNJ	Biodiversity Beyond National Jurisdiction
BOEM	Bureau of Ocean Energy Management
BOGA	Beyond Oil and Gas Alliance
BSEE	Bureau of Safety and Environmental Enforcement
CCS	Carbon capture and storage
CCUS	Carbon capture, utilization, and storage
CNOOC	China National Offshore Oil Corporation
COP	Conference of the Parties
DAC	Direct air capture
DOE	Department of Energy
DOI	Department of Interior
EBSA	Ecologically or biologically significant marine areas
EEZ	Exclusive economic zone
EIA	Environmental impact assessment
EGR	Enhanced gas recovery
EOR	Enhanced oil recovery
EPA	Environmental Protection Agency
EPBC	Environment Protection and Biodiversity Conservation
ETS	European Union Emissions Trading System
FEED	Front-end engineering and design
IEA	International Energy Agency
IEEFA	Institute for Energy Economics and Financial Analysis
IIJA	Infrastructure Investment and Jobs Act
IPCC	Intergovernmental Panel on Climate Change
IRS	Internal Revenue Service
LNG	Liquefied natural gas
MARPOL	International Convention for the Prevention of Pollution from Ships
MPRSA	Marine Protection, Research, and Sanctuaries Act of 1972
NEPA	National Environmental Policy Act
NOPSEMA	National Offshore Petroleum Safety and Environmental Management Authority
NOPTA	National Offshore Petroleum Titles Administration
OCS	Outer Continental Shelf
OECD	Organisation for Economic Co-operation and Development
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
SECARB	Southeast Regional Carbon Sequestration Partnership
SOLAS	Safety of Life at Sea
UNCLOS	United Nations Convention on the Law of the Sea
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change

Executive Summary

Facing growing scrutiny over their role in the climate crisis, polluting industries are increasingly looking to the oceans to dispose of their carbon dioxide (CO_2) waste. Rather than phase out oil, gas, and coal, many industries that produce and rely on fossil fuels claim they can instead capture their CO_2 emissions and store them indefinitely by injecting them under the sea floor or below the Earth's surface on land. The fossil fuel industry sees this process, known as carbon capture and storage (CCS), as a lifeline for its climate-damaging business operations. However, despite decades of attempts, the fossil fuel industry has failed to demonstrate the viability of CCS at scale. Carbon capture's poor track record has not stopped polluters from touting the promise of CCS and the possibility of turning the seabed into a storage site for their CO_2 waste. But offshore CCS is no solution to fossil fuel pollution. Instead, it represents a new threat to the world's oceans and a dangerous distraction from real progress on climate change.

Key Findings

Offshore CCS is being pushed at a never-before-seen scale. As of mid-2023, companies and governments have announced plans to construct more than fifty new offshore CCS projects throughout the world. If built and operated as proposed, these projects would entail a 200-fold increase in the amount of CO_2 injected under the seabed annually. While that represents a step-change from present levels, it would still be only a drop in the bucket compared to needed emissions reductions. Injecting 450 million metric tons (tonnes) of CO_2 per year would amount to only about 1.5 percent of annual global CO_2 emissions at current rates.

Pooling CO_2 from different sources in one storage site is a risky endeavor. Many of the proposed projects are designed to collect CO_2 emissions from multiple industrial facilities and inject them into shared subsea storage "hubs" — an approach that has never been tested. Combining various CO_2 streams with different types of impurities could pose technical challenges and risks to infrastructure that may endanger projects' feasibility, as well as their safety. Until now, global experience with offshore CCS has been based on just two projects in Norway, both of which encountered unpredicted problems despite their relatively simple designs and small scales. Far from a proof of concept, those projects prove the complexity of offshore CCS and raise serious concerns about proposals to ramp it up in size and scope.

Far from curbing fossil fuel emissions, some proposed offshore CCS projects are covering up expanded fossil fuel production and use. Over a dozen offshore CCS schemes have been proposed alongside new fossil fuel projects, including fossil-based hydrogen production and new fossil gas drilling. In some cases, fossil fuel companies are using CCS to justify the development of new offshore oil and gas fields with high CO_2 concentrations.

Injecting CO_2 under the seabed presents uncalculated risks and untested monitoring challenges. Whether onshore or offshore, injecting CO_2 under the Earth's surface has the potential to contaminate groundwater, cause earthquakes, and displace deposits of brine, which can be toxic. These risks have never been confronted at scale, and the magnitude of offshore injection contemplated by proponents would create unprecedented challenges in managing reservoir pressure and monitoring CO_2 plumes in the depths of the ocean. Scaling offshore CCS would also require a massive buildout in onshore and offshore infrastructure, pipelines, and other CO_2 transport vessels, like ships and railcars, which pose additional environmental, human rights, health, and safety risks from displacement, leaks, ruptures, and other disturbances.

Proposed CO_2 storage hubs are concentrated in areas most prone to leaks. The single biggest risk of CO_2 leakage comes from the interaction of injected CO_2 with legacy oil and gas wells. And yet the sites being heavily targeted for offshore CCS development are zones of long-standing, intensive oil and gas drilling, such as the US Gulf of Mexico and the European North Sea, where old wells abound. More than half of proposed offshore CCS projects plan to use depleted wells as storage sites.

The risks associated with offshore CCS put more pressure on the world's already-stressed oceans. The push for offshore CCS reflects the same attitude that has left the oceans in crisis today: treating them as a limitless resource to exploit and a bottomless receptacle for humanity's waste. The existing offshore oil and gas industry has already pushed the oceans to the brink with frequent pipeline and shipping leaks, while decommissioned infrastructure is often left unmonitored at the bottom of the sea. The failure of industry and regulators to manage this existing offshore infrastructure calls into question their ability to safely manage the entirely new network of undersea equipment required for offshore CCS. Leaks and other accidents could pose major hazards to sensitive marine organisms and make the surrounding seawater more acidic, compounding the ocean acidification crisis. And of course, release of the CO_2 would undo any purported climate benefits of CCS. Such impacts would further jeopardize the right to a clean, healthy, and sustainable environment and other human rights.

Offshore CCS projects are costly and largely dependent on public subsidies. CCS is inherently expensive, and the costs for its deployment are only heightened offshore. These high costs are driving industry demands for public subsidies, which effectively pay polluters to bury some of their pollution rather than require them to stop generating it in the first place. Significant portions of CCS's high costs are being borne by the public, through tax credits, loan guarantees, and other forms of financing. Governments have already poured billions into research and development and other subsidies for the current spate of offshore projects — and that's not including the billions more in tax credits for which many projects would qualify once in operation.

Existing legal regimes provide important bulwarks against the risks of offshore CCS, but must be strengthened. Existing domestic and international laws and regulations must be interpreted and applied to protect the oceans, communities, and the climate from the threat posed by offshore CCS. Laws governing the seas, environmental protection, biodiversity conservation, and human rights restrict activities that can cause local or transboundary harm and require precaution in the face of uncertainty regarding the extent or nature of the risk. In countries where major storage hubs have been proposed, such as the United States, Norway, and Australia, proper application of these regimes and related national laws should put the brakes on the buildout of offshore CCS projects.

Evolving CCS-specific laws and regulations must take into consideration the myriad risks from offshore CO_2 injection and the outstanding questions regarding long-term monitoring, management, and liability. Now is the time for governments to strengthen measures to prevent harm — *before* more public funds are diverted to offshore CCS and more damage is done.

Whether onshore or offshore, CCS has been repeatedly proven to fail. Most flagship CCS projects have fallen short of their promised storage targets or failed to get off the ground due to cost overruns. Even among the small handful of commercial CCS projects running today, many have faced unforeseen challenges that throw the technology's feasibility and safety into question. Yet the false promise of CCS keeps fossil fuel facilities running and provides cover for continued expansion of oil and gas production.

Avoiding catastrophic climate change requires immediate measures to accelerate the just and equitable transition away from fossil fuels and to safeguard vital natural ecosystems, like those found in the world's oceans. Offshore CCS does neither.

Introduction

Since the 1970s, polluting industries have experimented with technology to trap their emissions.[1] Using either membranes or chemicals, carbon capture systems aim to isolate the carbon dioxide (CO_2) from a gas stream or a smokestack, preventing it from reaching the atmosphere and dispersing.[2] The CO_2 can then be injected underground into geologic formations, ostensibly to be stored indefinitely, or used for other purposes. For decades, most companies capturing some of their emissions have done so not to prevent pollution, but to make use of the CO_2 to pump more oil out of the ground. The vast majority of the CO_2 captured at existing carbon capture and storage (CCS) projects around the world is used in oil fields, where it is injected into depleted wells to force more oil to the surface, a process known as enhanced oil recovery (EOR).

Carbon Storage in Theory

Once CO_2 is captured, operators can inject it underground or under the seabed into a variety of different geologic formations, including saline aquifers, oil and gas reservoirs, coal seams, basalt formations, and organic shale formations.[3] While storage in each of these formations is theoretically possible, there are geologic variables at each injection site that make it difficult to predict the behavior of the CO_2 underground.[4] In principle, each of these formations can hold the CO_2 underground at a temperature and pressure that keeps the CO_2 in a supercritical state, meaning that it has properties of both a liquid and a gas. Depending on the site's geology, the CO_2 may dissolve into some of the brine underground or trigger a chemical reaction that slowly turns the carbon into a solid mineral, over thousands of years, but most injected CO_2 is physically held underground by a seal known as a caprock.[5] Descriptions of how CO_2 storage may work must be interpreted in light of the limited experience with CO_2 sequestration to date, the site-specific nature of geologic variations and leakage pathways, and the difficulty of tracking these developments over geological rather than human timescales.

Carbon Capture, Transport, and Offshore Storage

Source: Provided by the Global CCS Institute.

While fossil fuel companies did not originally pursue carbon capture as a climate measure, their framing of the technology began to change around the turn of this century when they faced new scrutiny for their greenhouse gas emissions. In order to avert the need for regulation and continue their operations, fossil fuel companies poured billions of dollars into demonstration projects and CCS research on the premise that carbon capture could address their products' pollution problem.[6] Governments also provided billions in subsidies to help prop up CCS schemes.[7]

From the 1990s and into the late 2010s, companies launched various projects in different parts of the world that installed carbon capture equipment at polluting facilities with plans to inject the captured CO_2 underground.[8] Some of these projects, like the Kemper and Petra Nova coal plants in the US, planned to use the captured CO_2 for EOR, extracting more hydrocarbons while purporting to provide "clean" energy.[9] Others, like the In Salah project at a gas field in Algeria, sought to inject emissions underground for "permanent" storage.[10] But despite these efforts, most CCS projects — including the aforementioned examples — have been abject failures, falling dramatically short of their capture targets or hitting cost overruns that made them financially unviable.[11] Following this series of disappointments, only a few small networks of CO_2 pipelines now exist worldwide, nearly all of which are for EOR.[12]

> In practice, most CCS projects have been **abject failures, falling dramatically short of their capture targets or hitting cost overruns** that made them financially unviable.

Carbon capture introduces new environmental, human rights, health, and safety hazards beyond those posed by climate change. **Regardless of how the captured carbon is used, any CCS project requires significant energy inputs and a web of different facilities to function, and all of this infrastructure poses risks to the public.** CO_2 processing facilities, for example, release large amounts of air pollutants like sulfur dioxide, while carbon capture equipment is known to greatly increase the amount of ammonia that a facility spews into the air.[13] Running carbon capture equipment is also enormously energy-intensive, increasing the overall emissions of the facility where the capture equipment is installed.[14] This is known as an "energy penalty." The transport of CO_2 can also be dangerous for workers and bystanders. At high concentrations, CO_2 is a toxic gas and an asphyxiant capable of causing "rapid 'circulatory insufficiency,' coma and death."[15] When a CO_2 pipeline ruptured in Mississippi in 2020, dozens of people nearby were knocked unconscious and at least forty-five wound up in the hospital.[16]

Seemingly impervious to the failures and risks of CCS, and buoyed by expanded public subsidies,[17] fossil fuel companies are now pushing forward a new wave of offshore CCS proposals. As detailed in the appendix accompanying this report, many of these new plans aim to pool CO_2 emissions from regional industrial clusters and transport this waste by pipeline, rail, or ship to a centralized location or "hub" offshore where it can be injected under the seabed. Nearly all of these projects plan to store the CO_2 in either depleted oil and gas fields, which are prone to leaks, or in saline aquifers, which are filled with brine that could contain heavy metals or substances that could cause contamination when displaced by the added CO_2.[18] These offshore hub projects are now widespread, with proposals in Europe, Asia, Australia, and the US. And while the potential projects differ in size and scope, each one is aimed at expanding or maintaining polluting activities that must ultimately be eliminated or dramatically scaled down to avoid catastrophic climate change.[19] **Together, they represent a step-change in the size and complexity of offshore CCS.**

Proponents are billing many of the new offshore CCS projects as crucial for reaching climate goals or for jump-starting the "carbon management" economy. Large projects like Norway's Northern Lights (discussed further below), are marketed not just as a climate measure, but as an important business opportunity.[20] This framing has led to massive government support, and **in the last decade alone, governments around the world have invested billions in the development of offshore CCS through various climate-related grant programs.**[21]

> Seemingly impervious to the *failures* and *risks* of CCS, and buoyed by expanded public subsidies, fossil fuel companies are now pushing forward a **new wave** of offshore CCS proposals.

Of the sixty offshore projects proposed as of August 2023, the vast majority risk prolonging the lives of existing fossil fuel facilities by purportedly reducing their CO_2 emissions rather than shuttering them. In addition to keeping polluting facilities in operation, at least thirteen proposed offshore CCS projects are associated with the development of new fossil fuel resources.[22] Using CCS to extend reliance on fossil fuels runs directly counter to climate science. The politically endorsed scientific consensus, reflected in the latest reports of the Intergovernmental Panel on Climate Change (IPCC), is that **avoiding truly catastrophic climate change requires an immediate end to new fossil fuel projects and an accelerated shutdown of existing facilities.**[23]

Capturing and storing fossil fuel emissions, rather than simply eliminating them, would require an enormous buildout of new carbon storage infrastructure. In total, the planned offshore projects aim to store more than 200 times as much CO_2 under the ocean each year as the world currently stores offshore, according to a CIEL analysis of publicly available information regarding proposed offshore CCS projects.[24] While that would represent a significant change from present levels, the total projected capture amount of 450 million metric tons (tonnes) remains relatively insignificant from a climate change perspective, amounting to approximately 1.5 percent of current annual global CO_2 emissions from energy and industry.[25] Even as offshore CCS projects capture industry attention and government funds, the risks associated with them remain largely unstudied and untested.

The very idea that offshore CO_2 storage is feasible at all is based almost entirely on two small projects, both in Norway. These storage ventures both encountered problems in their early phases and prove that CO_2 storage is a challenging and unpredictable task.[26] Moreover, uncertainties remain regarding the permanence of storage, processes for long-term monitoring, and liability for leaks. Many of these risks have yet to be fully assessed, let alone comprehensively regulated.[27]

Beyond the well-established physical threats of carbon injection, the push to expand offshore CCS reflects an attitude toward the world's oceans that has left them in crisis today: treating them as a limitless resource to exploit and a bottomless receptacle for humanity's waste. The oil and gas industry is one of the worst perpetrators of this attitude, having punched holes in the ocean floor for extraction since the 19th century.[28] The long history of industrial offshore activity is replete with deadly accidents and devastating environmental disasters, and reviews of pipeline safety data show that leaks and other problems occur more frequently in offshore operations than onshore.[29] Offshore pipeline and oil shipping leaks are already so common that one recent study of satellite images found enough oil patches on the ocean to coat all of France twice over.[30] And once decommissioned, pipelines and other offshore equipment are often left unmonitored at the bottom of the sea.[31]

> In addition to keeping **polluting facilities** in operation, at least thirteen proposed offshore CCS projects are associated with the development of *new* fossil fuel resources.

Offshore CCS represents the next frontier of ocean abuse by the fossil fuel industry. After years of plundering the seas for oil and gas, the fossil fuel industry now plans to use the ocean floor as the final dumping ground for its waste. This new carbon management scheme could put the already taxed marine environment under greater stress, threatening beleaguered populations of marine mammals, the livelihoods of fishing communities, and the integrity of the ocean's natural climate regulation system.

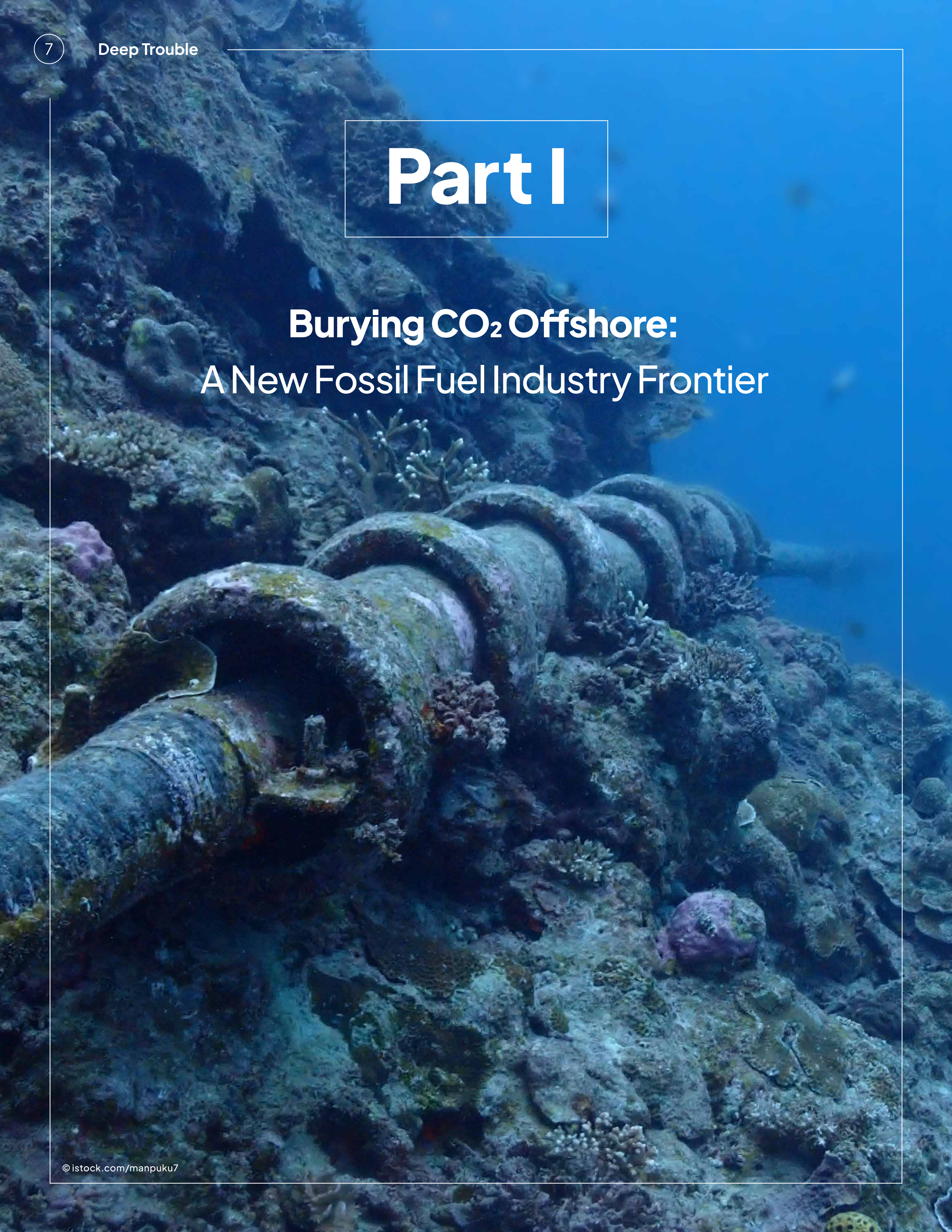
> After *years* of plundering the seas for oil and gas, the fossil fuel industry now plans to use the ocean floor as the **final dumping ground** for its **waste.**

Whether on land or under the sea, CCS is not a solution to the climate crisis. Experience shows it is costly and ineffective, and only prolongs dependence on fossil fuels. Rather than find ways to phase out oil, gas, and coal and dismantle polluting infrastructure, proposed CCS mega-projects in the sea would entrench the fossil fuel system.

Part I of this briefing introduces the concept, historical context, and rapid proliferation of offshore CCS projects and proposals. Part II discusses the most significant risks and hazards associated with offshore CCS at each stage of its operations, from capture to transport, injection, and storage. These risks include potential leakage from CO_2 pipelines, ships, storage reservoirs, and old oil and gas wells; the foreseeable, damaging impacts of escaped CO_2 on sensitive marine environments; the challenges of managing pressure, monitoring storage, and responding to incidents at great depths; and the problems with using CCS for EOR. Part III discusses how the public is picking up the tab for the high costs of offshore CCS through various government subsidies and examines the domestic and international legal and regulatory regimes that can and must be applied to prevent offshore CCS from harming people and the environment.

Part I

Burying CO_2 Offshore: A New Fossil Fuel Industry Frontier



© istock.com/manpuku7

The idea of deliberately injecting CO_2 into subsurface reservoirs offshore has existed for decades, but to date, applications of the technique have been extremely limited and small-scale. **Beginning in 2020, there was a dramatic increase in proposals to inject CO_2 offshore, marking a step-change in the number and scale of projects planning to deploy the technology globally.** Today, the fossil fuel industry is leading a push to convert the seabed into a disposal site for planet-warming pollution by pooling CO_2 in storage "hubs" under the ocean floor.

This massive proposed scaling of offshore CCS is largely concentrated in areas that have been the sites of intense oil and gas drilling for decades, such as the US Gulf of Mexico (where ExxonMobil and Chevron are proposing CCS hubs) and the European North Sea (where Equinor is leading the Northern Lights hub project). These projects, discussed further below, represent a new frontier of the fossil fuel industry's decades-long exploitation of the oceans.

The Troubling History of Offshore CCS

To date, global experience with sub-seabed CO_2 injection has stemmed from just two projects off the coast of Norway. While frequently cited as proof of concept for offshore CCS, these small-scale, single CO_2-source projects are not representative of the massive and complex buildout that proponents are now pushing forward. **Closer examination of these projects' performance suggests that they should be regarded not as success stories, but rather as cautionary tales about the challenges of offshore CO_2 injection and monitoring.**

The world's first offshore CCS project, called Sleipner, began operating in 1996. The Norwegian petroleum company Statoil (now Equinor) started capturing CO_2 from its Sleipner gas field and injecting it into saline reservoirs beneath the North Sea in order to avoid paying the 1991 Norwegian CO_2 tax.[32] In 2008, Statoil launched a second CCS project that began capturing CO_2 from its offshore operations at the Snøhvit gas field and reinjecting it beneath the seabed.[33]

In both projects, geologists failed to accurately predict how the injected CO_2 would behave underground. At Sleipner, the CO_2 migrated upward from its intended storage point into a different layer of the subsurface.[36] The Snøhvit project turned out to have significantly less storage capacity than expected, forcing Equinor to sink an unplanned USD225 million or so into identifying the problem and developing a new storage site.[35] A 2023 report on Sleipner and Snøhvit from the Institute for Energy Economics and Financial Analysis (IEEFA) points to the projects' problems as evidence that storing CO_2 underground is "not an exact science,"[36] and that CCS, even after "extensive repeated study, using the most modern methods, is not foolproof."[37]

Both the Sleipner and Snøhvit basins are among the most well-studied geological fields in the world, and still, the injected CO_2 behaved in unpredicted ways.[38] Because every site has unique geology, each project will have its own set of risks and engineering challenges. **This means that individual CCS projects have limited bearing on the feasibility of offshore CCS in other locations and at different scales.**

The pervasive concept of offshore "CCS hubs" introduces additional complexities beyond what stand-alone facilities like Sleipner and Snøhvit were designed for. Both Sleipner and Snøhvit involve CO_2 captured from a single source, while many new CCS proposals envision storing CO_2 from multiple sources in one location.[39] Because different industrial processes produce CO_2 streams with different chemical makeups, hub operators would need to ensure that the substances they accept from different industries would not damage their infrastructure or elevate risks. Impurities like water, hydrogen sulfide, sulfur oxides, or carbon monoxide can all be present in industrial CO_2 streams at varying levels.[40] These impurities can cause pipeline corrosion[41] and compound the dangers workers would face from a blowout: Even with pure CO_2, a blowout could be deadly due to the risk of asphyxiation, but impurities could make a rupture toxic as well.[42]

Finally, both the Norwegian projects are relatively small in scale: They each have a maximum injection rate of less than 1 million tonnes per year.[43] This amounts to less than one thirtieth of Norway's annual emissions, and pales in comparison to the much larger ambitions of major proposed projects, discussed below.

Despite the significant challenges with these two relatively simple projects, industry leaders still often refer to Sleipner and Snøhvit as success stories that substantiate the safety and feasibility of much larger, more complex offshore CCS projects, such as the hubs being proposed worldwide. The projects have emboldened Equinor and the Norwegian government to promote Norway as a primary destination for CO_2 waste from other countries.[44]

Until now, these two projects have received little scrutiny in Norwegian political debate or in the broader environmental movement — perhaps due in part to the dearth of independent research into CCS free of funding or participation by the oil and gas industry, including at Norwegian higher education institutions.[45] As major financial, legal, and political decisions are made regarding the development and regulation of offshore CO_2 storage, such scrutiny is both timely and necessary.

The New Wave of Offshore CCS Hubs

Amid the global push for CCS, the fossil fuel industry and governments are now increasingly announcing planned projects and initiatives for offshore CO_2 storage. As of August 2023, there were at least fifty-seven proposals for offshore carbon sequestration worldwide, the vast majority of which are planned for operation by 2030. **Combined, these projects would increase the rate of offshore CO_2 injection to as much as 200 times current levels, storing a projected maximum of 450 million tonnes of CO_2 under the seabed per year, compared to about 2 million today.**[46] Most of these projects are clustered in a few key regions, including the European North Sea, the US Gulf of Mexico, and the South China Sea.

In Europe, several countries bordering the North Sea are actively developing offshore CO_2 storage plans, including Norway, Denmark, the Netherlands, the United Kingdom, and Belgium. The Norwegian government and petroleum industry in particular are pushing the development of additional offshore carbon storage projects as the country's Ministry of Petroleum and Energy touts the promise of a "new, commercial industry on the Norwegian [continental] shelf."[47] In Norway, developments are underway for a new offshore CCS project — led by Equinor in partnership with Shell and Total — called Northern Lights. The Norwegian government is providing 80 percent of the funding for the first phase.[48] The project would seek to inject 1.5 million tonnes per year of CO_2 in its first phase and up to 5 million in its second.[49] This second phase would increase the amount of CO_2 injected under the seabed by a large margin, but even so, it remains a drop in the proverbial bucket: The carbon injected would amount to less than one tenth of 1 percent of Europe's annual CO_2 emissions from fossil fuels in 2021.[50]

As of August 2023, there were *at least* fifty-seven proposals for offshore carbon sequestration **worldwide,** the *vast majority* of which are planned for operation by 2030.

In addition to the Northern Lights project, several other countries or companies have announced major CO_2 storage projects in the North Sea, including off the coast of the Netherlands, Denmark, and the UK.[51] For example, in the Netherlands, an oil company called Neptune Energy is teaming up with Rosewood Exploration, EBN Capital, and Exxon's Dutch subsidiary XTO Netherlands on a proposal to store up to 9 million tonnes of CO_2 per year in the L10 offshore CCS project in the Dutch segment of the North Sea.[52] In the UK, BP along with Eni, Equinor, National Grid, Shell, and Total are developing plans to store as much as 23 million tonnes of CO_2 per year off the UK coast under the banner of the Northern Endurance Partnership.[53] In

Denmark, a consortium of twenty-three companies are pursuing the Greensand offshore carbon storage project, planning to store up to 8 million tonnes of CO_2 per year by 2030.[54] Each project intends to store emissions from multiple industrial sources at a scale and complexity that contrasts starkly with Sleipner's less than 1 million tonnes from a single, high-purity CO_2 source.

Denmark's embrace of CCS is at odds with its commitment to phase out fossil fuels. As a founding member of the Beyond Oil and Gas Alliance (BOGA) launched in 2021 at the 26th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC COP26),[55] Denmark promised to sunset oil and gas production domestically by 2050. And yet, the offshore CCS projects Denmark is promoting only prolong reliance on oil and gas.

Offshore CO_2 storage projects are also emerging in the Asia-Pacific region. In Timor-Leste, the Australian gas company Santos is planning an offshore CCS project located at the Bayu-Undan gas field in the Timor Sea.[56] The region is governed by the Maritime Boundary Treaty between the two countries and some portions of the project fall under the jurisdiction of Australia, while others will be subject to the laws of Timor-Leste.[57] This project targets storage of up to 10 million tonnes of CO_2 per year.[58] While Santos has billed the Bayu-Undan storage project as a potential regional CCS hub, the company's own announced plans involve using CCS to reduce emissions from its controversial Barossa offshore gas field development, which contains CO_2 concentrations nearly double those of any other gas project in Australia.[59] Although there is no requirement for Barossa or any other project in the area to use CCS, claims that Bayu-Undan will become a CCS hub have become central for Santos, other gas companies, and government agencies in justifying new gas projects in Australia.[60]

While Santos continues to tout its CCS plans in the area, the Barossa development has faced significant local resistance and legal challenges. In December 2022, an Australian court upheld a previous ruling that ordered Santos to pause drilling until the company properly consulted with Indigenous groups on the Tiwi Islands near the development.[61] Santos's CCS claims have also been the subject of a greenwashing lawsuit filed in Australia in 2021 and updated in June 2023 to expand allegations concerning the role of CCS in the company's net-zero plan.[62]

In June 2022, China's state-owned oil company the China National Offshore Oil Corporation (CNOOC) completed construction of the country's first offshore CCS project located at the company's Enping oilfield in the South China Sea.[63] Additional offshore projects have been proposed in the waters near Malaysia, Thailand, and South Korea.[64]

Finally, three major offshore CO_2 storage projects have been proposed in the US by oil majors Chevron, ExxonMobil, and Repsol, as well as a few other partner companies. Together, these projects propose to store significant quantities of CO_2 under the seabed in the Gulf of Mexico. ExxonMobil's proposal in the Houston Ship Channel, in particular, is proposing to inject as much as 100 million tonnes of CO_2 per year under the seabed. These projects, along with the wider interest in the Gulf of Mexico as a primary target for CCS proponents, are discussed below.

