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Making Products out of Thin Air: Accelerating Direct Air Capture Technologies

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INTRODUCTION

The many challenges created by climate change require a multifaceted approach, including technological advancements, public policy, and advocacy. There are many ways to combat climate change. Climate action includes, among other things, transitioning to renewable energy resources, phasing out oil and gas, and developing low-carbon transportation measures. These actions are necessary to decrease greenhouse gas emissions by nearly half by 2030 and to reach net-zero emissions by 2050, in accordance with the targets set by the Paris Agreement to limit global warming to 1.5°C.[1] The rising awareness of global warming and the severity of its consequences are driving more climate action than ever before. There are increasingly more collaborations between countries to reduce greenhouse gas emissions and a rising market for cleaner sources of energy. However, reducing greenhouse gas emissions and transitioning to renewable energy is not enough at present.[2] Even a universal and comprehensive transition to renewable energy, which is still far from becoming a reality, will not suffice at this point.[3] Achieving net-zero emissions by 2050 will not reverse global warming but merely stop temperatures from continuing to rise.[4] There is also a need to address historical greenhouse gas emissions that have accumulated in the atmosphere since the beginning of the Industrial Revolution. It will take thousands of years for the planet to cool down due to the accumulation of emissions that will continue to increase until all countries around the world achieve net-zero emissions.[5] Therefore, achieving net-zero

1 INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, GLOBAL WARMING OF 1.5° C 53–69 (Valérie Masson-Delmotte et al., eds., 2018).

2 David Keith, *What's the Least Bad Way to Cool the Planet?*, N.Y. TIMES (Oct. 1, 2021), https://www.nytimes.com/2021/10/01/opinion/climate-change-geoengineering.html [https://perma.cc/85ZD-EPZF].

3 *Id.*

4 *Id.*

5 *See* Rebecca Lindsey, *Climate Change: Atmospheric Carbon Dioxide*, CLIMATE.GOV (June 23, 2022), https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide [https://perma.cc/T8RY-K5Y8].

emissions will not be enough to combat global warming.[6] Rather, net-negative should be our global objective until reaching climate stability.

While currently no technology can address all greenhouse gases, the technology to address carbon dioxide ("carbon") exists. Direct air capture ("DAC") can extract historical carbon emissions, also known as legacy carbon, the most common greenhouse gas in the atmosphere.[7] Many emerging technologies capture carbon from ambient air, but each technology works differently. Some technologies are executed in large plants, while others utilize small devices scattered all over the world. However, the main idea is similar: DAC technology works to offset global emissions, thereby furthering the goal of achieving global net-negative emissions, by capturing carbon from the air. Currently, DAC technologies' carbon capture capacity is very limited and expensive.[8] Thus, investing in research and development is necessary to create cheaper and more efficient DAC technology.[9]

The breakthrough by Fritz Haber in the 1900s is an example of a direct air capture solution that has saved billions of people's lives by capturing nitrogen from the atmosphere and utilizing it in fertilizers. In the mid-1900s, the world population was growing rapidly, and experts predicted worldwide famine since the pace of food production did not correspond to the rate of population growth.[10] The fertilization process at that time relied on animal manure and bat guano, which became increasingly scarce,[11] and without a breakthrough, the gloomy prediction could have become a reality. In 1908, chemist Fritz Haber developed a method that later became the Haber-Bosch process, which can create large amounts of ammonia for fertilizer by capturing nitrogen from the air and combining it with hydrogen.[12] Haber is essentially responsible for the breakthrough in the fertilization capacity

6 Keith, *supra* note 2.

7 Clive Thompson, *Is Sucking Carbon out of the Air the Solution to Our Climate Crisis?*, MOTHER JONES (Nov.–Dec. 2021), https://www.motherjones.com/environment/2021/10/sucking-carbon-engineering-global-thermostat-co2-direct-air-capture-climeworks-solution-climate-crisis-big-oil-boondoggle-ipcc/ [https://perma.cc/V7YC-V6FR].

8 *Id.*

9 *Id.*

10 BILL GATES, HOW TO AVOID A CLIMATE DISASTER: THE SOLUTIONS WE HAVE AND THE BREAKTHROUGHS WE NEED 115 (Alfred A. Knopf, 2021).

11 *Id.* at 123–26.

12 *Id.*

that helped feed the growing population and thus saved billions of people from experiencing famine.[13]

Haber's story should inspire the use of DAC to tackle climate change. Governments should support carbon capture and conversion and develop DAC technology as well as a carbon market in the coming years. Governmental support could greatly advance technological development and make carbon capture more economically feasible.[14]

Placing a global emphasis on the adoption of carbon capture technology is necessary to achieve net-negative emissions. This Article focuses on scaling up the direct air capture market. Part I will explain the differences between the two main uses of captured carbon—geologic sequestration and carbon conversion to products—and will present the challenges of each carbon sequestration method. Part II will examine several challenges facing the carbon conversion method, including research, development, policies, and regulations. Part III will present breakthrough solutions of the carbon conversion method. Part IV will include recommendations for expanding the carbon capture and conversion markets and will emphasize the significant role government support plays in accelerating direct air capture technologies through research and development. Part V will emphasize the sociopolitical advantages of carbon capture and conversion. Part VI will explain why the carbon capture method should be used in addition to other mitigation measures, such as renewable energy and other green solutions.

I
CAPTURE CARBON FROM THE AIR, SEQUESTRATION, AND CONVERSION

Employing methods of carbon capture is necessary in order to achieve net-negative emissions. There are different solutions to manage carbon that has been captured. This Part will present two main approaches to capturing carbon, as well as the benefits of both in terms of achieving net-negative emissions.

There are two main approaches for capturing carbon: one is capturing carbon at the source, and the second is extracting carbon from ambient air. Employment of both methods will contribute to the goal

13 Amitai Etzioni, *Carbon Capture Is a Climate Change Game Changer*, THE NAT'L INTEREST (Oct. 31, 2021), https://nationalinterest.org/feature/carbon-capture-climate-change-game-changer-195652 [https://perma.cc/7MF2-ZUFV].

14 *Id.*

of achieving net-negative emissions. Employment of capturing carbon at the source contributes to reaching net-zero, while employment of carbon capture from ambient air can contribute to reaching net-negative.

