Julie Ann Wrigley Global Futures Laboratory
Arizona State University

the center for negative carbon emissions

The socio-economic and technical context for Direct Air Capture in decarbonization pathways

Technical Workshop Report

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Authors: Stephanie Arcusa, Klaus Lackner, Robert Page, Vishrudh Sriramprasad, William Brandt, Jacob Moore, Matthew Green, Sourabh Patil

I-WEST

About Arizona State University

Arizona State University, ranked No. 1 “Most Innovative School” in the nation by U.S. News & World Report for seven years in succession, has forged the model for a New American University by operating on the principles that learning is a personal and original journey for each student; that they thrive on experience and that the process of discovery cannot be bound by traditional academic disciplines. Through innovation and a commitment to accessibility, ASU has drawn pioneering researchers to its faculty even as it expands opportunities for qualified students. Learn more at *www.asu.edu*.

About the Julie Ann Wrigley Global Futures Laboratory

The Julie Ann Wrigley **Global Futures Laboratory** at Arizona State University represents the urgent belief that we can and must make a meaningful contribution to ensuring a habitable planet and a future in which well-being is attainable. The Global Futures Laboratory is the world’s first laboratory dedicated to the health of the planet and its inhabitants. It is built upon the deep expertise of ASU and leveraging an extensive network of partners for an ongoing and wide-ranging exchange across all knowledge domains to address the complex social, economic and scientific challenges spawned by the current and future threats from environmental degradation. This platform positions a new world headquarters for an international array of scientists, scholars and innovators and lays the foundation to anticipate and respond to existing and emerging challenges and use innovation to purposefully shape and inform our future. For more information visit *globalfutures.asu.edu.*

About the Center for Negative Carbon Emissions

The Center for Negative Carbon Emissions (CNCE) is focused on developing next-generation carbon-management technologies that can capture carbon dioxide (CO_2) directly from ambient air in an outdoor operating environment. CNCE has demonstrated a thermal and moisture swing sorbent cycle for capturing carbon dioxide (CO_2) from air using a passive technology. CNCE aims to advance this technology as it applies to closing the carbon cycle with carbon recycling, reducing atmospheric concentration through CO_2 disposal, and the economic and policy considerations from its availability. For more information, visit *https://globalfutures.asu.edu/cnce/.*

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1. Introduction

Direct Air Capture (DAC) is a promising technology for climate change mitigation as it offers a solution to decarbonizing hard-to-abate sectors and removing historical emissions through sequestration. DAC can also supply carbon dioxide (CO_2) for a range of uses from niche markets to synthetic fuels. DAC will have a role to play as the world transitions to a carbon neutral economy. A plan for such a transition is being developed for the Intermountain West (I-WEST) region of the United States, consisting of the states of Arizona, New Mexico, Colorado, Utah, Wyoming, and Montana as well as the Sovereign Nations. To discuss the role of DAC in this transition and beyond, the Center for Negative Carbon Emissions (CNCE) and Arizona State University (ASU) hosted a Technical Workshop on Direct Air Capture on January 19th, 2022, for stakeholders in the region and beyond. The workshop was part of a series organized for the Intermountain West Energy and Sustainability Transition (I-WEST) initiative by Los Alamos National Laboratory (LANL).

The four-and-a-half-hour DAC workshop consisted of three presentations by subject matter experts, three panels, and one interview. Through this workshop, the organizers attempted to provide a holistic view of DAC technology by spanning a variety of topics from the technical aspects to its social and economic side. Additionally, presenters and panelists who specialize in different areas and work in different industries, were brought in to provide a variety of perspectives to the participants.

The workshop started with an introduction from the director of the CNCE, Dr. Matt Green. It continued with a presentation introducing the greater I-WEST project and its relationship to DAC by Dr. Jolante Van Wijk from LANL. Dr. Van Wijk then interviewed Dr. Klaus Lackner, the CNCE's founder and previous director, as well as the inventor of DAC technology, over the details of DAC. After the interview, the three panels were presented, starting with the panel on CO_2 utilization and sequestration moderated by Dr. Stephanie Arcusa from the CNCE. This panel included the organizer of the geologic sequestration workshop as part of the I-WEST series, as well as several representatives from CO_2 utilization companies. The next panel, moderated by William Brandt, from ASU's Lightworks, was focused on the potential for industrial use of DAC and hosted panelists from various technology and consulting firms which have shown some form of interest in DAC. The last panel, moderated by Jacob Moore, ASU's Assistant Vice-President for Tribal Relations, focused on workforce requirements and potential for tribal involvement in DAC. This panel was composed of employees from a construction company and energy experts from the Navajo Nation. Finally, the workshop concluded with two presentations covering the economics and policy spaces around DAC by Dr. Michael Hanemann from ASU and Dr. Peter Minor from the non-profit organization Carbon180, respectively.

