EcoAction Magazine

STEM Beyond Boundaries

EcoAction Magazine x STEM Beyond Boundaries Joint Write Project - Carbon Capture Technology

This is a joint writing project between EcoAction Magazine and STEM Beyond Boundaries. All the research, peer-editing, and graphic designing are conducted in a collaborative and peer-learning manner.

ECOACTION MAGAZINE

EcoAction Magazine is a monthly magazine that empowers students in all communities to tackle environmental issues through projects involving innovative green technologies. The magazine features various environmentally friendly technologies, diving into their implications and applications, aspiring to inspire youth actions by raising awareness and breaking the stigma around environmental protection.

STEM SPARKS READS MAGAZINE

The Stem Beyond Boundaries magazine (Stem Sparks Reads) is a monthly magazine that informs and shares information about STEM to younger students from all over the country. Every month the magazine freaturees a specific topic and has sections such as history, fun facts, and even quizzes to help engage readers and strive to spark their interest in the STEM field. Our goal is to help create and share the power that STEM has to bring people together through the art of literature.

WHAT IS IT ABOUT?

As the world seeks cleaner and more sustainable ways to power our homes and cities, green energy has emerged as a key solution. Wind turbines, sustainable hydrogen, carbon capture, with their unique employment of different natural energies, are capable of fulfilling this need for clean energy. But how exactly do these climate technologies work? And specifically carbon capture for this issue of the magazine. What principles allow us to turn something invisible, like carbon, into a source of clean energy? This issue explores the fascinating science behind the carbon capture technology, from the physics of the natural element to the multi-faceted implications of the technology. This magazine has it all!

CATALOGUE

JOINT WRITE

This is a joint writing project between EcoAction Magazine and STEM Beyond Boundaries. If you would like to read more of these joint writing magazines, please reach out.

Any questions?

Please reach out to EcoAction Magazine via email ecoactionmagazine@outlook.com

Please reach out to STEM Beyond Boundaries through their website: stembeyondboundaries.org

THE SCIENCE BEHIND CARBON CAPTURE STORAGE

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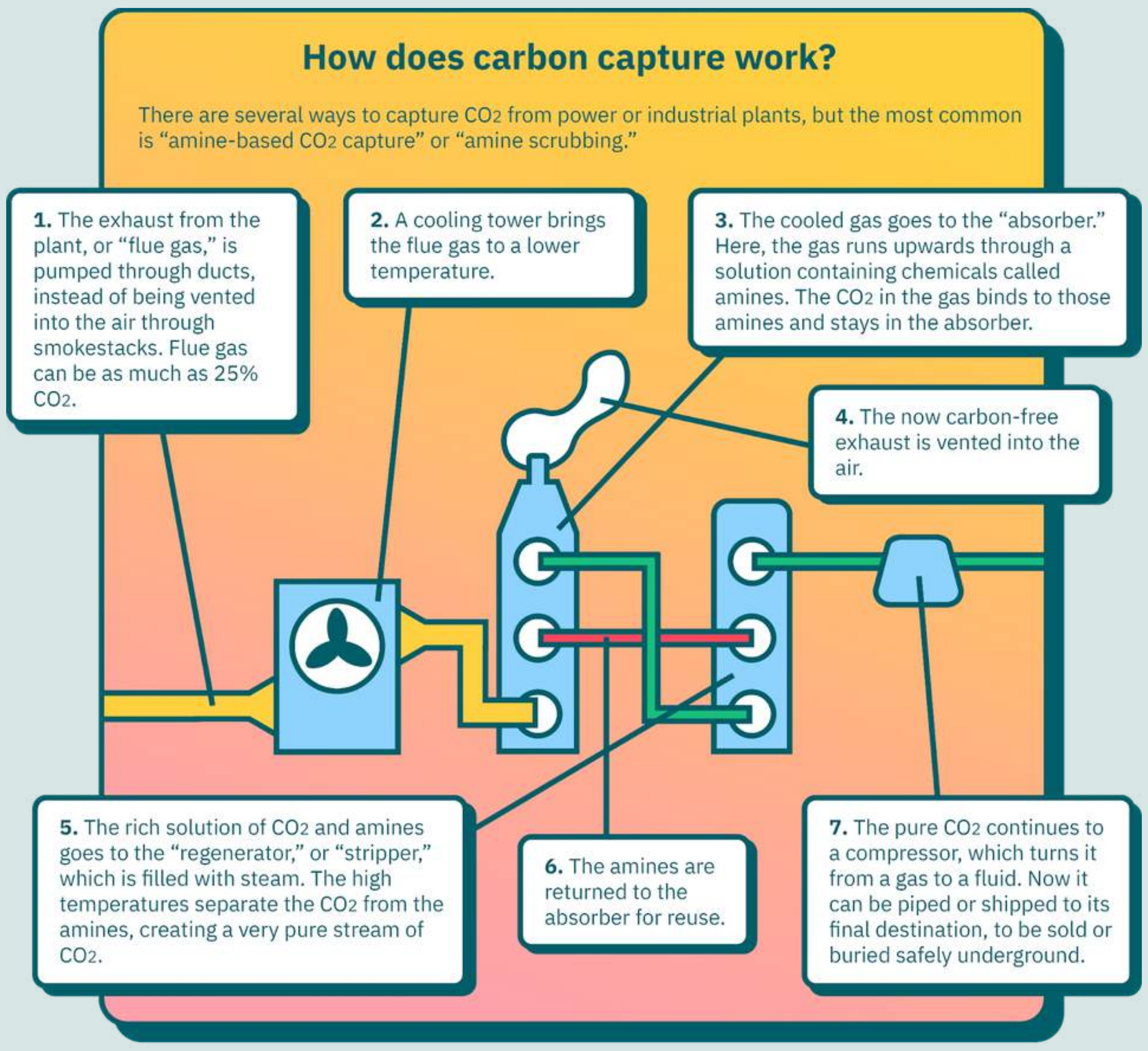
INTRODUCTION

Let's start simply: what is CCS? CCS stands for Carbon Capture & Storage, and it's a technology that is used to help reduce the carbon emissions on the planet. CCS is not a singular gadget or technology, but rather a collection of technologies put together! They aim to remove carbon emissions and carbon dioxide (CO2) that are created through the burning of fossil fuels emitted into the atmosphere, where it's then collected and stored deep underground. Carbon Capture uses storage and injection technology to keep 90% of CO2 emissions from big power plants and fossil fuel burnings. Carbon Capture Storage technology can now be broken up into three popular options big capture companies may reach for. Methods in the name of clean energy include burning, separation, and oxygen.