A. Capturing Carbon at the Source

Capturing carbon at the source is one method of carbon capture that will help achieve net zero emissions. Capturing carbon at the source is designed to be executed by large-scale industries responsible for vast amounts of carbon emissions.[15] For example, devices can be placed on smokestacks in power plants to remove carbon dioxide from fossil fuel combustion.[16] Another example is capturing carbon that is emitted through chemical reactions, such as in the process of cement production.[17]

Capturing carbon at the source in large and concentrated quantities could prevent further accumulation of carbon in the air. The carbon that has been captured can be sequestered underground or used for commercial purposes, as will be discussed below.[18] This approach does not remove carbon from the atmosphere but rather prevents new emissions from entering it. This method is essential to employ to achieve net-zero emissions and contributes greatly to tackling global warming.[19] However, because this method reduces carbon emissions only from the source, employing it alone is insufficient because it does not deal with legacy carbon.[20]

B. Capturing Carbon from Ambient Air

The second approach is to capture carbon from ambient air, which is one of the most promising and necessary solutions to reach net-zero, and ultimately net-negative, emissions. Capturing carbon from ambient

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15 *See* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, *supra* note 1, at 140.

16 *See id.* at 116.

17 INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2014: MITIGATION OF CLIMATE CHANGE 758–59 (Ottmar Edenhofer et al., eds. 2014).

18 INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CARBON DIOXIDE CAPTURE AND STORAGE 330–35 (Bert Metz et al., eds. 2005).

19 Eloy S. Sanz-Pérez et al., *Direct Capture of CO_2 from Ambient Air*, 116 CHEM. REVS. 11840, 11841–43 (2016).

20 *See id.*

air is the only technology that enables extracting legacy carbon that has accumulated since the beginning of the Industrial Revolution.[21]

Several companies have developed different DAC technologies, and each of them has a different process they use to capture carbon.[22] For example, Climeworks' project Orca is the first industrial-scale plant that currently has the capacity to capture approximately 4,000 tons of carbon annually, and it is rapidly scaling its operations.[23] Other companies, such as Carbon Engineering, are developing plants with a projected capturing capacity of 1 million tons annually.[24] While these companies develop different systems, the common ground between the technologies is the ability to capture ambient air, separate carbon molecules, and concentrate and release carbon-free air.[25] On the other end of the spectrum, other companies are creating small devices with much more limited capturing capacity, which, due to their size, shape, and carbon-capturing capacity are often referred to as mechanical trees. The mechanical trees are small devices with artificial "leaves" lined with dry sorbents that capture carbon and separate it from the air.[26] After carbon is captured, it can be injected underground and stored permanently or converted and stored in various products.[27]

C. Differences Between Carbon Capture Methods

In comparison to capturing carbon at the source, capturing carbon from ambient air is less dependent on location and can be employed in various locations worldwide.[28] On the other hand, the concentration of carbon in the atmosphere is very diluted, and the amount of carbon that direct air capture technology can capture presently is limited.[29] Currently, all DAC plants using either method around the world can

21 Thompson, *supra* note 7.

22 *Id.*

23 Peter Wilson, *Is Carbon Capture Here?*, N.Y. TIMES (Oct. 31, 2021), https://www.nytimes.com/2021/10/31/climate/is-carbon-capture-here.html [https://perma.cc/8MEG-VBAZ]; *see generally* Sara Budinis, *Direct Air Capture*, INT'L ENERGY AGENCY (Sept. 2022), https://www.iea.org/reports/direct-air-capture [https://perma.cc/53JZ-27PA].

24 Budinis, *supra* note 23.

25 *Id.*

26 Thompson, *supra* note 7.

27 Katie Lebling & Jennifer Wilcox, *Direct Air Capture: Resource Considerations and Costs for Carbon Removal*, WORLD RES. INST. (Jan. 29, 2021), https://impakter.com/direct-air-capture-resource-considerations-and-costs-for-carbon-removal/ [https://perma.cc/A9XZ-KYWR].

28 Christoph Beuttler et al., *The Role of Direct Air Capture in Mitigation of Anthropogenic Greenhouse Gas Emissions*, FRONTIERS IN CLIMATE, Nov. 2019, at 1, 5.

29 *Id.*

capture 10,000 tons of carbon from the atmosphere per year in total.[30] However, in order to provide substantial mitigation and maximize climate impact, DAC technology needs to scale up the capturing capacity and reach gigatons of removals annually.[31] Hence, prioritizing research and development is necessary to develop a cheaper and more efficient DAC technology and eventually reach global net-negative emissions.[32]

D. Solutions and Uses for Captured Carbon

Direct air capture is one of the most promising solutions to mitigate climate change. One of the main advantages of direct air capture is that it allows upcycling and repurposing carbon. Different solutions for carbon have both their strengths and weaknesses. The two main uses of captured carbon are geologic sequestration and carbon utilization. Carbon utilization is a very broad category, which includes carbon conversion into product, as well as utilization of carbon in different processes. In contrast, carbon sequestration involves different processes of injecting the carbon underground for long-term storage.

1. Carbon Sequestration

One solution for captured carbon is sequestration, where carbon is captured and converted into a geological formation and then stored underground.[33] The main advantage of sequestration is the ability to permanently remove carbon from the atmosphere, maximizing its climate benefit.[34] Carbon sequestration has the potential to store vast amounts of historical carbon emissions thus contributing greatly to reaching net-negative emissions.[35] One example of carbon sequestration is employed by Climeworks in collaboration with Carbfix. Carbfix has turned carbon into rock through underground mineralization, a process that takes two to three years.[36]

Several concerns have been expressed with regard to carbon sequestration, such as carbon leakage, seismic activity, and water

30 Letter from Carbon180 to Jennifer M. Granholm, Sec'y of Energy (Feb. 1, 2022) (on file with author).

31 *Id.*

32 Beuttler et al., *supra* note 28.

33 Thompson, *supra* note 7.

34 *Id.*

35 *Id.*

36 Wilson, *supra* note 23.

pollution.[37] Climeworks and Carbfix state that the process of sequestration and storing carbon underground is safe.[38] However, there are still concerns regarding pipeline leaks that could be disastrous to the environment and communities living in proximity to such pipelines.[39] This raises one of the main challenges with regard to large-scale sequestration, which is developing laws and regulations, both nationally and internationally, that will ensure the safety of the sequestration process.

