A SYNTHESIS AND OPTIMIZATION OF PATENTED

DIRECT AIR CAPTURE TECHNOLOGY

A DISSERTATION IN
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by
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A SYNTHESIS AND OPTIMIZATION OF PATENTED

DIRECT AIR CAPTURE TECHNOLOGY

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ABSTRACT

An engineering method termed direct air capture is used to take CO_2, the predominant global warming greenhouse gas, out of the atmosphere directly. Given that CO_2 levels in the air are only 0.04%, it presents a technical challenge. Ambient air has a concentration that is 2-4 orders of magnitude lower than other typically targeted sources for CO_2 capture, like flue gases from energy production and industrial activities. Nevertheless, direct air capture has drawn more attention recently, partly because of the creation and implementation by a small number of start-ups. An increasing quantity of research is being done on novel direct air capture materials and methods, and it's important to comprehend the costs and environmental effects of direct air capture. The author believes that this engineering tool should be one of many tools utilized in the fight against climate change. This dissertation seeks to gather and analyze critical information on fifteen recently issued United States patents and then synthesize the findings from those fifteen patents and then to optimize the critical components of the patented direct air capture technology to advance the state of the art in carbon removal to ameliorate the impacts of increasing carbon concentrations in the atmosphere.

APPROVAL PAGE

The faculty listed below, appointed by the Dean of the School of Graduate Studies, have examined the dissertation titled "A Synthesis and Optimization of Patented Direct Air Capture Technology," presented by Robert J. Lambrechts, candidate for the Doctor of Philosophy degree, and certify that in their opinion it is worthy of acceptance.

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I am deeply indebted to all the members of my Supervisory Committee for their time and effort in shepherding me through the Ph.D. process at UMKC. To Professors Katherine Bloemker and John Kevern I would like to express my deepest appreciation for your guidance, humor and indulging my unquestionably misguided interest in securing a doctorate degree. To Professors Julia Crowley and Caroline "Mollie" Davies, a special thank you for your willingness to work with me on class schedules and paper writing as I journey through my PhD course requirements. To Professor Ceki Halmen I would like to acknowledge your support not only in my efforts to obtain this degree but your kindness over the years and professionalism in coordinating the scheduling of the courses that I have taught for UMKC for many years.

DEDICATION

I dedicate this work to my wife Mary Angela and even though I must now apologize to her that the preparation of this manuscript was a surreptitious undertaking, she made it all possible.

I also dedicate this work to my grown children Gabrielle and Jimmy, my son-in-law Konstantin and to my grandson Caspian. They are the ones who will inherit a world that is looking increasingly more hostile from a climate perspective. If my work in direct air capture can in some way positively influence and advance the state of the art, reduce the concentration of carbon dioxide in the atmosphere and ameliorate the effects of a warming planet then all my efforts in preparing this dissertation will not have been in vain. I pray daily that all the predictions regarding the coming adverse consequences of global warming will not come to pass and that you will continue to prosper on this beautiful “Goldilocks” planet.

CHAPTER 1

INTRODUCTION

"An investment in knowledge pays the best interest."

Benjamin Franklin

This manuscript discusses the role of non-profits, government and the private sector in addressing the growing climate crisis with specific emphasis on the role of the government and private sector partnership in advancing the state of the art in direct air capture technology to reduce the concentration of global warming gases in the atmosphere.

The Intergovernmental Panel on Climate Change (IPCC) of the United Nations provides the most accurate assessments of the state of the planet and the likely course of climate change. It is considered the gold standard because it is conservative and only incorporates new research that is beyond doubt. The most recent report states that if we act on emissions soon, instituting right away all the promises made in the Paris Accords but never actually implemented, we are likely to get about 3.2 degrees of warming[1], or about three times as much warming as the planet has seen since the start of industrialization.

This would bring the previously unthinkable collapse of the planet's ice sheets not just into the realm of the possible but also the very likely. Eventually, that would inundate not only Miami and Dhaka but also Shanghai, Hong Kong, and a hundred more cities around the world.[2] According to numerous recent analyses, even a swift halt of carbon emissions

[1] O. Rosane, "'A File of Shame': World on Track for 3.2 Degrees Celsius of Warming, Latest IPCC Report Warns," EcoWatch, April 4, 2022, https://www.ecowatch.com/ipcc-report-climate-change.html.
[2] R. J. Nicholls et al., "Ranking of the World's Cities Most Exposed to Coastal Flooding Today and in the Future," Climate Adapt, September 11, 2022, https://climate-adapt.eea.europa.eu/en/metadata/publications/ranking-of-the-worlds-cities-to-coastal-flooding.

might bring us that kind of heat by the end of the century.[3] The tipping point for that collapse is thought to be approximately two degrees.[4]

Even while most modeling, by default, ends at that time, the relentless march of climate change does not stop at 2100. Because of this, some researchers who study global warming refer to the following 100 years as the "century of hell."[5] Climate change is both long and quick, almost longer than we can fathom. It is swift, far faster than it seems we have the capacity to detect and admit. When reading about global warming, one will frequently come across comparisons from the earth's history: the thinking goes, sea levels were here when the planet was last this much warmer. These circumstances are not random occurrences.

The geologic record is the best model we have for understanding the extremely complex climate system and determining just how much damage will result from raising the temperature by two, four, or six degrees.[6] The sea level was there mostly because the world was that much warmer. This is why it is so alarming that recent research into the planet's distant past indicates that our current climate models may be significantly underestimating the amount of warming we may expect by the year 2100. In other words, temperatures may eventually increase by a factor of two above what the IPCC projects.

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[3] "By 2100, Deadly Heat May Threaten Majority of Humankind," *Science*, June 19, 2017, https://www.nationalgeographic.com/science/article/heatwaves-climate-change-global-warming.
[4] R. Hersher, "Humans Must Limit Warming to Avoid Climate Tipping Points, New Study Finds," NPR, September 8, 2022, https://www.npr.org/2022/09/08/1121669011/humans-must-limit-warming-to-avoid-climate-tipping-points-new-study-finds.
[5] D. Carrington, "Humanity at the Climate Crossroads: Highway to Hell or a Livable Future?" *The Guardian,* March 20, 2023, https://www.theguardian.com/environment/2023/mar/20/humanity-at-climate-crossroads-highway-to-hell-or-a-livable-future.
[6] Caroline H. Lear et al., "Geological Society of London Scientific Statement: What the Geological Record Tells Us about Our Present and Future Climate," *Journal of the Geological Society,* 178, https://doi.org/10.1144/jgs2020-239.

If we meet our Paris emissions objectives, we could still see four degrees of warming, which would result in irreversible loss of biodiversity, including coral reef systems and substantially exacerbated water scarcity in many regions.[7] The President of the World Bank has articulated that the explored consequences of an increase of the global earth temperatures of 4 C are indeed devastating.[8]

Human memory and experience do not provide a useful analogue for how we might conceptualize those thresholds, but much like with world wars or cancer recurrences, you do not want to see even one. At two degrees, the ice sheets will start to melt, 696 million people would experience water shortages, the world's largest cities will become uninhabitable, and even in the northern latitudes, summer heat waves will claim thousands of lives every year.[9]

In India, there would be thirty-two times as many intense heat waves, each lasting five times as long and exposing ninety-three times more people to the elements.[10] If current rates of warming continue, drought conditions as indicated for the baseline may become almost usual conditions here in a few decades, with the median drought duration rising to prevail up to 20% of the time under 3°C of warming. For Western and Southern Africa, the Caribbean, Central America, southern Europe, and West Asia, significant increases in

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[7] "Impacts of a 4°C Global Warming," GreenFacts, 2023, https://www.greenfacts.org/en/impacts-global-warming/l-2/index.htm.
[8] "Impacts of a 4°C Global Warming."
[9] Shreeshan Venkatesh and Sushmita Seggupta, "36 Per Cent Cities to Face Water Crisis by 2050," Down to Earth, March 31, 2018, https://www.downtoearth.org.in/news/climate-change/36-per-cent-cities-to-face-water-crisis-by-2050-59985.
[10] "For Every 1°C Rise in Temperature, a Billion People Will Endure Insufferable Heat," Earth.org, May 7, 2020, https://earth.org/for-every-1c-rise-in-temperature-a-billion-people-will-endure-insufferable-heat/.

drought length are also anticipated when projected across regions.[11] The area destroyed by wildfires each year would more than quadruple in the Northwestern United States.[13]

At four degrees, significant parts of the world could experience medium to high levels of food insecurity by the 2080s, reversing the whole development path of those regions.[14] Currently it is estimated that 37% of all heat-related deaths are attributable to human-induced climate change.[15] Failure to achieve the Paris temperature goals could result in climate-related catastrophic disasters causing $600 trillion in losses worldwide.[16]

By 2100, even if we manage to keep the planet's temperature at two degrees, we will still have an atmosphere with a carbon content of 500 ppm or possibly higher.[17] When that occurred sixteen million years ago, the globe was not two degrees warmer; rather, it was between five and eight degrees warmer, resulting in a sea level rise of around 130 feet, which was sufficient to redraw the American coastline as far west as I-95.[18] Although some of these processes take thousands of years to complete, they are also irreversible, making them in essence permanent.

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[11] Gustavo Naumann et al., "Global Changes in Drought Conditions Under Different Levels of Warming," *Geophysical Research Letters* 45, no. 7 (2018): 3285–96, https://doi.org/10.1002/2017GL076521.
[13] Chris Lehman, "Oregon State Government Adapts as Wildfires Take Their Toll," OPB News, September 12, 2017, https://www.opb.org/news/series/wildfires/oregon-wildfire-forest-management-eagle-creek-chetco-bar/.
[14] "Comparing Climate Impacts at 1.5°C, 2°C, 3°C and 4°C," WWF Climate and Energy, accessed August 28, 2023, https://wwfint.awsassets.panda.org/downloads/backgroundercomparing_climate_impacts_at_1_5c__2c__3c_4c.pdf.
[15] David Richards, "Global Study Evaluates Heat-Related Deaths Associated with Climate Change," National Institute of Environmental Health Sciences, Global Environmental Health Newsletter, August 2021, https://www.niehs.nih.gov/research/programs/geh/geh_newsletter/2021/8/articles/global_study_evaluates_heatrelated_deaths_associated_with_climate_change.cfm.
[16] Patrick Galey, "Paris Climate Goals Failure Could Cost World $600 tn," PhysOrg, April 14, 2020, https://phys.org/news/2020-04-paris-climate-goals-failure-world.html.
[17] Daniel R. Taub, "Effects of Rising Atmospheric Concentrations of Carbon Dioxide on Plants," The Nature Education Knowledge Project, March 10, 2021, https://www.nature.com/scitable/knowledge/library/effects-of-rising-atmospheric-concentrations-of-carbon-13254108/.
[18] Howard Lee, "What Happened Last Time It Was as Warm as It's Going to Get Later This Century?" ARS Technica, June 18, 2018, https://arstechnica.com/science/2018/06/are-past-climates-telling-us-were-missing-something/.

The high end of the probability curve proposed by the U.N., which is the worst-case result of the worst-case emissions path, places us at eight degrees in the end-of-the-century, business-as-usual scenario.[19] Humans at the equator and in the tropics would not be able to move outside at such temperature without perishing.

Direct heat effects would be the least of it in that world, which would be eight degrees warmer: the oceans would eventually rise two hundred feet, flooding what are now two-thirds of the world's major cities; very little of the planet's land could effectively produce any of the food we consume; forests would be torn by rolling firestorms; coasts would be punished by increasingly intense hurricanes; and the suffocating hood of tropical disease would roil.[20]

Only the unanswered question of how people would react exists between that scenario and the world we currently inhabit. Due to the lengthy processes by which the globe adjusts to greenhouse gases, some more heat is already baked in. However, all those future paths—to two degrees, three degrees, four degrees, five degrees, or perhaps eight—will be largely shaped by the actions we take now.

Other than our own lack of motivation to alter our route, which we have not yet shown, nothing is preventing us from reaching four degrees. It is unlikely that climate change will truly make the planet uninhabitable because of the size and ecological diversity of the planet. We humans have shown ourselves to be an adaptable species and will likely continue to do so to outwit a deadly threat, and because the devastating effects of warming will soon become too extreme to ignore or deny if they have not already. However, if we do nothing to

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[19] DNews, "What Would 8 Degrees of Warming Look Like?" Seeker, December 2, 2015, https://www.seeker.com/what-would-8-degrees-of-warming-look-like-1770539854.html.
[20] Mark Booth, "Chapter Three–Climate Change and the Neglected Tropical Diseases," Science Direct, March 28, 2018, https://doi.org/10.1016/bs.apar.2018.02.001.

reduce carbon emissions and industrial activity continues its current increasing trajectory for the next 30 years, entire regions would be uninhabitable by today's standards by the turn of the century.

Direct air capture technology, a crucial advancement in carbon capture technology, presents a promising solution to address the urgent global issue of climate change. By directly removing carbon dioxide from the atmosphere, direct air capture technology offers a scalable and location-independent approach towards atmospheric carbon reduction. Its importance lies in its potential for carbon negativity, where more carbon dioxide can be removed than emitted, facilitating a pathway to meet global climate targets. Furthermore, its adaptability to various scales of implementation from industry to individual buildings, and the potential to store or repurpose captured carbon for other uses such as synthetic fuel production, make it a versatile tool in our climate mitigation arsenal.

While technical and economic challenges persist, ongoing research and development, along with progressive policy support, have shown positive trends, underscoring the role of direct air capture as a significant player in the fight against climate change. Future progress in this area will depend on addressing these challenges, emphasizing the need for ongoing innovation and investment in this key technology.

Patents are instrumental in addressing climate change due to their roles in innovation, dissemination of technology, and commercial development. Patents encourage innovation by granting an inventor an exclusive right to benefit from their innovation, patents provide a critical incentive for research and development (R&D). This R&D is vital in creating advanced technologies to mitigate and adapt to climate change. Examples include energy efficiency technology, carbon capture and storage, renewable energy sources, and climate-resilient agricultural practices.

Patents also ensure the dissemination of technical information. Once a patent is granted, its details are published, fostering the spread of knowledge. Other inventors can build upon this public information to create improved or alternative technologies, potentially leading to breakthroughs in climate change solutions.

Patents help in securing investment for commercializing new technologies. The exclusivity provided by patents allows potential investors to see a pathway to return on their investment, encouraging the growth of new companies and the expansion of existing ones in the climate technology sector.

In the context of global climate change, patents can facilitate technology transfer between countries. They can encourage developed countries to share their advanced climate-friendly technologies with developing nations under mutually agreed terms. At the same time, the patent system needs to strike a balance between incentivizing innovation and ensuring accessibility of climate change technologies, especially for developing nations. Creative solutions like patent pools, licensing agreements, or exceptions for environmental technologies could play a role in achieving this balance.

Chapter 2 of this dissertation will discuss the efforts of one specific Lenexa, Kansas based non-profit -- Heart to Heart International -- and their considerable efforts to secure World Health Organization (WHO) certification as a Type 1 Mobile Emergency Medical Team (EMT). As the frequency and power of climate induced disasters, *i.e.*, floods, droughts, heat waves and hurricanes, increase there is a growing need for high quality first responders capable of quickly mobilizing to the country experiencing the disaster. Those entities certified by the WHO as EMTs will be the “go to” organizations called upon by the health departments of the countries experiencing the disaster.

As a former Board Chair of Heart to Heart International and as a licensed emergency medical technician I have had on the ground experience in a disaster zone and recognize the growing global need for such volunteer relief services. The fingerprints of climate change on many of these disasters is unmistakable from a scientific perspective and a rigorous certification process such as that afforded by the WHO will serve to ensure high quality medical care and logistical support to communities in need.

Unless the concentration of carbon dioxide residing in the earth’s atmosphere is reduced, it is advanced by many in the scientific community that powerful climate induced catastrophes such as heat waves will not only continue but increase in frequency and scale.[21] Unless atmospheric carbon dioxide concentrations are reduced there will be ever more frequent and intense extreme events.[22] If both near and long term efforts to reduce the magnitude of greenhouse gas emissions does not materialize, the focus unquestionably must shift in a significant fashion to efforts to extract the carbon dioxide directly from the atmosphere.

As part of a rising understanding of the significance of environmental issues among publicly traded firms, the U.S. Securities and Exchange Commission (SEC) presented a regulatory proposal in March of 2022 to improve and standardize climate-related disclosures for investors. Chapter 3 of this dissertation discusses this proposed disclosure regulation and how publicly traded companies must not only disclose risks that are reasonably likely to have

[21] “July 2023 Confirmed as Hottest Month on Record,” World Meteorological Organization, August 14, 2023, https://public.wmo.int/en/media/news/july-2023-confirmed-hottest-month-record.
[22] “July 2023 Confirmed as Hottest Month on Record.”

a material impact on their business, results of operations, or financial condition, but also to disclose information about its direct greenhouse gas (GHG) emissions (Scope 1) and indirect emissions from purchased electricity or other forms of energy (Scope 2), as well as specific types of greenhouse gas emissions from upstream and downstream activities in its value chain.[23]

Chapter 4 discusses the significance of patents in developing and advancing direct air capture technology as well as the U.S. government's efforts to spur innovation through incentives in the patenting process. Chapter 4 also identifies fifteen (15) patents that focus upon direct air capture technology. The dissertation discusses the prosecution history of the patents detailing the basis for allowance under the patent laws of the United States.

Chapter 5 provides the conclusions of the analysis provided in Chapter 4 and focuses upon the most desirable attributes of the diverse patented technologies to attempt to optimize the design of a direct air capture device. The focus of the analysis is to maximize the capacity to reduce the concentration of atmospheric carbon dioxide as quickly as possible. This necessarily entails scalability and minimal utilization of fossil fuel resources that provides the thermodynamic driver to achieve the carbon dioxide desorption from the ad/absorbent.

A literature search was performed on all topics covered in this dissertation and the results of that comprehensive literature search is interspersed throughout this dissertation. The results of the literature search has been documented in the citations found throughout this manuscript.

[23] Zach Warren, "Upcoming SEC Climate Disclosure Rules Bring Urgency to ESG Data Strategy Planning," Reuters, January 30, 2023, https://www.reuters.com/legal/legalindustry/upcoming-sec-climate-disclosure-rules-bring-urgency-esg-data-strategy-planning-2023-01-30/.

CHAPTER 2

NON-PROFITS AND CLIMATE CHANGE

2.1 Non-Profits and Disaster Relief

As I prepare this dissertation in mid-September of 2023, more than 5,000 people were killed in Libya after torrential rains caused two dams to burst near the coastal city of Derna, destroying much of the city and carrying entire neighborhoods into the sea.[1] More than 20,000 people have been displaced in the eastern settlements of Shahhat, Al-Bayada and Marj.[2] The country is particularly vulnerable to extreme storms and climate change.[3] According to the United Nations, warming causes the Mediterranean Sea's waters to expand and its sea levels to increase, eroding shorelines and causing flooding, with low-lying coastal parts of Libya being particularly at risk.[4]

UN agencies and partners are responding to this Libyan disaster and emergency teams are being mobilized to support those affected and are working with local, national and international partners to secure urgently needed humanitarian assistance to people in the affected areas.[5] The UN is working closely with Libyan authorities to assess needs and support ongoing relief efforts.[6] As this chapter will discuss in detail, the WHO certification process is intended to provide the country experiencing the disaster with a list of highly

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[1] Mohammaed Abdusamee, Vivian Nereim, and Isabella Kwai, "More than 5,000 Dead in Libya as Collapsed Dams Worsen Flood Disaster," *New York Times*, September 13, 2023, https://www.nytimes.com/2023/09/12/world/middleeast/libya-floods-dams-collapse.html?campaign_id=2&emc=edit_th_20230913&instance_id=102585&nl=todaysheadlines&regi_id=15721329&segment_id=144597&user_id=e73b08231afc067a4b7a427d9a8ba400.
[2] Abdusamee, "More than 5,000 Dead."
[3] Abdusamee, "More than 5,000 Dead."
[4] Abdusamee, "More than 5,000 Dead."
[5] "Humanitarian Response Ramps Up as Floods of 'Epic Proportions' Leave Thousands Dead," Reliefweb, Libya, September 12, 2023, https://reliefweb.int/report/libya/libya-humanitarian-response-ramps-floods-epic-proportions-leave-thousands-dead.
[6] "Humanitarian Response Ramps Up."

qualified emergency medical teams of varying capabilities that can readily mobilize to disaster sites specified by the host country. The WHO certification process is intended to assist the host country in avoiding the undesirable convergence of people and materials, often time people without the requisite skills and the delivery of materials that are inappropriate for the site thereby complicating the overall coordination at the disaster response.

Non-profit organizations play a pivotal role in responding to climate change-induced disasters. Their activities span from immediate disaster response and recovery to advocacy and policy influence, to education and awareness, and to research and innovation. Non-profit organizations often act as first responders in the aftermath of climate disasters, providing critical relief services and assisting in longer-term recovery efforts. The American Red Cross, for instance, provides disaster relief operations that include food, shelter, and emotional support to affected communities.[7]

Non-profits also work on various initiatives to help communities better adapt to the impacts of climate change and build resilience. The Environmental Defense Fund is an example of a non-profit organization that works on climate resilience, developing programs to help communities build resilience to climate change.[8]

Non-profit organizations play a crucial role in influencing climate policy at local, national, and international levels. For instance, the Natural Resources Defense Council (NRDC) works to shape policy on climate change and clean energy at all levels of government. Non-profits help raise awareness about climate change and its impacts. For instance, the Climate Reality Project, founded by former U.S. Vice President Al Gore,

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[7] "Disaster Relief," American Red Cross, 2023, https://www.redcross.org/about-us/our-work/disaster-relief.html.
[8] "Our Work Delivering Bold Climate Change Solutions," Environmental Defense Fund, accessed August 28, 2023, https://www.edf.org/our-work.

focuses on education and advocacy related to climate change.[9] Some non-profits conduct or fund research to improve our understanding of climate change and develop innovative solutions. For example, the Rocky Mountain Institute works on developing and deploying clean energy solutions (Rocky Mountain Institute, 2021).[10]

2.2 Climate Change and Infectious Diseases

Climate change is expected to influence the prevalence and spread of infectious diseases, including those carried by vectors such as mosquitoes and ticks, as well as waterborne and foodborne illnesses.[11] This impact is due to a variety of interrelated factors including an alteration of ecosystems.[12] Climate change can disrupt local ecosystems, potentially leading to an increase in the habitats suitable for the vectors of certain diseases, such as mosquitoes carrying malaria or ticks carrying Lyme disease.[13] Furthermore, the disruption of ecosystems can lead to closer contact between wildlife and human populations, increasing the risk of zoonotic diseases (those transmitted from animals to humans).[14]

Second, many vectors and pathogens are sensitive to conditions such as temperature and rainfall. Warmer temperatures can accelerate the lifecycle of vectors such as mosquitoes, increasing their population and the potential for disease spread. Similarly, changes in rainfall can create more breeding sites for these vectors.[15] Increased heat and humidity can also enhance the survival and proliferation of bacteria and viruses.

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[9] "Global Warming," NRDC, June 7, 2023, https://www.nrdc.org/issues/global-warming.
[10] "About," RMI, 2023, https://rmi.org/about/.
[11] Camilo Mora et al., "Over Half of Known Human Pathogenic Diseases Can Be Aggravated by Climate Change," *Nature Climate Change* 12 (2022): 869–75, https://doi.org/10.1038/s41558-022-01426-1.
[12] Mora, "Over Half of Known Human Pathogenic."
[13] Mora, "Over Half of Known Human Pathogenic."
[14] Mora, "Over Half of Known Human Pathogenic."
[15] "Does Climate Change Increase the Spread of Infectious Disease?" National Academies, December 7, 2022, https://www.nationalacademies.org/based-on-science/does-climate-change-increase-the-spread-of-infectious-diseases.

The frequency of extreme weather events such as floods and hurricanes are predicted to increase due to climate change.[16] These events can lead to outbreaks of diseases such as cholera or other diarrheal diseases due to the contamination of water supplies. Climate change can lead to displacement of populations, overcrowding, and resource scarcity, all of which can facilitate the spread of infectious diseases. For instance, crowded conditions can increase the transmission of respiratory infections like tuberculosis or COVID-19.[17]

Given these impacts, public health measures, alongside efforts to mitigate climate change, are crucial to manage the increased risk of infectious diseases due to climate change. This could involve surveillance and control of disease vectors, improvements in water and sanitation infrastructure, development, and distribution of vaccines, and strengthening healthcare systems, particularly in vulnerable regions.

2.3 Non-Profits and Disaster Relief

Non-profit organizations play a pivotal role in responding to climate change-induced disasters. Their activities span from immediate disaster response and recovery to advocacy and policy influence, to education and awareness, and to research and innovation. Non-profit organizations often act as first responders in the aftermath of climate disasters, providing critical relief services and assisting in longer-term recovery efforts. The American Red Cross, for instance, provides disaster relief operations that include food, shelter, and emotional support to affected communities.[18]

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[16] Ali Swenson, "Extreme Weather Events Are Becoming More Severe, Not Less," AP Fact Check, March 15, 2023, https://apnews.com/article/fact-check-extreme-weather-events-climate-change-169250036362.
[17] Kefyalw Addis Alene, Wangdi Kinley, and Archie C. A. Clements, "Impact of Covid-19 Pandemic on Tuberculosis Control: An Overview," National Library of Medicine, September 5, 2020, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7558533/.0.
[18] "Disaster Relief."

Non-profits also work on various initiatives to help communities better adapt to the impacts of climate change and build resilience. The Environmental Defense Fund is an example of a non-profit organization that works on climate resilience, developing programs to help communities build resilience to climate change.[19]

Non-profit organizations play a crucial role in influencing climate policy at local, national, and international levels. For instance, the Natural Resources Defense Council (NRDC) works to shape policy on climate change and clean energy at all levels of government (NRDC, 2021). Non-profits help raise awareness about climate change and its impacts. For instance, the Climate Reality Project, founded by former U.S. Vice President Al Gore, focuses on education and advocacy related to climate change.[20] Some non-profits conduct or fund research to improve our understanding of climate change and develop innovative solutions. For example, the Rocky Mountain Institute works on developing and deploying clean energy solutions (Rocky Mountain Institute, 2021).[21]

2.4 Background on Heart to Heart International

One of my motivations for obtaining my doctorate degree is the I believe it complements my desire and capacity to be of service to others. A doctorate degree provides me with a more potent voice in the rally cry to greater action to timely address global warming. For over a decade I have served in some capacity with a Lenexa, Kansas based non-profit called Heart to Heart International (HHI) the mission of which is responding globally to man made and natural disasters. Many of them undoubtedly influenced by climate change.

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[19] "Our Work Delivering Bold Climate Change Solutions."
[20] "Global Warming."
[21] "About," RMI.

HHI is a non-profit organization that is dedicated to improving global health through providing medical aid and disaster relief. The organization was founded in 1992 by Dr. Gary Morsch, a primary care physician who practiced in Olathe, Kansas, and Jim Kerr a Kansas City pharmacist – both active members of a local Rotary Club.[22] The original mission contemplated for HHI was an airlift of 75 tons of medical supplies to hospitals in Russia.[23] At the time, it was the largest ever private humanitarian airlift and was supported by a C5 Galaxy transport aircraft provided by the U.S. Air Force at the request of U.S. Senator Bob Dole, the senate majority leader at that time.[24] Donated aid was distributed to 32 Russian hospitals and nine orphanages.[25] A gift from the heart of America to the heart of Russia.

Many former Soviet governments, as well as Vietnam, India, China received more airlifts of pharmaceuticals and medical supplies.[26] Since that time, HHI has developed from a non-profit that primarily provided medical relief airlifts to one that provides medical supplies to non-profit partners and clinics all around the United States and the rest of the world. HHI also sends out medical response teams in the wake of disasters and assists clinics in the United States in enhancing their laboratory capabilities.

In underdeveloped nations, HHI aims to increase access to healthcare and support long-term health systems. To achieve this, they fund health education initiatives, offer medical gear and supplies, and collaborate with regional partners to develop and improve local healthcare systems. HHI carries out medical missions to underserved populations all around the world in addition to disaster relief. Access to basic medical treatments and care,

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[22] The Rotary Wheel, Olathe Rotary Club, June 18, 2018, https://clubrunner.blob.core.windows.net/00000004400/en-ca/files/sitepage/newsletter-photo-archive/june-2018-newsletter/june-2018-newsletter-5-pagesdoc.pdf.
[23] The Rotary Wheel.
[24] The Rotary Wheel.
[25] The Rotary Wheel.
[26] The Rotary Wheel.

including immunizations, primary care, and maternity and child health services, is made possible through these missions. To guarantee that people have continued access to medical care, HHI has also created permanent clinics and health centers in some of the places where it operated (such as Haiti).

HHI collaborates with regional groups and governments to improve local healthcare infrastructure, train healthcare professionals, and provide access to necessary medical supplies and tools. This work also aims to increase the capacity of regional healthcare systems. As a result, communities are better able to respond to medical emergencies and offer continuing healthcare to their residents.

Over time, HHI broadened the scope of its purpose to include helping people in communities afflicted by natural calamities, wars, and other crises. The Ebola outbreak in West Africa in 2014–2015, the Haiti earthquake in 2010, and the Indian Ocean tsunami in 2005 are just a few examples of the humanitarian crises and disasters to which HHI has responded.[27]

Providing communities with access to necessary medical resources and services is central to HHI's purpose of empowering them to enhance their health and general well-being. By offering a wide range of services, such as disaster relief, medical missions, and healthcare capacity building, HHI can do this. Disaster response is one of HHI's main areas of emphasis. The non-profit has a quick response team that can be sent to disaster-hit areas in a matter of days to help those in need by giving them medical care and supplies. Hurricanes, earthquakes, and floods are just a few of the disasters to which HHI can respond.

[27] The Rotary Wheel.

Additionally, the non-profit has helped communities afflicted by conflict, as well as refugees and internally displaced people.

HHI is a well-known leader in the field of global health, and it has a solid track record of offering first-rate medical assistance and disaster relief. The group is well known for its creative and successful approach to global health, and it has a strong commitment to transparency and responsibility. HHI is a significant organization that contributes to improving global health by offering medical assistance and disaster relief. Communities are effectively empowered by the organization's focus on disaster response, medical missions, and healthcare capacity building to enhance their health and well-being.

Some additional details about HHI are that in 2021 the non-profit had contributions and grants of $282,692,413.[28] The vast majority of this revenue came from the valuation of donated medical products from major national pharmaceutical companies.[29] HHI has a *Charity Navigator* rating of Four-Stars (highest rating – most fiscally responsible) with a charity score of 98%.[30] Ms. Kim Carroll, HHI's CEO for the past eight years is a seasoned executive with extensive experience in the pharmaceutical sector holding numerous senior management positions with companies such as Aventis, The Medicines Company, EUSA Pharma and Jazz Pharmaceuticals. She manages a workforce of about 30 employees and oversees an organization that at any one time may have $50 million of medical supplies in the Lenexa, Kansas warehouse.

[28] "Candid," Heart to Heart International, accessed August 28, 2023, https://beta.candid.org/profile/7711804?keyword=heart+to+heart+international&action=Search.
[29] "Candid," Heart to Heart International.
[30] "Candid," Heart to Heart International.

2.5 Ebola Outbreak in 2014

Humans and non-human primates including monkeys, gorillas, and chimpanzees are the main targets of the deadly and extremely contagious Ebola virus.[31] The virus can be spread by direct contact with the blood, saliva, organs, or other bodily fluids of infected animals, as well as by coming into touch with contaminated surfaces and objects.[32]

Ebola symptoms often show up 2 to 21 days after infection and can include fever, a strong headache, muscle pain, weakness, and fatigue as well as nausea, vomiting, diarrhea, and abdominal discomfort that isn’t related to any other symptoms (bleeding or bruising).[33] These symptoms can worsen quickly and cause death in a week, possibly in a few days, in some cases. Modern medicine and public health initiatives have been successful in bringing down this number and lessening the virus’s effects on people and communities, even though historically the fatality rate of this infection topped 80%.[34]

In what is now the Democratic Republic of Congo, the Ebola virus was initially discovered in 1976 close to the Ebola River.[35] The virus has since expanded throughout Africa on several occasions, with West Africa seeing the largest and most pervasive outbreak between 2014 and 2016. More than 28,000 cases and over 11,000 fatalities were caused by this pandemic, which also afflicted Guinea, Liberia, and Sierra Leone.[36]

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[31] “What Is Ebola Disease?” Centers for Disease Control and Prevention, accessed August 28, 2023, https://www.cdc.gov/vhf/ebola/about.html.
[32] “What Is Ebola Disease?”
[33] “What You Need to Know about Ebola,” Centers for Disease Control and Prevention, December 10, 2015, https://www.cdc.gov/vhf/ebola/pdf/what-need-to-know-ebola.pdf.
[34] Ayten Kadanali and Gul Karagoz, “An Overview of Ebola Virus Disease,” National Library of Medicine, April 24, 2015, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5175058/.
[35] “History of Ebola Virus Disease,” Centers for Disease Control and Prevention, last reviewed May 17, 2023, https://www.cdc.gov/vhf/ebola/history/summaries.html.
[36] “Ebola Virus Outbreak: Facts, Symptoms, and How to Help,” World Vision, accessed August 28, 2023, https://www.worldvision.org/health-news-stories/2014-ebola-virus-outbreak-facts#:~:text=The%202014%20outbreak%20of%20Ebola,emergency%20ended%20in%20June%202016.

