CALDAC Technical Volume

The Technical Volume is one piece of the formal application that UC Berkeley submitted to DOE on March 13, 2023. The Technical Volume presents background and context for the project and the goals and aspirations for the project, if successful.

Berkeley Law

Center for Law, Energy, & the Environment

Regional Direct Air Capture Hub Proposal:

CALDAC - Community ALliance for Direct Air Capture

Topic Area 1 (Phase 0) Proposal: Feasibility Study

Lead Organization: *Regents of the University of California on behalf of the University of California, Berkeley (UC Berkeley)*

Project Lead: *Dr. Louise Bedsworth, Executive Director, Center for Law, Energy & the Environment (CLEE), UC Berkeley*

Project Team Members:

- **Technical and Social Feasibility Planning:**
  Lawrence Berkeley National Laboratory (LBNL); Electric Power Research Institute (EPRI); AECOM; Clean Energy Systems (CES); Fresno State University; Cal State University Bakersfield; PSE Healthy Energy; Project 2030; Data for Progress; Carbon180; Valley Onward
- **Technology Providers:**

  DAC: *Mosaic, Capture6, Origen, AirMyne;* ***CO_2 to Products Technologies:*** *Blue Planet, CarbonBuilt; and* ***Energy Storag****e: Rondo Energy*
- **Host of Sites(s) to Be Considered:**
  Up to three biomass carbon removal and storage (BiCRS) facilities owned by Clean Energy System located throughout the San Joaquin Valley of California: Delano Plant in Kern County, CA; Mendota Plant in Fresno County, CA; and Madera Plant in Madera County, CA.

Associated Project Partners and Alliance Supporters:
Heirloom; UC Davis; UC Merced; ARCHES; Bloom Energy; Berkshire Hathaway Energy; NAWI

Project Budget: *$4,472,940 (total project cost); $2,999,999 (DOE funds requested); $300,000 (cash cost-share), $1,142,941 (in-kind cost-share)*

Feasibility Study to Co-Create a Community **AL**liance **for D**irect **A**ir **C**apture **(CALDAC)**

1. PROJECT OVERVIEW

BACKGROUND

The Center for Law, Energy, and the Environment (CLEE) at the University of California, Berkeley will lead a study to assess the feasibility of developing a **C**ommunity **Al**liance for **D**irect **A**ir **C**apture (CALDAC) in the Southern San Joaquin Valley in California. CLEE is an interdisciplinary research center at Berkeley Law that examines the technical, legal, and policy dimensions of climate change and environmental problems. CLEE has extensive experience leading interdisciplinary teams to address complex environmental challenges. CLEE brings technical expertise in climate change, energy, water, and climate equity and strength as a convenor and facilitator of stakeholder dialogues. CLEE is partnered with Lawrence Berkeley National Laboratory (LBNL), who brings deep technical expertise in carbon removal technology, geologic storage, and the energy and environmental impacts of direct air capture. Additional partners include a range of technology providers, energy companies, community groups, and academic institutions.

INTRODUCTION

The transition to a carbon neutral economy requires widespread deployment of clean, renewable energy sources, zero-emission transportation options, carbon capture and sequestration (CCS), and carbon dioxide removal (CDR) through natural processes and engineered solutions including direct air capture (DAC). The global environmental effect of this transition is positive. However, these transitions have disparate impacts at a local scale and there are issues of distributional, procedural, recognition, and restorative justice.[1] Some U.S. communities that have experienced the worst pollution from high-emitting industries, poverty, and systemic discrimination are now being considered as sites for new climate technologies, including DAC facilities. As these facilities are being deployed, it is necessary to develop a new model for energy transitions to ensure the communities benefit from new technology and do not bear the burdens and negative impacts of these transitions as they have in the past. A growing body of scholarship on co-production demonstrates that local participation and knowledge contribute to the generation of actionable and useful knowledge[2,3] and that approaches with greater public participation and engagement contribute to more legitimate and publicly accepted decisions.[4],[5] Bottom-up community-led approaches to transformation reflect the diverse contexts in energy transitions.[6]

California provides an opportunity to develop this model for the deployment of DAC technology. Governor Newsom directed the California Air Resources Board (CARB) to establish