Although the projects discussed in this section are among the largest proposed offshore carbon storage ventures in the world, even if feasible, they would store only a marginal percentage of global emissions. Combined, the developments would have a projected storage capacity of 450 million tonnes per year or less,[65] around 1.5 percent of average global CO_2 emissions from fossil fuels and industry, estimated at approximately 37 gigatonnes in 2022.[66] These storage rates would be further reduced by the additional greenhouse gas emissions required to capture, transport, and inject the CO_2. So in addition to locking in place polluting facilities for decades to come, the projects' actual emissions reductions would be relatively trivial from a global perspective. Indeed, the IPCC has characterized CCS in both the energy and industrial sectors as one of the highest-cost options with the lowest potential to reduce emissions by 2030 — the most crucial period for climate change mitigation.[67]

CO_2 Injection into Sediments on the Seafloor or into the Water Column Is Prohibited

Injecting CO_2 in geologic formations below the seabed (offshore CCS) is distinct from two other techniques for oceanic CO_2 storage that have been proposed in the past, neither of which is in active development, and both of which run afoul of existing prohibitions under international law. The first is injection of CO_2 into the sediments on the seafloor in the deep ocean. This concept relies on the high-pressure, low-temperature environment of the deep ocean to keep the CO_2 stable and secure. [68] However, the Intergovernmental Panel on Climate Change (IPCC) has found that "the majority of sediments of the abyssal deep ocean floor are too thin and impermeable to be suitable for geological storage."[69] The second is direct injection of CO_2 into the water column at great depths. Like sediment injection, the idea relies on the high-pressure, low-temperature environment of the deep ocean to contain CO_2 in liquid form.[70]

Direct release of CO_2 into ocean water without containment is considered ocean dumping and is prohibited under international law, pursuant to the 1996 amendment to the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (commonly referred to as the "London Protocol" and discussed in greater detail below).[71] Regional and national laws pertaining to CCS, such as the EU Directive on CCS, also expressly prohibit the "storage" of CO_2 in the water column.[72]

Norway Sells Carbon Storage to the World

In 2020, the Norwegian government announced plans to launch a large-scale CCS demonstration project in an effort to create a new market for CO_2 disposal as a service across the European continent.[73] The project, known as Longship, would be an open-source network of CCS infrastructure that includes carbon capture at industrial facilities throughout the continent, paired with transport and storage in a sub-seabed site located off the western coast of Norway. The Norwegian government will fund two-thirds of the project, an estimated USD1.57 billion (NOK 16.8 billion), while the remaining costs will be shared among the project's partners.[74]

The transport and storage component of the project, known as Northern Lights, is among the furthest along of proposed offshore CCS projects and is emblematic of efforts to turn the North Sea into a disposal site for CO_2. Operated as a partnership between oil companies Equinor, TotalEnergies, and Shell, the Northern Lights project involves transporting CO_2 captured from European industrial facilities by ship to an onshore receiving terminal and then moving it back offshore via pipeline for injection into a storage reservoir beneath the North Sea.[75] The subsea storage site is located about 2,600 meters (1.6 miles) beneath the seabed. Phase 1 of the project aims to capture and store 1.5 million tonnes of CO_2 per year and be operational by 2024.[76]

The Longship project was initially planned to start with carbon capture at two Norwegian facilities, the Heidelberg Materials cement plant in Brevik and the Hafslund Oslo Celsio waste-to-energy plant. Construction is underway at Heidelberg Materials, but the Hasflund Oslo Celsio plant suspended the installation of carbon capture equipment in April 2023 after the project exceeded its budget.[77] Northern

Lights has already reserved a capacity of 0.8 million tonnes CO_2 per year for these sources[78] and, it is likely that these delays at Hasflund Oslo Celsio will mean that the first phase of the project will inject less CO_2 than initially estimated.[79]

Longship is seeking additional emitters within and outside of Norway to sign onto the project, exemplifying how the "carbon management" economy depends on steady pollution streams. In late August 2022, the project announced an agreement with the Norwegian fertilizer firm Yara to transport and store CO_2 captured from Yara's Sluiskil ammonia plant in the Netherlands. At the time, the deal was touted as "the world's first commercial agreement on cross-border CO_2 transport and storage."[80] In May 2023, the Northern Lights project announced its second commercial deal with the Danish energy company Ørsted to store 430,000 tonnes of liquefied CO_2 captured from its Asnæs and Avedøre biomass power stations.[81] Ørsted announced the deal with Northern Lights the same day that it finalized a contract with the Danish Energy Agency to subsidize carbon capture at its plants for twenty years, starting in 2026.[82]

Although Northern Lights is pitched as a major project, its potential contribution to climate mitigation is quite limited. The project aims to scale up beyond the starting goal of storing 1.5 million tonnes of CO_2 per year, adding 3.5 million tonnes of capacity to reach 5 million tonnes depending on market demand.[83]

This represents a potential five-fold increase in the offshore injection rate compared to Norway's flagship Sleipner project, and with it, increased complexities. But the scale of emissions must be kept in perspective: **Norway's emissions alone amounted to about 49 million tonnes carbon dioxide equivalent (CO_2e) in 2021.**[84] **The CO_2 volumes that this project aims to bury — drawn from the entire continent — are minor in comparison.**

Companies Set Sights on the Gulf of Mexico

At the time of publication, no commercial-scale offshore CO_2 storage projects exist in the US. However, private industry, as well as state and federal government actors, are now rapidly advancing plans for subsea carbon storage. **The Gulf of Mexico is the primary target for offshore CCS because of its estimated large storage potential and the region's existing high concentration of industrial facilities.**[85] The injected CO_2 would be for geologic sequestration and potentially for EOR.[86] As detailed below, Chevron and ExxonMobil are each leading projects to develop major hubs off the Texas coast, while Cox Operating, Crescent Midstream, and Repsol are partnering on a project that will repurpose depleted oil and gas wells off the coast of Louisiana for CO_2 storage.

Norwegian company Equinor is a major proponent of CCS, sometimes featuring it in advertising.

In early May 2022, Chevron announced it would be participating in a joint venture to develop a CCS project called Bayou Bend off the coast of Jefferson County, Texas.[87] Offshore oil and gas producer Talos Energy and a CCS development firm called Carbonvert initiated the joint venture by winning the offshore lease bid offered by the Texas General Land Office — the first and so far only offshore lease in the US designated for carbon storage.[88] The lease covers over 40,000 acres in Texas state waters, off the coast of where major petrochemical facilities are concentrated, and Chevron is now describing the offshore project as a potential CO_2 storage "hub."[89]

ExxonMobil has pitched a similar CCS hub concept involving offshore storage; in 2021 the company announced a proposed USD100 billion carbon capture "hub" for the Houston Ship Channel industrial area, with the captured CO_2 envisioned for offshore storage in the Gulf of Mexico.[90] Exxon has said that its proposal is dependent (in part) on government funding,[91] and though other oil and chemical companies have indicated interest in joining,[92] this costly hub project has not yet advanced beyond the concept phase (and may never do so).[93]

ExxonMobil has also been eyeing other areas of the Gulf of Mexico. During a November 2021 federal offshore lease sale, the company bid on almost 100 leases in shallow waters where oil reserves were mostly depleted, leading analysts to speculate that the company planned to use the leased area for CO_2 storage rather than new drilling.[94] In February 2022, a federal court invalidated this lease sale due to an incomplete assessment of the leases' climate impact, but the subsequent passage of the Inflation Reduction Act reinstated it.[95] During this final sale, which was held in March 2023, ExxonMobil again bid on nearly seventy leases, which analysts again said were likely intended for CO_2 storage.[96] Beyond their purchase of potential CCS acreage, ExxonMobil executives have also touted "carbon management" as a major emerging business. During a presentation in April 2022, the company projected that there will be a $4 trillion market for CCS by 2050.[97]

In December 2022, Cox Operating, Crescent Midstream, and Repsol announced their intentions to build Project Lochridge, a Gulf Coast CO_2 storage hub off the coast of Louisiana. The project, which received USD8.4 million in funds from the US Department of Energy (DOE), would repurpose some of the 600 depleted wells[98] that Cox owns in the Gulf of Mexico and convert them into CO_2 storage wells.[99] Crescent Midstream has already completed the front-end engineering and design for a 110-mile CO_2 pipeline between Geismar and Grand Isle, Louisiana, using the company's existing rights of way, or areas where they have permission to pass over property.[100]

In September 2023, the state governments of Texas and Louisiana awarded licenses for two new CCS projects in their respective state waters. In Texas, Repsol is leading a project with partners Carbonevert, POSCO, and Mitsui, which plans to store more than 20 million tonnes of CO_2 in 140,000 acres offshore of Corpus Christi.[101] In Louisiana, Carbonvert and Castex Energy plan to develop a 24,000-acre project off the coast of Cameron Parish. They plan to begin injecting CO_2 in 2027.[102] The developers of both projects say they plan to source the carbon from industrial emitters near each site.[103]

State governments are also leading the charge to bury CO_2 emissions under the Gulf's floor. A group of governors and state legislatures that make up the Southern States Energy Board, supported by DOE funding, is leading an effort to explore offshore CO_2 storage in the Gulf of Mexico.[104] The offshore initiative is part of the Southeast Regional Carbon Sequestration Partnership (SECARB),[105] which has been in place since 2003. A five-year offshore-focused project, SECARB Offshore, which started in 2018,[106] is a partnership between industry, government, and academic institutions to assess the potential for implementation of offshore CO_2 injection in the Gulf, either for geologic storage or for EOR.[107] With little public fanfare or oversight, SECARB has been injecting CO_2 into coal seams onshore and examining opportunities for CO_2 injection offshore.[108] A related project called the Gulf of Mexico Partnership for Offshore Carbon Storage (GoMCarb) primarily aims to "assess whether [subsurface geologic storage reservoirs] are candidates for enhanced oil recovery (EOR)."[109] GoMCarb cites the potential for EOR to offset the cost of CO_2 injection projects,[110] but is silent regarding the emissions impacts of using captured CO_2 to extract more fossil fuels.

The US federal government is also actively promoting offshore CO_2 storage. The Biden administration's Ocean Climate Action Plan includes "[d]evelop[ing] a marine geologic sequestration program for the U.S. Outer Continental Shelf" as one of its actions.[111] This plan follows the bipartisan Infrastructure Investment and Jobs Act (IIJA), signed into law in 2021, which authorized the use of the Outer Continental Shelf (OCS) for CO_2 storage. A provision in the IIJA amended the Outer Continental Shelf Lands Act to allow for "the injection of a carbon dioxide stream into sub-seabed geologic formations for the purpose of long-term carbon sequestration," and mandated the US Department of Interior (DOI) to establish regulations pertaining to such offshore sequestration within one year.[112] The Bureau of Ocean Energy Management (BOEM) and the Bureau of Safety and Environmental Enforcement (BSEE), both within the DOI, missed the one year deadline, and as of September 2023, the agencies were still developing these regulations.[113] (See further discussion of the US regulatory regime for CCS and environmental protections in Part III.)

While CO_2 storage is now authorized throughout the entire US OCS (pending federal regulations), it is clear that the Gulf of Mexico is the main target of both industrial and governmental interest. **Like the North Sea in Europe, the Gulf of Mexico has long been an epicenter of fossil fuel production in the US, as the source of 15 percent of the nation's oil output and 5 percent of its dry natural gas.[114] Government agencies are now increasingly exploring the Gulf's potential as a disposal site for industry's CO_2 emissions.** BOEM in particular has studied the Gulf's offshore sequestration potential. Their assessment identified "numerous potential depleted reservoirs for geologic storage of CO_2" and the agency claims the geology of the Gulf is "conducive to safely and permanently store large amounts of CO_2 in subsurface reservoirs."[115] This determination stands in stark contrast to the limitations and uncertainties identified in the Bureau's *Best Management Practices* report, discussed below.

Part II

From Source to Sea:

Risks and Impacts
Across the CCS Life Cycle

© BSEE

Many CCS proponents portray offshore carbon storage as benign and distant from communities, but these assessments ignore both the inherent risks of CO_2 injection and the broader footprint of carbon capture and transportation. First, offshore carbon storage cannot be considered in isolation from the polluting facilities from which CO_2 is sourced. **While carbon capture equipment may reduce the CO_2 emitted from a facility, it perpetuates, and can even increase, the release of other air pollutants that harm public health and the environment, undermining human rights.** Moving CO_2 from these facilities to offshore storage sites would also require land-based transportation networks that could traverse population centers. The buildout of such infrastructure and the threat of pipeline leaks and ruptures puts communities in jeopardy.

The risks of offshore CO_2 injection must be considered in the context of the myriad pressures facing global oceans and seas, including those from increasing temperatures, acidification, nitrogen and other chemical pollution, and the proliferation of microplastics.[116] Oceans are a key part of the climate system and are currently warming at unprecedented rates as they soak up much of the heat resulting from mounting greenhouse gas emissions.[117] Beyond the warming effect of those emissions, the accumulation of CO_2 in the oceans is making seawater more acidic, with devastating consequences for coral reefs and other marine life.[118]

Despite these growing stressors on oceans, offshore CCS proponents now hope to turn the world's seas into disposal sites for their fossil fuel waste streams, threatening to compound existing problems. At least one offshore CCS project, the Ghasha concession fields project in the United Arab Emirates, which will accompany a new gas development, has been proposed within the Marawah Marine Biosphere Reserve, known for its population of endangered dugongs.[119]

The CCS process itself presents hazards to the climate and environment. Whether onshore or offshore, injecting CO_2 under the Earth's surface has the potential to contaminate groundwater, cause earthquakes, and displace deposits of toxic brine.[120] Brines can be detrimental to surrounding sea life because they can have salt concentrations far in excess of seawater and can contain contaminants such as heavy metals.[121] Preventing or mitigating hazards associated with CCS is even more technically challenging and expensive at great depths under the sea, where the dynamics of CO_2 may be harder to ascertain than on land and the resulting problems harder to resolve.[122]

The risks of offshore CO_2 injection **must** be considered in the context of the *myriad pressures* facing global oceans and seas, including those from increasing temperatures, acidification, nitrogen and other chemical pollution, and the proliferation of microplastics.

This section discusses the risks of leaks from pipelines or storage sites, the consequences of pressure management failures at injection sites, and the heightened challenge of managing accidents in deepwater marine environments. These potential risks to offshore operations are magnified by accelerating climate impacts, such as hurricanes and warming waters, the intensity and frequency of which are driven by the very industries seeking to entrench their operations with CCS. Regulatory and knowledge gaps, and weak enforcement capacity, only heighten worries around safety and environmental impact.


© whitcomberd - stock.adobe.com

Hidden Hazards at Every Stage

It isn't only the offshore storage of CO_2 that presents possible hazards. Each stage of the CCS process — capture, transport, injection, and storage — has the potential to harm communities and the environment, jeopardizing the right to a clean, healthy, and sustainable environment and other human rights.

Capture

Carbon capture's first impacts occur at the capture phase where, by design, it supports the continued operation of polluting facilities such as power stations and petrochemical plants. **The addition of capture equipment creates its own emissions through the consumption of energy and the use of chemicals, while potentially extending the lifespan of the facilities to which it is attached.**

While properly functioning carbon capture equipment can in theory reduce CO_2 emissions from a facility, experience has shown that it consistently fails to do so at the rates promised by proponents.[123] Moreover, carbon capture does not address upstream emissions from the production or processing of the fuel on which it runs, or the downstream emissions from the material produced by a facility, nor does it reduce the facility's release of various other air pollutants beyond CO_2.[124] In fact, **research indicates the operation of carbon capture equipment could increase emissions of harmful fine particulate matter (PM2.5) and nitrogen oxide, and significantly increase toxic ammonia emissions.**[125] Perpetuating this pollution is particularly harmful to communities neighboring the facilities, which are often marginalized populations facing clustered sources of pollution that generate significant cumulative impacts on health, the environment, and human rights, including the right to a clean, healthy, and sustainable environment.[126]

The threat of CCS exacerbating air pollution is especially acute in the US Gulf Coast region, where communities have long been subject to environmental racism and heightened toxic burdens.[127] **Major deployment of CCS onshore and offshore, as has been proposed in the region, would introduce new risks while threatening to lock in health-harming infrastructure in what is infamously known as "Cancer Alley" — an 85-mile stretch of fossil fuel and petrochemical facilities along the Mississippi River in Louisiana.**

Transport

When moving CO_2 from an emitting source to an injection site, whether onshore or offshore, it will most often be compressed to a liquid or supercritical state so that it is dense enough to transport through a pipeline or be contained in another vessel.[128] Pipelines must be built to specific standards to accommodate the high pressures needed to contain CO_2 as a highly condensed and hazardous substance for transport.[129] Carriers meant to ship large quantities of CO_2 also need to be specially designed, using specific materials capable of handling the low temperatures necessary for keeping CO_2 in a supercritical state.[130]

Existing oil and gas pipelines, designed to withstand much less pressure, cannot readily be repurposed for moving large amounts of CO_2,[131] and a large vessel capable of storing CO_2 does not yet exist, much less a fleet of them.[132] Both of these transport methods also pose significant hazards to communities, the climate, and the marine environment, as discussed below.

Pipelines

Most proposed offshore CCS projects plan to capture emissions at an onshore facility and then transport them by pipeline to an offshore storage site. The buildout and operation of these transport networks threaten the communities through which they will run, putting people in danger from potential CO_2 leaks or ruptures. Unlike gas or oil pipelines, the risk from a CO_2 pipeline rupture is not combustion, but asphyxiation. **CO_2 is heavily pressurized and denser than air, so if a pipeline bursts, large volumes can be released extremely quickly and stay close to the ground, threatening people in a wide radius from the release.**[133] The grave risk of such an event was laid bare in 2020, when a pipeline rupture in Satartia, Mississippi, hospitalized dozens of residents.[134]

The aftermath of a CO_2 pipeline rupture in Satartia, Mississippi, in 2020.

There are few other documented experiences with CO_2 pipeline ruptures to date worldwide, but that is likely due to the very small number of active CO_2 pipelines in existence. The US, for example, has the largest pipeline network in the world and only has about 8,000 kilometers (km) (about 5,000 miles) of active CO_2 pipelines, compared with 425,605 km (about 265,000 miles) of oil and gas pipelines.[135] Although experience operating CO_2 pipelines is limited, extensive experience with oil and gas pipelines makes one thing clear: Pipelines leak. One 2019 data analysis by FracTracker found that over an eight-year period in the US, there were more than 2,000 recorded incidents with gas pipelines alone. These incidents resulted in more than 100 deaths and nearly 600 injuries.[136]

Unlike gas or oil pipelines, the **risk** from a CO_2 pipeline rupture is not *combustion,* but *asphyxiation.*

While CO_2 pipeline ruptures in populous areas are not yet common, other incidents involving CO_2 releases demonstrate the potential dangers to communities. Fire suppression systems that use CO_2 have been a known hazard in some industries for decades. Malfunctions from these systems can cause a sudden release of the gas similar to what could happen during a pipeline rupture. A study from the US Environmental Protection Agency (EPA) found that CO_2 releases from fire extinguishing systems killed at least seventy-two people and injured 145 between 1975 and 2000.[137]

The buildout of CO_2 pipelines in the undersea environment is also a concern. Such a buildout would face several obstacles, including the challenges presented by seawater infiltrating pipelines during their construction offshore.[138] The risk of pipeline leaks is heightened by operating offshore, as documented in an analysis of oil and gas pipeline leaks in Louisiana and Texas. Coastal Texas, for example, has a pipeline leakage rate sixteen times higher than the national average, while coastal Louisiana's per-mile leakage rate is nearly six times the national rate.[139] As Scott Eustis, author of the analysis and community science director for the organization Healthy Gulf, succinctly states: "Steel and saltwater don't mix."[140]

Plans to pool CO_2 from multiple sources in offshore hubs also present risks to pipelines. As noted in a 2018 report from the US BOEM, *Best Management Practices for Offshore Transportation and Sub-Seabed Geologic Storage of Carbon Dioxide,* **the presence of water, contaminants, or impurities such as hydrogen sulfide in the CO_2 stream increases the risks of pipe corrosion.**[141] In contrast to most CO_2 transported in the US to date, which has come from relatively pure underground CO_2 reservoirs, "CO_2 that will be stored in the [US OCS] will be captured from industrial sources and may contain impurities."[142]

The safe operation of CO_2 pipelines offshore faces regulatory and knowledge gaps. In the US, BOEM cites "gaps in regulations related to the corrosive and potentially harmful characteristics of wet or impure streams of CO_2."[143] Even with the established risk of pipe corrosion, "[t]here is a large knowledge gap in emergency planning and response to a CO_2 pipeline leak in the offshore [setting]."[144]

Furthermore, evidence indicating insufficient oversight of the existing offshore oil and gas pipeline system does not bode well for oversight of new offshore CO_2 pipelines. According to a 2021 Government Accountability Office report, the BSEE "does not have a robust oversight process for ensuring the integrity of approximately 8,600 miles of active offshore oil and gas pipelines located on the seafloor of the Gulf of Mexico."[145]

Although experience operating CO_2 pipelines is limited, extensive experience with oil and gas pipelines makes one thing clear: **Pipelines leak.**

This problem is not unique to the US; similar concerns exist regarding oversight and monitoring of pipeline integrity in other jurisdictions. In Europe, for example, scientists discovered leaks from abandoned oil and gas infrastructure in the North Sea, another heavily drilled ocean region.[146] The study's authors concluded that based on the number of leaking wells they found, the British sector of the North Sea alone has the potential to release 900 to 3,700 tonnes of methane every year.[147]

Ships

Some offshore CO_2 storage projects intend to use ships rather than pipelines to transport CO_2 to injection sites.[148] However, shipping CO_2 poses a host of concerns for the climate, crews, and costs.

First and foremost, shipping CO_2 increases emissions in one of the most difficult-to-decarbonize transport sectors.[149] Generating fossil fuel emissions to transport fossil fuel emissions is counterproductive at best. Refrigerating the CO_2 cargo — which must be kept under high pressure and low temperature to be transported in liquid form — and powering the ship requires burning more fossil fuels. Research by oil and gas industry analyst Rystad, considering potential CO_2 shipping routes, found that some vessels traveling long distances could produce emissions equivalent to as much as 5 percent of the CO_2 being transported.[150] As the IPCC has noted, "marine transport induces more associated CO_2 transport emissions than pipelines due to additional energy use for liquefaction and fuel use in ships."[151] In addition to emissions from energy consumption, routine operational processes, such as boil-off and purging (required before loading new CO_2 cargo), release emissions as well.[152]

Second, the potential for the release of CO_2 due to tank ruptures presents unprecedented safety concerns. It is impossible to estimate the risk of such releases, as there is little experience with commercial CO_2 shipping beyond small-scale vessels for food or other industries.[153] It is clear, however, that such releases would present an immediate risk to those on board the vessel, as well as potentially stop the ship's engines as the CO_2 displaces air.[154]

In addition to the direct threat to people in the vicinity of the release, the CO_2 would affect the marine environment as well. As the IPCC notes, "[i]ts interactions with the sea would be complex: hydrates and ice might form, and temperature differences would induce strong currents. Some of the gas would dissolve in the sea, but some would be released to the atmosphere."[155]

Finally, transporting CO_2 via ship is on the whole more expensive than via pipeline, raising additional financial hurdles in project operation. Though both shipping and pipelines increase in cost as distance increases, shipping CO_2 is considerably more expensive for distances up to 800 km.[156] By comparison, the Northern Lights project plans to store CO_2 100 km offshore.[157] Shipping CO_2 is not only more expensive than piping CO_2, but also more costly than shipping other liquefied gases. Compared to shipping liquefied petroleum gases, shipping CO_2 may cost 30 to 50 percent more on a similarly sized and designed ship.[158]

Injection

The injection of high-pressure CO_2 under the seabed is a complicated process that creates significant risks and uncertainties beyond just leakage. The aquifers into which CO_2 could be injected are not simply empty pockets underground, but porous rock formations that can be filled with brine, water, sand, or other materials.[159] CCS operators propose injecting CO_2 into the "pore space" that these other substances occupy.[160] Injecting the CO_2 into this space displaces whatever was there before, elevating the pressure underground and often pressurizing areas well beyond the boundaries of the injection site. Too much pressure can cause the caprock, the impervious rock layer that seals the brine and CO_2 underground, to crack, causing a leak.[161] Operators must also limit pressure build up in order to avoid triggering earthquakes, a known risk with any subsurface injection.[162]

In several early flagship CCS projects, operators struggled to predict how pressures would build up under the subsurface and to adequately manage it.[163] For Equinor's Snøhvit offshore CCS project in Norway, engineers predicted that the formation used for CO_2 injection was capable of storing eighteen years' worth of captured CO_2 at the planned injection volumes.[164] Less than two years into operation, pressures began to rise beyond the predicted levels. Unable to continue injection as planned, the project's operators were forced to plug and abandon the original well and develop a new injection site.[165]

Uncontrolled underground pressure has presented similar risks at onshore CCS sites, such as the In Salah project in Algeria. There, following several years of CO_2 injection, pressures mounted so high that they fractured the caprock and caused the ground to swell at the surface, forcing the operators to suspend the project.[166]

Though largely untested on the ground, one theoretical way researchers propose managing pressure changes is by extracting brine and other fluids from the aquifer to make room for the injected CO_2.[167] Thus far, this remains largely in the experimental phase, with most studies relying on computer modeling. There is only one large commercial project and a handful of physical test sites in the world that actively remove fluids to manage pressure in permanent carbon storage wells.[168]

The one commercial project, the Gorgon Project on Barrow Island in Australia, does not inspire confidence that this method can be easily deployed.

Brine waste from petroleum production.

Gorgon's operator, Chevron, has fallen far short of its targeted CO_2 injection volumes every year since it began injecting CO_2 in 2019, due to problems with its pressure management system.[169] Chevron designed the system to pull water out of an underground layer of sandstone and then reinject that water into a separate formation closer to the surface.[170] But when the project operators turned the pressure management system on, the pipes clogged with sand.[171] The pressure building underground caused the government of Western Australia to restrict the amount of CO_2 that Gorgon could inject underground and to order the company to install additional seismic monitoring equipment in order to detect earthquakes.[172] Though the CCS facility was a major part of the Australian government's approval for the new Gorgon gas project, Chevron has only captured about one-third of what they originally promised.[173]

Even if brine extraction does work to relieve pressure at a given project, it still presents risks. **Brine can leak from pipelines[174] and needs to be properly managed and disposed of to avoid contaminating the environment.** As acknowledged in an EU-funded report involving Statoil (now Equinor), the high salinity of brine can be toxic to benthic (deep sea) organisms like coral and sea anemones.[175] According to the report, if brine is "allowed to percolate to the surface of the seabed, such brines could cause a ten-fold increase in local salinity in surface sediments and seabed depressions, thus representing a potentially severe source of osmotic shock to benthic organisms."[176]

Storage

While proposed projects are premised on the idea that large amounts of carbon can be injected under the seabed, new studies demonstrate the risks of assuming that the ocean has a vast storage capacity. Researchers warn that the dynamics within each individual geologic formation are unpredictable, and that macro estimates of geologic storage capacity are likely flawed. Such research suggests that many regional inventories of CO_2 storage capacity may overestimate the amount of carbon that can be safely injected into a given formation.[177] The bottom line is that building out industrial-scale CCS may not be as feasible as current regional inventories suggest and pressure management techniques may not function as planned.[178]

> Building out industrial-scale CCS *may not be as feasible* as current regional inventories suggest and pressure management techniques *may not function as planned.*

One study, based on samples from the Danish North Sea, found that legacy deposits of oil in offshore wells can react with injected CO_2 to form bitumen, a viscous hydrocarbon substance, creating blockages and reducing the ability to inject more CO_2.[179] The study could have major implications for the host of projects that plan to inject CO_2 into depleted oil and gas fields, including Denmark's planned flagship CCS project, Project Greensand, which is currently in the pilot phase in the North Sea.[180]

In addition to the risk of leaks during transport, either by pipeline or by ship, leaks may also happen at CO_2 storage sites, potentially returning substantial amounts of CO_2 to the atmosphere or releasing it into the ocean. According to one estimate, **if CCS is widely deployed onshore and offshore, even a 0.1 percent leakage rate could cause up to 25 gigatonnes of additional CO_2 emissions in the 21st century, posing a major risk to the climate.**[181]

BOEM's 2018 *Best Management Practices* report repeatedly acknowledged the risks of leakage, not only from transport but from storage as well. "CO_2 leakage from a storage reservoir via an injection well or a previously existing [plugged and abandoned] well could pose risks to (1) other sub-seabed resources, (2) the ocean water column, (3) environmental resources in the water column and on the seafloor, or (4) platform workers, and result in emissions to the atmosphere," the report warned.[182] The BOEM report continued, stating that as on land, **"abandoned wellbores will also pose the greatest risk to CO_2 containment failure in offshore settings."**[183] If not properly plugged or abandoned, these wells can serve as leakage pathways.[184]

Despite the fact that legacy oil and gas wells pose the single greatest risk of CO_2 leakage at offshore storage sites, the areas being heavily targeted for offshore CCS development are precisely those zones where old wells abound: sites of long-standing oil and gas drilling. In the Gulf of Mexico, for example, intensive offshore oil and gas drilling, dating back decades, has left the seabed pockmarked with thousands of abandoned wells.[185] They are typically not inspected, and BOEM acknowledges that it does not know the number or extent of wells leaking in the Gulf.[186] A 2020 study also concluded that thousands of tonnes of methane are leaking from old bore holes in the North Sea each year.[187] Interaction with these wells poses a significant risk of containment failure. There is little reason to believe that injecting CO_2 into areas where countless existing leaks from oil and gas wells go undetected or unreported would guarantee "permanent" storage.

In the event that an offshore CO_2 leak does occur, emerging evidence suggests that it may adversely impact ocean chemistry and threaten the surrounding environment, with consequences for marine life and human health. One study that simulated CO_2 leaks in the Norwegian continental shelf found that dissolved CO_2 causes seawater to become more acidic, which could damage marine ecosystems in the vicinity of the leak.[188] For example, high CO_2 levels may alter the body fluid chemistry of fish and disturb their ability to breathe.[189] More acidic seawater is especially harmful for calcareous (shell-forming) organisms such as corals, shellfish, and specific groups of phytoplankton.[190] Generally, CO_2 leaking from sub-seabed reservoirs risks harming benthic creatures and their habitats.[191] As continued CO_2 emissions drive increasing CO_2 concentrations in the oceans, such local acidification would only compound the global burden of ocean acidification, which already threatens marine life.

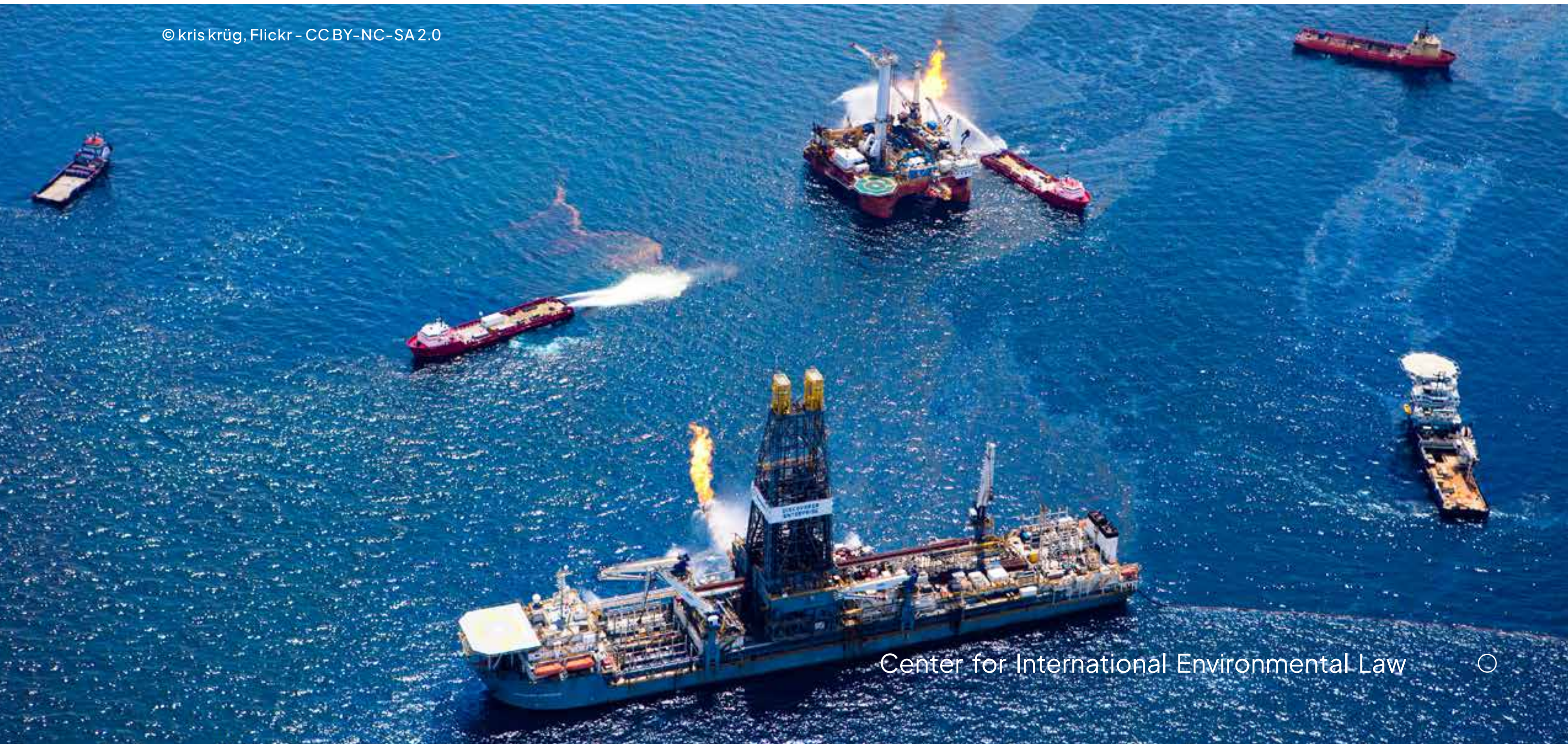
There is little reason to believe that injecting CO_2 into areas where **countless existing leaks from oil and gas wells** go *undetected* or *unreported* would guarantee "permanent" storage.

