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The Potential of Incentivized Carbon Capture: A Literature Review

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ABSTRACT

The current debate over reducing anthropomorphic activity has not succeeded in reducing the global carbon footprint, which speeds toward what climate scientists called the irreversible "tipping point." To combat global warming, climate change, and catastrophic environmental damage, technologies can be developed to combat the refusal to reduce industry. The emerging tested technology of carbon capture, utilization, and storage (CCUS) allows for companies to not only offset greenhouse gas emissions with one another but to actually reduce the amount of carbon dioxide that persists in the atmosphere. Although current scale is inadequate to balance the carbon output, the technology is ready for companies to launch and invest, if only incentivization is made available as well. Because CCUS has the potential to contribute to slowing down or even lowering the global temperature increase, its challenges and opportunities should continue to be explored and discussed to find an optimal way to deal with climate change. This paper suggests that the cooperation of governments, companies, and supranational organizations could result in meaningful impact to lower the global carbon footprint and fight climate change.

Introduction

As scientists study the Earth's processes and many cycles—nitrogen, carbon, water, for example—they continue to gain more understanding of humans' role in the environment. Despite the recent droughts in many desert and coastal communities around the world, the focus remains on the carbon cycle because of the modern threat known as global warming and climate change. According to popular science textbooks, the carbon cycle is Earth's way of regulating the amount of carbon stored in the Earth as fossil fuels, the land as certain rocks like limestone, soil and the trees, and finally carbon dioxide in the ocean and the atmosphere. Since the Industrial Revolution of the eighteenth and early nineteenth centuries, human actions have increased the amount of carbon dioxide moving in the carbon cycle (*Causes of Climate Change*, 2017). Even the carbon cycle has received more attention as climate scientists look at different parts of it, separating it into the "fast" and "slow" cycles (Riebeek, 2011). One major problem for people is that carbon is stored as fossil much more slowly than it is used, making fossil fuels nonrenewable in our lifetime; however, there are many smaller processes that can occur quickly, and that gives scientists hope to make change.

This greater understanding has made it more clear that humans have the power to impact Earth's environment more than they like to believe. What this means is that people have the ability to alter Earth's system through technology, action, and choices. Today, the scientific term for human effects on the Earth is "anthropomorphic activity." This covers all the actions, especially harmful ones, that come from humans' use of industry. For example, people are responsible for air, land, and ocean pollution, the plastics that do not properly recycle, and the increase in carbon dioxide that warms up the Earth system by heating up the atmosphere, ocean, and the land (Lindsey, 2009). Due to high activity using fossil fuels and deforestation for transportation, con-

struction, and manufacturing, the last century has created a society of people who create environmental challenges of "energy, consumption, biodiversity, water, inequality, technology and much more," which is presented in Columbia University's Climate School newspaper, *State of the Planet* (Goldmark, 2023).

Starting in elementary school, students often learn about global warming and climate change. Once they attend high school, they may even do experiments that teach them more about the chemistry of greenhouse gases and the physics of air and water currents. In classes like advanced Chemistry or AP Environmental Sciences, students learn how carbon dioxide, greenhouses gases, and the atmosphere's circulation contribute to global temperature increase. However, these are more modern additions to education, and many older adults who vote and make policy decisions may not understand as much modern science once they are done with school. For this reason, scientific debates still continue, and it remains difficult to convince the public to take action.

Today's greatest debate is the "tipping point," or the critical day when people cannot undo the damage to the Earth. According to Paul Collins' summary of the 2022 Intergovernmental Panel on Climate Change (IPCC) report, data models show that humans will pass the 1.5°C threshold by 2040 (2023). A consensus of climate scientists shows that this temperature increase would be "catastrophic," showing an increase of flooding, hurricanes, and other extreme weather events (Collins, 2023). In fact, as reported in *Fortune* magazine, airline passengers and pilots have reported challenging skies with "an increase in both the frequency and the intensity of climate-related issues" such as "clear-air turbulence," or invisible air changes that cannot be predicted (Barber, 2023). Thus, the debate over the tipping point is not just a theory about what could happen in the future. As the Earth approaches the tipping point, problems will become more obvious, such as weather problems and dangerous events like sudden changes in heat or rain.