CAPTURING THE CO2

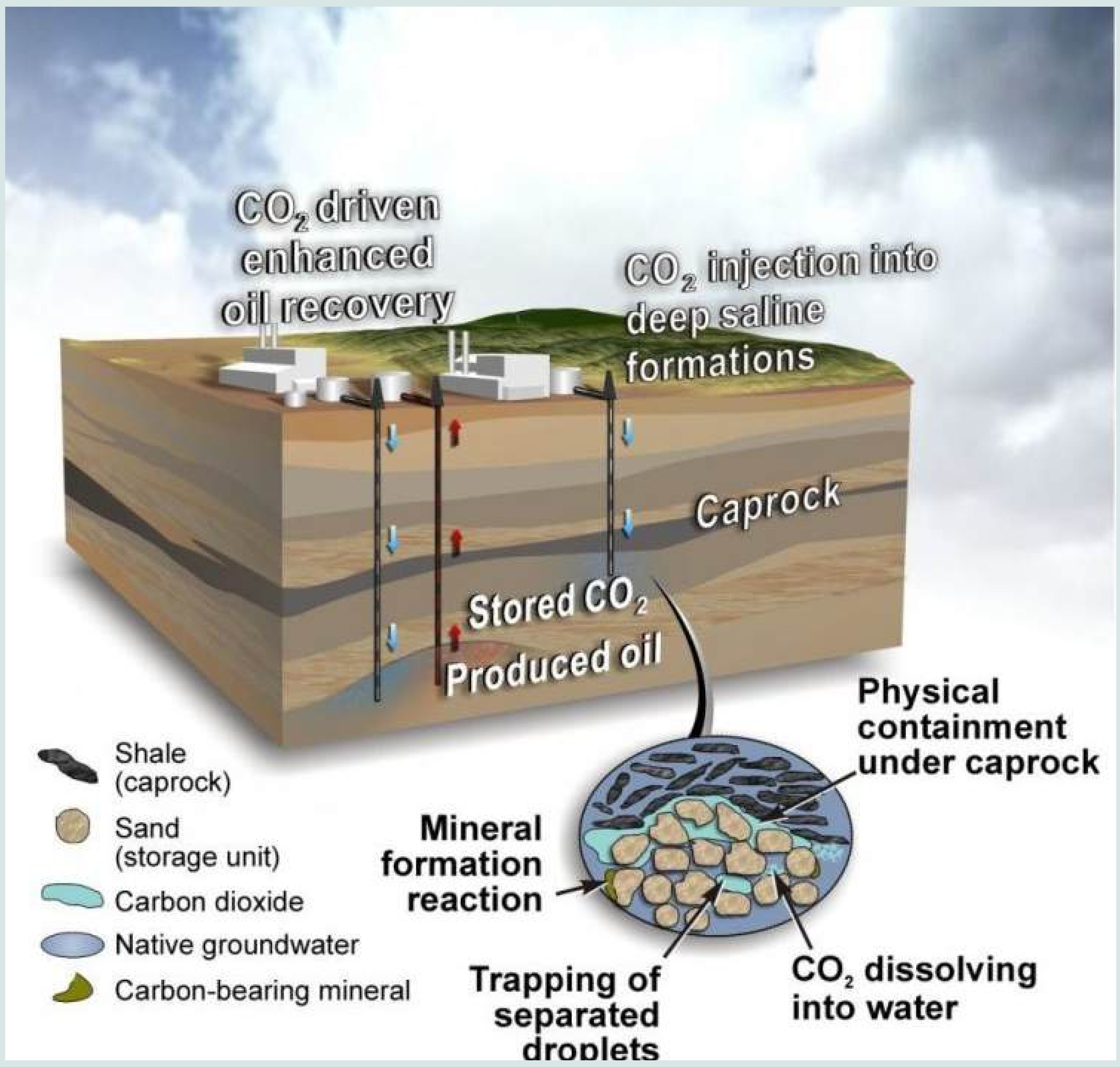
Current and popular efficient methods of capturing CO2 for projects include but are not limited to: Pre-combustion carbon capture (burning), post-combustion carbon capture (uses previously mentioned chemicals to separate gas and liquid) and oxyfuel carbon capture. For burning, fuel is gasified to produce a syngas that consists mainly of carbon monoxide (CO) and hydrogen (H2). A reaction will convert the CO to CO2, then a physical solvent will typically separate the CO2 from the H2. For power generation, pre-combustion carbon capture can be combined with an integrated gasification combined cycle (IGCC) power plant that burns the H2 in a combustion turbine. Next, post-combustion causes chemical solvents to separate carbon dioxide of the flue gas from fossil fuel combustion. Lots of power plants for carbon capture are likely to use this method. Finally, oxyfuel carbon capture uses fossil fuel combustion in pure oxygen (as opposed to air) so that the exhaust gas is carbon-dioxide rich, facilitating the capture.

HOW IT WORKS

The first step to the CCS process is that it first compresses the CO2 gas into a liquid form so that it can travel through various underground pipes that are about 2,500 feet underground. The unused liquid is then met with reservoirs and formations where it sits with other unusable waters (such as saltwater). CCS technology has been able to remove 50 million tons of CO2 gas every year, which is roughly the amount a small country such as Peru or Greece could produce in such a time frame. Current technology and projects actually require further chemicals to remove CO2 out of its liquid compounds.