Currently, the U.S. Food and Drug Administration (FDA) has approved two medications to treat EVD in both adults and children that is brought on by the Zaire ebolavirus, a type of the Ebola virus.[37] Three monoclonal antibodies are combined in Inmazeb™, the first medication to be approved in October 2020.[38] The second drug, Ebanga™, is a single monoclonal antibody and was approved in December 2020.[39] Monoclonal antibodies (commonly referred to as mAbs) are proteins made in laboratories or other manufacturing facilities that function similarly to natural antibodies to prevent a pathogen, such as a virus, from multiplying after it has infected a person.[40] These specific mAbs attach to the glycoprotein on the surface of the Ebola virus, preventing the virus from entering a person's cells.[41]

In a randomized controlled study conducted in the Democratic Republic of the Congo during the 2018–2020 Ebola outbreak, both of these treatments as well as two others were assessed.[42] Patients taking either of the two FDA-approved therapies had a significantly greater overall survival rate. The effectiveness of Inmazeb™ and Ebanga™ against species other than the *Zaire ebolavirus* has not been tested.[43]

Avoiding interaction with wild animals, avoiding contact with blood and bodily fluids of infected people, and staying away from places where Ebola outbreaks are known to occur

[37] "Ebola Treatment/Therapeutics," Centers for Disease Control and Prevention, accessed August 28, 2023, https://www.cdc.gov/vhf/ebola/treatment/index.html.
[38] "Ebola Treatment/Therapeutics."
[39] "Ebola Treatment/Therapeutics."
[40] "Ebola Treatment/Therapeutics."
[41] "Ebola Treatment/Therapeutics."
[42] "Ebola Treatment/Therapeutics."
[43] "Ebola Treatment/Therapeutics."

are all part of disease prevention.[44] In 2015, HHI played a critical role in responding to the Ebola outbreak in West Africa. The Ebola outbreak, which began in 2014, quickly became the deadliest outbreak of the virus in history.[45] The World Health Organization (WHO) declared the outbreak a Public Health Emergency of International Concern in August 2014. HHI responded to the outbreak by deploying teams of medical professionals and volunteers to the affected countries of Liberia, Sierra Leone and Guinea.

No discussion of HHI's efforts to combat Ebola would be complete without a discussion of the role that Jim Mitchum played. Executive Search firm EFL Associates in the summer of 2014 recommended Jim Mitchum to serve as HHI's new CEO. In the late summer of 2014 Jim was selected by the HHI Board of Directors as the new CEO.[46] Jim, a former senior executive of several pharmaceutical companies (EUSA, Enturia, Sanofi-Aventis, Aventis and Hoechst Marion Roussel AG), sought additional personal challenges following his retirement from the pharmaceutical world and he certainly found those challenges at HHI.[47]

Just weeks after his installment as CEO Jim departed for Liberia where he was instrumental in setting up an Ebola treatment unit. Because of the enormous complexity of dealing with such a dangerous disease in a part of the world where resources are limited, only HHI and Médecins Sans Frontières / Doctors Without Borders (MSF) were able to establish Ebola treatment units (EBU) to address the outbreak.[48] Jim regularly coordinated with the

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[44] "Ebola Virus Outbreak: Facts, Symptoms, and How to Help," World Vision, accessed August 28, 2023, https://www.worldvision.org/health-news-stories/2014-ebola-virus-outbreak-facts#:~:text=The%202014%20outbreak%20of%20Ebola,emergency%20ended%20in%20June%202016.
[45] "History of Ebola Virus Disease."
[46] Recollections of B. Lambrechts, who served on the HHI Board of Directors from 2011 to 2106 and then as Board Chair from 2017 to 2019.
[47] Jim Mitchum, interview with author, September 20, 2022.
[48] Abdusamee, "More than 5,000 Dead in Libya."

U.S. military while in Liberia and received considerable logistical support from the U.S. Army.[49]

Jim and his staff helped to train local healthcare workers on how to safely care for patients, and with extensive logistical support from HHI, personal protective equipment (PPE) was distributed to help stem the spread of the virus. Jim raised awareness about the virus and how to prevent it from spreading, this was a critical task as the outbreak was affecting the local communities and people were unfamiliar with the transmissibility of the disease.

Mitchum's work was critical in the fight against Ebola in Liberia. His selfless dedication helped to save lives and slow the spread of the virus. He worked tirelessly, often in dangerous and challenging conditions, to provide medical care and support to patients, and to train and support local healthcare workers.

Dr. Rick Randolph, an Overland Park primary care physician who served as the Chief Medical Officer for HHI also played a critical role in responding to the Ebola outbreak in West Africa as part of the organization's efforts. Dr. Randolph, a former U.S. Army Ranger, retired colonel, and someone accustomed to bleak and austere environments because of his military deployments also traveled to West Africa, where he provided comprehensive medical care and support to Ebola patients, trained local healthcare workers on how to safely care for patients, and distributed PPE to help prevent the spread of the virus.[50]

Rick was also highly instrumental in establishment of the Ebola treatment units, and he worked tirelessly to raise awareness about the virus and how to prevent it from spreading.

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[49] Abdusamee, "More than 5,000 Dead in Libya."
[50] Dr. Rick Randolph, interview with author, September 20, 2022.

Dr. Randolph's medical expertise and dedication were critical in the fight against Ebola in the affected countries.

2.6 Background on the World Health Organization

The United Nations' World Health Organization (WHO) is a specialized organization with a charge to address global public health. It was founded in 1948 with the intention of creating a healthy world for everyone.[51] In order to accomplish this, WHO takes the lead on global health concerns, sets standards and norms, formulates evidence-based policy alternatives, offers technical assistance to nations, and monitors and evaluates health trends.[52]

WHO's work is divided into several key areas. The first is communicable diseases that consist of HIV/AIDS, TB, and malaria. WHO aims to prevent and control the spread of these diseases and to accomplish the conduct extensive research to better comprehend these diseases and create new tools and strategies for battling them, as well as offering technical assistance to nations to assist them in enhancing their surveillance, diagnostic, and treatment systems.[53]

Next on the list are non-communicable diseases such as cancer, diabetes, and heart disease. This involves promoting a healthy lifestyle, aiming to diagnose and treat certain diseases earlier, and lowering risk factors that lead to their development.[54] The next area promoted by WHO is health systems. WHO works to improve healthcare systems in many nations. In addition to encouraging policies and practices that help guarantee that everyone

[51] *Constitution of the World Health Organization*, World Health Organization, Forty-fifth edition, Supplement: October 20, 2006.
[52] "World Health Organization: History, Organization, & Definition of Health," *Encyclopedia Britannica,* August 24, 2023, https://www.britannica.com/topic/World-Health-Organization.
[53] *Strategizing National Health in the 21st Century: A Handbook* (World Health Organization, 2016), https://apps.who.int/iris/handle/10665/250221.
[54] *Strategizing National Health in the 21st Century*, 184.

has access to the health care they require, this also entails offering technical assistance to nations for improving their health workforce, infrastructure, and financing.[55]

WHO seeks to address emergencies and humanitarian crises. In response to health emergencies and humanitarian catastrophes including natural disasters, armed conflicts, and infectious disease epidemics, WHO is crucial. This involves trying to ensure that those in need have access to proper healthcare as well as offering affected nations technical aid and support.[56] WHO also aggressively promotes health and disease prevention. WHO seeks to encourage illness prevention as well as healthy lifestyles. This include educating the public and disseminating information, as well as attempting to foster conditions that support positive conduct.[57]

WHO's mission also encompasses research and innovation. To advance knowledge, technology, and protocols for health, WHO undertakes and funds research in fields important to public health. This covers tasks like monitoring, evaluating, and monitoring as well as health research and development.[58]

WHO is crucial for coordinating international initiatives aimed at enhancing health and addressing threats to it. To fulfill its mandate, it collaborates closely with other UN agencies, governments, nongovernmental groups, and the private sector. WHO also offers

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[55] "Health Workforce," World Health Organization, accessed August 29, 2023, https://www.who.int/health-topics/health-workforce#tab=tab_1.
[56] "Health Emergencies," World Health Organization, accessed August 29, 2023, https://www.who.int/our-work/health-emergencies.
[57] "Health Promotion," World Health Organization, accessed August 29, 2023, https://www.who.int/westernpacific/about/how-we-work/programmes/health-promotion.
[58] "Research," World Health Organization, accessed August 29, 2023, https://www.who.int/health-topics/research#tab=tab_1.

technical aid and training to nations to assist them in enhancing their health systems and responding to medical emergencies.[59]

Within the framework of the United Nations, WHO serves as the leading and coordinating body for health. It is tasked with exercising leadership in matters of global health, defining standards and norms, directing the direction of health research, articulating alternatives for evidence-based policy, assisting developing nations with technical needs, and tracking and evaluating health trends.[60]

A World Health Assembly made up of delegates from each Member State and an Executive Board made up of 34 members chosen for three-year periods manage WHO.[61] The general management and direction of WHO is under the Director-General.[62] Africa, the Americas (with headquarters located in Washington D.C.), the Eastern Mediterranean, Europe, South-East Asia, and the Western Pacific are the six geographic areas where the WHO has regional offices in addition to its headquarters in Geneva, Switzerland.[63]

Overall, WHO plays a critical role in ensuring that people have access to the healthcare they need by offering technical assistance, advice, and support to nations and communities, striving to prevent and control the spread of diseases, and promoting policies and practices that do so.

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[59] "Working for Better Health," World Health Organization, accessed August 29, 2023, https://www.who.int/about/what-we-do/who-brochure.
[60] United Nations, Office of the Secretary-General's Envoy on Youth, accessed August 29, 2023, https://www.un.org/youthenvoy/2013/09/who-world-health-organisation/.
[61] "Governance," World Health Organization, accessed August 29, 2023, https://www.who.int/about/governance.
[62] Dr. Tedros Adhanom Ghebreyesus is the current Director General of WHO. He is originally from Ethiopia.
[63] "Governance," World Health Organization.

2.7 Providers of EMTs

The primary no-cost sources of EMTs are from the government, nongovernmental organizations, the Red Cross and Red Crescent movement, academic institutions, professional associations, the commercial sector, and self-improvised groups.[64] Government EMTs may be either military or civilian. Government teams, of which 25% were military comprised twenty-six per cent of the EMTs deployed to the Ebola Virus Disease (EVD) outbreak.[65] The distinction between state supported EMTs and other players is further complicated by the fact that many of the non-governmental EMTs that reacted to the outbreak were entirely funded by their governments.[66]

Thirty percent of the teams that responded to the Nepal earthquake were government teams, while 37 percent were military teams.[67] Over 40 nations have currently signed on to the WHO EMT project and asked for peer evaluation and quality assurance of their teams. While some governments have joined their civil and military teams in a hybrid model for overseas deployments, many governments also have military medical corps that are increasingly capable of responding with field hospitals in humanitarian and disaster operations.[68]

Credible national EMTs who are prepared to respond to domestic situations and who make up the foundation of the initial response are now present in much greater numbers.[69] As may be seen in the example of the governments of various European nations, who are trying

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[64] "The Regulation and Management of International Emergency Medical Teams," World Health Organization and International Federation of Red Cross and Red Crescent Societies, June 2017, https://extranet.who.int/emt/sites/default/files/WHOIFRCReport.PDF, 12-13.
[65] "The Regulation and Management of International Emergency Medical Teams."
[66] "The Regulation and Management of International Emergency Medical Teams."
[67] "The Regulation and Management of International Emergency Medical Teams."
[68] "The Regulation and Management of International Emergency Medical Teams."
[69] "The Regulation and Management of International Emergency Medical Teams."

to combine their resources to offer an EMT Type 3, some government contributors are collaborating to update the type of EMT provided.[70]

There are numerous non-governmental organizations (NGOs) that are registered in their own states and may routinely or irregularly send medical response teams to a crisis.[71] Others may concentrate on providing health care (general or specialized) in a small number of nations or regions and will respond to emergencies in their geographic coverage areas. Some have extensive experience in this field and have a global reach, such as Médecins sans Frontières (MSF).[72] Other (usually smaller) actors who lack field presence and humanitarian expertise could also make sporadic interventions.[73]

There will likely be difficulties with relation to the proliferation, coordination, quality, and competence of these actors given the various sorts and variants of EMT providers. The quick rise in the number of teams showing up to help in the wake of widely reported disasters is the most obvious and recent trend in the deployment of EMTs.[74] For instance, only one field hospital (operated by the U.S. military) and a small number of medical teams provided assistance following the devastating earthquake that struck Guatemala in 1976 that resulted in 23,000 fatalities.[75]

One hundred eighty organizations (from all sectors) registered with the UN coordination agency in Banda Aceh, the area most severely devastated by the Indian Ocean tsunami (2004).[76] In Haiti (2010), there were around 400 organizations "offering health

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[70] "The Regulation and Management of International Emergency Medical Teams."
[71] "The Regulation and Management of International Emergency Medical Teams."
[72] "The Regulation and Management of International Emergency Medical Teams."
[73] "The Regulation and Management of International Emergency Medical Teams."
[74] "The Regulation and Management of International Emergency Medical Teams."
[75] "The Regulation and Management of International Emergency Medical Teams."
[76] "The Regulation and Management of International Emergency Medical Teams."

care."[77] 150 EMTs were observed by WHO after Typhoon Haiyan in the Philippines in 2013, and comparable numbers were registered in the response to the 2015 Nepal earthquake (149 EMTs).[78]

This multiplication of actors does not necessarily apply to all threats or situations, as evidenced by the dearth of initial responders to the West African EVD outbreak. According to an MSF report, the abundance of EMTs in "simple" abrupt onset disasters is in sharp contrast to the number of organizations and EMTs willing to respond to protracted conflict and complicated situations.[79]

2.8 Type 1 Mobile Emergency Medical Team (EMTs)

EMTs have a lengthy history of reacting to disasters with a rapid onset, including the earthquake in Haiti, the tsunami in the Indian Ocean, and the floods in Pakistan. EMTs have traditionally specialized in trauma and surgery, but the West African Ebola (2014–2016) outbreak has demonstrated their value in responding to outbreaks and other types of emergencies. The Ebola response saw the greatest deployment of EMTs for an outbreak (58 teams), although those numbers pale in comparison to the teams sent to Haiti after the 2010 earthquake and the large number of teams sent to respond to Typhoon Haiyan in November 2013.[80]

In comparison to requirements for sudden onset disasters and trauma, emergency health response requirements are more extensive. They must be equipped with teams to assist people afflicted by flood, conflict, and chronic crises like famine, as well as the capacity to

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[77] "The Regulation and Management of International Emergency Medical Teams."
[78] "The Regulation and Management of International Emergency Medical Teams."
[79] "Where Is Everyone? Responding to Emergencies in the Most Difficult Places," Doctors Without Borders, July 2014, http://www.msf.org/sites/msf.org/files/msf-whereiseveryone_-def-lr_-_july.pdf.
[80] "Emergencies: Emergency Medical Teams," World Health Organization, accessed August 29, 2023, https://www.who.int/news-room/questions-and-answers/item/emergencies-emergency-medical-teams.

treat a wide spectrum of ailments, from communicable to noncommunicable diseases.[81] In all events involving potential health repercussions, clinical surge capacity is required, and EMTs play a crucial role in restoring and maintaining vital medical services. EMTs adhere to the WHO Classification and Minimum Standards for Foreign Medical Teams in Sudden Onset Disasters criteria when performing their duties.[82] The concepts and fundamental requirements for how registered EMTs must conduct themselves and proclaim their operating capabilities are covered in these guidelines.

Lessons learned from the Haitian health response and a Pan American Health Organization examination of foreign field hospitals in the wake of sudden-impact disasters that same year laid the foundation for the creation of principles, criteria, and standards for international medical teams.[83] This drove the creation of the Emergency Medical Team (EMT) Initiative and the publication of the Classification and Minimum Standards for Foreign Medical Teams in Sudden Onset Disasters (SODs), which resulted in the first application of this classification system during Typhoon Haiyan in the Philippines in 2013.[84]

The International Health Regulations (2005), also known as IHR (2005), which mandate that Member States develop minimum public health capabilities to "detect, assess, notify, and report events" and to "respond promptly and effectively to public health risks and public health emergencies of international concern," also influenced the creation of the

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[81] "Emergencies: Emergency Medical Teams."
[82] "Emergencies: Emergency Medical Teams."
[83] "Foreign Field Hospitals after the 2010 Haiti Earthquake: How Good Were We?" *Emergency Medicine Journal*, March 7, 2012, https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=e6011f640d5863d9e6ac1004c354395a405e2e89.
[84] "Classification and Minimum Standards for Foreign Medical Teams in Sudden Onset of Disasters," World Health Organization, April 5, 2013, https://www.who.int/publications/i/item/classification-and-minimum-standards-for-foreign-medical-teams-in-sudden-onset-of-disasters.

Initiative.[85] The Joint External Evaluation (JEE) tool, which was released in February 2016, is a voluntary mechanism that aids Member States in evaluating advancements made toward achieving the fundamental capacities required by IHR (2005).[86]

Medical countermeasures and personnel deployment targets processes for sending and receiving public health and medical personnel from international partners during public health emergencies were among the many aspects evaluated by the JEE. Case management for IHR (2005) related hazards was also included. Recently, Resolution EB 146.R104 urged Member States, organizations for regional economic integration, international, regional, and national partners, donors, and partners to increase the importance of local health workforces.[87] Additionally, the resolution urges the creation of efficient and effective national, subnational, and regional EMTs in accordance with WHO classification minimum standards.[88]

For emergency medical teams that can deliver cutting-edge medical care on the go, the World Health Organization (WHO) Type 1 Mobile Emergency Medical Team (EMT) accreditation is a widely recognized credential.[89] These teams are made up of highly skilled

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[85] "196 nations have entered into a legally binding agreement known as the International Health Regulations (IHR) 2005 to develop the capacity to identify and report potential public health emergencies globally. IHR provide that all nations must be able to identify, evaluate, communicate, and react to public health emergencies." "International Health Regulations," World Health Organization, 2023, https://www.who.int/health-topics/international-health-regulations#tab=tab_1.

[86] A Joint External Evaluation (JEE) is a voluntary, cooperative, multisectoral procedure to evaluate a country's capacity to prevent, detect, and quickly address public health concerns, whether they arise naturally or as a result of intentional or unintentional occurrences. The JEE assists nations in prioritizing possibilities for improved readiness and response by assisting them in identifying the most critical gaps in their human and animal health systems. "Joint External Evaluation (JEE)," World Health Organization, 2023, https://www.who.int/emergencies/operations/international-health-regulations-monitoring-evaluation-framework/joint-external-evaluations.

[87] "Executive Board 146th Session: Resolutions and Decisions Annexes," World Health Organization, February 2020, https://apps.who.int/gb/ebwha/pdf_files/EB146-REC1/B146_REC1-en.pdf#page=19.

[88] "Executive Board 146th Session."

[89] "Classification and Minimum Standards for Emergency Medical Teams," World Health Organization, June 18, 2021, https://www.who.int/emergencies/partners/emergency-medical-teams.

medical personnel such as doctors, nurses, and paramedics who can perform a variety of medical treatments, including surgical procedures, in difficult settings.

Currently Team Rubicon[90] and International Medical Corps[91] are the only U.S. based non-profits that are certified as Type 1 mobile emergency medical teams. A Type 1 mobile EMT is qualified to provide daytime care for stabilizing acute trauma and non-trauma presentations, making referrals for additional research or inpatient care, and providing community-based primary care while having the flexibility to work in different locations throughout a deployment.[92]

The WHO Type 1 Mobile Medical EMT certification assures that emergency medical teams can deliver high-quality care on the scene, even in the most difficult circumstances. This is one of its main advantages. This is crucial since access to medical care is sometimes poor or nonexistent in disaster and war settings. Additionally, the accreditation ensures that emergency medical teams can collaborate effectively and efficiently, which is essential for treating patients with prompt and efficient care.[93]

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[90] On June 28, 2018, the World Health Organization visited Team Rubicon's National Operation Center in Dallas, Texas and certified Team Rubicon as the first NGO in North America to be verified as an EMT Type-1 Mobile Team (the 18th Emergency Medical Team in the world). For two and a half years, Team Rubicon worked with stakeholders to drive the professionalization of their medical capability, which resulted in Team Rubicon receiving this certification.

[91] On June 9, 2021, the World Health Organization classified humanitarian organization International Medical Corps as an Emergency Medical Team (EMT) Type 1 provider, capable of deploying quickly and providing medical services in response to a disaster anywhere in the world.

[92] "Does Climate Change Increase the Spread of Infectious Disease?" Section 3.2, p. 14. Type 1 mobile teams are particularly important after flooding or storms where populations are dispersed in ad hoc shelters and remote villages, and are also useful in responses to small island states. Tasking of mobile teams generally becomes sector coverage rather than single site deployment.

[93] Some of the key characteristics of a Type 1 provider is that they are light, portable, adaptable, can work in remote areas to access small communities either operating from suitable existing structures or supplying their own mobile outpatient facilities, such as tents or specially equipped vehicles as mobile medical clinics. Type 1 teams are expected to have a base of operations allowing resupply and full compliance with all requirements of self-sufficiency, sterility, cold chain, and supply chain.

The promotion of evidence-based practices in emergency care is another crucial feature of the WHO Type 1 Mobile Medical EMT certification. This means that teams who have received WHO certification must treat patients using the most current, evidence-based methodologies and standards.[94] This contributes to both ensuring that patients get the best care possible and raising the bar for emergency medicine globally.

Teams must adhere to several stringent requirements as part of the laborious procedure to become certified as WHO Type 1 Mobile EMTs. This entails having a specific number of medical specialists on the team, having the required tools and supplies, and being able to show that the team can deliver cutting-edge care in the field. Teams must also take part in regular training sessions and drills to maintain their qualification. The government of the afflicted nation faces a serious difficulty in balancing immediate requirements with the scope of the response and the difficulties in organizing and supervising responders' operations because of this surge in EMTs. Few national legal systems are well prepared for the possibility of accepting foreign help, which causes haphazard rulemaking and uncertainty after a tragedy, when it is least practical.

2.9 WHO Certification Process

There are eight steps in the WHO EMT Global Classification procedure. An expression of interest kicks off Stage 1.[95] The applicant team submits an online application, specifying the category of EMT or specialized care team into which it wishes to fall. The Global Classification application is completed by an interview conducted by the WHO

[94] "Evidence, Policy, Impact: WHO Guide for Evidence-informed Decision Making," World Health Organization, January 2022, https://www.who.int/publications/i/item/9789240039872.
[95] "Classification and Minimum Standards for Emergency Medical Teams: The Global Classification, 2021," World Health Organization, https://extranet.who.int/emt/sites/default/files/BlueBook2021.pdf.

Global and Regional EMT Secretariat.[96] For example, in the case HHI is seeking a Type 1 Mobile EMT certification. Stage 2 is a self-assessment using the guiding principles and technical standards to establish the starting point and accompanying needs to satisfy the international minimum standards for their claimed type.[97]

Then, in Stage 3, the EMT Global Secretariat designates a principal mentor to accompany the team throughout the procedure until final verification, in accordance with the Regional EMT Secretariat. Technical experts are available to mentor the team to help with queries pertaining to clinical, logistical, or WASH[98]-related topics.

By reviewing their SOPs and/or creating new ones, the candidate team starts the process of adhering to the worldwide minimum requirements in Stage 4.[99] The applicant team needs to start educating their employees, modifying their clinical, logistical, and WASH equipment, and gathering supporting documentation.[100] The HHI team began meeting well over a year ago to discuss operating procedures and periodically meeting at the HHI offices to familiarize participants with communications gear, water purification equipment, tents, sleeping bags and even such mundane details as how to properly load a backpack with

[96] "Classification and Minimum Standards for Emergency Medical Teams."
[97] "Classification and Minimum Standards for Emergency Medical Teams."
[98] Water supply, personal hygiene, environmental sanitization, handling medical waste, sanitation, vector and pest control, and dead corpse management are all covered by WASH technical standards. The EMT must have access to or provide a reliable water supply capacity with redundancy in case the supply is interrupted. Without clean water, EMTs are unable to offer safe medical care and run the danger of spreading infectious diseases to their personnel, patients, and the local population, increasing already existing public health issues. Again, emphasizing the requirement for a robust component to support the operation of each EMT, EMTs must assure the availability of technical knowledge to carry out water management tasks. To guarantee proper operation, adequate equipment must be in place to treat enough raw water in accordance with the requirements for each kind and level of EMT. A water quantity estimate must be made by the EMT using the following minimal guidelines as a guide: 40–60 liters per staff member per day, 5 liters for outpatients, 40–60 liters for inpatients per day, and 100 liters for deliveries and surgical interventions. The EMT is responsible for ensuring that the treatment technologies and techniques used to treat water from the local raw water resources are in compliance with national and WHO regulations. The water treated with a disinfectant must have less than 5 nephelometric units of turbidity and no more than 0.5 to 1 mg per L of residual chlorine at the tap (NTU). Furthermore, at the time, there are no fecal coliforms per 100 ml at the point of delivery.
[99] "Classification and Minimum Standards for Emergency Medical Teams."
[100] "Classification and Minimum Standards for Emergency Medical Teams."

required equipment.[101] The mentor, which many HHI volunteers have not met, is tasked with assisting the applicant team throughout the entire SOP development process.

The pre-verification visit occurs in stage 5.[102] Before the mentor's visit, the candidate team must deliver a comprehensive evidence package to them. The package contains all SOPs and pertinent paperwork, a roster of all trained staff, and a list of equipment that is ready for deployment. This pre-verification visit's goal is to ensure that all the prerequisites are in place before moving on to the next stage. The candidate team and mentor should agree on whether the team is prepared to be verified.[103]

The verification visit occurs at stage 6.[104] When a peer review team determines that a candidate team satisfies international minimum requirements, it suggests that it be classified in the category for which it applied. This visit is being organized by the EMT Global Secretariat or the EMT Regional Secretariat.[105] The verification team recommends the team for categorization in a formal letter addressed to the WHO Director-General and includes a report therein. A follow-up call could be made six months following the verification visit to gauge how far the report's suggestions have come along.[106]

The Global Classification is ultimately under the control of the EMT Global Secretariat, which also oversees team and mentor coordination and follow-up. Additionally, it verifies the availability of the resources required for the Global Classification's creation

[101] Comment by Bob Lambrechts, a member of the HHI team seeking Type 1 Mobile EMT certification.
[102] "Classification and Minimum Standards for Emergency Medical Teams."
[103] Comment by Bob Lambrechts.
[104] Comment by Bob Lambrechts.
[105] Comment by Bob Lambrechts.
[106] Comment by Bob Lambrechts.

and oversees each step of the procedure to guarantee accuracy. Each of the six WHO regions' EMT Regional Secretariats shares responsibility for the procedure.[107]

The EMT Regional Secretariat collaborates with appropriate resources, facilitates the coordination of teams and mentors in each region, and aids in the settlement of any issues that may come up between teams and mentors or at any stage of the process. Teams commit to working under a set time frame to achieve international minimum requirements to be categorized and registered for international deployments.[108] The organization must pledge to have the essential tools, personnel, tools, and protocols that have been properly established and tested.[109]

Throughout the process, mentors agree to offer technical assistance and advise, along the lines of their expertise, with suggestions for how the team might meet the required minimum technical standards. The EMT Secretariat receives regular updates from mentors regarding the performance and status of the teams they have been assigned, as well as fair and unbiased advice regarding the team's verification preparedness. Peer reviewers oversee that the team conforms with the EMT Initiative's guiding principles, core standards, and technical standards during the verification visit.[110]

The team gets added to the global register of globally deployable EMTs at stage 7, once the EMT Global Secretariat has approved the verification visit report.[111] Five years are allotted for the registration's validity. Stage 8 is known as the reclassification stage. The team must confirm that it continues to adhere to worldwide minimum standards five years after

[107] Comment by Bob Lambrechts.
[108] Comment by Bob Lambrechts.
[109] Comment by Bob Lambrechts.
[110] Comment by Bob Lambrechts.
[111] Comment by Bob Lambrechts.

classification and that it has adapted to any new protocols or criteria established by the EMT initiative.[112]

Most experts concur that there is a growing gap between the two primary types of EMT providers in terms of quality and capacity. On the one hand, there are the conventional, established (and bigger) humanitarian actors and government teams, especially those working on domestic response, who are continuously enhancing their readiness, training, and capacity using experience and financial investment in their growth. On the other hand, it appears that the number of improvised, ill-equipped, and under-prepared EMTs is rising.[113] However, there is no official documentation that reports on this tendency because, up until recently, there were no minimal standards or monitoring methods that were widely accepted for EMTs.[114]

Understanding the humanitarian actors is necessary to tell them apart from the frequently destructive “amateurs.” Local health authorities frequently lack this information when dealing with a natural catastrophe for the first time, which can cause issues with quality control, capacity, and efficacy.[115]

2.10 Conclusion

Massive casualties are more likely to occur in major metropolitan areas due to the impacts of more frequent catastrophic sudden onset disasters, which will be exacerbated by human density. This is especially true in nations with constrained health care infrastructure. Sudden onset disasters will inevitably happen and could impact any number of cities that are unprepared. Even the most advanced medical facilities can be destroyed by a sudden onset

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[112] Comment by Bob Lambrechts.
[113] “The Regulation and Management of International Emergency Medical Teams,” 14.
[114] “The Regulation and Management of International Emergency Medical Teams.”
[115] “The Regulation and Management of International Emergency Medical Teams.”

disaster that affects a major city, endangering the ability of local actors and facilities to respond. To add to the pool of EMT providers, many nations that are susceptible to future sudden onset disasters are creating their own field hospitals and disaster medical teams.

EMTs will attempt to attend to the most sudden onset disasters that receive international media coverage whether they are requested or not due to the global drive of humanitarian solidarity. The need for EMTs will increase as interest from low- and middle-income countries increases. As the tsunami and earthquake in Japan in 2011 show, countries with poor socio-economic development are by no means the only ones who can benefit from the help of EMTs. No nation can completely rule out the potential of needing outside medical help in the event of an extreme sudden onset disaster, regardless of how industrialized or sophisticated it is. Under no circumstances is refusing such help a feasible technological or political solution.[116]

Wealthy nations are typically those that provide EMTs to disaster sites around the world. To secure certification by the WHO the EMTs require materials, *i.e.*, water treatment equipment, satellite communication equipment and medical supplies that are very expensive. Donations from supportive members of the community in the wealthier nations are often how these supplies are purchased by the EMT. In wealthy nations such as the United States the wealth that is transferred to EMTs to support their global efforts is often generated in the stock market. The next chapter in this dissertation will address the potential regulation of securities by the U.S. Securities and Exchange Commission to provide investors with a heightened understanding of the role that securities can play in combating climate change.

[116] "The Regulation and Management of International Emergency Medical Teams," 56.

CHAPTER 3

THE ROLE OF THE SECURITIES AND EXCHANGE COMMISSION IN ADDRESSING CLIMATE CHANGE

3.1 Asset Valuations Do Not Reflect Climate-Related Risks

While much of the world is seeing the adverse impacts from climate change and WHO qualified NGOs are working to relieve immense suffering another part of the population is engaged in the business of investing to generate the wealth to support relief operations. Every year in the international capital markets, investors transact more than $250 trillion worth of stocks, bonds, and other long-term assets.[1] Many of these investors are becoming more concerned with the relationship between climate change and the assets they buy and sell. Some investors have financial concerns about climate change because they think it places certain investments at risk and wish to acquire assets that will do well in a world that is undergoing profound climate change.[2] Other investors consider their investments having a climate impact for ethical reasons. They want to assist climate solutions by funding businesses whose goods operations serve to mitigate the effects of climate change. In contrast, they seek to encourage these companies to consider their impact on the climate more by not investing in those that are the biggest contributors to climate change.[3]

The U.S. Commodity Futures Trading Commission, BlackRock, McKinsey, and an increasing number of other financial organizations have come to the opinion that markets are

[1] Gita Rao and Aaron Krol, “Investing and Climate Change,” Climate Portal, September 21, 2022, https://climate.mit.edu/explainers/investing-and-climate-change.
[2] Rao and Krol, “Investing and Climate Change.”
[3] Rao and Krol, “Investing and Climate Change.”

not adequately identifying and pricing climate change-related risks.[4] A consortium of thirty-nine central banks acknowledged in April 2019 that there is an increasing danger that asset valuations may not fully reflect climate-related financial risks.[5] Central bankers are beginning to question whether they are taking undue risk by merely trusting processes that have not factored in the tremendous danger that is out there, Christine Lagarde noted.[6] Ninety-three percent of institutional investors agree with her, according to a poll, that climate risk has not yet been priced in by all the major financial markets internationally.[7]

The strength of future climate policy will to a great extent be influenced by the results of highly unpredictable national elections. However, there are steps that may be taken by both market participants and government regulators to address the market failure that is currently developing because of the ongoing disregard for exposure to climate-related risks. For instance, it is possible to forecast the net global sea level increase over the next fifteen years with some degree of certainty, but market actors still appear to ignore these predictions when assessing risks to assets.[8]

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[4] Olivia White and Greg Wilson, "A 2021 Risk Agenda for Boards of Directors at U.S. Banks," McKinsey & Company, February 4, 2021, https://www.mckinsey.com/industries/financial-services/our-insights/a-2021-risk-agenda-for-boards-of-directors-at-us-banks.