As the increase continues to occur and the Earth accelerates toward a dangerous, uncertain future, scientists shout for the public to pay attention and demand responsible decisions from the government. It is not clear at the moment how countries will respond as they compete for economic power and make promises to cooperate for the Earth's sake. Whether or not people change their activity may not be the answer, and new scientific breakthroughs show that there may be other hopes. As Plato once said, "Necessity is the mother of invention," and Elon Musk more recently commented in his 2017 Ted Talk that "technology does not automatically improve." Combined, these statements present a challenge and opportunity for people to see technology as the only possible way to innovate solutions to slow down or eventually reverse the effects of anthropomorphic activity—and to avoid reaching the dreaded tipping point.

Focus of Inquiry

Multiple approaches to research have highlighted the need for people to reduce their carbon footprint, recycle more, and reuse products as much as possible. While this campaign is still important, a new opportunity to focus on technology has emerged due to improvements in global technology, as well as the lack of cooperation by nations who value their economy over the environment. Therefore, this paper approaches the global warming footprint from the other side of the equation: how to balance carbon emissions by using technology rather than reducing carbon dioxide output alone.

Specifically, this paper aims to 1) introduce potential solutions options to combat global warming regarding fossil fuels, 2) identify the approach with the most potential in today's technology and future development, and 3) discuss government regulations and global policies that could be implemented to support the use of the potential solution called carbon capture and utilization.

Methodology

As I began my research, I investigated the most popular alternatives to fossil fuel combustion. Ideas like solar panels, wind farms, and geothermal turbines have already been implemented, but they still do not make up a large percentage of energy output compared to traditional fossil fuels. Seeing that this trend is going to continue unless laws are suddenly changed, I decided to research the ways scientists are trying to reduce carbon footprint after the fact. This led me to an interesting discussion of post-combustion methods to limit carbon dioxide in the air using a method called carbon capture. Many versions of carbon capture exist, making the research possible to go wider and deeper in investigating a solution.

Ultimately, I chose to identify and compare multiple methods of carbon footprint reduction, and I identified carbon capture, utilization, and storage (CCUS) as the potential solution with the most impact using today's science and laws. To make the solution more clear, I also investigated how governments regulate companies and the economy, as well as the importance behind making laws that protect consumers and the environment. A balance of environmental protection and economic regulation would be the most beneficial way to support companies to invest in CCUS technology.

To present the information in the most logical format, I chose to synthesize my research in the form of a literature review. This allowed me to outline the different categories of my findings in a way that shows the developments of my thought process in their correct sequence. Finally, the literature review serves to discuss findings that support the cautious recommendation made in the conclusion.

Literature Review

The Ongoing Focus on Reducing Fossil Fuel Consumption

Ever since the Industrial Revolution began in England and polluted the Thames River, the spread of environmental damage has grown. The modern environmental movement began in the 1960s when an oil spill polluted the Santa Barbara coast in California, the worst spill America had ever seen (Hamilton, 2019). As America and the rest of the world continues to depend more on fossil fuels, oil disasters have grown more dangerous. For example, twenty years after the Santa Barbara well spill, the *Exxon Valdez* oil tanker crashed in Alaska in 1989, spilling 11 million gallons of oil (*Exxon Valdez*, 2020). Similarly, an oil well spill in the Gulf of Mexico occurred in 2010, spilling over 12 times the amount of the oil tanker spill in Alaska, at a total of 134 million gallons; the company, British Petroleum, paid a $5.5 billion penalty because its oil rig explosion caused "up to $8.8 billion in natural resource damages" (*Deepwater Horizon – BP Gulf of Mexico Oil Spill*, 2023).

Today, people are more concerned with saving the environment than ever before, yet the dependence on fossil fuel creates a major conflict. While polls on *Statista* indicate up to 84% of people surveyed around the world want to reduce combustion of fossil fuels, that number does not reflect the total accurately; though economically motivated, China responded with 90% in favor of stopping, while in the United States only 3 out of 4 people polled wish to turn off fossil fuel gas usage (Armstrong, 2022). These statistics are significant because it is not just how many people around the world want to stop using fossil fuels, but really where those people live and how much impact they will have by making decisions to actually stop using fossil fuels. Supplementing the information, data journalist Florian Zandt provides a chart showing that America leads oil consumption with over 19 million barrels a day compared to China's over 14 million, though China's rate has grown much more quickly due to industrialization (2023b). An interesting point of the data differences between US and China is that "over the last ten years, China has become the global battery electric vehicle (BEV) forerunner" nearly 500 times as much battery usage in 2022 compared to 2012 (Zandt, 2023a). Still, China's development of electrification does not actually signify a decrease in oil consumption; instead, the use of both signals the continuing growth of China's industries.