The IPCC special report, *Carbon Dioxide Capture and Storage*, published in 2005, raises a number of legal and regulatory issues regarding carbon storage through underground sequestration from national and international perspectives, including property rights matters, long-term liability associated with potential carbon leakages, longevity of the underground storage, long-term monitoring of the injected fluids, and more.[40] The proper regulations to facilitate carbon capture and storage in a safe way should be further researched, and there are several aspects that should be taken into consideration. Current laws containing regulations for subsurface operations include mining laws, laws on drinking water, and more.[41] However, it is necessary to develop policies and regulations further to specifically address how subsurface operations, like carbon injection and underground storage, take into account the environmental impact of carbon injection on geological formation.[42] In addition, legislation should further regulate underground carbon injection, monitoring, verification, and reporting.[43]

Furthermore, carbon sequestration with underground storage raises legal issues regarding the proprietary rights of adjacent landowners that might be affected by carbon injections in adjacent land. Landowners' concerns should be accounted for and be made an integral part of planning permits that authorize carbon storage near their land.[44] For example, landowners might be entitled to compensation due to the potential impact of carbon injection, such as migration of carbon

37 Sandra Ó. Snæbjörnsdóttir et al., *Carbon Dioxide Storage Through Mineral Carbonation*, NAT. REV. EARTH & ENV'T, at 90–102 (2020).

38 Wilson, *supra* note 23.

39 Thompson, *supra* note 7.

40 INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CARBON DIOXIDE CAPTURE AND STORAGE 252–57 (Bert Metz et al., eds. 2005).

41 *Id.* at 255.

42 *Id.* at 252–57.

43 *Id.* at 234–52.

44 *See* DJL Farm LLC v. EPA, 813 F.3d 1048 (7th Cir. 2016).

underground to their "pore space."[45] Moreover, permits should take into consideration impacts on air quality and the safety of large-scale sequestration.[46]

2. Carbon Conversion

Carbon conversion is a very important way to help scale DAC, achieve net-negative emissions, and combat global warming. Various industries currently use carbon in their products and in their production process. Carbon conversion can be divided into two main categories: permanent and temporary removal.[47]

Permanent removal of carbon refers to carbon sequestration in long-lasting products, thus removing it from the atmosphere without reemitting it.[48] For instance, sequestering carbon in concrete permanently removes it from the air and creates more durable, high-quality concrete.[49] Since the concrete industry is a vast global industry, it has enormous potential as a large-scale solution for captured carbon. Such a broad industry could provide a market for captured carbon, which will help reduce the price per ton of carbon capture.[50]

Temporary removal involves carbon conversion in short-lived products or processes; the removal of carbon is not permanent. Also referred to as the catch-and-release method,[51] carbon emissions are released by certain products and processes and then caught and used again.[52] Industries that currently use carbon in their products include soda beverages, synthetic fuels, and more.[53] This method can be used to contribute to reducing the price of carbon capture if the source of

45 *In re* Archer Daniels Midland Co., UIC Appeal No. 14-72 (EAB Oct. 28, 2014) (Petition for Review), https://yosemite.epa.gov/oa/eab_web_docket.nsf/Filings%20By%20Appeal%20Number/BD177D7747F2760685257D7F006C8B0D/$File/J.%20Sprague...1.pdf [https://perma.cc/2EGS-3MZ6].

46 *Id.*

47 David Roberts, *Pulling CO2 out of the Air and Using It Could be a Trillion-Dollar Business*, https://www.vox.com/energy-and-environment/2019/9/4/20829431/climatechange-carbon-capture-utilization-sequestration-ccu-ccs (last updated Nov. 22, 2019, 2:45PM) [https://perma.cc/FT9J-YY3T].

48 *Id.*

49 Ben Soltoff, *The High-Hanging Fruit is Reachable. The Question Is How Soon?* (Nov. 16, 2021), https://www.greenbiz.com/article/high-hanging-fruit-reachable-question-how-soon [https://perma.cc/Z2G5-PY2V].

50 *See* BILL GATES, FINANCING THE CLEAN INDUSTRIAL REVOLUTION 1–11 (2021).

51 Thompson, *supra* note 7.

52 Lebling & Wilcox, *supra* note 27.

53 Roberts, *supra* note 47.

carbon will be replaced with carbon from the atmosphere.[54] However, this method does not remove carbon permanently but rather temporarily recycles carbon; after consumption, it returns to the atmosphere.[55] Using carbon in short-lived products would likely increase the demand for carbon, which will help reduce the price of carbon capture and thus help scale up carbon capture technologies.[56]

One of the most controversial uses of carbon is the process of enhanced oil recovery, whereby oil companies inject carbon into oil wells to increase the output.[57] On the one hand, fossil fuel industries currently have the most extensive use of carbon.[58] On the other hand, increased use of carbon by fossil fuel industries conflicts with the trend of phasing out oil and gas extraction.[59] Environmentalists are thus concerned that direct air capture used in this manner will preserve the reliance on fossil fuel industries as a primary source of energy,[60] as discussed further below.

The most significant difference between carbon sequestration and conversion is economic feasibility. The main challenge regarding large-scale employment of direct air capture is economical. Currently, there are several small-scale DAC plants, and the price per ton of captured carbon ranges between $250 and $600, depending on the technology.[61] Thus, further research and development is required to make DAC cheaper and more efficient. Global greenhouse gas emissions are estimated at fifty-one billion tons a year. Because the goal is not only to offset emissions but to remove historical emissions that have accumulated in the atmosphere, funding carbon capture at the current price would require an investment of trillions of dollars annually, which is simply unattainable. Therefore, sequestration, which relies on donations and government investments, is not economical. It will not sustain long-term and large-scale direct air capture activities, which are necessary to achieve carbon neutrality and net-negative carbon emissions. In comparison, using carbon as a commodity and trading it in the free market can overcome this economic challenge. However, for carbon trading to be effective in reducing the price of

54 *Id.*
55 *Id.*
56 *Id.*
57 Lebling & Wilcox, *supra* note 27.
58 *Id.*
59 *Id.*
60 *Id.*
61 *Id.*

carbon capture, and thereby furthering the goal of achieving net-negative emissions, it is necessary to increase the demand for carbon in the market and create more products that contain carbon, as will be further detailed below.[62]

II
THE CHALLENGES OF CARBON CONVERSION

The potential for the carbon capture and conversion market is estimated at $1 trillion dollars in the United States and $6 trillion dollars globally.[63] Carbon capture is a newer field that has lots of room to expand through research and entrepreneurship efforts. There are countless ways to utilize carbon in various products and processes, with many emerging solutions in this field. For instance, carbon can be used in construction materials, polymers, synthetic fuels, or even new materials, such as carbon fiber.[64] Nevertheless, the carbon capture and conversion markets face several challenges to live up to their full potential.