[5] "Network for Greening the Financial System Has Made a Call for Action to Address Climate Change as a Source of Financial Risk," Green Finance for Latin America and the Caribbean, April 25, 2019, https://greenfinancelac.org/resources/news/the-network-for-greening-the-financial-system-has-made-a-call-for-action-to-address-climate-change-as-a-source-of-financial-risk/.

[6] Carolynn Look, "Lagarde Says ECB Needs to Question Market Neutrality on Climate," Bloomberg, October 14, 2020, https://www.bloomberg.com/news/articles/2020-10-14/lagarde-says-ecb-needs-to-question-market-neutrality-on-climate.

[7] "Climate Change and Artificial Intelligence Seen as Risks to Investment Asset Allocation, Finds New Report by BNY Mellon Investment," Bloomberg, September 16, 2019, https://www.bloomberg.com/press-releases/2019-09-16/climate-change-and-artificial-intelligence-seen-as-risks-to-investment-asset-allocation-finds-new-report-by-bny-mellon-investm.

[8] Brett McDonnell et al., "Green Boardrooms?" *Connecticut Law Review* 53, no. 335 (2021), https://digitalcommons.lib.uconn.edu/law_review/499/.

Companies now confront a variety of new hazards as the effects of climate change become more pronounced. The physical effects of climate change, such as worsening natural disasters from risky flooding and deadly heatwaves, must be addressed by businesses. As states and nations take initiatives to minimize greenhouse gas emissions, they must also adjust to altering consumer preferences and a more complex regulatory environment.

These climate-related hazards put businesses and their investors at risk financially. An international nonprofit organization called CDP (formerly the Carbon Disclosure Project) that focuses on environmental disclosure revealed in a 2019 poll that 215 of the largest global firms were at risk from climate impacts of around $1 trillion.[9] By way of comparison, the total market capitalization of the U.S. stock market at the end of 2022 was about $40.5 trillion.[10]

Financial performance[11] is impacted by a company's preparation for and response to climate risks, and investors are seeking clearer and more comprehensive information so they can make educated choices. For instance, the United Nations-sponsored Principles for Responsible Investment are supported by over 4,000 investment companies that manage over $120 trillion in assets.[12] These signatories, which include major U.S. asset managers BlackRock, Vanguard, State Street, and others, pledge to include environmental, social, and

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[9] *See,* "World's Biggest Companies Face $1 Trillion in Climate Change Risks," CDP, June 4, 2019, https://www.cdp.net/en/articles/media/worlds-biggest-companies-face-1-trillion-in-climate-change-risks.
[10] This figure represents the total market capitalization of all U.S. based public companies listed on the New York Stock Exchange, Nasdaq Stock Market or OTCQX U.S. Market, according to "Total Market Value of the U.S. Stock Market," Siblis Research, 2022, https://siblisresearch.com/data/us-stock-market-value/.
[11] *See, Report on Climate-Related Financial Risk.* Financial Stability Oversight Council, 2021, https://home.treasury.gov/system/files/261/FSOC-Climate-Report.pdf.
[12] *See,* "Principles for Responsible Investment, 2021," United Nations Environment Programme and United Nations Global Compact, https://www.unpri.org/download?ac=10948.

governance (ESG) considerations, such as climate risk, in their investment research and to demand disclosure from the businesses in which they invest.[13]

The SEC in 2022 proposed a regulation requiring companies to disclose information about climate-related risks, such as drought, wildfires, or market shifts, that are likely to influence their business, as well as climate goals or planning processes that the company has developed in response to climate risks. The SEC seeks to provide investors "consistent, comparable, and credible information that is thus decision useful."[14]

3.2 The Role of the Securities and Exchange Commission

The Securities and Exchange Commission (SEC) is the primary regulatory body responsible for overseeing the securities markets in the United States. One of its important functions is to ensure that investors have access to accurate and timely information about companies in which they invest. Given the increasing importance of climate change and its potential impact on the financial performance of companies, the SEC over a decade ago issued guidance on the disclosure of climate-related risks and opportunities in SEC filings.[15]

The 2010 SEC interpretive guidance encouraged companies to provide information about the impacts of climate change on their operations and financial performance. The guidance suggested that companies should disclose information about their greenhouse gas emissions, energy use, and other climate-related impacts, as well as the risks and opportunities associated with climate change. However, this guidance was not mandatory,

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[13] *See*, "BlackRock, Vanguard and State Street Update Corporate Governance and ESG Policies and Priorities for 2022," Gibson Dunn, January 25, 2022, https://www.gibsondunn.com/blackrock-vanguard-and-state-street-update-corporate-governance-and-esg-policies-and-priorities-for-2022/.
[14] "The Enhancement and Standardization of Climate-Related Disclosures for Investors," Securities and Exchange Commission, accessed August 29, 2023, https://www.sec.gov/rules/proposed/2022/33-11042.pdf.
[15] "Commission Guidance Regarding Disclosure Related to Climate Change," Securities and Exchange Commission, accessed August 29, 2023, http://www.sec.gov./rules/interp/2010/33-9106.pdf.

and many companies did not provide the level of detail or specificity that the SEC had recommended.[16]

In response to growing concerns about the lack of information available to investors about the impacts of climate change on companies, the SEC proposed a rule and guidance on climate change disclosure.[17] The new rule when finalized[18] (presumably) will require companies to disclose the potential impact of climate change on their operations and financial performance, including the potential risks and opportunities associated with the transition to a low-carbon economy. Companies are also required to provide information about their greenhouse gas emissions, energy use, and other climate-related impacts, as well as their risk management strategies for dealing with climate change.[19]

SEC Commissioner Caroline A. Crenshaw claims that the Proposed Rule is a response to the market's current trends.[20] Some companies are already making environmental claims to customers, disclosing climate-related risks in reports, and pursuing emissions reduction strategies. This rule seeks to standardize and enhance those efforts across public companies by establishing clear requirements. She points out that two-thirds of the S&P 500

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[16] "Commission Guidance Regarding Disclosure."

[17] "Proposed Rule: The Enhancement and Standardization of Climate-Related Disclosures for Investors." The Daily Journal of the United States Government. Securities and Exchange Commission, April 11, 2022, https://www.federalregister.gov/documents/2022/04/11/2022-06342/the-enhancement-and-standardization-of-climate-related-disclosures-for-investors, 87 Fed. Reg. 21334, (April 11, 2022) (to be codified at 17 CFR Parts 210, 229, 232, 239, 249).

[18] On January 4, 2023, the United States Securities and Exchange Commission updated its 2023 rule-making agenda, setting April 2023 for release of its final climate-related disclosure rule.

[19] Exchange Act Release No. 94478, "Proposed Rule: The Enhancement and Standardization of Climate-Related Disclosures for Investors," U.S. Securities and Exchange Commission, March 21, 2022, https://www.sec.gov/rules/2022/03/enhancement-and-standardization-climate-related-disclosures-investors.

[20] "Statement by Commissioner Crenshaw on Proposed Mandatory Climate Risk Disclosure," Harvard Law School Forum on Corporate Governance, March 22, 2022, https://corpgov.law.harvard.edu/2022/03/22/statement-by-commissioner-crenshaw-on-proposed-mandatory-climate-risk-disclosures/.

companies have set a target for carbon emissions, and between 2019 and 2020, 33% of all annual reports filed by public corporations included disclosure connected to climate.[21]

The existential threat posed by climate change to human and natural environments is one of its many manifestations. Climate change affects the physical environment, but it also has an economic impact that necessitates significant adaptation from businesses across the economy.[22] The phrase ". . . the biggest economic transformation since the Industrial Revolution,"[23] accurately describes the impending change. Without taking any action, estimates indicate that by 2050, climate change will have significantly reduced the global GDP.[24]

The economic impacts of climate change and the necessary adaptive measures, despite their relevance, are still poorly understood since there is insufficient data at the level of individual enterprises.[25] Importantly, these economic effects and the requirement for economic adaptation are independent of issues that may still be up for discussion in some circles, such as the extent to which human activity is to blame for climate change and whether or not its environmental effects can be slowed down or reversed.[26]

The proposed SEC rule was well-received by the market, and many participants were eager to discuss some of its technical specifics, which, like any initial regulatory release,

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[21] Nicole Sullivan, "Unpacking the 490-Page Proposed SEC Climate Disclosure Rule," Carbon Better, December 1, 2022, https://carbonbetter.com/story/sec-climate-disclosure/.
[22] *See, e.g.,* Renee Cho, "How Climate Change Impacts the Economy," Columbia Climate School: State of the Planet, June 20, 2019, https://news.climate.columbia.edu/2019/06/20/climate-change-economy-impacts/.
[23] *See*, Ben Geman and Andrew Freedman, "Climate Spending Is a Story of the Century," AXIOS, April 9, 2021, https://www.axios.com/2021/04/09/climate-spending-century-investment.
[24] *See*, "The Economics of Climate Change," Swiss Re Institute, April 22, 2021, https://www.swissre.com/institute/research/topics-and-risk-dialogues/climate-and-natural-catastrophe-risk/expertise-publication-economics-of-climate-change.html.
[25] *See, e.g.,* Emma Cox, "See Your Climate Blind Spots," World Economic Forum Annual Meeting, May 25, 2022, https://www.weforum.org/agenda/2022/05/see-your-climate-blind-spots/ (highlighting relevant evidence).
[26] *See, e.g.,* Kevin Anderson and Jessica Jewell, "Debating the Bedrock of Climate-Change Mitigation Scenarios," *Nature*, September 16, 2019, https://www.nature.com/articles/d41586-019-02744-9.

could use some fine-tuning during the notice-and-comment rulemaking process. Surprisingly, though, a few opponents also opted to criticize the SEC's choice to pursue a climate disclosure regulation.[27] They did not want to change the rule; instead, they wanted to get the SEC to drop it either directly or through public pressure.[28] Many of these objections have already begun to surface soon after the SEC launched the climate disclosure project in 2021.

Forecasting macroeconomic energy demand, making educated guesses about the efficacy of carbon regulation, and emerging technologies, modeling the relationship between atmospheric gas concentrations and global temperatures, projecting how a rise in temperature will alter the earth's climate systems, and calculating how those changes will affect tangible economic assets are all part of evaluating climate risk.

The endeavor calls for abilities beyond those of a standard financial analyst primarily because of the vast quantities of data, and models that are still being developed. Risk projections become more questionable with each step of the estimation process. The calculation of the economic impact of climate change may occasionally be overshadowed by this uncertainty, especially in circumstances that are longer-term and macroeconomic.[29]

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[27] SEC Chair Gary Gensler said, "Our core bargain from the 1930s is that investors get to decide which risks to take, as long as public companies provide full and fair disclosure and are truthful in those disclosures. Today, investors representing literally tens of trillions of dollars support climate-related disclosures because they recognize that climate risks can pose significant financial risks to companies, and investors need reliable information about climate risks to make informed investment decisions. Today's proposal would help issuers more efficiently and effectively disclose these risks and meet investor demand, as many issuers already seek to do. Companies and investors alike would benefit from the clear rules of the road proposed in this release. I believe the SEC has a role to play when there's this level of demand for consistent and comparable information that may affect financial performance. Today's proposal thus is driven by the needs of investors and issuers." "SEC Proposes Rules to Enhance and Standardize Climate-Related Disclosures for Investors," U.S. Securities and Exchange Commission, March 21, 2022, https://www.sec.gov/news/press-release/2022-46.

[28] *See*, "U.S. Chamber Comments on SEC's Proposed Rule on Mandatory Climate Disclosures," U.S. Chamber of Commerce, June 16, 2022, https://www.uschamber.com/finance/u-s-chamber-comments-on-secs-proposed-rule-on-mandatory-climate-disclosures.

[29] *See*, Patrick Bolton et al., "The Green Swan: Central Banking and Financial Stability in the Age of Climate Change," Banque de France, January 2020, https://www.bis.org/publ/othp31.pdf.

Investors can only value risks that they are aware of, and there has been growing attention to the lack of disclosure of climate-related risks, which keeps investors in the dark. The financial industry estimates of the economy-wide effects of climate change, which range broadly from $4.2 to $43 trillion,[30] and the total impacts stated by individual corporations in their financial reporting, differ significantly. According to a recent study, top-down forecasts of costs to financial assets were at least two orders of magnitude more than the entire value of aggregated financial risk declared through both voluntary and mandated business disclosures, which was only tens of billions of dollars.[31] Public enterprises should prepare for losses from climate change of nearly $3 trillion over the course of the next 15 years, according to the UN Finance Initiative.[32]

The recent wildfires in California are one recent instance of this under-assessed and unreported climate danger. 2018 saw Pacific Gas and Electric (PG&E) proactively inform the non-profit CDP of its climate-related risks.[33] The business identified wildfire risk increases brought on by climate change as a possible liability and predicted 2017 claim payouts of $2.5 billion.[34] When PG&E revealed in January 2019 that company was declaring bankruptcy and

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[30] "The Cost of Inaction: Recognizing the Value at Risk from Climate Change," The Economist Intelligence Unit, accessed August 29, 2023, https://impact.economist.com/perspectives/sites/default/files/The%20cost%20of%20inaction_0.pdf. (reporting $43 trillion loss at high end of loss estimates, under 6°C of warming, which current consensus suggests we will not reach anytime in the next century).

[31] Allie Goldstein et al., "The Private Sector's Climate Change Risk and Adaptation Blind Spots," *Nature Climate Change*, 9 (December 10, 2019): 18–25, https://www.nature.com/articles/s41558-018-0340-5.

[32] *Climate-related Risk Drivers and their Transmission Channels.* Basel Committee on Banking Supervision. Bank for International Settlements, April 2021. https://www.bis.org/bcbs/publ/d517.pdf. (Modeling a market portfolio of 30,000 companies and calculating value at risk, using a 15-year horizon under a scenario where warming is limited to 2°).

[33] "Climate Change Response 2018," Climate Disclosure Project, PG&E Corporation, https://www.pgecorp.com/corp_responsibility/reports/2018/assets/PGE_CDP_Climate_Change_Response_2018.pdf.

[34] Brad Plumer, "Companies See Climate Change Hitting Their Bottom Lines in the Next 5 Years," *New York Times*, June 4, 2019, https://www.nytimes.com/2019/06/04/climate/companies-climate-change-financial-impact.html.

would be responsible for $30 billion in liabilities related to wildfires, any investor who had relied on this information to be a fair predictor of future liability would have been extremely disappointed.[35] Over eighty percent of PG&E's share price was lost in just two months.[36]

Damages from climate change are anticipated to affect the economy far more broadly than what the average investor may assume from reading the financial news in the mainstream media. Warmer days lead to decreased labor productivity,[37] an increase in infectious diseases,[38] and a reduction in the efficiency of energy transfer.[39] And yet, more than one thousand American manufacturing companies claim they do not expect any risks due to climate change when voluntarily disclosing their environmental risks to CDP.[40]

According to a recent study by the Brookings Institution, municipalities subject to increased physical risk often fail to disclose this risk in their municipal bond disclosures.[41] Recent studies have brought attention to the rising, but still mostly unforeseen, possibility of simultaneous temperature- and weather-induced crop failures in important breadbaskets

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[35] Russell Gold, "PG&E: The First Climate-Change Bankruptcy, Probably Not the Last," *Wall Street Journal,* January 18, 2019, https://www.wsj.com/articles/pg-e-wildfires-and-the-first-climate-change-bankruptcy-11547820006.

[36] Gold, "PG&E: The First Climate Change Bankruptcy."

[37] *See,* Tord Kjellstrom et al., "The Direct Impact of Climate Change on Regional Labor Productivity," *Archive Environmental Occupational Health,* Winter 64, no. 4 (2009): 217–27, https://pubmed.ncbi.nlm.nih.gov/20007118/ (concluding that "[w]orkers may need to work longer hours, or more workers may be required, to achieve the same output and there will be economic costs of lost production and/or occupational health interventions against heat exposures").

[38] *See,* Arthur Wyns, "Climate Change and Infectious Disease," *Scientific American,* April 9, 2020, https://blogs.scientificamerican.com/observations/climate-change-and-infectious-diseases/.

[39] Matthew Bartos et al., "Impacts of Rising Air Temperatures on Electric Transmission Ampacity and Peak Electricity Load in the United States," IOP Science, Environmental Research Letters, https://iopscience.iop.org/article/10.1088/1748-9326/11/11/114008. ("As atmospheric carbon concentrations increase, higher ambient air temperatures may strain power infrastructure by simultaneously reducing transmission capacity and increasing peak electricity load.")

[40] "Major Risk or Rosy Opportunity: Are Companies Ready for Climate Change?" CDP, 2019, https://www.cdp.net/en/research/global-reports/global-climate-change-report-2018/climate-report-risks-and-opportunities. (Showing that 1,041 manufacturing companies report no climate-related risk [as compared to 300 reporting physical risks, 326 reporting transition risks, and 472 reporting both]).

[41] Parker Bolstad et al., "Flying Blind: What Do Investors Really Know about Climate Change Risks in the U.S. Equity and Municipal Debt Markets?" Hutchins Center Working Paper #67, September 2020, https://www.brookings.edu/wp-content/uploads/2020/09/WP67_Victor-et-al.pdf.

around the world.[42] This possibility for unanticipated climate risk correlation and its similarity to the 2008 mortgage crisis have been referenced by Lael Brainard, a board member of the Federal Reserve's Governing Board.[43]

In a recent study, 439 institutional investors were asked to rate the risks associated with climate change.[44] Only 10 percent of respondents rank it as their top concern, compared with standard financial and operating risks. The opinions of the ninety percent of those polled conflict not just with scientific predictions but also with the allocations of their own portfolios, the majority of which contain fossil fuel assets that, if valued correctly, are consistent with a future that would warm by at least 3°C.[45]

Voluntary reporting frameworks are not a fix for the issue of insufficient climate risk disclosures. Companies can pick and choose which reporting frameworks, or categories of risk within those frameworks, they disclose in the absence of regulation and uniformity. This is especially clear in the fossil fuel firms' voluntary disclosure to CDP, which reports the existence of abundant opportunities and few risks from climate change.[46] As of 2018, fewer than four of the eleven suggested disclosure indicators under the Task Force on Climate-Related Disclosures (TCFD) were given by the average voluntarily complying company.[47]

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[42] Andrew Freedman, "Extreme Weather Patterns are Raising the Risk of a Global Food Crisis, and Climate Change Will Make This Worse," *Washington Post,* December 9, 2019, https://www.washingtonpost.com/weather/2019/12/09/extreme-weather-patterns-are-raising-risk-global-food-crisis-climate-change-will-make-this-worse.

[43] Lael Brainard, "Why Climate Change Matters for Monetary Policy and Financial Stability," Address at the Federal Reserve Bank of San Francisco's The Economics of Climate Change Research Conference (November 8, 2019). Transcript available in the Board of Governors of the Federal Reserve System.

[44] *See,* "Wall Street Investors React to Climate Change," UT News, Feb 17, 2020, https://news.utexas.edu/2020/02/17/wall-street-investors-react-to-climate-change/.

[45] Alastair Marsh, "'Portfolio Warming' Is the New Climate Anxiety for Fund Managers," Bloomberg, February 23, 2021, https://www.bloomberg.com/news/features/2021-02-23/climate-change-s-impact-on-portfolios-is-axa-s-mega-investors-new-anxiety.

[46] *Major Risk or Rosy Opportunity: Are Companies Ready for Climate Change?*

[47] *Task Force On Climate-Related Financial Disclosures, 2019 Status Report 7.* Task Force On Climate-Related Financial Disclosures, 2019, https://www.fsb.org/wp-content/uploads/P050619.pdf. ("[O]nly around 25% of

Only nine percent of businesses have talked about the adaptability of their business models to climate change, indicating that they have been particularly sluggish to use scenario analysis and discuss operational risk related to climate change.[48] Furthermore, disclosures tend to focus on transition risks much more than they do on physical dangers.[49] These voluntary disclosures are still not standardized, making it challenging for stakeholders to evaluate and contrast them across different businesses.[50] A substantial number of businesses ignore climate risk disclosure requirements or other voluntary frameworks. Many of the S&P 500 companies also do not disclose their own (Scope 1) emissions.[51]

The systemic character of the risk itself is one harm that results from the failure to evaluate climate risk.[52] Academics and regulators have mostly studied the systemic aspect of climate risk in terms of its potential to lead to a chain reaction of financial disasters.[53] If the financial sector's reluctance to take climate risk into account has really led to overvaluation of some industrial stocks, the market may gradually correct the mispricing in a sluggish price decrease as it takes fresh facts into account. Or the market could abruptly correct, setting off a series of events that ripple through the financial sector.

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companies disclosed information aligned with more than five out of the 11 recommend disclosures and only 4% of companies disclosed information aligned with at least 10 of the recommended disclosures.").

48 *Task Force On Climate-Related Financial Disclosures, 2019 Status Report 7,* vi.

49 Editorial Board, "Labor vs. the ESG Racket," *Wall Street Journal,* November 15, 2020, https://www.wsj.com/articles/labor-vs-the-esg-racket-11605482618.

50 Virginia Harper Ho, "Modernizing ESG Disclosure," *University of Illinois Law Review,* 277 (June 6, 2022), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3845145.

51 "How Much Can Financiers Do about Climate Change?" *The Economist,* June 20, 2020, https://www.economist.com/briefing/2020/06/20/how-much-can-financiers-do-about-climate-change.

52 *See,* Kern Alexander, Rahul Dhumale, and John Eatwell, "Global Governance of Financial Systems: The International Regulation of Systematic Risk," Oxford University Press, September 8, 2005, https://global.oup.com/academic/product/global-governance-of-financial-systems-9780195166989?cc=us&lang=en& (stating that bank runs and currency collapses can be caused by networked individual financial actors taking on too much risk, and that these "extra costs of risk" can be pushed onto society at large as a negative externality).

53 Mark Carney, "Resolving the Climate Paradox: Remarks at the Arthur Burns Memorial Lecture in Berlin," September 22, 2016, https://www.bis.org/review/r160926h.pdf (transcript available in the Bank of England online) ("Minsky moment").

The likelihood of a significant and abrupt realignment, sometimes known as a bubble collapse, increases when asset prices diverge further from fundamentals.[54] Six percent of the typical investment fund's equity interests are in the fossil fuel industry, according to a recently released "climate stress test of the financial system," and another 36% are in "climate-policy sensitive" industries including utilities, mining, housing, and transportation.[55] The amount of unaccounted risk builds up at the portfolio level if each of these industries has not evaluated and disclosed their exposure to climate risk.

3.3 Reporting of Emissions

Under the proposed SEC disclosure rule, an issuer must consider (1) direct output, (2) energy purchases, and (3) downstream usage to determine a company's true impact on climate change and more particularly emissions of greenhouse gases, such as hydrofluorocarbons[56] (HFCs), water vapor, methane, ozone, carbon dioxide, and nitrous oxide. Direct emissions, also referred to as Scope 1 emissions, are typically measured using a source test, which measures a gas stream over a short interval, or through continuous emissions monitoring, which measures a gas stream over an extended period of time, such as smokestacks atop manufacturing facilities or heavy industrial sites.[57]

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[54] Raghuram G. Rajan, "Has Financial Development Made the World Riskier?" National Bureau of Economic Research, Working Paper No. 11728 (November 2005): 1, 21–3, 25, https://www.nber.org/system/files/working_papers/w11728/w11728.pdf.

[55] Stefano Battiston et al., "A Climate Stress-test of the Financial System," *Nature Climate Change* 7 (2017): 283–4, https://www.nature.com/articles/nclimate3255.

[56] HFCs are "fluorinated chemicals commonly used as replacements for ozone-depleting substances in applications such as air conditioning, refrigeration, fire suppression, solvents, foam blowing agents, and aerosols. HFCs are highly potent greenhouse gasses with global warming potentials that can be hundreds to thousands of times greater than carbon dioxide (CO2)." "Climate Change Regulatory Actions and Initiatives," U.S. Environmental Protection Agency, last updated June 11, 2022, https://www.epa.gov/climate-change/regulatory-actions-and-initiatives#Findings. HFCs are the subject of the American Innovation and Manufacturing Act of 2020, which resulted in an EPA rule that seeks to decrease production and consumption of HFCs by 85% by 2035. American Innovation and Manufacturing Act of 2020, 42 U.S.C. § 7675.

[57] "Managing Air Quality—Emissions Measurement," U.S. EPA, last updated November 7, 2022, https://www.epa.gov/air-quality-management-process/managing-air-quality-emissions-measurement.

A source test has the drawback of frequently missing leaks or non-point source emissions.[58] When using source testing and predictive modeling, however, emissions can be understated.[59] Second, emissions from energy purchases, or Scope 2 emissions, rely on data made available by power companies, which has the same flaws as statistics on direct emissions.[60] Third, it is more challenging to evaluate and quantify Scope 3 emissions[61], which are downstream uses like supply chains and customers.[62]

Consider a refinery as an illustration to help put these three scopes into perspective. To start, the facility would document the emissions that its processes directly manage. Scope 1 emissions would be those coming from, for example, the fluid catalytic cracking units. The refinery would then have to think about the energy needed to run its operations, its Scope 2 emissions, and get in touch with the power company to find out what these emissions are. The refinery would also need to calculate emissions from sources it does not own or control, like any tanker trucks used to carry its refined fuels, employee commutes, and downstream waste as well as emissions from sources throughout its supply chain.

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[58] Clay S. Bell, Timothy L. Vaughn, and Daniel J. Zimmerle, "Evaluation of Next Generation Emission Measurement Technologies Under Repeatable Test Protocols," *Elementa: Science of the Anthropocene* 8, no. 1 (January 1, 2020), https://www.semanticscholar.org/paper/Evaluation-of-next-generation-emission-measurement-Bell-Vaughn/094678da307583931e4b2cdbfea75ba851325d18.

[59] *See, e.g.*, Maggie Astor, "Methane Leaks in New Mexico Far Exceed Current Estimates, Study Suggests," *New York Times*, March 24, 2022, https://www.nytimes.com/2022/03/24/climate/methane-leaks-new-mexico.html?smid=url-share.

[60] Jocelyn C. Turnbull et al., "Independent Evaluation of Point Source Fossil Fuel CO_2 Emissions to Better than 10%." *Proceedings of the National Academies of Science*, 113, no. 37 (August 29, 2016): 10287–91, https://doi.org/10.1073/pnas.160282411. (Demonstrating the necessity of independent emissions analyses to determine the veracity or falsity of self-reported emissions data.)

[61] Edgar G. Hertwich and Richard Wood, "The Growing Importance of Scope 3 Greenhouse Gas Emissions from Industry," IOP Science, Environmental Research Letters, October 5, 2018, https://iopscience.iop.org/article/10.1088/1748-9326/aae19a. (Stating that direct emissions are known as scope 1; emissions from energy are known as scope 2; and value-chain emissions are known as scope 3.)

[62] Gireesh Shrimali, "Scope 3 Emissions: Measurement and Management," Stanford University Working Paper, April 2021, https://sfi.stanford.edu/publications/risk-metrics-and-management/scope-3-emissions-measurement-and-management. (Showing why scope 3 emissions have not been a major historical focus for emissions calculations.).

Additionally, the Proposed Rule seeks to make Scope 3 emissions disclosure mandatory, but only for the biggest issuers and after an on-ramp period. Scope 3 disclosure would enable an evaluation of progress towards GHG reduction targets and give investors a more thorough understanding of a company's strategy, perhaps lowering the danger of greenwashing. As stated in the Proposed Rule:

Scope 3 emissions disclosures would help investors to understand and assess the registrant's strategy. For example, Scope 3 emissions disclosures would allow an investor to better understand how feasible it would be for the registrant to achieve its targets through its current strategy, to track the registrant's progress over time, and to understand changes the registrant may make to its strategy, targets, or goals. Scope 3 emissions disclosures would thus be important to evaluating the financial effects of the registrant's target or goal. In addition, this disclosure could help prevent instances of greenwashing or other misleading claims concerning the potential impact of Scope 3 emissions on a registrant's business because investors, and the market would have access to a quantifiable, trackable metric.[63]

The information was needed to evaluate any financial or business consequences to the company, which was the main point of the narrative explanation for the requirement. A registrant with significant Scope 3 emissions may incur greater costs when procuring essential inputs if policy changes result in required emissions cuts. A registrant might experience a major change in demand for its products if consumer attitudes shift to favor less carbon-intensive products. Registrants that ignore these risks or choose unfavorable actions to address them risk becoming less profitable in the long run than registrants who recognize these risks and successfully address them.

[63] "The Enhancement and Standardization of Climate-Related Disclosures for Investors."

The potential financial risks a company may face because of any transition to a lower carbon economy may thus be better communicated to investors through Scope 3 emissions disclosure. Investors might examine how GHG emissions affect the registrant's operations and overall company strategy in conjunction with reported financial information if Scope 3 information was published. This would enable them to make more educated investment or voting decisions.[64]

With smaller reporting entities excluded, the SEC recommended requiring disclosure for larger issuers. For expedited and large accelerated filers, disclosure would be necessary "if material" or if the business has set Scope 3 emission reduction plans or goals.[65] Emissions from "outsourced activities that it previously conducted as part of its own operations" were to be taken into account when establishing materiality for issuers.[66] The Proposed Rule implied the requirement for an explanation if it was regarded irrelevant overall[67] or with regard to specific categories.[68]

The Proposed Rule would require more detailed information after Scope 3 disclosure has been triggered. The breakdown of Scope 3 emissions into categories of upstream and downstream activities would be necessary. The Scope 3 emissions would need to be listed

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[64] "The Enhancement and Standardization of Climate-Related Disclosures for Investors" at 21379.
[65] Exchange Act Release No. 94478, "Proposed Rule: The Enhancement and Standardization of Climate-Related Disclosures for Investors," U.S. Securities and Exchange Commission, March 21, 2022, https://www.sec.gov/rules/2022/03/enhancement-and-standardization-climate-related-disclosures-investors. ("This latter proposed disclosure requirement could assist investors in tracking the progress of the registrant toward reaching the target or goal so that investors can better understand potential associated costs.")
66 Proposed Item § 229.1504(c)(8). "Proposed Rule: The Enhancement and Standardization of Climate-Related Disclosures for Investors"; see also Exchange Act Release No. 94478 (Mar. 21, 2022) ("This proposed approach, which is consistent with the GHG Protocol, would help ensure that investors receive a complete picture of a registrant's carbon footprint by precluding the registrant from excluding emissions from activities that are typically conducted as part of operations over which it has ownership or control but that are outsourced in order to reduce its Scopes 1 or 2 emissions.")
[67] Exchange Act Release No. 94478 (Mar. 21, 2022). ("If a registrant determines that its Scope 3 emissions are not material, and therefore not subject to disclosure, it may be useful to investors to understand the basis for that determination.")
[68] Exchange Act Release No. 94478 (Mar. 21, 2022).

separately for each category and identified. Under the Proposed Rule an energy firm that manufactures oil and gas products might discover that the final usage of its sold products falls under a sizable category of activity causing Scope 3 emissions. A producer may discover that a sizable group of activities contributing to Scope 3 emissions are related to the emissions produced by its suppliers during the processing of its sold products, the production of goods or services it has purchased, or the fuel used by its third-party transporters and distributors of those goods and services and of its sold products.[69]

For "significant" categories of upstream or downstream activities, Scope 3 emissions are to be separately disclosed. Upstream activities can include emissions generated from, purchased goods and services; capital goods; fuel and energy-related activities not included in Scope 1 or Scope 2 emissions; transportation and distribution of purchased goods, raw materials, and other inputs; waste generated in a registrant's operations; business travel by a registrant's employees; employee commuting by a registrant's employees; and a registrant's leased assets related principally to purchased or acquired goods or services.