Although campaigns to reduce fossil fuel usage have existed for decades, the movements to change the public's behavior have focused on two main issues. First, the campaigns to reduce carbon footprint have

continued since the famous 3 Rs: Recycle, Reduce, Reuse (Gordon, 2015). In this original campaign for sustainability, people were encouraged to recycle metal, plastic, and paper products as much as possible, reduce their use of fuel and disposable products, and reuse—or repurpose—products so that they could keep landfills free of trash. However, the campaign's impact was not enough to handle higher population growth and industries of growing nations around the world. Second, science fiction and technology booms have made people believe that a large variety of sustainable alternatives exist or can be developed. For example, today people can purchase solar panel electricity service and see wind farms around the desert and flat lands. Despite being visible near cities, the truth is that these energy sources are only a small fraction of the energy used in the US. According to the U.S. Energy Information Administration (EIA), renewable energy sources made up about 21.5% of electricity production and just 13% of America's total power consumption (*How Much of U.S. Energy Consumption and Electricity Generation Comes From Renewable Energy Sources?*, 2022). Therefore, the demand for fossil fuel consumption does not show signs of slowing, and if people are to avoid crashing past the climate change "tipping point," it would help to consider other alternatives through technology.

Challenges of Employing Electrification as a Fossil Fuel Replacement

With science fiction and technology news, people have begun to hear about possible solutions. Clearly, leaving the planet to live on the moon or Mars, or producing a miracle energy source that will supply infinite free power, are impossible wishes at the current level of technology. Furthermore, shifting completely to electrification is not recommended because even though electricity can power anything on Earth, it also builds up heat where it is used, and the real problem is not how much electricity we can supply but how it is stored and delivered. Currently, the American power grid, and most of those around the world, store very little energy in the form of batteries; instead, the power is produced and delivered on demand (*Utility-Scale Energy Storage: Technologies and Challenges for an Evolving Grid*, 2023). Thus, while an electrical power grid can be expected to supply enough electricity in general, a crucial problem occurs due to lack of reservoir and for delivery.

In short, electricity without storage is like having no lakes or reservoirs to guard against times of drought. Without long-term storage, any moment that the electrical utility companies fail to provide enough power, an outage can occur. That means air-conditioning will not function, computers will shut off immediately, losing work progress, and traffic lights will not perform their jobs. Power outages and lack of internet can shut down the economy, especially industries that rely on real-time computing such as aviation industry and stock trading. If electrification is not reliable to constantly deliver enough energy, it will not be able to replace combustion fuel. Furthermore, if electrical energy is not stored, then companies are not likely to improve the infrastructure used to deliver electric power. Currently, electricity delivery is limited by the quality of cables and wires. Moreover, no matter what material they are made of, they will lose efficiency over distance, which is another major challenge to using electrification to replace fossil fuels. Compared to oil drums and gasoline, which keep their energy value when transported to other locations, electricity is always wasted as it travels through cables, making it so much more important to improve delivery ability before electrification can be for everybody.

The Shift Toward Pollution Cleanup Methods

As part of the greater public view, companies and individuals perform volunteer cleanups. While these activities do help the environment on a daily basis, many companies enjoy a greater benefit called "optics" (Blitz, 2020). Though the term originally means the study of sight and light, today companies use it to say that they have a positive image in the public. For example, a company that may pollute lakes and rivers may hide such activities, but they will do everything they can to make sure the news hears about their donations to charity or volunteer services to help others in need. In this way, companies receive the benefit of positive optics by actually doing very little, and their helpful activities actually help them much more in return as positive marketing.

Despite the truth that many companies just want to appear helpful, many organizations try to help the environment sincerely. For example, the Ocean Cleanup project now aims to become the largest cleanup in history, with a goal of 90% removal of floating ocean plastic pollution even as the world continues to pollute a million tons annually (Slat, 2021). Even much smaller projects can become impactful with ambition and willpower. In the case of Marino Morikawa, the man who cleaned El Cascajo Lake in Peru by himself, scientific knowledge, applied research, and technology proved to be the right solution. After earning his Ph.D. in Japan, Morikawa returned to Chancay, Peru, and he spent every day working to clean up his childhood recreational lake. Using his knowledge of nanotechnology, Morikawa created an edible powder that was safe for people and the environment, which was like magic: mixed in the lake, it would grab contaminated particles and float on the surface, and in a few months of daily filtering, the water became clear and brought back the animals and tourists (Nas Daily, 2019). Both cleanup projects, in the ocean and in the lake, sought to clean up the water and heal the environment after damage made by humans.