A. Challenges in Scaling Carbon Conversion

Carbon conversion is a necessary investment for the fight against climate change because it significantly contributes to achieving net-negative emissions. The carbon capture and conversion markets have plenty of room to grow in order to live up to their full potential. Although many products and solutions for carbon capture and carbon utilization are in their early stages, proper investments can help them reach their potential for environmental action.[65] The carbon capture market also has room for extensive entrepreneurship in order to find new products that will incorporate carbon.[66] Investing the financial resources and entrepreneurship required to scale carbon conversion should be a priority. Every product that comes as a result of carbon conversion means a little less carbon in the atmosphere.

The oil industry has potential to be a major driver of carbon conversion due to its current status as one of the few large-scale

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62 *See id.*

63 RORY JACOBSON & MATT LUCAS, A REVIEW OF GLOBAL AND U.S. TOTAL AVAILABLE MARKETS FOR CARBONTECH (2018).

64 Roberts, *supra* note 47.

65 *See id.*

66 *See id.*

industries that currently uses carbon.[67] Large-scale employment of carbon utilization is a key component in the expansion of carbon capture technologies.[68] However, among the industries that currently use carbon in their products, such as the oil industry and the food and beverages industries, the largest consumer of carbon is the oil industry.[69]

The controversial use of carbon by the oil industry is "enhanced oil recovery"—a process that produces more gas, thereby increasing carbon emissions.[70] Because of the use of carbon for the purpose of enhanced oil recovery, the collaboration between oil companies and direct air capture companies generates resistance from environmentalists. However, proponents of this collaboration argue that the oil industry has the potential to be a key driver in the development of direct air capture technologies. The oil industry is one of the few industries that currently consume carbon on a large scale, whereas many carbon-infused products are in the early developmental stages and will require more time to become large-scale carbon consumers.[71] Moreover, the oil industry has the potential to make a difference in the DAC market and drive down the price of carbon capture technologies in the foreseeable future.[72]

Undoubtedly, there are disadvantages to using carbon for enhanced oil recovery; the oil and gas industries perpetuate environmental and public health implications, such as air pollution, thereby acting against environmentalist interests.[73] However, one might have to consider the need to make oil companies part of the solution and not part of the problem.[74] Fossil fuels are, currently, the primary sources of energy, and the transition to renewable energy will be gradual and will take several decades to complete worldwide.[75] Therefore, policy should aim to use the oil industry for the benefit of the direct air capture market. Even though enhanced oil recovery does not contribute directly to

67 *Id.*
68 *Id.*
69 *Id.*
70 Lebling & Wilcox, *supra* note 27.
71 *Id.*
72 Thompson, *supra* note 7.
73 *Id.*
74 *Id.*
75 *Id.*

mitigating climate change, it can be the catalyst for direct air capture technologies and the carbon conversion market.[76]

There is a concern that oil and gas companies will use carbon capture for greenwashing, an excuse to keep the status quo and keep scaling their businesses. This issue directly influences the transition to renewable energy as it threatens to hinder its progress.[77] The renewable energy market continues to grow every year, and the technology continues to improve.[78] Still, the renewable energy market faces two main challenges: power storage with batteries and energy distribution to geographical locations that lack sufficient sun or wind.[79] Renewable energy must scale up aggressively in order to achieve net-zero emissions. However, Rome was not built in a day, and phasing out oil and gas sources needs to be done gradually. Policymakers should enact laws that set milestones to phase out fossil fuel extraction. A prime example of a successful policy that gradually instructs phasing out oil and gas extraction can be found in Los Angeles County.[80] However, for the time being, as long as fossil fuels are still widely consumed, we should aim to use them for the benefit of the direct air capture market. Until fossil fuel industries are phased out completely, direct air capture should be used to offset carbon emissions and create, in effect, a closed loop. Until the transition to renewable energy is complete, we can achieve carbon neutrality by offsetting the emissions derived from fossil fuels through direct air capture.[81]

B. Lack of Policies and Regulations Necessary for Large-Scale Carbon Conversion

The carbon conversion market requires the development of polices, regulations, and safety procedures to scale. Because a high concentration of carbon dioxide has far-reaching implications for the environment

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76 *Id.*

77 Lebling & Wilcox, *supra* note 27.

78 Thompson, *supra* note 7.

79 *Id.*

80 Holly J. Mitchell & Sheila Kuehl, *Protecting Communities Near Oil and Gas Drilling Operations in Los Angeles County*, L.A. CNTY. BD. OF SUPERVISORS (Sep. 15, 2021), https://file.lacounty.gov/SDSInter/bos/supdocs/161767.pdf [https://perma.cc/2GAU-LY7N]; Beth Kent, *Los Angeles County Passes Motions to Protect Environmental Justice Communities from Urban Oil Drilling*, LEGAL PLANET (Sept. 29, 2021), https://legal-planet.org/2021/09/29/los-angeles-county-passes-motions-to-protect-environmental-justice-communities-from-urban-oil-drilling/ [https://perma.cc/426T-GJ7D].

81 Thompson, *supra* note 7.

and public health, it is essential to regulate this market in advance. One pillar, for example, is the challenge of carbon transportation. After the carbon has been captured, it needs to be transferred to its final destination, such as a beverage factory, for conversion. However, such transportation requires a network adapted to transfer high-pressure carbon. This infrastructure needs to be built from scratch, since it is impossible to use oil and gas pipelines.[82] Therefore, subnational, national, and international collaboration in policymaking is necessary to enable large-scale transfers of carbon from one location to another.