Attendees of the workshop were introduced to DAC, and how it intersects with various other technologies and disciplines. Additionally, attendees were given the opportunity to interact with the panelists and presenters by asking questions after the discussions. This document reports the workshop's findings.

2. Findings

The workshop covered a wide variety of topics. To more easily break this down, this summary will be split into six sections including Context, Technology, Economics, Policy, Society & Justice, and Timing.

Context:

The most likely scenario to reducing the atmospheric CO_2 concentration to 350 ppm in the future involves an overshoot above the 1.5-2°C limit committed under the Paris Agreement. The strong likelihood of an overshoot scenario means that thousands of gigatons of sequestration will be required over the coming century, more if fossil carbon use is not reigned in. This extra demand from new fossil fuel will most likely make negative emissions more expensive. Reframing carbon as a waste management problem, instead of simply a pollution problem, can offer more options. Carbon waste management as a service would require that all carbon emissions be sequestered, and the requirement would be more efficient to happen upstream, at the source.

Direct air capture (DAC) can be defined as a technical means of getting carbon back from the environment which does not use photosynthesis as an intermediary. DAC by itself does not constitute a Negative Emissions Technology (NET) or a solution for decarbonization nor for climate restoration, it is when combined with either carbon utilization or carbon sequestration that it becomes one. DAC for decarbonization includes products that substitute the use of fossil fuels, including liquid fuels and natural gas.

Additionally, for climate restoration DAC must involve carbon sequestration (i.e., Direct Air Capture and Storage known as DACS), which can be temporary if liability for the carbon escaping is accepted but must ultimately be durable on timescales of tens of thousands of years. Quantification, verification, monitoring, and certification of the entire chain of activity is a pillar of the DACS industry that must be addressed. Certification of quantities and origin of raw materials such as carbon from air and energy from renewables as well as the intended use of the carbon either in short lived products or sequestration, will need to follow yet-to-be established standards that expand upon those currently existing.

If DAC succeeds as an industry, it will be very large but likely not larger than the aviation industry, energy industry, or automobile industry. Land need for power generation, water usage considerate to local climatic conditions, potential emission of volatiles from sorbents, and sorbent waste disposal will all need to be addressed.

Insights on Context for Direct Air Capture:

- Reframing carbon as a waste management problem, instead of simply a pollution problem, can offer more options

- Quantification, verification, monitoring, and certification of the entire chain of activity is a pillar of the DACS industry that must be addressed.

Technology:

Mechanical DAC systems contact sorbents such as solvents and amine-based solids to CO_2 and remove the CO_2 from the sorbent using fans. Sorbents need to last a very long time in terms of cycles or years to keep cost low. A priority in DAC research is to develop more sorbents and to develop environmentally friendly large-scale waste disposal procedures for sorbents since every ton of CO_2 captured requires approximately 10 kg of sorbent. Additionally, non-amine sorbents, material regeneration, and low temperature plasma CO_2 activation technologies are being developed. Small, modular designs would provide flexibility, would be highly distributed, could attach themselves to existing infrastructure, and could be limited to consumers that do want the technology on their land or property. For example, in the brewing and beverage industry, carbon re-capture from the fermentation process can be highly useful to smooth out the supply curves of smaller breweries because they won't have to depend on the CO_2 shipments to come in. Additionally, using the recaptured CO_2 reduces the capital expenditures. Small-scale DAC design also allows the bypassing of intermediate pilots and other scale-up risks that other larger-scale designs will have to go through. Passive DAC systems, which are easily designed as small and modular, appear to offer one of the only pathways to economic feasibility when considering systems, costs, and infrastructure. Designed to run on intermittent power, passive DAC would ensure continued use without fossil energy. Passive DAC systems can work in a range of wind speeds but will struggle with vast variability.

DAC also has the unique advantage of not requiring transport for the captured CO_2 which is a benefit in terms of infrastructure and logistics and can be co-located with sequestration sites such as saline bearing reservoirs and mineralization in volcanic basalt formations, or directly with the consumers in the case of DAC-to-fuel. With regards to storage, the most promising storage formations in the I-WEST region are in saline bearing reservoirs. These are currently being used most prominently for enhanced oil recovery (EOR) since the deployment of DAC for sequestration has so far been limited. A rare example can be seen in Project Orca in Iceland by Climeworks. However, even at Orca, sequestration is happening at a relatively small scale. When looking at DAC-to-fuel and Renewable Natural Gas, if produced using renewable energy, synthetic fuels are one of several promising avenues to decarbonize the economy, particularly to substitute fossil fuels for transport, and to store energy chemically economically over longer periods of time compared to batteries. Several companies are working on regeneration processes that can directly create liquid fuels or natural gas in one step instead of having to go through intermediary steps. With these advantages, the big challenge with locating DAC falls to finding a renewable reliable source of power near the end-use site.