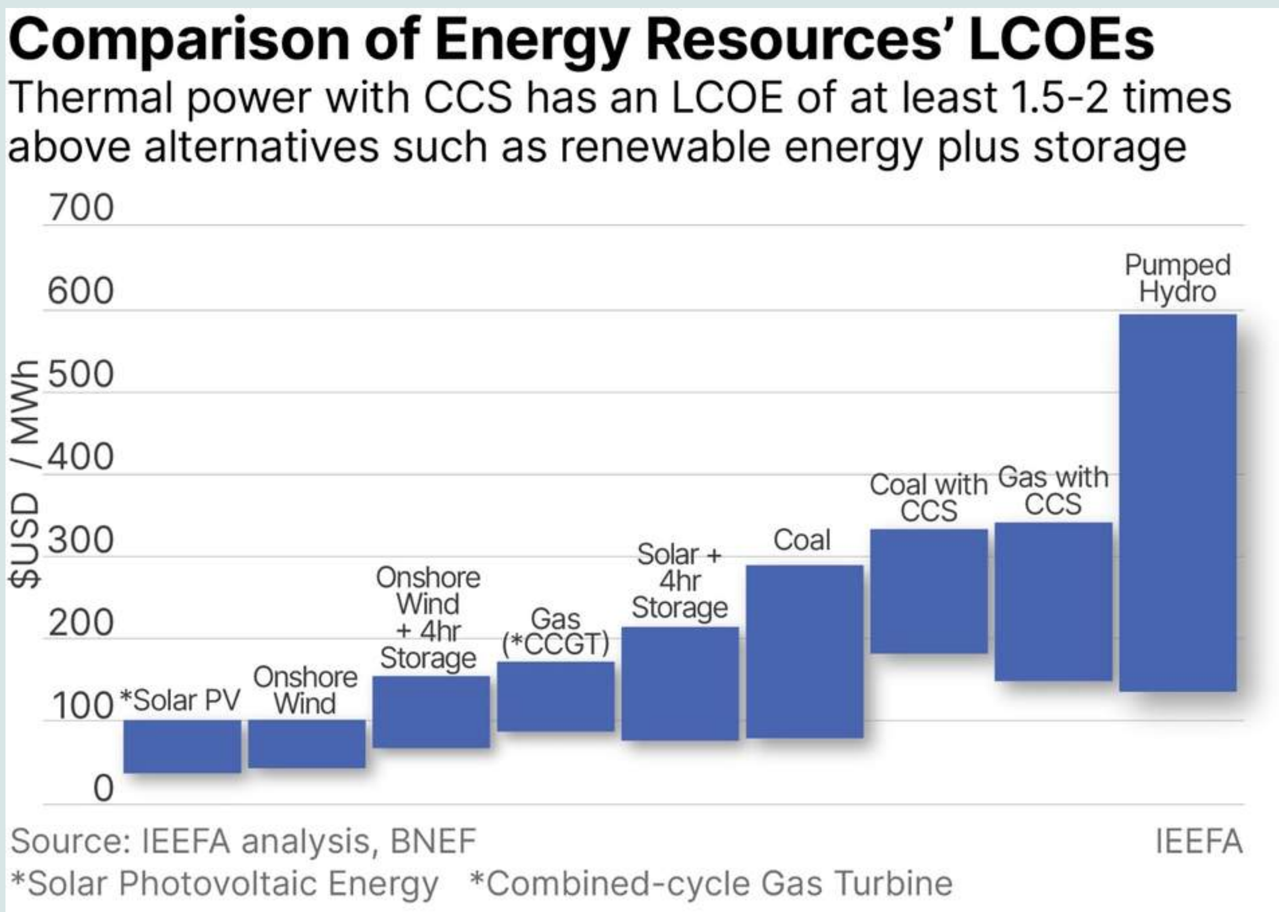
CCS STORAGE

What does CCS storage actually look like? First of all, CCS storage can be very risky, which will be discussed in the next section. The geography for CCS also matters! The space for storage must be airtight and resistant to the gases, not allow the gas to leak back through and into the surface where it reaches the atmosphere, and it also has to be an area not prone to earthquakes. There are many sites where CO2 can be injected and stored due to its non-flammable and relatively non-toxic nature, however each site takes careful evaluation before being decided as a safe place. The conditions that need to be considered include systems for measurement, monitoring, verification, accounting, and risk assessment. Scientists need to find a place that is easy to observe in case anything goes wrong, and as well as possible risks to the surrounding environment. Furthermore, they need to assess how likely a leak would occur, then carefully evaluate how that would impact surrounding civilians.



CARBON CAPTURE - COMPARISON

Researcher: Allison Lin   Editor: Claire Lin   Graphic Designer: Claire Lin



INTRODUCTION

As the world works to reduce greenhouse gas emissions and slow climate change, many solutions have been proposed, including renewable energy, reforestation, and energy efficiency improvements. One technology that has gained significant attention is Carbon Capture and Storage (CCS). CCS is a process that captures carbon dioxide (CO_2) emissions from industrial sources or power plants and stores them deep underground so they do not enter the atmosphere. Compared to many other climate mitigation strategies, CCS offers several important environmental benefits, especially in sectors where emissions are difficult to eliminate.

ALTERNATIVE SOURCES

One of the best environmental advantages of CCS is its ability to reduce emissions from existing industrial facilities. Many sectors such as cement, steel, and chemical production produce large amounts of CO_2 as part of their core manufacturing processes. Unlike electricity generation, these industries can't easily switch to renewable energy alone. CCS allows these facilities to continue operating while capturing up to 90% of their carbon emissions. By preventing these emissions from entering the atmosphere, CCS can significantly reduce the overall carbon footprint of heavy industry.

While renewable energy sources like solar and wind are essential for long-term decarbonization, transitioning the entire global energy system takes time. CCS helps bridge this gap by lowering emissions from fossil fuel based power plants during the transition period. This reduces the immediate environmental impact while renewable energy infrastructure continues to expand. Without CCS, some countries may struggle to meet climate targets while maintaining stable energy supplies.

Compared to some alternative climate solutions, CCS can require less land and fewer natural resources. For example, large solar and wind farms require significant land area and materials such as metals and rare earth elements. In contrast, CCS facilities are typically added to existing industrial plants, meaning they often require less additional land. This can help reduce habitat disruption and the environmental impacts associated with large scale land development.

ENVIORNMENTAL

Another major environmental benefit of CCS is its ability to enable negative emissions when combined with bioenergy systems. Technologies such as Bioenergy with Carbon Capture and Storage (BECCS) capture carbon released from burning biomass and store it underground. Because the plants used for biomass absorbed CO_2 while growing, the overall process can remove carbon dioxide from the atmosphere. This is an advantage over many other climate strategies that only reduce emissions rather than actively removing existing carbon from the air.

It is important to note that CCS is not intended to replace renewable energy or conservation efforts. Instead, it works best as part of a broader climate strategy. By reducing emissions from industries that are otherwise difficult to decarbonize, CCS complements renewable energy, electrification, and efficiency improvements. This combined approach increases the likelihood of meeting global climate targets while minimizing environmental damage.

Carbon Capture and Storage provides a valuable environmental tool in the fight against climate change. Unlike some alternatives that only work in specific sectors, CCS can reduce emissions from heavy industry, support the transition to renewable energy, require relatively little additional land, and even enable negative emissions technologies. While it is not a single solution to the climate crisis, CCS plays an important role in a comprehensive strategy to protect the environment and reduce global carbon emissions.