Developing policies and regulations is necessary to grow the carbon capture and conversion markets, and it is better to put them in place now and not turn a blind eye to these markets' progress. The decision to enact laws ex ante, before the growth of direct air capture and the carbon conversion markets, or ex post, is a chicken-and-egg paradox. If regulations are enacted after the markets develop, methods will already be solidified, and establishing proper regulations will be more challenging. On the other hand, setting policies and regulations in advance can help further develop the carbon capture and conversion markets.

III
THE POTENTIAL OF CARBON CONVERSION PRODUCTS

This chapter presents examples of the different carbon conversion solutions that are currently being developed. The carbon conversion solutions presented here are only a drop in the bucket, as many other great solutions currently exist. Each example below represents a solution that has the potential to expand the carbon capture market by using carbon from the atmosphere to make various products, thereby expanding carbon capture's ability to aid in achieving net-negative emissions. Furthermore, encouraging more innovation and entrepreneurship in the carbon conversion market will greatly benefit the direct air carbon capture market, which is essential to stopping and even reversing global warming.

One of the biggest potential markets for carbon is concrete.[83] Concrete has been used as a primary material in construction for decades and is currently the most widely used construction material on Earth—used in roads, bridges, etc.[84] Due to the large scale of the

82 *Id.*

83 *Id.*

84 *Greenhouse Gases: Set in Green Concrete*, THE ECONOMIST, Nov. 6, 2021, at 69.

concrete market, it has significant potential to increase the demand for carbon and thus reduce the cost of direct air capture.

One example of a company that does carbon conversion in the concrete market is CarbonCure, a company that injects carbon into concrete, creating long-term carbon storage. CarbonCure's product has already been used in the construction process.[85] Using carbon in concrete also allows for less cement to be used in this process.[86] Reducing cement utilization is an important mitigation strategy in the construction sector since the cement industry accounts for eight percent of global carbon emissions annually.[87] Moreover, this method of concrete production is beneficial from an economic standpoint since it creates a higher-quality product.[88] Adding carbon in the concrete process makes the concrete more durable, with a similar effect as mixing water to harden concrete.[89] Currently, CarbonCure has been purchasing carbon that had been captured by gas companies at the source.[90] However, transitioning to direct air capture companies as the main suppliers of carbon will greatly expand the carbon market and will substantially reduce the price of direct air capture.[91]

Another potential market for carbon is synthetic fuels. Synthetic fuels are created with a combination of hydrogen and carbon monoxide and emit less carbon than fossil fuels.[92] Synthetic fuels can power large combustion engines, such as those used in aircrafts, ships, and trucks.[93] In comparison, renewable energy sources are still unable to power such large motors because their batteries are too heavy and require a long charging time.[94] Thus, synthetic fuels are a necessary mitigation strategy for the transportation system and can overcome the technological challenges facing renewable energy. Synthetic fuels will not fully eliminate carbon emissions, but they will reduce them substantially.[95] Large employment of synthetic fuels is therefore

85 *Id.*
86 *Id.*
87 *Id.*
88 *Id.*
89 *Id.*
90 *Id.*
91 Thompson, *supra* note 7.
92 *Green Aviation: Liquid Sunshine*, THE ECONOMIST, Nov. 6, 2021, at 70.
93 Thompson, *supra* note 7.
94 *Id.*
95 *Id.*

another way to accelerate the expansion of the carbon market.[96] Moreover, utilization of captured carbon in the production of synthetic fuels will potentially achieve net-zero emissions.[97]

There are a variety of ways to repurpose captured carbon in order to produce different products and materials. Carbontech is a progressive market, and there are already many carbon conversion projects spread throughout many countries, while many more are continuing to emerge.[98] In addition to the examples above, there are other sectors that utilize carbon in their products, such as food and beverages, building materials, agriculture, chemicals, and more.[99] There are endless opportunities to develop new products, such as yoga mats, fishmeal, and carbon-negative diamonds.[100] Still, there is a long road ahead to expand the carbon conversion market.[101] However, the sky is not the limit, and it is just the beginning for the carbon capture and conversion markets.

IV
DEVELOPING CARBON CAPTURE AND CARBON CONVERSION

There are two main pathways to scaling up the carbon capture and conversion markets. The first is to scale up the existing technologies through market-based mechanisms, such as carbon conversion into products or massive deployment of DAC facilities. The second is to expand research and development to develop more efficient, less power-intensive, and cheaper DAC technologies that would be easier to scale. This section will focus on the critical role of research and development in advancing carbon capture and conversion technologies. In addition, scaling up the DAC market requires increasing the demand for carbon and policy measures that will incentivize the use of carbon from direct air capture. There are several elements that might help expand the carbon capture and conversion markets, which should be taken into consideration.

Expanding research and development of direct air capture and carbon conversion technologies is required to improve the performance

96 *Greenhouse Gases: Set in Green Concrete*, *supra* note 84.

97 Thompson, *supra* note 7.

98 JACOBSON & LUCAS, *supra* note 63.

99 *Id.*

100 Myisha Majumder, *These Companies Are Seeking to Turn Carbon into Value*, GREENBIZ (Jan. 11, 2021), https://www.greenbiz.com/article/these-companies-are-seeking-turn-carbon-value [https://perma.cc/PX8W-PP8R].

101 *See* JACOBSON & LUCAS, *supra* note 63.

of these technologies.[102] Research and development will advance the next generation of these technologies to be more efficient, less power-intensive, and more affordable.[103] Government support is crucial to enhancing this bleeding-edge technology to reach its full potential. Generally, governments play a unique role with regard to investing in unproven or underdeveloped technologies, where the market is more apprehensive and less likely to invest resources.[104] When government-funded research develops technologies that are potentially profitable, markets will form and shift in order to capitalize on such advancements and will further the research and innovation on their own. Therefore, governments should invest initial resources in such technologies, especially when they could potentially serve the public interest, such as with direct air capture.

A prime example of government support is the CHIPS and Science Act (hereinafter "Chips Act"), enacted on August 9, 2022.[105] The Chips Act is intended, inter alia, to support research and development of emerging technologies. Generally, the purpose of the Chips Act is to strengthen the American semiconductor industry, and it allocates $280 billion to fund the support of domestic production in this field.[106] In addition, the Chips Act includes funds for climate change initiatives and allocates more than $11.2 billion for investments in technologies and new research for combating climate change.[107] It is worth mentioning that the Chips Act allocates only $1 billion to carbon removal research and development.[108] The recent enactment of the Chips Act is an important first step in the right direction toward accelerating direct air capture technology, and it will hopefully be a precedent for similar initiatives in the future. However, far more significant investments are needed in this technology if we are to make a difference in combating climate change.