Adverse impacts could extend beyond the ocean depths. As a risk assessment of subsea CO_2 sequestration adopted in 2006 under the London Convention and London Protocol warned: "At the extreme, a substantial and rapid gas release at the seafloor could cause damage to the marine environment, interference with other legitimate uses of the sea, including fishing and maritime transport, with the potential for associated risks to human health."[191]

Additionally, substantial unintended CO_2 leakage could pose a hazard to offshore platform workers. As the IPCC states: "For those sites where separate-phase CO_2 reaches the ocean surface, hazards to offshore platform workers may be of concern for very large and sudden release rates.[193]

Studies meant to assuage the concern of leakage from undersea storage sites are limited and largely unconvincing. An example from BOEM's *Best Management Practices* report illustrates this well. In considering the risks posed by leakage, the report relies primarily on a small study that examined 4 tonnes of CO_2 injected into the seafloor. It quotes the study, saying "[e]nvironmental impacts from small-scale leakage will be minimal and not ecologically significant, although in the unlikely event of larger leaks, impact could be locally more significant."[194] However, the report acknowledges that "[i]t will be difficult to scale up results [from this study] in a realistic way."[195]

Overall, the risks from underwater CO_2 leakage are significant and cannot be ignored. Leakage from storage sites is a clear possibility, and oil and gas wells increase the risks for such leaks. If leaks happen, they could adversely affect ocean chemistry and the marine environment, and if the leakage is large and sudden, it could potentially reach the surface, posing a hazard to ocean platform workers or ship crews.



Blowouts and Potential Sub-Seabed Disasters

The aforementioned risks can be difficult to manage for any project that transports or injects CO_2 underground, but the marine environment presents additional challenges. Existing industrial activity offshore — like offshore oil and gas operations — already demonstrates this. **Offshore operations are significantly more expensive than the onshore equivalents and more difficult to monitor.** Both the operators and government inspectors must rely on expensive modes of transportation — boats or helicopters — to reach offshore installations.[196] Leaks and infrastructure problems on the water are often not as readily apparent as those onshore, and weather and water conditions can prevent timely repairs or emergency response.[197]

In the event of a storage well failure or other extreme release of CO_2 offshore, the problem may be very difficult, if not impossible, to correct. While BOEM's *Best Management Practices* report suggests that existing industry practices and regulations for dealing with offshore oil and gas well accidents or "blowouts" should apply to offshore CO_2 injection, the report cautions that "there are additional concerns with wells exposed to supercritical CO_2," noting "CO_2 might cause wells to fail" due to its incompatibility with certain commonly used materials.[198]


© GetArchive

If there is a leaking CO_2 well or a blowout, the mitigation measures used for oil and gas well accidents, like a physical barrier, won't work to contain CO_2. The only option may be to stop injection altogether.[199] As the BOEM report clearly states: **"It will be too late for effective mitigation if problems are not identifi[ed] until after emplacement of the CO_2. Significant uncertainties about the long-term performance of a CO_2 storage site should be resolved prior to injection of large volumes of CO_2; if uncertainties cannot be resolved, injection should be stopped."**[200] And, if injection is halted, the CO_2 that would have been captured to supply the injection site will end up simply vented into the atmosphere, assuming the underlying emitting activity is not also paused. This would undermine any climate rationale for operating a carbon capture system in the first place.

CCS as Cover for Fossil Fuel Expansion

While offshore CCS creates many tangible and immediate dangers, a buildout of multiple CCS projects presents a fundamental risk to the world's efforts to phase out fossil fuels. Aside from locking in existing polluting facilities with carbon capture equipment, some proposed offshore CCS projects are being used to justify building new fossil hydrogen production facilities, fossil gas power plants, and even new offshore oil and gas developments.[201]

> Some proposed offshore CCS projects are being used to **justify** building **new** *fossil hydrogen* production facilities, *fossil gas* power plants, and even new *offshore oil and gas* developments.

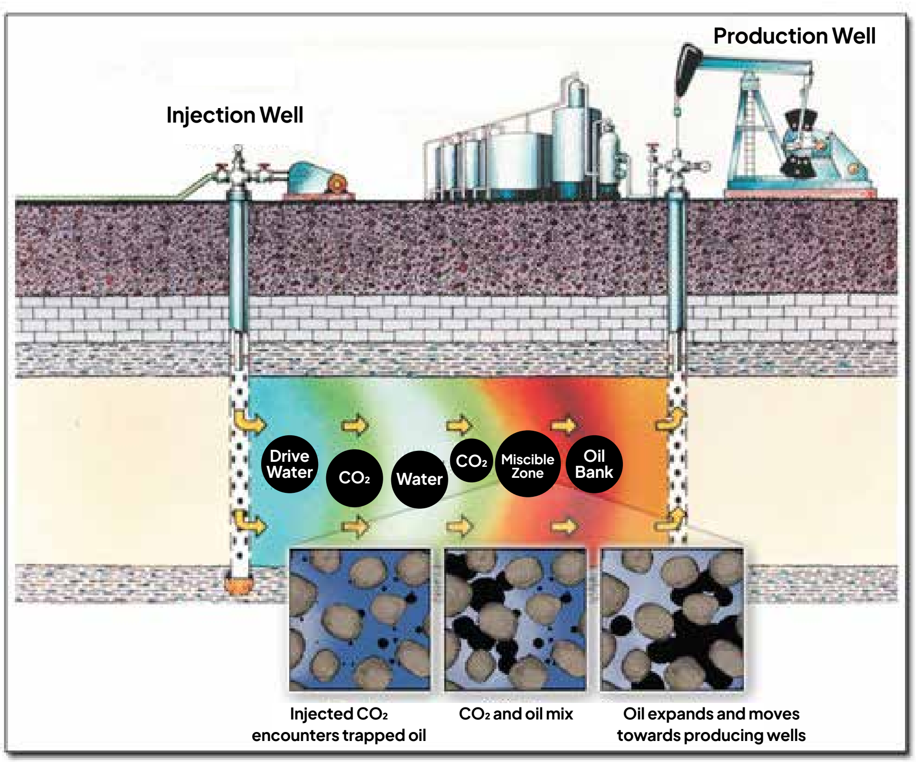
In many of these cases, the CCS components of the fossil fuel project have been used to capture government subsidies, or feature prominently in the operating companies' own net-zero goals. For example, the Australian government granted AUD40 million

(USD26.7 million) to the Burrup CCS hub on the premise that it would reduce emissions, despite the fact that the hub would service the development of new gas fields.[202] Similarly, the Malaysian State oil and gas company PETRONAS lists the development of the Kasawari gas field and an accompanying CCS project as part of its plans to reach net zero by 2050. In its PETRONAS Pathway 2050 net-zero emissions plan, the company quotes an executive claiming that the gas project is "a demonstration of PETRONAS' commitment to sustainability."[203]

These two projects, as well as Santos's Bayu-Undan CCS project in Australia and Timor-Leste, are all planned alongside new gas projects in fields with high concentrations of CO_2.[204] Aside from the obvious climate concerns created by expanding gas production and producing CO_2-intensive gas, high CO_2 concentrations also pose a host of technical concerns for developers, like a higher risk of corrosion in pipelines and other equipment.[205] Complicating these projects even further is the fact that CO_2 cannot be present in large quantities in natural gas (methane) if producers are going to create liquefied natural gas (LNG) for transport.[206] This makes removing the CO_2 from this gas a technical necessity for these projects rather than a sustainability feature, as proponents claim. Even if the CCS were to operate perfectly, experts agree that these projects will still have relatively high emissions intensities.[207] For example, the Barossa gas project, for which the Bayu-Undan CCS project is being built, would still likely be far more carbon intensive than the average Australian LNG project, according to an IEEFA report released last year.[208]

Beyond traditional fossil fuel development, **there is also a risk that the carbon captured from CCS will eventually facilitate further hydrocarbon extraction via EOR or enhanced gas recovery (EGR).**[209] With this technique, oil and gas producers are able to increase production from depleted wells by injecting high-pressure CO_2 into the well, which forces more oil or gas up to the surface. EOR has been

The Enhanced Oil Recovery Process Using CO_2



Source: Provided by the Office of Fossil Energy and Carbon Management.

applied onshore for decades and constitutes the only significant commercial market for captured CO_2 today. To date, the vast majority of CO_2 captured from polluting sources is used for EOR (about 73 percent of current capacity, and between 80 to 90 percent of historic carbon captured)[210] because oil and gas companies will pay for CO_2 to extract more out of their wells. In fact, the fossil fuel industry's push to expand CCS is driven in no small part by its need for cheap sources of CO_2 to squeeze more profit from existing oil and gas fields.[211]

At present, offshore EOR is much more limited than onshore EOR, with only a few projects implemented to date, including some small pilots and one larger project at a gas field off the coast of Brazil.[212] Critically, the one large offshore EOR project does not use CO_2 captured from energy production or other industrial processes. Rather, the Lula field offshore EOR project in Brazil's Santos Basin, operated by Petrobras since 2011, sources CO_2 from the Basin's subsea gas reservoir. The CO_2 is separated from the hydrocarbon gas and reinjected back into the reservoir to stimulate more gas extraction.[213]

While offshore EOR/EGR does not yet exist beyond these limited projects, oil and gas companies and governments may turn to it in the near future as an approach to extend the production of offshore reserves. Some government agencies have already studied the potential for offshore EOR using captured CO_2, noting that it would enable continued offshore production. In a 2016 strategy document, the UK's Oil and Gas Authority (now renamed the North Sea Transition Authority) indicated that offshore EOR could increase recoverable hydrocarbons from the UK continental shelf and extend the life of producing fields by up to ten years, but cautioned that this approach is economically challenging since it is capital-intensive and has high operating costs.[214] The US DOE has also assessed offshore EOR potential with great interest.[215] A 2019 report submitted to DOE states: "By adapting the current offshore infrastructure and strategically developing CO_2 transportation modems, the Gulf of Mexico can continue producing large amounts of oil and gas. There is potential to access an estimated 1.89 billion barrels of remaining oil while simultaneously storing CO_2."[216]

EOR is fundamentally at odds with needed climate action. Expanding production of fossil fuels, onshore and offshore, is indefensible in the face of the climate emergency — let alone as a component of a practice purporting to reduce greenhouse gas emissions. Using captured CO_2 waste from the burning of fossil fuels to pump more oil and gas out of the ground so that they too can be burned will only serve to perpetuate fossil fueled-warming. EOR further props up the fossil fuel industry at a time when fossil fuels must be rapidly phased out to confront the dangerous and deadly climate crisis.[217]

Part III

Preventing Harm from Offshore CCS:
The Legal and Policy Landscape

Proponents are racing ahead with a slate of planned offshore CCS projects, but financial hurdles and legal requirements may yet put the brakes on the buildout. Offshore CCS projects, particularly at the scale being proposed in various sites around the world, are easily multibillion-dollar undertakings. For now, burying CO_2 underground — whether onshore or off — is quite literally a sunk cost. Without a market for storing CO_2 or a meaningful penalty for failing to do so, CCS is just an expense,[218] and the big polluters promoting it are counting on the public to foot the bill. But subsidizing CCS turns the polluter pays principle on its head. CCS also diverts resources away from proven climate solutions that have the capacity to reduce emissions far more effectively and quickly, at far lower cost and much less risk to communities and the environment.

Subsidizing CCS turns the polluter pays principle **on its head.**

The proposed development of offshore CO_2 storage sites is not only financially flawed; it may also be legally impermissible, given the range of potential harms and uncertainties detailed in the preceding section. Wherever they may be located, offshore CCS projects implicate domestic and international laws that regulate activities affecting the oceans, coastlines, ecosystems, and atmosphere. While not all jurisdictions have regulations expressly addressing offshore CO_2 injection, existing laws concerning marine pollution and biodiversity protection, environmental impact assessment and mitigation, hazardous transport, and industrial activities may constrain the deployment of CCS in the ocean. As understandings of the risks and hazards of offshore CO_2 injection develop, regulatory regimes will need to evolve to ensure maximum protection against adverse impacts to people and the environment.

Steep Subsidies for Subsea CO_2 Injection

The high cost of offshore CCS is reason enough to rule out its use. **Together with the substantial risks the technology poses and the drag it places on efforts to phase out fossil fuels, the case for using public funds to subsidize subsea CO_2 injection becomes indefensible.**

CCS is inherently expensive. According to the IPCC, it is among the highest-cost measures with the lowest potential to reduce emissions from the energy and industry sectors this decade — the critical period for preventing global warming above 1.5°C and the truly catastrophic impacts that would ensue.[219] The costs to deploy CCS are only heightened offshore. Just as offshore oil and gas drilling comes with a higher price tag compared to onshore, offshore CO_2 transport and storage is exceedingly costly given the challenges of constructing and operating infrastructure in the ocean environment.[220] Building new, specially designed offshore pipelines and ships to transport the CO_2, upgrading offshore platforms or other equipment, and instituting effective pressure management and monitoring, for example, require significant and ongoing expense.[221]

Cost overruns have led CCS projects to fail, offshore and on.[222] Past experience in Norway demonstrates the serious cost concerns with offshore CCS projects. In 2006, Equinor announced plans with Shell to develop a CO_2-EOR project off the coast of Norway. The project, which would have been the world's first offshore CO_2-EOR project, proposed capturing CO_2 from a gas-fired power plant and transporting it for injection offshore in the Draugen and Heidrun oil fields. As Equinor noted in a press release, the project would require "substantial" government funding.[223] The proposal ultimately fell through, as it was determined to be uneconomical due to high costs associated with drilling additional wells, modifying existing wells and infrastructure, installing new platform equipment, and building a new pipeline to transport the CO_2 offshore.[224]

Mongstad, another proposed offshore CCS project in Norway (announced in 2007), was also scrapped over cost concerns. This project, which the Norwegian Prime Minister had compared to the US moon landing, would have involved capturing carbon at an onshore gas plant and refinery, along with offshore injection and storage of the captured CO_2 under the Norwegian North Sea.[225] From its outset, Mongstad faced delays, and the government's handling of the project prompted an outcry that led to calls for the energy minister's resignation.[226] The Norwegian government sank nearly USD1 billion (NOK10.5 billion) into developing the CCS project until abandoning it in 2013, citing high costs.[227]

The steep cost of offshore carbon storage has three important implications. First, it explains why so many of the projects proposed today are large "hub" or consortium projects, which pool costs as well as CO_2. Many individual industrial or power sources of CO_2 emissions would not be able to bear the full cost of offshore CO_2 injection and storage infrastructure.[228] Developing large multi-source projects may help spread out the expense, lowering costs to individual companies. But it heightens the complexities, hazards, and risks of contamination, as discussed above.

Second, high costs are driving industry demands for public subsidies. Polluters are effectively asking governments to pay them to bury some of their pollution, rather than curb their emissions in the first place and pay for the damage they have caused. Significant portions of these high costs are being borne by the public. In countries where governments are pursuing an agenda of offshore carbon storage, they are funneling public funds to the cause through tax credits, loan guarantees, and other forms of financing.[229]

Like onshore CCS, emerging plans for offshore CO_2 storage are heavily dependent on these government subsidies[230] and, when projects run over budget or underperform (as CCS projects have a long history of doing),[231] the public is likely to end up bearing those costs. **Not only does CCS itself stymie the energy transition by prolonging the operation of polluting facilities, but plowing public subsidies into offshore CCS also diverts scarce funds from proven, available, and needed climate measures that support the transition to a fossil-free future.**

Polluters are effectively **asking governments to pay them to bury some of their pollution,** rather than curb their emissions in the first place and **pay for the damage they have caused.**

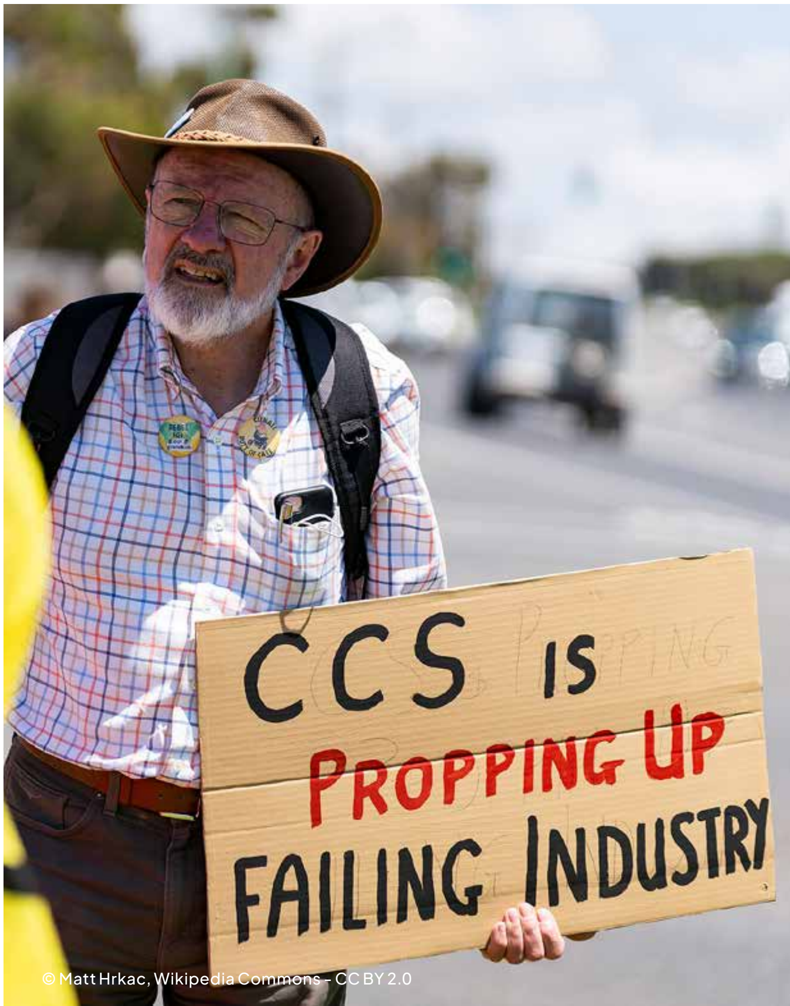
Governments around the world have so far provided or announced tens of billions of US dollars in funding for the development of sixty planned offshore storage projects.[232] The total amount of public subsidies for offshore CCS may be higher still. At least GBP21 billion of the announced subsidies identified by CIEL comes from two announcements for CCS funding in the UK.[233] The UK government has not determined how those funds will be apportioned, but did indicate that four "clusters" — the East Coast Cluster, Hynet Northwest, Acorn, and Viking — will have access to some portion of that money.[234] Each of these clusters constitutes a hub made up of multiple carbon capture projects that plan to pool their CO_2 for injection in a shared offshore storage site.[235] Norway and the Netherlands are also developing projects with multibillion-dollar government investments. In Norway, the government has agreed to fund two-thirds of the Longship project with more than USD1.5 billion.[236] The Netherlands has provided about USD2.5 billion for carbon capture to the industrial customers of the planned Porthos storage project at the Port of Rotterdam.[237] Government officials and project organizers have at various times described each of these projects as crucial for decarbonizing Europe,[238] but **even operating at the top of their projected storage capacity, estimates show that the projects could only store 56.5 million tonnes of CO_2 per year combined, less than 1 percent of Europe's emissions in 2021.**[239]

While much government financial support for offshore CCS is for project development, the 45Q tax credit in the US subsidizes CCS once a project begins operating.[240] The credit, which lasts for 12 years from the date CCS equipment is turned on, gives operators up to $85 per tonne of CO_2 sequestered underground or under the seabed and up to $60 per tonne of CO_2 used for EOR.[241] To be eligible for the credit, the CO_2 must be captured from an anthropogenic source like a power plant or an industrial facility.[242] For-profit companies can choose to receive the 45Q credit as a direct payment, rather than a tax liability offset, for the first five years of their project's operation.[243] There are not yet any operational offshore CCS projects in the US that qualify for 45Q, but at least one Gulf of Mexico CCS developer, Crescent Midstream, has referenced the tax credit as crucial for making CCS projects financially viable.[244]

As high as the costs of building these projects are, few available project budgets delve into the full operational costs of offshore CCS, including the costs of long-term monitoring and maintenance of storage sites, as well as liability for any damages caused. Because methodologies for monitoring and managing pressure under the seabed and responding to leaks are still being developed,[245] some necessary measures may not figure in project proponents' estimates. Moreover, uncertainty over who bears liability for leaks or hazards in the long-term — whether the private operators who inject the CO_2 or the public authorities in the jurisdiction where the storage site is located — makes it difficult to price the risk and require adequate financial assurances to cover maintenance, prevention, and mitigation of adverse impacts (see discussion of liability risks in "Filling Regulatory and Knowledge Gaps" below). Finally, the high costs of offshore CO_2 storage further incentivize EOR, as a way to monetize the captured CO_2. **Even with public subsidies, many projects will likely still be uneconomical.** As governments and companies seek ways to finance CCS offshore, they may look to the same source of revenue that has funded the great majority of onshore CCS: selling CO_2 for EOR.

The fossil fuel industry has a long history of turning waste streams into profit streams, and the push for CCS on- and offshore is just the latest example. **With uncapped tax credits, like 45Q in the US,[246] policymakers have handed oil and gas companies a virtual blank check, allowing them to capitalize on subsidies to convert their CO_2 pollution into a profitable commodity in the "carbon management" economy.** However, governments cannot simply greenlight projects that run afoul of environmental, health, and safety regulations; threaten transboundary harm; or put the global commons at risk. They have a duty to take measures to protect the marine environment and human life and health from the foreseeable risks of harm posed by offshore CCS, and corporations must abide by those regimes. Existing and evolving legal frameworks are a critical bulwark against the dangers of turning the ocean into a dumping ground for fossil fuel pollution.

The fossil fuel industry has a long history of turning waste streams into profit streams, and the push for CCS on- and offshore is just the latest example.



Existing Protections Against Offshore CCS Risks

Domestic Law

In most instances, **the legal frameworks most immediately implicated by proposed offshore CCS projects will be domestic environmental impact assessment (EIA) laws that bear on project permitting decisions; laws protecting plant and animal species and their habitats, including fisheries management; and broader coastal zone management laws and marine and maritime pollution laws.** Even if not CCS-specific, these laws, and the regulations implementing them, will affect whether, where, and how offshore CCS may proceed. A comprehensive overview of potentially relevant instruments is beyond the scope of this report. This section briefly outlines some such laws in the US, Australia, and Norway — three key geographies for offshore CCS projects — as an illustration of the existing domestic legal and regulatory regimes that can and should be invoked to prevent risks and adverse impacts from offshore CCS.

Many countries have overarching environmental protection laws that have been or will likely be triggered by offshore CO_2 transport, injection, and storage projects. In the US, the National Environmental Policy Act (NEPA) requires federal agencies to conduct environmental review for major federal actions, which include projects with federal funding and those subject to federal approval or regulation.[247] Such actions that significantly affect the environment necessitate environmental impact statements and a requisite public comment period.[248] The Fiscal Responsibility Act of 2023 included rollbacks of environmental review standards vital to confronting the buildout of environmentally destructive projects.[249] The provisions that accelerate the timeline and weaken the scope of NEPA review may make it harder to ensure that the risks and impacts of offshore CCS in federal waters are adequately assessed prior to project approval or that their foreseeable adverse impacts are prevented or mitigated. However, the essential requirement for the government to assess the direct, indirect, and cumulative environmental impacts of a proposed action prior to making decisions remains.

> Impact assessment and consultation requirements may prove vital to preventing the authorization of CCS projects that pose **significant risks** to *people, human rights,* and *the environment.*

Environmental review laws in other countries targeted for offshore CCS hubs impose similar impact assessment and consultation requirements, which may prove vital to preventing the authorization of CCS projects that pose significant risks to people, human rights, and the environment. Australia's Environment Protection and Biodiversity Conservation Act (EPBC) similarly requires thorough review of actions that may impact matters of national environmental significance, including activities involving the marine environment.[250] The eight matters covered under the act include Commonwealth marine areas, which would be implicated in any offshore CCS project, though other matters such as national heritage places, wetlands of international importance, or migratory species protected under international agreements, for example, could be involved as well. Norway's Planning and Building Act likewise requires EIAs for major projects,[251] and the Pollution Control Act requires EIAs prior to permitting an activity that may involve serious pollution.[252] CCS-specific regulations in Norway, discussed further below, likewise contain EIA requirements.[253] Moreover, the Supreme Court of Norway has interpreted Article 112 of the Norwegian constitution to require the government to take environmental protection measures, enabling legal challenge when such duties have been grossly neglected.[254]

As discussed above, leaks from offshore CCS projects could change the ocean's chemistry, harming sensitive marine species. Additional offshore activity, like the construction of pipelines or the expansion of shipping routes, could also harm marine fauna by creating noise pollution and other hazards.[255] **Laws protecting certain species may prohibit or constrain development of CCS projects in offshore areas with sensitive or protected populations of flora or fauna.** Many such statutes do not just prohibit hunting or capturing particular species, but also protect the habitats and ecosystems supporting protected species.

In the US, for example, the Endangered Species Act[256] and the Marine Mammal Protection Act[257] both restrict activities that harm endangered species or marine mammals, including indirectly or incidentally. The Gulf of Mexico, an area targeted for offshore CO_2 injection, is home to at least twenty endangered and protected species, including marine mammals such as the sperm whale.[258] Australia's EPBC includes "[l]isted threatened species and ecological communities" among the "matters of national environmental significance" protected by the act, and activities that may impact them require review and approval.[259] Santos, the Australian company developing the Barossa gas project and the affiliated Bayu-Undan CCS project, acknowledged the presence of eleven threatened species within the area of their proposed CO_2 pipeline.[260] In Norway, the Nature Diversity Act provides a framework for listing and protecting priority species and their habitats within Norway's territorial waters.[261] The North Sea is home to several threatened species, including the critically endangered sturgeon and several endangered sharks and seals.[262] Turning the seabed into a CO_2 storage zone may have untold impacts on these and other species.

Such protections may also be found in regulations surrounding the maintenance of fisheries, such as the Magnuson-Stevens Fishery Conservation and Management Act in the US.[263] The act requires consultation on potential adverse effects to essential fish habitats, and allows the creation of Habitat Areas of Particular Concern for the conservation and protection of fish stocks, which apply further scrutiny and restrictions on projects in their zones. In Norway, the Marine Resources Act, which applies not only in the territorial sea but also on Norway's continental shelf,[264] requires fisheries management to apply an "ecosystem approach that takes into account habitats and biodiversity."[265] **Given uncertainties about the potentially significant risks and impacts of CO_2 injection on surrounding marine life, development of offshore injection sites may run afoul of these and other required protections.**

Laws governing competing uses of the lands and waters in coastal areas are also common across jurisdictions, although they vary in the extent of national coordination and enforcement. In the US, for example, the Coastal Zone Management Act of 1972 "requires federal actions that are reasonably likely to affect any land or water use or natural resource of the coastal zone be consistent with enforceable policies of a state's federally-approved coastal management program."[266] In Norway, coastal planning and management is primarily governed by the Planning and Building Act. In Australia, there is no national coastal legislation or plan, so management of the coastal zone is largely the responsibility of the states and territories.[267]

Offshore CCS activity will also implicate general pollution prevention and control legislation applicable to the marine environment. In Norway, for example, the Pollution Control Act, which applies to activities on the continental shelf, sets forth a general duty to avoid pollution and to mitigate its effects, and establishes a permitting regime for activities that may cause pollution, subject to EIA requirements and applicable regulations.[268] In the US, the Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA), regulates marine pollution by dumping. It codifies the requirements of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter of 1972, known as the London Convention, which is discussed further below. Legislation enacted in 2021 excluded CO_2 injected for sequestration offshore from MPRSA's definition of material that may not be dumped in the oceans.[269] Consequently, CO_2 injection for sub-seabed storage would not be considered a prohibited form of dumping under MPRSA, but whether, where, and how it may be carried out may nevertheless be constrained by the act's provisions and related regulations.

The preceding laws are a limited set illustrating the legal landscape in a few key countries. Numerous other national or subnational laws, varied in breadth and scope, may directly or indirectly regulate, restrict, or otherwise apply to the development of offshore CCS projects. Because offshore CCS projects are frequently connected (financially, contractually, and physically) to sources of emissions onshore, the relevant legal frameworks will necessarily include laws addressing onshore activity, too. Ultimately, the set of domestic legal instruments relevant to offshore CCS projects will be particular to a given jurisdiction, but multiple laws will apply. **When existing laws are interpreted, as they should be, to better protect communities, the environment, and the global climate, consistent with the precautionary principle and the rights of future generations, they will operate to restrict deployment of CCS in the oceans.**

International Law

Because of the interconnected nature of the world's oceans, activities at sea always have the potential to cause cross-border harm. Whether an offshore CCS project is national or international in scope, it must comply with applicable international law and the domestic laws of the countries in whose jurisdiction it is located. While international instruments may not always be directly or readily enforceable by private actors in different jurisdictions, governments bound by them must ensure their conduct and regulations adhere to them. International requirements and protections thus provide critical benchmarks against which to assess the permissibility of proposed CCS activities and the adequacy of government safeguards.

Numerous international and regional agreements restrict the types of activities that can be conducted in and on the oceans, and the manner in which they are carried out. **From customary international law and global treaties governing the law of the sea to regional agreements on protection of the marine environment, biodiversity conservation, and maritime safety, existing international law may prohibit or constrain the transport and injection of CO_2 offshore.** This section provides a limited overview of some potentially applicable regimes.

> Under UNCLOS, coastal States have sovereign rights to explore and exploit the natural resources of the continental shelf, but must do so "pursuant to their environmental policies and in accordance with their duty to protect and preserve the marine environment."

The UN Convention on the Law of the Sea (UNCLOS) is the primary international legal framework governing the ocean, to which 169 countries are Party, with the notable exception of the US.[270] It sets forth "a legal order for the seas and oceans," defining the scope of States' jurisdiction and control over waters, and establishing permissible uses and activities in different parts of the seas and oceans, including activities on the seabed and subsoil.[271] Coastal countries generally have jurisdiction over the marine area (waters and seabed) extending 12 nautical miles from their officially recognized coastline,[272] called the "territorial sea," as well as the waters adjacent to and extending beyond that and up to 200 nautical miles from the coastline, called the "exclusive economic zone" (EEZ).[273] Jurisdiction in the EEZ includes the "continental shelf," the seabed and subsoil of the submarine areas beyond a country's territorial sea to the outer edge of the continental margin, or up to 200 nautical miles from the country's shore if the natural shelf does not extend as far.[274] Some proposed offshore CCS projects foresee injection of CO_2 into the seabed in States' territorial waters,[275] whereas others involve injection in areas within EEZs.[276] Under UNCLOS, coastal States have sovereign rights to explore and exploit the natural resources of the continental shelf,[277] but must do so "pursuant to their environmental policies and in accordance with their duty to protect and preserve the marine environment."[278]

A 2022 meeting of the International Maritime Organization.