However, these projects actually have zero impact on the use of fossil fuels themselves. Furthermore, it is unfortunate that people think that these people's efforts to clean up the Earth will let everyone else continue to pollute. Therefore, the environmental problem right now is complicated by the fact that people continue to demand more oil consumption, and they are encouraged by some cleanup efforts that are famous yet unable to undo the real damage in the atmosphere and the oceans—carbon dioxide buildup.

Carbon Capture, Utilization, and Storage (CCUS)

One of the emerging breakthroughs in pollution cleanup is a technology that pulls carbon dioxide directly out of the air. Called carbon capture (CC), the process can be quite simple or advanced. In its earliest form, industrial polluters like chemical factories and manufacturers began to use "scrubber" systems to clean the exhaust gases that left their business (*Scrubber*, n.d.). With this process, gases could be filtered by either a solid powder ("dry scrubbing") or with the addition of liquids that the gas would contant on the way out, with contaminants sticking to the liquid filter ("wet scrubbing"). Since they have become popular in use, their operation has not changed much because the known pollutants react with certain chemicals reliably. Still, while sulfur and some amounts of smog and particulate matter (PM) can be captured, carbon dioxide is a smaller gas that generally escapes into the air outside. Thus, today's focus on capturing carbon dioxide itself, the primary greenhouse gas of concern, has led to new options as governments acknowledge the potential for proper carbon capture and storage (CCS). For example, with proven technologies now in the public, the government of the United Kingdom announced in 2019 that it approved of and would support CCS technology under its Industrial Strategy and Clean Growth Strategy in an effort to fully decarbonize the UK's economy (*CCS Explained*, 2023).

In America, successful CCS proof of concept projects have been recognized as well. For instance, Cornell University's McGovern Center funded a startup company, Dimensional Energy, which proved its technology could contribute to negative carbon emissions in the Carbon X Prize competition as a finalist (Friedlander, 2021). CEO and cofounder Jason Salfi explained that the small-scale models led to the construction of a pilot reactor in Wyoming where testing proved that their solar fuels reactor could achieve "10-ton per year scale … carbon dioxide into a carbon-neutral fuel" (Friedlander, 2021). Currently, the company's Tucson Technology Center is working to convert their carbon-neutral compounds into sustainable aviation fuel, which could help airline companies and the aviation industry continue to improve its image and services after years of pandemic difficulty.

CCS projects now dot the globe, with projects running in China, Iceland, and every climate zone in between. Multiple technologies have made it possible for carbon capture to occur in any type of skye: hot or cold, dry or wet, most polluted or not. Still, the most attractive options are for CCS projects that can be placed within cities to show their effects live. For example, even in 2009, the concept of a "smog tower" was implemented in China, downwind of yellow smog produced by industrial waste: the tower is self-powered by solar

energy and natural direction of the wind, which lets the building filter smog out of the air without extra operating cost, and in 2018 China now boasts the world's largest air purifier building, which local residents agree has made noticeable improvements in air quality index values (Smith, 2018).

The final step in carbon capture is to add value through utilization over just storage. Thus, carbon capture, utilization, and storage (CCUS) is the current best form of carbon capture, which means that several benefits are identified at the same time. First, carbon is removed from the atmosphere to truly clean the air. Second, this carbon can be converted into a stable solid form that can be stored and placed out of the carbon cycle, the way fossil fuels or ocean floor sediments were supposed to do before human activity. Finally, the products can even be repurposed, such as by adding hydrogen to create fuels or other compounds to produce plastics. These products would be considered carbon-neutral because they reuse carbon that would be wasted and put into the atmosphere anyway, and no new oil would be combusted to extract them (Budinis et al., 2023). A truly cost-saving benefit of CCUS technologies is that they can be "retrofitted to existing power and industrial plants, allowing for their continued operation" (Budinis et al., 2023). Thus, these technologies can supplement scrubbers and result in much cleaner energy use. In the end, while companies would not actually consume less fossil fuel, CCUS implementation would at least achieve the same desired goal of reducing carbon footprint, or atmospheric carbon dioxide.