Despite the progress that has been made on a variety of designs, none of the technologies are mature and it is too early to lock into one technology. In the future, we can look to artificial intelligence and machine learning to help accelerate calculations to discover more efficient technology or optimize performance.

Insights on Direct Air Capture Technology:

- A priority in DAC research is to develop more sorbents and to develop environmentally friendly large-scale waste disposal procedures.
- DAC has the unique advantage of not requiring transport for the captured CO_2 and can be co-located with sequestration sites or directly with the consumers in the case of DAC-to-fuel.
- Passive DAC systems are easily designed as small and modular and appear to offer one of the only pathways to economic feasibility when considering systems, costs, and infrastructure

Economics:

The most significant economic challenge for DAC is lowering the cost per ton of CO_2 from $500 today to under $100. There is currently no guarantee the industry can get there. As most industries follow a cost-curve, the DAC industry will need to find out if it does too by learning by doing and numbering up through mass production instead of scaling up. Hypothetically, if one billion dollars was spent subsidizing the improvement and scalability of DAC, a clear determination could be made on whether this technology will follow other technologies on the learning curve or if it is an exception.

Realistically, first movers can help bring down the cost of DAC by purchasing from promising companies. For example, the company Stripe purchased 1,600 tons from four DAC companies at prices ranging from $300-2000/ton CO_2. Additionally, although sequestration of CO_2 is regarded as the best way to accomplish negative emissions, CO_2 utilization can also play a big role in bringing down the cost. CO_2 utilization in niche markets fetch high prices (e.g., $260-500/ton for the brewing industry) and production of CO_2 gas from DAC rather than fossil fuels directly by the consumer could reduce supply chain issues. In this instance, tracking the progress of green hydrogen is important because carbon utilization and hydrogen are interconnected. For example, the production cost of Renewable Natural Gas depends on the value of hydrogen and depends on hydrogen programs. Additionally, targeting niche CO_2 utilization could help lower cost in the short term. The closer DAC can get to the end consumer, the more evident DAC technology will be as a viable tool to harvest carbon and make useful chemistries. This would enhance acceptability and awareness of the potential of DAC. In the discussion between balancing sequestration and utilization, the cost of sequestration could be the tipping point for moving from a majority-utilization market to a majority-sequestration market.

DAC companies ought to develop viable business models, a plan to move to bankability as quickly as possible, engage with banks and advisors early, identify what the economics are for the project, and explore counterparties. For now, DAC business models are in the early stages of maturity. Along with policy, corporate decarbonization plans, net-zero pledges, science-based target setting, and a focus on carbon removal offsets as opposed to offsets of emission avoidance or reduction appear to be developing a market for DAC in various forms.

Insights about the Economics of Direct Air Capture:

- The most significant economic challenge for DAC is lowering the cost per ton of CO_2 from $500 today to under $100. First movers can help bring down the cost of DAC by purchasing from promising companies.

- The closer DAC can get to the end consumer, the more evident DAC technology will be as a viable tool to harvest carbon and make useful chemistries.

- For now, DAC business models are in the early stages of maturity.

Policy:

Government regulation and standard setting for DAC would make the industry functional and safe. For example, by clarifying requirements for measurement and verification, and best practices for the industry. Government can also pass supporting policies for DAC by buying materials to build low-carbon or carbon negative buildings, through buying CO_2 from DAC plants, or even building their own DAC plants. 45Q, a federal tax credit that allows companies to earn up to $50 per ton of sequestered CO_2, is a good start but does not provide enough incentive and has a participation barrier that is too high. Solutions to both are contemplated in the Build Back Better Act for example, by increasing the $50/ton to ~$180/ton sequestered, and by decreasing or eliminating the minimum amount of CO_2 sequestered to qualify for the tax credit. Additionally, 45Q could be restructured to include sequestration through mineralization and direct payment would remove some of the inefficiency in the financing through tax equity. There are also a few other policies and programs that are either already in place or that have been proposed. For example, the California Low-Carbon Fuel Standard (LCFS) allows companies to collect up to $200 per ton of CO_2. Moving forward, new power-to-gas programs and improved LCFS from California would continue to incentivize DAC-to-fuel or Renewable Natural Gas technologies. Additionally, the Carbon Removal Leadership Act (CRLA) debated in the state of New York aims to increase government procurement into high quality removal.