All other areas of the oceans are considered the "high seas" and are beyond national jurisdiction, meaning no country has sovereign rights over them, but all countries have certain obligations regarding their use and impacts on them. The seabed in zones beyond national jurisdiction, referred to in UNCLOS as "the Area," is considered the common heritage of humanity.[280] UNCLOS requires measures be taken to ensure effective protection of the marine environment in the Area, including conservation of the flora and fauna and natural resources, as well as human life.[281] To date, however, there are no known proposals to inject CO_2 under the seabed in areas beyond national jurisdiction, and because no State can assert sovereignty over the Area through permanent occupation, injection of CO_2 for storage below the seabed is impermissible in international waters.[281]

While most States that are hotspots of offshore CCS development have ratified UNCLOS and are bound by its provisions, including the UK, Norway, and Australia, the US is a notable outlier. It has, however, recognized many of the convention's provisions as customary international law and aligned its policy with those concerning traditional uses of the oceans.[282] In the US, coastal states have jurisdiction over territorial waters closest to shore — those extending up to 3 nautical miles, or in the case of Florida and Texas, up to 9 nautical miles offshore — while the federal government has jurisdiction over the rest of the territorial waters and EEZ up to 200 nautical miles offshore ("US waters").[283] Individual states in the US have rights to submerged lands in their waters while the federal government has claim to lands of the Outer Continental Shelf, seaward of state waters.[284]

UNCLOS does not explicitly address CCS, but its provisions regarding marine pollution — defined in Article 1(4) as the introduction of substances or energy into the marine environment with deleterious effects including harm to marine life and human health — **may bear on whether and how offshore CCS can be carried out.** The general obligations to protect the marine environment[285] and to prevent, reduce, and control pollution,[286] including pollution from new technologies,[287] would implicate any CCS activities taking place on the ocean. States have a duty to take all measures necessary to address pollution arising from any source, and to ensure that activities under their jurisdiction or control do not cause environmental damage in their own territories or in other jurisdictions.[288] **States must avoid and minimize pollution from the use of technologies under their jurisdiction or control,[289] and ensure that measures deployed to curb pollution of the marine environment do not transfer damage or hazards from one area to another, or transform one type of pollution into another.[290]**

CCS proponents characterize CCS as a pollution control technology, aimed at reducing impacts of CO_2 emissions, including impacts on the marine environment.[291] To be consistent with UNCLOS, offshore CCS must not introduce new forms of pollution or transform CO_2 emissions into a new hazard on the seas. Leakage of CO_2 into the oceans from pipelines or storage wells could constitute a form of regulated marine pollution, as could leakage of produced waters or brine related to CCS operations. Moreover, UNCLOS requires States to conduct EIAs prior to undertaking or approving activities that pose risks of adversely affecting the marine environment, which would include the construction of CCS infrastructure and the injection and storage of CO_2.[292] Multiple regional agreements pertaining to ocean protection incorporate similar requirements, implementing aspects of UNCLOS.[293]

Evolving legal regimes for the high seas may prove relevant to CCS as they are interpreted and applied. The newest legally binding instrument under UNCLOS, the Biodiversity Beyond National Jurisdiction Agreement (BBNJ Agreement or High Seas Treaty), finalized in 2023, addresses the conservation and sustainable use of marine biological diversity in areas beyond national jurisdiction.[294] Its provisions have yet to be applied in relation to offshore CCS, and for the reasons discussed above, it is unlikely that offshore CO_2 injection would be proposed in international waters. However, CCS in territorial waters and the EEZ could have impacts beyond national jurisdiction. **If offshore CCS induces any alterations to marine chemistry or sub-surface dynamics that affect areas of the high seas, it could implicate the BBNJ Agreement.** Notably, the agreement reinforces the requirement for EIAs, mandating them for activities beyond national jurisdiction over which a State has control, as well as activities within national jurisdiction that may affect areas beyond it.[295] Moreover, the BBNJ Agreement draws on the criteria for ecologically or biologically significant marine areas (EBSAs) under the Convention on Biological Diversity to identify marine areas beyond national jurisdiction that require protection.[296]

To be consistent with UNCLOS, offshore CCS **must not** introduce new forms of pollution or transform CO_2 emissions into **a new hazard** on the seas.

Some international and regional agreements, including those regulating trade in waste, protecting maritime safety, and requiring EIAs for transboundary activities, may affect offshore CCS projects, depending on their specific parameters, locations, and countries of relevance.[297] Both the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Disposal,[298] and the "Basel Ban" amendment[299] prohibit the transfer of hazardous waste from Organisation for Economic Co-operation and Development (OECD) and European Union countries to other countries, while the Bamako Convention prohibits the import of hazardous waste into African countries.[300] CO_2 is not mentioned in either instrument, and to date, has not been taken up by the Parties, so its transport is not expressly restricted under either convention.[301]

However, because under certain conditions, CO_2 exhibits some of the properties of hazardous waste outlined in Annex III to the Basel Convention, it could be argued that it should fall within the scope of the convention, subjecting its transport, injection, and disposal to regulation and restriction.

Other international agreements that protect human health and the environment at sea also may bear on offshore CCS projects. The International Convention for the Safety of Life at Sea (SOLAS)[302] may also have bearing on the permissibility of transporting CO_2 by ship; the conditions for transport; and necessary measures to protect people aboard ships from the dangers of CO_2 leakage or rupture from pipelines, vessels, or sub-seabed sites. The convention addresses ships transporting liquefied gases in bulk, which could bear on requirements for CO_2 vessels.[303] Similarly, the International Convention for the Prevention of Pollution from Ships (MARPOL) would regulate the emissions from vessels carrying CO_2. In particular, amendments in 2011 instituted emissions requirements for greenhouse gases. Leaks or emissions of cargo CO_2 could count toward overall ship emissions and constrain the ability of said ships to meet emissions requirements.[304]

Agreements that address transboundary activities or impacts also may be applicable to offshore CCS or impose notification and consultation requirements for CCS projects at sea. For example, the Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention) — a UN Economic Commission for Europe (UNECE) convention that counts forty-five Parties, including the EU, but which is now open to any UN Member State — requires Parties to undertake early EIAs for activities that could have potentially significant transboundary impacts and ensure consultation with the public in affected States.[305] Although the Espoo Convention does not explicitly address CCS or CO_2 transportation, aspects of offshore CCS could arguably fall under some activities listed in the convention's Appendix I as likely to cause significant adverse transboundary impact, such as: large-diameter pipelines for the transport of oil, gas, or chemicals; waste disposal installations; offshore hydrocarbon production; and major storage facilities for petroleum, petrochemical, and chemical products.[306] Moreover, EIA requirements may apply to activities not explicitly listed in Appendix I, if they are determined likely to have significant transboundary impacts under the criteria set out in Appendix III.[307] That assessment process and the convention's requirement that Parties take steps to prevent, reduce, and control significant transboundary environmental impacts could require States engaging in offshore CCS to undertake consultation processes in affected countries and implement measures to prevent harms.[308]

Strengthening the Evolving Legal Regime for Offshore CCS

Beyond the general legal frameworks that may apply to offshore CCS, the legal and regulatory framework specific to the capture, transport, injection, and storage of CO_2 is evolving at the domestic and international levels. The number of different statutes and regulations regarding CCS, particularly at the national and sub-national levels, and the pace at which they are being developed, means an exhaustive survey is well beyond the scope of this report. This section highlights several notable CCS-specific rules to give a sense of some of the relevant international and domestic regimes and institutions involved, and to help identify where further strengthening of protections may be required.

The London Convention and London Protocol are the most developed international instruments addressing offshore CCS. The 1972 London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter and the 1996 London Protocol that modernized the agreement (together referred to as the London Convention/London Protocol) are designed to protect the oceans and seas from human activities. The protocol takes a more restrictive approach than the convention, and codifies the precautionary principle, requiring States to take "appropriate preventative measures" when "there is reason to believe that wastes or other matter introduced into the marine environment are likely to cause harm even when there is no conclusive evidence to prove a causal relation between inputs and their effects."[309] Most States with a high concentration of proposed offshore CCS projects are Party to the London Protocol. This includes Norway, the UK, and Australia, among others.[310] The US, however, is Party only to the London Convention; it has signed but not ratified the London Protocol.[311] Existing federal laws in the US, including the MPRSA, also known as the Ocean Dumping Act, implement the London Convention and align with many provisions of the protocol.[312]

The protocol prohibits dumping — defined as deliberate disposal of wastes or other matter at sea — except for categories of waste or materials listed in Annex 1. A 2006 amendment to Annex 1 of the London Protocol (which entered into force in 2007), added injection of CO_2 from capture processes to the list of substances that may be considered for ocean dumping, under certain defined conditions. The stipulated conditions authorize CO_2 injection only to the extent that the disposal is into a sub-seabed geological formation, the injected substance consists "overwhelmingly of carbon dioxide," and no wastes or other matter are added.[313] **Direct CO_2 injection without containment remains illegal.**

After the amendment entered into force in 2007, the Parties adopted "Specific Guidelines for Assessment of Carbon Dioxide Streams for Disposal in Sub-seabed Geological Formations," elaborating on the regulatory framework under international environmental law.[314] The guidelines address risks associated with CO_2 injection and recommend a number of prevention and mitigation measures, including assessing alternatives to CCS that would prevent the CO_2 waste stream at source, the risk of impurities being introduced into the stream, site selection factors, and monitoring measures.[315]

At present, the London Convention/London Protocol prohibits the cross-border transport of CO_2 for sub-seabed injection.[316] Article 6 of the London Protocol, which bars the export of waste or other matter for dumping in the marine environment, was amended in October 2009 to enable export of CO_2 streams for transboundary CCS.[317] However, the amendment, which was proposed by Norway, will not take effect until sixty days after it is ratified by two-thirds of Contracting Parties to the London Protocol.[318] As of mid-2023, only ten States had ratified it.[319] In 2019, to enable transboundary projects to advance, Norway and the Netherlands spearheaded a resolution, adopted by the Contracting Parties to the London Protocol, allowing for the provisional application of the 2009 amendment between States that expressly agree to it.[320] As of the time of writing, six States — Belgium, Denmark, the Netherlands, Norway, South Korea, Sweden, and the UK — have ratified the 2009 amendment and submitted declarations allowing for its provisional application among them.[321]

For now, transboundary transfer of CO_2 waste between countries is only permissible under the London Protocol where both States have ratified the 2009 amendment and agreed to its provisional application. Denmark and Belgium were reportedly the first countries to reach a bilateral agreement permitting CO_2 export in 2022.[322] Acknowledging that moving CO_2 across borders is impermissible otherwise, Norway is reportedly negotiating legally binding bilateral agreements with several countries, including Belgium and France, in order to be able to import CO_2 from those States for injection into the Norwegian continental shelf.[323] Australia is currently considering amendments to its national dumping law, the Environment Protection (Sea Dumping) Act 1981, which would permit international export of CO_2 to countries with whom an agreement is in place, including Non-Contracting Parties to the London Protocol.[324] Without such amendments, the export of captured CO_2 from the Darwin gas processing plant to the Bayu-Undan field in East Timor would be prohibited. The reforms have faced criticism and are perceived to be part of a push to shift the problem of emissions overseas.[325]

Like the London Convention/London Protocol, the Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention") governing activities in the North Atlantic also explicitly addresses CO_2 injection at sea. The OSPAR Convention regulates what substances may be dumped in the marine environment, and subject to what conditions. Since 2007, OSPAR prohibits "the placement of carbon dioxide streams in the water column or on the seabed,"[326] but permits sub-seabed injection of CO_2 into geologic formations, subject to conditions similar to those under the London Protocol amendment. **The OSPAR decision pertaining to CCS, however, goes further and requires that CO_2 injected is "intended to be retained permanently and *will not lead to significant adverse consequences for the marine environment, human health and other users.*"**[327] Parties to the OSPAR Convention have begun a program to evaluate monitoring of CO_2 stored in subsea geologic formations, a necessary step in ensuring that the storage well meets the aforementioned requirements.[328]

In 2009, the European Union adopted what was considered to be the first comprehensive legal framework meant to manage environmental risks from CCS.[329] The CCS Directive outlines a regulatory regime for geological storage of CO_2, including storage within the EEZs and on the continental shelves of EU Member States.[330] The directive's stated aim is the establishment of "a legal framework for the environmentally safe geological storage of carbon dioxide" defined as "permanent containment of CO_2 in such a way as to prevent and, where this is not possible, eliminate as far as possible negative effects and any risk to the environment and human health."[331] **Member States retain authority not to allow CO_2 storage in their territory or areas thereof.**[332] The directive sets forth minimum requirements for storage permits, to be overseen by competent national authorities, and specifies certain environmental requirements to ensure that projects prevent and minimize adverse impacts on health and the environment.[333] But whether those requirements will be sufficient to avert harm remains to be seen. Much depends not only on the strength of regulatory provisions, but the robustness of their enforcement.

At the national level, not all countries have CCS-specific laws, regulations, or directives, and of those that do, not all are complete, let alone adequate on their own to prevent adverse environmental, human rights, health, and safety impacts or ensure sufficient oversight. Among the topics that may be covered in such regimes are: permitting processes and requirements for CO_2 injection wells and related infrastructure, safety standards, monitoring requirements, and financial assurances for long-term liability as well as transfer of responsibility to public authorities.

At the national level, not all countries have CCS-specific laws, regulations, or directives, and of those that do, not all are complete, let alone adequate on their own to prevent adverse environmental, human rights, health, and safety impacts or ensure sufficient oversight.

Norway, for example, has an established framework regulating offshore CCS, primarily under the Norwegian Petroleum Act and the Pollution Control Act.[334] Norway implemented the EU CCS Directive in 2014 through domestic regulations relating to offshore CO_2 storage and transportation[335] and additional provisions under pollution and petroleum regulations.[336] Both the Petroleum Safety Authority and Norwegian Environmental Agency have responsibilities with respect to issuance of licenses and permits required, including the review of an EIA.[337]

In Australia, the Offshore Petroleum and Greenhouse Gas Storage Act of 2006 addresses permitting for CO_2 injection offshore in the Commonwealth marine area, as well as some dimensions of financial assurance for liability.[338] The National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) is responsible for environmental and safety oversight for CCS, including approval of the environmental plan necessary to obtain a CO_2 injection license, while the National Offshore Petroleum Titles Administration (NOPTA), issues storage titles in federal waters.[339] Where offshore CCS takes place in the waters of one of Australia's states or territories, state-specific CCS legislation may apply and projects may be subject to both state and Commonwealth requirements.[340]

At present, there is no comprehensive federal framework or regulatory regime for CCS in the US, but a patchwork of applicable laws. As set forth in an overview published by the US EPA in October 2023, many different federal and state regulatory and statutory authorities may apply to CCS site selection, capture, transportation, and sequestration of CO_2.[341] Offshore CO_2 injection wells in state waters are subject to permitting requirements and regulations under the Safe Drinking Water Act Underground Injection Control program, which may be administered by the US EPA or a state if it has been granted primary enforcement responsibility or "primacy."[342] Leasing or permitting for CCS into sub-seabed geological formations in federal waters is governed by the Outer Continental Shelf Lands Act. The US DOI's BOEM is currently developing regulations for CCS on the OCS, but as of the time of publication, no draft had been released. BOEM notes: "The proposed rule will address the transportation and geologic sequestration aspects of a development, including leasing; siting of storage reservoirs; environmental plans and mitigations; facility and infrastructure design and installation; injection operations; monitoring; incident response; financial assurance; and safety."[343] The contours of the proposed rule remain publicly unknown, including how it will address thorny issues of long-term monitoring, the potential for and environmental impacts of CO_2 leakage, and liability for related costs.

At present, there is **no comprehensive federal framework** or **regulatory regime** for CCS in the US, but a *patchwork* of applicable laws.

The critical issues of post-closure monitoring and liability were among the topics identified as priorities by the International Energy Agency (IEA) in its 2010 Model Regulatory Framework for CCS Activities.[344] Other issues included the classification of CO_2 (whether as a hazardous substance, pollutant, waste stream, or other material), the composition of the CO_2 stream and regulation of impurities, and responsibility for emissions impacts from transboundary transport and sub-surface storage of CO_2.

Now is the time for policymakers and regulators to consider the **myriad identified risks** and **knowledge gaps** — *before* more public funds are diverted to offshore CCS and more damage is done.

Ultimately, the framework for CCS regulation remains in flux, and decisions made in the next several years to prohibit, restrict, or accelerate aspects of offshore CO_2 storage will affect the trajectory of global climate action. Now is the time for policymakers and regulators to consider the myriad identified risks and knowledge gaps — before more public funds are diverted to offshore CCS and more damage is done. Proper interpretation and enforcement of existing legal regimes, in a manner that prioritizes protection of the environment, human rights, and communities, likely would mean that many planned offshore CCS projects cannot proceed. At the same time, as more detailed regulations specific to CCS are elaborated, decision makers must consider the significant uncertainties and gaps in our understanding of what turning the seabed into a disposal site for fossil fuel industry waste could entail. **The priority of CCS regulations should be to prevent harm and ensure precaution, not funnel investment or fast-track the buildout.**

Filling Regulatory and Knowledge Gaps

Significant knowledge gaps make it nearly impossible to ensure that regulations adequately prevent and protect against all environmental, health, and safety risks posed by CCS. This lack of knowledge, coupled with the failure of many governments to enforce existing regulations on the ocean, particularly in oil and gas extraction, raises concerns about how offshore CCS would be conducted or regulated.

At present, the geological and biological dynamics of the deep sea remain largely unknown,[345] casting doubt on our understanding of the consequences of injecting billions of tons of CO_2 under the seabed in deep waters, or of the damage that a CO_2 rupture or leak at such depths could cause. As scientists have observed, our interference in the deep sea may be outpacing our understanding of its functions[346] — and offshore CCS is no exception. **BOEM, the primary US federal agency regulating the offshore energy sector, has acknowledged that it does not know whether abandoned oil and gas wells in the Gulf of Mexico are leaking, and if so, what the environmental impacts are.[347] This does not inspire confidence that CO_2 storage in the Gulf or elsewhere will be better monitored and maintained, let alone permanently secured or kept free of leaks.**

As scientists have observed, our interference in the deep sea may be **outpacing our understanding of its functions** — and offshore CCS is *no exception.*

These concerns over the ability of governments and corporations to effectively manage the risks of CO_2 storage are only heightened by the lack of clear, comprehensive regulations targeting offshore CCS.

© istock.com/temmuz can arsiray

Purity of CO_2 Streams

The lack of uniform approaches to controlling the CO_2 mix in pipelines and injection sites raises safety concerns and doubts about the technical feasibility of proposed offshore storage hubs. Existing legal regimes relating to CCS do not set firm or uniform requirements for reporting on or regulating the purity or composition of CO_2 streams. The EU CCS Directive, like the London Protocol, merely provides that "[a] CO_2 stream shall consist overwhelmingly of carbon dioxide."[348] Without a more precise definition for what constitutes a CO_2 stream, producers may transport and store CO_2 with varying compositions. As discussed in Part II, certain impurities common in captured CO_2 can damage transport and well infrastructure or could be toxic for workers in the event of a leak. These potential problems are of particular concern with proposed offshore hubs that may mix several CO_2 streams with different levels of impurities.

Though the potential hazards of impure CO_2 streams on infrastructure are well documented, scientists acknowledge that there is no commonly accepted model that predicts how much and how quickly each type of impurity will corrode a steel pipeline.[349] This critical gap in knowledge makes it difficult for regulators to write rules around CO_2 purity, and governments in both the US and Europe acknowledge the lack of existing regulations on this topic. A 2021 report from the US Council on Environmental Quality notes that, "[t]he federal pipeline safety regulations do not include standards for CO_2 composition or purity."[350] A report from the European Union's CCUS Projects Network similarly noted that "there is no commonly agreed specification for CO_2 transport by pipeline."[351] **Moving forward with large-scale offshore CCS projects in the absence of such knowledge or corresponding regulations courts disaster.**

> The lack of uniform approaches to controlling the CO_2 mix in *pipelines* and *injection sites* raises **safety concerns and doubts** about the technical feasibility of proposed offshore storage hubs.

Long-Term Monitoring and Liability

To achieve its purported climate impacts and avoid adding harmful emissions to the atmosphere, offshore CCS would need to ensure that injected CO_2 remains underground, without leaking, for thousands of years. **The considerable timescales for CCS present complex legal and regulatory questions regarding the responsibility for long-term monitoring and liability for environmental and climate damage associated with leaks or accidents.** This issue has plagued the development of CCS for years,[352] and is particularly complicated in projects involving transboundary transportation of CO_2 or storage in geologic formations that could extend across jurisdictions or have transboundary impacts in the event of leakage (such as CCS operations in the ocean).

A technical paper published by the UNFCCC in 2012 reveals how legally complex these issues can become when CO_2 is moved across borders or is stored in offshore areas where territorial jurisdiction may not be clear.[353] The paper analyzed multiple scenarios for cross-border CCS, identifying numerous gaps and unanswered legal questions regarding attribution of liability in case of a leak or accident during transport or storage. While this paper and other studies have identified some of the legal hurdles that offshore CCS projects could face, the regulations remain in flux. This is particularly concerning given the rise of multinational offshore hub proposals, which could involve CO_2 pooled from multiple sources, transported through multiple jurisdictions, and touched by multiple actors, likely implicating laws in several jurisdictions.

Beyond the question of jurisdiction over cross-border offshore CCS activities, the allocation of liability between private and public actors poses further challenges. Even in cases where jurisdiction is clear, governments still need to determine if and when responsibility for monitoring, leaks, and accidents will shift from the project's operators to the State. CCS is by no means the first activity that has required regulators to consider the potential private-to-public transfer of a multi-generational liability risk. From natural disasters to medical liability to the management of nuclear waste, complex problems have prompted governments all over the world to step in to protect their residents by assuming partial or full liability.[354] Some of these cases have similarities to long-term CO_2 sequestration. The management of nuclear waste, for example, was assumed by many governments during the last century as an incentive for the nuclear energy industry.[355] But while regulations regarding nuclear waste management provided for the transfer of liability to the State, their implementation does not inspire confidence or provide a model for mitigating long-term risks and costs. Not a single country in the world has found a permanent solution for high-level nuclear waste, and the cost estimates for long-term monitoring of the waste range in the tens of billions of dollars.[356]

Given the long time frames and the uncertainties about how CO_2 will behave in the event of earthquakes or other geological changes, the burden that CCS could represent for government authorities and future generations for countless years to come should not be understated. Still, many countries that plan to expand CCS have developed regulations that put the long-term liability for CCS projects on the State or subnational entities.

> The burden that CCS could represent for *government authorities* and *future generations* for countless years to come should **not be understated.**

In the US, for example, some states have adopted laws that would have the state government assume long-term liability for CCS projects after closure. This could also apply to offshore CCS in state waters. Both Texas and Louisiana, the primary targets for offshore CCS projects in the US, have such laws. Louisiana's law previously allowed the transfer of liability to the state as little as ten years after CO_2 injection ceases, but a 2023 amendment that will take effect in 2024 delays transfer of liability until at least fifty years after closure.[357] In Texas, the state's School Land Board will assume long-term ownership of CO_2 storage wells offshore following a verification process to ensure that the storage is "permanent."[358] Given the limited experience with CO_2 sequestration to date and significant outstanding scientific uncertainties, it is unclear how — and how reliably — any storage site can be deemed "permanent."

While some US states have addressed long-term liability in their coastal waters, the law remains murky in federal waters. At the point of publication, given the dearth of federal regulations on offshore CCS, it is unclear whether the operator or the federal government would be responsible for CO_2 wells on the OCS once injection ends. Both industry and environmental groups have flagged the long-term liability issue as one of the most important questions for BOEM to take up in its forthcoming regulatory process.[359]

In Europe, regulators also plan to have the State assume responsibility for carbon storage wells, with required contributions from private operators to cover monitoring costs for a minimum period. Under the EU CCS Directive, responsibility for a CO_2 injection site may be transferred to the competent State authority a minimum of twenty years after the site closes or when that authority determines that "all available evidence indicates that the stored CO_2 will be completely and permanently contained."[360] The directive leaves many of the particularities of the transfer of liability and financing arrangements for long-term management up to EU Member States, but stipulates that, prior to the transfer of responsibility, an operator's financial contributions to the relevant state must cover "at least the anticipated cost of monitoring for a period of 30 years."[361] After the transfer, the government may not recover any costs from the operator "unless there are leakages or significant irregularities as a result of operator's negligence, concealment of data, wilful deceit or failure to exercise due diligence."[362] Many uncertainties remain as to how anticipated costs of monitoring are calculated and whether the provisions will be adequate to safeguard people and the environment in the long term.

Beyond legal liability for an accident or leak, these transfers of ownership or responsibility for monitoring must also take into account the financial implications resulting from enormous public subsidies. The proliferation of subsidies that incentivize or remunerate operators for their projected emissions reductions, coupled with State obligations for long-term monitoring, means that the public may end up effectively paying twice. CCS leaks not only risk harm to people and the environment; they also risk reversal of any emissions reductions the project may have realized. **If subsidies are paid up front, and then a leak occurs after the operator has handed off monitoring responsibility to the State, the public could first pay a CCS operator to store their CO_2 waste and then pay again to clean up the mess left behind, all while receiving no climate benefit from the project.**

Legal frameworks regarding CCS must also consider how to account for tax breaks or emissions credits following a CO_2 leak.[363] In the US, for example, a taxpayer who captures CO_2 from a qualified facility may be eligible for a tax credit per tonne of CO_2 stored in a geologic reservoir or utilized for EOR.[364] If the CO_2 injected underground is later found to leak, and the amount leaked exceeds the amount stored in the year the leak is reported, the US tax authority, the Internal Revenue Service (IRS), may "recapture" the corresponding tax credit by having the entity or entities that claimed it pay it back on their next tax return.[365] While this mechanism exists in the US tax code, recent amendments to the IRS regulations reduced the period during which the IRS can reclaim tax credits for leaks from five to three years after the project's final qualifying injection, and in some cases less.[366] Moreover, unless the IRS's monitoring and enforcement capacity vastly expands to keep up with the anticipated growth of CCS credits claimed, robust application of this provision may not be feasible. The ability of the IRS to "recapture" credits in the event of leakage depends largely on the taxpayer or party contracted to secure the CO_2 storage site reporting the volume leaked, subject to third party verification. **In essence, recent legislative and regulatory changes have made it easier and more lucrative for taxpayers to claim CCS credits, while leaving the IRS with limited means and limited time to ensure that the country is actually getting the capture and storage it's paying for.**

In the EU, financial incentives for CCS operate in part through the region's cap and trade system. The Emissions Trading System (ETS) limits how much polluters can emit and allows the exchange of carbon credits between entities covered by the cap.[367] Under the EU's 2009 CCS Directive, CO_2 streams captured, transported, and stored through CCS are not considered as emissions, but in the event of a leak the operator must surrender any emissions trading allowances earned through the CCS project.[368] The operator must also take corrective measures if a leak occurs, or cover the State's costs for doing so.[369]

Betting significant public funds and our collective climate future on a *"carbon management"* strategy that hinges on **unproven techniques** and a **largely untested** — and heretofore poor — enforcement system is a wager the world simply **cannot** afford.

The success or failure of any of these CCS-specific regulations depends heavily on the robustness of the monitoring programs developed to ensure the safe storage of CO_2. But there, the track record to date gives cause for concern. Considering the significant failures and shortcoming witnessed with monitoring and decommissioning of existing oil and gas infrastructure (which is even more costly offshore in deep water), it seems likely that offshore CO_2 storage will face similar problems.[370] Betting significant public funds and our collective climate future on a "carbon management" strategy that hinges on unproven techniques and a largely untested — and heretofore poor — enforcement system is a wager the world simply cannot afford.

Both *onshore* and *offshore,* CCS is little more than a **dangerous distraction** from the *urgent* and *imperative* task of phasing out coal, oil, and gas.

© istock.com/manpuku7

Conclusion & Recommendations

Injecting CO_2 under the seabed will not fix the problem of fossil fuel pollution. Instead, it is poised to introduce new threats to the ocean, the climate, human rights, and the coastal and frontline communities whose air, lands, and waters will be affected by CCS buildout and the operation of the facilities where capture equipment is installed. **The surest and fastest way to curb CO_2 emissions from fossil fuels is to curb the production and use of fossil fuels.** Both onshore and offshore, CCS is little more than a dangerous distraction from the urgent and imperative task of phasing out coal, oil, and gas.

The false promise of CCS only prolongs reliance on these dirty energy sources, delaying the necessary transition to a fossil-free future. What's more, it introduces new risks. Just as there are potential dangers associated with underground CO_2 storage on land, **storing CO_2 under the seabed puts the marine environment in jeopardy.** Leakage could occur from corroding pipelines and from underwater storage sites, especially old oil and gas wells. Practices for managing pressure during CO_2 injection are largely untested offshore, and in the case of a blowout or extreme leakage there is little that can be done to mitigate the hazard, aside from stopping injection.

The limited knowledge and experience with subsea carbon injection underscores the risky nature of the practice and the potential for unintended consequences. Already, oceans are acidifying and human activities are threatening fragile marine environments. Intentionally transporting CO_2 in the oceans and injecting it under the seabed on a vast scale could compound these threats.

Not only does CCS delay the energy transition, it also provides cover for fossil fuel expansion projects and enables further production through EOR. Injecting CO_2 into depleted wells to extract more hydrocarbons continues to attract public subsidies despite the fact that it has no climate benefits. Given the financial incentives, increased resistance to oil and gas exploitation onshore, and growing restrictions on opening up new fields, it may only be a matter of time before the oil industry seeks to implement widespread CO_2-EOR offshore.

Finally, **new markets for carbon storage services treat CO_2 as a profitable commodity rather than a liability, which generates perverse incentives for companies and countries to sustain the supply of CO_2.** Rather than creating new industries whose business models depend on continued pollution, governments should be aligning interests toward a rapid and just transition away from fossil fuels.

While the full extent of the risks posed by offshore CCS is not yet well understood, the potential for adverse impacts on our already taxed oceans, the significant human rights violations and harms to the communities burdened by fossil fuel facilities and CCS infrastructure, and the paucity of climate benefits, demands that governments exercise precaution and refrain from investing in offshore CCS.

To that end, governments must:

Halt the rush to develop offshore CO_2 storage hubs. In view of the significant risks, uncertainties, and regulatory gaps, governments should not permit large-scale offshore CO_2 injection. The geologic variability among different injection sites, feasibility concerns regarding long-term CO_2 storage, and the difficulty of monitoring industrial activities at sea all weigh against a buildout of offshore CCS.

End public subsidies for CCS, including offshore projects. Governments should instead direct public resources to available and effective climate change solutions, like energy efficiency and demand reduction measures and the replacement of fossil fuels with renewable energy.

Enshrine protections against and restrictions on international CO_2 trade and storage, especially while questions of monitoring, verification, security of storage, and liability remain.

Avert the risks that the new push for offshore CCS poses to oceans and ocean environments. The world's oceans are already suffering the consequences of accelerating climate change and decades of offshore oil and gas drilling. Governments enforcing existing marine protection laws must prevent CCS from compounding these stressors, and guarantee adequate regulations to ensure that CO_2 from any ships, pipelines, and storage sites, as well as byproducts of CCS, do not contaminate the oceans or adversely impact coastal communities.

Interpret existing legal frameworks to better protect communities, the environment, and our global climate. Environmental impact, species protection, biodiversity conservation, and health and safety regimes should be interpreted in line with the precautionary principle to avoid and minimize the risks of offshore CCS and prevent harm to oceans, biodiversity, and communities.