The Proposed Rule also gave several examples of downstream activities that could generate Scope 3 emissions. These included, transportation and distribution of a registrant's sold products, goods, or other outputs; processing by a third party of a registrant's sold products; use by a third party of a registrant's sold products; end-of-life treatment by a third party of a registrant's sold products; a registrant's leased assets related principally to the sale or disposition of goods or services; a registrant's franchises; and investments by a registrant.[70]

[69] "The Enhancement and Standardization of Climate-Related Disclosures for Investors."
[70] The proposal recognized the overlapping nature of the categories and would require issuers "to use their best judgment" in making the determinations. *See,* Exchange Act Release No. 94478 (Mar. 21, 2022). ("In some

The sources of data, including emissions from people along the "value chain," and if the data was verified, are to be disclosed as well. Both upstream (the production process) and downstream (activities by end consumers) activities are included in the value chain.[71] The idea allowed for the possibility of data coming from "economic research, published databases, government statistics, industry groups, or other third-party sources," in addition to sources inside the value chain.[72]

Even though the data were obtained from outside sources, the Proposed Rule makes clear that the issuer still had some degree of control and potential impact on Scope 3 emissions. A registrant may not own or control the operational activities in its value chain that result in Scope 3 emissions, but it is still possible for it to have an impact on those activities. For instance, it may work with its suppliers and downstream distributors to take actions to lower those entities' Scopes 1 and 2 emissions (and thereby help lower the registrant's Scope 3 emissions) and any associated risks. As a result, a registrant may be able to lessen the difficulties associated with gathering the information necessary for Scope 3

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cases, the category in which an emissions source belongs may be unclear, or the source might fit within more than one category. In those cases, registrants would need to use their best judgment as to the description of the emissions source and provide sufficient transparency as to the reasoning and methodology to facilitate investor understanding of the emissions category and source.")

[71] Exchange Act Release No. 94478, n. 440 (Mar. 21, 2022). ("The proposed rules would define a registrant's value chain to mean the upstream and downstream activities related to a registrant's operations. Upstream activities include activities that relate to the initial stages of producing a good or service [e.g., materials sourcing, materials processing, and supplier activities]. Downstream activities include activities that relate to processing materials into a finished product and delivering it or providing a service to the end user [e.g., transportation and distribution, processing of sold products, use of sold products, end of life treatment of sold products, and investments].")

[72] *See*, Exchange Act Release No. 94478, n. 440 (Mar. 21, 2022). (Proposing to define "value chain" as upstream and downstream activities related to a registrant's operations. Upstream activities in connection with a value chain may include activities by a party other than the registrant that relate to the initial stages of a registrant's production of a good or service [e.g., materials sourcing, materials processing, and supplier activities]. Downstream activities in connection with a value chain may include activities by a party other than the registrant that relate to processing materials into a finished product and delivering it or providing a service to the end user [e.g., transportation and distribution, processing of sold products, use of sold products, end of life treatment of sold products, and investments].")

disclosure. A registrant's Scope 3 emissions may change over time, and this information may help investors understand how the registrant is addressing transition risk.

Additionally, the Proposed Rule provides several illustrations of how the control might be used to lower Scope 3 emissions. Compared to the emissions from producing the cars, the great bulk of the GHG emissions footprint of car manufacturers comes from the tailpipe emissions of the vehicles that customers drive. Through the passage of higher fuel efficiency rules and by government programs that promote the production and demand for electric vehicles, a transition to reduce tailpipe emissions is already under way. Leading automakers have declared their intentions to increase the production of electric vehicles in response to rising demand for them both domestically and internationally. Many have also made commitments to produce all-electric fleets or attain net-zero emissions.

Automobile manufacturers now face greater financial risks, which are partially reflected in their Scope 3 emissions. Investors can evaluate if a specific manufacturer is taking action to reduce or adapt to the risks posed by a switch to lower emission vehicles using Scope 3 emissions data on a car manufacturer's suppliers and the use of its supplied products.[73]

Financial hazards for businesses might arise from modifications in institutional investors' and financial institutions' criteria. To develop portfolios that will help them achieve their goals, as more financial institutions and investors start to set their own GHG

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[73] Exchange Act Release No. 94478, n. 440 (Mar. 21, 2022). ("For example, a registrant could seek to reduce the potential impacts on its business of its upstream emissions by choosing to purchase from more GHG emission-efficient suppliers or by working with existing suppliers to reduce emissions. A registrant could also seek to reduce the potential impacts on its business of downstream emissions by producing products that are more energy efficient or involve less GHG emissions when consumers use them, or by contracting with distributors that use shorter transportation routes. Being able to compare Scope 3 emissions over time could thus be a valuable tool for investors in tracking a registrant's progress in mitigating transition and other climate-related risks.")

emissions reduction targets, they may consider the entire GHG emissions footprint of the businesses they finance or invest in. Financial institutions and investors may concentrate on Scopes 1 and 2 emissions for businesses in select sectors, especially in sectors where Scopes 1 and 2 account for the bulk of businesses' overall GHG emissions footprint.

As a result, Scope 3 emissions may provide a more accurate picture of a company's exposure to transition risks than Scopes 1 and 2 emissions alone in other industries where they account for a sizeable amount of a company's overall GHG footprint. For example, Scope 3 emissions from the production of oil and gas products are likely to be significant and hence essential to comprehending the risks associated with climate change for a registrant.

Finally, disclosure of Scope 3 also has the potential to shed light on initiatives to outsource emissions reduction under Scope 1 and 2. Instances where a registrant tries to cut its overall Scope 1 and 2 emissions by outsourcing carbon-intensive activities may also be brought to light by the disclosure of Scope 3 emissions.

To have fewer Scope 1 or 2 emissions than a comparable company that has retained direct ownership and control over more of its production operations, a registrant, for instance, could contract out a few high-emission manufacturing activities. As a result, Scope 3 emissions reporting might increase transparency and aid in preventing any attempts by registrants to hide from investors the entire extent of the climate-related risks connected to their GHG emissions.

The Proposed Rule contains a safe harbor provision for disclosure pertaining to Scope 3 emissions because of the calculation's unique[74] and difficult[75] requirements as well as the

[74] Exchange Act Release No. 94478, n. 440 (Mar. 21, 2022). ("We acknowledge that a registrant's material Scope 3 emissions is a relatively new type of metric, based largely on third-party data, that we have not previously required. We are proposing the disclosure of this metric because we believe capital markets have

additional difficulty in gathering data for Scope 3 emissions.[76] If a claim about Scope 3 emissions is made without a reasonable basis or was disclosed other than in good faith, it will be regarded as fraudulent.[77] Any declaration made on Scope 3 emissions in a document filed with the Commission is covered by the safe harbor. The safe harbor was created to mitigate liability related to emissions that were "based on third-party knowledge."[78]

The Proposed Rule staggers Scope 3 reporting compliance, giving companies considerable time to discern how they want to comply with the reporting requirements. The Proposed Rule offers an extra year before requiring reporting of Scope 3 emissions for these types of emissions. The first Scope 3 emission disclosures are required by the Proposed Rule for Large Accelerated Filers in 2025 (filing for FY 2024), and for Accelerated and Non-Accelerated Filers in 2026 (filing for FY 2025), even though the Proposed Rule sets the earliest compliance requirements for 2024 (filing for FY 2023).

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begun to assign financial value to this type of metric, such that it can be material information for investors about financial risks facing a company. Scope 3 emissions disclosure is an integral part of both the TCFD framework and the GHG Protocol, which are widely accepted.")

[75] Exchange Act Release No. 94478, n. 440 (Mar. 21, 2022). ("We also recognize, as discussed below, that the reporting of Scope 3 emissions may present more challenges than the reporting of Scopes 1 and 2 emissions. But in light of the fact that a GHG emissions reporting regime may be incomplete without the reporting of Scope 3 emissions, we are proposing to include them, with an appropriate transition period and safe harbor, at the outset.")

[76] Exchange Act Release No. 94478, n. 440 (Mar. 21, 2022). ("Unlike Scopes 1 and 2 emissions, Scope 3 emissions typically result from the activities of third parties in a registrant's value chain and thus collecting the appropriate data and calculating these emissions would potentially be more difficult than for Scopes 1 and 2 emissions.")

[77] The definition was, in all material respects, lifted from the safe harbor in Rule 175. *See*, 17 C.F.R. § 230.175(d) ("For the purpose of this paragraph (f), the term fraudulent statement shall mean a statement that is an untrue statement of material fact, a statement false or misleading with respect to any material fact, an omission to state a material fact necessary to make a statement not misleading, or that constitutes the employment of a manipulative, deceptive, or fraudulent device, contrivance, scheme, transaction, act, practice, course of business, or an artifice to defraud as those terms are used in the Securities Act of 1933 or the Securities Exchange Act of 1934 or the rules or regulations promulgated thereunder.")

[78] Exchange Act Release No. 94478 (Mar. 21, 2022) ("It also may encourage more robust Scope 3 emissions information, to the extent registrants feel reassured about relying on actual third-party data as opposed to national or industry averages for their emissions estimates.")

3.4 Conclusion

Insofar as it closely resembles the Proposed Rule, the SEC's final rule will probably be challenged under the Administrative Procedure Act.[79] The Scope 3 disclosures could be one reason for a challenge. Industry organizations will probably attempt to have the rule suspended pending litigation by claiming that the SEC can only mandate disclosure of "material" emissions and that any reporting related to Scope 3 disclosures falls outside of that authority. A Louisiana federal district court issued a preliminary injunction,[80] prohibiting the use of the Biden Administration's social cost of carbon figure,[81] so it is possible that a court would be sympathetic to an argument that the public interest and balance of equities weigh in favor of granting an injunction if such a challenge is raised.

The SEC's Proposed Rule builds on the initiatives of other federal regulators that have already made progress in identifying and evaluating the risks that climate change poses to the U.S. financial markets. The U.S. Commodity Futures Trading Commission ("CFTC") released a report titled *Managing Climate Risk in the U.S. Financial System*[82] in the fall of 2020, and in 2021 it established a Climate Risk unit within the CFTC. Currently, the CFTC only mandates very limited disclosures from the businesses it regulates, but it is anticipated

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[79] Administrative Procedure Act, 5 U.S.C. § 551 et seq. (1946).
[80] *State of Louisiana v. Joseph R. Biden* (W.D., Louisiana), Case No. 2:21-cv-01074-JDC-KK, March 10, 2022.
[81] President Biden issued an Executive Order last year instructing federal agencies to charge carbon dioxide emissions at roughly $51 per ton (the Trump administration had lowered the fee to about $7 per ton). Ten states filed a lawsuit in Louisiana district court contesting the social cost of carbon estimate used by the Biden administration, claiming that the Executive Order did not follow the correct administrative procedure requirements. The Biden Administration's assessment is not to be used, according to a preliminary injunction imposed by the court. The injunction affects all government agencies and has a broad scope. It is anticipated that the Fifth Circuit will reject the lower court's injunction on appeal, and the Supreme Court will hear this matter.
[82] "Managing Climate Risk in the U.S. Financial System," *Report of the Climate-Related Market Risk Sub-Committee Mark Advisory Committee of the U.S. Commodity Futures Trading Commission,* September 15, 2020, https://www.cftc.gov/sites/default/files/2020-09/9-9-20%20Report%20of%20the%20Subcommittee%20on%20Climate-Related%20Market%20Risk%20-%20Managing%20Climate%20Risk%20in%20the%20U.S.%20Financial%20System%20for%20posting.pdf.

that the report's findings and the SEC's Proposed Rule will lead to more thorough climate risk disclosures in the markets for commodities and commodity derivatives. Additionally, the Federal Reserve Board, the Financial Stability Oversight Council, the Federal Housing Financing Agency, and the Federal Insurance Office of the Treasury Department are putting the finishing touches on the practical measures required to evaluate, mitigate, and be ready for climate change risks.

The Proposed Rule marks a significant turning point. The Proposed Rule establishes a higher bar for compliance, but the mindset and strategy must go farther. Intentional enterprise redesign, or "green sheeting" businesses from top to bottom, needs to be embraced by leaders, and it needs to happen quickly. To attain net zero in the timeframe most individuals have committed will take a lot of problem-solving. From the standpoint of the earth, the years between now and 2030 are crucial, and what is done in those years will be critically important.

While many companies are aggressively attempting to address climate change as part of their environmental, social and governance (ESG) initiatives, many are looking to technical innovation to help combat the increasing concentration of greenhouse gases in the atmosphere. Chapter 4 of this dissertation will investigate the role of the U.S. Patent system's efforts to accelerate innovation to address climate change. Chapter 4 will also investigate 15 U.S. issued patents that seek to address the removal of carbon dioxide from the atmosphere by decelerating and preferably reversing the growth of carbon dioxide in the atmosphere.

CHAPTER 4

THE ROLE OF PATENTS IN ADVANCING THE STATE OF THE ART IN DIRECT AIR CAPTURE

4.1 Patents

Patents are instrumental in addressing climate change due to their roles in innovation, dissemination of technology, and commercial development. Because patents grant an inventor the exclusive rights to benefit from their innovation, patents provide a critical incentive for research and development (R&D). This R&D is vital in creating advanced technologies to, for example, mitigate and adapt to climate change. Examples include energy efficiency technology, carbon capture and storage (CCS), renewable energy sources, and climate-resilient agricultural practices.

Patents also ensure the dissemination of technical information. Once a patent is granted, its details are published, fostering the spread of knowledge. Other inventors can build upon this public information to create improved or alternative technologies, potentially leading to breakthroughs in climate change solutions. Patents further assist in securing investment for commercializing new technologies. The exclusivity provided by patents allows potential investors to see a pathway to return on their investment, encouraging the growth of new companies and the expansion of existing ones in the climate technology sector. Patent filings relating to direct air capture show a sharp increase from 2017, with over seventy new priority applications filed in 2020. The challenges associated with direct air capture clearly provide scope for innovation and solutions, reflected in the increased number of patent filings.

In the context of global climate change, patents can facilitate technology transfer between countries. They can encourage developed countries to share their advanced climate-friendly technologies with developing nations under mutually agreed terms. However, it is worth noting that the patent system needs to strike a balance between incentivizing innovation and ensuring accessibility of climate change technologies, especially for developing nations. Creative solutions like patent pools, licensing agreements, or exceptions for environmental technologies could play a role in achieving this balance.

4.2 Statutory Patentability Requirements

A patent may not be granted to an applicant for an invention that lacks novelty.[1] Therefore, the claimed invention is ineligible for patent protection if it was, among other things, in use by the general public, offered for sale, or mentioned in a publication prior to the filing date of the patent application.[2] The novelty criterion requires that the invention differ from what has come before.[3] The "prior art" refers to references, such as publications and other patents, that indicate what was known in the field at the time of the applicant's stated invention in order to establish a lack of innovation on the side of the PTO examiner.[4]

A single reference must reveal all of the limits in a patent claim in order to disprove a lack of originality (or, to put it another way, to show that a patent claim is "anticipated"). This reference is typically a patent or publication.[5] An applicant "shall be entitled to a patent unless" the invention is not original, according to the statutory rule governing novelty.

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[1] *See generally* 35 U.S.C. § 102. Conditions for Patentability; Novelty.
[2] 35 U.S.C. § 102.
[3] 35 U.S.C. § 102.
[4] 35 U.S.C. § 102.
[5] *Acoustic Tech., Inc. v. Itron Networked Sols., Inc.*, 949 F.3d 1366, 1373 (Fed. Cir. 2020). ("In an anticipation analysis, the dispositive question is whether a skilled artisan would 'reasonably understand or infer' from a prior art reference that every claim limitation is disclosed in that single reference." [quoting *Akamai Techs., Inc. v. Cable & Wireless Internet Servs., Inc.*, 344 F.3d 1186, 1192 [Fed. Cir. 2003]]).

Consequently, the Act lays the onus of proving that the invention is not unique on the PTO.[6] According to the law, references that are not considered prior art that would bar patenting[7] include disclosures made by the inventor or a co-inventor within a year of the patent application filing date.[8] This creates a "grace period" of one year for innovators to disclose details about their innovation without losing their opportunity to obtain a patent.[9]

An innovation that is not a clear advancement over the prior art is also ineligible for patenting by the applicant.[10] The applicant may not be granted a patent "if the differences between the claimed invention and the prior art are such that the claimed invention as a whole would have been obvious before the effective filing date of the claimed invention."[11] If the prior art makes a claimed invention obvious, the Supreme Court has mandated that four elements be taken into account: (1) the extent and content of the prior art; (2) the distinctions between the prior art and the claimed invention; (3) the level of ordinary skill in the art; and (4) any ancillary factors (also known as objective indicators of non-obviousness).[12] Commercial success, long-felt but unmet needs, and other people's failures are examples of secondary considerations / objective indicators that may be taken into account when evaluating obviousness.

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[6] 35 U.S.C. § 102.
[7] *See generally,* 35 USC § 102(b).
[8] 35 USC § 102(b); specifically § 102(b)(1).
[9] Peter Lee, "Patents and the University," *Duke Law Journal* 63 (2013): 1–87, https://scholarship.law.duke.edu/dlj/vol63/iss1/1.
[10] *See,* 35 U.S.C. § 103.
[11] *See,* 35 U.S.C. § 103.
[12] *Graham v. John Deere Co. of Kansas City*, 383 U.S. 1, 17-18 (1966). ("Under § 103, the scope and content of the prior art are to be determined; differences between the prior art and the claims at issue are to be ascertained; and the level of ordinary skill in the pertinent art resolved. Against this background, the obviousness or non-obviousness of the subject matter is determined. Such secondary considerations as commercial success, long felt but unsolved needs, failure of others, etc., might be utilized to give light to the circumstances surrounding the origin of the subject matter sought to be patented.")

These factors may show whether the idea would have been obvious at the time of invention.[13] Multiple prior art references may also be used to show that a claim would have been evident, even though one prior art reference is typically sufficient to show lack of novelty.[14] However, it is insufficient to prove that an invention would have been obvious by merely showing that all of the limitations in a claim were disclosed across numerous references.[15] Instead, the party opposing the patent must additionally demonstrate that a skilled individual would have had a cause to combine the various references. For instance, a party may claim that a person of ordinary competence would have had a motive to incorporate apart from another reference into the system revealed in one reference.

4.3 U.S. PTO Climate Change Mitigation Pilot Program

The Climate Change Mitigation Pilot Program was launched by the U.S. Patent and Trademark Office (USPTO) in June 2022. This program is consistent with and in support of President Biden's Executive Order 14008,[16] which provides in summary that a severe climate disaster will affect not only the United States but the entire planet. To prevent the most disastrous effects of that catastrophe and to take advantage of the opportunity that addressing climate change affords, the world has a limited window of opportunity to pursue action both domestically and internationally. To dramatically improve global activity, domestic effort

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[13] *Apple Inc. v. Samsung Elecs. Co*., 839 F.3d 1034, 1048 (Fed. Cir. 2016) (en banc). ("[E]vidence rising out of the so-called 'secondary considerations' must always when present be considered en route to a determination of obviousness." (Quoting *Transocean Offshore Deepwater Drilling, Inc. v. Maersk Drilling USA, Inc.,* 699 F.3d 1340, 1349 [Fed. Cir.2012]).

[14] S*ee, e.g., KSR Int'l Co. v. Teleflex Inc.,* 550 U.S. 398, 422-26 (2007) (Determining that claims would have been obvious in view of two references.)

[15] *KSR Int'l Co. v. Teleflex Inc.,* 550 U.S. 398, 422-26 (2007) at 418. ("[A] patent composed of several elements is not proved obvious merely by demonstrating that each of its elements was, independently, known in the prior art.")

[16] "Executive Order on Tackling the Climate Crisis at Home and Abroad," The White House, January 27, 2021, https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/.

must be coordinated with international leadership. We must work together to meet the situation by listening to science.

According to the USPTO, the Climate Change Mitigation Pilot Program aims to have a positive climate impact by accelerating the evaluation of patent applications for technologies that reduce greenhouse gas emissions. Applications using greenhouse gas reduction technology are advanced out of turn for review (granted special status). The Applicant does not have to submit a special fee or meet the other requirements of the accelerated examination program for qualifying applications.

Applications are required to include at least one claim on a method or apparatus that reduces greenhouse gas emissions to slow down global warming. Original utility nonprovisional applications that claim the benefit of only one prior application's filing date, which is either a nonprovisional application or an international application designating the United States, are eligible to participate in this program under 35 U.S.C. §§ 120, 121, 365(c), or 386(c). A petition to make special must be submitted in accordance with 35 U.S.C. § 371 either simultaneously with the application or entry into the national stage, or within 30 days of the application's filing date. The fee for the petition to make special under 37 CFR § 1.102(d) has been waived for this program.

4.4 Major Players in the Direct Air Capture Space

Climeworks AG, a Swiss company that specializes in carbon dioxide capture from ambient air, has been dominant in direct air capture patent filings since 2013. It uses filters made of granulated and highly porous materials that contain amines to bind the carbon dioxide from the air. The carbon dioxide is subsequently released into a high CO_2 stream for storage. In 2021, Climeworks launched Orca, the world's largest direct air capture and storage plant.[17] The current plant captures and permanently removes from the air about 4 kTpa of CO_2. The company announced in June 2022 that work had begun on constructing Mammoth, its second commercial direct air capture and storage plant, designed to capture 36 kTpa when operational.[18]

Another central player in the direct air capture field is Carbon Engineering. Their system integrates two main cycles - the first cycle is the absorption of CO_2 from the atmosphere in a device called an “air contactor” using an alkaline hydroxide solution. The second cycle regenerates the capture liquid used in the air contactor and delivers pure CO_2 as a product. These cycles operate in tandem continuously, producing a concentrated stream of CO_2 gas as an output, and requiring energy, water, and small material make up streams as inputs.[19] The captured atmospheric CO_2 can be stored underground, used for enhanced oil recovery, or turned into low-carbon synthetic fuels.

4.5 History of Direct Air Capture

Separation procedures are frequently used in the production of essential global resources like chemicals, energy, foods, and medications. These could be based on membranes, extraction, sorption, drying, evaporation, distillation, drying, and non-thermal processes like crystallization (given roughly in descending order of energy-intensity).[20] Separations currently make up between 10% and 15% of the energy used worldwide due to

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[17] “Orca Is Climeworks’ New Large-scale Carbon Dioxide Removal Plant,” Climeworks, 2023, https://climeworks.com/roadmap/orca.
[18] “Groundbreaking on Climeworks’ Newest Facility Has Started,” Climeworks, 2023, https://climeworks.com/news/climeworks-announces-groundbreaking-on-mammoth.
[19] Maxx Chatsko, “Climate Change Technology Company that Could Lead to a Green Future, and It’s Not Solar,” *The Motley Fool,* August 8, 2015, https://www.fool.com/investing/general/2015/08/08/1-climate-change-technology-company-that-could-lea.aspx.
[20] “A Research Agenda for Transforming Separation Science,” National Academies of Sciences, 2019, https://doi.org/10.17226/25421.

the prevalence of separation procedures and the substantial usage of energy-demanding, thermal separation techniques.[21]

The evolution of gas separation techniques fuel gases (such as CH_4, H_2, *etc*.), industrial gases (such as N_2, O_2, *etc*.), and noble gases (such as Ar, He, *etc*.) are all produced via gas separation methods. Additionally, they form the basis of numerous emissions control methods (such as for CO_2, SO_x, *etc*.). To frame the discussion of direct air capture materials and techniques that follow, a very basic overview of the history of gas separation is helpful.

Distillation has been used for centuries and is now widely used in the petrochemical sector, for example, to recover ethylene when saturated hydrocarbons are steam cracked. The development of cryogenic distillation for air separation in the late 19th century remains the most economically viable method for producing high-purity N_2, O_2, and Ar on a wide scale.[22] Cryogenic distillation is nearly always used to create rare gases like Ne, Kr, Xe, and others. Flue-gas desulfurization was the first use of sorption-based gas separation techniques in the early 20th century,[23] and more recently, H_2 production in the sorbent-enhanced water-gas shift reaction following steam-methane reforming.[24]

The second part of the 20th century saw the commercialization of gas separation membranes, which are today used to produce H_2 and O_2, as well as to purify CH_4. Recent advancements have been made in biological and electrochemical methods of gas separation. To separate CO_2 as part of carbon capture and sequestration procedures, all of these gas

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[21] D. D. Sholl and R. P. Lively, "Seven Chemical Separations to Change the World." *Nature,* April 26, 2016, https://doi.org/10.1038/532435a.
[22] "A Research Agenda for Transforming Separation Science."
[23] G. Nonhebel, "A Commercial Plant for Removal of Smoke and Oxides of Sulphur from Flue Gases," *Transactions of the Faraday Society* 32 (1936): 1291–6, https://pubs.rsc.org/en/content/articlelanding/1936/tf/tf9363201291#!.
[24] Douglas Patrick Harrison, "Sorption-Enhanced Hydrogen Production: A Review," *Industrial & Engineering Chemistry Research* 47 (2008): 6486 –6501, https://pubs.acs.org/doi/10.1021/ie800298z.

separation techniques (distillation, sorption, membranes, electrochemical, and biological) have been researched and in some cases used.

The majority of direct air capture development has been concentrated on sorption processes,[25] with the largest demonstrations using base- or hydroxide-based (*i.e.,* liquid) chemistry in the sorption stage, applied either as functionalized solid sorbents or liquid sorbents. In these processes, sorbents are cycled between “loaded” and “unloaded” states, with CO_2 being absorbed/adsorbed in the first stage and desorbed in the second.

A bit of basic chemistry may be appropriate here in that when one substance enters the volume or bulk of another substance, this process is Absorption. Solid soaks the liquid or gas rather than any forces applied on molecules. The substance which gets absorbed is called absorbate and the substance which absorbs is called the absorbent. Absorption can be a chemical or a physical process.[26] The phenomenon of adhesion of the molecules of a substance on the surface of a liquid or solid is adsorption. The substance which gets adsorbed on a surface is called the adsorbate and the substance on which it is adsorbed is known as an adsorbent. The interface is the surface where the process takes place.[27]

One difference between direct air capture and the other non-photosynthesis-based negative emission technologies (NETs) stems from this cycling: in direct air capture, the materials are used and re-used after regeneration numerous times, but in other NETs like enhanced weathering (EW), the sorbent capacity is only used once. The sorption (also known as “loading”) and desorption (also known as ““unloading”) are mediated by a “swing”

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[25] C. J. E. Bajamundi et al., “Capturing CO2 from Air: Technical Performance and Process Control Improvement,” *Journal of CO2 Utilization* 30 (2019): 232–9.
[26] “Absorption vs. Adsorption,” Diffen, accessed August 29, 2023, https://www.diffen.com/difference/Absorption_vs_Adsorption.
[27] “Absorption vs. Adsorption.”

process, in which pressure, temperature, humidity, and/or other variables are controlled in a cyclic (either geographically or temporally) way. Sorbents may be placed in fluidized, stationary, or moving beds, or they may be supported by high surface area structures like monoliths or fibers. The main energy need of the process is shifted from cooling, heating, or compressing the entire stream to the desorption stage, where CO_2 is more concentrated.[28]

4.6 Literature Review of Direct Air Capture

Liquid sorbent systems.

Aqueous alkali hydroxide solutions.

The concentration of CO_2 at the source (0.04% or 420 ppm in air), which is 2 to 3 orders of magnitude lower than that found in most industrial separation applications, is the most noticeable difference when separating CO_2 from air. Chemical sorbents with high CO_2-binding affinities are commonly used for CO_2 capture due to the very dilute nature of CO_2 in the atmosphere. Using a calcium hydroxide solution, which is known to have a high binding energy with carbon dioxide to create calcium carbonate, is one typical approach.[29]

One of the simplest approaches for capturing CO_2 from the air is pools of calcium hydroxide that are either passive or agitated, with calcium carbonate precipitating and accumulating.[30] Following separation and drying, calcium carbonate must go through a process known as calcination at temperatures exceeding 700 °C to transform into calcium oxide and release the trapped CO_2 as a concentrated stream.

As a trade-off necessary for the selective binding of the very dilute CO_2, the significant binding energy of CO_2 with calcium hydroxide causes most of the energy input

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[28] Xiaoyang Shi et al., "Sorbents for the Direct Capture of CO_2 from Ambient Air," PubMed, April 27, 2020, https://doi.org/10.1002/anie.201906756.
[29] Eloy S. Sanz-Pérez et al., "Direct Capture of CO2 from Ambient Air," *Chemical Reviews* 116, no. 19 (August 25, 2016): 11840–76, https://doi.org/10.1021/acs.chemrev.6b00173.
[30] Sanz-Pérez et al., "Direct Capture of CO2."

into this process to go toward the regeneration of the sorbent. Although effective at trapping CO_2, the energy cost associated with calcium hydroxide regeneration and other drawbacks, such as the limited solubility, forced researchers to focus their efforts on finding a better sorbent in the future.[31]

Aqueous amine solvents.

Numerous amines can achieve a similar percentage capture to frequently recommended liquid sorbents for direct air capture (such as hydroxides), according to a screening of aqueous amines, but with the potential to save energy due to their lower regeneration temperature.[32] The maximum proportion of capture from air is provided by the quick and high-yield synthesis of amine carbamate in sterically unimpeded amines, as compared to carbonates and bicarbonates.[33] However, as carbamate decomposition occurs gradually during the regeneration cycle, rapid cycling may result in a reduction in capacity (or percentage capture under same capture conditions). This problem seems to be resolved by using a catalyst that is introduced to the amine to promote regeneration.[34] The evaporative loss of amines, which are unstable in air, would result in unfavorable economics (and in some cases, harmful emissions), it was noted in early analyses of direct air capture with amine solvents.[35] Recent process modeling work on direct air capture demonstrated the need

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[31] Klaus S. Lackner, "The Thermodynamics of Direct Air Capture of Carbon Dioxide," *Energy* 50 (February 2013): 38–46, https://doi.org/10.1016/j.energy.2012.09.012.
[32] Francesco Barzagli et al., "Screening Study of Different Amine-Based Solutions as Sorbents for Direct CO_2 Capture from Air," *ACS Sustainable Chemistry & Engineering,* August 28, 2020, https://doi.org/10.1021/acssuschemeng.0c03800.
[33] Barzagli et al., "Screening Study."
[34] Francesco Barzagli and Fabrizio Mani, "Direct CO_2 Air Capture with Aqueous 2-(Ethylamino) Ethanol and 2-(2-Aminoethoxy) Ethanol: 13C NMR Speciation of the Absorbed Solutions and Study of the Sorbent Regeneration Improved by a Transition Metal Oxide Catalyst," *Inorganica Chimica Acta* 518, no. 1 (April 2021), https://doi.org/10.1016/j.ica.2021.120256.
[35] D. Keith, K. Heidel, and R. Cherry, "Capturing CO2 from the Atmosphere," in *Geo-engineering Climate Change: Environmental Necessity or Pandora's Box?* Brian Launder and J. Michael T. Thompson, eds. (Cambridge University Press, 2010), 107–26.

for additional equipment to reduce such evaporative losses as well as the need for novel amines with insignificant vapor pressures to lower capital costs from earlier estimates on the scale of 10^3 \$ per tCO_2.[36] Although new amines are being developed for direct air capture, the current emphasis is on hydrophobic amines to address problems with water co-absorption which results in a higher energy need during the regeneration of the amine. [37]

Aqueous amino acids have been researched for direct air capture as a solution to some of the aforementioned problems because they are non-volatile and ecologically acceptable.[38] The method typically involves the crystallization of a low water solubility guanidinium carbonate salt, which, when heated, regenerates the amino acid sorbent (guanidine) and releases CO_2. Concentrated solar power has been employed as an energy input because this step is endothermic to increase the process' sustainability.[39] Recent research has improved the system's cycle capacity by utilizing the platform's structural variety, with initial regeneration energy requirements on the order of 100 GJ per tCO_2.[40]

Solid sorbent systems.

Due to their stability in the presence of airborne moisture, low-temperature regeneration conditions (between 50 and 120 °C), and flexibility in the selection of affordable supports (usually mesoporous silicas), solid-supported amines have attracted

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[36] Ali Kiani, Kaiqi Jiang, and Paul Feron, "Techno-Economic Assessment for CO_2 Capture from Air Using a Conventional Liquid-Based Absorption Process," Frontiers in Energy Research, May 29, 2020, https://doi.org/10.3389/fenrg.2020.00092.

[37] Fuyuhiko Inagaki et al., "CO2-Selective Absorbents in Air: Reverse Lipid Bilayer Structure Forming Neutral Carbamic Acid in Water without Hydration," *Journal of the American Chemical Society* 139, no. 13 (March 24, 2017): 4639–42, https://doi.org/10.1021/jacs.7b01049.

[38] Charles A. Seipp et al., "CO2 Capture from Ambient Air by Crystallization with a Guanidine Sorbent," *Angewandte Chemie* 129, no. 4 (December 21, 2016): 1062–5, https://doi.org/10.1002/ange.201610916.