Policy will be a critical tool to enable DAC by supporting innovation, building capacity, reducing cost to a reasonable level through direct procurement, providing room for new ideas to be tested, and making sure the technology is accessible by anyone. Developing permitting for sequestration options beyond saline wells, like mineralization, would provide further incentives. Additionally, reducing friction for new players to get validation from accrediting companies would help development and deployment.

Lastly, it will be important to remember that as these various economic policies which are meant to promote the development of DAC are analyzed, they should be centered between a top-down and bottom-up approach. That is, they should be analyzed by looking at firms more like consumers, and modeled to meet goals through change, coordination, and connection between actors. This type of approach will encompass a variety of perspectives and provide the most suitable path towards a just and rapid scaling of DAC technology.

Insights on Direct Air Capture Policy:

- Government regulation and standard setting for DAC would make the industry functional and safe.

- Economic policies developed to promote DAC development should be centered between a top-down and bottom-up approach to include the broadest variety of perspective.

Society & Justice:

DAC-related workforce will grow as the technology develops. In the next 5-10 years, science and engineering jobs will be needed to support research and development efforts, and deployment of demonstration units. As the technology develops, and deployment increases, traditional and specialty craft personnel will be required to manufacture, execute, build, and operate the DAC plants. Supply chain, fabrication, and business-related jobs would also be expected to increase. DAC jobs are likely to be high-paying but also require diverse skills spanning across disciplines. Training for that will be necessary to operate the DAC technology safely.

DAC has two main advantages. DAC can provide a pathway to a net-zero emission world that will positively impact communities affected by climate change. Moreover, DAC can create jobs in economically distressed communities or communities once reliant on the fossil fuel industry. Many of the Tribal Nations in the I-WEST region are in one or both categories listed above. Tribes and rural communities have been and are continuing to be disproportionately impacted by climate change, the transition away from fossil fuels, and the activities producing the resources. In this scenario, public benefits businesses can provide a model for DAC businesses to maximize public good, create high paying jobs, and revenue that directly impact communities. Navajo Power is one such example, developed to support economics that would replace lost jobs and revenue from the fossil fuel industry shutdowns on Navajo Nation and beyond.

Entities working on the energy transition, including those focused on DAC, ought to be convened to produce a strategic plan that bridges across organizations and across to Tribal Nations. Tribal Nations are interested in learning about and utilizing DAC and want to be active owners and receive the maximum benefits of the technology. However, deal restructurings are needed to maximize benefits to Tribal Nations in exchange for land access. Ways of combining old and new industries, including training and education certification programs, ought to be devised. Additionally, developing capacity in terms of the ability to negotiate legally, technical training, business development, human power, educational capacity, and so on, and capital in terms of an infusion of resources on Tribal Lands ought to be a pre-requisite to discussions about new projects. High-quality community engagement and cross-cultural communication has so far not been considered during past energy transitions and DAC can and should address some of these past mistakes. For example, by obtaining prior informed consent from communities for DAC projects.

Insights on the Social and Justice aspects of Direct Air Capture:

- Traditional and specialty craft personnel will be required to manufacture, execute, build, and operate the DAC plants.

- Public benefits businesses can provide a model for DAC businesses to maximize public good, create high paying jobs, and revenue that directly impact communities.

Timing:

DAC is still a nascent technology that is constantly changing and should not be locked-in at this stage. In the short term, other technologies like Biomass Carbon Removal and Storage (BiCRS) will be more affordable and reliable, but in the medium-to-long term DAC will take over because it looks to be scalable to a larger size. Additionally, there are various corporate actors who are willing and eager to be “bridge customers” to carry the market from the current price of DAC technology to scalable and affordable prices in the medium-to-long term timespan. On the utilization side, within 5 years it is anticipated that DAC-to-fuel systems will be able to function to a megaton scale. However, regarding sequestration, there are only a few projects which are succeeding through the permitting process (e.g., EPA’s class VI wells), although the newly passed Infrastructure Bill will provide support to ease the backlogs and develop reliable state-run programs.

Insights on the Timing of Direct Air Capture:

- DAC is still a nascent technology that is constantly changing and should not be locked-in at this stage.