Strengthen regulatory regimes at the domestic and international levels to prevent harm from offshore CCS. CCS-specific provisions must foreground rigorous study and enforcement, not fast-track approvals and investments.

Include impacts from the upstream sources of CO_2 in any assessments of offshore storage projects. Given the risk that installation of carbon capture equipment entrenches and exacerbates pollution from the underlying facilities, regulators considering downstream CO_2 disposal sites must view them together with the upstream pollution and risks they enable.

Rule out shipping CO_2 long distances for injection, as an inherently inefficient and intrinsically dangerous strategy for "managing carbon." Burning fossil fuels or fossil fuel-derived energy to ship fossil fuel pollution from one location to another for "disposal" does not make climate or economic sense. Instead, governments should prioritize preventing emissions in the first place.

Prohibit the use of CCS for EOR or EGR, including in offshore environments. Using oil or gas production to finance a purported emissions reduction technology, and in turn, using purported CO_2 reduction to increase oil or gas production, is counterproductive and a distortion of climate policy.

Prioritize measures that address the root causes of the climate crisis, not its symptoms. During this critical decade to avoid even more catastrophic climate change, governments must tackle the production and use of fossil fuels, not merely manage fossil fuel emissions. Getting to the root of the issue will reap benefits not only for the climate, but also for human rights and health, biodiversity, economic stability, and global security.

Endnotes

1. The IEA Greenhouse Gas R&D Programme (IEAGHG), A Brief History of CCS and Current Status, undated, https://ieaghg.org/docs/General_Docs/Publications/Information_Sheets_for_CCS_2.pdf.
2. "Carbon Storage FAQs," National Energy Technology Laboratory (NETL), accessed September 29, 2023, https://netl.doe.gov/carbon-management/carbon-storage/faqs/carbon-storage-faqs.
3. NETL, Carbon Storage FAQs.
4. Institute for Energy Economics and Financial Analysis (IEEFA), Grant Hauber, Norway's Sleipner and Snøhvit CCS: Industry models or cautionary tales? June, 14, 2023, https://ieefa.org/resources/norways-sleipner-and-snohvit-ccs-industry-models-or-cautionary-tales; Richard Middleton et al. "Effects of geologic reservoir uncertainty on CO_2 transport and storage infrastructure," International Journal of Greenhouse Gas Control vol. 8 (May 2012): 132–142, https://doi.org/10.1016/j.ijggc.2012.02.005; "Broadband Processing Improves CO_2 Monitoring," Petroleum Geo-Services (PGS), accessed October 2, 2023, https://www.pgs.com/company/resources/case-studies/broadband-processing-improves-CO2-monitoring/ ("The rate of CO_2 migration was predicted to be in the order of 100 m per year, however, 4D seismic monitoring has indicated a migration speed of up to 300 m per year."); Bob Harrison, "Are We Overconfident in Predicting CO_2 Plume Migration?" accessed October 2, 2023, https://www.linkedin.com/pulse/we-overconfident-predicting-CO2-plume-migration-bob-harrison-fei/.
5. NETL, Carbon Storage FAQs.
6. See Center for International Environmental Law (CIEL), Carroll Muffett and Steven Feit, Fuel to the Fire, February 2019, 19–22, https://www.ciel.org/reports/fuel-to-the-fire-how-geoengineering-threatens-to-entrench-fossil-fuels-and-accelerate-the-climate-crisis-feb-2019/.
7. See Government Accountability Office (GAO), Carbon Capture and Storage: Actions Needed to Improve DOE Management of Demonstration Projects, December 20, 2021, https://www.gao.gov/products/gao-22-105111 (evaluating the results of the more than USD1 billion invested in CCS demonstration projects since 2009); see also IEA, 20 years of carbon capture and storage, 2016, https://iea.blob.core.windows.net/assets/24c3d26b-aa44-4b54-b9c0-5201d4d86a04/20YearsofCarbonCaptureandStorage_WEB.pdf at page 39 ("Between 2007 and 2010, around USD 30 billion in CCS funding initiatives was announced globally (GCCSI, 2010).")
8. IEEFA, Bruce Roberston and Milad Mousavian, The Carbon Capture Crux: Lessons Learned, September 1, 2022, ieefa.org/resources/carbon-capture-crux-lessons-learned.
9. IEEFA, Suzanne Mattei and David Schlissel, The ill-fated Petra Nova CCS project: NRG Energy throws in the towel, October 5, 2023, https://ieefa.org/resources/ill-fated-petra-nova-ccs-project-nrg-energy-throws-towel; National Energy Technology Lab (NETL), Kemper County Energy Facility: Demonstration of a coal-based transport gasifier, September 2017, https://www.netl.doe.gov/sites/default/files/netl-file/NT42391.pdf.
10. Bruce Roberston and Milad Mousavian, The Carbon Capture Crux.
11. Bruce Roberston and Milad Mousavian, The Carbon Capture Crux.
12. See GCCSI, CO_2RE database.
13. See Environment Texas, Ari Philips and Luke Metzger, Illegal Air Pollution in Texas 2020, Oct. 2020, 18; European Environment Agency (EEA), Carbon capture and storage could also impact air pollution, November 23, 2020, https://www.eea.europa.eu/highlights/carbon-capture-and-storage-could.
14. Intergovernmental Panel on Climate Change (IPCC), Leon Clarke, et. al, Energy Systems (Chapter 6), In: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, April 4, 2022, 641–42, https://www.ipcc.ch/report/ar6/wg3/.
15. P. W. Parfomak & P. Folger, Congressional Research Service, Carbon Dioxide (CO2) Pipelines for Carbon Sequestration: Emerging Policy Issues (2007), at 15; US Environmental Protection Agency, CO_2 Appendix B – Overview of Acute Health Effects, undated, https://www.epa.gov/sites/default/files/2015-06/documents/co2appendixb.pdf.
16. Julia Simon, "The U.S. Is Expanding CO_2 Pipelines. One Poisoned Town Wants You to Know Its Story," National Public Radio (NPR), May 21, 2023, https://www.npr.org/2023/05/21/1172679786/carbon-capture-carbon-dioxide-pipeline.
17. See, e.g., Evan Halper, "How a pricey taxpayer gamble on carbon capture helps Big Oil," The Washington Post, October 9, 2022, https://www.washingtonpost.com/business/2022/10/09/carbon-capture-oil-gas/; Ole Ketil Helgesen, "Norway takes aim at CCS with huge government investment," Upstream, September 21, 2020, https://www.upstreamonline.com/energy-transition/norway-takes-aim-at-ccs-with-huge-government-investment/2-1-878651.
18. Anna Wendt et al., "A multi-criteria CCUS screening evaluation of the Gulf of Mexico, USA," International Journal of Greenhouse Gas Control Volume 118 (2022): https://doi.org/10.1016/j.ijggc.2022.103688; see also Faraaz Ahmad et al., "Fate of radium on the discharge of oil and gas produced water to the marine environment," Chemosphere Volume 273 (2021): https://doi.org/10.1016/j.chemosphere.2021.129550 (discussing the occurrence and impact of radioactive material in produced waters in offshore oil and gas extraction).
19. For a list of proposed projects and more details, see this report's appendix.
20. "About the Longship Project," Northern Lights, accessed October 2, 2023, norlights.com//about-the-longship-project/.
21. See this report's appendix.
22. See this report's appendix.
23. IPCC, Hoesung Lee, et al., Climate Change 2023 Synthesis Report, March 2023, 19, https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_SPM.pdf.
24. The world currently stores around 2 million tonnes in aquifers. This does not include offshore EOR. See this report's appendix for new project totals. For current world totals See Global CCS Institute, "CCS Facilities Database," https://www.globalccsinstitute.com/CO2re/.
25. International Energy Agency, CO_2 Emissions in 2022, March 2023, https://www.iea.org/reports/CO2-emissions-in-2022.
26. Grant Hauber, Norway's Sleipner and Snøhvit CCS, 18–23; 25–31.
27. On uncertainties regarding risks of CCS, see P. Larkin et al, "Uncertainty in risk issues for carbon capture and geological storage: findings from a structured expert elicitation," Int. J. Risk Assessment and Management, Vol. 22, Nos. 3/4, 2019, 429–463. On research and regulatory gaps, see Center for Progressive Reform, Uncertainties and Gaps in Research on Carbon Capture and Storage in Louisiana, June 2023, https://cpr-assets.s3.amazonaws.com/wp/uploads/2023/06/ccs-in-louisiana-rpt-june2023-final.pdf (reviewing peer literature regarding risks and uncertainties associated with CCS).
28. US Energy Information Agency, Oil and Petroleum Products Explained: Offshore Drilling, accessed October 30, 2023, https://www.eia.gov/energyexplained/oil-and-petroleumproducts/offshore-oil-and-gas-in-depth.php.
29. "The World's Worst Offshore Oil Rig Disasters." Offshore Technology, accessed October 2, 2023, https://www.offshore-technology.com/features/feature-the-worlds-deadliest-offshore-oil-rig-disasters-4149812/; Healthy Gulf, Scott Eustis, New Report: Oil & Gas Pipeline Integrity in Texas and Louisiana, 2010-2020, October 18, 2021, healthygulf.org/2021/10/18/new-report-oil-gas-pipeline-integrity-in-texas-and-louisiana-2010-2020/.
30. Sasha Warren, "Ocean Oil Slick Map Reveals Enough Greasy Patches to Cover France—Twice," Scientific American, June 16, 2022, https://www.scientificamerican.com/article/ocean-oil-slick-map-reveals-enough-greasy-patches-to-cover-france-mdash-twice/.
31. See, e.g., GAO, Offshore Oil and Gas: Updated Regulations Needed to Improve Pipeline Oversight and Decommissioning, March 2021, www.gao.gov/assets/gao-21-293.pdf; Bureau of Ocean Energy Management (BOEM), Gulf of Mexico Regional Office, Impact of Abandoned Oil and Gas Wells on Air and Water Quality in the Gulf of Mexico, March 30, 2021, www.boem.gov/sites/default/files/documents/environment/environmental-studies/GM-22-01.pdf.
32. "Sleipner Fact Sheet: Carbon Dioxide Capture and Storage Project," Massachusetts Institute of Technology (MIT), accessed October 2, 2023, https://sequestration.mit.edu/tools/projects/sleipner.html.
33. "Carbon storage started on Snøhvit," Equinor, accessed October 2, 2023, https://www.equinor.com/news/archive/2008/04/23/CarbonStorageStartedOnSnhvit.
34. See "Broadband Processing Improves CO2 Monitoring," Petroleum Geo-Services (PGS), accessed October 2, 2023, https://www.pgs.com/company/resources/case-studies/broadband-processing-improves-CO2-monitoring/ ("The rate of CO_2 migration was predicted to be in the order of 100 m per year, however, 4D seismic monitoring has indicated a migration speed of up to 300 m per year."); Bob Harrison, "Are We Overconfident in Predicting CO_2 Plume Migration?" accessed October 2, 2023, https://www.linkedin.com/pulse/we-overconfident-predicting-CO2-plume-migration-bob-harrison-fei.
35. See Olav Hansen et al. "Snøhvit: The History of Injecting and Storing 1Mt CO_2 in the Fluvial Tubåen Fm." Energy Procedia (Fall 2013), https://www.sciencedirect.com/science/article/pii/S187661021300492X; Grant, IEEFA, Sleipner and Snøhvit, pg. 30.
36. Hauber, Norway's Sleipner and Snøhvit CCS, 5.
37. Hauber, Norway's Sleipner and Snøhvit CCS, 14.
38. See generally Grant Hauber, Norway's Sleipner and Snøhvit CCS.

39. MIT, Sleipner Fact Sheet.
40. Murugan, Arul et al. "Performing Quality Assurance of Carbon Dioxide for Carbon Capture and Storage," Journal of Carbon Research (Fall, 2020), https://doi.org/10.3390/c6040076.
41. A. Razak et al, "Physical and chemical effect of impurities in carbon capture, utilisation and storage," Journal of Petroleum Exploration and Production Technology vol. 13 (2023), 1235–1246, https://doi.org/10.1007/s13202-023-01616-3; Benedikt Paschkea and Alfons Kathera, "Corrosion of Pipeline and Compressor Materials due to Impurities in separated CO2 from fossil-fuelled Power Plants," Energy Procedia vol. 23 (2012) 207–215, https://doi.org/10.1016/j.egypro.2012.06.030.
42. Murugan, Arul et al., Performing Quality Assurance of CO_2 for CCS.
43. See "Sleipner Fact Sheet: Carbon Dioxide Capture and Storage Project," MIT, accessed October 2, 2023, https://sequestration.mit.edu/tools/projects/sleipner.html.
44. See e.g., Terje Aasland, "How can Europe and Norway cooperate to scale up the CCS market?" (Northern Lights Summit, Brussels, June 23, 2022), https://www.regjeringen.no/en/aktuelt/how-can-europe-and-norway-cooperate-to-scale-up-the-ccs-market/id2920559/; Another offshore CCS project in Norway that was highly publicized when proposed (and swept under the rug when it folded), Mongstad, never got off the ground. The cost overruns it faced and other feasibility challenges are discussed further below in Part III.
45. See e.g., Air Pollution and Climate Secretariat, Air Pollution and Climate Secretariat, Carbon Capture and Storage in Norway - The moon landing that failed, ("There is a lack of critical debate about the shortcomings and unproven aspects of CCS technology in general in Norway. One reason is the lack of independent academic research into CCS technology."), October 1, 2015, https://www.airclim.org/sites/default/files/documents/APC32-CCS-in-Norway_0.pdf; See also, "Sub-seabed carbon dioxide storage," (a research initiative funded under an EU program, in which Shell is the "principal industry partner"), Strategies for Environmental Monitoring of Marine Carbon Capture and Storage, accessed October 2, 2023, https://www.stemm-ccs.eu/.
46. See this report's appendix.
47. Norwegian Ministry of Petroleum and Environment, "Three applications for permits to store CO_2 in the North Sea." News release, June 8, 2022. https://www.regjeringen.no/en/aktuelt/three-applications-for-permits-to-store-CO2-in-the-north-sea/id2917885/. See also Global CCS Institute, CCS Commercial and Regulatory Frameworks: Lessons Learned from CCS Front-runners in Norway, March 15, 2023, https://www.globalccsinstitute.com/resources/multimedia-library/ccs-commercial-and-regulatory-frameworks-lessons-learned-from-ccs-front-runners-in-norway/.
48. Nicola Jones, "Solution or Band-Aid? Carbon Capture Projects Are Moving Ahead," Yale Environment 360, June 7, 2022, https://e360.yale.edu/features/solution-or-band-aid-carbon-capture-projects-are-moving-ahead.
49. CCUS around the world: Northern Lights, International Energy Agency (IEA), accessed October 2, 2023, https://www.iea.org/reports/ccus-around-the-world/northern-lights.
50. See "What we do," Northern Lights, accessed October 2, 2023, https://norlights.com/what-we-do/. For 2021 emissions totals, see: Crippa, M et al., Joint Research Center (European Commission), CO_2 emissions of all world countries, 2022, doi:10.2760/730164.
51. See e.g., "Project," Porthos CO_2 Transport and Storage, accessed October 2, 2023, https://www.porthosCO2.nl/en/project/; "What is Project Greensand?" Project Greensand, accessed October 2, 2023, https://www.projectgreensand.com/en/hvad-er-project-greensand; British Petroleum (BP), "New collaboration to develop offshore CCUS infrastructure," BP, News release, October 26, 2020, https://www.bp.com/en/global/corporate/news-and-insights/reimagining-energy/northern-endurance-partnership-to-develop-offshore-ccus-infrastructure.html.
52. Neptune Energy, "ExxonMobil, Rosewood and EBN to Cooperate on L10 Carbon Capture and Storage," News release, June 20, 2022, https://www.neptuneenergy.com/media/press-releases/year/2022/neptune-energy-exxonmobil-rosewood-and-ebn-cooperate-l10-ccs; "L10 Area CCS Development, Dutch North Sea," Neptune Energy, accessed October 2, 2023, https://www.neptuneenergy.com/esg/l10-area-ccs-development.
53. BP, "New collaboration to develop offshore CCUS infrastructure," News release, October 26, 2020. https://www.bp.com/en/global/corporate/news-and-insights/reimagining-energy/northern-endurance-partnership-to-develop-offshore-ccus-infrastructure.html; "East Coast Cluster," East Coast Cluster, accessed October 2, 2023, https://eastcoastcluster.co.uk/.
54. "What is Project Greensand?" Project Greensand, accessed October 2, 2023.
55. Beyond Oil and Gas Alliance (BOGA), "At COP26, 11 National and Subnational Governments Launch the Beyond Oil & Gas Alliance," News release, October 11, 2021, https://beyondoilandgasalliance.org/wp-content/uploads/2021/11/11-10-21-BOGA-Press-Release.pdf.
56. Amanda Battersby, "World's largest CCS project set for sanction in 2023," Upstream, June 15, 2022, https://www.upstreamonline.com/energy-transition/world-s-largest-ccs-project-set-for-sanction-in-2023/2-1-1238083.
57. National Offshore Petroleum Safety and Environmental Management Authority. Project - Bayu-Undan Field Development, Accessed October 27, 2023,. https://info.nopsema.gov.au/offshore_projects/11/show_public.
58. Santos, "Globally significant carbon capture and storage project a step closer," News release, March 9, 2022, https://www.santos.com/news/globally-significant-carbon-capture-and-storage-project-a-step-closer/.
59. John Robert, "IEEFA Australia: Carbon Capture and Storage No Answer for Santos Barossa Gas Project," IEEFA, October 25, 2021, https://ieefa.org/resources/ieefa-australia-carbon-capture-and-storage-no-answer-santos-barossa-gas-project.
60. Solutions for Our Climate, Dongjae Oh and Somin Kim, Betting on a Sinking Ship: Banks Behind the Barossa Gas Field's FPSO Vessel, April 2023, at 3, https://forourclimate.org/hubfs/Betting%20on%20a%20Sinking%20Ship_Banks%20Behind%20the%20Barossa%20Gas%20Field%E2%80%99s%20FPSO%20Vessel-1.pdf.
61. Sonali Paul, "Australia court ruling on Santos raises risks for offshore gas projects," Reuters, December 2, 2022, https://www.reuters.com/business/energy/australia-court-rejects-santos-bid-resume-barossa-gas-drilling-2022-12-02/; Ben Butler and Lisa Cox, "Tiwi Islanders win court battle with Santos over drilling in traditional waters," The Guardian, September 21, 2022, https://www.theguardian.com/environment/2022/sep/21/tiwi-islanders-win-court-battle-with-santos-over-drilling-in-traditional-waters. In April 2023, community members from the Tiwi Islands lodged human rights grievances with multiple banks regarding their involvement in the Barossa gas project. See Jack Hislop, "Tiwi Islands traditional owners lodge human rights complaint against banks over $1.5b Santos loan," Australian Broadcasting Corporation (ABC), April 4, 2023, https://www.abc.net.au/news/2023-04-04/tiwi-islands-human-rights-complaint-bank-santos-barossa-gas/102184122; Angela Macdonald-Smith, "Banks targeted in fresh Santos gas battle," Financial Review, April 4, 2023, https://www.afr.com/companies/energy/banks-targeted-in-fresh-barossa-gas-battle-20230404-p5cxv0.
62. See "Australian environmental group sues Santos over clean energy claims," Reuters, August 26, 2021, https://www.accr.org.au/news/australasian-centre-for-corporate-responsibility-updates-case-against-santos-in-federal-court/; Daniel Fitzgerald, "Gas giant Santos accused of 'greenwashing' clean energy claims, in Federal Court case," ABC News, August 30, 2022, https://www.abc.net.au/news/rural/2022-08-31/santos-accused-of-greenwashing-by-accr-in-federal-court-case/101385728. The South Korean gas company involved in the Barossa project, SK E&S, has also faced a lawsuit accusing it of greenwashing based on its claims that CCS makes the gas from Barossa "CO_2-free." See Solutions for Our Climate (SFOC), "S. Korean gas giant SK E&S sued in a landmark case over greenwashing," News release, December 22, 2021, https://forourclimate.org/en/sub/news/view.htmlidx113.
63. "China's CNOOC completes first offshore carbon capture site," Reuters, June 14, 2022, https://www.reuters.com/business/environment/chinas-cnooc-completes-first-offshore-carbon-capture-site-2022-06-15/.
64. Amanda Battersby, "PETRONAS Advances Massive Carbon Capture and Storage Project," Upstream Online, July 6, 2022, https://www.upstreamonline.com/field-development/petronas-advances-massive-carbon-capture-and-storage-project/2-1-1253191; "Carbon capture and storage (CCS) project," PTT Exploration and Production (PTTEP), accessed October 3, 2023, https://www.pttep.com/en/Sustainability/Carbon-Capture-And-Storage.aspx; "CCS demonstration project using the Donghae-1 depleted gas reservoirs," Korea National Oil Corporation (KNOC) accessed October 3, 2023, https://www.knoc.co.kr/ENG/sub03/sub03_9_1.jsp.
65. This total is based on project-specific data collected in this report's appendix.
66. IEA, CO_2 Emissions in 2022, March 2023, https://www.iea.org/reports/CO2-emissions-in-2022.
67. IPCC, Energy Systems (Chapter 6), Figure SPM.7.
68. Zenz House, Kurt et al. "Permanent carbon dioxide storage in deep-sea sediments," PNAS (Fall 2006), https://doi.org/10.1073/pnas.060531810.
69. IPCC, Carbon Dioxide Capture and Storage, chap. 5, 200, https://www.ipcc.ch/report/carbon-dioxide-capture-and-storage/.
70. See IPCC, Carbon Dioxide Capture and Storage, chap. 6 at 295
71. See 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (as amended in 2006), at Annex 1, para 4.1 (specifying that CO_2 "may only be considered for ocean dumping if disposal is into a sub-seabed geological formation"), www.cdn.imo.org/localresources/en/OurWork/Environment/Documents/PROTOCOLAmended2006.pdf.
72. EU CCS Directive (2009), Art. 2(4). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009L0031.
73. IEA, Northern Lights.
74. "Costs of the Longship Project," CCS Norway, accessed October 3, 2023, https://ccsnorway.com/costs/.
75. Northern Lights, What we do.
76. Northern Lights, What we do.

77. Nora Buli, "Carbon Capture Project in Norway Temporarily Halted by High Costs," Reuters, April 26, 2023, https://www.reuters.com/world/europe/carbon-capture-project-norway-temporarily-halted-by-high-costs-2023-04-26/.
78. "How to store CO_2 with Northern Lights," Northern Lights, accessed October 3, 2023, https://norlights.com/how-to-store-CO2-with-northern-lights/.
79. Northern Lights, How to store CO_2.
80. Northern Lights, "Major milestone for decarbonizing Europe," News release, August 29, 2022, https://norlights.com/news/major-milestone-for-decarbonising-europe%ef%bf%bc/.
81. Northern Lights, "Northern Lights enters into cross-border transport and storage agreement with Ørsted," News release, May 15, 2023, https://norlights.com/news/northern-lights-enters-into-cross-border-transport-and-storage-agreement-with-orsted/.
82. Danish Energy Agency, "The first tender of the CCUS subsidy scheme has been finalized: the Danish Energy Agency awards the contract to Ørsted's full scale CCS project," News release, May 15, 2023, https://ens.dk/en/press/first-tender-ccus-subsidy-scheme-has-been-finalized-danish-energy-agency-awards-contract.
83. Northern Lights, What we do.
84. "Emissions to air," Statistics Norway, last modified June 8, 2022, https://www.ssb.no/en/natur-og-miljo/forurensning-og-klima/statistikk/utslipp-til-luft.
85. See "About GoMCarb," Gulf Coast Carbon Center, visited Oct. 31, 2023, https://gccc.beg.utexas.edu/research/gomcarb.
86. Meckel, T.A et al. "Carbon capture, utilization, and storage hub development on the Gulf Coast," Greenhouse Gasses: Science and Technology (Fall 2021): 619, 624-625, 630 (in pdf version). https://doi.org/10.1002/ghg.2082.
87. Chevron, "Talos and Carbonvert announce proposed joint venture expansion to enhance the Bayou Bend CCS project offshore Jefferson County, Texas," News release, May 3, 2022, https://www.chevron.com/newsroom/2022/q2/chevron-talos-and-carbonvert-announce-proposed-joint-venture-expansion.
88. Chevron, Talos and Carbonvert announce proposed joint venture.
89. "Bayou Bend aims to be first US offshore carbon storage hub," Chevron, accessed July 5, 2022, https://www.chevron.com/newsroom/2022/q3/bayou-bend-aims-to-be-first-us-offshore-carbon-storage-hub.
90. Carolyn Davis, "ExxonMobil Eyeing $100B Carbon Capture Project in Houston Area," Natural Gas Intelligence, April 20, 2021, https://www.naturalgasintel.com/exxonmobil-eyeing-100b-carbon-capture-project-in-houston-area-with-burial-at-sea/; "Charting a bold concept for a lower-carbon future," Energy Factor by ExxonMobil, last modified April 21, 2021, https://energyfactor.exxonmobil.com/reducing-emissions/carbon-capture-and-storage/lcs-houston-ccs-concept/.
91. Reuters and Jennifer Hiller, "Exxon floats $100 bln carbon storage project requiring public, private financing," Reuters, April 19, 2021, https://www.reuters.com/business/sustainable-business/exxon-proposes-massive-carbon-capture-storage-project-houston-2021-04-19/.
92. ExxonMobil, "Industry support for large-scale carbon capture and storage continues to gain momentum in Houston," News release, January 20, 2022, https://corporate.exxonmobil.com/news/newsroom/news-releases/2022/0120_industry-support-for-large-scale-carbon-capture-and-storage-gains-momentum-in-houston.
93. Nicholas Kusnetz, "Exxon's Long-Shot Embrace of Carbon Capture in the Houston Area Just Got Massive Support from Congress," Inside Climate News, September 25, 2022, https://insideclimatenews.org/news/25092022/exxon-houston-ship-channel-carbon-capture/. "In short, many experts say, Exxon's vision is an extreme long-shot—some would say bad-faith—proposal for the largest-ever deployment of a technology that has failed to prove itself at scale, despite billions of dollars of public subsidies and private investments and decades of effort."
94. Justine Calma, "Exxon's new Gulf of Mexico leases aren't what they seem," The Verge, November 18, 2021, https://www.theverge.com/2021/11/18/22789506/exxonmobil-gulf-of-mexico-lease-sale-carbon-capture-sequestration.
95. BOEM, "In compliance with IRA, BOEM reinstates Lease Sale 257 bids." News release, September 14, 2022. https://www.boem.gov/newsroom/press-releases/compliance-ira-boem-reinstates-lease-sale-257-bids#:~:text=BOEM%20originally%20held%20the%20lease,avoid%20potential%20ocean%20user%20conflicts.
96. Sabrina Valle, "Big Oil Splits over Production vs Carbon Storage in Gulf of Mexico Auction," Reuters, March 29, 2023, https://www.nasdaq.com/articles/big-oil-splits-over-production-vs-carbon-storage-in-gulf-of-mexico-auction.
97. Sabrina Valle, "Exxon Sees Carbon Capture Market at $4 Trillion by 2050," Reuters, April 21, 2022, https://www.reuters.com/business/sustainable-business/exxon-sees-carbon-capture-market-4-trillion-by-2050-2022-04-19/.
98. Sabrina Valle, Exxon Sees Carbon Capture Market.
99. "Project Selections for FOA 2610: CarbonSAFE Phase II - Storage Complex Feasibility," US Department of Energy, accessed October 4, 2023, https://www.energy.gov/fecm/project-selections-foa-2610-carbon-safe-phase-ii-storage-complex-feasibility.
100. "Gulf of Mexico Carbon Capture and Sequestration Partnership Hub Announces Development of One of the Largest CO_2 Offshore Storage Projects," Globalnewswire, December 20, 2022, https://www.globenewswire.com/en/news-release/2022/12/20/2577338/0/en/Gulf-of-Mexico-Carbon-Capture-and-Sequestration-Partnership-Hub-Announces-Development-of-One-of-the-Largest-CO2-Offshore-Storage-Projects.html.
101. "Corpus Christi Carbon Storage Hub Awarded to World-Class Team Led by Repsol," Businesswire, September 5, 2023, https://www.businesswire.com/news/home/20230905545977/en/Corpus-Christi-Carbon-Storage-Hub-Awarded-to-World-Class-Team-Led-by-Repsol.
102. Carbonvert, Castex Energy Execute Deal for Operation of Louisiana's First Offshore CO_2 Storage Hub," Offshore Engineer, September 20, 2023, https://www.oedigital.com/news/508178-carbonvert-castex-energy-execute-deal-for-operation-of-louisiana-s-first-offshore-CO2-storage-hub.
103. Repsol, Carbonvert, Mitsui, POSCO, "Corpus Christi Carbon Storage Hub Awarded to World-class Team Led by Repsol," BusinessWire, September 5, 2023, https://www.businesswire.com/news/home/20230905545977/en/Corpus-Christi-Carbon-Storage-Hub-Awarded-to-World-Class-Team-Led-by-Repsol; Carbonvert, "Carbonvert, Castex joint venture executes operating agreement for offshore carbon storage hub in Louisiana," News Release, September 18, 2023, https://carbonvert.com/press/carbonvert-castex-joint-venture-executes-operating-agreement-for-offshore-carbon-storage-hub-in-louisiana/.
104. "Southeast Regional Carbon Storage Partnership: Offshore Gulf of Mexico," US Department of Energy, National Energy Technology Laboratory, accessed September 18, 2023, https://www.netl.doe.gov/projects/project-information.aspx?k=FE0031557.
105. "SECARB: Southeast Regional Carbon Sequestration Partnership," Southern States Energy Board, accessed October 30, 2023, https://www.sseb.org/programs/secarb/.
106. SECARB Offshore," Southern States Energy Board, accessed October 30, 2023, https://www.sseb.org/programs/offshore/; see also Ben Wernette, "Southeast Regional Carbon Storage Partnership: Offshore Gulf of Mexico (DE-FE0031557)," August 17, 2022, https://netl.doe.gov/sites/default/files/netl-file/22CM_CTS17_Wernette.pdf.
107. "SECARB Offshore," Southern States Energy Board, accessed October 4, 2023, https://www.sseb.org/programs/offshore/.
108. "SECARB: Southeast Regional Carbon Sequestration Partnership," Southern States Energy Board, accessed October 4, 2023, https://www.sseb.org/programs/secarb/.
109. "Gulf of Mexico Partnership for Offshore Carbon Storage (GoMCarb)," Bureau of Economic Geology Gulf Coast Carbon Center, accessed May 2, 2022, https://www.beg.utexas.edu/gccc/research/gomcarb.
110. GCCC, Gulf of Mexico Partnership.
111. Ocean Policy Committee, Ocean Climate Action Plan March 2023, 40, https://www.whitehouse.gov/wp-content/uploads/2023/03/Ocean-Climate-Action-Plan_Final.pdf.
112. Infrastructure Investment and Jobs Act of 2021, Pub. L. No. 117-58, §40307, November 15, 2021, https://www.congress.gov/117/plaws/publ58/PLAW-117publ58.pdf.
113. US Dept. of Interior, Bureau of Ocean Energy Management, 2024-2029 National OCS Oil and Gas Leasing Proposed Final Program, September 2023, at 7-2, https://www.boem.gov/sites/default/files/documents/oil-gas-energy/leasing/2024-2029_NationalOCSProgram_PFP_Sept_2023.pdf.
114. "Gulf of Mexico Fact Sheet," US Energy Information Administration, accessed May 2, 2022, https://www.eia.gov/special/gulf_of_mexico/.
115. Michael Celata, "Offshore Carbon Storage," (PowerPoint presentation, BOEM, May 19, 2022), slide 9, https://www.boem.gov/sites/default/files/documents/about-boem/regulations-guidance/BOEM-5th-International-Conference.pdf; see also: Carlos Alonso et al., "Identification of Tier 1 Depleted Reservoirs in the Gulf of Mexico," (PowerPoint presentation, BOEM, March 2022), slide 16, https://www.boem.gov/sites/default/files/documents/about-boem/BOEM-Depleted-Reservoir.pdf.
116. See Ulrich Bähr, Heinrich Böll Foundation, The Ocean Atlas, May 2017, https://eu.boell.org/en/2017/06/02/ocean-atlas-understanding-threats-our-marine-ecosystems.
117. Oliver Milman, "Hottest ocean temperatures in history recorded last year," The Guardian, January 11, 2022, https://www.theguardian.com/environment/2022/jan/11/oceans-hottest-temperatures-research-climate-crisis.
118. "Understanding Ocean Acidification," National Oceanic and Atmospheric Administration (NOAA) - Fisheries, accessed October 4, 2023, https://www.fisheries.noaa.gov/insight/understanding-ocean-acidification#.
119. ADNOC, "Minimizing our marine footprint," Accessed October 27, 2023, https://www.adnoc.ae/en/Our-Projects/Hail-Ghasha/Minimizing-our-Marine-Footprint.