A necessary element in the scaling of the carbon market is expanding the variety of applications in order to increase the demand for carbon. There are currently several applications for carbon. This includes traditional industries such as fertilizer, agriculture, food, beverage,

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102 Etzioni, *supra* note 13.

103 Thompson, *supra* note 7.

104 GATES, *supra* note 10.

105 CHIPS and Science Act of 2022, Pub. L. No. 117-167, 136 Stat. 1366 (2022).

106 *Id.*

107 *Id.* § 10771.

108 *Id.* § 10771(6)(c).

fossil fuel, and more.[109] The next step to expanding this market is creating policies that incentivize traditional industries, for example, by providing low-interest loans and grants, to substitute captured carbon for their carbon sources.[110]

Another element of market expansion is the development of carbon conversion technologies. As with traditional industries, it is necessary to create policies that incentivize advancements in this market. There are many existing applications, such as concrete and synthetic fuels. However, further development of carbon conversion technologies requires investments in research and development by both the private and public sectors.[111] The carbontech market is currently underdeveloped, and there are many opportunities for innovation. Advancing the carbon conversion market requires policies and incentives to attract more investors and entrepreneurs and lower Green Premiums.[112] Government funds are necessary to accelerate research and development in the carbon capture market. For example, recently the United States Congress introduced the Innovation and Competition Act intended, inter alia, to promote research and development in several technologies.[113] One policy proposal is to allocate twenty-five percent of the $250 billion that is part of this bill to develop direct air capture and carbon conversion technologies.[114]

Policymaking is a necessary element in the development of the carbon capture and carbon conversion markets. Currently, in the United States, companies are not incentivized to incorporate carbon in their products. A prime example is LanzaTech, a carbon conversion company that decided to scale and deploy its technology outside the United States because of the lack of incentives for sustainable fuels from carbon.[115] In this case, the Renewable Fuel Standard program, a federal program that requires transportation fuel sold in the United

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109 INTERNATIONAL ENERGY AGENCY, PUTTING CO2 TO USE: CREATING VALUE FROM EMISSIONS (2019), https://www.iea.org/reports/putting-co2-to-use [https://perma.cc/SMA7-ZX5W].

110 SCALE Act, S. 799, 117th Cong. (2021).

111 *See* INTERNATIONAL ENERGY AGENCY, *supra* note 109.

112 The Green Premium is the additional cost of choosing a clean technology over one that emits more greenhouse gases. GATES, *supra* note 10, at 58–64.

113 United States Innovation and Competition Act of 2021, S. 1260, 117th Cong. (2021).

114 Etzioni, *supra* note 13.

115 Amy Harder, *Carbon Recycling Pioneer LanzaTech Eyes Going Public*, CIPHER (Jan. 5, 2022), https://go.breakthroughenergy.org/index.php?action=social&chash=46ba9f2a6976570b0353203ec4474217.354&s=bad97c655476f96a390a72c05a742011 [https://perma.cc/7QRF-K4BD].

States to contain a minimum volume of renewable fuels, provides credits for four different categories: biomass-based diesel, cellulosic biofuel, advanced biofuel, and total renewable fuel.[116] However, the program excludes renewable fuel made from carbon.[117] Amending the program by adding carbon as a legitimate material for creating sustainable fuels is an example of an incentive that could accelerate the carbon capture and conversion markets in the United States.[118]

Further examples of existing incentives that require amendment are the Credit for Carbon Oxide Sequestration under Section 45Q of the Internal Revenue Code[119] and California's Carbon Capture and Sequestration Protocol under the Low Carbon Fuel Standard.[120] In contrast to the previous example, which is a general regulation for sustainable fuels, these regulations are intended specifically to incentive direct air capture technologies; however, they do not sufficiently incentivize the carbon conversion market. Under California's Low Carbon Fuel Standard, in order for a company to be eligible for tax credits, it has to be the one that removes the carbon from the atmosphere and geologically sequesters it or transfers it by contracting with another entity for sequestration.[121] In other words, only companies that capture carbon are eligible for tax credits.[122] Hence, this regulation does not incentivize carbon sequestration companies, only companies that capture carbon.[123] Moreover, unlike Section 45Q, according to California's Low Carbon Fuel Standard, DAC companies that perform carbon utilization do not qualify for tax credits since only geological sequestration or enhanced oil recovery are recognized as qualified uses of carbon.[124] Therefore, it can be argued that there are more opportunities to encourage the development of the

116 *Overview for Renewable Fuel Standard*, U.S. ENV'T PROT. AGENCY, https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard (last visited Sept. 27, 2022) [https://perma.cc/HA87-T2T6].

117 *See id.*

118 Harder, *supra* note 115.

119 Credit for Carbon Oxide Sequestration, 26 C.F.R. § 1.45Q-1 (2021).

120 *Frequently Asked Questions: Carbon Capture and Sequestration Project Eligibility*, CAL. AIR RES. BD. (Dec. 2021), https://ww2.arb.ca.gov/sites/default/files/2021-12/ccs_project_eligibility_faq_12-1-21.pdf [https://perma.cc/HK8X-R6M3].

121 *Id.*

122 *Id.*

123 *See id.*

124 *Id.*

market outside the Low Carbon Fuel Standard and transportation sector by promoting carbon capture and utilization in other sectors.[125]

Eligibility for a tax credit under Section 45Q is based on DAC companies.[126] Currently, DAC companies can choose to retain the tax credits or to transfer them to companies that perform carbon utilization, sequestration, or enhanced oil recovery.[127] DAC companies may elect to transfer part or all of their tax credits, and they may choose to transfer their tax credits to one or multiple companies.[128] This method does not sufficiently incentivize companies to transition from their current carbon suppliers to DAC companies to purchase captured carbon. One policy recommendation is to provide independent eligibility for companies that perform carbon utilization under Section 45Q. Thus, DAC companies will not have to incentivize utilization companies with their own incentives, but rather utilization companies will be eligible to receive their own tax credits. Furthermore, the existing federal regulations do not provide strong enough incentives, as it is still not economically feasible for many companies to perform carbon capture.[129] Therefore, proponents of direct air capture suggest amending the current regulations and offering additional and higher tax credits in order to propel the carbon market.[130] The Inflation Reduction Act, enacted on August 16, 2022, is an excellent example of increasing the incentives for carbon capture.[131] This act, among other things, aims to increase the tax credit per ton of carbon capture.[132] This bill will be very beneficial in accelerating carbon capture technology.