Carbon Capture - History

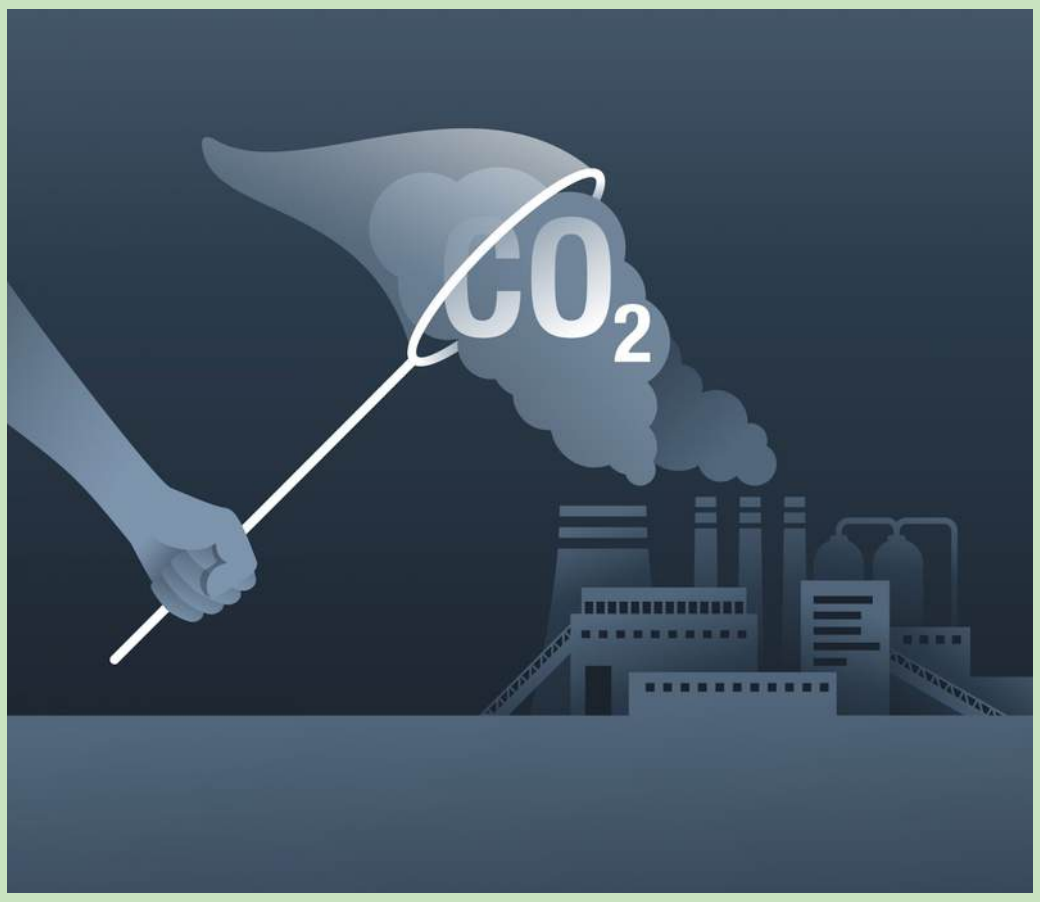
Researcher: Chloe Lin & Chloe Hsu Editor: Claire Lin Graphic Designer: Claire Lin

Milestones in Carbon Capture Developments

The United States provides a crucial contribution to the carbon market today.The idea of CCS (Carbon capture and storage) started in the 1970's, which originated from industrial gas in the 1920's. CCS is the idea of capturing CO2 and preventing it from going into the atmosphere. In the 1990s, scientists started thinking about what would happen if they stored CO2 instead of releasing it. In 1996, Norway launched the Sleipner Project, which was the first large CCS project. The Sleipner Project stored CO2 under the North Sea. It was the world's first CCS project. At the end of 2012, though, there were 5 large CCS projects. In the beginning, there were challenges such as high cost. The largest CCS project is Shute Creek in Wyoming run by the Exxonmobil company with its capacity being 7.7 million metric tons!

Protecting the Environment

Deployment of carbon capture is ideal and necessary when working towards reducing climate change and net-zero emissions. You may be asking yourself, what impact does carbon dioxide have to the environment? Well, carbon dioxide needs to be stored away from the atmosphere (especially in such large quantities), for it is constantly warming up our planet. According to Carnegie Mellon University, carbon capture and storing carbon emissions underground is a safe option when addressing our changing Earth, which needs our help and protection the most. This will drastically protect the human environment for the better. Carbon capture originated in the mid 20th century, and CCS (Carbon Capture and Storage) has cost us high amounts of money during the early development stages.



Future of CCS

Carbon capture is where we take CO2 from the atmosphere and store it in underground geological surfaces to reduce carbon emissions and contribute to decarbonization. In order for the system to function correctly, we inject the carbon emissions into the pores of the rocks that are trapped underground for safe and effective storage. Much of the produced carbon dioxide can be captured this way using compression, transportation, and injection. Integrating carbon capture is beneficial for the environment because carbon emissions are becoming more and more unavoidable, for example, when manufacturing cement. 340 million metric tons of carbon emissions were emitted in 2019. And with the strategy of carbon capture, we can predict the amount of carbon capture annually to be around 122 million metric tons. The carbon capture can be repurposed for other resources such as oil extraction. Carbon capture can play into different factors when addressing and acting against climate change, and is a beneficial option when handling our situation. But, in the future, there should be more efficient ways to capture CO2 besides carbon capture.

Carbon Capture Projects

Over 1000 carbon capture projects have been done as of 2024, which are primarily led by Europe and the United States. These projects are government funded into working towards mitigating climate change, and are only 2 of the many projects that helped shape our current CCS situation. You'll learn more about the future for CCS, and AI's role in carbon capture in the next section.

Sleiper Project, North Sea (1996)

Located in Norway, and the storage method used is injecting the CO2 into the Utsira Formation (a sandstone aquifer) which is under the seabed. This project helped show mineralization processes and also helped develop a better understanding of the basics of CCS, and what adjustments could be made in the future.

Boundary Dam 3, BD3 (2014)

Located near Estevan, Saskatchewan, in Canada. This project was the first ever fully-integrated CCS facility running on a coal-fired power plant in the whole world! BD3 not only showed intriguing outcomes of reduced carbon emissions from industrial processes, but also shared a reality of how carbon capture can be used to our advantage for sustainable energy. Carbon Capture can provide outlets for promoting climate change and help us reduce carbon emissions.

Carbon Capture - Risks and Dangers that come with Carbon Capture Storage

Researcher: Romero Santiago Editor: Claire Lin Graphic Designer: Claire Lin

Introduction

Carbon capture, while being a seemingly incredible way to mitigate the amount of carbon dioxide in our atmosphere, presents some risks that could lead to catastrophic events. The primary method of storing this captured carbon underground, in truth, could lead to consequences on a terrible scale, present dangers regarding groundwater, seismic activities, and more.

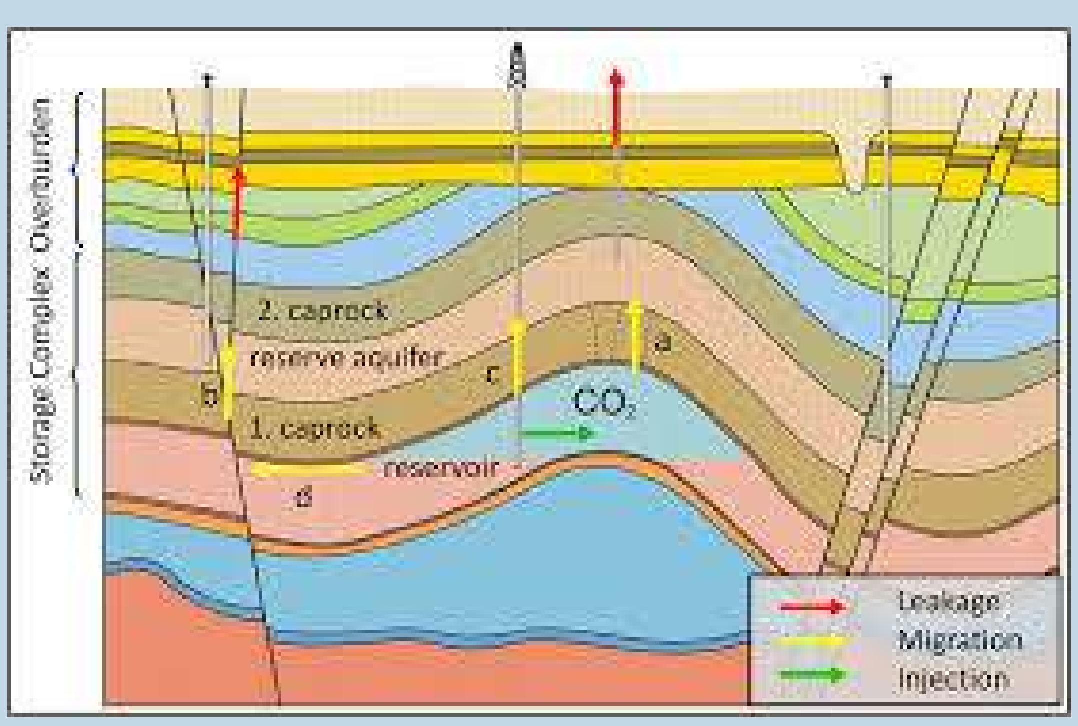
Whenever stored underground, the stored CO2 runs the risk of leaking, either gradually or suddenly. This allows it to combine with other subterranean compounds, known as volatile organic compounds (VOCs), or elements to create deadly gasses. Some examples include hydrogen sulphide and mercury, both of which serve as a lethal threat to underground life and live above ground if the pent-up gasses leaked a sufficient amount.