[39] Flavien M. Brethomé et al., "Direct Air Capture of CO2 via Aqueous-Phase Absorption and Crystalline-Phase Release Using Concentrated Solar Power," *Nature Energy* 3, no. 7 (May 7, 2018): 553–9, https://doi.org/10.1038/s41560-018-0150-z.

[40] Neil J. Williams et al., "CO2 Capture via Crystalline Hydrogen-Bonded Bicarbonate Dimers," *Chem* 5, no. 3 (March 2019): 719–30, https://doi.org/10.1016/j.chempr.2018.12.025.

substantial attention for direct air capture. They are employed in industry-standard direct air capture procedures, such as the Climeworks facility located in Hinwil, Switzerland.[41]

Prior studies address these materials in detail, with a lot of the work concentrating on poly(ethylenimine) (PEI) on mesoporous silica because of PEI's high amine content and commercial accessibility.[42] Some research on sorbent development has concentrated on comprehending and reducing oxidative degradation and urea formation in silica-supported amines, which have been reported to occur, respectively, during elevated-temperature sorbent regeneration and in CO_2-rich atmospheres.[43] This has involved the use of functionalization, which modifies the distribution of primary, secondary, and tertiary amines,[44] and to remove oxidation-catalyzing metal ions, which results in a significant reduction in the deactivation rate when compared to the classic PEI on mesoporous silica.[45] Replacing PEI with poly(propylenimine) (PPI) on mesoporous silicas resulted in increased capacity and higher resistance to oxidative degradation which may be more suitable for scale-up.[46]

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[41] "Climework's First Industrial-Scale Direct Air Capture Plant in Hinwil," Climeworks, 2023, https://climeworks.com/news/climeworks-builds-first-commercial-scale-direct-air-capture-plant. The Climeworks CO_2 capture technology is based on a cyclic capture / regeneration process and a novel filter. During the capture process, atmospheric CO_2 is chemically bound to the surface of the filter. Once the filter is saturated, the CO_2 is released by heating it to a temperature of about 100°Celsius (212°F), thereby delivering high-purity gaseous CO_2. The CO_2-free filter can be re-used for numerous capture /regeneration cycles.

[42] Sanz-Pérez et al., "Direct Capture of CO2."

[43] Simon H. Pang, Ryan P. Lively, and Christopher W. Jones, "Oxidatively-Stable Linear Poly(Propylenimine)-Containing Adsorbents for CO_2 Capture from Ultradilute Streams," *ChemSusChem* 11, no. 15 (July 9, 2018): 2628–37, https://doi.org/10.1002/cssc.201800438.

[44] Woosung Choi et al., "Epoxide-Functionalization of Polyethyleneimine for Synthesis of Stable Carbon Dioxide Adsorbent in Temperature Swing Adsorption," *Nature Communications* 7, no. 1 (August 30, 2016), https://doi.org/10.1038/ncomms12640.

[45] Kyungmin Min et al., "Oxidation-Stable Amine-Containing Adsorbents for Carbon Dioxide Capture," *Nature Communications* 9, no. 1 (February 20, 2018), https://doi.org/10.1038/s41467-018-03123-0.

[46] Simon H. Pang et al., "Design of Aminopolymer Structure to Enhance Performance and Stability of CO2 Sorbents: Poly(Propylenimine) vs Poly(Ethylenimine)," *Journal of the American Chemical Society* 139, no. 10 (March 3, 2017): 3627–30, https://doi.org/10.1021/jacs.7b00235.

A proof-of-concept for scalable, structured direct air capture contactors has also been researched using cellulose acetate-silica fibers filled with PEI.[47] CO_2 with a purity of 98% was created using a combination temperature-vacuum swing regeneration with dry air as the input. A true process would require co-captured water to be condensed to produce high-purity CO_2, but with a wet air input, about 65% CO_2 was produced.

In comparison to the ordered mesoporous silica frameworks generally used in direct air capture investigations, silica gels have lower costs and are more widely available. However, because of their smaller surface areas, silica gels are projected to perform poorly. Recent research has demonstrated that adding water to the amine grafting procedure (to provide surface hydroxyl groups for amine attachment) produces sorbents that seem to be competitive with those using mesoporous frameworks.[48] The amine-based sorbent Lewatit® VP OC 1065 (a polystyrene matrix with amine groups is believed to be (very similar to) the adsorbent that Climeworks uses in their first-generation direct air capture process[49] shows humidity-enhanced sorption of CO_2, demonstrating that water also plays a significant role during capture. For a direct air capture system based on such solid amine sorbents, complete water, and CO_2 co-adsorption isotherm models have recently been created. This is a helpful step in enabling the benchmarking of sorbents and more precise process modeling.[50]

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[47] Achintya R. Sujan et al., "Direct CO2 Capture from Air Using Poly(Ethylenimine)-Loaded Polymer/Silica Fiber Sorbents," *ACS Sustainable Chemistry & Engineering* 7, no. 5 (February 5, 2019): 5264–73, https://doi.org/10.1021/acssuschemeng.8b06203.
[48] John-Timothy Anyanwu, Yiren Wang, and Ralph T. Yang, "Amine-Grafted Silica Gels for CO2 Capture Including Direct Air Capture," *Industrial & Engineering Chemistry Research* 59, no. 15 (December 3, 2019): 7072–9, https://doi.org/10.1021/acs.iecr.9b05228.
[49] John Young et al., "The Impact of Binary Water–CO2 Isotherm Models on the Optimal Performance of Sorbent-Based Direct Air Capture Processes," *Energy & Environmental Science* 14, no. 10 (2021): 5377–94, https://doi.org/10.1039/d1ee01272j.
[50] John Young et al., "The Impact of Binary Water–CO2 Isotherm Models."

Metal organic frameworks.

Due to the chemistry of metal-organic frameworks (MOFs), they are generally of interest for gas separations.[51] They must have moisture resistance, which is unusual for MOFs in general, and be susceptible to amine functionalization to be used as chemisorbents in direct air capture. MIL-101(Cr) has been investigated because it is water stable and offers numerous options for amine functionalization (physical impregnation with liquid amines or amine adsorption onto metal sites). It is important to strike a balance between high CO_2 absorption but poor kinetics due to pore obstruction or amine loss at high amine loading and low CO_2 uptake with low amine loading.[52] The CO_2 is inserted into the metal-amine bond to generate ammonium carbamate chains in the cooperative insertion mechanism used by the Mg2(dobpdc) family of MOFs to capture CO_2. The framework metal or the connected amine can be changed, which allows for tuning of the metal-amine bond strength.[53] Furthermore, although methods for creating composites with hydrophobic binders are starting to emerge, problems with handling during application and pressure drop, for example, may also be addressed, the stability of powders under humidity is a problem.[54] The usage of MOFs in direct air capture may be too costly given their current price.[55]

[51] Jia Liu, Yajuan Wei, and Yanli Zhao, "Trace Carbon Dioxide Capture by Metal-Organic Frameworks," *ACS Sustainable Chemistry & Engineering* 7, no. 1 (November 30, 2018): 82–93, https://doi.org/10.1021/acssuschemeng.8b05590.
[52] Lalit A. Darunte et al., "Direct Air Capture of CO2 Using Amine Functionalized MIL-101(Cr)," *ACS Sustainable Chemistry & Engineering* 4, no. 10 (September 23, 2016): 5761–8, https://doi.org/10.1021/acssuschemeng.6b01692.
[53] Rebecca L. Siegelman et al., "Controlling Cooperative CO2 Adsorption in Diamine-Appended Mg2(Dobpdc) Metal–Organic Frameworks," *Journal of the American Chemical Society* 139, no. 30 (July 19, 2017): 10526–38, https://doi.org/10.1021/jacs.7b05858.
[54] Jinkyoung Park et al., "Shaping of a Metal–Organic Framework–Polymer Composite and Its CO2 Adsorption Performances from Humid Indoor Air," *ACS Applied Materials & Interfaces* 13, no. 21 (May 18, 2021): 25421–27, https://doi.org/10.1021/acsami.1c06089.
[55] Xiaoyang Shi et al., "Sorbents for the Direct Capture of CO_2 from Ambient Air."

Contactor design.

Moving huge volumes of air in such a way that there is enough contact between the CO_2 molecules in the air and the surfaces of the material or device that mediates capture is a significant challenge for all direct air capture systems. Contacting is the name given to this direct air capture step. Due to their relatively advanced degree of development, sorbent-based processes have received almost all the attention in the work on contactors for direct air capture. Like the creation of high-purity CO_2, which was also described above, practically all the research done to date on this topic has been on sorbent regeneration techniques to accomplish this. This section examines contacting and sorbent regeneration for the commercial-scale direct air capture processes that use liquid sorbents (Carbon Engineering) and solid sorbents (Climeworks), covering recent research on alternate approaches for each.

It is crucial to note that there is a trade-off between the strength of the sorbent interaction with CO_2 and the exposed surface area of the sorbent (noting, of course, that the strength of the sorbent interaction with CO_2 also impacts sorbent regeneration conditions). For example, a contactor with a high exposed specific surface area per unit volume can use a weaker sorbent to achieve the same amount of capture for a given contactor volume.[56] Electrical fans (also known as forced draft) have been necessary in every instance of commercial scale direct air capture, regardless of the kind of sorbent, to overcome pressure drop in contactors.

Therefore, it has been necessary to optimize the relationship between pressure drop and the amount of CO_2 removed, as well as between operating and capital costs (high air

[56] Noah McQueen et al., "A Review of Direct Air Capture (DAC): Scaling Up Commercial Technologies and Innovating for the Future," *Progress in Energy* 3, no. 3 (April 16, 2021): 032001, https://doi.org/10.1088/2516-1083/abf1ce.

flows increase forced-draft costs but call for smaller contactors). So, for any direct air capture contactor, pressure drop per unit surface area is of significance..”[57]

4.7 Carbon Negative Shot

In 2021 the U.S. Department of Energy launched the *Carbon Negative Shot*, an all-hands-on-deck call for innovation in carbon dioxide removal pathways that will capture carbon dioxide from the atmosphere and store it at gigaton scales for less than $100/net metric ton of carbon dioxide-equivalent, to advance the development of this new but essential industry.[58]

Four initiatives under the Carbon Negative Shot will aid in the development of a profitable carbon dioxide removal sector in the U.S. These programs, which were made possible by $3.7 billion in funding provided by the Bipartisan Infrastructure Law, will aid in boosting private sector investment, advancing monitoring and reporting procedures for carbon management technologies, and giving grants to state and local governments so they can purchase goods made from carbon emissions that have been captured. Together with robust measures to reduce carbon emissions, large-scale deployment of carbon management systems is essential to addressing the climate issue.[59]

The Bipartisan Infrastructure Act offers the critical investments required to expand the commercial application of CO_2-removal or -capture technology. The Inflation Reduction Act also makes significant improvements to the federal Section 45Q tax credit for the capture and geologic storage of CO_2, in addition to the cash made available under the Bipartisan

[57] Geoffrey Holmes and David W. Keith, “An Air-Liquid Contactor for Large-Scale Capture of CO_2 from Air,” *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 370, no. 1974 (September 13, 2012): 4380–403, https://doi.org/10.1098/rsta.2012.0137.
[58] “Biden-Harris Administration Announces $3.7 Billion to Kick-Start America’s Carbon Dioxide Removal Industry,” National Energy Technology Laboratory, December 14, 2022, https://netl.doe.gov/node/12239.
[59] “Biden-Harris Administration Announces $3.7 Billion.”

Infrastructure Law. According to a DOE study, the Bipartisan Infrastructure Law and the Inflation Reduction Act will reduce greenhouse gas emissions by 40% in the entire economy by 2030 compared to 2005 levels.[60]

The DOE's Office of Fossil Energy and Carbon Management (FECM) is introducing the Direct Air collection Prize, which will provide support and prize money totaling $115 million to encourage various methods of direct air collection. The Direct Air Capture Pre-Commercial Prize offers rewards worth up to $15 million to foster and hasten the development of ground-breaking direct air capture technology. For removing CO_2 from the atmosphere, the Direct Air Capture Commercial Prize offers up to $100 million in awards to approved direct air capture installations.[61]

The Regional Direct Air Capture Hubs program is being introduced by the DOE's Office of Clean Energy Demonstrations (OCED) in collaboration with FECM. To build four domestic regional direct air capture hubs, the DOE will invest $3.5 billion. These hubs will each showcase a direct air capture technology or suite of technologies at commercial scale, with the potential to capture at least 1 million metric tons of CO_2 annually from the atmosphere and store that CO_2 permanently in a geologic formation or through its conversion into products. With additional funding opportunities anticipated in the upcoming years, the first funding opportunity announcement makes available more than $1.2 billion to start the process of conceptualizing, designing, planning, building, and operating direct air capture hubs.[62]

[60] "Biden-Harris Administration Announces $3.7 Billion."
[61] "Biden-Harris Administration Announces $3.7 Billion."
[62] "Biden-Harris Administration Announces $3.7 Billion."

Carbon Utilization Procurement Grants - FECM will oversee the Carbon Utilization Procurement Grants Program, which will award grants to states, local governments, and public utilities to support the commercialization of technologies that reduce carbon emissions as well as the procurement and use of commercial or industrial products created from captured carbon emissions. The DOE will give grants totaling up to $100 million.[63]

The Technology Commercialization Fund (TCF), a bipartisan initiative -- By enhancing measuring, reporting, and verification best practices and capabilities, DOE's Office of Technology Transitions (OTT), in collaboration with FECM, will issue a Lab Call to hasten the commercialization of carbon dioxide removal technologies, including direct air capture. To assist projects headed by DOE National Laboratories, facilities, and locations and supported by numerous business partnerships throughout the burgeoning carbon dioxide removal sector, OTT estimates allocating $15 million.[64]

4.8 Direct Air Capture Patents

The patents listed below in FIGS. 1-15 are recently issued patents by the U.S. Patent Office focused upon direct air capture technology. These patents represent the state of the art in carbon capture technology. While pending applications were originally to be included for analysis in this dissertation, the author ultimately determined that because there would be no prosecution history available from the U.S. patent office on some of the patent applications, it would be less intellectually beneficial to include them since the patent office would not have developed a record that could be assessed and analyzed.

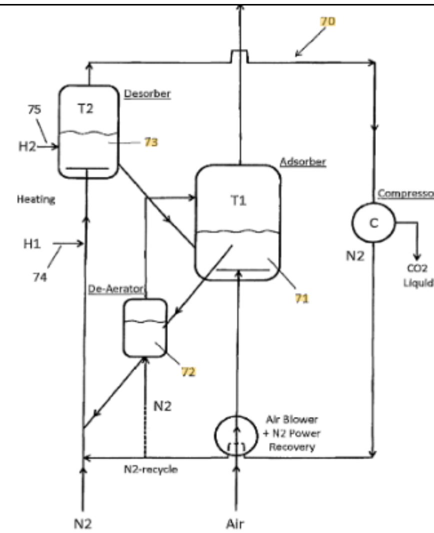
For each of the patents listed below the prosecution history has been analyzed. The prosecution history is the record of examination that exists at the patent office for each issued

[63] "Biden-Harris Administration Announces $3.7 Billion."
[64] "Biden-Harris Administration Announces $3.7 Billion."

patent. The prosecution history provides an assessment of the improvements in the state of the art of the claimed invention as negotiated between the U.S. Patent Office Examiner and the Applicant, typically through their patent counsel.

The prosecution history provides a record as to the basis for patentability considering the “prior art” references that were located by the Examiner and developed through advocacy on the part of the patent counsel for the Applicant and the Examiner on behalf of the United States. It is this publicly available examination record that allows for a historical review of the path to patentability of the application. The patent office seeks to identify where the lines of innovation are drawn such that an apparatus, system or method that is insufficiently novel or is statutorily obvious will not secure patent protection.

Figure 4.1. U.S. Patent No. 10,807,042 titled Moisture swing carbon dioxide enrichment process

Title	Moisture Swing carbon dioxide enrichment process
App. No.	16/438,502
Patent No.	10,807,042
Issue Date	10/20/2020
Assignee	Climeworks AG
Inventor Name	Antonie Bijl, Timo Roestenberg, Rafael Rodriguez Mosqueda, Gerrit Brem Paul O'Connor
Representative Figure	 *Figure 4. 1*
Description of Technology	A process is disclosed for reversibly absorbing carbon dioxide to an alkali metal or earth alkaline absorbent. For absorption the absorbent is contacted with a first gas composition. For desorption the absorbent is contacted with a second gas composition. The moisture contents of the first and second gas compositions are controlled so that during the absorption step the absorbent is converted to a bicarbonate, and during the desorption step the absorbent is converted to a carbonate hydrate. Compared to prior art processes the process of the invention requires less energy input. The process of the invention is particularly suitable for producing a carbon dioxide enriched gas for accelerating plant growth in a greenhouse.
Exemplary Claim Language	A process for reversibly absorbing CO_2 to an alkali or earth alkaline metal absorbent, said process comprising: a CO_2 absorption step wherein the alkali or earth alkaline metal absorbent is contacted with a first gas composition; and a CO_2 desorption step wherein the alkali or earth alkaline metal absorbent is contacted with a second gas composition, wherein the respective moisture contents of the first and second gas compositions are controlled such that during the absorption step the alkali or earth alkaline metal absorbent is converted to a bicarbonate, and during the desorption step the alkali or earth alkaline metal absorbent is converted to a carbonate hydrate, wherein the first gas composition is optionally dried, and wherein moisture is added to the second gas composition prior to contacting the absorbent.

The disclosed process is for removing carbon dioxide from the surrounding air and consists of an improved swing absorption/desorption method for producing carbon dioxide rich gases. Low water vapor pressures in the range of 0.001 bar and 0.0150 bar are recommended for the absorbing gas. The absorbing gas may benefit from being dried, for instance by passing a flow of the gas through a bed of desiccant or dry zeolite; however, this will require an energy input to accomplish. Greater absorption efficiency often more than makes up for the additional energy cost of the drying stage.

The disclosure provides that care must be taken not to remove crystal water from the carbonate material during the desorption step. A water vapor pressure range of 0.020 bar to 0.2 bar is preferred for the desorbing gas as disclosed at claim 5. The process can be referred to as a moisture swing absorption/desorption process since the first gas, or the absorbing gas, and the second gas, or the desorbing gas, have different moisture contents.

Combining the moisture swing with a moderate temperature swing is purportedly beneficial. For instance, the temperature of the first gas may be between 250 K and 300 K, whereas the temperature of the second gas might be between 300 and 400 K.

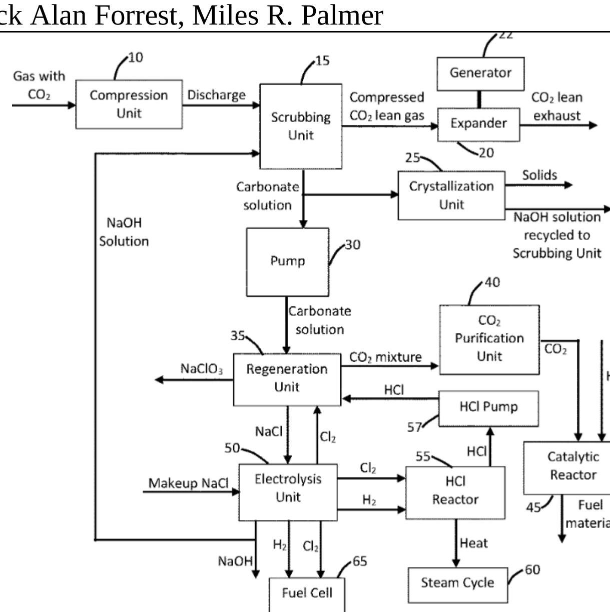
The prosecution history provides that the '042 patent was terminally disclaimed over U.S. Patent No. 10,350,547 [Application No. 15/101,465] also assigned to Climeworks AG. The prosecution history of the '547 patent details that the most pertinent prior art record belongs to Lee [non-patent literature – *The effect of relative humidity on CO_2 capture capacity of potassium-based sorbents* – Korean Journal of Chemical Engineering vol. 28, No. 2pp 480-486 (published Feb 2011)]. Lee teaches to maintain K_2CO_3 as the sesquihydrate, rather than in anhydrous form to enhance the CO_2 capture capacity. The sesquihydrate may easily be transformed to anhydrous K_2CO_3 by thermal desorption even at low temperatures under very low concentration of water vapor.

Given that Lee desorbs water from its K_2CO_3 x $5H_2O$ at 50-100°C (within claim 8's range) in N_2 with a 0-9.0 vol% humidity content (at 1 atm, this calculates to a water vapor P of 0-0.91 bar, within claim 7's range). Lee does; however, state that its anhydrous K_2CO_3's CO_2 removal capacity is inferior compared to its K_2CO_3 x $5H_2O$ as previously detailed. Employing a water vapor P such as in claim 7 (or with any moisture added to Lee's second/regeneration gas stream comprising pure N_2, as claim 8 requires) would render Lee's CO_2 absorbent unsuitable for its stated purpose of CO_2 removal. Thus, modifying Lee to meet claim 7 (or 8, which depends from claim 7) or 11 would appear to involve a non-obvious modification. Claim 7 requires that the second gas composition have a water vapor pressure from 0.020 bar to 0.20 bar.

Lee was also found to absorb CO_2 from a mixed gas by contacting the mixed gas with an alkali metal carbonate-based absorbent (K_2CO_3 x $5H_2O$), the moisture contents of the mixed gas and second gas are adjusted / controlled as desired.

In summary, to overcome the Lee reference, the first independent claim of the '042 patent required that the first gas (ambient air) is optionally dried, and that moisture is added to the second gas prior to contacting the absorbent. Additionally, for independent claim 17 during the desorption step, crystal water is not removed from the carbonate hydrate and the second gas composition has a temperature from 300 K to 400 K.

Figure 4.2. U.S. Patent No. 11,559,766 titled Alkali-based removal of chemical moieties from gas streams with chemical co-generation

Title	Alkali-based removal of chemical moieties from gas streams with chemical co-generation
Application No.	17/552,676
Patent No.	11,559,766
Issue Date	January 24, 2023
Assignee	8 Rivers Capital LLC
Inventor Name	Xijia Lu, Brock Alan Forrest, Miles R. Palmer
Representative Figure	 *Figure 4. 2*
Description of Technology	This innovation provides a variety of advantages over prior art systems and methods. Advantages can include any one of more of the following: elimination of solid reactants that are typically required in carbon dioxide removal systems; regeneration of part or all the reactants used in the process; generation of one or more value added chemicals; increased density of processes that can be carried out; reduction in process equipment size, complexity, and cost; integration of process heat; elimination of fossil fuel combustion as an energy source; and/or using renewable electricity as one energy source or the sole energy source.
Exemplary Claim Language	A method for capture of carbon dioxide with co-generation or one or more chemicals, the method comprising: contacting a gaseous carbon dioxide containing stream in a scrubbing unit with an alkali solution to form a carbonate solution and output a carbon dioxide lean gas stream; reacting the carbonate solution with a halogenated compound to form one or more metal salts and output a stream comprising carbon dioxide; reacting the one or more metal salts with water under electrolysis conditions to regenerate the alkali solution and form one or more further chemicals; and using the one or more further chemicals in at least one additional reaction effective to form one or both of electrical energy and heat.
Detail	First Office Action Allowance

The ‘766 patent focuses on systems and procedures for the direct capture of at least one moiety (*i.e.*, carbon dioxide) from one or more streams (for instance, air and/or another gaseous stream). The system can provide for the production of one or more value-added chemicals, such as hydrogen (H_2), chlorine (Cl_2), hydrogen chloride (HCl), sodium chloride (NaCl), potassium chloride (KCl), sodium hydroxide (NaOH), potassium hydroxide (KOH), sodium carbonate (Na_2CO_3), potassium carbonate (K_2CO_3), sodium hypochlorite (NaClO), potassium hypochlorite (KClO) or sodium chlorate (NaCl).

Compared to systems and procedures in the prior art, the present disclosure offers a number of benefits. Any one or more of the following are advantages: reducing the size, complexity, and cost of process equipment; eliminating the need for solid reactants, which are typically needed in carbon dioxide removal systems; producing one or more value-added chemicals; increasing the density of processes that can be carried out; eliminating the need for fossil fuel combustion as an energy source; integrating process heat; using renewable electricity as one energy source or the solvent.

The current disclosure offers a method for direct capture (including direct air capture) of carbon dioxide with co-generation of one or more compounds. In one example of a carbon dioxide capture system, the following components can be found in the system: a compression unit to provide a compressed carbon dioxide containing gas discharge stream; a scrubbing unit to contact the compressed carbon dioxide containing gas discharge stream with an alkali solution to form a carbonate solution and output a carbon dioxide lean gas stream; and a regeneration unit to react the carbonate solution with a halocarbon.

The alkali solution can be made up of a mixture of one or more metal salts, with the metal of choice being one of the alkali metals, alkaline earth metals, or their mixtures. A sodium hydroxide solution can be included in the alkali solution. The system may also include a crystallization component designed to take in at least some of the carbonate solution and produce one or more solids. It is also possible to further arrange the crystallization unit to produce an alkali solution that may be recycled back into the scrubbing unit. The system may also include a carbon dioxide purification device that is set up to take in the stream of carbon dioxide produced by the regeneration unit.

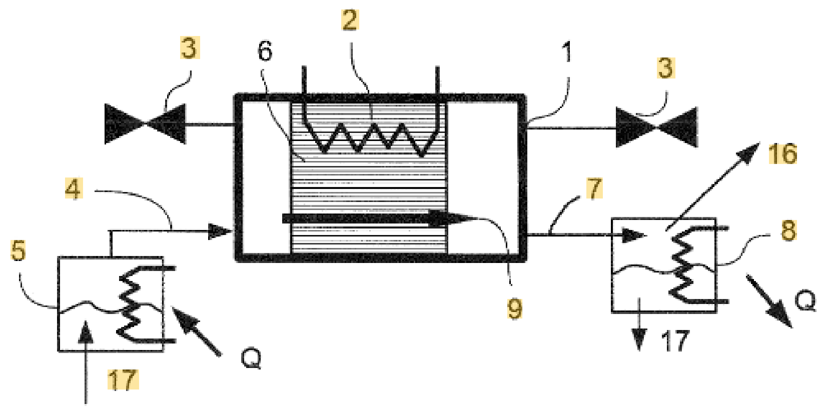
A method for capturing carbon dioxide can include a first step of contacting a gaseous carbon dioxide-containing stream in a scrubber with an alkali solution to form a carbonate solution and output a carbon dioxide lean gas stream. Next, reacting the carbonate solution with a halogenated compound to form one or more metal salts and output a stream including carbon dioxide; and reacting the one or more metal salts with water under electrolysis conditions.

The method can also include processing the stream of carbon dioxide in a carbon dioxide purification system designed to produce a stream of carbon dioxide that is essentially clean. The purification system for carbon dioxide may be a cryogenic system. The procedure can also include reacting a portion of the stream of essentially pure carbon dioxide with hydrogen to create fuel that is made of hydrocarbons. To generate energy, the approach can also include expanding one or more pressured streams. Hydrogen and a halogen gas are two possible examples of the one or more additional compounds that are created. The process can also include forming an acid by reacting at least a portion of the hydrogen with a portion of the halogen gas.

The prosecution history provides that one of the more relevant references of record is U. S. Pat. 4,069,117. This patent describes a method and system for removing the emissions of carbon dioxide from a gas stream by scrubbing the gas with an aqueous solution comprising alkali metal hydroxide to (to evidently generate a carbonate salt by-product); contacting this (carbonate salt-containing) by-product scrubbing solution with hydrochloric acid to generate what appears to be an alkali metal chloride-containing solution and providing this alkali metal chloride-containing solution into an electrolysis cell to re-generate the alkali metal hydroxide-containing solution (which appears to be subsequently re-cycled back to the gas decarbonation / purification step) and also hydrogen and chlorine gases in a manner that seems to meet most of the limitations recited in at least the Applicants' independent claims 25 and 38.

However, the Applicants' independent claims 25 and 38 also require that the "further chemicals" (which correspond with the hydrogen and chlorine gases emitted from the electrolysis cell, as described in at least the independent claim 1 in U. S. Pat. 4,069,117) be used to generate either or both of electrical energy or heat — and at least this particular feature is not taught or suggested in U. S. Pat. 4,069,117. In contrast, col. 2 lines 18-23 in U. S. Pat. 4,069,117 suggest the use of hydrogen gas and chlorine gas to manufacture what appears to be an aqueous solution of hydrochloric acid. However, there is no hint or suggestion in col. 2 lines 18-23 or any other portion of this U. S. Pat. 4,069,117 to use generated hydrogen gas and chlorine gas to either generate electrical energy and/or heat (as embraced in the scope of at least the Applicants' independent claims 25 and 38). Hence, the Applicants' independent claims 25 and 38 (as well as the claims that are directly or indirectly dependent thereon) were allowed over the teachings provided in U. S. Pat. 4,069,117 without the need to amend the claims.

Figure 4.3. U.S. Patent No. 10,279,306 titled Steam assisted vacuum desorption process for carbon dioxide capture

Title	Steam assisted vacuum desorption process for carbon dioxide capture
Application No.	15/324,775
Patent No.	10,279,306
Issue Date	May 7, 2019
Assignee	Climeworks AG
Inventor Name	Christopher Gebald, Nicolas Repond, Jan Andre Wurzbacher
Representative Figure	 *Figure 4. 3*
Description of Technology	A method for separating gaseous carbon dioxide from a mixture by cyclic adsorption/desorption using a unit containing an adsorber structure with sorbent material, wherein the method comprises the following steps: (a) contacting said mixture with the sorbent material to allow said gaseous carbon dioxide to adsorb under ambient conditions; (b) evacuating said unit to a pressure in the range of 20-400 $mbar_{abs}$ and heating said sorbent material to a temperature in the range of 80-130° C.; and (c) re-pressurization of the unit to ambient atmospheric pressure conditions and actively cooling the sorbent material to a temperature larger or equal to ambient temperature; wherein in step (b) steam is injected into the unit to flow-through and contact the sorbent material under saturated steam conditions, and wherein the molar ratio of steam that is injected to the gaseous carbon dioxide released is less than 20:1.
Exemplary Claim Language	A method for separating gaseous carbon dioxide from a gas mixture containing said gaseous carbon dioxide as well as further gases different from gaseous carbon dioxide by cyclic adsorption/desorption using a sorbent material adsorbing said gaseous carbon dioxide, using a unit containing an adsorber structure with said sorbent material, the unit being evacuable to a vacuum pressure of 400 $mbar_{abs}$ or less, and the adsorber structure being heatable to a temperature of at least 80° C for the desorption of at least said gaseous carbon dioxide and the unit being openable to flow-through of the gas mixture and for contacting it with the sorbent material for the adsorption step, wherein the method comprises the following sequential and in this sequence repeating steps: (a) contacting said gas mixture with the sorbent material; (b) evacuating said unit to a pressure in the range of 20-400; and (c) actively cooling the sorbent material under a pressure of the one in step.

The disclosed invention relates to a method for separating gaseous carbon dioxide from a gas mixture, where the gas mixture is preferably air containing the gaseous carbon dioxide by cyclic adsorption/desorption using a sorbent material adsorbing the gaseous carbon dioxide. The disclosed method uses a unit with an adsorber structure and sorbent material that can be evacuated to a vacuum pressure of 400 $mbar_{abs}$ or less and that can be heated (reversibly) to at least 80° C for the desorption of the gaseous carbon dioxide. Additionally, the unit can be opened to allow the gas mixture to cross the flow path and contact the sorbent material during the adsorption process.

The procedure includes the following sequential steps, which are repeated in this order as often as required: (a) putting the gas mixture in contact with the sorbent material to perform an adsorption step in which at least the gaseous carbon dioxide is allowed to adhere to the sorbent material under conditions of ambient atmospheric pressure and temperature. Gaseous water is typically present in gas mixtures, and this water will at least partially be absorbed by the sorbent material. This adsorbed water will later, during the desorption step, also be released from the sorbent material and will add to the water condensed downstream of the unit. As a result, it will also add to the water condensed from the steam separately injected into the system in succeeding step (b).

Step (b) requires removing at least some of the desorbed gaseous carbon dioxide from the unit and at least partially separating gaseous carbon dioxide from other gases by evacuating the unit to a pressure in the range of 20-400 $mbar_{abs}$ and heating the sorbent material in the unit to a temperature in the range of 80-130° C.

Step (c) requires returning the system to normal atmospheric pressure while actively lowering the temperature of the sorbent material to that of the surrounding air. As a result, steps (a) through (c) are performed in this order as often as necessary and desired preferably at least 10,000 times. The terms "ambient atmospheric pressure" and "ambient atmospheric temperature" in the context of this disclosure refer to the pressure and temperature conditions to which a plant operated outdoors is exposed; for example, typically ambient atmospheric pressure refers to pressures in the range of 0.8 to 1.1 bar_{abs} and typically ambient atmospheric temperature refers to temperatures in the range of 40 to 60° C., more typically 30 to 45° C. The process' preferred gas input is ambient air, which typically has a CO_2 content in the range of 0.03 to 0.06% by volume. Although air with a CO_2 content of 0.1-0.5% by volume or more can be utilized as an input for the process, it is generally preferred that the input CO_2 concentration of the input gas combination be in the range of 0.01-0.5% by volume.