Policymakers should develop frameworks for regulations that will incentivize and expand the carbon market to create new applications for carbon. There are many ways to facilitate the growth of the carbon conversion industry. First, policymakers should identify and fund existing carbon solutions in sectors that have the potential to scale up,

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125 ETHAN N. ELKIND ET AL., CAPTURING OPPORTUNITY: LAW AND POLICY SOLUTIONS TO ACCELERATE ENGINEERED CARBON REMOVAL IN CALIFORNIA 8 (2020), https://law.ucla.edu/sites/default/files/PDFs/Publications/Emmett%20Institute/Capturing%20Opportunity.pdf [https://perma.cc/LRD2-VEV5].

126 26 C.F.R. §1.45Q-1.

127 *Id.*

128 *Id.*

129 *See* Thompson, *supra* note 7.

130 *Id.*

131 Inflation Reduction Act of 2022, Pub. L. No. 117-169, 136 Stat. 1818.

132 MOLLY F. SHERLOCK ET AL., CONG. RSCH. SERV., R47202, TAX PROVISIONS IN THE INFLATION REDUCTION ACT OF 2022 (H.R. 5376) 8–9 (2022), https://crsreports.congress.gov/product/pdf/R/R47202 [https://perma.cc/TP36-35XX].

such as the construction sector. Funding such early market opportunities will accelerate their growth and attract potential investors.[133] Second, governments should institute guidelines for all public agencies, instructing them to transition to products that utilize carbon. For example, all government agencies, as well as all entities supported by public funds, should be required to use building materials with carbon. These guidelines will support the development of the market and will accelerate the transition to carbon-injected materials.[134] Third, policymakers should invest in and support research and development in carbon applications in order to find more solutions and uses for carbon. Fourth, policymakers should establish performance-based standards for carbon products in order to encourage the market to favor them.[135]

In sum, policymakers will play a significant role in facilitating and expanding the future carbon capture and conversion markets. Providing incentives for the private market and investing in research and development, along with public procurement of carbon products, will accelerate the growth of the carbon capture and conversion markets and will encourage the transition to carbon-injected products. Policy support is essential to create a widespread transition to these products. A critical part of transitioning to green energy and a green economy is the expansion of carbon capture, sequestration, and utilization.

V
THE SOCIOPOLITICAL ADVANTAGES OF CARBON CONVERSION

In order to mitigate climate change and reach net-zero emissions by 2050, it is imperative to consider every possible measure. The carbon conversion measure has a significant role to play in helping our future endeavors.[136] This measure has many advantages, but the main reason to prioritize carbon conversion is not technical but sociopolitical.[137] While other measures that climatologists recommend require people to change their lifelong habits and lifestyles, carbon conversion does not. With other measures, it is necessary that people change their driving and flying habits, their favorite foods, or their favorite assets in favor of more environmentally friendly ones, like substituting internal

133 INTERNATIONAL ENERGY AGENCY, *supra* note 109, at 5.

134 *Id.*

135 *Id.*

136 Etzioni, *supra* note 13.

137 *Id.*

combustion engine cars with electric cars.[138] In comparison, carbon conversion applications can help people keep their cars and make fuels from captured carbon that work in internal combustion engine vehicles.[139] Furthermore, implementing other mitigation strategies will require industries to change their materials and processes and create more sustainable products, which they often oppose due to the high expenses other mitigation strategies will entail. This opposition further impedes climate change mitigation.[140]

Even if we implement all the climatologists' recommendations to mitigate climate change, other than carbon capture and conversion, they cannot promise that we will not experience extreme events such as severe heat waves, fires, floods, or sea level rise. In the best-case scenario, the repercussions will not get worse.[141] Today, some people care about environmental issues and implement sustainability principles in their personal lives or their businesses out of altruism and for the benefit of others and, of course, future generations.[142] The last Climate Change Conference of the Parties (COP26), in Glasgow, emphasized that there are still controversial debates between nations regarding the different actions that should be taken to mitigate climate change.[143] For example, even though some of the wealthier countries are committed to helping vulnerable countries prepare for the impacts of global warming, their contribution is not enough, and it is hard to presume that other nations will do their share.[144] The COVID-19 pandemic is a case study of a global crisis with broad consequences on social, national, and international aspects. Climate change mitigation requires even more altruistic actions than the COVID-19 pandemic.[145] Thus, if COVID-19 recognition and safety measures, such as wearing masks or getting vaccinated, have faced such high opposition, then climate change measures are likely to face much stronger opposition.[146]

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138 *Id.*

139 *See id.*

140 *Id.*

141 *Id.*

142 *Id.*

143 *COP26 Climate Summit: Here's What Happened on the Final Day of the COP26 Climate Talks*, N.Y. TIMES (Nov. 13, 2021), https://www.nytimes.com/live/2021/11/13/climate/cop26-glasgow-climate-summit [https://perma.cc/EM3F-27QD].