H2O

Water is also another compound that poses a threat; it corrodes the pipelines that hold the CO2, making the capture system much more susceptible to leakage and reaffirming the previous risks. It's also a nasty compound on its own; in 1986, a bubble of carbon dioxide that formed in a lake in Cameroon ended up killing about a thousand denizens. However, the underground gas industry faces these issues already and are well equipped to prevent this from happening, therefore serving as an inspiration to how carbon capture can be conducted safely.

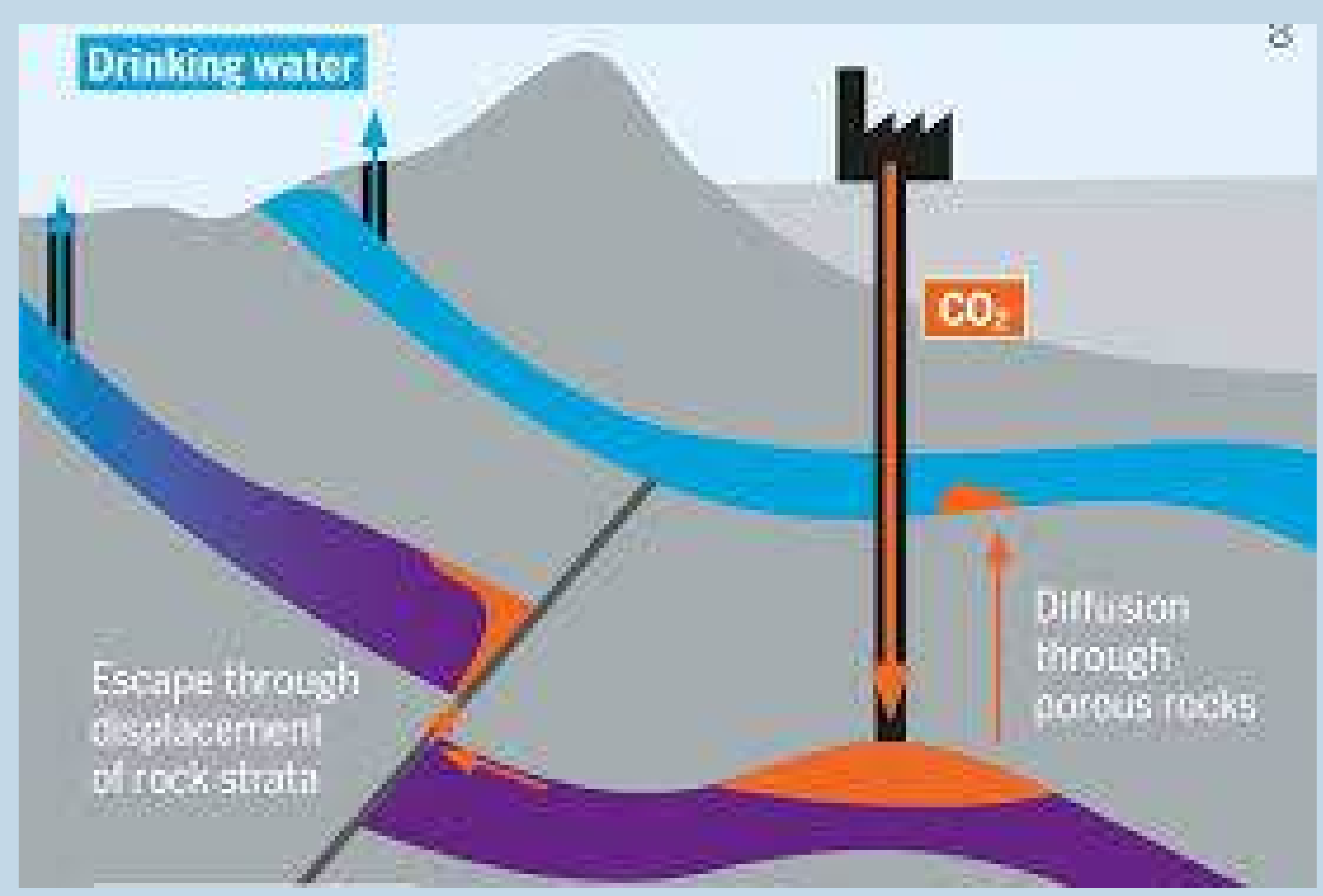
Economics

This technology could also serve as a problem economically. If these methods were to be funded by the federal government, there would definitely be a significant uptick in taxes as well. Some critics call out this system and state that carbon capture is merely a 'quick fix' and paying more taxes for this is illogical, instead being more in favor of renewable energy and more supposedly permanent solutions.



Leakage

FWhile leakage can be a problem that is controlled, the seismic repercussions that carbon capture could cause are a true threat. The sheer amount of CO2 being injected into the ground could induce tremors and could very easily generate a fatal earthquake. Not only would this lead to property damage and the potential loss of lives, but it would also let the captured carbon escape back into the atmosphere, reversing the work that has been put into containing it. This sudden return of CO2 to the atmosphere could potentially result in a harmful chemical reaction as well.