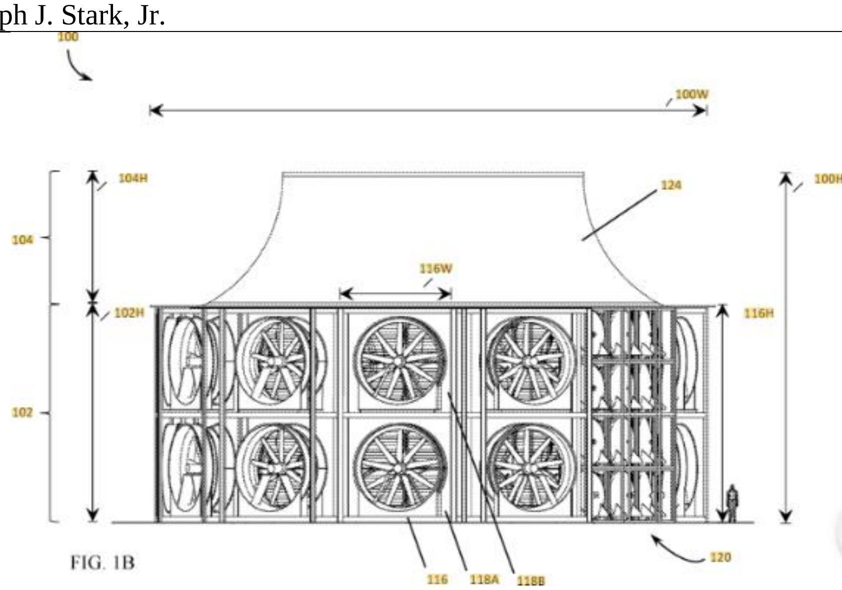
The proposed method is unique in that, among other things, steam is injected into the unit in step (b) under saturated steam or superheated steam conditions, with a superheated steam temperature of up to 130° C at the pressure level in said unit, and where the molar ratio of steam that is injected during the entire step (b) to the gaseous carbon dioxide released during the entire step (b) is less than 40:1. This can also be expressed as a molar ratio of less than 40:1 between the amount of steam that is injected and the amount of gaseous carbon dioxide that is emitted throughout step (b).

Two key differences between the proposed process and prior art include, among other things, the addition of a step for separating gaseous carbon dioxide from water by condensation in or near the unit (1) during step (b) and the fact that the molar ratio of steam injected during step (b) to gaseous carbon dioxide released during step (b) is less than 40:1 and preferably less than 20:1. Given the state of the prior art, a person skilled in the art would not have taken the steps into account because the similarly low ratio of steam to gaseous carbon dioxide would have seemed improper and ineffectual for effectively carrying out the operation.

The fact that steam is used primarily as a purging gas under vacuum conditions at moderate temperatures, typically around 130° C, during step (b), which are therefore not harmful to sorbent materials suitable for direct air capture, is one of the key differences between the proposed processes and the prior art.

The Examiner, in a final office action rejected claim 27 under 35 U.S.C. § 112 as being indefinite. The Applicant elected to cancel claim 27. The Examiner also rejected claim 15 as being anticipated by WO 2014/073004 under 35 U.S.C. § 102(a)(1). Again, Applicant elected to cancel this claim mooting the rejection. Lastly, the Examiner rejected claim 27 under 35 U.S.C. § 103 as being unpatentable over WO ‘004 in view of Suzuki et al. (7,712,605). The Applicant mooted the rejection by, as previously noted, cancelling the claim. The Examiner ultimately allowed claims 1-14, 16-26, 28 and 29.

Figure 4.4. U.S. Patent No. 11,389,761 titled System and method for improving the performance and lowering the cost of atmospheric carbon dioxide removal by direct air capture

Title	System and method for improving the performance and lowering the cost of atmospheric carbon dioxide removal by direct air capture
Application No.	17/345,851
Patent No.	11,389,761
Issue Date	July 19, 2022
Assignee	Air to Earth Holdings LLC
Inventor Name	Joseph J. Stark, Jr.
Representative Figure	 *Figure 4. 4*
Description of Technology	Systems and methods for an atmospheric carbon dioxide removal that includes a plurality of carbon capture containers, a plurality of fans, an air diverter, and a velocity stack. Each of the carbon capture containers has an outwardly facing side and an inwardly facing side with the inwardly facing side facing an enclosed space. The fans are disposed adjacent to the carbon capture containers. The fans are arranged to move air through the carbon capture containers in a first direction from the outwardly facing side into the enclosed space. The air diverter is disposed within the enclosed space and receives the air flowing in the first direction and redirects the air to flow in a second direction that is angled upwardly from the first direction. The velocity stack is disposed on top of the enclosed space and is configured to accelerate the flow of the air in the second direction.
Exemplary Claim Language	A carbon capture container, comprising: a sorbent material holding apparatus having a sidewall and a first opening on a first side of the sorbent material holding apparatus and a second opening on an opposing second side of the sorbent material holding apparatus; one or more sorbent material holding sub containers disposed in the sorbent material holding apparatus, each of the one or more sorbent material holding sub containers having a grated or screened sidewall, an open first end, and a plugged second end; a sorbent material disposed in each of the one or more sorbent material holding

	sub containers; a frame surrounding a portion of the sorbent material holding apparatus such that the frame supports the sorbent material holding apparatus.

Disclosed is a direct air capture structure for removing atmospheric carbon dioxide that provides enhanced performance purportedly at a lesser unit price than current atmospheric carbon dioxide removal structures. The disclosure comprises a sorbent media-filled cylinder, a fan for forcing air through the cylinder and over the sorbent media, and a regeneration station for extracting carbon dioxide from the sorbent media are some sample implementations of the structure.

In a first embodiment, the direct air capture structure includes cylinders filled with sorbent media that are stacked circularly. In a second embodiment, many fans could be positioned outside the ring of sorbent media-filled cylinder stacks. The fans force air into the interior of the direct air capture structure from the exterior of the structure, passing through the cylinders, over the sorbent media.

In this way, carbon dioxide from the advection of bulk air flow through the cylinder is captured by the sorbent medium. In a first design, the direct air capture structure includes one or more regeneration stations positioned all around its outside. Each regeneration station can lock onto a cylinder and remove the sorbent media’s carbon dioxide collection. To move the sorbent media-filled cylinder stacks from a state of carbon collection—where the fans blow air through the cylinders—to a state of carbon release, where the regeneration station removes the collected carbon from the sorbent media—the direct air capture structure may rotate.

In another design, an air shifting structure might be built inside the direct air capture structure to control the airflow into and out of it. A fabric material organized in such a way as to direct air flow away from the sides of the structure and out of the open top of the structure may be included in an element of the air shifting structure.

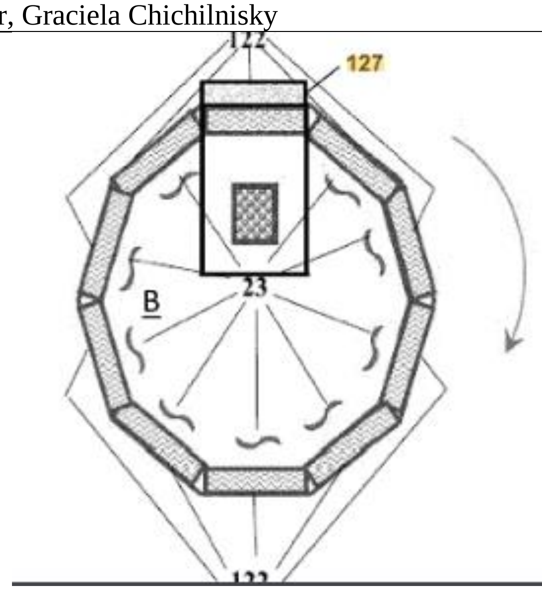
To speed up the flow of air out of the direct air capture structure, a roof structure may in some cases be erected on top of it. A feature of the roof structure could make it broader at the bottom than the top, with a greater aperture at the bottom. In one aspect, the outside walls of the direct air capture structure's roof structure may slope inward and upward. The roof structure is configured for accelerating the movement of air upward and away from the structure.

A regeneration station creates a seal all the way around a cylinder containing sorbent media. To remove air from the cylinder housing the sorbent medium, the regeneration station preferably creates a vacuum inside it. To remove any remaining air from the sorbent media-containing cylinder, the regeneration station optionally fills and flushes the cylinder with water. The cylinder may also be heated by the regeneration station to encourage the release of carbon dioxide from the sorbent media-containing cylinder.

To further encourage the release of carbon dioxide from the sorbent media-containing cylinder and to cool it, the regeneration station may in some instances create a vacuum inside the cylinder. To further encourage the release of carbon dioxide from the sorbent media-containing cylinder, the regeneration station may fill and pressurize the cylinder with cold water. In one instance, the cylinder may be mechanically vibrated by the regeneration station to encourage the release of carbon dioxide into the cold water from the sorbent media-containing cylinder. The carbon dioxide may then be captured at the regeneration station and transported via pipes to the central balance of the plant for use or disposal.

This patent application was initially rejected as being anticipated by Hrycak (2005/0160913); however, the Applicant was able to overcome the rejection by identifying for the Examiner that Hrycak requires the plurality of gas-permeable adsorbent sheets 200a to be spaced apart from each other by separating screens 204. The Applicant amended claim 18 to recite that "one or more sorbent material holding sub containers" with a "partially open first end" and a "plugged second end." Hyrcak does not disclose that the sheets and separating screens are sorbent material holding sub containers" with a "partially open first end" and a "plugged second end." With this amendment the Examiner determined that Hrycak does not anticipate claim 18.

Figure 4.5. U.S. Patent No. 10,512,880 titled Rotating multi-monolith bed movement system for removing CO_2 from the atmosphere

Title	Rotating multi-monolith bed movement system for removing CO_2 from the atmosphere
Application No.	15/898,531
Patent No.	10,512,880
Issue Date	December 24, 2019
Assignee	Global Thermostat Operations, LLC
Inventor Name	Peter Eisenberger, Graciela Chichilnisky
Representative Figure	 *Figure 4. 5*
Description of Technology	A system for removing carbon dioxide from a carbon dioxide laden gas mixture, the system comprising two groups of carbon dioxide removal structures, each

	removal structure within each group comprising a porous solid mass substrate supported on the structure; and a sorbent that is capable of adsorbing or binding to carbon dioxide, to remove carbon dioxide from a gas mixture, the sorbent being supported upon the surfaces of the porous mass substrate solid; an endless loop support for each of the groups of the removal structures, the endless loop support being so arranged as to move the support structures of each group along a closed curve while being exposed to a stream of the gas mixture; and a sealable regeneration box at one location along each of the endless loop supports, in which, when a porous solid mass substrate is sealed in place therein, carbon dioxide adsorbed upon the sorbent is stripped from the sorbent and the sorbent regenerated; each removal structural supporting a porous substrate in a position to be exposed to a flow of carbon dioxide laden gas mixture so as to allow for the removal of CO_2 from the gas mixture; the number of removal structures to the number of regeneration boxes being directly determined by the ratio of the time to adsorb CO_2, from a base level to desired level on the sorbent, to the time to strip the CO_2 from the desired level back to the base level.
Exemplary Claim Language	A method for removing carbon dioxide from a carbon dioxide laden gas mixture, the method comprising: providing at least two groups of removal structures and two moving endless sloops for supporting each of the two groups each of which move around a closed endless loop for each group, each removal structure within each group comprising a porous solid substrate supported on each of the removal structures, each porous substrate having a sorbent supported upon its surfaces, the sorbent being capable of adsorbing or binding to carbon dioxide; exposing each individual carbon dioxide removal structure to a stream of the carbon dioxide laden gas mixture, during an adsorption time, to remove carbon dioxide from the gas mixture, each of the removal structures supporting the porous substrates on its respective closed endless loop being in a position such that the sorbent is exposed to a flow of carbon dioxide laden gas mixture so as to allow for the removal of CO_2 from the gas mixture; providing a regeneration box adjacent each loop at one location; successively sealably placing one of the carbon dioxide removal structures into a regeneration box at one location along each of the endless loop supports; exposing the sorbent on each removal structure sealably placed within each regeneration box to process heat at a temperature of less than 130° C. during a regeneration time to strip the CO_2 from the sorbent, such that when a removal structure is sealed in place therein carbon dioxide sorbed upon the sorbent is stripped from the sorbent and captured, and the sorbent regenerated; the number of removal structures provided on each loop to the number of regeneration boxes provided adjacent each loop, being directly proportional to and directly determined by the ratio of the adsorption time, to the regeneration time, the adsorption time being the time to adsorb, on the sorbent, CO_2 from the gas mixture, from a base level to a desired level on the sorbent, and the regeneration time being the time to strip the CO_2 from the sorbent, in the regeneration box, from the desired level back to the base level, on the sorbent.

The disclosed invention details a system for extracting carbon dioxide from ambient air. A process and system have been developed in accordance with the disclosed technology, using assemblies with several monoliths, or beds, combined with a single regeneration box in a configuration dependent upon the ratio of the speed of adsorption to the speed of regeneration of the sorbent. The monoliths are supported on a closed loop track, preferably forming a closed curve, and are rotated along the track in succession while being exposed to a moving stream of ambient air or a mixture of gases that primarily includes ambient air. The rotation stops at one point along the track, and one of the monoliths is placed into a sealed box for processing to remove CO_2 from the sorbent and renew the sorbent.

The monoliths are rotated around the track as the sorbent is regenerated until the next monolith is ready to enter the regeneration box, at which point the rotation of all the monoliths is stopped. Each monolith is made of a porous substrate with carbon dioxide-adsorbing amine sites on its surfaces, preferably with a large percentage of primary amines.[65] The monoliths adsorb CO_2 from the flowing gas streams as they move along the rail until each one enters the sealed box. The sorbent is treated once it has been sealed inside the box so that the CO_2 is taken from it, regenerating the sorbent. The stripped CO_2 from the box is captured and the next monolith is rotated into position to be transferred into the regeneration box. The monolith with the regenerate sorbent exits the sealed box and moves along the track with the other monoliths to adsorb more CO_2.

The monolith can be placed in a box at the site of stripping or regeneration that is either above or below the grade of the track, or it can be positioned so that the monolith

[65] Fernando Vega et al., "Solvents for Carbon Dioxide Capture," IntechOpen, August 16, 2018, https://doi.org/10.5772/intechopen.71443. When tertiary amines are compared to primary and secondary amines for the CO_2 separation process, there are three key differences between them. The direct reaction of primary and secondary amines with CO_2 via the Zwitterion mechanism results in the formation of carbamate. Due to the steady carbamate production throughout the absorption process, these amines displayed a limited thermodynamic capacity to absorb CO_2. On the other hand, because they lack the required N-H bond, tertiary amines can only produce a bicarbonate ion and protonated amine by the base-catalyzed hydration of CO_2. Tertiary amines exhibit poor CO_2 absorption rates because hydration is slower than the direct reaction by carbamate production.

enters the box at the same grade level as the track, producing a seal with the monolith. The system must have a sub-system for raising or lowering the monolith in cases where the regeneration box is below or above grade. A more complicated sealing arrangement will be needed in systems where the regeneration box is on grade with the rails in order to provide a seal along the sides in addition to the top and/or bottom surfaces.

The fundamental idea behind this method is that CO_2 is removed from the environment by passing air, or air mixed with effluent gas, over a bed of sorbent material, preferably at or near ambient temperatures. After the sorbent has absorbed the CO_2, the CO_2 must be collected, and the sorbent must be renewed. To liberate the CO_2 and regenerate the sorbent, the final step involves heating the sorbent with steam inside a sealed containment box.

After the CO_2 is removed from the container, the sorbent can be used to reabsorb CO_2 from the atmosphere. The process is primarily constrained by the fact that the sorbent may become inactive if exposed to air at a temperature that is “too high.” Before the monolith exits the box and is reintroduced to the air stream, the sorbent must be cooled. Adsorption of CO_2 from ambient air often takes longer than release of CO_2 during the regeneration process. When treating ambient air, the current generation of sorbent will necessitate an adsorption period as the adsorption period is roughly ten times longer than that needed for CO_2 release and sorbent regeneration.

The current framework for an individual rotational system consists of ten monoliths and a single regeneration unit. This ratio of adsorption time to desorption time, and consequently the number of monoliths needed in a system, should decrease as the sorbent’s effectiveness improves over time. One hour of adsorption time would be feasible, using just one regeneration box to feed five monoliths if an increased loading of the sorbent is used. Additionally, the relative treatment times will change depending on the amount of CO_2 present in the gas mixture being treated.

Both throughout the adsorption cycle and the regeneration cycle in the sealed box, the chemical and physical activity within the monoliths is basically the same as that detailed in the previously co-pending applications Ser. Nos. 13/886,207 and 13/925,679. The disclosures of those concurrent applications are amended by the new disclosure that is made here and are incorporated by reference as if they were reprinted in full here.

The number of rotating monoliths in the system is based on the relative times to accomplish the necessary adsorption and the desired regeneration. Each rotating system provides one sealable regeneration box for each group of rotating monoliths. Furthermore, it has been discovered that higher efficiencies and lower costs are attained by spatially relating and timing the operation of two of the rotating systems in a manner that permits the interaction of the regeneration boxes for the two rotating monolith systems, causing each to be preheated by the heat left over from regeneration in the other; this also effectively cools the regenerated monolith before it is brought back to its adsorption stage.

According to this invention, the interaction between the regeneration boxes is accomplished by reducing the pressure of the first box system so that, after the release of CO_2, the steam and water still present in the first box evaporate, and the system cools to the saturation temperature of the steam at its lowered partial pressure. Additionally, as will be discussed further below, the heat generated during this process is used to warm up the second sorbent bed in advance, resulting in a sensible heat recovery rate of around 50% and a reduction in both energy and water consumption. Even if an oxygen-resistant sorbent is used, this approach can still be applied. During the development phase, the sorbent's sensitivity to oxygen de-activation at higher temperatures is being addressed, and it is anticipated that its performance will improve with time.

To prevent deactivation by the oxygen in the air, it is preferable to chill the sorbent bed before exposing it to the air. The system pressure is decreased to achieve this cooling, which lowers the steam saturation temperature. As a result of the system's temperature being reduced, this has been shown to be effective in resolving the sorbent deactivation problem. As a result, the bed loses considerable energy as it is cooled during the depressurization process. To release the CO_2 and regenerate the sorbent, a fresh bed that has completed its CO_2 adsorption step must be heated. Even though steam at atmospheric pressure might produce this heat, doing so would increase running costs.

A two-bed design concept has been created to reduce this operational expense. A second box containing a bed that has finished adsorbing CO_2 from the air and that is to be heated to start the CO_2 removal and sorbent regeneration step is partially pre-heated using the heat that is removed from the box that is being cooled by reducing the system pressure, and thus the steam saturation temperature.

As a result, the steam consumption is decreased by raising the temperature of the second box using heat from the first box's cooling process. By adding steam, preferably at atmospheric pressure, the remaining heat duty for the second box is accomplished. The other rotating monoliths in each of the two boxes are subjected to the same procedure, which increases the system's thermal efficiency.

This application was finally rejected on January 22, 2019, based upon a patent to Goto (6,521,026) in view of Gidaspow (3,865,924). The application under review being directed to a method for removing CO_2 from a gaseous mixture. The Applicant amended independent claim 11 and replaced it with independent claim 22 to avoid the objection raised by the Examiner as to lack of definiteness in the claims defining the present application.

Goto discloses a rotor which is formed of a plurality of sectors identified as “1c”; the sectors alternately rotate through a portion of the rotor exposed to an effluent gas containing CO_2 and a second portion where the adsorbent within each sector that has adsorbed CO_2 and the sectors are exposed to a substantially higher temperature (upward of 600°C) in order to cause the CO_2 to be de-sorbed and thus regenerate the sorbent in each of the sectors. These two portions are of substantially equal size, *i.e.*, 180°, of the circumference, for each of the adsorption portion and the desorption portion of the rotor.

Apparently, the sectors, identified in Goto as 1c are formed around the entire circumference of the rotating cylinder, and each sector 1c is filled with an “absorbing/separating agent, which reversibly absorbs or releases carbon dioxide gas in accordance with changes in temperature.” (See Co1. 4, lines 14-17.) The overall rotor containing the plurality of sectors 1c rotates and as it rotates the several sectors move from “a high temperature section 1h and a low temperature section 1L, which are provided as partitioned sections around the rotation shaft 1a of the rotor 1b.”

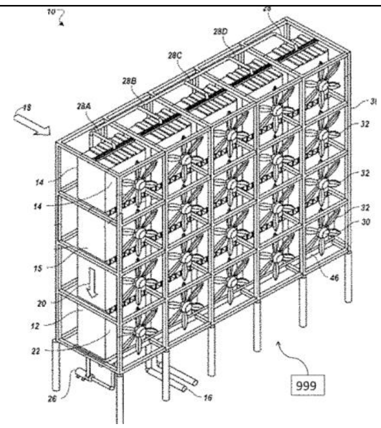
Nowhere in the text of Goto is there any suggestion or disclosure of an embodiment of the Goto system where the absorbing portion of the rotor is in any sense larger than the portion of the rotor that is exposed to the separating agent. The drawings depicting the rotating embodiment of the Goto invention, are FIGS. 1-4 and a review of these figures makes it abundantly clear that the two portions are substantially equal.

This is further confirmed by the second embodiment of the Goto invention, as depicted in FIG. 5 of the drawings of Goto, and as described at Col. 9, line 40, as follows: "FIG. 5 conceptually shows the structure of the main part of a fixed regenerative carbon dioxide gas separator according to the present invention." There is again no suggestion that there be more than these two fixed portions alternating between adsorbing or separating the CO_2. Although there is a suggestion to include additional reaction towers, for example "the number of reaction towers may be appropriately determined in accordance with the pressure loss value of the separator, all the amounts of the effluent gas and the carrier gas."

In no way is any of this a disclosure or suggestion that a different number of absorbers and separators should be used to increase the efficiency of a system where there is a large differential between the speed of adsorption from the gas mixture being treated and the speed of the desorption, or separation, to regenerate the sorbent. This proposal is present in none of Goto, Gidaspow or Wright and there exists no further disclosure or suggestion that the applicant's invention is possible or obvious.

In claim 19 the Examiner raised the issue of the applicant's definition of the relationship between the number of capture structures and the number of regeneration boxes as not a specific number. The Applicant asserted that the point of the invention is that it allows the operator of such a system to tailor the system as the availability of different sorbents and different compositions of mixed gases to be treated without having to completely restructure a particular operating process.

Figure 4.6. U.S. Patent No. 11,504,667 titled Carbon dioxide capture method and facility

Title	Carbon dioxide capture method and facility
Application No.	16/384,401
Patent No.	11,504,667
Issue Date	November 22, 2022
Assignee	Carbon Engineering LP
Inventor Name	David Keith, Maryan Mahmoudkhani, Alessandro Biglioli, Brandon Hart, Kenton Robert Heidel, Michael Foniok
Representative Figure	 *Figure 4. 6*
Description of Technology	A carbon dioxide capture facility is disclosed comprising packing formed as a slab, and at least one liquid source. The slab has opposed dominant faces, the opposed dominant faces being at least partially wind penetrable to allow wind to flow through the packing. The at least one liquid source is oriented to direct carbon dioxide absorbent liquid into the packing to flow through the slab. The slab is disposed in a wind flow that has a non-zero incident angle with one of the opposed dominant faces. A method of carbon dioxide capture is also disclosed. Carbon dioxide absorbing liquid is applied into packing in a series of pulses. A gas containing carbon dioxide is flowed through the packing to at least partially absorb the carbon dioxide from the gas into the carbon dioxide absorbing liquid.
Exemplary Claim Language	A carbon dioxide capture facility for removing carbon dioxide from atmospheric ambient air, comprising: at least one liquid having a capacity to absorb atmospheric carbon dioxide; at least one structural framework that comprises a plurality of interconnected structural members to form a plurality of three-dimensional modules that are in parallel airflow communication, wherein each three-dimensional module of the plurality of three-dimensional modules is configured to at least partially support: a structured packing material vertically sectionalized into a plurality of packing sections arranged end to end, vertically-adjacent packing sections of the plurality of packing sections arranged to define at least one vertical spacing in the structured packing material, each packing section of the plurality of packing sections defining a plurality of flow passages and positioned to receive an atmospheric ambient air flow in a direction from a first opposed dominant face of the structured packing material, through the plurality of flow passages, and toward a second opposed dominant face of the structured packing material opposite the first opposed dominant face, each packing section of the plurality of

	packing sections positioned to receive the at least one liquid having the capacity to absorb the atmospheric carbon dioxide through the plurality of flow passages, the structured packing material at least partially enclosed in the plurality of three-dimensional modules; and at least one fan positioned to influence the atmospheric ambient air flow through the first or second opposed dominant faces, each packing section of the plurality of packing sections comprising a dimension between the first and second opposed dominant faces that is parallel to the atmospheric ambient air flow and that is parallel to a depth dimension of the structured packing material, the fan positioned to circulate the atmospheric ambient air flow comprising the atmospheric carbon dioxide through the plurality of flow passages to bring the atmospheric carbon dioxide into contact with the at least one liquid having the capacity to absorb the atmospheric carbon dioxide; and at least one pump configured to apply the at least one liquid over the plurality of packing sections at a flow rate such that the atmospheric ambient air flow simultaneously enters each of the plurality of three-dimensional modules at a first carbon dioxide concentration range and leaves each of the plurality of three-dimensional modules at a second carbon dioxide concentration range less than the first carbon dioxide concentration range.

Disclosed in this patent is a carbon dioxide capture facility with packing shaped like a slab 15 and at least one liquid source 16. The slab has opposing dominant faces, and airflow can pass through the packing at least partially through the opposing dominant faces. The positioning of at least one liquid source allows carbon dioxide-absorbent liquid to flow into the packing and through the slab. An airflow that has a nonzero incidence angle with one of the opposing dominating sides is where the slab is located.

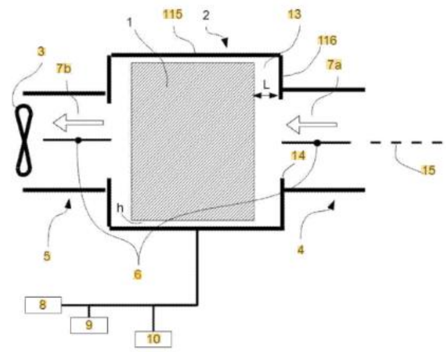
Also described is a method for capturing carbon dioxide. Pulses of carbon dioxide-absorbing liquid are applied to the packing. To absorb the carbon dioxide at least partially from the gas into the carbon dioxide absorbing liquid, a gas containing carbon dioxide is passed through the packing. Even though the liquid flows intermittently, the gas will flow continuously. Depending upon the embodiment, the liquid and gas may move in a crossflow geometry. For the purposes of this disclosure, crossflow refers to a situation in which the liquid and gas flows are orthogonal or perpendicular to one another.

Also disclosed is a gas-liquid contactor with packing and at least one liquid source. The packing is made of a slab-like structure with opposing dominating faces that are at least somewhat wind permeable. This allows wind to pass through the packing. The direction of at least one liquid source is such that the liquid is directed into the packing and through the slab. A wind flow that has a non-zero incidence angle with one of the opposing dominating sides is where the slab is located.

Multiple claims in this application were found to be obvious considering Meek (3,363,885) taken together with Curtis (5,227,095) in view of Christophersen (4,215,079) and further in view of Liu (8,414,853). Applicant amended independent claims 23 and 44 by incorporating the limitation of a structured packing material vertically sectionalized into a plurality of packing sections arranged end to end, vertically adjacent packing sections arranged to define at least one vertical spacing in the structured packing material. The Examiner allowed independent claims 23 and 44 and their respective dependents with the inclusion of the above referenced limitation.

Figure 4.7. U.S. Patent No. 10,232,305 titled Direct air capture device

Title	Direct air capture device
Application No.	15/315,930
Patent No.	10,232,305
Issue Date	March 19, 2019
Assignee	Climeworks AG
Inventor Name	Christopher Gebald, Werner Meier, Nicolas Repond, Tobias Ruesch, Jan Andre Wurzbacher

Representative Figure	 Figure 4. 7
Description of Technology	A vacuum chamber (**2**) for a direct air capture process and enclosing an interior space (**13**) for housing an adsorber structure (**1**) is given comprising a contiguous circumferential wall structure (**115**) along an axis (**15**), which circumferential wall structure (**115**) in an axial direction is closed by an inlet and an outlet axial wall (**116**), respectively. Both axial walls (**116**) comprise at least one closing stainless steel lid (**6**) allowing for, in an open position, gas to be circulated through the vacuum chamber (**2**) for passing an adsorber structure (**1**), and, in a closed position, to close the interior space (**13**) and to allow evacuation of the interior space (**13**) down to pressure of 500 mbar$_{abs}$ or less.
Exemplary Claim Language	A vacuum chamber for a direct air capture process and enclosing an interior space for housing an adsorber structure comprising: a contiguous circumferential wall structure arranged around an axis, which circumferential wall structure in an axial direction is closed by an inlet and an outlet axial wall, respectively, both axial walls comprising at least one circular closing lid allowing for, in an open position, gas to be circulated through the vacuum chamber for contacting the adsorber structure, and in a closed position, to close the interior space and to allow evacuation of the interior space down to a pressure of 500 mbar$_{abs}$, and less, wherein at least one of said axial walls is provided with a circular opening with a contact ring portion, which circular opening can be closed in a gas tight manner by said circular closing lid in the form of a single circular steel lid plate, having a thickness in the range of 4-12 mm and having a diameter in the range of 0.5-1.5 m and larger than said circular opening and in a closed state contacting said contact ring in an axial direction, wherein said contact ring on its axial surface facing said lid plate in closed position, is provided with a full perimeter circular elastic sealing element.

A goal of the disclosed invention is to provide a vacuum chamber for a direct air capture device that has a low thermal mass while also having a high mechanical stability to support the use of low vacuum pressures. The goal of the current invention is to provide a new closure mechanism for a vacuum chamber suitable for a direct air capture process that allows for a large flow cross-section to be available in the open position while also enabling a tight and robust seal even under challenging environmental conditions with a high mechanical stability at low thermal mass.

The first aspect of the invention proposes a vacuum chamber for a direct air capture process and enclosing an interior area for housing an adsorber structure, which need not be a vacuum chamber including ribbing parts. It is made up of a continuous circumferential circular, rectangular, or square wall structure that is closed in one axial direction by an intake axial wall and the other by an outlet axial wall. In order to close the interior space and permit evacuation of the interior space down to pressures of 500 $mbar_{abs}$ (about 7.3 psi) or even lower, both axial walls have at least one closing lid that can be opened to allow gas to circulate through the vacuum chamber to contact the adsorber structure.

When the structure is described as being configured to permit evacuation of the interior space down to a pressure of 500 $mbar_{abs}$ and less, it is intended to mean that the structure is capable of withstanding internal pressures of 500 $mbar_{abs}$ or lower, preferably at or below 101.325 KPa, when standing in an environment of ambient atmospheric pressure (about 1 atm, *i.e*. the construction is therefore designed to be able to endure pressures of up to 200 $mbar_{abs}$ or even lower, 5 $mbar_{abs}$. Therefore, the structure can endure a pressure differential between the interior and exterior spaces of 0.95, 0.99, or even 0.99999 bar, which is very close to or even around 1 bar.

A single circular lid plate having a diameter just a little bit larger than the circular opening and in a closed state contacting the contact ring in an axial direction can be used to seal the circular opening in a gas-tight manner according to the first aspect of this invention. Preferably, both axial walls are provided with the circular opening and contact ring. In the closed state, the lid plate's axial surface facing the contact ring has a full perimeter circular elastic sealing element.

Such a construction is both mechanically stable and highly efficient. In fact, the circular lid can slightly deform inward under the weight of the actuation mechanism in the closed position, automatically compensating for sealing flaws (distortions of the contact ring and/or of the lid, contaminations of the sealing portion such as dust, insufficient sealing ring quality).