120. Steven T. Anderson. "Risk, Liability, and Economic Issues with Long-Term CO_2 Storage—A Review." Natural Resources Research (2017): 26, 89–112. https://doi.org/10.1007/s11053-016-9303-6.

121. Wendt et al, CCUS screening evaluation Gulf of Mexico; see also Ahmad et al., Fate of radium on the discharge of oil and gas produced water to the marine environment (discussing the occurrence and impact of radioactive material in produced waters in offshore oil and gas extraction).

122. Carl Erbrich et al., "Challenges of offshore geotechnical engineering," Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering (2005), https://www.issmge.org/publications/publication/challenges-of-offshore-geotechnical-engineering; van der Zwaan, B., and Gerlagh, R., "Offshore CCS and ocean acidification: a global long-term probabilistic cost-benefit analysis of climate change mitigation," Climatic Change (Spring 2016): 137, 157-170, doi:10.1007/s10584-016-1674-5.

123. Bruce Roberston and Milad Mousavian, The Carbon Capture Crux.

124. See Mark Z. Jacobson, "The health and climate impacts of carbon capture and direct air capture," Energy Environ. Sci. vol. 12 (2019), 3567-74. https://doi.org/10.1039/C9EE02709B.

125. "Carbon capture and storage could also impact air pollution" European Environment Agency, November 17, 2011 (last modified November 23, 2020), https://www.eea.europa.eu/highlights/carbon-capture-and-storage-could; see also A. Waxman et al., "What are the likely air pollution impacts of carbon capture and storage?" Working Paper, October 2, 2023, available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4590320.

126. See Baskut Tuncak (Special Rapporteur on the Implications for Human Rights of the Environmentally Sound Management and Disposal of Hazardous Substances and Wastes), Rep. on Twenty-Five Years of the Mandate on Toxics, UN Doc. A/75/290, para. 11, Aug. 5, 2020, https://www.ohchr.org/en/documents/thematic-reports/a75290-report-twenty-five-years-mandate-toxics; Center for Effective Government, Living in the Shadow of Danger, Jan. 2016, https://www.foreffectivegov.org/shadow-of-danger.

127. See generally United Nations Office of the High Commissioner for Human Rights, "USA: Environmental racism in 'Cancer Alley' must end - experts." News release, March 2, 2021. https://www.ohchr.org/en/press-releases/2021/03/usa-environmental-racism-cancer-alley-must-end-experts; Greenpeace, Tim Donaghy and Charlie Jiang, Fossil Fuel Racism, April 13, 2021, https://www.greenpeace.org/usa/wp-content/uploads/2021/04/Fossil-Fuel-Racism.pdf.

128. National Petroleum Council, "Chapter Six: CO_2 Transport" in Meeting the Dual Challenge, December 2019, 6-4, https://dualchallenge.npc.org/files/CCUS-Chap_6-030521.pdf.

129. National Petroleum Council, "Chapter Six: CO_2 Transport," 6-8, 6-9.

130. Al Baroudi, Hisham et al., "A review of large-scale CO_2 shipping and marine emissions management for carbon capture, utilisation and storage," Applied Energy (Spring 2011), https://www.sciencedirect.com/science/article/pii/S0306261921000684.

131. National Petroleum Council, "CO_2 Transport," 6-10, 6-11. "The use of an existing natural gas pipeline is not a practical option for CO_2 transport for large flow rates…over long distances of hundreds of miles and more."

132. Al Baroudi, Hisham et al., CO_2 shipping and marine emissions management.

133. EPA, Carbon Dioxide as a Fire Suppressant: Examining the Risks: Appendix B, 2000, 1-2, https://www.epa.gov/sites/default/files/2015-06/documents/CO2appendixb.pdf.

134. Dan Zegart, "The Gassing Of Satartia,"Huffpost, August 26, 2021, https://www.huffpost.com/entry/gassing-satartia-mississippi-CO2-pipeline_n_60ddea9fe4b0ddef8b0ddc8f.

135. Ruth Ivory-Moore, "Scaling up CO_2 Pipeline Deployment in the U.S. - Findings from Listening Sessions Hosted by the Global CCS Institute," accessed October 6, 2023, https://www.globalccsinstitute.com/news-media/insights/scaling-up-CO2-pipeline-deployment-in-the-u-s-findings-from-listening-sessions-hosted-by-the-global-ccs-institute/; Global Energy Monitor, "Oil Pipelines by Country: Global Gas Infrastructure Tracker," accessed October 6, 2023, https://docs.google.com/spreadsheets/d/1OYH6D7c-D0FsL5GzBGijtkmvQCTkBUclj-UVoOieUFo/edit#gid=0; Global Energy Monitor, "Global Pipeline km by country and status: Global Gas Infrastructure Tracker," accessed October 6, 2023, https://docs.google.com/spreadsheets/d/1NbEpGt2K5nY0XTSB_vlOy-w9Ug8ZmvvOaRPuO9TglSIw/edit#gid=0.

136. Matt Kelso, "Pipeline Incidents Continue to Impact Residents," (Table 1), accessed October 6, 2023, https://www.fractracker.org/2018/12/pipeline-incidents-impact-residents/.

137. US Environmental Protection Agency, Carbon Dioxide as a Fire Suppressant: Examining the Risks, February 2000, 16, https://www.epa.gov/sites/default/files/2015-06/documents/co2report.pdf.

138. BOEM, Rebecca C. Smyth and Susan D. Hovorka, Best Management Practices, December 2017, 84, 84, https://espis.boem.gov/final%20reports/5663.pdf.

139. Eustis, New Report: Oil & Gas Pipeline Integrity.

140. Scott Eustis, New Report: Oil & Gas Pipeline Integrity.

141. Rebecca C. Smyth and Susan D. Hovorka, Best Management Practices, 37.

142. Rebecca C. Smyth and Susan D. Hovorka, Best Management Practices, 37.

143. Rebecca C. Smyth and Susan D. Hovorka, Best Management Practices, 12.

144. Rebecca C. Smyth and Susan D. Hovorka, Best Management Practices, 84.

145. GAO, Offshore Oil and Gas: Updated Regulations Needed to Improve Pipeline Oversight and Decommissioning, April 2019, https://www.gao.gov/products/gao-21-293; see also CIEL, Eisen et al., Toxic Assets: Making Polluters Pay When the Wells Run Dry and Bill Comes Due, April 2021, https://www.ciel.org/reports/toxic-assets-making-polluters-pay-when-wells-run-dry-and-the-bill-comes-due/.

146. Böttner, Christoph et al., "Greenhouse gas emissions from marine decommissioned hydrocarbon wells: leakage detection, monitoring and mitigation strategies," International Journal of Greenhouse Gas Control (Fall 2020), https://www.sciencedirect.com/science/article/pii/S1750583619306504?via%3Dihub.

147. Böttner, Decommissioned hydrocarbon wells: leakage detection.

148. See, e.g., Northern Lights, What We Do. ("We are developing an open and flexible infrastructure to transport CO_2 from capture sites by ship to a terminal in western Norway."); "CStore1," deepC Store, accessed October 6, 2023, https://www.deepcstore.com/cstore1 ("Covering the entire CCS value chain, CStore1 consists of … Shipping liquid CO_2 from industrial sources to CStore1's Floating Storage and Injection (FSI) Hub located in offshore Northern / Western Australia.").

149. Bo Lu. et al., "Challenges of decarbonizing global maritime container shipping toward net-zero emissions," NPJ Ocean Sustainability 2 (2023), https://doi.org/10.1038/s44183-023-00018-6.

150. RystadEnergy, "CO_2 sets sail: Carbon shipping on the rise as emitters search for league-scale storage options," News release, September 3, 2023, https://www.rystadenergy.com/news/CO2-sets-sail-carbon-shipping-on-the-rise-as-emitters-search-for-large-scale-stor.

151. IPCC, Richard Doctor et al., Chapter 4: Transport of CO_2, In: Carbon Dioxide Capture and Storage IPCC Special Report, 2005. 192, https://www.ipcc.ch/site/assets/uploads/2018/03/srccs_chapter4-1.pdf.

152. Richard Doctor et al., Chapter 4: Transport of CO_2, 186-187.

153. Hisham Al Baroudi et al., CO_2 shipping and marine emissions management, 28.

154. Hisham Al Baroudi et al., CO_2 shipping and marine emissions management, 189.

155. Hisham Al Baroudi et al., CO_2 shipping and marine emissions management, 189.

156. "Shipping and offshore pipeline transportation costs of CO_2 by distance," accessed October 6, 2023, https://www.iea.org/data-and-statistics/charts/shipping-and-offshore-pipeline-transportation-costs-of-co2-by-distance.

157. Northern Lights, Northern Lights Brochure, 4, https://norlights.com/wp-content/uploads/2021/08/Northern-Lights_brochure-June-2021-1-1.pdf.

158. Richard Doctor et al., Chapter 4: Transport of CO_2, 190.

159. NETL, "Carbon Storage FAQs."

160. NETL, "Carbon Storage FAQs."

161. IPCC, Carbon Dioxide Capture and Storage, 227.

162. Zoback, Mark D., and Steven M. Gorelick. "To Prevent Earthquake Triggering, Pressure Changes Due to CO_2 Injection Need to Be Limited." Proceedings of the National Academy of Sciences (Fall 2015). https://doi.org/10.1073/pnas.1508533112.

163. Grant Hauber, Norway's Sleipner and Snøhvit CCS, 25-27.

164. Grant Hauber, Norway's Sleipner and Snøhvit CCS, 25.

165. Grant Hauber, Norway's Sleipner and Snøhvit CCS, 26-27.

166. Grant Hauber, Norway's Sleipner and Snøhvit CCS, 26-27.

167. "Enhanced Water Recovery': Brine Extraction with CO_2 Geological Storage as Part of CCS," Global CCS Institute, accessed July 7, 2023, https://www.globalccsinstitute.com/news-media/insights/enhanced-water-recovery-brine-extraction-with-CO2-geological-storage-as-part-of-ccs/.

168. Global CCS Institute, Enhanced Water Recovery.

169. IEEFA, Bruce Robertson and Milad Mousavian, Gorgon Carbon Capture and Storage: The Sting in the Tail, April 2022, 5, https://ieefa.org/wp-content/uploads/2022/03/Gorgon-Carbon-Capture-and-Storage_The-Sting-in-the-Tail_April-2022.pdf.

170. Chevron, Fact Sheet: Gorgon Carbon Capture and Storage, July 2022, https://australia.chevron.com/-/media/australia/publications/documents/gorgon-carbon-capture-and-storage--fact-sheet.pdf.

171. Jamie Smyth and David Sheppard, "Monster problem: Gorgon project is a test case for carbon capture," Financial Times, July 25, 2021, https://www.ft.com/content/428e60ee-56cc-4e75-88d5-2b880a9b854a; Peter Milne, "Chevron's Gorgon emissions to rise after sand clogs \$3.1B C02 injection system," Boiling Cold, January 12, 2021, https://www.boilingcold.com.au/chevrons-gorgon-co2-emissions-to-rise-sand-clogs/.

172. Peter Milne, "Gorgon Emissions to Soar until Chevron Fixes CO_2 Injection," Boiling Cold, January 1, 2022, https://www.boilingcold.com.au/regulator-limits-chevrons-troubled-gorgon-CO2-injection-to-one-third-capacity/; Chevron, Gorgon Gas Development and Jansz Feed Gas Pipeline Environmental Performance Report 2022, November 4, 2022, https://australia.chevron.com/-/media/australia/our-businesses/documents/gorgon-gas-development-and-jansz-feed-gas-pipeline-environmental-performance-report-2022.pdf.

173. Daniel Mercer, "World's biggest carbon capture plant running at one third capacity, Chevron Australia reveals," ABC News, May 17, 2023, https://www.abc.net.au/news/2023-05-17/chevron-australia-carbon-capture-storage-gorgon-third-capacity/102357652; Mercer, Adam, "Emissions from WA Gas Project with World's Largest Industrial Carbon Capture System Rise by More than 50%," The Guardian, April 20, 2023, https://www.theguardian.com/environment/2023/apr/21/emissions-wa-gas-project-chevron-carbon-capture-system-pilbara-coast.
174. ("Combined salt water, brine, and produced water pipeline releases were the most frequently reported nonpetroleum substance, with over 300 events.") US Department of Transportation, Pipeline and Hazardous Materials Safety Administration, Study of Nonpetroleum hazardous liquids transported by pipeline, 21, https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/docs/news/55526/study-nonpetroleum-hazardous-liquids-transported-pipeline-july-13-2015.pdf.
175. European Commission, Sub-seabed CO_2 Storage: Impact on Marine Ecosystems (ECO_2), Final Report Summary, April 2015, 16, https://cordis.europa.eu/project/id/265847/reporting.
176. European Commission, CO2 Storage Marine Ecosystems, 16.
177. Lane, Joe et al., Uncertain storage prospects create a conundrum for carbon capture and storage ambitions, "Nature Climate Change" (Fall 2021): 925–36. https://www.nature.com/articles/s41558-021-01175-7; Lane, Joe, et al., Uncertain Storage Prospects, 925–36.
178. See generally, Lane, Joe et al., Uncertain Storage Prospects.
179. Stenshøj, Rasmus, et al., "Hydrocarbon Residue in a Danish Chalk Reservoir and Its Effects on CO_2 Injectivity," Marine and Petroleum Geology (Fall 2023): 2, https://doi.org/10.1016/j.marpetgeo.2023.106424.
180. "First Carbon Storage," Project Greensand, accessed October 9, 2023, https://www.projectgreensand.com/en/first-carbon-storage.
181. Vinca, Adriano et al., "Bearing the Cost of Stored Carbon Leakage," Frontiers Energy Research (May 2018): 6. https://www.frontiersin.org/articles/10.3389/fenrg.2018.00040/full.
182. Smyth and Hovorka, Best Management Practices, 34.
183. Smyth and Hovorka, Best Management Practices, 37.
184. Smyth and Hovorka, Best Management Practices, 9.
185. James Dinneen, "14,000 oil and gas wells remain unplugged in the Gulf of Mexico," New Scientist, May 8, 2023, https://www.newscientist.com/article/2372336-14000-oil-and-gas-wells-remain-unplugged-in-the-gulf-of-mexico/; Jeff Donn and Mitch Weiss, "Gulf awash in 27,000 abandoned wells," NBC News, July 6, 2010, https://www.nbcnews.com/id/wbna38113914; Richard Wray, "Abandoned oil wells make Gulf of Mexico 'environmental minefield,'" The Guardian July 7, 2010, https://www.theguardian.com/business/2010/jul/07/abandoned-oil-wells-gulf-mexico.
186. BOEM, Gulf of Mexico Regional Office, Impact of Abandoned Oil and Gas Wells on Air and Water Quality in the Gulf of Mexico (GOM) (GM-22-01), Environmental Studies Program: Studies Development Plan FY 2022-2023, accessed October 9, 2023, https://www.boem.gov/sites/default/files/documents/environment/environmental-studies/GM-22-01.pdf.
187. Böttner, Christoph et al., Greenhouse gas emissions from marine decommissioned hydrocarbon wells, 13.
188. Dissanayake, Anusha et al., "Simulations of Subsea CO_2 Leakage Scenarios," Trondheim Conference on CO_2 Capture, Transport and Storage (Summer 2021): 388, https://sintef.brage.unit.no/sintef-xmlui/bitstream/handle/11250/2786880/Simulations%20of%20Subsea%20CO2%20Leakage%20Scenarios.pdf?sequence=1.
189. "Risk Assessment and Management Framework for CO_2 Sequestration in Sub-Seabed Geological Structures," adopted at the joint session of the 28th Consultative Meeting of Contracting Parties under the London Convention and the 1st Meeting of Contracting Parties under the London Protocol, October 30 - November 3, 2006, para. 4.5, at 14, https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/CO2SEQUESTRATIONRAMF2006.doc.
190. "Risk Assessment and Management Framework," para 4.5, at 14; see also Conradim M et al. "Lethal and Sublethal Responses in the Clam Scrobicularia Plana Exposed to Different CO_2-Acidic Sediments." Environmental Research (Winter 2016): 642. https://pubmed.ncbi.nlm.nih.gov/27619209/; Goulding, T. A. et al., "Assessment of the Environmental Impacts of Ocean Acidification (OA) and Carbon Capture and Storage (CCS) Leaks Using the Amphipod Hyale Youngi," Ecotoxicology (Spring 2017:) 521, 525, 530-531, https://link.springer.com/article/10.1007/s10646-017-1783-6; Basallote, M.D. et al., "Lethal Effects on Different Marine Organisms, Associated with Sediment-Seawater Acidification Deriving from CO_2 Leakage," Environmental Science and Pollution Research (Summer 2021), 2554-2555, https://link.springer.com/article/10.1007/s11356-012-0899-8.
191. IPCC, Carbon Dioxide Capture and Storage, 5. See also Rastelli, Eugenio et al., "Impact of CO_2 leakage from sub-seabed carbon dioxide capture and storage (CCS) reservoirs on benthic virus–prokaryote interactions and functions," Frontiers in Microbiology (Fall 2015), https://doi.org/10.3389/fmicb.2015.00935.
192. "Risk Assessment and Management Framework," para 1.11, at 7.
193. IPCC, Carbon Dioxide Capture and Storage, 243.
194. Smyth and Hovorka, Best Management Practices, 36
195. Smyth and Hovorka, Best Management Practices, 35.
196. See Rod Nickel and Sabrina Valle, "Insight: This Decade's Oil Boom Is Moving Offshore - Way Offshore," Reuters, August 31, 2022, https://www.reuters.com/business/energy/this-decades-oil-boom-is-moving-offshore-way-offshore-2022-08-31; See also Eric Lipton, "Offshore Oil and Gas Operators Want Less Regulation, but Surprise Inspections Find Serious Safety Problems," The New York Times, March 18, 2018, https://www.nytimes.com/2018/03/18/us/offshore-drilling-safety-regulation.html.
197. Nickel and Valle, Oil boom moving offshore.
198. Smyth and Hovorka, Best Management Practices, 70.
199. Smyth and Hovorka, Best Management Practices, 60.
200. Smyth and Hovorka, Best Management Practices, 73.
201. There are at least fourteen offshore CCS projects that are being proposed alongside new fossil fuel projects. This includes six new natural gas developments, one new gas power plant, one new enhanced oil recovery project, and seven blue hydrogen projects. See this report's appendix for details on each project.
202. Esmarie Iannucci, "Greenpeace Takes a Swipe at Burrup Hub Investment," Mining Weekly, October 20, 2023, https://www.miningweekly.com/article/greenpeace-takes-a-swipe-at-burrup-hub-investment-2022-04-19; Clean State and The Conservation Council of Western Australia, Burrup Hub: Australia's most polluting fossil fuel project (undated), 8, https://d3n8a8pro7vhmx.cloudfront.net/ccwa/pages/13865/attachments/original/1632735886/CCWA_Clean-State_Burrup-Hub_Report_WEB-READER.pdf?1632735886.
203. PETRONAS, PETRONAS' Pathway to Net Zero Carbon Emissions 2050, April 2023, 12, https://www.petronas.com/sites/default/files/download/pdf/PETRONAS%20Pathway%20to%20NZCE%202050%20Third%20Edition%20Apr%202023.pdf.
204. Damon Evans, "Questions swirl around Petronas' Kasawari CCS," Energy Voice, March 11, 2021, https://www.energyvoice.com/oilandgas/asia/361503/questions-swirl-around-petronas-kasawari-ccs/; Clean State and CCWA, Burrup Hub, 8; Daniel Fitzgerald, "Future of Santos's $4.7 billion Barossa project unclear after safeguard mechanism reforms," Australian Broadcasting Corporation, March 30, 2023, https://www.abc.net.au/news/rural/2023-03-31/santos-barossa-gas-project-unclear-safeguard-mechanism-reforms/102154622.
205. Md Faudzi Mat Isa and Muhammad Akkil Azhar, "Meeting Technical Challenges in Developing High CO_2 Gas Field Offshore," Petronas Carigali SBN BHD, http://members.igu.org/html/wgc2009/papers/docs/wgcFinal00529.pdf; Trung Ghi, "Unlocking High CO_2 Gas Fields – Contributing to the Carbon Economy," Arthur D. Little, September 2021, https://www.adlittle.com/id-en/insights/viewpoints/unlocking-high-CO2-gas-fields-%E2%80%93-contributing-carbon-economy.
206. Weiland, Ralph and Nathan Hatcher, "Improving CO_2 absorber performance in LNG production," Digital Refining, April 2015, https://www.digitalrefining.com/article/1001070/improving-CO2-absorber-performance-in-lng-production#.
207. Regarding the Petronas Kasawari project, see Trent Jacobs, "What you should know about offshore and sour gas CCS: High cost, leak mitigation, and transportation," Journal of Petroleum Technology, June 1, 2022, https://jpt.spe.org/what-you-should-know-about-offshore-and-sour-gas-ccs-high-cost-leak-mitigation-and-transportation; Damon Evans, "Petronas advances giant Kasawari CCS project as FEED competition heats up," Energy Voice, June, 6, 2021, https://www.energyvoice.com/oilandgas/asia/369987/petronas-advances-giant-kasawari-ccs-project-as-feed-competition-heats-up/. For the Barossa project, see IEEFA, John Robert, "Even with a duplicate pipeline and CCS, emissions from Santos's proposed Barossa project remain the same," February 16, 2022, https://ieefa.org/articles/ieefa-australia-even-duplicate-pipeline-and-ccs-emissions-santoss-proposed-barossa-project.
208. Robert, Emissions at the Barossa project remain the same.
209. CIEL, Fuel to the Fire, 14–16.
210. Robertson and Mousavian, The Carbon Capture Crux, 10.
211. CIEL, Fuel to the Fire, 15.
212. National Petroleum Council, Chapter Eight – CO_2 Enhanced Oil Recovery In: Meeting the Dual Challenge: A Roadmap to At-Scale Deployment of Carbon Capture, Use, and Storage, December 2019, 8–15, https://www.energy.gov/sites/default/files/2021-06/2019%20-%20Meeting%20the%20Dual%20Challenge%20Vol%20III%20Chapter%208.pdf.
213. Southern States Energy Board, David E. Riestenberg et al., SOSRA Infrastructure Development Recommendations (Deliverable 9.2.a), September 30, 2019, 13, https://www.osti.gov/servlets/purl/1582439.
214. Oil & Gas Authority, Enhanced Oil Recovery (EOR) Strategy, 2016, 4, https://www.nstauthority.co.uk/media/1143/eor_strategy_final-2016.pdf.
215. See e.g., NETL, Malone, Taylor et al., CO_2-EOR Offshore Resource Assessment, June 2014, https://doi.org/10.2172/1523638; Southern States Energy Board, SOSRA Infrastructure Development Recommendations.
216. Southern States Energy Board, SOSRA Infrastructure Development Recommendations, 1.

217. See e.g., Trout, Kellly et al., "Existing fossil fuel extraction would warm the world beyond 1.5 °C," Environmental Research Letters (May 2022), https://iopscience.iop.org/article/10.1088/1748-9326/ac6228; Welsby, Dan et al., "Unextractable fossil fuels in a 1.5 °C world," Nature (Fall 2021): 230–234, https://doi.org/10.1038/s41586-021-03821-8.
218. See IPCC, AR6 WGIII, 643 ("CCS always adds cost").
219. IPCC, AR6 WGIII, Figure SPM.7.
220. "Oil and petroleum products explained: Offshore oil and gas," US Energy Information Administration, accessed October 11, 2023, https://www.eia.gov/energyexplained/oil-and-petroleum-products/offshore-oil-and-gas-in-depth.php; IEA, Offshore Energy Outlook (2018), 23, https://iea.blob.core.windows.net/assets/f4694056-8223-4b14-b688-164d6407bf03/WEO_2018_Special_Report_Offshore_Energy_Outlook.pdf; see also, a 2021 study stating: "Similar to offshore pipelines, offshore CO_2 storage is generally more expensive than onshore storage" and noting that offshore pipelines "tend to be more expensive due to the more complicated offshore equipment required for construction on the ocean floor." Smith, Erin et al., "The cost of CO_2 transport and storage in global integrated assessment modeling," International Journal of Greenhouse Gas Control (July 2021): 2, 4 (in pdf version), https://doi.org/10.1016/j.ijggc.2021.103367.
221. See e.g., Advisory Council of the European Technology Platform for Zero Emission Fossil Fuel Power Plants, The Costs of CO_2 Storage: Post-demonstration CCS in the EU, 2011, 26–27, https://www.globalccsinstitute.com/archive/hub/publications/119816/costs-CO2-storage-post-demonstration-ccs-eu.pdf; see also: IPCC, Herzog, Howard and Koen Smekens (Chapter 8: Cost and economic potential), In: IPCC Special Report on Carbon dioxide Capture and Storage, 2005, 344–346, https://www.ipcc.ch/site/assets/uploads/2018/03/srccs_chapter8-1.pdf.
222. Robertson and Mousavian, The Carbon Capture Crux.
223. Equinor, "World's largest project to use CO_2 for enhanced oil recovery offshore," Press release, March 8, 2006. https://www.equinor.com/news/archive/2006/03/08/WorldsLargestProjectToUseCO2ForEnhancedOilRecoveryOffshore.
224. Nick Terdre, "CO_2 for EOR off Norway under study," Offshore Magazine, September 1, 2007, https://www.offshore-mag.com/regional-reports/article/16760801/CO2-for-eor-off-norway-under-study.
225. Jens Stoltenberg, "Red-green moon landing," (October 21, 2006), https://www.regjeringen.no/no/dokumentarkiv/stoltenberg-ii/smk/taler-og-artikler/2006/rodgronn-manelanding/id273361/; Air Pollution and Climate Secretariat, Carbon Capture and Storage in Norway, 4, 13, 19.
226. Fouche, Gwladys, "Norway Delays CCS Project Again, Angers Greens," Reuters, March 1, 2011, https://www.reuters.com/article/us-norway-ccs/norway-delays-ccs-project-again-angers-greens-idUSTRE72036Q20110301; "Norwegian Energy Minister Resigns amid Record Dry Spell and Investment Forecast Cuts," S&P Global, March 7, 2011, https://www.spglobal.com/marketintelligence/en/mi/country-industry-forecasting.html?id=1065929150.
227. Solheim, Hilde, Hvem, hva og hvorfor om Mongstad, January 22, 2014, https://www.aftenposten.no/norge/i/aq5M/hvem-hva-og-hvorfor-om-mongstad; Air Pollution and Climate Secretariat, Carbon Capture and Storage in Norway, 4, 20.
228. Global CCS Institute, David Kearns et al.,Technology Readiness and Costs of CCS, March 2021, 5, https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Technology-Readiness-and-Costs-for-CCS-2021-1.pdf.
229. See generally, Global CCS Institute, Cevikel, Selim and Jerrad Thomas, The Investment Case for CCS: Policy Drive and Case Studies, 2023, https://www.globalccsinstitute.com/wp-content/uploads/2023/09/The-Investment-Case-for-CCS-Global-CCS-Institute.pdf (discussing multiple forms of subsidies and incentive schemes available for carbon capture). On EU support for CCS, see generally, European Commission, Carbon capture, storage and utilisation, accessed October 31, 2023, https://energy.ec.europa.eu/topics/oil-gas-and-coal/carbon-capture-storage-and-utilisation_en.
230. See, e.g., Project Greensand, What is Project Greensand?; Nicola Jones, "Solution or Band-Aid? Carbon Capture Projects Are Moving Ahead," Yale Environment 360, June 7, 2022, https://e360.yale.edu/features/solution-or-band-aid-carbon-capture-projects-are-moving-ahead; Bart H. Meijer, "Dutch govt grants $2.4 bln in subsidies to huge carbon storage project," Reuters, May 9, 2021, https://www.reuters.com/business/sustainable-business/dutch-govt-grants-24-bln-subsidies-huge-carbon-storage-project-2021-05-09/.
231. See Robertson and Mousavian, The Carbon Capture Crux.
232. See this report's appendix for a list of subsidized projects.
233. See HM Treasury, Policy Paper: Spring Budget 2023, https://www.gov.uk/government/publications/spring-budget-2023/spring-budget-2023-html#annex-a-financing ("The government will also provide up to £20 billion funding for early deployment of CCUS, to help meet the government's climate commitments. A shortlist of projects for the first phase of CCS deployment will be announced later this month. Further capture projects will be able to enter a selection process for Track 1 expansion to be launched this year, and 2 additional clusters will be selected through a Track 2 process, with details announced shortly."); "PM outlines his Ten Point Plan for a Green Industrial Revolution for 250,000 jobs," Prime Minister's Office, MP Boris Johnson, November 18, 2020, https://www.gov.uk/government/news/pm-outlines-his-ten-point-plan-for-a-green-industrial-revolution-for-250000-jobs.
234. Global CCS Institute, "The Global CCS Institute Welcomes the UK Government's Decision to Support both Viking and Acorn CCUS Cluster Projects," press release, August 1, 2023, https://www.globalccsinstitute.com/news-media/press-room/media-releases/the-global-ccs-institute-welcomes-the-uk-governments-decision-to-support-both-viking-and-acorn-ccus-cluster-projects/.
235. See this report's appendix for project descriptions.
236. "Costs of the Longship Project," CCS Norway, accessed October 3, 2023, https://ccsnorway.com/costs/.
237. See this report's appendix.
238. See, e.g., Firth, Sammie, "Porthos Project Must Be First Step towards Europe-Wide CO_2 Storage Infrastructure," Clean Air Task Force, October 18, 2023, https://www.catf.us/2023/10/porthos-project-must-be-first-step-towards-europe-wide-CO2; "East Coast Cluster Selected as One of the UK's First Two Carbon Capture and Storage Projects," East Coast Cluster, Accessed October 26, 2023, https://eastcoastcluster.co.uk/press-release-east-coast-cluster-selected-as-one-of-the-uks-first-two-carbon-capture-and-storage-projects/; "The Hynet North West: A Project Marker in the Journey towards the Net Zero Target," Eni, Accessed October 26, 2023, https://www.eni.com/en-IT/net-zero/hynet-cattura-CO2-uk.html; Carbon Clean, "Acorn Project Selects Carbon Clean's Technology for Plant Feed Study," September 19, 2022, https://www.carbonclean.com/news/acorn-project-partners-select-carbon-clean.
239. See this report's appendix for projections regarding total captured emissions; for Europe's total CO_2 emissions in 2021, see Crippa, M et al., Joint CO_2 emissions of all world countries.
240. "Section 45Q Credit for Carbon Oxide Sequestration," IEA, last modified August, 21 2023, https://www.iea.org/policies/4986-section-45q-credit-for-carbon-oxide-sequestration.
241. 26 U.S.C. § 45Q (b)(1)(A)(i)(I)-(II), (ii)(I)-(II). Per tonne figures of $85 and $60 reflect the maximum amount available if prevailing wage and apprenticeship requirements are satisfied, providing a five-times multiplier for the applicable credits of $17 and $12, respectively. 26 U.S.C. §45Q(h).
242. 26 U.S.C. § 45Q (c)(1)(A)-(B)
243. See 26 U.S. Code § 6417(a), (b)(3), (d)(1), (d)(3)(C).
244. Blum, Jordan, and Jerry Ashcroft, Crescent begins to shine bright after rapid, but quiet, growth, Hart Energy, August 4, 2023, https://finance.yahoo.com/news/crescent-begins-shine-bright-rapid-210000159.html.
245. Kearns et al., "Technology Readiness and Costs of CCS", 23.
246. 26 U.S.C § 45Q. See Leslie Kaufman & Kevin Crowley, "There Are Fortunes to Be Made in the Carbon Capture Gold Rush," Bloomberg, January 11, 2023, https://www.bloomberg.com/news/articles/2023-01-11/there-are-fortunes-to-be-made-in-the-carbon-capture-gold-rush#xj4y7vzkg.
247. National Environmental Policy Act of 1969, § 102, 42 U.S.C. §4332; see also 40 CFR § 1508.18 (defining "major federal action").
248. 42 U.S.C. §4332(C); see also 40 C.F.R. parts 1502, 1503, & §1506.11.
249. Fiscal Responsibility Act, § 321(a)(3), 2 U.S.C. §900. See also National Environmental Policy Act, NEPA.gov, Amendments to NEPA from the Fiscal Responsibility Act of 2023 (last visited Sept 15, 2023), https://ceq.doe.gov/laws-regulations/fra.html.
250. Environmental Protection and Biodiversity Conservation Act 1999 (Cth) Ch 4 (Austl.).
251. Planning and Building Act (2008), Act of 27 June 2008 No. 71 relating to Planning and the Processing of Building Applications, §§ 4-1. Unofficial translation at https://www.regjeringen.no/en/dokumenter/planning-building-act/id570450/.
252. Pollution Control Act, Act of 13 March 1981 No. 6 Concerning Protection Against Pollution and Concerning Waste, Unofficial translation at https://www.regjeringen.no/en/dokumenter/pollution-control-act/id171893/#.
253. See, e.g., Regulations relating to exploitation of subsea reservoirs on the continental shelf for storage of CO_2 and relating to transportation of CO_2 on the continental shelf, laid down by Royal Decree on 5 December 2014 pursuant to Section 3 of Act No. 12 of 21 June 1963 relating to scientific research and exploration for and exploitation of subsea natural resources other than petroleum resources. Submitted by the Ministry of Petroleum and Energy, https://www.npd.no/en/regulations/regulations/exploitation-of-subsea-reservoirs-on-the-continental-shelf-for-storage-of-and-transportation-of-co/.