3. Workshop Agenda

January 19, 2021
8:00AM – 1:00PM MT

WebEx link to be emailed

8:00	Introduction, COP 26 & Direct Air Capture	**Peter Schlosser** Arizona State University
8:15	Welcome	**Matt Green** Arizona State University
8:30	Why DAC & I-WEST	**Jolante Van Wijk** Los Alamos National Laboratory
8:45	Q&A on DAC • Will DAC Work? When? • How much volume?	**Jolante Van Wijk** **Klaus Lackner** Arizona State University
9:30	CO_2 Panel Session *Focused on uses of captured CO_2* • Panel participants: Eric Dahlgren (Aircela), Derek Vikara (NETL), Raghubir Gupta (Susteon), Gary Nicholas (SanTan Brewing Company)	**Stephanie Arcusa** Arizona State University
10:15	Break	
10:30	Will Industry use DAC? *Select panel of companies who will or are considering the application of DAC technology* • Panel Participants: Julius Kusuma (Meta), Alex Dewar (Boston Consulting), Joanna Klitzke (Stripe), Chris Otte (CIBC)	**Bill Brandt** Arizona State University
11:15	Workforce and DAC *Jobs that the new energy transition will create in the Inner Mountain West* • Panel Participants: Tony Skrelunas (Tribe-Awaken), Algert Prifti (B&V)	**Jacob Moore** Arizona State University
12:00	Economics	**Michael Hanemann** University of California Berkeley
12:15	Policy: Next 15 years	**Peter Minor** Carbon180
12:30	Thank you and Close	**Matt Green**

4. Workshop Panel Discussion Topics

Dr. Klaus Lackner Q&A Discusion Topics:

Moderator: Jolante van Wijk (Los Alamos National Laboratory)=

- How do you define DAC?
- What is the capacity and technology approach of currently operating facilities?
- Which DAC technology approaches are mature? Which may become mature in the next decade?
- What technology approaches look favorable / unfavorable in the I-WEST region?
- What drives the siting of DAC facilities in both technology-agnostic and technology-centric views? Can you comment on:
    - infrastructure
    - economics
    - societal
    - environmental
    - disposal/use: energy resources, agriculture, fuels, etc
- What sites could be considered in the I-WEST region?
- Where do you see synergy of DAC with other aspects of the energy transition?
- What is a reasonable I-WEST employment scenario in the next 5 and 10-15 years, considering technical, scaling, infrastructure, political, environmental, social, and economic challenges?

Product Panel Discussion Topics:

Moderator: Stephanie Arcusa (Arizona State University)

Panelists: Eric Dahlgren (Aircela), Derek Vikara (NETL), Raghubir Gupta (Susteon), Gary Nicholas (SanTan Brewing Company)

- Can you introduce yourself and your company?
- Can you please explain your company's technology, what the product is, and what will the outcome be?
- What are your anticipated volumes and timings for the next 5-15 years?
- Eric: Who are your intended consumers?
- Gary: Whare are the benefits of installing CO2 capture technology in a brewery?
- Gary: How does the volume of the CO2 generated by fermentation compare to other uses?
- Gary: What is the potential for DAC in the brewing/ beverage industry?

- Raghubir: What infrastructure or regulation would your technologies need to scale and succeed?
- Derek: What geological sequestration is required for DAC?
- Derek: What types of sequestration are available in the I-WEST region, and of what capacity are they?
- Derek: What makes DAC a good candidate to pair with sequestration?

Industry Panel Discussion Topics:

Moderator: Bill Brandt (Arizona State University)

Panelists: Julius Kusuma (Meta), Alex Dewar (Boston Consulting), Joanna Klitzke (Stripe), Chris Otte (CIBC)

- Can you give some context around what your company does, and how it approaches DAC technology as a carbon management tool?
- Alex: Do we have enough momentum developing to meet the corporate goals or do we need something extra to push us?
- Joanna: What do you see as the next step for Strip after you've done the initial work?
- Chris: What are your thoughts on what would be helpful to put the financing together?
- Julius: How is Meta thinking about new collaborations that could address the points we've raised like aggregating demand and pulling the supply chain between capacity so that DAC systems can get off the ground?
- How are companies thinking about corporate positioning from a strategic point of view, not just now but in the next five years and beyond?

Workforce Panel Discussion Topics:

Moderator: Jacob Moore (Arizona State University)

Panelists: Tony Skrelunas (Tribe-Awaken), Algret Prifti (Black & Veatch), Chris Deschene (Tosidoh)

- Algert: What type of jobs does DAC provide and how will the job market grow over the next 5, 10, and 15 years?
- Algert: What are the benefits and drawbacks of the DAC jobs in terms of location, training levels, requirements, safety issues, etc..
- Tony: What are your thoughts around DAC and job opportunities and economic development in general and as it pertains to the tribes?
- Chris: What are your thoughts around DAC and job opportunities and economic development in general and as it pertains to the tribes?