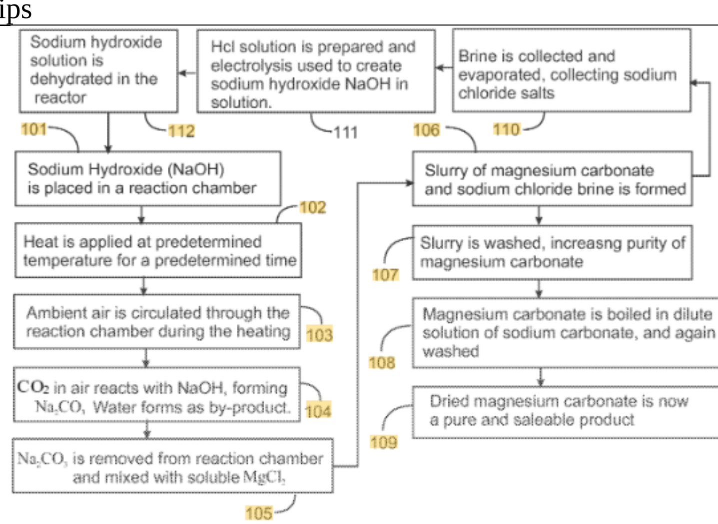
In a first preferred implementation of this second aspect, the contact ring has a full perimeter circular groove that is open and facing the lid from the outside (as seen from the interior space), and where, preferably, an O-ring made of an elastic material is situated. This O-ring's chord diameter should be between 2 and 15 millimeters, more preferably between 3-6 millimeters.

The lid is circular, preferably stainless steel or steel plate with a diameter between 0.4 and 1.5 meters, preferably 0.75 to 1.25 meters, a thickness between 4 and 12 millimeters, preferably between 6 and 10 millimeters, and is preferably free of any stiffening element aside from attachment elements for attaching the mechanism for actuating and controlling the lid.

Whenever stainless-steel plates or other stainless-steel elements are mentioned in the following, they generally refer to steel elements, ideally stainless-steel elements. The diameter of the lid is preferably between 105 and 145 times the thickness of the lid plate, to allow for the deformation of the lid plate. This application received a first office action allowance consequently, the prosecution history is limited for this patent.

The Examiner rejected claims 6-11, 22 and 24-29 under 35 U.S.C. § 112(b) as being indefinite. The Applicant amended each claim to address the indefiniteness rejection and the Examiner advised that claims 1-5, 12-21 and 30-34 were allowed and that claims 6-11, 22 and 24-39 would be allowable if rewritten to overcome the rejection under 35 U.S.C. § 112(b). Applicant amended the claims in a manner to secure their allowance.

Figure 4.8. U.S. Patent No. 11,484,831 titled Direct air capture system removing carbon dioxide

Title	Direct air capture system removing carbon dioxide
Application No.	17/405,950
Patent No.	11,484,831
Issue Date	November 1, 2022
Assignee	Not assigned
Inventor Name	Eric Phillips
Representative Figure	 *Fig. 1* *Figure 4. 8*
Description of Technology	A direct air capture (DAC) system for removal of carbon dioxide from ambient air has a reaction chamber having an air intake opening and an air exhaust opening, an air movement mechanism positioned to move air from outside through the reaction chamber, utilizing the air intake and the air exhaust openings, and a mechanism introducing sodium hydroxide into the reaction chamber. Carbon dioxide in the air moved through the reaction chamber interacts chemically with the sodium hydroxide, producing sodium carbonate and water.
Exemplary Claim Language	A direct air capture (DAC) system for removal of carbon dioxide from ambient air, comprising: a reaction chamber having an air intake opening and an air exhaust opening; an air movement mechanism positioned to move air from outside through the reaction chamber, utilizing the air intake and the air exhaust openings;

	a mechanism introducing sodium hydroxide into the reaction chamber; and a mechanism heating the sodium hydroxide to a temperature of about 49 degrees Celsius; characterized in that carbon dioxide in the air moved through the reaction chamber interacts chemically with the sodium hydroxide, producing sodium carbonate and water.

An air movement mechanism is positioned to move air from the outside through the reaction chamber using the air intake and the air exhaust openings, and a mechanism is introduced into the reaction chamber to add sodium hydroxide. This direct air capture system for removing carbon dioxide from ambient air is provided in one embodiment of the invention. Sodium hydroxide and carbon dioxide in the air passing through the reaction chamber mix chemically to produce sodium carbonate and water.

In one implementation, the system also includes a heating mechanism for the sodium hydroxide. Additionally, in one embodiment, a temperature of about 49 degrees Celsius is reached when the sodium hydroxide is heated. A permeable membrane impregnated with sodium hydroxide and suspended in the reaction chamber serves as the mechanism for introducing sodium hydroxide in one embodiment. In one implementation, the system also includes a heating element located close to the membrane, which heats both the membrane and its content.

In one variation, the temperature of the sodium hydroxide is raised to around 49 degrees Celsius. A misting system that draws sodium hydroxide from an external source and introduces it into the reaction chamber as a mist is another version of the mechanism used to introduce sodium hydroxide. In one version, the system also includes a heating device close to the external source of sodium hydroxide, which warms the sodium hydroxide before dispensing it as a mist. And in one variation, a temperature of roughly 49 degrees Celsius is reached when the sodium hydroxide is heated.

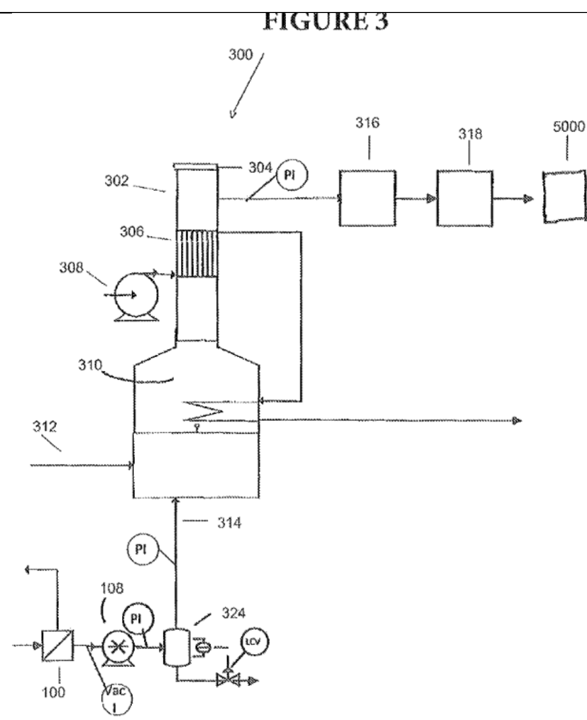
A method for direct air capture to remove carbon dioxide from ambient air is provided in another aspect of the invention. It involves adding a certain amount of sodium hydroxide to a reaction chamber with air intake and exhaust openings as well as an air movement mechanism that is positioned to move air from the outside through the reaction chamber. The air movement mechanism is then used for a specified amount of time.

In one variation, the process also includes a step where a device is used to heat the sodium hydroxide while air is moving over it. A step of withdrawing sodium carbonate from the reaction chamber and mixing it with soluble magnesium chloride is also included in one version of the process, which results in a slurry of magnesium carbonate and sodium chloride brine. Additionally, one embodiment of the process includes a step of washing the slurry to improve the magnesium carbonate's purity.

In one variation, the procedure further includes boiling the magnesium carbonate in a diluted sodium carbonate solution, washing it once more, and drying it to create a magnesium carbonate product that can be sold. One implementation of the process includes the steps of collecting the brine and turning it into sodium chloride salt through evaporation. Preparing a sodium chloride solution and using electrolysis to produce sodium hydroxide in solution are two aspects of one implementation of the method. Additionally, in one embodiment, the process includes dehydrating the sodium hydroxide solution before adding it to the reaction chamber so that it can react with carbon dioxide in air circulating through the chamber.

Claims 1, 2, 4, 7 and 10 were rejected under 35 U.S.C. § 103 as being unpatentable over WO 2017 004 712. The Applicant amended claims 1, 4, 7 and 10. Specifically, claim 1 was amended to include the limitation of a mechanism heating the sodium hydroxide to a temperature of about 49 degrees Celsius. Claims 4 and 7 were amended to include a reaction chamber, an air movement mechanism, and a heating element proximate the membrane by which the membrane and its content are heated. Lastly, claim 10 was amended to require operating a mechanism heating the sodium hydroxide during a period with air passing over the sodium hydroxide. These amendments resulted in the allowance of the application.

Figure 4.9. U.S. Patent No. 11,638,902 titled Apparatus and method for direct air capture of carbon dioxide from the atmosphere

Title	Apparatus and method for direct air capture of carbon dioxide from the atmosphere
Application No.	17/671,408
Patent No.	11,638,902
Issue Date	May 2, 2023
Assignee	Black Swan, LLC
Inventor Name	Brian Kolodji
Representative Figure	 *Figure 4. 9*
Description of Technology	An apparatus utilizing a membrane unit to capture components from atmospheric air, including carbon dioxide, enriches the carbon dioxide concentration, and delivers the enriched concentration of carbon dioxide to a sequestering facility. The membrane is configured such that as a first gas containing oxygen, nitrogen and carbon dioxide is drawn through the membrane, a permeate stream is formed where the permeate stream has an oxygen concentration and a carbon dioxide concentration higher than in the first gas and a nitrogen concentration lower than in the first gas.
Exemplary Claim	An apparatus for reducing fuel consumption in a flue gas generator comprising:

Language	a membrane unit comprising an outer surface and an inner surface, wherein the membrane unit is configured such that as a first gas comprising a first concentration of nitrogen, a first concentration of oxygen, a first concentration of water, and a first concentration of carbon dioxide is drawn into the outer surface and passes through the membrane, a permeate stream exits the inner surface where the permeate stream comprises a second concentration of nitrogen, a second concentration of oxygen, a second concentration of water, and a second concentration of carbon dioxide wherein the second concentration of oxygen is greater than the first concentration of oxygen, the second concentration of water is greater than the first concentration of water, the second concentration of carbon dioxide is greater than the first concentration of carbon dioxide, and the second concentration of nitrogen is less than the first concentration of nitrogen; a vacuum-generating device which applies a vacuum to the membrane unit; a permeate collection device which collects the permeate stream; and a flue gas generator which receives at least a portion of the permeate stream wherein the flue gas generator comprises an economizer.

A permeate containing an enriched concentration of carbon dioxide, oxygen, and water as well as a reduced concentration of nitrogen is produced by embodiments of the present invention that take advantage of the special property of membranes to economically achieve direct air capture of carbon dioxide from the atmosphere. Embodiments of the present invention use low pressure “leaf” membrane units to remove nitrogen from the atmosphere, thereby mildly or moderately increasing the concentrations of the carbon dioxide and the oxygen in the permeate, rather than processes that yield highly purified concentrations of carbon dioxide and oxygen at significant capital expense and significant operating costs. To provide meaningful benefits, the resulting permeate stream does not need to be highly cleaned.

Embodiments of the invention may employ membrane components with characteristics resembling those of the cellulose acetate-based sheet or spiral wound type membrane units used in the Separex™ membrane product as manufactured by Honeywell/UOP, or other polymeric based membrane products such as “plate and frame” type Polaris™ membranes as manufactured by MTR, Inc., or hollow fiber type membrane units such as Cynara™ membranes as manufactured by Schlumberger, or PRISM™ membranes. However, these well-known membrane devices need a substantial supporting structure and blowers or compressors to function.

The oxygen and carbon dioxide concentrations of a gas stream processed via the membrane units are enriched by the employment of the membrane materials and products mentioned above. In comparison to nitrogen, carbon dioxide and oxygen pass through the membrane more quickly, generating a permeate stream that is enriched or concentrated in carbon dioxide and oxygen compared to the “feed” stream. It should be noted that the word “feed” used in this disclosure is used rather loosely and does not refer to a stream provided to the membrane by an intake or other similar structure.

A “feed” side of the membrane, which is also sometimes referred to as the “outer side” but should not be limited to an exterior position, is exposed to a gas, principally air, which is brought into the membrane unit by a vacuum applied to the membrane unit with embodiments of the currently disclosed leaf membranes. Nitrogen is primarily dispersed into the environment on the same side of the membrane as the “feed” stream because it diffuses through the membrane relatively slowly compared to oxygen, carbon dioxide, and water.

A flue gas generator may be positioned between the membrane unit and the sequestration facility in one implementation of the invention. Conventionally, the combustion processes used in flue gas generators employ atmospheric air to create a flue gas that has carbon dioxide concentrations that are significantly higher than those present in atmospheric air. As previously mentioned, the permeate stream produced by the disclosed membrane units contains higher carbon dioxide and oxygen contents than ambient air.

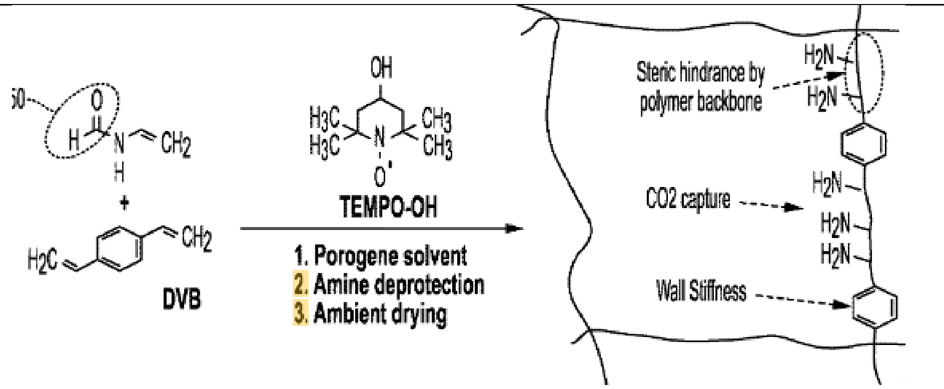
A combustion process that uses the permeate stream instead of atmospheric air produces flue gas with a carbon dioxide content that is significantly higher than when utilizing regular combustion air. The above-mentioned sequestration facilities may then make use of this carbon dioxide-enriched flue gas. There may be no requirement for downstream pressurization in some invention implementations since the flue gas generator may be pressurized. Embodiments of the invention may also include a secondary (or tertiary) enrichment system that feeds secondary membrane units housed in conduit or piping or a cryogenic oxygen enrichment system with the permeate from a first-stage membrane unit.

For the purpose of applying suction to the membrane units, a special vacuum system may be used. The vacuum required to process a feed gas through the disclosed leaf membranes is created using the very straightforward and low power described bellows system. Also revealed is a technique for directly capturing carbon dioxide in the air by using membrane components in a vacuum.

Claims 1-7, 10-18 and 20 were considered allowable by the Examiner except for an obviousness-type double patenting rejection. Applicant overcame the rejection by filing a terminal disclaimer over claims 1-13, 16 and 17 of U.S. Patent No. 11,247,176 titled Apparatus and method for direct air capture of carbon dioxide from the atmosphere.

Figure 4.10. U.S. Patent No. 11,612,852 titled Tunable, rapid uptake, aminopolymer aerogel sorbent for direct air capture of CO_2

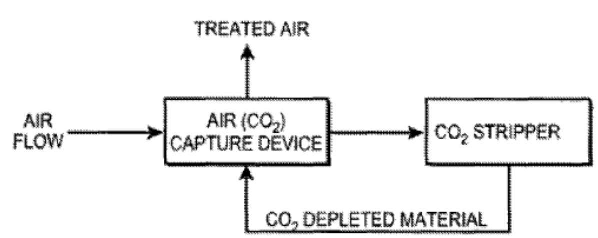
Title	Tunable, rapid uptake, aminopolymer aerogel sorbent for direct air capture of CO_2
Application No.	17/211,588
Patent No.	11,612,852
Issue Date	March 28, 2023
Assignee	Palo Alto Research Center, Inc.
Inventor Name	Mahati Chintapalli, Stephen Meckler, Gabriel Iftime, Rahul Pandey, Mary Louie, Eugene Shin Ming Beh

Representative Figure	 *Figure 4. 10*
Description of Technology	A porous polymer aerogel, wherein the aerogel has greater than 5 wt % of amine containing vinyl monomers integrated into a polymer backbone. A method of fabrication of a porous polymer aerogel amine material, includes preparing a solution comprising at least a solvent, amine monomers having protected amino groups, one or more crosslinkers, one or more radical initiators, and a nitroxide mediator, removing oxygen from the solution, heating the solution to promote polymerization and to produce a polymerized material, performing solvent exchange with the polymerized material, causing a deprotection reaction in the polymerized material to remove groups protecting the amino groups, soaking and rinsing the material to remove excess reagents and any byproducts of the deprotection reaction, and drying the material to produce the amine sorbent. A system to separate CO_2 from other gases, comprising a polymer porous aerogel sorbent having greater than 5 wt % of amine containing vinyl monomers integrated into a polymer backbone.
Exemplary Claim Language	A porous polymer aerogel, the aerogel having greater than 5 wt % of amine containing vinyl monomers covalently integrated into a polymer backbone, wherein the amine containing vinyl monomers have a molecular weight of less than 100 g/mol.

Disclosed in this patent is a porous polymer aerogel with more than 5 weight percent of amine-containing vinyl monomers integrated into a polymer backbone is offered in accordance with the aspects shown below. The method of making a porous polymer aerogel amine material according to the aspects shown here includes making a solution with at least a solvent, amine monomers, one or more crosslinkers, one or more radical initiators, and a nitroxide mediator, removing oxygen from the solution, heating the solution to encourage polymerization and produce a polymerized material, exchanging solvents with the polymerized material, and causing the polymerized material to become porous.

The Examiner rejected this application on various grounds including lack of novelty and obviousness. Claims 5, 6 and 11-17 were rejected under 35 U.S.C. § 102(a) as being anticipated by Fonnum (WO00/56790) as illustrated by Jamart (U.S. Publication No. 2017/0252718), or in the alternative under 35 U.S.C. § 103 as being unpatentable over Fonnum as illustrated by Jamart. Applicant cancelled 32 claims and added 20 new claims asserting that the prior art did not show, teach or suggest a polymer aerogel of a vinylamine monomer and a crosslinking monomer. The vinyl monomer must be covalently integrated into a polymer backbone wherein the amine containing vinyl monomer has a molecular weight of less than 100 g/mol. With the addition of the new claims the Examiner found that the claims were no longer anticipated or obvious and permitted the claims to proceed to allowance.

Figure 4.11. U.S. Patent No. 10,150,112 titled Air collector with functionalized ion exchange membrane for capturing ambient CO_2

Title	Air collector with functionalized ion exchange membrane for capturing ambient CO_2
Application No.	15/133,513
Patent No.	10,150,112
Issue Date	December 11, 2018
Assignee	Carbon Sink Inc.
Inventor Name	Allen B. Wright, Eddy J. Peters
Representative Figure	 *Figure 4. 11*
Description of Technology	An apparatus for capture of CO_2 from the atmosphere comprising an anion exchange material formed in a matrix exposed to a flow of the air.
Exemplary Claim Language	An apparatus for capture of CO_2 from ambient air, the apparatus comprising: a) an air capture device comprising a corrugated anion exchange material that captures CO_2 from ambient air upon exposure to the ambient air; b) a release mechanism for releasing the captured CO_2 and regenerating the corrugated anion exchange material; and

	c) a concentrator that concentrates the acidic gas released from said corrugated anion exchange material.

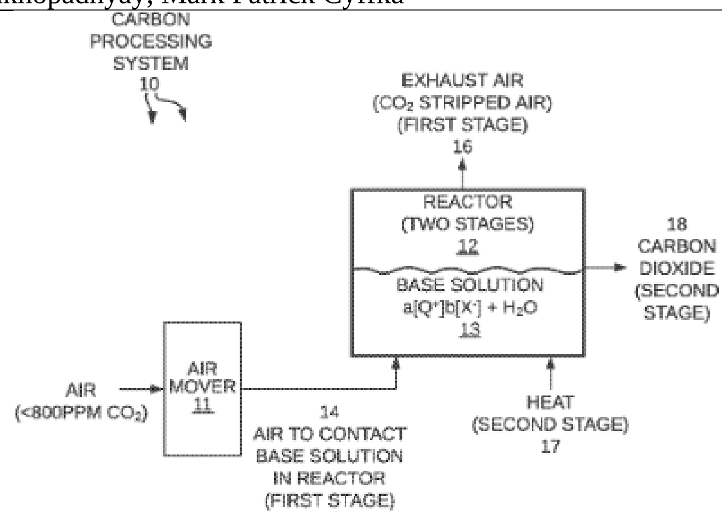
The direct capture of CO_2 and other acid gases from the air using solid phase, anion exchange materials is made possible by this invention, which in one aspect offers practical physical configurations of active air contacting elements, processes for the manufacture of the active elements, and configuration options of an air collector device.

According to the current invention, the air capture device is the front-end element of a larger system that is intended to chemically remove the captured CO_2 from the air capture device, concentrate the CO_2 for later permanent disposal, reconstitute the process chemicals, and reactivate the CO_2 capture materials in preparation for the subsequent capture cycle. A functionalized anion exchange polymer is used in the air capture device to create a reasonably high surface area that minimizes airflow resistance. An open matrix or unordered mesh of “noodle-like” strands, resembling those in evaporative or humidifier pads, is one implementation of the anion exchange polymer. As an alternative, the anion exchange polymer is coated on the surfaces of a support material that has been shaped into cells and meets specific performance requirements for crucial capture.

The disclosure provides a detailed specification for the chemical performance of the solid phase ion exchange material in the concurrent PCT Application Serial No. PCT/US06/029238, filed on July 28, 2006. One part of this application focuses on mechanical configurations and air-side performance improvements to guarantee that the total system’s low energy requirements are satisfied while also ensuring a reliable design with repeatable air capture performance. Another feature of this application is a comprehensive mechanism for reforming CO_2 into other molecules, which will effectively stop the release of the captured CO_2 back into the atmosphere.

This application received a first office action notice of allowance so the prosecution history on this application is limited. The application has been terminally disclaimed by U.S. Patent No. 8,088,197 titled *Removal of carbon dioxide from air* which requires a store of ambient air, an anion exchange material in contact with a flow of the ambient air, and a collector that collects CO_2 separated from the anion exchange material subsequent to the capture of the CO_2 by the anion exchange material.

Figure 4.12. U.S. Patent No. 11,612,853 titled Fully automated direct air capture carbon dioxide processing system

Title	Fully automated direct air capture carbon dioxide processing system
Application No.	17/948,492
Patent No.	11,612,853
Issue Date	March 28, 2023
Assignee	Airmyne Inc.
Inventor Name	Sudip Mukhopadhyay, Mark Patrick Cyffka
Representative Figure	 CARBON PROCESSING SYSTEM FIG. 1 *Figure 4. 12*
Description of Technology	A carbon processing system comprises an air mover and a multi-stage reactor. The multi-stage reactor processes ambient air and generates carbon dioxide and generates exhausted gas released to ambient air. In operation, air contacts the base solution via the air mover. The air reacts with the base solution thereby generating a base solution having carbon dioxide and generating exhaust (absorption reaction). Next, the exhaust is released from the reactor. Next, heat is applied to the base solution having carbon dioxide thereby generating carbon

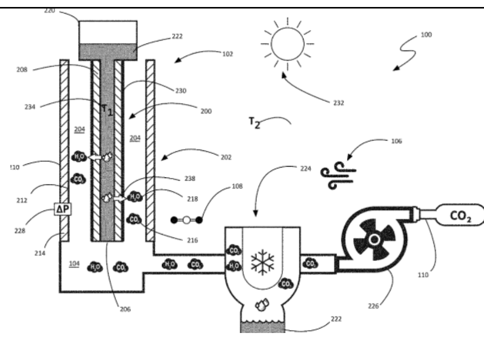
	dioxide and generating a base solution without carbon dioxide (desorption reaction). The base solution without carbon dioxide generated after applying heat is reusable in processing new air. The absorption reaction and desorption reaction are reversible reactions resulting in regeneration of the base solution into its form prior to contact with the air yielding high scalability and less processing volume as required by many conventional carbon processing techniques.
Exemplary Claim Language	A method comprising: contacting air with a base solution in the presence of packing material, wherein air reacts with the base solution thereby generating a base solution having carbon dioxide and generating exhaust; releasing the exhaust; applying heat to the base solution having carbon dioxide thereby generating carbon dioxide and generating base solution without carbon dioxide; and compressing the carbon dioxide.

When the air mover is in use, air encounters the base solution. The carbon processing system uses a base solution that is regenerated during the novel process and reused during each carbon processing cycle. This provides for significant automation capabilities and scalability of the carbon processing system. The base solution, such as a dissolved salt, and air interact, creating an exhaust and a base solution that contains CO_2. It is an absorption reaction in this initial stage. The reactor then releases its exhaust. Compared to air that encounters the base solution, released exhaust contains less CO_2. The base solution with CO_2 is then heated, producing CO_2 and a base solution devoid of CO_2.

It is a desorption reaction in the second step. Heat application produces a base solution without CO_2, which can be used to treat fresh air. The base solution is restored to its original state before contacting the air thanks to the reversible reactions of absorption and desorption. In comparison to several traditional carbon processing methods, the carbon processing system is extremely scalable and uses less processing volume.

An Examiner interview was held on January 4, 2023, and the Applicant and Examiner agreed that limiting all the independent claims to compressing the carbon dioxide would overcome the rejection based on at least US 2019/0193019 (Okano) and render the independent claims allowable over the art of record.

Figure 4.13. U.S. Patent No. 11,478,745 titled Device and method for CO_2 capture through circumscribed hollow membranes

Title	Device and method for CO_2 capture through circumscribed hollow membranes
Application No.	17/010,799
Patent No.	11,478,745
Issue Date	October 25, 2022
Assignee	Arizona Board of Regents of ASU
Inventor Name	Klaus Lackner
Representative Figure	 *Figure 4. 13*
Description of Technology	A device and method for carbon dioxide capture using circumscribed hollow membranes is disclosed. The device includes a hollow membrane unit having an inner conduit composed of a vapor membrane, and an outer conduit having an inside surface circumscribing the inner conduit forming a lumen. The outer conduit includes a CO_2 pump membrane. The device also includes a mechanical pump maintaining a pressure differential between the lumen and the atmosphere, providing a product stream of CO_2-rich gas from the lumen. The vapor membrane is sufficiently hydrophobic and porous to contain liquid water while also allowing water vapor formed by evaporation to pass through into the lumen. As water vapor passes from the lumen to the atmosphere through the CO_2 pump membrane, a carbon concentration gradient is formed and maintained across the CO_2 pump membrane. The carbon concentration gradient actively pumps CO_2 out of the atmosphere and into the lumen.
Exemplary Claim Language	A device for carbon dioxide capture, comprising: a hollow membrane unit, comprising: an inner conduit closed at one end, the inner conduit comprising a vapor membrane; an outer conduit having an outside surface exposed to an atmosphere and an inside surface circumscribing the inner conduit forming a lumen between the inner conduit and the inside surface of the outer conduit, the outer conduit comprising a CO_2 pump membrane, the lumen comprising a CO_2-rich gas and a water vapor, the water vapor being substantially saturated; and a light-absorbing material; a water supply in fluid communication with the inside of the inner conduit; a mechanical pump in fluid communication with the lumen, the mechanical pump

	maintaining a pressure differential of at least one atmosphere between the lumen and the atmosphere and providing a product stream comprising the CO_2-rich gas; and a cold trap coupled to the hollow membrane unit and the mechanical pump such that the mechanical pump is in fluid communication with the lumen of the hollow membrane unit through the cold trap; wherein the vapor membrane contains liquid water provided by the water supply, the vapor membrane being sufficiently hydrophobic and porous to contain the liquid water received while also allowing water vapor to pass through the vapor membrane into the lumen, the water vapor formed by the evaporation of the liquid water; wherein the CO_2 pump membrane is CO_2-permeable and wherein, as water vapor passes from the lumen to the atmosphere through the CO_2 pump membrane, a carbon concentration gradient is formed and maintained across the CO_2 pump membrane with a first concentration at the outside surface that is higher than a second concentration at the inside surface, said carbon concentration gradient actively pumping CO_2 out of the atmosphere and into the lumen; and wherein the liquid water inside the inner conduit is heated by sunlight absorbed by the light-absorbing material to a temperature that is above an ambient temperature, thereby facilitating the evaporation of the liquid water to introduce water vapor into the lumen.

The carbon dioxide capture device disclosed in this patent consists of a hollow membrane unit with an inner conduit that is closed at one end. There is a vapor membrane inside the inner conduit. The hollow membrane unit also consists of an outer conduit with an interior surface that surrounds the inner conduit and an exterior surface that is exposed to the atmosphere, creating a lumen between the inner conduit and the exterior surface. A CO_2 pump membrane is part of the outside conduit, and a CO_2-rich gas and highly saturated water vapor are present in the lumen. A substance that absorbs light is also included in the hollow membrane unit.

The apparatus consists of a mechanical pump and a water supply in fluid connection with the lumen and the inner conduit, respectively. The mechanical pump delivers a product stream that contains the CO_2-rich gas while maintaining a pressure differential of at least one atmosphere between the lumen and the atmosphere. For the mechanical pump to be in fluid contact with the lumen of the hollow membrane unit through the cold trap, the device also contains a cold trap that is connected to the hollow membrane unit, the mechanical pump, and the cold trap. Since the vapor membrane is sufficiently hydrophobic and porous to hold the liquid water received while enabling water vapor to travel through it into the lumen, the vapor membrane holds the liquid water supplied by the water supply. The evaporation of the liquid water produces the water vapor.

A carbon concentration gradient is formed and maintained across the CO_2 pump membrane with a first concentration at the outside surface that is higher than a second concentration at the inside surface. This carbon concentration gradient actively pumps CO_2 out of the atmosphere and into the lumen. The CO_2 pump membrane is CO_2-permeable. As water vapor passes from the lumen to the atmosphere through the CO_2 pump membrane. As a result of sunlight being absorbed by the light-absorbing material, the liquid water inside the inner conduit is heated above ambient temperature, allowing for the evaporation of the liquid water and the introduction of water vapor into the lumen.

Specific embodiments might include one or more of the enumerated characteristics. Strong base anionic materials may be present in the CO_2 pump membrane. At almost the same pace as CO_2 and water vapor are delivered to the lumen through the water membrane and the CO_2 pump membranes, the mechanical pump may remove CO_2-rich gas and water vapor from inside the lumen. The system may also include several hollow membrane units connected to a manifold, each of which may have an inner conduit in fluid communication with the water supply and an interior lumen in fluid communication with a mechanical pump via the manifold.

A device for carbon dioxide capture may, in accordance with another element of the disclosure, include a hollow membrane unit with an inner conduit that is closed at one end.

There is a vapor membrane inside the inner conduit. The hollow membrane unit also consists of an outer conduit with an interior surface that surrounds the inner conduit and an exterior surface that is exposed to the atmosphere, creating a lumen between the inner conduit and the exterior surface.

A CO_2 pump membrane is part of the outside conduit, and a CO_2-rich gas and water vapor are both present in the lumen. The apparatus consists of a mechanical pump and a water supply in fluid connection with the lumen and the inner conduit, respectively. The mechanical pump delivers a product stream that contains the CO_2-rich gas while maintaining a pressure differential between the lumen and the atmosphere.

Since the vapor membrane is sufficiently hydrophobic and porous to hold the liquid water received while enabling water vapor to travel through it into the lumen, the vapor membrane holds the liquid water supplied by the water supply. The evaporation of the liquid water produces the water vapor. A carbon concentration gradient is formed and maintained across the CO_2 pump membrane with a first concentration at the outside surface that is higher than a second concentration at the inside surface. This carbon concentration gradient actively pumps CO_2 out of the atmosphere and into the lumen. The CO2 pump membrane is CO_2-permeable. As water vapor passes from the lumen to the atmosphere through the CO_2 pump membrane.

Specific embodiments might include one or more of the enumerated characteristics. The device might also have a cold trap connected to the mechanical pump, the hollow membrane unit, and/or both such that the mechanical pump could be in fluid communication with the hollow membrane unit's lumen through the cold trap. To facilitate the evaporation of the liquid water and the introduction of water vapor into the lumen, the liquid water inside the inner conduit may be heated to a temperature that is higher than the ambient temperature. The liquid water inside the inner conduit may be heated by sunlight absorbed by the light-absorbing material, which may be a component of the hollow membrane unit.

Strong base anionic materials may be present in the CO_2 pump membrane. At almost the same pace as CO_2 and water vapor are delivered to the lumen through the water membrane and the CO_2 pump membranes, the mechanical pump may remove CO_2-rich gas and water vapor from inside the lumen. It's possible that the water vapor inside the lumen is significantly saturated. The gadget might also come with several hollow membrane components connected to a manifold. Each hollow membrane unit may have an inner conduit that is in fluid communication with the water supply or a lumen that is in fluid communication with the mechanical pump via a manifold.

Another component of the disclosure states that one way to capture carbon dioxide is to fill an inner conduit with liquid water from a water supply that is in fluid communication with the inner conduit. The outer conduit has a CO_2 pump membrane that is CO_2-permeable, and it is encircled by an inner conduit that has a vapor membrane. The outer conduit has an outside surface that is exposed to the atmosphere and an inside surface that faces the inner conduit, creating a lumen that runs the length of the outer conduit. The method further comprises allowing the liquid water inside the inner conduit to evaporate and pass through the vapor membrane, the vapor membrane being sufficiently hydrophobic and porous to contain the liquid water while also allowing water vapor to pass through the vapor membrane into the lumen.