[1] Carley, S. and D. Kanisky. 2020. The Justice and Equity Implications of the Clean Energy Transition. *Nature Energy* 5 (August): 569-577.
[2] Hickey, G. 2018. Co-Production from Proposal to Paper. *Nature* 562(4 October): 29-30.
[3] Mach, K., et al. 2020. Actionable Knowledge and the Art of Engagement. *Current Opinion in Environmental Sustainability* 42: 30-37.
[4] Coburn, J. 2007. Community Knowledge in Environmental Health Science: Co-Producing Policy Expertise. *Environmental Science and Policy* 10: 150-161.
[5] Graff, M.; D. Konisky; and S. Carley. 2018. Stakeholder Perceptions of the United States Energy Transition: Local-Level Dynamics and Community Responses to National Politics and Policy. *Energy Research & Social Science* 43(September): 144-157
[6] Bazillian, M.D.; S. Carley; D. Konisky; H. Zerriffi; Sandeep Pai; and Brad Handler. 2021. Expanding the Scope of Just Transitions: Toward Localized Solutions and Community-Level Dynamics. *Energy Research & Social Science* 80 (October): 102245.

carbon removal targets of 20 million tonnes of CO_2-eq and 100 million tonnes of CO_2-eq by 2030 and 2045, respectively. The AB 32 Scoping Plan, the State's blueprint for meeting its climate goals includes carbon capture and storage (CCS) and carbon dioxide removal (CDR) through both natural and working lands and direct air capture. CARB's Environmental Justice Advisory Committee (EJAC) expressed concern about the use of CCS and mechanical CDR, including air quality, technical viability, safety, and its potential to allow polluting facilities in impacted communities to continue operating longer or substitute the technology for making emission reductions that would benefit the community. The Scoping Plan calls for additional stakeholder processes around CDR.[7]

PROJECT GOALS

This project will undertake a comprehensive assessment of the technical and social and governance feasibility of establishing CALDAC. This innovative proposal centers the local community in DAC hub development. The feasibility assessment will include two intersecting and interconnected elements:

1. Technical feasibility of the DAC Hub, including technology partners, location, business model, ownership, and CO_2 storage/utilization option(s), and
2. Social and governance feasibility of an innovative, community-led DAC hub design and ownership model that works with local stakeholders as core partners.

These two elements will be connected throughout the course of the project. The DAC hub needs to be anchored in strong technical and technological capacity and capture the needs and concerns of the community. It is vital to establish a strong working relationship with stakeholder groups who experience the benefits and risks of such an endeavor. Our process will provide a platform for co-creation among many community groups, environmental justice organizations, labor organizations, academic institutions, and technology providers. The diverse team that is assembled here will co-produce research questions and scenarios to capture the social, environmental, and technological implications of a DAC hub. Communities in the San Joaquin Valley have experienced a long history of disinvestment, pollution, and power imbalances. As a result, establishing the mutually beneficial and respectful partnerships needed for such an approach will require addressing important trust issues.

We will ensure that any technological solutions are fully vetted to ensure they are socially responsible and in line with community needs and values. We will use a community engagement process to consider a suite of viable options (e.g., energy sources, governance structures, monitoring considerations) to learn under what configurations (if any) a DAC Hub might be locally supported. This will build on early research Data for Progress conducted in the region on community perceptions of and preconditions for DAC deployment, which showed high levels of interest among community members. Community groups will be fully integrated into the project team as equal partners, informing the decision-making and design process according to local social and environmental needs and concerns.

This approach will be especially important in the focus location for the feasibility study, the southern San Joaquin Valley. The region extends from just north of Fresno to Kern County north

[7] CARB. 2022. *AB 32 Scoping Plan*. November. https://ww2.arb.ca.gov/sites/default/files/2022-12/2022-sp.pdf

of Bakersfield. Figure 1 shows the three possible sites in California's San Joaquin Valley that are currently considered as host locations for CALDAC. Communities and residents in the study region have experienced chronically poor air quality, pollution from high emitting industries including oil and gas, emissions from major freight corridors and dairies, and extreme water shortage. As a result, many community members have high levels of distrust and skepticism around deployment of new technologies or facilities, especially those that could provide a pathway to extend the life of high emitting sources. Therefore, building a community-led and informed approach for a DAC hub will require establishing accessible opportunities for deep engagement, partnership, learning, and listening to overcome this mistrust.

Figure 1: Potential DAC hub locations in California's Southern Joaquin Valley. Site options include Mendota and Madera near Fresno in the north, and Delano near Bakersfield in the south. These sites could be expanded and integrated into a carbon management network across California, for DAC and other carbon management technologies. Connecting infrastructure for such an integrated network as shown above is not included in this proposal.