Wildlife

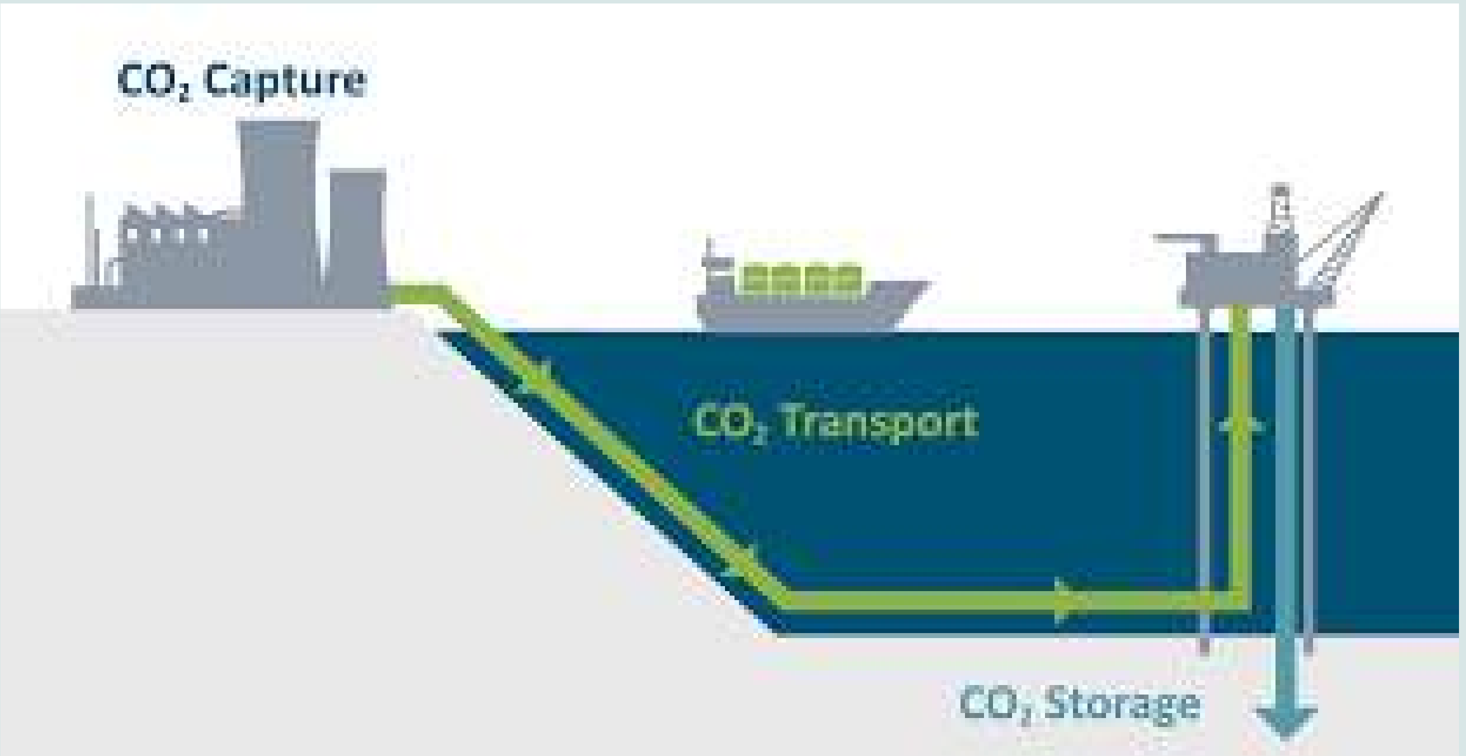
The volatility of the current state of carbon capture technology could harm the ecosystem and wildlife around the facilities. An accident could cause an unexpectedly significant rise in carbon dioxide in the area, affecting the breathable air of the animals or humans in the vicinity. If it were to be more explosive, the loss of several beings' lives would be guaranteed. Ideally, to lower the risk of harming the environment possible, these facilities will have to be in deserted areas with the lowest amount of wildlife possible to prevent the least amount of casualties in the face of disaster.

Conclusion

Along with the environmental benefits carbon capture technology brings, a list of dangers and risks to consider come along with it. The technology will have to be reworked in certain ways to bring these risks down as much as possible before it is implemented at a mass scale.

The Future Progressions of Carbon Capture Storage

Researcher: Claire Lin   Editor: Claire Lin   Graphic Designer: Claire Lin



Introduction

Have you ever wondered what the world is actually doing to help climate change? What areas are we improving on and what does our future on this planet look like? Well, there are some technologies that are being used to help reduce climate change, and one of those technologies is CCS. CCS stands for Carbon Capture and storage, and it's a way of reducing Carbon Dioxide emissions (CO2). This storage technology has the power to greatly help to reduce climate change on Earth. CCS follows a simple three-step process: Capturing the CO2, transporting it, and then storing it deep underground. Although this may sound easy to do, there are actually a lot of challenges and risks that come with trying to capture CO2 and making that process sustainable and safe. In this section, you will learn about the future CO2 has with us and how it can be used to save the planet.

CCS Workings & Benefits

Carbon Capture storage technology will first separate the carbon from the emissions that are produced in industrial processes. These industries could be factories, companies, or other power plants that are currently in use. The technology will then transport those emissions via pipelines underground so that it is safe. Finally, it is injected permanently into rock formations underground for storage, typically about 1 kilometer underneath the Earth's surface. Due to this expensive and energy consuming process, you may wonder what some of the benefits are of CCS. Capturing carbon from industries can take away some of the emissions that are very difficult to collect. CCS gives us a way to remove carbon from the atmosphere without doing much harm to humans or any other area of the environment.

Future of CCS

Due to how important Carbon Capture storage technology is for safe and efficient energy transition, investments of carbon capture are about to reach 80 billion dollars. Predicted CCS growth is expected to lower costs by 14% by 2030. This means that there will be less capacity, transport, and storage costs. The strongest predicted growth rate will happen in 2030, and scientists estimated that CCS will capture 6% of global carbon by 2050, which is twelve times as much compared to the 0.5% predicted capture amount by 2030. Soon, we hope that the carbon market will support the growth of carbon capture technologies, in order to protect our climate. However in the future we may need direct air capture so that we can capture emissions from anywhere in the atmosphere, but right now the main focus is to expand the technology as much as possible.

AI's Role

Scientists say that AI algorithms can be used to help improve the efficiency and effectiveness of the capture process. The AI framework for CCS can create a faster carbon capturing process and reduce costs, due to how quickly and accurately AI can operate. Going a bit back in time, the goal of the 2016 Paris Agreement of having global temperature increased limited to 1.5 Celcius, meaning that emissions will have to be reduced by half by the end of this decade. The role AI plays in Carbon Capture is that AI could have the power to scope CO2 emissions and capture this using patent landscape analysis (studying data to reveal trends). As technology advances, we can expect that AI will play a bigger and more important role in our future.

Boundary Dam in Canada is the world's first commercial combustion CCS system made using coal fire. AI has been used numerous times to help update the system, implementing machine learning algorithms to help with efficiency. Systematic algorithms can include things such as adjusted circulation rates,reboiler steam supply, and absorber pressure drop. AI has helped to keep the plant's energy penalty reduced by more than 8% cutting costs and time to create maximum efficiency.

The Northern Lights Project in Norway is a developed CO2 that has open access transfer to the North Sea. It requires accurate modeling of the surface to detect CO2 behavior, and we've seen patterns of AI simulation software helping to create a better storage site. AI has been proven to help detect anomalies to ensure safety and again maximize storage capacity.