Discussion

Incentivization of Corporate Adoption of CCUS Practices

The Dilemma of Customers

At the moment, other than non-profit organizations, companies are rather unwilling to invest in carbon capture projects for their own use. While the technology is understood and companies may invest in non-profit groups, corporations themselves lack an obvious immediate benefit when producing their own CCUS facilities and providing the services to the public. That is, those who benefit from the service being provided—citizens, residents, the Earth—are not the ones to pay for the projects themselves either. This produces a problem similar to the original environmental "tragedy of the commons": those who pollute are not usually the ones who pay the cost of polluting; similarly, those who can provide the service are unlikely to when no profitable scenario exists. Thus, CCUS at the moment is stagnant due to its perception as goodwill projects that do not have the capacity to impact the world's carbon footprint.

In the case of the Xiao tower in China, the company responsible for its construction benefits from positive optics, an important marketing benefit as mentioned earlier, but no direct profits are traced to the tower. Citizens are happier, even thankful, but the company's profits actually remain the same. Therefore, it is important for companies to see incentives for them to initiate larger scale of projects. Those incentives can be through changing government regulations or subsidies, as well as laws as a result of changing public demands.

Government Regulation

Countries generally regulate their own economies to some extent, but regulation is a hated word by industrialists who see it as a barrier to economic growth. Whenever an industry is restricted in some way, it cannot develop as quickly as it could without limitations. For example, carbon dioxide removal is a new industry, yet even the older problem of reducing carbon emissions has not been addressed properly. Thus, some scientists advocate for focusing on drastic emissions reduction, which they believe can be achieved more easily than the upscaling or CCUS technology, which currently cannot pull enough CO_2 out of the sky to prevent the "tipping point" from becoming reality someday (Ho, 2023, 9). However, the fact that an even older industry has yet to face adequate regulation does not mean that the new industry should not be pursued; it may even suggest that it is

time to move on, since hoping for companies to clean up their operations may just be a dream that will never come true.

While individual governments have not always succeeded in regulating their polluters, the international community has shown more success through the United Nations and voluntary organizations. Though they do not have the force of law, supranational organizations, or those that bring countries together to cooperate, have power in steering countries in the right direction. On occasion, some agreements even carry legally binding requirements, like the Kyoto Protocol, which was introduced and adopted in 1997 and put into place by 2005. This system of agreement, monitoring, and regulation succeeded with its member nations, and it serves as an example of how to continue into newer treaties like the Paris Agreement.

Governments may not always regulate their economies, but countries still act to make positive change when properly incentivized. For example, investors in China have shown faith in clean energy, raising $7.5 billion in 2005 and increasing that commitment to $101 billion in just ten years, with another $44 billion in foreign clean energy projects; this decision dwarfs the European Union's total $40 billion investment in clean energy in 2015 (Smith, 2018). What this example shows is that countries do end up regulating themselves in some form, whether it is the government forcing the rest of the nation, the country agreeing with others to allow a global group to monitor and regulate them, or economic interest that invests the money to make a change.

Exemplars of Current and Imminent Regulation: Depending on who is asked, America is either too strict or too lenient when it comes to environmental regulations. In California, however, a drastic regulation is set to take place in 2035 as the Advanced Clean Cars II regulations take effect. Under the rule, zero emission vehicles (ZEVs) will become the only new cars available for purchase in 2035 and later (*Cars and Light-Trucks Are Going Zero - Frequently Asked Questions*, 2023). As planned, gasoline cars will still be allowed for used car purchases and trade between other drivers, allowing a transition that could take over ten to fifteen years. To support this move, California is investing in development and supporting automakers, and it is important to note that decisions like this made in the most populous state have effects on the rest of the country.

Similarly, the European Union is banning combustion engines beyond 2035, but in a slightly different regulation, e-fuels will be allowed, creating an exemption for combustion cars as long as they use synthetic fuels that reduce carbon dioxide emissions; environmentalists see this move as an effort by luxury carmakers to stall the ban on traditional internal combustion engine (ICE) vehicles (Calma, 2023). In both the US and the EU, the move to ban ICE vehicles means a drastic change due to the existing car culture and infrastructure of gas stations; electric vehicle manufacturers will have to increase the presence of recharging stations that can match Tesla's supercharger rates. Furthermore, investments in car batteries and alternative fuel cells will require billions of dollars and years of innovation.