DOE IMPACT

The DOE funding will provide resources needed to bring technology providers, community groups, and other stakeholders together to meaningfully engage and inform potential DAC hub design, governance, and, if successful, operation. Funding will support stakeholder compensation and, if desired, staffing and capacity at community-based organizations. This innovative, community-based approach will center equity, community benefits, environmental justice, and a just transition for the communities that rely economically on carbon-intensive industries in all phases of the project, providing a new paradigm for community-led and focused climate and energy transitions. Within the first nine months of the feasibility study, we will develop principles and criteria to guide DAC hub development and a community-centered ownership model that is tailored to support underserved communities, minimize environmental impacts, and promote workforce development (a hub by the community for the community). While many proposals for DAC center on techno-economic feasibility alone, we consider socio-cultural considerations to be equally as important determinants of project success. Therefore, we will consider both technical and social/governance considerations in our go/no-go decisions.

COMMUNITY BENEFITS

California's San Joaquin Valley includes eight counties covering approximately 27,000 square miles and has a population of approximately 4 million, nearly 25 percent of whom live below the poverty line. The region experiences the worst air quality in the nation due to the presence of emissions-heavy industries like oil and gas, agriculture, and warehouse distribution. Fresno and Bakersfield, two of the largest cities in the San Joaquin Valley, rank in the top four most polluted U.S. cities and first and second for cities most polluted by particle pollution.[8] Fresno County is home to the most disadvantaged census tract in the State of California as measured by CalEnviroScreen 4.0, a spatial tool that identifies communities most affected by pollution, health vulnerability, and concentrated poverty.[9]

The region experiences economic vulnerabilities, especially in light of climate change. Six of the eight counties in the San Joaquin Valley are among the top 10 agricultural producers in the United States. Fresno County is the top producer and had nearly $8 billion in sales in 2018. However, the region faces pressure from drought and water availability. Agriculture in the region depends on California's complex system of dams, reservoirs, levees, canals, pumps, and pipelines to provide millions of acre-feet of irrigation water from both groundwater and surface water resources. The San Joaquin Valley also has a long history of oil and gas production. In 2019, Kern County ranked as the seventh oil-producing county in the nation. However, California's plan to reach carbon neutrality includes a sharp phase down of in-state oil and gas production, as identified in the California Air Resources Board's 2022 Scoping Plan.

If designed well, deployment of a DAC hub in this region could provide important community-wide economic and environmental benefits to low-income, energy-burdened communities that will experience the economic impacts from a shift away from historical reliance on fossil fuels and impacts of climate disruption on the agricultural economy.

CLIMATE VULNERABILITIES AND RESILIENCE STRATEGY

The San Joaquin Valley currently experiences high temperatures and periods of prolonged drought, both of which will increase in severity with the changing climate.[10] The technical feasibility assessment will consider how these conditions will affect the DAC Hub performance.

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[8] American Lung Association. 2022. State of the Air Report

[9] Office of Environmental Health Hazard Assessment. 2021. CalEnviroScreen 4.0.

[10] Fernandez-Bou, A.S., et al, 2021. Regional Report for the San Joaquin Valley Region on Impacts of Climate Change. California Natural Resources Agency. Publication number: SUM-CCCA4-2021-003

2. TECHNICAL DESCRIPTION, INNOVATION AND IMPACT

DAC HUB CONCEPT

CALDAC is envisioned as a "connected" hub that integrates multiple DAC technologies, other carbon removal approaches, carbon utilization solutions, carbon-free, clean energy providers and energy storage solutions, water management, as well as geological storage providers. The CALDAC project team is starting with a core group of technology partners (DAC and CO_2-to-products) as project team members in the proposal application and will welcome additional partners during the feasibility study phase if it makes technical and economic sense. We imagine this hub as part of a regional and coordinated cluster of carbon dioxide removal facilities that incorporates multiple technologies and surrounds them with shared energy resources, storage options, infrastructure and equipment (Figure 2).