144 *Id.*

145 Etzioni, *supra* note 13.

146 *Id.*

According to polls, climate change action has been gaining public support in recent years.[147] According to one poll, sixty-nine percent of Americans believe that the United States should take aggressive action to slow global warming.[148] Another survey examined how Americans view climate and found that sixty-five percent of Americans think the government should do more to mitigate climate change.[149] Another survey conducted after the 2020 U.S. presidential election and published by the Yale Program on Climate Change Communication and the George Mason University Center for Climate Change Communication found that "[m]ajorities of registered voters support a range of policies to reduce carbon pollution and promote clean energy."[150]

However, introducing policy measures that place a financial burden on people faces significant opposition, even among climate action supporters.[151] For example, implementing a carbon tax or carbon pricing would affect customers since the industries will pass on the cost of taxes to them, which will increase everyday expenses, such as electricity and gas bills.[152] According to the first poll mentioned above, among those who support climate change action, only twenty-nine percent would be likely to do so if their electricity bills increased by $100 annually, and only thirty-four percent were likely to do so if taxes increased by $100 annually.[153] Indeed, recent carbon pricing has led to a slight increase in gas prices and the ensuing overwhelming response.[154] This example is also related to the return to coal use. Nations have given precedence to coal alternatives but have receded from these alternatives the moment gas prices increased.[155] Similarly, politicians promise to encourage mitigation actions but, when push

147 *Id.*

148 Valerie Volcovici, *Americans Demand Climate Action (As Long As It Doesn't Cost Much): Reuters Poll*, REUTERS (June 26, 2019), https://www.reuters.com/article/us-usa-election-climatechange/americans-demand-climate-action-reuters-poll-idUSKCN1TR15W [https://perma.cc/LEJ9-HRQN].

149 ALEC TYSON & BRIAN KENNEDY, PEW RSCH. CTR., TWO-THIRDS OF AMERICANS THINK GOVERNMENT SHOULD DO MORE ON CLIMATE 5 (David Kent ed., 2020).

150 ANTHONY LEISEROWITZ ET AL., POLITICS & GLOBAL WARMING 5 (2021).

151 Etzioni, *supra* note 13.

152 Ed Hirs, *What Will an American Carbon Tax Cost You?*, FORBES (July 21, 2020), https://www.forbes.com/sites/edhirs/2020/07/21/what-will-an-american-carbon-tax-cost-you/?sh=5730d4766c76 [https://perma.cc/V7W9-B7SK].

153 Volcovici, *supra* note 148.

154 Etzioni, *supra* note 13.

155 *Id.*

comes to shove, refrain from phasing out coal.[156] In addition, another source of resistance comes from anti-green backlash targeting advocates of pro–climate action measures due to an aversion to changing the status quo.[157]

Therefore, carbon capture and carbon conversion are very attractive from a public interest standpoint.[158] From a sociopolitical point of view, these measures are more appealing than others and presumably have the ability to accelerate mitigation actions in the short term.[159] One of the main advantages of carbon capture is that it does not require industries and individuals to make drastic changes to their habits and lifestyles. Other mitigation strategies require people to use public transportation, reduce their meat consumption, or change their aviation habits, which face significant resistance from the public. However, carbon capture and conversion technologies allow people to maintain their lifestyles for the most part, due to the ability to offset the emissions generated by everyday activities. Nonetheless, it is important to underscore that developing and deploying other measures is also important, as will be presented in the next section. Most importantly, direct air capture is not an excuse to keep producing large-scale emissions and to forgo other mitigation measures.[160]

VI
CARBON CAPTURE AS ONE PIECE OF THE CLIMATE CHANGE PUZZLE

Carbon capture and conversion are not substitutes but rather supplements to other mitigation measures. To achieve the IPCC's target to limit global warming to 1.5°C, it is essential to reduce greenhouse gas emissions in a multitude of ways.[161] Transitioning to renewable energy is one of the most crucial steps to tackling global warming, and it is necessary to keep scaling up and deploying those measures while making them more affordable. In addition, if we are going to rely on it as a primary source of energy, it is imperative to face the obstacles of renewable energy, such as intermittency and power storage. However, by the time we reach net-zero emissions, global

156 *Id.*

157 *Id.*

158 *Id.*

159 *See* AMITAI ETZIONI & RICHARD REMP, TECHNOLOGICAL SHORTCUTS TO SOCIAL CHANGE 3–4 (Russel Sage Foundation 1973); Etzioni, *supra* note 13.

160 Etzioni, *supra* note 13.

161 INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, *supra* note 1.

temperatures will have risen, and it will take thousands of years to balance Earth's climate due to gases that have already accumulated in the atmosphere.[162]

The missing piece of the puzzle is how to cool down the planet. Several measures could balance the planet's climate, such as capturing carbon from ambient air, geoengineering, or planting trees.[163] Nevertheless, carbon removal is undoubtedly the safest and fastest way to rebalance the climate.[164] As noted above, carbon removal is not a replacement for other measures, especially renewable energy. It is crucial that industries can power themselves with renewable energy. Moreover, it is essential that direct air capture facilities use renewable energy so they will not emit more carbon than they extract. Consequently, there is the potential to integrate solutions and technologies that could help mitigate climate change.[165]

The concrete industry is a good example that demonstrates the potential for combining different ways to reduce emissions, including renewable energy, direct air capture, and green solutions. First, the concrete production process includes mixing cement. The production of cement is responsible for carbon emissions from fuel combustion and from the calcination reaction.[166] One mitigation effort in the concrete industry is transitioning to green materials that will reduce carbon emissions.[167] Second, concrete manufacturers can utilize renewable energy to power their factories.[168] Third, concrete can be used as a carbon conversion method and store carbon for the long term.[169] Therefore, integration of green source solutions, renewable energy, and carbon capture and conversion is the winning combination.

IN CONCLUSION

Direct air capture technologies will play a major part in the achievement of net-zero emissions and will eventually serve the ultimate goal of achieving net-negative emissions and reversing much of the damage caused by global warming. Carbon capture and carbon

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162 Keith, *supra* note 2.

163 *Id.*

164 *Id.*

165 *Id.*

166 *Greenhouse Gases: Set in Green Concrete*, *supra* note 84, at 69.

167 *Id.* at 70.

168 *Id.*

169 *Id.*

conversion technologies are necessary to tackle the carbon that has been accumulating in the atmosphere since the Industrial Revolution. These technological solutions have significant potential for contributing to abating global warming and cooling down the planet by capturing carbon and sequestering it in permanent geological formations or storing carbon through utilization and conversion into products. The nascent carbon industry requires further support and development to reach its full potential in the foreseeable future. Many direct air capture facilities are in the early stages and need further research and development. It is critical to invest in research and development in direct air capture technology to increase its capacity and make it more efficient and affordable. Governments should invest in research and development in order to accelerate direct air capture technologies due to the crucial role they will play in climate stabilization.[170] Policymakers will have a significant role in advancing direct air capture and conversion technologies by promoting innovation and encouraging carbon market growth.

170 ETZIONI & REMP, *supra* note 159, at 197–225.