254. Grunnloven [Grl.] [Constitution] May 17, 1814 (rev. 2014), Art. 112 (Nor.). Unofficial translation at https://lovdata.no/dokument/NLE/lov/1814-05-17; Greenpeace Nordic Association v. Ministry of Petroleum and Energy, Case No. 20-051052SIV-HRET (Norwegian Supreme Court, 2020), paras 142. Unofficial translation at www.klimasøksmål.no/wp-content/uploads/2021/01/judgement_translated.pdf.

255. Erik E. Cordes, et al., "Environmental Impacts of the Deep-Water Oil and Gas Industry: A Review to Guide Management Strategies," Front. Environ. Sci., vol. 4, article 58 (16 September 2016): 7-9, https://doi.org/10.3389/fenvs.2016.00058, (discussing impacts from offshore oil and gas activities).

256. Endangered Species Act, 16 U.S.C § 1531-1544.

257. Marine Mammal Protection Act, 16 U.S.C. §1361-1362, §1371-1393.

258. See "Threatened and Endangered Species List Gulf of Mexico," NOAA Fisheries, accessed 30 October 2023, https://www.fisheries.noaa.gov/southeast/consultations/threatened-and-endangered-species-list-gulf-mexico.

259. EPBC of 1999, supra note 186, at pt I para 3, and at pt XIII div 1 sub-div C para 18.

260. See discussion of protected species in this summary of the project's EIA, pg. 21-22: https://ntepa.nt.gov.au/__data/assets/pdf_file/0007/1231927/ser-executive-summary.pdf.

261. Naturmangfoldloven [Nature Diversity Act], 19 June 2009, No. 100, §§2, 23, 24. Unofficial translation at https://www.regjeringen.no/en/dokumenter/nature-diversity-act/id570549/.

262. Walday, Mats, and Tone Kroglund, European Environmental Agency § (2002), Section 3.1.3. https://www.eea.europa.eu/publications/report_2002_0524_154909/regional-seas-around-europe/NorthSea.pdf.

263. Fishery Conservation and Management Act (Magnuson-Stevens Act), 16 U.S.C. §§1801-1891(d).

264. Marine Resources Act, Act of 6 June 2008 no. 37 relating to the management of wild living marine resources, §4, https://www.fiskeridir.no/English/Fisheries/Regulations/The-marine-resources-act.

265. Marine Resources Act, § 7.

266. US Environmental Protection Agency, Regulatory and Statutory Authorities Relevant to Carbon Capture and Sequestration (CCS) Projects, accessed 30 October 2023, https://www.epa.gov/system/files/documents/2023-10/regulatory-and-statutory-authorities-relevant-to-carbon-capture-and-sequestration-ccs-projects.pdf.

267. See Carmen E. Elrick-Barr, Policy is rarely intentional or substantial for coastal issues in Australia, Ocean & Coastal Management Vol. 207, 15 June 2021, 105609, at 2, https://doi.org/10.1016/j.ocecoaman.2021.105609.

268. Pollution Control Act, §§ 4, 7, 11-20, Unofficial translation at: https://www.regjeringen.no/en/dokumenter/pollution-control-act/id171893/#.

269. See Infrastructure, Investment and Jobs Act, Public Law 117-58—November 15, 2021, §40307(c), 135 Stat. 1003 ("A carbon dioxide stream injected for the purpose of carbon sequestration under subparagraph (E) of section 8(p)(1) of the Outer Continental Shelf Lands Act (43 U.S.C. 1337(p)(1)) shall not be considered to be material (as defined in section 3 of the Marine Protection, Research, and Sanctuaries Act of 1972 (33 U.S.C. 1402)) for purposes of that Act (33 U.S.C. 1401 et seq.).").

270. "United Nations Convention on the Law of the Sea," United Nations Treaty Collection, accessed November 4, 2023, https://treaties.un.org/pages/ViewDetailsIII.aspx?src=TREATY&mtdsg_no=XXI-6&chapter=21&Temp=mtdsg3&clang=_en#1.

271. United Nations Convention on the Law of the Sea (UNCLOS), Dec. 10, 1982, 1833 U.N.T.S. 397.

272. See UNCLOS, arts. 2-5. In instances where the coasts of two States are opposite each other, delimitation of the territorial seas may vary (depend on the median line and other circumstances). Id. art. 15.

273. UNCLOS, arts. 55-57.

274. UNCLOS, art. 76.

275. For example, the Cameron Parish CO_2 Hub in Louisiana and the Corpus Christi Offshore project in Texas. See this report's appendix for details on the projects.

276. For example, the Bayu-Undan CCS project in Australia and TImor-Leste will be some 300 km offshore, the Polaris Carbon Storage project in Norway will be about 100 km offshore. See this report's appendix for details on the projects.

277. UNCLOS, art. 77.

278. UNCLOS, art. 193.

279. UNCLOS, art. 136.

280. UNCLOS, arts. 145-146. UNCLOS stipulates that States may lay pipelines on the high seas, UNCLOS art. 112, and specifically mentions the need for protection of the seabed against harms caused by drilling, waste disposal, dredging, and the installation, operation and maintenance of infrastructure on the seas, id. art. 145.

281. See United Nations Framework Convention on Climate Change (UNFCCC), Transboundary carbon capture and storage project activities, UN Doc. FCCC/TP/2012/9, November 1, 2012, paragraph 45, https://unfccc.int/resource/docs/2012/tp/09.pdf.

282. See The U.S. Position on the U.N. Convention on the Law of the Sea (UNCLOS), Office of the Staff Judge Advocate, U.S. Indo-Pacific Command, 97 Int'l Law Studies 81, 82 (2021) ("Following adoption of the Convention in 1982, it has been the policy of the United States to act in a manner consistent with its provisions relating to traditional uses of the oceans and to encourage other countries to do likewise.") https://digital-commons.usnwc.edu/cgi/viewcontent.cgi?article=2949&context=ils; see also National Ocean Service, What is the Law of The Sea?, https://oceanservice.noaa.gov/facts/lawofsea.html (last visited October 17, 2023) ("The United States recognizes that the 1982 Convention reflects customary international law and complies with its provisions.").

283. See 43 U.S.C. § 1312 (providing that "[t]he seaward boundary of each original coastal State is approved and confirmed as a line three geographic miles distant from its coast line"); "Outer Continental Shelf," US Dept of Interior, Bureau of Ocean Energy Management, accessed October 30, 2023, https://www.boem.gov/oil-gas-energy/leasing/outer-continental-shelf.

284. "Federal Offshore Lands" US Dept. of Interior, Bureau of Ocean Energy Management, accessed October 30, 2023, https://www.boem.gov/oil-gas-energy/leasing/federal-offshore-lands#:~:text=The%20Submerged%20Lands%20Act%20(SLA,and%20the%20Gulf%20of%20Mexico.

285. UNCLOS, art. 192.

286. UNCLOS, art. 194

287. UNCLOS, art. 196.

288. UNCLOS, art. 194.

289. UNCLOS, art. 196.

290. UNCLOS, art. 195.

291. The applicability of UNCLOS dumping provisions to deliberate injection of CO_2 under the seabed in different parts of the oceans depends on whether CO_2 is considered waste, and if CO_2 injection for sub-seabed sequestration is considered disposal. Article 210 of UNCLOS defines pollution by marine dumping as "any deliberate disposal of wastes or other matter from vessels, aircraft, platforms or other man-made structures at sea" but excluding "placement of matter for a purpose other than the mere disposal thereof." (Art. 1) UNCLOS requires states to enact laws and measures to prevent, reduce, and control such pollution. Because the London Convention/London Protocol sets the relevant global standard on marine dumping, its treatment of CO_2 injection could control the interpretation under UNCLOS.

292. UNCLOS, art. 206. ("When States have reasonable grounds for believing that planned activities under their jurisdiction or control may cause substantial pollution of or significant and harmful changes to the marine environment, they shall, as far as practicable, assess the potential effects of such activities on the marine environment and shall communicate reports of the results of such assessments in the manner provided in article 205.")

293. See, e.g., UNFCCC, Transboundary carbon capture and storage project activities, 13-14 nn. 50-53 (discussing the OSPAR Convention for the North Atlantic, the 2010 Amended Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Western Indian Ocean, the1983 Cartagena Convention for the Caribbean Sea; the 1976 Barcelona Convention for the Mediterranean Sea; the 1992 Helsinki Convention for the Baltic Sea; the 1982 Jeddah Convention for the Red Sea and Gulf of Aden; the 1978 Kuwait Convention for the Persian Gulf; the 1981 Lima Convention for the Southeast Pacific; and the 1986 Noumea Convention for the South Pacific).

294. Draft agreement under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (4 March 2023), https://www.un.org/bbnj/sites/www.un.org.bbnj/files/draft_agreement_advanced_unedited_for_posting_v1.pdf [hereinafter BBNJ Agreement].

295. BBNJ Agreement, Part IV, arts. 27-39.

296. See, e.g, Convention on Biological Diversity et al., Special Places in the Ocean: A Decade of Describing Ecologically or Biologically Significant Marine Areas (EBSAs) (2021), at 40-41, https://www.cbd.int/marine/ebsa/booklet-ebsa-impact-en.pdf.

297. For a discussion of possible international legal instruments and their relevance to transboundary CCS projects, see FCCC/TP/2012/9, https://unfccc.int/resource/docs/2012/tp/09.pdf.

298. The Convention on the Control of Transboundary Movement of Hazardous Wastes and Their Disposal of 22 March 1989 (1673 U.N.T.S. 126).

299. Amendment to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal. Geneva, 22 September 1995.

300. Bamako Convention on the Ban of the Import into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa, 30 January 1991 (entered into force April 22, 1998), 2101 UNTS 177, https://www.informea.org/en/treaties/bamako-convention/text.

301. See IEA, Carbon Capture and Storage Model Regulatory Framework, November 2010, at 32-33, https://www.iea.org/reports/carbon-capture-and-storage-model-regulatory-framework.

302. International Convention for the Safety of Life at Sea, 1974 (with annex and final act of the International Conference on Safety of Life at Sea, 1974), 1184 UNTS 3 (entered into force 25 May 1980).
303. SOLAS, amended, Ch. VII, part C. See also Element Energy et al, Shipping CO_2 – UK Cost Estimation Study, November 2018, at 54–55, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/761762/BEIS_Shipping_CO2.pdf (discussing the SOLAS Convention and the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code).
304. Marpol Annex VI, November 17, 2022, https://www.bahamasmaritime.com/wp-content/uploads/2022/11/MN061-MARPOL-Annex-VI-v1.1.pdf; Marpol Annex VI, Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP), accessed 30 October 2023, https://www.marpol-annex-vi.com/eedi-seemp/.
305. Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention), 1989 U.N.T.S. 309, February 25, 1991.
306. Espoo Convention, Appendix I, paras. 8, 10, 15, 16.
307. Espoo Convention, Appendix III.
308. See UNFCCC, Transboundary carbon capture and storage project activities, paras 50–52.
309. London Protocol, art. 3(1).
310. See International Maritime Organization, "Map of Parties to the London Convention/Protocol" (status as of April 2022), https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/LC_LP/Map%20of%20Parties%202022.pdf. In Australia, for example, the Environment Protection (Sea Dumping) Act 1981 implements the requirements of the London Protocol, https://www.legislation.gov.au/Series/C2004A02478. In the UK, the London Protocol is implemented via the Marine and Coastal Access Act 2009, in England, Wales and Northern Ireland and the Marine (Scotland) Act 2010, https://questions-statements.parliament.uk/written-questions/detail/2020-04-29/41436.
311. "Ocean Dumping: International Treaties," United States Environmental Protection Agency, accessed on 30 October 2023, https://www.epa.gov/ocean-dumping/ocean-dumping-international-treaties#:~:text=The%20United%20States%20signed%20the,Parties%20to%20the%20London%20Protocol.
312. See "Ocean Dumping: International Treaties," United States Environmental Protection Agency, accessed on 30 October 2023, https://www.epa.gov/ocean-dumping/ocean-dumping-international-treaties#:~:text=The%20London%20Protocol%20entered%20into,the%20purpose%20of%20ocean%20dumping.
313. London Protocol Annex 1: Wastes or other matter that may be considered for dumping, section 1.8.4, https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/PROTOCOLAmended2006.pdf.
314. 2012 Specific Guidelines for the Assessment of Carbon Dioxide for Disposal into Sub-Seabed Geological Formations, Adopted 2 November 2012 (LC 34/15, annex 8), https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/2012%20SPECIFIC%20GUIDELINES%20FOR%20THE%20ASSESSMENT%20OF%20CARBON%20DIOXIDE.pdf.
315. 2012 Specific Guidelines for the Assessment of Carbon Dioxide for Disposal into Sub-Seabed Geological Formations.
316. While the movement of CO_2 across borders for injection is considered a prohibited form of export of a material for dumping, "[t]ransboundary movement of CO_2 streams after injection is not export in the sense of article 6, of the London Protocol (see resolution LP.3(4), adopted on 30 October 2009, Recital 12)." Guidelines, footnote 3, https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/2012%20SPECIFIC%20GUIDELINES%20FOR%20THE%20ASSESSMENT%20OF%20CARBON%20DIOXIDE.pdf.
317. Resolution LP.3(4) on the Amendment to Article 6 of the London Protocol (adopted on 30 October 2009), https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/LCLPDocuments/LP.3(4).pdf.
318. London Protocol, Art. 21(3).
319. Those countries include Norway, the UK, the Netherlands, the Islamic Republic of Iran, Finland, Estonia, Sweden, Denmark, the Republic of Korea and Belgium. See "45th Consultative Meeting of Contracting Parties to the London Convention and the 18th Meeting of Contracting Parties to the London Protocol (LC 45/LP 18)," International Maritime Organization, accessed November 4, 2023, https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/LC-45-LP-18.aspx. In June 2023, Australia took steps toward ratifying the amendment, by introducing an amendment to its national legislation, the Environment Protection (Sea Dumping) Act 1981, to allow for international export of CO_2. See Parliament of Australia, "Environment Protection (Sea Dumping) Amendment (Using New Technologies to Fight Climate Change) Bill 2023," available at: https://www.aph.gov.au/Parliamentary_Business/Bills_LEGislation/Bills_Search_Results/Result?bId=r7052.
320. Resolution LP.5(14) on the Provisional Application of the 2009 Amendment to Article 6 of the London Protocol (2019) available as Annex 2 in the report of the meeting LC 41/LP 14, https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/LC_LP/LP%20provisional%20application%202009%20amendment.pdf.
321. "45th Consultative Meeting of Contracting Parties to the London Convention and the 18th Meeting of Contracting Parties to the London Protocol (LC 45/LP 18)," IMO.
322. See Naida Hakirevic Prevljak, "Danish-Belgian CCS agreement paves way for creating 'actual market' for maritime transport of CO_2", Offshore Energy, October 3, 2022, https://www.offshore-energy.biz/danish-belgian-ccs-agreement-paves-way-for-creating-actual-market-for-maritime-transport-of-CO2/. See also EU London Protocol Analysis, Sept 2022, https://climate.ec.europa.eu/document/dfbbc90c-071e-4088-ada2-7af467084b30_en.
323. Global CCS Institute, "CCS Commercial and Regulatory Frameworks: Lessons Learned from CCS Front-runners in Norway", 15 March 2023, https://www.globalccsinstitute.com/wp-content/uploads/2023/03/GCCSI-Webinar-CCS-Learnings-in-Norway.pdf; Government of Norway, "Belgium and Norway will work closer on cross-border transport and storage of CO_2." News release, April 24, 2023, https://www.regjeringen.no/en/aktuelt/belgium-and-norway-will-work-closer-on-cross-border-transport-and-storage-of-CO2/id2973472/; "Norway and France to cooperate on carbon capture and storage," Reuters, December 19, 2022, https://www.reuters.com/business/energy/norway-france-cooperate-carbon-capture-storage-2022-12-19/.
324. See Environment Protection (Sea Dumping) Amendment (Using New Technologies to Fight Climate Change) Bill 2023, Part 1, clause 3. London Protocol, Article 6(2)(1), https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/238284/8046.pdf.
325. See Samantha Hepburn, "Australia has introduced a new bill that will allow us to ship carbon emissions overseas. Here's why that's not a great," The Conversation, June 27, 2023, https://theconversation.com/australia-has-introduced-a-new-bill-that-will-allow-us-to-ship-carbon-emissions-overseas-heres-why-thats-not-a-great-idea-208456; see also Submissions received by the Senate Standing Committee on Environment and Communications, Parliament of Australia, from Environmental Defenders Office, IEEFA, and others, available at https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Environment_and_Communications/SeaDumpingBill/Submissions.
326. OSPAR Decision 2007/1 (OSPAR 07/25/1, Annex 5).
327. OSPAR Convention Annex II, Art. 3 (June 2007), https://www.ospar.org/site/assets/files/1169/pages_from_ospar_convention_a2.pdf (emphasis added). See also OSPAR Decision 2007/02 (OSPAR 07/24/01, Annex 6), regarding the safe storage of CO_2 in geological formations and Guidelines for risk assessment and management of storage of CO_2 streams in geological formations (OSPAR Agreement 2007-12) https://www.ospar.org/work-areas/oic/carbon-capture-and-storage.
328. OPSAR, Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic 2030, 2021, S12.03, https://www.ospar.org/documents?v=46337. ("By 2024 OSPAR will review the results of monitoring that is undertaken in relation to carbon dioxide storage to assess whether the monitoring techniques deployed are adequate to demonstrate that carbon dioxide streams are retained permanently in the storage complex. By 2026 OSPAR will evaluate the effectiveness of OSPAR measures to ensure that carbon dioxide streams are retained permanently in the storage complex and will not lead to any significant adverse consequences for the marine environment, human health and other legitimate uses of the maritime area.")
329. See UNFCCC, Transboundary carbon capture and storage project activities, 8.
330. EU CCS Directive of 2009, art. 2. Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006.
331. EU CCS Directive (2009), art. 1.
332. EU CCS Directive (2009), art. 4(1).
333. EU CCS Directive (2009), art. 1.
334. See Regulations relating to exploitation of subsea reservoirs on the continental shelf for storage of CO_2 and relating to transportation of CO_2 on the continental shelf, https://www.npd.no/en/regulations/regulations/exploitation-of-subsea-reservoirs-on-the-continental-shelf-for-storage-of-and-transportation-of-co/.
335. Forskrift om utnyttelse av undersjøiske reservoarer på kontinentalsokkelen til lagring av CO_2 og om transport av CO_2 på kontinentalsokkelen, FOR-2014-12-05-1517 (Regulations relating to exploitation of subsea reservoirs on the continental shelf for storage of CO_2 and relating to transportation of CO_2 on the continental shelf).
336. Forskrift om begrensning av forurensning (forurensningsforskriften), FOR-2021-07-10-2383; Forskrift til lov om petroleumsvirksomhet, FOR-1997-06-27-653 (Petroleum Regulation).

337. See the description of the regulatory process in: Gassnova, Regulatory lessons learned from longship this report discussing regulatory lessons from Longship, 2022, 15–17, https://gassnova.no/app/uploads/sites/6/2022/07/Regulatory-lessons-learned-from-Longship-FINAL-WEB-1.pdf.

338. Offshore Petroleum and Greenhouse Gas Storage Act 2006, No. 14, 2006 (as amended and in force on 18 October 2023), https://www.legislation.gov.au/Details/C2023C00337.

339. See Australian Government, Dept of Industry, Science and Resources, "Offshore greenhouse gas storage," accessed on 30 October 2023, https://www.industry.gov.au/mining-oil-and-gas/offshore-greenhouse-gas-storage; see also Australian Government, Dept. of Climate Change, Energy, the Environment and Water, "Carbon Capture, Use and Storage," accessed on 30 October 2023, https://www.dcceew.gov.au/climate-change/emissions-reduction/carbon-capture-use-storage.

340. See Tim Power, "How Australian laws and regulations affect carbon capture and storage," White & Case, January 29, 2021, https://www.whitecase.com/insight-our-thinking/how-australian-laws-and-regulations-affect-carbon-capture-and-storage.

341. See US Environmental Protection Agency, Regulatory and Statutory Authorities Relevant to Carbon Capture and Sequestration (CCS) Projects, accessed 30 October 2023, https://www.epa.gov/system/files/documents/2023-10/regulatory-and-statutory-authorities-relevant-to-carbon-capture-and-sequestration-ccs-projects.pdf.

342. See US Environmental Protection Agency, "Primary Enforcement Authority for the Underground Injection Control Program," accessed on 30 October 2023, https://www.epa.gov/uic/primary-enforcement-authority-underground-injection-control-program-0.

343. US Office of Information and Regulatory Affairs, View Rule: DOI/ASLM, Carbon Sequestration, RIN: 1082-AA04 (Spring 2023), https://www.reginfo.gov/public/do/eAgendaViewRule?pubId=202304&RIN=1082-AA04.

344. IEA, Carbon Capture and Storage Model Regulatory Storage Information Paper, November, 2010, https://iea.blob.core.windows.net/assets/252aa6c0-c59b-4151-a86f-8d19373a360d/model_framework.pdf.

345. "Shocking gaps in basic knowledge of deep sea life," University of Oxford, accessed October 13, 2023, https://www.ox.ac.uk/news/2017-08-21-shocking-gaps-basic-knowledge-deep-sea-life-3.

346. University of Oxford, Shocking Gaps Deep Sea Life.

347. BOEM, BOEM Gulf of Mexico Regional Office, Impact of Abandoned Oil and Gas Wells, September 18, 2023, https://www.boem.gov/sites/default/files/documents/environment/environmental-studies/GM-22-01_0.pdf.

348. EU CCS Directive (2009), art, 12(1).

349. Smyth and Hovorka, Best Management Practices, 37.

350. The White House, Council on Environmental Quality Report to Congress on Carbon Capture, Utilization, and Sequestration, 2021, 41, https://www.whitehouse.gov/wp-content/uploads/2021/06/CEQ-CCUS-Permitting-Report.pdf.

351. CCUS Projects Network, Dr Peter A Brownsort, Briefing on carbon dioxide specifications for transport, November 29, 2019, https://www.ccusnetwork.eu/sites/default/files/TG3_Briefing-CO2-Specifications-for-Transport.pdf.

352. For example, when CCS projects were considered under the Kyoto Protocol Clean Development Mechanism, the issue of liability was among the complexities addressed by State parties. See, e.g., UNFCCC, Decision 10/CMP.7 Modalities and procedures for carbon dioxide capture and storage in geological formations as clean development mechanism project activities, UN Doc. FCCC/KP/CMP/2011/10/Add.2, Section 5, page 29–30; https://www.ciesin.columbia.edu/repository/entri/docs/cop/Kyoto_CMP7_dec10.pdf.

353. See UNFCCC, Transboundary carbon capture and storage project activities, 18–31.

354. Ingelson, Allan et al., "Long-term liability for carbon capture and storage in depleted North American oil and gas reservoirs - a comparative analysis," 31 Energy Law Journal 431 (2010), https://www.eba-net.org/wp-content/uploads/2023/02/10-20_431_ccs_liability.pdf.

355. Allan et al., Long-term liability for CCS in North American oil and gas reservoirs - a comparative analysis, 461.

356. Greenpeace, Roche, Pete et al., The Global Crisis of Nuclear Waste, November 2018, 8.

357. 30 La. Stat. § 1109 ("Cessation of storage operations; liability release") (effective 10 January 2024).

358. International Energy Agency, Legal and Regulatory Frameworks for CCUS: An IEA CCUS Handbook (2022), at 70, https://iea.blob.core.windows.net/assets/bda8c2b2-2b9c-4010-ab56-b941dc8d0635/LegalandRegulatoryFrameworksforCCUS-AnIEACCUSHandbook.pdf.

359. Brandon Mulder, "Long-term liability rules needed for scaling Gulf offshore carbon storage projects: experts," S&P Global, April 28, 2022, https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/042822-long-term-liability-rules-needed-for-scaling-gulf-offshore-carbon-storage-projects-experts.

360. EU CCS Directive (2009), art. 18.(1)(a).

361. EU CCS Directive (2009), art. 20 (1).

362. EEU CCS Guidance Document 3 (GD3) for Transferring Responsibility to Member States, at 17; EU CCS Directive (2009), preamble at (35).

363. See, e.g., EU CCS Directive (2009), at preamble para 30, arts. 11, 17, 18 (requiring "the surrender of [emissions trading] allowances in cases of leakage pursuant to Directive 2003/87/EC and preventive and remedial action pursuant to Articles 5(1) and 6(1) of Directive 2004/35/EC").

364. 26 U.S.C. §45Q.

365. 26 C.F.R. §1.45Q-5 Recapture of Credit.

366. "Final IRC Section 45Q regulations on carbon oxide sequestration clarify requirements, reduce recapture period," Ernst & Young LLP, Tax News Update, 27 January 2021, https://taxnews.ey.com/news/2021-0198-final-irc-section-45q-regulations-on-carbon-oxide-sequestration-clarify-requirements-reduce-recapture-period.

367. See "EU Emissions Trading System (EU ETS)," European Commission, accessed 13 October 2023, https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en.

368. Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006, preamble at (30), arts. 16, 11(4), 17(2), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0031; see also EU Directive 2003/87/EC (requiring surrender of emissions trading allowances for any leaked emissions).

369. EU CCS Directive (2009), preamble at (30), art. 16.

370. See, e.g., GAO, Offshore Oil and Gas: Updated Regulations Needed; Center for International Environmental Law, Toxic Assets: Making Polluters Pay When the Wells Run Dry and Bill Comes Due (2021), https://www.ciel.org/reports/toxic-assets-making-polluters-pay-when-wells-run-dry-and-the-bill-comes-due/.

Appendix

Offshore Carbon Capture and Storage Projects

Except where otherwise indicated, the project information below came from the International Energy Agency's CCUS Projects Database and the Global CCS Institute's CO2RE Database. Additional information came from project sponsor or operator websites and news reports. This list is not exhaustive, but was created with the best publicly available information on current and proposed offshore carbon capture and storage (CCS) projects as of November 2023.

This information is also available in a spreadsheet here:

Country	Project	Details
Australia	Bayu-Undan CCS	Plans are underway for an offshore CCS storage hub in the Bayu-Undan gas field in the Timor Sea, located off the coast of Timor-Leste. The project is a joint venture led by Australian gas company Santos in partnership with Italian oil company Eni. The South Korea firm SK E&S Co is doing front-end engineering and design (FEED) on the project. In June 2022, several Japanese companies (JERA, Tokyo Gas, and Inpex) announced plans to join the project, as they operate as partners in gas projects in northern Australia, and they also are considering exporting (via ship) CO_2 captured from Japanese facilities for offshore storage in Bayu-Undan. Santos claims it will be able to eventually store up to 10 million tonnes of CO_2 in the field per year. Santos, as lead operator of the Darwin liquefied natural gas (LNG) facility, plans to incorporate CCS as part of its offshore gas and LNG operations. Those plans include developing the offshore Barossa gas field, located approximately 300 kilometers (km) off the coast of Darwin in northern Australia. The gas from the Barossa field has a high CO_2 concentration, which is much higher than any other gas field in Australia. Santos is seeking to exploit Barossa to replace gas production from the nearly depleted Bayu-Undan field, and is building a duplication offshore pipeline to connect Barossa to Santos' Darwin LNG terminal. Santos envisions adding CCS to its Barossa project, which would involve transporting captured CO_2 300 km to the Darwin terminal and then piping it back offshore another 500 km for injection into the Bayu-Undan field — a costly and emissions-intensive endeavor to move CO_2 over long distances.
Australia	Bonaparte CCS Assessment G-7-AP	Led by Japanese oil company INPEX, this project would study and develop offshore CO_2 storage in the Bonaparte Basin located off the coast of Australia's Northern Territory. INPEX is the lead operator (with a 53 percent interest) and is partnering with TotalEnergies and Woodside Energy in the assessment joint venture, which secured a permit in August 2022. INPEX operates the Ichthys LNG plant near Darwin and is looking to add CCS to the plant and potentially build a carbon capture hub in the area that could utilize offshore storage. INPEX claims that the hub could store up to 2.5 million tonnes of CO_2 per year.
Australia	Burrup CCS Hub	This project is under early development (feasibility studies) to assess potential for a commercial-scale, multi-user CCS hub located in western Australia. Woodside Energy, along with BP and Japan Australia LNG (Mitsubishi Australia), are the developers; they along with Shell and Chevron have acquired a greenhouse gas permit for the Northern Carnarvon Basin off the coast of the Burrup Peninsula in northwestern Australia. The CCS hub is being proposed as part of a larger LNG buildout in the area, linking existing facilities and developing new offshore gas resources. Woodside also signed a memorandum of understanding (MOU) with three Japanese companies in September 2023 to explore the possibility of industries in Japan shipping their CO_2 for storage in Australia. The Australian government pledged up to USD26.7 million (AUD40 million) in funding for the design and construction of the carbon capture, transportation, and storage network.
Australia	Santos Bonaparte CCS Assessment	Santos is also exploring CO_2 storage in the Bonaparte Basin, having acquired a permit covering an offshore area of over 26,000 km2. The company owns 40 percent of the assessment project and has partnered with Chevron and SK E&S, which each own 30 percent of the project.