The only problem with AI is data quality. AI requires and needs access to a variety of good quality and accurate data in large amounts, and in CCS we tend to see a lot of data that spreads across multiple domains. Precise CO2 modeling from AI means that we need to have access to large data collections. To do this, AI must be coded very well, using updated models and systems in order for it to reach its full potential. Technology and efficiency must go hand in hand in order for it to benefit CCS. AI may not erase all of the challenges tied to CCS, but it can definitely help when limitations of the technology are laid out and recognized. We believe that AI can and should bridge the gap between technology and research in the Carbon Capture storage world.

Challenges

Generally, when there is great technology, there are typically also some challenges that come along with it. For CCS, some challenges include costs, public criticism, technical difficulties, safety, storage capacity, and regulatory requirements. Sometimes, CCS is seen as a distraction to the efforts made for renewable energy sources, and these can cause commercial challenges. Lately, scientists have discovered that the cost of storing CCS has been really high, and companies are hesitant to invest due to the possible economic challenges. Some projects of CCS have been government funded, but arguments claim that more funding is needed/required. Some of the biggest storage challenges include the fact that the capacity of storage is limited and not all places have that storage available for the long term. Assessing possible storage locations takes a lot of time and also money, which is why it's not as common. Lastly, the infrastructure challenges include how storage space is so remote heavy transportation is required. The network of pipelines used for CCS is both expensive and could possibly restrict construction. Leakage is also possible even after CCS is safely secured and stored. How leakage happens is through corrosion, for example when CO2 comes into contact with water it can create carbonic acid. The corrosion in metal and pipes are hard to detect and repair is both dangerous as well as costly. For these reasons, CCS is expensive and hard to execute properly and safely, making it a difficult yet powerfully impactful solution to climate change.

Politics

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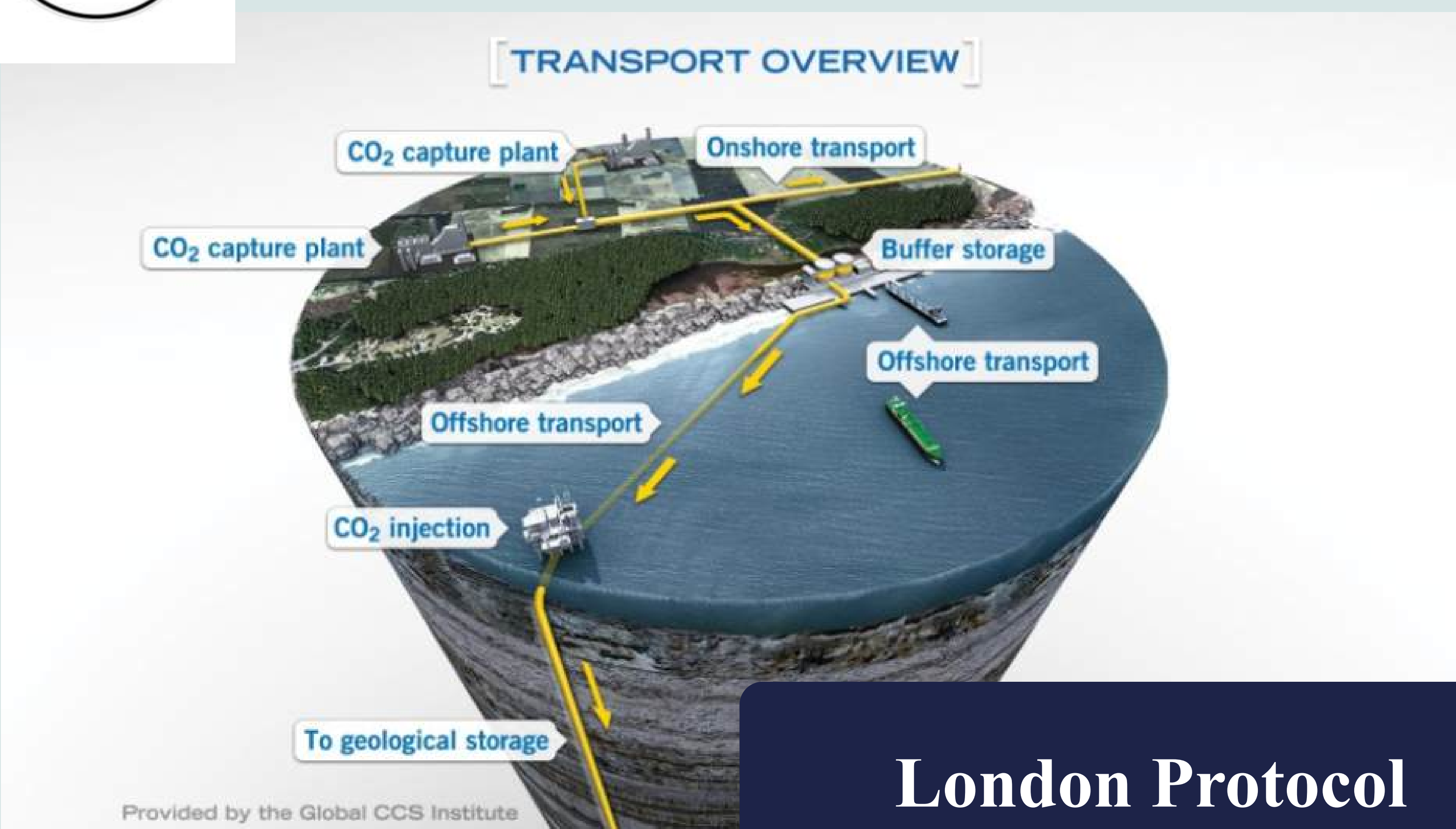


Introduction

The usage of carbon capture has been an ongoing discussion in our current world. CCS (Carbon Capture and Storage) and CCUS (Carbon Capture, Utilization, and Storage) allow for a more renewable strategy in managing carbon excretion from industrial sources. Many countries and international groups have pushed policies to integrate and encourage industries to use CCUS and CCS. Of course, some countries have pushed back against the act for numerous reasons. We'll explore a few below.