Across the Pacific, the Vietnamese government has also taken a strong stance against carbon pollution with its plan to ban all motorbikes by 2030. According to the Hanoi People's Committee, the 2025-2030 economic development program outlines and approves "motorcycle restrictions [to] be imposed in the metropolitan districts by 2030" (*Hanoi to Ban Motorbikes in 12 Inner Districts by 2030*, 2023). Although headlines shocked readers, the regulation is not immediately as strict as people may think. Despite being called a total ban, it is a total ban within the city of Hanoi that will take place in phases. Still, this is one of the strongest commitments to anti-pollution and can make a noticeable impact, as Hanoi is rated the second-most polluting city with 75% of its 8 million vehicles being motorcycles; the ban is expected to increase use of the city's public transportation system, but it will also test the city's infrastructure as transportation patterns change in the next decade.

These regulations are expected to take place in the next twelve years, and they will slowly shift the way the younger generation interacts with the planet in terms of traveling and considering their use of fuel more carefully. However, government regulations like these often fail to change company behavior, so alternative incentives will also be necessary.

Existing Incentivization Models

Incentivization for CCUS tech companies already exists without government intervention if the technology can scale. If a company were to invest in CCUS technology, it could clean up both its image and carbon footprint, lowering its annual emissions. In many countries, international agreements have placed limits on how much pollution companies can release, with penalties for going over those rates. Thus, CC could count as subtraction from a company's emissions, bringing them below and saving them from costly penalties. Over time, the amount saved would justify the amount invested, similar to the way customers who purchase solar panels end up saving electricity costs by not having to purchase electricity from the power company.

Another option that makes it possible for companies to make profit is to sell their captured carbon as "credit" to other companies facing penalties. Known as carbon credits, permits are given to companies, allowing them a certain amount of greenhouse gas emission; for example, one ton of CO_2 released would be considered one yearly credit in the American cap-and-trade program (Kenton, 2023). Although many people consider carbon credits a way for companies to create more pollution, or that it encourages waste, the credits actually "create a monetary incentive for companies to reduce their carbon emissions" or enable operation at a higher cost, with penalties used to fund anti-pollution programs (Kenton, 2023).

CCUS technology also offers a chance for companies to become leaders in a growing industry. Though investments may be heavy at first, the failure to reduce emissions means that more and more companies will come to rely on CCUS providers, so new markets will be available, especially as customers are found in "steel, cement, refining chemicals, glass, and ceramics" industries (*CCS Explained*, 2023). Adding to the exciting news of CCUS is the fact that although carbon dioxide products were initially made and stored in geological reservoirs, it is now possible for CCU products to be converted into consumer goods such as food, beverages, sustainable fuel, and alcohols that can be used in perfumes and vodkas (Kim, 2022). This form of product may take some time before the public accepts it fully, but the potential for other products to be made from carbon waste means that people will finally be putting "reduce, recycle, reuse" to even high level of application. That means a product that can be sold as credit while being stored as waste could further generate profit by becoming a resource that does not have to be extracted from the Earth, doubling its usefulness.

Conclusion

CCUS technology is not just the science fiction of vacuuming the sky. In fact, it is a viable technology that is on the verge of being commercialized to make a real impact in the world. While current scaling shows that companies have proved their concepts but are not yet operating on large scales, it will be possible in the near future for carbon capture to made a noticeable reduction in atmospheric carbon dioxide levels, which will slow down the rise in global temperatures.

Due to the unwillingness of people and companies to reduce their demand for fossil fuels, laws and policies cannot depend on just regulating companies to stop them from using oil. While it would be ideal for people responsibly limit themselves, unless every person on Earth makes a commitment, it is still the same as dreaming for a better future. Rather, the increased use of CCUS technology to the level that it can actually make carbon-neutral industries is a potential solution with real impact if governments, companies, and international groups work together to make it worth the business.

Limitations

Although the literature review is intended to be comprehensive, data for numerous countries of interest were not available or ready to translate. In terms of country and global policies, a lack of familiarity with some principles and terms made research more difficult in this direction. Most of all, the focus on CCUS limited the

amount of exploration of other sustainable alternatives that are still in development, making this study less inclusive than it could be. Further research could include more history to supplement the amount of technical discussion; other studies could focus on non-economic angle or purely scientific reasoning to provide persuasion as well.

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