Country	Project	Details
Australia	CarbonNet Project	Funded and managed by the state of Victoria, the CarbonNet Project is a planned CO_2 transport and storage network for the Latrobe Valley. The project's planners claim that the facility can store up to 6 million tonnes of CO_2 per year at the project's Pelican Site, a deep saline formation about 8 km off the southeastern Australian coast in the Gippsland Basin. The project is currently in the engineering phase while awaiting its storage permit. It is expected to begin operation in 2027. The Australian and Victorian governments are investing AUD150 million (USD101.6 million) in the project and are in talks with private investors that want to commercialize the project.
Australia	CStore1 Project	Plans are underway for developing what is described as the first offshore "floating" CCS hub for Australia and the Asia-Pacific region. The project involves capturing and liquefying CO_2 from multiple industrial emitters, shipping the CO_2 to a floating storage and injection platform located off the coast of northern/western Australia, and then injecting it into sub-seabed geological formations. Technip Energies, deepC Store, and Mitsui O.S.K. Lines are the companies developing the project. The Australian government provided a AUD5 million (USD3.5 million) grant for the project's development and to facilitate negotiations between deepC store and Japan's Nippon Steel Corporation, which may provide CO_2 for the project. The project aims to store between 1.5 and 7.5 million tonnes of CO_2 per year.
Australia	Reindeer CCS	Santos has acquired a permit covering a smaller area — over 3,500 km2 — in the Carnarvon Basin off the coast of western Australia in the company's declining Reindeer gas fields. Chevron is also a 50 percent owner of the project. According to a Santos climate change report, the company plans to have a facility capable of storing up to 2.4 million tonnes of CO_2 per year operating by 2028. The project is located beyond Santos's gas fields in the Reindeer gas field and the company envisions this project as a possible CCS hub for western Australia, accepting additional CO_2 from other emitters in the region.
Australia	South East Australia CCS Hub	ExxonMobil and BHP are planning this project to store CO_2 in the Gippsland Basin off the coast of Gippsland in Australia's southeast region. The project is under early development, with the initial phase seeking to transport CO_2 captured from the onshore Longford gas plant to the offshore area for injection into a depleted gas field. Exxon claims the hub project could capture up to 2 million tonnes of CO_2 per year and says initial operation could start in 2025.
Belgium	Antwerp@C	This initiative, purportedly to help decarbonize the Port of Antwerp, involves building cross-border carbon capture, utilization, and storage (CCUS) infrastructure for transporting captured CO_2 by pipeline and/or ship to a site for offshore storage. The project involves a consortium consisting of Air Liquide, Borealia, BASF, ExxonMobil, INEOS, TotalEnergies, Fluxys, and the Port of Antwerp. The project received a EUR144.6 million (USD159 million) grant for its FEED studies through the EU Commission's Connecting Europe Facility grant program. The project planners hope to use the project to reduce emissions at the port by half by 2030.
Brazil	Petrobras Santos Basin Pre-Salt Oil Field CCS	This is an offshore oil and gas extraction site that has, since 2013, employed CCS to separate CO_2 from the fossil gas extracted and injected it back into the oil field for enhanced oil recovery (EOR). The operation, owned by Petrobras, is located in the Santos Basin off the coast of Brazil. It injects an estimated 0.7 million tonnes of CO_2 captured from its own operations every year.
Bulgaria	ANRAV	Heidelberg Materials and PetroCeltic aim to create the first full-chain CCUS project in Eastern Europe with the ANRAV project, which will capture CO_2 from Heidelberg's Devnya cement plant and transport it by pipeline for permanent storage in the depleted Galata gas field in the Black Sea. The project's backers say that ANRAV could eventually become a CCUS "cluster" for Eastern Europe, storing CO_2 from emitters from around the region. Heidelberg Materials says the project could be operational by 2028. The EU Innovation Fund gave EUR190 million (USD208 million) in funding to the project in January 2023. These funders say that ANRAV could eventually store 1.5 million tonnes of CO_2 per year.
China	CNOOC Enping Offshore CCS Project	The China National Offshore Oil Corporation (CNOOC) launched China's first offshore carbon storage project in June 2023. Located in the South China Sea, the project was built as part of the new Enping 15-1 offshore oil development, capturing and processing CO_2 from oil production and pumping it into saline reservoirs below the sea. The project claims the capacity to inject 300,000 tonnes of CO_2 per year into the reservoirs.
China	Daya Bay CCS Hub	CNOOC, Shell, ExxonMobil, and the Guangdong Provincial Development and Reform Commission signed an MOU in June 2022 to create an offshore CCS hub in Daya Bay, a National Economic and Technological Development Zone in China's Guangdong province. The companies are now conducting studies with the aim of developing a project capable of storing 10 million tonnes of CO_2 per year from Shell's Nanhai petrochemical plant and other industrial sites.
China	Ledong CO_2-EOR	Run by CNOOC, this project in the Yinggehai basin in the South China Sea captures CO_2 from natural gas production and reinjects it to extract more gas from the aging wells through enhanced gas recovery (EGR). The project launched in December 2022 and can reinject 30,000 tonnes of CO_2 per year.
Denmark	Bifrost	Announced in 2021, Bifrost's operators plan to begin storing 3 million tonnes of CO_2 per year in the Danish North Sea in 2030, and to study the possibility of eventually increasing that storage capacity to up to 16 million tonnes. The project is being planned through the Danish Underground Consortium, a partnership between TotalEnergies, the Norwegian Energy Company (Noreco), and Nordsofonden. Ørsted and the Technical University of Denmark are also partners in the project. The partners plan to use existing pipeline infrastructure to store CO_2 from emitters around the region in depleted gas wells in the Harald field. The Danish government's Energy Technology Development and Demonstration Program provided USD11.5 million (DKK75 million) in funding for the project.
Denmark	Project Greensand	An offshore CCS project called Project Greensand plans to inject CO_2 into a depleted oil field in the Danish North Sea. The project involves twenty-three Danish and international partners (including academic institutions and chemical companies) and is backed by DKK197 million (USD29.4 million) in funding from the Danish government. Project Greensand aims to be operational by 2025 and store 1.5 million tonnes of CO_2, with potential to scale up to 8 million tonnes by 2030. The recent agreement between Denmark and Belgium to collaborate on cross-border CO_2 transport for storage in the Danish North Sea is part of the Greensand project.
France	CalCC	This project aims to capture CO_2 from the Lhoist Group's Réty lime production plant and transport the CO_2 by pipeline to the Port of Dunkirk, where it will be liquefied and shipped for storage in the North Sea. Air Liquide is building the carbon capture equipment, which they say will reduce the plant's greenhouse gas emissions by 87 percent. The project aims to capture 600,000 tonnes of CO_2 per year starting in 2028. In 2022, the project received EUR125 million (USD140 million) in funding from the EU Innovation Fund.

Country	Project	Details
France	K6 Program	The project organizers for K6 hope to become the first "carbon-neutral" cement producers in Europe by capturing 8.1 million tonnes of CO_2 over ten years from a plant in Lumbres. The CO_2 will be transported to the Port of Dunkirk for storage in the North Sea. The project organizers, Equiom and Air Liquide, plan to begin operation in 2028. In 2022, the EU Innovation Fund issued EUR153 million (USD172 million) in funds for the project.
Greece	Prinos CCS	London-based Energean plans to develop CO_2 storage in its depleted wells in the Prinos and Epsilon oil fields in the Aegean Sea. The company claims that the project will include a blue hydrogen facility, and could become a regional carbon capture hub for the Mediterranean. The company commissioned a feasibility study from Haliburton in 2022 and the company says it hopes to begin storing 1 million tonnes of CO_2 per year by 2025. The Greek government and the European commission approved EUR300 million (USD334 million) in grants from the European pandemic recovery plan for the project in 2021.
Indonesia	Pertamina Exxon Indonesia Hub	ExxonMobil and Pertamina, Indonesia's national oil company, announced a partnership in 2022 to study the possibility of creating a CCS hub in Indonesia. The companies are exploring three offshore oil and gas fields — one in West Java and two in East Kalimantan — as possible storage sites. The companies claim that the project will have a geologic storage potential of up to 3 billion tonnes of CO_2.
Ireland	Ervia Cork CCS	Ervia, a State-owned utility in Ireland, completed feasibility studies for a project to capture CO_2 from emitting facilities in Cork and transport the CO_2 using existing gas pipelines for storage in the Kinsale field, a depleted offshore gas field. The project received a EUR1.4 million grant (USD1.49 million) for preliminary studies through the EU Commission's Connecting Europe Facility grant program.
Italy	Ravenna CCS Hub	This CCS project is under early development by Italian oil company Eni and its partner Snam. It aims to capture CO_2 from power stations and other industries and inject the CO_2 offshore in depleted gas fields in the Adriatic Sea. The storage site would be off the coast of Ravenna in northeastern Italy. The project aims to start its first phase by injecting 25,000 tonnes of CO_2 in 2024. The project operators plan to begin commercial operation by 2026, injecting 4 million tonnes of CO_2 per year, and then to ramp up to storing 16 million tonnes of CO_2 per year by 2030.
Japan	Japanese Advanced CCS Projects	In June 2023, the Japanese government announced its support for seven CCS projects with a combined goal of sequestering 13 million tonnes per year by 2030. The projects are distributed throughout Japan, with one project set to transport CO_2 to Malaysia and another to a site somewhere in Oceania. Six of these projects — Tomakomai Area CCS, Metropolitan Area CCS (near Tokyo), Tohoku Region West Coast CCS, Northern to Western Kyushu Offshore CCS, Offshore Malay CCS, and Oceania CCS — are planning to use offshore storage facilities. The Japanese trade ministry has earmarked JPY3.5 billion (USD25 million) for CCS in the 2023-24 budget, but it is not clear how much total funding the government will provide for each project.
Malaysia	Petronas Kasawari CCS project	Construction is underway for an offshore CCS project involving CO_2 separation from offshore gas production in the Kasawari gas field and injection of the CO_2 into a depleted reservoir. The project is led by Malaysia's national oil and gas company, Petronas Carigali. The CCS project is being pushed as a means to make new offshore gas development feasible in parts of Malaysia that are known to have extremely high CO_2 concentrations. The SK316 block where the new development is proposed has gas that contains up to 35 percent CO_2, much higher than the average natural gas field. Petronas has set their injection targets at 4 million tonnes of CO_2 per year. The project is set to begin in 2025.
Malaysia	Lang Lebah CCS project	etronas and Thai petroleum exploration firm PTTEP plan to capture CO_2 from the Lang Lebah gas plant on shore in Sarawak. The project will then pipe the CO_2 to an offshore platform for injection in depleted gas wells in the Golok gas field. The project is a part of the broader Lang Lebah gas development meant to spur natural gas production off the coast of Sarawak.
Netherlands	Aramis	This planned project would aggregate CO_2 collected from industry at a hub located at the Port of Rotterdam. Pipelines and ships would transport the CO_2 offshore to platforms for injection beneath the North Sea. The CO_2 would be stored 3 to 4 km (approximately 1.8 to 2.5 miles (mi)) under the sea in depleted gas reservoirs. Aramis is a collaboration between TotalEnergies, Shell, EBN, and Gasunie. The project plans to store at least 7.5 million tonnes of CO_2 a year and to scale up to 22 million tonnes per year by 2030.
Netherlands	L10 Offshore CCS	This proposed project is under early development, led by the offshore oil and gas company Neptune Energy, in partnership with EBN, Tenaz Energy, and XTO Netherlands (Exxon's Dutch subsidiary). The project seeks to inject between 4 and 9 million tonnes of captured CO_2 per year into depleted gas fields in the Dutch North Sea starting in 2026.
Netherlands	Porthos	Porthos is a networked CCS project collecting CO_2 from facilities in the Port of Rotterdam and transporting it via pipeline to an offshore platform approximately 20 km (12.4 mi) off the coast, where it will be injected into depleted gas fields in the North Sea. Porthos aims to store 2.5 million tonnes per year of CO_2 at a depth of more than 3 km (1.86 mi) under the sea. Developers of the project include EBN and Gasunie, along with the Port of Rotterdam Authority. The project has attracted huge subsidies from the Dutch and Belgian governments. The Porthos storage and transfer project has so far collected EUR109.7 million (USD123.1 million) for studies and infrastructure, while the project's customers were granted EUR2.1 billion (USD2.4 billion) through the Dutch Sustainable Energy Production and Climate Transition Incentive Scheme (SDE++) for carbon capture. The project is planned to become operational in 2026.
Netherlands	NoordKaap	This project from Neptune Energy and CapeOmega aims to develop industrial "clusters" around Europe to source captured CO_2. The NoordKaap project would then transport that CO_2 by ship for storage in the Dutch North Sea. The companies signed a letter of intent with the Eemshaven biomass station to study the possibility of storing the plant's captured CO_2. The companies are seeking additional emitters around Europe and plan to begin injecting CO_2 in 2028.
Norway	Sleipner	The Sleipner project is the world's first offshore CCS operation, capturing CO_2 from gas production at the offshore Sleipner gas field and sequestering it in rock formations beneath the North Sea. The CCS project has been operating since 1996 and is run by Equinor. The project stores about 1 million tonnes of CO_2 per year.
Norway	Snøhvit	This project is an offshore LNG development operated by Equinor that has been using CCS since 2008. The CO_2 is captured at a facility on the island of Melkøya, where the gas is processed. A pipeline then transports the CO_2 back to the Snøhvit gas field, where it is stored beneath the seabed in the southern Barents Sea. The project stores about 700,000 tonnes of CO_2 per year.

Country	Project	Details
Norway	Barents Blue/Polaris Carbon Storage	Horisont Energi and Baker Hughes plan to develop a "blue" ammonia project (ammonia production paired with CCS) located in northern Norway. The project also involves storage of the captured CO_2 offshore in the Barents Sea. The storage site is called Polaris, located about 100 km (61 mi) off the coast of Finnmark. The project's planners intend to begin by storing 2 million tonnes of CO_2 per year. In 2021, the project was given a grant of NOK482 million (USD48 million) through an EU Commission program.
Norway	Errai CCS	Horisont Energi and Neptune Energy plan to develop this CO_2 storage project using both onshore and offshore storage in Norway. The onshore terminal, based in Rogaland, will accept CO_2 shipments from throughout Europe and serve as an intermediate storage area. The final storage area will be in the Norwegian North Sea. The project's planners say that Errai will be able to store between 4 and 8 million tonnes of CO_2 per year by 2026.
Norway	Kollsnes DAC Facility	US company Oxy Low Carbon Ventures has teamed up with the Canadian company Carbon Engineering with the goal of producing direct air capture (DAC) facilities across the world. This project with Carbon Removal, a Norwegian company, would put a DAC facility in the Kollsnes industrial park with the goal of capturing 500,000 tonnes of CO_2 per year starting in 2027. Nordic Leisure Travel Group has signed on to purchase carbon offsets from the project. While there is no formal agreement in place, the project's designers have said they may store the captured CO_2 in the Northern Lights storage project.
Norway	Luna	In October 2022, the Norwegian government granted Wintershall Dea a storage license in the North Sea for the Luna project. Wintershall Dea and its partner Cape Omega estimate that they will be able to inject up to 5 million tonnes of CO_2 per year into an area 120 km west of Bergen. The project is in early development.
Norway	Northern Lights	This project involves transporting CO_2 captured from Norwegian industrial facilities (such as the Brevik cement plant) as well as European emitters outside Norway via ship to an onshore terminal and then injecting it via pipeline to a storage reservoir in the North Sea. The subsea storage is located about 2600 meters (1.6 mi) beneath the seabed. The project (in Phase 1) aims to capture and store 1.5 million tonnes of CO_2 per year and be operational by 2024. Operators say the project could eventually ramp up to store 5 million tonnes of CO_2 per year. Northern Lights is described as "the transport and storage component of Longship, the Norwegian government's full-scale carbon capture and storage project." The Northern Lights project is operated as a partnership involving Equinor, TotalEnergies, and Shell. The Norwegian government plans to spend NOK16.8 billion on the project (USD1.57 billion). The European Commission also gave EUR7.2 million (USD7.6 million) in 2019 and 2021.
Norway	Smeaheia	In 2022, the Norwegian government granted Equinor a CO_2 storage license in the North Sea for the Smeaheia project. Equinor says that it plans to develop a project to store up to 20 million tonnes of CO_2 per year in Smeaheia, but has released no additional information about the project.
Norway	Trudvang	val, a Norwegian energy company, obtained a CO_2 storage license in the North Sea and is partnering with Storegga and Neptune Energy to develop the Trudvang project. The group plans to transport industrial emissions from sources around northern Europe by ship to an onshore terminal and then transport them by pipeline for undersea storage. The companies plan to store up to 9 million tonnes of CO_2 per year starting in 2029.
Poland	Go4ECOplanet	The Holcim group, a Swiss building materials company, plans to install carbon capture equipment at the Lafarge cement production plant in Kujawy. The captured CO_2 will then be transported by train to the Port of Gdansk where a ship will take it for storage in the North Sea. The project's designers claim they will capture 100 percent of the plant's emissions by 2027 and store 10.2 million tonnes of CO_2 over ten years. The project received more than EUR228 million (USD256 million) from the EU Innovation fund in 2022.
South Korea	Donghae CCS project	Led by the Korea National Oil Corporation, a State-owned oil company, this is a planned CCS demonstration project involving the capture of CO_2 from industrial facilities, transport of the CO_2 via ship, and injection into the depleted offshore Donghae gas field in the East Sea. The Donghae field ceased production at the end of 2021 and the project operators aim to store 1.2 million tonnes per year. The project is in the FEED phase.
Sweden	Slite CCS	Heidelberg Materials plans to capture carbon from its Slite cement plant on the Swedish island of Gotland starting in 2030. The project aims to capture 1.8 million tonnes of CO_2 each year and send it for storage in the North Sea off the coast of Norway. The project's planners are exploring the possibility of storing the CO_2 with Northern Lights.
Thailand	PTTEP Arthit CCS	This project is under development (preliminary FEED) for offshore CCS at the Arthit gas field in the Gulf of Thailand. Thailand's national petroleum exploration and production company PTTEP is developing the project, designed to be a component of its ongoing offshore gas extraction. Between 700,000 and 1 million tonnes of CO_2 per year would be separated from the produced gas, then compressed and reinjected back under the seabed for storage in saline aquifers and depleted reservoirs. PTTEP plans to start operating the project in 2026.
United Arab Emirates	Ghasha Concession Fields	CCS is planned as an integral part of development of the Ghasha offshore gas fields, which contain "sour gas," or fossil gas with high levels of hydrogen sulfide. The CO_2 would be removed from the extracted gas and injected back into the depleted wells. The project is located within the Marawah Marine Biosphere Reserve, an important international feeding ground for dugongs and other endangered species. Technip Energies is conducting the FEED and Abu Dhabi National Oil Company (ADNOC) is leading the project, which is scheduled to be operational in 2025. The amount of carbon planned for sequestration is still being analyzed.
United Kingdom	Acorn	This is a proposed venture consisting of several projects in Scotland that plan to utilize offshore CO_2 storage in the North Sea. The project is a partnership between Storegga, Shell, Harbour Energy, and the North Sea Midstream Partners. The Acorn CCS project seeks to store captured CO_2 from the St. Fergus gas terminal in northeast Scotland along with transport and storage offshore. According to a project description from the Global CCS Institute, "[t]his would act as a seed [Acorn] from which to grow a cluster of capture, transport, and storage infrastructure." Another project is called Acorn Hydrogen, which plans to use fossil gas extracted from the North Sea to produce hydrogen, with the CO_2 captured and transported through the Acorn CCS infrastructure. Additionally there is planning for a DAC project (developed by Carbon Engineering and Storegga) that could utilize the Acorn offshore CO_2 storage site. The project hopes to store as much as 5 million tonnes of CO_2 per year, with elements of the project set to begin operation by 2025. The project received a total of €11 million (USD11.7 million) from the European Commission and GBP30 million (USD36.4 million) in funding from the UK Research and Innovation Fund. The Scottish government plans to give GBP80 million (USD96.7 million). Acorn is one of four offshore "clusters" that the UK Department for Energy Security & Net Zero plans to fund. That department has announced two funds worth GBP21 billion (USD25.5 billion) available for CCS projects, but the proportion of funding for each project has not yet been announced.

Country	Project	Details
United Kingdom	Bacton Thames Net Zero Initiative	Led by Eni, the Bacton Thames Net Zero initiative aims to capture at least 10 million tonnes of CO_2 per year from industry and power generation in the Bacton and Thames regions and transport it for storage in the depleted Hewett gas fields off the North Norfolk Coast. Eni says that the project could be operational by 2027.
United Kingdom	Caledonia Clean Energy Project	This planned new fossil gas power plant at the Caledonia facility in central Scotland has carbon capture built into the project. The CO_2 captured from the plant would be transported offshore for injection into the North Sea. A company called Summit Power is developing the project. In 2015, the UK and Scottish governments gave GBP4.2 million (USD5.5 million) for the project's feasibility studies. The project is planned for 2024 or later and could capture up to 3.1 million tonnes of CO_2 per year.
United Kingdom	Cory EfW Plant CCS	The Cory Group plans to add carbon capture to one existing and one new London-based energy-from-waste plants and to ship the captured CO_2 for permanent geological storage under the seabed. The project's planners plan to use the CCS project to create a carbon transport network on the Thames River that would allow other industrial facilities to transport CO_2 for storage in the same area. The project is in early development and the company has not released a potential storage site. The project planners say they plan to capture 1.3 million tonnes of CO_2 per year by 2030.
United Kingdom	East Coast Cluster	This initiative claims it will be able to manage almost 50 percent of the UK's industrial cluster CO_2 emissions. Projects in industrial carbon capture, hydrogen with CCS, and power generation with CCS are envisioned for the cluster, located in the Teesside and Humber areas on the east coast of England. The Northern Endurance Partnership is the transport and storage parts of the CCS cluster, transporting the CO_2 for offshore storage in the southern North Sea. Fossil fuel companies including BP, Equinor, and TotalEnergies are the partners operating Northern Endurance. The full cluster will involve a number of other companies including Phillips 66, INEOS, and Drax. The project's organizers say they plan to begin injecting CO_2 by 2026 and to ramp up to capture to as much as 23 million tonnes of CO_2 per year by 2035. Several of the cluster's partnerships (Northern Endurance Partnership, Zero Carbon Humber, Net Zero Teesside, and Humber Zero) received a combined GBP86,243,662 (USD104.8 million) in funding from the UK Research and Innovation Fund in 2021. The East Coast Cluster is one of four offshore "clusters" that the UK Department for Energy Security & Net Zero plans to fund. That department has announced two funds worth GBP21 billion (USD25.5 billion) available for CCS projects, but the proportion of funding for each project has not yet been announced.
United Kingdom	H21 North of England	A partnership between Equinor, Cadent Gas, and a host of other UK gas utilities, H21 is a plan to convert all of the gas utilities in northern England to hydrogen between 2028 and 2035. The blue hydrogen for the project would be produced with four steam methane reformers in Teeside fitted with capture equipment meant to gather 90 percent of the CO_2 released from the plants. The 5 million tonnes of CO_2 captured each year would be transported by pipeline out to the North Sea for sequestration. The project involves converting the existing gas network to a hydrogen network, converting all home appliances in the area to hydrogen appliances. The project received GBP9 million (USD11.7 million) in 2017 and another GBP6.8 million (USD8.8 million) in 2019 from the UK Office of Gas and Electricity Markets for studies meant to prove that hydrogen is safe.
United Kingdom	HyNet North West	HyNet is a proposed "blue" hydrogen project in North Wales on the west coast of Britain, involving fossil-based hydrogen production along with CCS. The captured CO_2 from the hydrogen plant and potentially other emitting facilities would be transported by underground pipeline for injection offshore into depleted gas fields in Liverpool Bay. Eni is developing the CO_2 transport and storage parts of the project. The project is planned to begin operating in 2025 with an initial capacity to inject 4.5 million tonnes per year and to increase to 10 million tonnes per year by 2030. The project won a GBP33 million grant (USD43.1 million) from the UK Research and Innovation Fund and GBP13 million from the UK Department of Business, Energy and Industrial Strategy. HyNet is one of four offshore "clusters" that the UK Department for Energy Security & Net Zero plans to fund. That department has announced two funds worth GBP21 billion (USD25.5 billion) available for CCS projects, but the proportion of funding for each project has not yet been announced.
United Kingdom	Medway Hub CCS	Britain's North Sea Transit Authority awarded Wintershall Dea and Synergia Energy a license in the southern North Sea to develop a CCS project to capture CO_2 from several power stations located on the Isle of Grain, liquefy and temporarily store the CO_2 at an LNG terminal; transport the liquefied CO_2 by tanker; and inject it from a floating injection, storage, and offloading vessel for storage in depleted gas fields in the North Sea. The project is still in the early stages of development, but developers say they are planning to inject more than 5 million tonnes of CO_2 each year.
United Kingdom	Morecambe CCS Hub	Spirit Energy plans to convert the North and South Morecambe depleted gas fields into a carbon storage hub capable of storing 5 million tonnes of CO_2 per year initially, with the possibility to scale up to 25 million tonnes. The project aims to store carbon from emitters throughout the region by accepting CO_2 transported to the site by pipeline, ship, and rail. The project received a carbon storage license in May 2023.
United Kingdom	Sullom Voe Terminal CCS	EnQuest has announced plans to add carbon storage capabilities to the Sullom Voe Terminal, an oil terminal the company operates in Shetland. The company says it plans to accept shipments of liquid CO_2 to the terminal and to use an existing pipeline to transfer the material offshore for permanent storage. The company says that they believe they will be able to store 10 million tonnes of CO_2 per year. EnQuest was awarded a license for the project in May 2023 by the North Sea Transition Authority in the agency's first round of license issuing.
United Kingdom	Viking CCS Network	Development is underway on this CCS network based in the Humber region. The network includes pipelines linking the VPI Immingham Combined Heat and Power Plant and the Phillips 66 Limited Humber Refinery to an offshore storage site in a depleted gas field in the southern North Sea Basin, 140 km offshore. The first phase of the project aims to capture and store up to 3.8 million tonnes of CO_2 per year from the Phillips 66 and VPI plants as early as 2027 and to eventually ramp up to 11 million tonnes per year by 2030. The project is funded through HumberZero, a decarbonization consortium run by Phillips 66 and VPI with GBP12.5 million (USD16.3 million) in matching funds from the UK government's Industrial Strategy Challenge Fund. Harbour Energy is running the storage hub component of the project. Viking is one of four offshore "clusters" that the UK Department for Energy Security & Net Zero plans to fund. That department has announced two funds worth GBP21 billion (USD25.5 billion) available for CCS projects, but the proportion of funding for each project has not yet been announced.

Country	Project	Details
United States	Bayou Bend CCS	Advanced planning and development is underway for what project developers say would be the first offshore CCS hub in the US, to be located in state-controlled waters off the coast of Texas in the Gulf of Mexico. Bayou Bend is a joint venture between Chevron (50 percent stake), Talos Energy (25 percent stake), and Equinor (25 percent stake), with Talos serving as project operator. This is one of several coastal CCS projects that Talos is planning along the Texas and Louisiana Gulf Coast. Bayou Bend proposes to inject CO_2 into subsurface reservoirs in an offshore area covering over 40,000 acres and leased by the Texas General Land Office as well as onshore reservoirs on 100,000 acres of land. The storage site is located off the coast of Jefferson County in southeast Texas, near Port Arthur. The project operators aim to store between 15 and 30 million tonnes of CO_2 by 2035.
United States	Cameron Parish CO_2 Hub	In September 2023, Castex Energy and Carbonvert announced an agreement with the state of Louisiana to build a carbon storage hub on a 24,000-acre tract of state waters off the coast of Cameron Parish near several large industrial polluters. The project planners claim that the area has the capacity to store more than 250 million tonnes of CO_2. The companies say they plan to begin injecting CO_2 in 2027.
United States	Coastal Bend CCS	Another of Talos Energy's planned projects, Coastal Bend CCS received USD7.3 million through the US Department of Energy's (DOE) CarbonSAFE program for a feasibility study of possible CO_2 storage sites in near offshore waters in the Texas Gulf Coast near Corpus Christi. The project received an additional USD9 million from the same program to study onshore storage. The Port of Corpus Christi Authority is managing the DOE funding and feasibility studies. Talos is exploring the site as a potential carbon capture hub for the region and estimates it could store between 50 and 100 million tonnes of CO_2.
United States	Corpus Christi Offshore	In September 2023, the Texas General Land Office granted Repsol a contract to develop a CO_2 storage project over 140,000 acres in Texas state waters. Carbonvert, POSCO, and Mitsui also have equity in the project. The project planners say they plan to capture CO_2 from industrial emitters in the region and store more than 20 million tonnes of CO_2 under the seabed each year.
United States	Houston Ship Channel CCS	ExxonMobil has proposed a USD100 billion CCS project in the Houston Ship Channel that would capture CO_2 from industrial facilities and store it offshore in the Gulf of Mexico. The project is envisioned as a hub involving multiple emitting facilities in the heavily industrialized and polluted corridor known as the Houston Ship Channel. More than a dozen petrochemical and fossil fuel companies have indicated interest in Exxon's proposal, which was first announced in April 2021. ExxonMobil claims that the project could sequester up to 100 million tonnes of CO_2 per year by 2040.
United States	Project Lochridge	Cox Operating, Crescent Midstream, and Repsol are planning to establish a CO_2 storage complex by repurposing existing infrastructure. Cox Operating plans to re-use some of its approximately 600 depleted wells off the coast of Louisiana to store CO_2, while Crescent Midstream has already completed the FEED for a 110-mile CO_2 pipeline that would use the company's existing rights-of-way. The companies' claim that the project area could hold up to 300 million tonnes of CO_2. The US DOE gave USD8.4 million in funding for the project in May 2023 as part of its CarbonSAFE program.

Deep Trouble

The Risks of Offshore Carbon Capture and Storage

Facing growing scrutiny over their contributions to climate change, polluting industries are increasingly looking for ways to cover up their continued emissions rather than phase out the fossil fuels driving them. One way companies claim the world can continue producing and using oil, gas, and coal without harming the climate is through carbon capture and storage (CCS), which purports to enable polluters to trap their carbon dioxide (CO_2) emissions and bury them underground or under the seabed.

Despite the fanfare around CCS, it is a costly and risky endeavor and nearly all the world's past CCS projects have experienced unexpected problems or failed outright. The technology's poor track record hasn't stopped the fossil fuel industry from championing new projects, and over the last few years, companies and governments have put forward a rash of new proposals that aim to store CO_2 emissions offshore under the seabed.

A new wave of proposed projects aims to pool CO_2 waste from various fossil fuel and industrial activities for injection in offshore storage "hubs" in oceans around the world. This untested technique, which involves a step change in the scale and complexity of offshore CCS, poses uncalculated risks. Some of the envisioned hubs are associated with the buildout of new fossil fuel projects, and most would store waste from industries that must be scaled down or phased out if the world is to avoid catastrophic climate change.

Deep Trouble: The Risks of Offshore Carbon Capture and Storage explains the threat presented by a massive buildout of offshore CCS infrastructure and uncovers the government financing and fossil fuel interests enabling and advancing this new wave of projects. The report concludes that governments must halt the expansion of offshore CCS by ending subsidies and support for these projects, while interpreting existing laws and strengthening emerging regulations to protect the oceans from absorbing even more of humanity's waste and safeguard communities, the environment, and the global climate.

ciel.org

Instagram
@ciel_org

Twitter
@ciel_tweets

Linkedin
linkedin.com/ciel.org

CIEL

CENTER for INTERNATIONAL ENVIRONMENTAL LAW