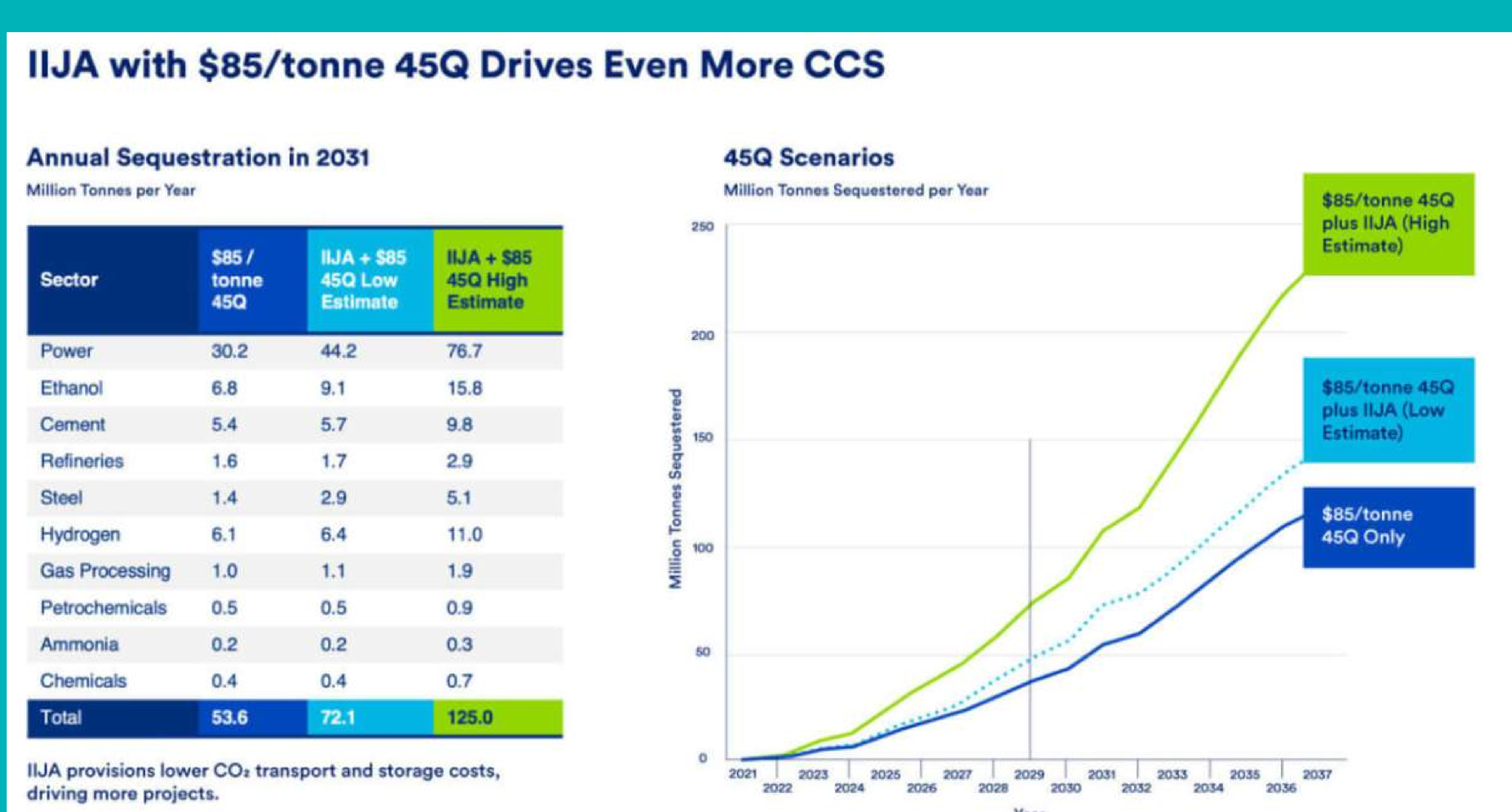
London Protocol

The London Protocol is a global international agreement under the International Maritime Organization that allows the capture and storage of carbon into seabeds in the ocean. It began operations in 2006, updating the previous London Convention of 1972. The London protocol applies strict regulations on seabed Carbon storage, but allows the carbon to be stored in more locations. Before the London Protocol, Carbon Dioxide, which was legally treated as a form of waste, was not allowed to be transported to another country for ocean dumping. But with the London Protocol, countries that might not have suitable geological sites for storage are able to ship their carbon to another country who can store carbon. A successful example would be Project Greensand in which carbon dioxide was transported from Belgium and injected into the Danish North Sea for storage. This protocol allows for all countries within the United Nations to dispose Carbon Dioxide properly and reduce carbon emissions.

CCUS ITC

Standing for Carbon Capture, Utilization, and Storage Investment Tax Credit, this Canadian carbon capture policy was introduced in 2021, and provides money for carbon capture equipment, up to 60% for Direct Air Capture (DAC) and up to 50% for other carbon capture equipments, reducing the risk of the high cost CCUS projects. Additionally, with federal carbon pricing system in Canada applying a tax on carbon emissions, meaning that emitters have to pay to emit their carbon, CCUS ITC allows for companies to avoid paying carbon taxes after they construct a carbon capturing system, which is a further incentive for companies to enroll in such programs to avoid taxes.

45Q Tax Credit



Sector	$85 / tonne 45Q	IIJA + $85 45Q Low Estimate	IIJA + $85 45Q High Estimate
Power	30.2	44.2	76.7
Ethanol	6.8	9.1	15.8
Cement	5.4	5.7	9.8
Refineries	1.6	1.7	2.9
Steel	1.4	2.9	5.1
Hydrogen	6.1	6.4	11.0
Gas Processing	1.0	1.1	1.9
Petrochemicals	0.5	0.5	0.9
Ammonia	0.2	0.2	0.3
Chemicals	0.4	0.4	0.7
Total	53.6	72.1	125.0

The 45Q Tax Credit is a carbon capture policy of the United States that helps overcome Carbon Capture's high cost problem. Through the Tax Credit, companies can trade carbon on a per-ton basis for tax credit. The company is paid if their carbon dioxide is permanently stored underground or utilized in other ways. Recently, under the Inflation Reduction Act and reinforced by the One Big Beautiful Bill Act, the 45Q Tax Credit, has increased the tax value from $85 per metric ton to $180 per metric Ton for Direct Air Capture projects. Through joining the 45Q Tax Credit, companies can use the gained money to fund other projects, which is usually the main incentive for the 45Q Tax Credit. The 45Q Tax Credit lasts for 12 years to provide financial support to companies to support their carbon capture projects such as building infrastructures. After the 12 years, the tax is no longer needed as the company would have created a carbon capture structure.

Poland's EU CCS Directive implementation

Poland's implementation of the EU CCS Directive, which permits safe geological storage of CO2 includes many restrictions on the ability to store carbon. One of these restrictions is the ban of onshore CO2 storage, meaning that no carbon can be stored onshore and must be either offshore or outside the country. This comes as a problem as Poland has extremely limited offshore sites, making it very difficult to store carbon. Another part of Poland's implementation includes its high minimum storage thresholds, requiring that companies must store high amounts of carbon if they do want to store carbon at all. This prevents pilot experiments for companies that want to experiment with small amounts of carbon storage, discouraging such early investment. Poland's implementation could be a reflection of its high reliance upon coal and its priority in domestic mining interests.

CONCLUSION

Many countries have undergone efforts to reduce carbon emissions through CCUS and other storage techniques. The funding of infrastructure makes the storage of carbon more accessible for companies and industrial settings. But at the same time, with differing economic situations in many countries, different countries would respond and implement carbon capture policies to better accommodate their economies. And as a result, it is important to acknowledge these differences when negotiating international policies to suit different country's needs.