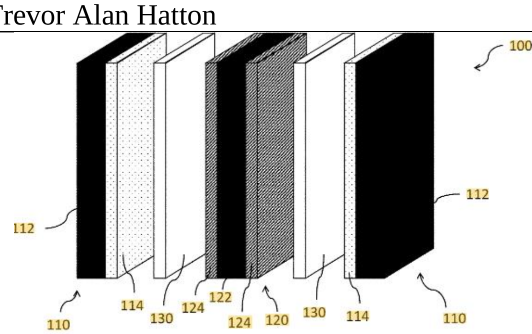
By allowing water vapor to pass from the lumen to the atmosphere through the CO_2 pump membrane, a carbon concentration gradient is formed and maintained, with a first concentration at the outside surface being higher than a second concentration at the inside surface. This carbon concentration gradient actively pumps CO_2 out of the atmosphere and into the lumen as a CO_2-rich gas. The technique further comprises the steps of removing water vapor and CO_2-rich gas from the lumen using a mechanical pump that is in fluid communication with the lumen, the mechanical pump maintaining a pressure differential between the lumen and the atmosphere, and the mechanical pump supplying a product stream comprising the CO_2-rich gas.

Specific embodiments might include one or more of the enumerated characteristics. Before infusing the water vapor, the lumen may first be extensively evacuated as part of the procedure. The process could also involve condensing the CO_2-rich gas and water vapor when they are expelled from the lumen. With a cold trap connected to the mechanical pump, the hollow membrane unit’s lumen, and the mechanical pump so that the mechanical pump is in fluid contact with the lumen through the cold trap, the water vapor may be condensed.

To facilitate the evaporation of the liquid water inside the inner conduit and introduce water vapor into the lumen, the method may further comprise heating the liquid water to a temperature that may be higher than the ambient temperature. In thermal contact with the inner conduit, a light-absorbing substance may absorb sunlight to heat the liquid water. At almost the same pace that CO_2 and water vapor are delivered to the lumen through the water membrane and the CO_2 pump membranes, the CO_2-rich gas and water vapor may be withdrawn from inside the lumen. It is possible that the water vapor inside the lumen is significantly saturated.

Claims 2, 9, 18 and 20 of this application were rejected by the Examiner pursuant to 35 U.S.C. § 112 as being indefinite for failing to particularly point out and distinctly claim the subject matter which the inventor regards as the invention. To expedite prosecution of the application, the Applicants elected to cancel claims 2, 9 and 18 and to amend the dependency of claim 20 to claim 19 and to require the water vapor within the lumen to be substantially saturated. Upon responding with these amendments, the Examiner allowed the claims.

Figure 4.14. U.S. Patent No. 11,598,012 titled Electrochemically mediated gas capture, including from low concentration streams

Title	Electrochemically mediated gas capture, including from low concentration streams
Application No.	17/005,243
Patent No.	11,598,012
Issue Date	March 7, 2023
Assignee	Massachusetts Institute of Technology
Inventor Name	Sahag Voskian, Trevor Alan Hatton
Representative Figure	 FIG. 2 *Figure 4. 14*
Description of Technology	Methods, apparatuses, and systems related to the electrochemical separation of target gases from gas mixtures are provided. In some cases, a target gas such as carbon dioxide is captured and optionally released using an electrochemical cell (e.g., by bonding to an electroactive species in a reduced state). Some embodiments are particularly useful for selectively capturing the target gas while reacting with little to no oxygen gas that may be present in the gas mixture. Some such embodiments may be useful in applications involving separations from gas mixtures having relatively low concentrations of the target gas, such as direct air capture and ventilated air treatment.
Exemplary Claim Language	A gas separation system comprising: a plurality of electrochemical cells in fluidic communication with a gas inlet and a gas outlet, wherein each of the electrochemical cells comprises: a negative electrode comprising a first electroactive species; a positive electrode; and a separator between the negative electrode and the positive electrode, the separator being capable of containing a conductive liquid; wherein the first electroactive species has: an oxidized state; and at least one reduced state in which the species is capable of bonding with a target

	gas, but for which a reaction with oxygen (O_2) has a change in Gibbs free energy that is greater than or equal to 0 kcal/mol at at least one temperature that is within a range greater than or equal to 223 K and less than or equal to 573 K.

This patent presents procedures, tools, and systems for the electrochemical separation of target gases from gas mixtures. An electrochemical cell is often used to catch a target gas, such as carbon dioxide, and then release it if desired (for example, by bonding to an electroactive molecule in a reduced state). Some embodiments disclosed herein are directed to selectively capturing the target gas in applications such as direct air capture and ventilated air treatment, where separations from gas mixtures having relatively low concentrations of the target gas are required.

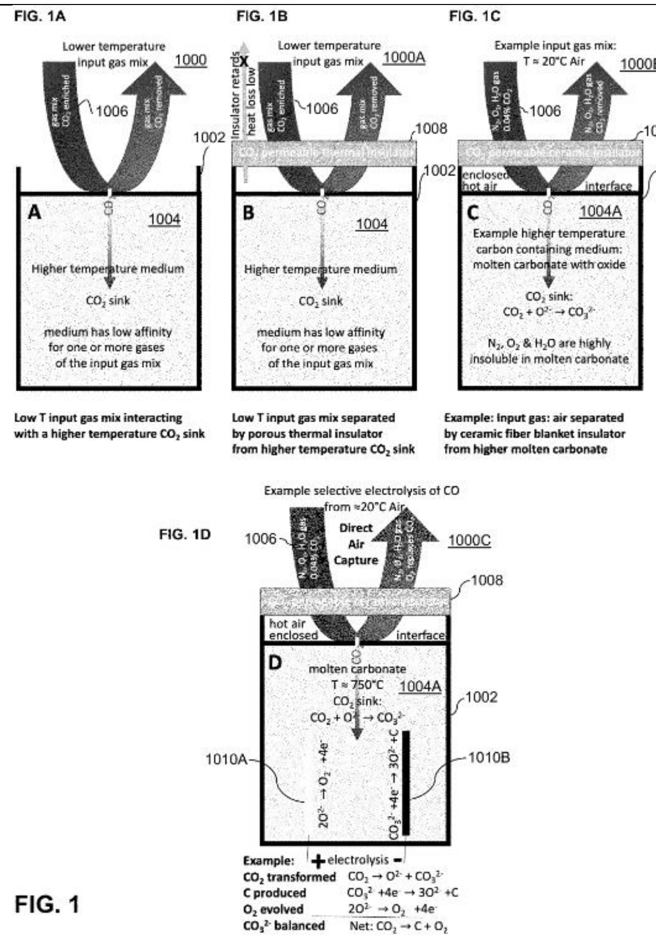
Target gas capture, even from streams of low-concentration target gas, can be useful but is challenging to carry out inexpensively and without the use of energy-intensive techniques. Existing conventional techniques and systems have several drawbacks, such as high energy needs and wasted heat. It can be desirable to remove CO_2 from industrial, power generation, and other such point sources. However, the low CO_2 concentration in these applications presents difficulties, possibly because of the weak driving forces and the significant amounts of other species present in the air in addition to CO_2. The direct air collection of CO_2 from the atmosphere at concentrations of roughly 420 ppm also raises similar issues.

The electrochemistry of O_2 can be crucial in the electrochemically-mediated separation of target CO_2. To help select appropriate redox-active compounds for electrochemical CO_2 separations, the standard reduction potential for the one-electron reduction of O_2 is a crucial parameter. A charge imbalance in the electrochemical cell can also result from the chemical oxidation of the electrochemically reduced (activated) electrodes by oxygen molecules. The target gas-capturing electrodes may occasionally become inactive toward the target gas because of this charge imbalance.

Independent claims 1 and 2 were rejected under 35 U.S.C. § 112(b) as being indefinite and 35 U.S.C. § 103 as purportedly being anticipated by U.S. Patent Publication No. 2017/0113182 by Voskian and by U.S. Patent Publication No. 2009/0291844 to Hou. Claims 1 and 2 were rejected because the phrase "for which the reaction with oxygen (O_2) is thermodynamically unfavorable" is purportedly a relative term. Claims 1 and 2 were amended to recite that a reaction with oxygen (O_2) has a change in Gibbs free energy that is greater than or equal to 0 Kcal/mol at at least one temperature that is within a range greater than or equal to 223° K and less than or equal to 573° K. With these amendments the Applicant asserted that Voskian no longer anticipates or renders obvious claims 1-2 as amended and the Examiner supported the assertion ultimately allowing the claims as amended.

Figure 4.15. U.S. Patent No. 11,633,691 titled Apparatus, System and Method for Direct Capture of Carbon-Containing Gas

Title	Apparatus, system, and method for direct capture of carbon-containing gas
Application No.	17/729,737
Patent No.	11,633,691
Issue Date	April 25, 2023
Assignee	Direct Air Capture LLC
Inventor Name	Stuart Licht, Gad Licht

Representative Figure	 *Figure 4. 15*
Description of Technology	The present disclosure relates to an apparatus, system, and method for selectively capturing a carbon-containing gas from an input gas mixture.
Exemplary Claim Language	A system for selectively transferring a carbon-containing gas from an input gas mixture, the system comprising: (a) a thermal insulator that permits net passage therethrough of the carbon-containing gas from the input gas mixture at a first temperature; (b) a plenum; (c) an anode and cathode positioned within the plenum; and (d) a molten electrolyte media, housed within the plenum between the anode and the cathode, the molten electrolyte media at a second temperature that is greater than the first temperature, the molten electrolyte media having a first affinity for carbon within the carbon-containing gas received from the thermal insulator and the molten electrolyte media acts as a carbon sink, wherein the molten electrolyte media defines a surface with a first surface area and wherein the upper surface is in fluid communication with the source of the input gas mixture; wherein the thermal insulator facilitates the net passage therethough of the carbon-containing gas to the surface of the molten electrolyte media, wherein the system is configured to selectively heat and electrolytically split the carbon-containing gas for generating a different chemical substance, and wherein the thermal insulator is positioned between a source of the input gas mixture and the plenum.

The Applicant received a non-final rejection of this application on August 25, 2022, and responded to the office action on November 22, 2022. The Applicant amended independent claim 1 by incorporating the limitations of dependent claims 16-17 into claim 1 which was sufficient to overcome the novelty rejection under 35 U.S.C. § 102 based upon Dakhil (U.S. Patent Application No. 202/0016535). Additionally, the inclusion of the limitations of claim 16 into independent claim 1 was sufficient to overcome the obviousness rejection under 35 U.S.C. § 103 over Dakhil.

Amended claim 1 now requires (1) an anode and cathode positioned within the plenum, (2) a molten electrolyte media, housed within the plenum between the anode and the cathode wherein the molten electrolyte media defines a surface with a flux area and wherein the upper surface is in fluid communication with the source of the input gas mixture, (3) wherein the thermal insulator facilitates the net passage therethrough of the carbon containing gas to the surface of the molten electrolyte media, and (4) the system is configured to selectively heat and electrolytically split the carbon containing gas for generating a different chemical substance. A notice of allowance mail was issued on December 13, 2022.

4.9 Synthesis Discussion

The title of this manuscript denotes a synthesis of the best attributes of patented technology as an outcome. The term “synthesis” is defined to mean a combination to form a theory or system. The objective of the patent analysis is an orchestrated combination of the physical structure and sorbent variety of multiple patented technologies to form an optimized solution. This discussion section seeks to combine the most advantageous attributes, specifically -- scalability, minimal energy consumption and ease of operation, of the fifteen identified systems and in the next section assemble them into an optimized system for extracting the maximum carbon dioxide from the atmosphere with the least amount of carbon being returned to the atmosphere using applied energy for the direct air capture.

The objective of the synthesis is not to utilize an attribute from each of the fifteen identified patents but to identify only those attributes among the fifteen patents that are considered most beneficial to rapid global implementation of direct air capture technology to move to an optimized solution.

This author is of the opinion that low temperature solid sorbents are the most appropriate choice for large scale mobilization of direct air capture systems. Low temperature solid sorbent direct air capture systems, such as those developed by Global Thermostat [10,512,880] and Climeworks [10,807,042; 10,279,306; 10,232,305] are of lower cost than high temperature direct air capture systems, such as liquid sorbent Carbon Engineering [11,504,667] because they have lower energy costs than high temperature systems and can capitalize on alternative heat sources such as waste heat. The least energy-intensive low temperature systems are those that use waste heat, which drastically decreases the demand for additional, expensive fossil fuel heat sources.[66]

Transferring solid sorbents to and from a regeneration chamber is more challenging than transferring liquids. Global Thermostat [10,512,880] and Air to Earth [11,389,761] have developed methodologies for heating of solid sorbent beds, comprising for example, Polyethyleneimine, to release the CO_2 that is captured. In these systems a loaded sorbent will descend into a regeneration chamber. The air will be pumped out, and water, likely in the

[66] By contrast, high temperature-electric and high temperature-hydrogen are energy intensive and thus also have low net CO_2 removals.

form of mist, will be added. The unloaded sorbent will rise back above the regeneration chamber to dry and then resume absorbing carbon dioxide. It is also critical to note that variations in sorbent particle size, reaction kinetics, packing surface area, can all be manipulated in such a way to claim an advantage over an alternative design.

Moving huge volumes of air in such a way that there is enough contact between the CO_2 molecules in the air and the surfaces of the material or device that mediates capture is a significant challenge for all direct air capture systems. There is a trade-off between the strength of the sorbent interaction with CO_2 and the exposed surface area of the sorbent. It is important to note that the strength of the sorbent interaction with CO_2 also impacts sorbent regeneration conditions. This is because a contactor with a high exposed specific surface area per unit volume can use a weaker sorbent to achieve the same amount of capture for a given contactor volume. Electrical forced draft fans also appear to be critical for many commercial scale direct air capture systems, regardless of the type of sorbent, to overcome the pressure drop in the contactors.

Therefore, it has been necessary to optimize the relationship between pressure drop and the amount of CO_2 removed, as well as between operating and capital costs (high air flows increase forced-draft costs but call for smaller contactors). So, for any direct air capture contactor, pressure drop per unit surface area is a critical efficiency metric. Air to Earth [11,389,761] has developed a contactor design that provides robust contact between the sorbent and the air flow.

Contactor design for solid sorbent systems can also take on many configurations such as Climeworks' fixed bed [10,232,305] and Air to Earth's moving bed design [11,389,761]. Having multiple fixed beds ensures that a portion of the sorbent is continually in an absorption mode but also increases the complexity of the overall direct air capture system. Presuming that direct air capture systems will be spread across the globe in decades to come, a less complicated system for contacting and unloading CO_2 from the sorbent will be important to maintain a steady rate of extraction of the global warming gas from the atmosphere.

Black Swan LLC [11,638,902] utilizes leaf membranes that operate under a vacuum, increasing the operational complexity of the carbon dioxide extraction process and potentially undesirably limiting the magnitude of extraction that may occur due to constraints on the volume of the vacuum containers that may be utilized. 8 Rivers Capital [11,559,766] relies upon an electrolysis unit whereby an alkali solution is used to remove carbon dioxide from the gas stream. As with Black Swan LLC, the design proposed by 8 Rivers Capital appears to increase the level of complexity of the removal process, relative to for example Global Thermostat by incorporating an electrolysis unit that is arranged to receive at least a portion of the one or more metal salts and configured to react with water to form an alkali material.

The Xerox owned patent [11,612,852] utilizes a polymer backbone that integrates a porous polymer aerogel that has greater than 5% by weight of an amine containing vinyl monomers but requires a regeneration temperature closer to 200° C, greater than that required by other referenced solid sorbent air capture systems and therefore this system is more energy intensive. The air capture device disclosed by Carbon Sink [10,150,112] utilizes a functionalized anion exchange polymer that is formed to provide a relatively large surface area which allows for air flow with minimum resistance. The air capture device is configured to ensure as complete as possible penetration and thorough liquid contact of all surfaces with a sorbent chemical to remove the captured CO_2 and to reactivate the membrane surfaces. The Carbon Sink patent does not provide details on the mechanism for releasing the captured CO_2 and regenerating the anion exchange material. Consequently, the level of energy input required to facilitate the release of the CO_2 is unclear. Airmyne's patent [11,612,853] also discloses the use of heat at a temperature of at least 200° C as necessary to release the CO_2 from the base solution. Again, a temperature that exceeds that required by other reviewed systems.

The patent assigned to the Arizona Board of Regents [11,478,745] discloses the use of circumscribed hollow membranes in a device and technique for carbon dioxide capture. The device consists of a hollow membrane unit with an inner conduit made of a vapor membrane and an outer conduit with an inner surface enclosing the inner conduit to produce a lumen. The membrane of the CO_2 pump is part of the outer conduit. A mechanical pump is also a part of the apparatus, maintaining a pressure differential between the lumen and the atmosphere and supplying a stream of CO_2-rich gas as a byproduct from the lumen.

Water vapor produced by evaporation can travel through the vapor membrane's pores and is contained by it because it is hydrophobic and porous enough to do so. A carbon concentration gradient is created and maintained across the CO_2 pump membrane as water vapor travels from the lumen to the atmosphere through the membrane. The gradient in carbon concentration drives CO_2 from the atmosphere into the lumen. While an interesting device for removal of carbon dioxide from water it appears to have little efficacy for direct removal of CO_2 directly from the ambient air but may have some merit for removal of carbon dioxide from seawater.

The patent assigned to MIT [11,598,012] is directed to electrochemical separation of target gases from gas mixtures. In the disclosure, the first electroactive species has an oxidized state and at least one reduced state in which the species is capable of bonding with a target gas, but for which a reaction with oxygen (O_2) is thermodynamically inefficient. The electrochemical cell is made up of a negative electrode that contains the first electroactive species, a positive electrode, and a separator between the negative electrode and the positive electrode. A reaction with oxygen (O_2) is thermodynamically unfavorable in some embodiments of the first electroactive species at least in one reduced state, which is at least one temperature greater than or equal to 223 K and less than or equal to 573 K.

Despite this, the species is still capable of bonding with a target gas in this reduced state. In some instances, the first electroactive species has at least one reduced state where it can bond with a target gas but is thermodynamically unfavorable for a reaction with oxygen (O_2) at least one temperature greater than or equal to 223 K and less than or equal to 373 K. The quantity of electrochemical cells or groupings of cells may purportedly be scaled to meet the needs of a direct air capture system for removal of CO_2 from ambient air.

The Direct Air Capture, LLC patent [11,633,691] utilizes a thermal insulator that permits net passage therethrough of the carbon-containing gas from the input gas mixture at a first temperature. The system also utilizes a plenum and an anode and cathode positioned within the plenum. The system requires a molten electrolyte media, housed within the plenum between the anode and the cathode, the molten electrolyte media at a second temperature that is greater than the first temperature. The molten electrolyte media has a first affinity for carbon within the carbon-containing gas received from the thermal insulator and the molten electrolyte media acts as a carbon sink.

The molten electrolyte media defines a first surface area and wherein the first surface is in fluid communication with the source of the input gas mixture. The thermal insulator facilitates the net passage of the carbon-containing gas to the surface of the molten electrolyte media. The system is configured to selectively heat and electrolytically split the carbon-containing gas for generating a different chemical substance, such that the thermal insulator is positioned between a source of the input gas mixture and the plenum. The second temperature referenced in this system is between about 400° C and about 850° C. This system as with others investigated requires high temperatures that may be unachievable with waste heat and therefore requiring fossil fuel to facilitate the heating of the molten electrolyte media.

To maximize net capture efficiency, energy sources must be carbon-free or extremely low in carbon; otherwise, using the energy will result in more CO_2 emissions than would be removed from the atmosphere throughout the process. While near-term energy requirements might be slightly greater, Climeworks' [10,807,042; 10,279,306; 10,232,305] solid sorbent system calculates an estimated long-term energy need of 7.2 GJ (or 2,000 kWh/tCO_2),[67] which is about one-fifth of a typical American household's annual electrical power consumption.

Estimates of 8.8 GJ/tCO_2 (or 2,400 kWh/tCO_2) for energy requirements have been made by Carbon Engineering [11,504,667].[68] Energy would be required in non-trivial amounts to scale up the direct air capture systems of today. By 2030, the United States may absorb 7-9 million tons of CO_2 annually, according to estimates made by the Rhodium

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[67] Katie Lebling et al., "6 Things to Know About Direct Air Capture," World Resources Institute, May 2, 2022, https://www.wri.org/insights/direct-air-capture-resource-considerations-and-costs-carbon-removal.
[68] Lebling, "6 Things to Know."

Group[69] and the direct air capture Council of the Bipartisan Policy Center,[70] respectively. Direct air capture at this scale would require between 0.3–0.4% of the country's current power production.[71]

Natural gas has been primarily recommended for the delivery of high-grade heat; however, this would be an inadvisable path to travel. Without accounting for its life cycle emissions, the direct natural gas-based CO_2 emissions from supplying 2000 kWhth of high-grade heat at 90% efficiency for the capture of 1 ton of atmospheric CO_2 would be 0.44 ton.[72] Each ton of ambient CO_2 captured by one of Carbon Engineering's [11,504,667] direct air capture units releases about 0.5 tons of CO_2.[73] The CO_2 can be trapped and used as a feedstock for other processes, however, after a few cycles of use, it would eventually escape to the ambient air.[74]

Fans are a critical component of nearly all direct air capture systems as they deliver the carbon dioxide laden air to the sorbent or solute for absorption / adsorption. While the electric drive motor on the fans in the various patents referenced in this manuscript may be somewhat universal in terms of construction, the configuration or arrangement of the fans in the direct air capture system can and does vary. Air to Earth's patent [11,389,761] provides a unique circular configuration for moving the requisite volume of air across the sorbent and into a diverter. Even more unique is the ability to move the disclosed sorbent media filled

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69 John Larsen et al., "Capturing Leadership: Policies for the U.S. to Advance Direct Air Capture Technology," Rhodium Group, May 9, 2019, https://rhg.com/research/capturing-leadership-policies-for-the-us-to-advance-direct-air-capture-technology/.

70 Sasha Mackler et al., "The Case for Federal Support to Advance Direct Air Capture," Bipartisan Policy Center, June 24, 2021, https://bipartisanpolicy.org/report/federal-dac-recommendations/.

71 "Frequently Asked Questions (FAQs)," U.S. Energy Information Administration (EIA), July 3, 2023, https://www.eia.gov/tools/faqs/faq.php?id=92&&t=3.

72 "What Is Direct Air Capture?" Carbon Engineering, 2018, accessed July 3, 2023, http://carbonengineering.com/about-dac/.

73 "What Is Direct Air Capture?"

74 "What Is Direct Air Capture?"

cylinder into a regeneration station for the extraction of the carbon dioxide from the sorbent media.

The fans are positioned outside of a ring of the cylinders filled with sorbent media allowing them to force air into the interior of the direct air capture structure from the exterior of the structure, passing through the cylinders and over the sorbent media. Importantly, for the system disclosed by the Air to Earth patent [11,389,761], each regeneration station can lock onto a cylinder and remove the sorbent media's carbon dioxide collection. Once the carbon dioxide has been evacuated and the sorbent has been regenerated, the cylinder returns to a position proximate a fan to capture the carbon dioxide once again.

4.10 Optimization Discussion

To optimize the direct air contact system the strategy employed by this author is to assess five general qualities: The low concentration of carbon dioxide in air necessitates the passage of large gas volumes through the contactor, necessitating (1) a low-cost air contactor; (2) the need for high CO_2 uptake at low partial pressures because selected sorbents need strong chemical interactions with CO_2; (3) rapid sorption/desorption kinetics, which leads to fast sorption and desorption, faster cycling, and therefore less sorbent needed for the same output; (4) low sorbent regeneration energy so that sensible heat from the process can be kept to a minimum since efficient process designs will also decrease the thermal mass of equipment that thermally cycles back and forth between sorption and desorption. Finally, (5) the optimized system should have minimal capital costs. While this manuscript attempts to optimize these characteristics drawing from the detailed description of the patents and the prosecution history, it must be fully recognized that in many cases hard data for comparison purposes does not yet exist.

Low-cost air contactors would certainly include those that are alkali based, comprised of for example, potassium hydroxide matrices. Caustic potash (KOH) already has a production level in the tens of millions of tons per year on a global scale and could certainly be ramped up should demand spike for use in direct air capture. Alternatively, Global thermostat has devised a method of extracting carbon dioxide from the air by employing a solid sorbent amine-modified monolith with low-pressure drop using high efficiency fans to produce a concentrated CO_2 stream. The amount of electricity needed to run fans and pumps can be reduced by designing shallow contactors that reduce pressure loss throughout the system. The CO_2 is released by a regeneration process using steam. The technology, which regenerates using low-value heat, can recover up to 50% of the regeneration heat.[75] For ambient air, the system developed by Global Thermostat requires about 15 minutes per cycle.

A downside to the Global Thermostat solid sorbent system as detailed above is that it is freshwater-intensive. Water loss to the environment may result from the hypothetical adsorption-based process considered here, which relies on saturated steam condensation on the adsorbent and contactor as the route of heat transfer. The potential water loss is understood as a trade-off for the enhanced heat transmission and overall process performance provided by this method of heat transfer.

[75] "Global Thermostat," Tech Portal, 2021, https://techportal.epri.com/developers/7afq9RnWSjKZzquewbaDXY.

CHAPTER 5

CONCLUSION

As direct air capture systems have only been developed and deployed by a small number of start-ups, research hurdles will continue to exist in its development and deployment. A focus on new materials and processes for direct air capture will present new opportunities, and the development of direct air capture systems will also raise challenges. Continued improvement of these materials and processes is essential, particularly in understanding their integration with the energy system, their evolving costs, and their sustainability from a wider frame of reference.

To expand our knowledge of direct air capture, unlock new levels of efficiency and sustainability, and broaden societal acceptance, researchers need to tackle some high-level problems quickly. Massive amounts of mitigation and adaptation are needed in response to climate change. This will entail a wide range of clean energy producing technologies, as well as greenhouse gas emission reduction technologies. Understanding the complexity, interdependencies, pace, and scale involved will continue to be of the utmost importance as the need for and interaction between these adaptation and mitigation factors will change over time.

Direct air capture has certain distinct advantages over other technologies for removing emissions. Society should capitalize on these benefits. For instance, carbon dioxide utilization is an essential technological enabler in almost all direct air capture deployment scenarios. It is also well recognized that carbon dioxide utilization (as opposed to storage) is less than ideal for reducing climate change. Therefore, direct air capture systems should be pursued as a deployment priority. Situations where carbon dioxide usage is economically advantageous should not be a diversion, but they might be valuable for demonstrating direct air capture technology.

Direct air capture is still very much in its infancy and carbon capture and sequestration processes are only now starting to be deployed at the scale necessary for substantial climate change mitigation. Increases in carbon capture and sequestration processes' capture rates will lighten the load on direct air capture and are thus a research and implementation priority. Sorbents, as detailed above in this manuscript, are a key component in the most advanced direct air capture processes.

Consideration must be given to manufacturing of sorbents at scale. New direct air capture techniques (*i.e.*, those that do not rely on sorbents) may provide customized solutions for certain situations and, more importantly, serve as an inspiration for brand-new direct air capture methodologies.

An area requiring further in-depth investigation is the economic and life-cycle performance of direct air capture technologies. The long-term cost of carbon dioxide remains an unknown. When powered by low-carbon energy sources, direct air capture can most assuredly attain high life-cycle carbon efficiencies; however, those life-cycle efficiencies can be considerably lower if powered by energy from systems that use fossil fuels.

The true potential of direct air capture systems is negated if for every kilogram of carbon dioxide extracted from the air a substantial percentage of carbon dioxide is released into the atmosphere during the burning of fossil fuels. Therefore, it is crucial to develop a set of uniform standards and benchmarks that would allow for a trustworthy comparison of direct air capture technologies.

There are multiple policy obstacles to overcome, such as how to fund pilot projects and then scale up direct air capture technologies in the hope of lowering prices. Direct air capture specific projects are becoming more prevalent as the technology has numerous advantages, including more flexibility in plant siting and the capacity to scale up. Although it is beneficial to provide funding at an early stage, the association of several of the first significant projects with the oil and gas industry has also given rise to worries that direct air capture will overshadow other mitigation approaches. Low levels of stakeholder and public knowledge have existed, but as the first significant projects have been implemented, direct air capture has come under more scrutiny. As interest in direct air capture has grown, some governments have started to fund initiatives to promote projects in the early stages of direct air capture and set lofty goals to reduce direct air capture costs.

In the end, direct air capture is still in its infancy, with its role in the energy system and efforts to mitigate climate change still being undefined. Nevertheless, the difficulties brought on by direct air capture urge us to step up our efforts to mitigate climate change and, more crucially, to keep coming up with innovative solutions to problems that seem insurmountable.

Tackling what appear to be insurmountable climate related problems is without question preferable to staying the course and watching the need for WHO certified emergency medical teams (EMT) grow at an unsustainable pace in order to respond to a growing litany of worldwide climate induced disasters. Just during the past month of my preparing this dissertation manuscript, wildfires have burned much of the once wetland and now tinderbox town of Lahaina, HI, killing 115 people,[1] a flood in Derna, Libya brought about by unusually powerful rains destroyed two dams with powerful flood waters killing at least 5,000 and displacing at least 20,000,[2] and hurricane Lee which was listed as a Category 5 is working its way up the East coast of the United States (fortunately a distance off the coast as of this writing). The global scale implementation of direct air capture systems capable of extraction of not millions, but billions of tons of carbon dioxide from the atmosphere is seen by the IPCC as a critical decarbonization strategy.[3]

As detailed above, other forces at play seeking to decelerate (and preferably reverse) the increasing concentration of carbon dioxide in our atmosphere is a proposed regulation from the U.S. Securities and Exchange Commission. As discussed above, finalization and implementation of this rule will provide securities investors at all levels with the tools needed to evaluate the actions being taken by publicly traded companies in their efforts to decarbonize, including the installation of direct air capture systems to negate carbon emissions elsewhere in their production facilities and supply chain. With this information at their fingertips investors can make more informed decisions about the companies deserving of their investment dollars at least from a greenhouse gas emission perspective.

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[1] Kaniela Ing, "The Climate Crisis and Colonialism Destroyed My Maui Home. Where We Must Go From Here," *Time,* August 17, 2023, https://time.com/6305817/maui-wildfires-climate-change-colonialism-essay/#:~:text=While%20West%20Maui%20is%20no,which%20propelled%20the%20fire%20further.

[2] Mohammaed Abdusamee, Vivian Nereim, and Isabella Kwai, "More than 5,000 Dead in Libya as Collapsed Dams Worsen Flood Disaster," *New York Times,* September 13, 2023, https://www.nytimes.com/2023/09/12/world/middleeast/libya-floods-dams-collapse.html?campaign_id=2&emc=edit_th_20230913&instance_id=102585&nl=todaysheadlines&regi_id=15721329&segment_id=144597&user_id=e73b08231afc067a4b7a427d9a8ba400.

[3] Matt Bright and Toby Lockwood, "What Does the Latest IPCC Report Say about Carbon Capture?" Clean Air Task Force, April 20, 2022, https://www.catf.us/2022/04/what-does-latest-ipcc-report-say-about-carbon-capture/.

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VITA

Robert J. Lambrechts was born in St. Louis, Missouri and grew up in various municipalities in St. Louis. Robert attended St. John Vianney High School. After graduating high school Robert attended the University of Missouri at Columbia and studied mechanical engineering. Robert graduated as an Honor's Scholar in 1981 and elected to pursue his master's degree in mechanical and aerospace Engineering. Upon the awarding of his master's degree in 1982 Robert was hired by the Bendix Corporation (now Honeywell Federal Manufacturing & Technologies, LLC) in Kansas City, Missouri to work as a robotics engineer designing and implementing robotic work cells used in the manufacture of non-nuclear components for nuclear weapons. In 1987 Robert returned to school to pursue a law degree at St. Louis University School of Law. Upon graduation from law school in 1990 Robert was hired by the Region VII office of the U.S. Environmental Protection Agency and proceeded to assist in the implementation of the Clean Air Act Amendments of 1990. In 1995 Robert departed the U.S. EPA and joined the general practice law firm of Lathrop & Norquist (now Lathrop GPM, LLP) in Kansas City and over his nearly three-decade career at the firm has represented a wide range of clients in the areas of environmental and intellectual property law. Robert also served 28 years as an Engineering Duty Officer in the United States Navy Reserve retiring in 2018 at the rank of Commander. Robert has also taught as an adjunct faculty member at the University of Missouri at Kansas City since 1993 teaching courses on environmental law and legal topics for engineers. Robert has served on the Boards of many non-profits over his career but is particularly proud of his service with Heart to Heart International an organization that is recognized globally as the gold standard for disaster relief organizations.