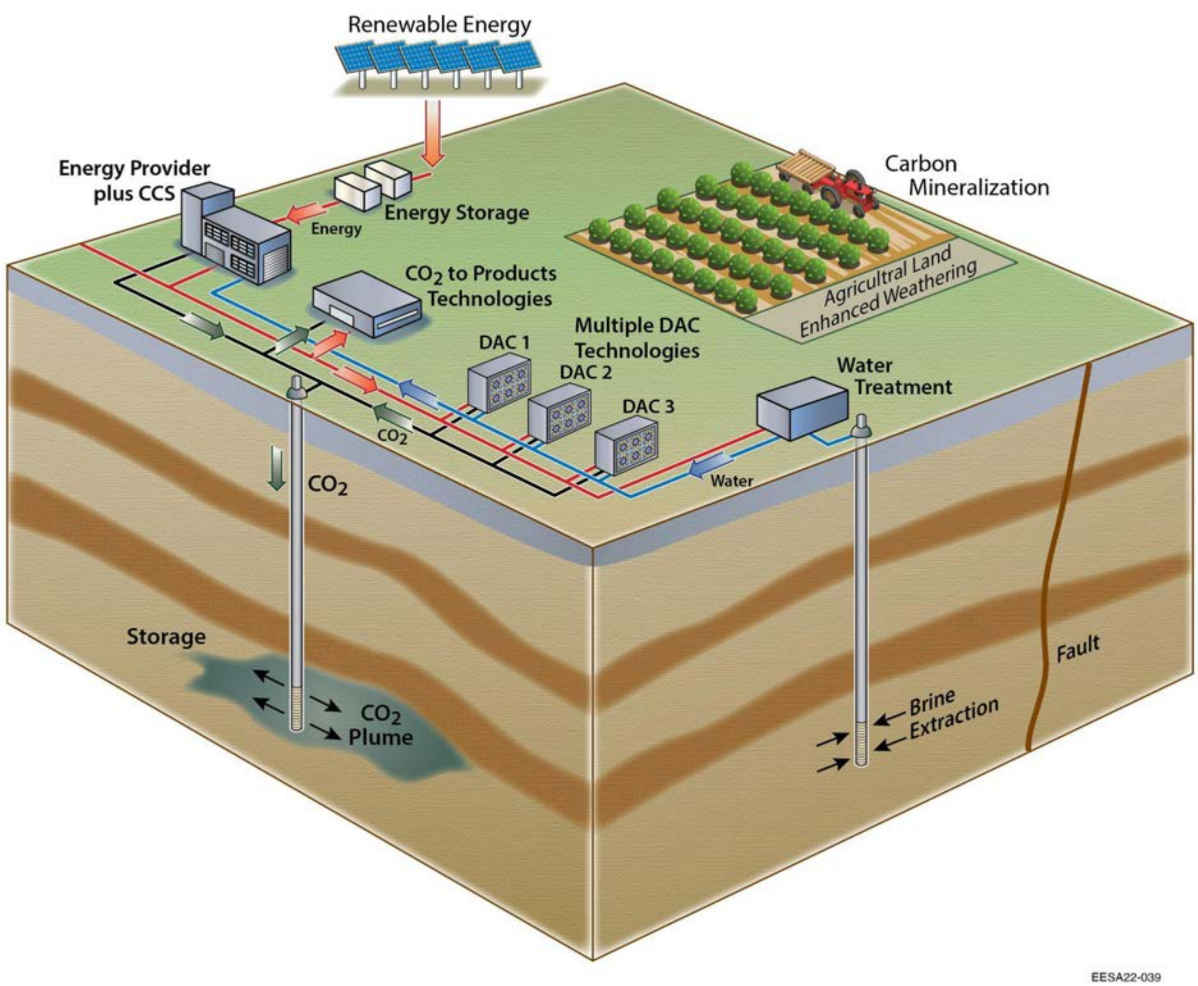


Figure 2: Illustration showing the connected nature of CALDAC integrating multiple DAC technologies with other carbon removal technologies, such as carbon mineralization/enhanced weathering, exploiting synergies and sharing energy resources, storage options, infrastructure and equipment. The figure schematically features one of the three DAC Hub sites envisioned for CALDAC, hosted by an energy provider with carbon capture and storage in development. The site host will provide some energy to the hub (most will be provided by renewable sources) and will offer geologic storage capacity or the >1 MTY CO_2 removed from air.

POTENTIAL HUB LOCATIONS

CALDAC's project partner Clean Energy Systems (CES) has acquired three sites in the Southern San Joaquin Valley that it is exploring as potential Biomass Carbon Removal and Storage (BiCRS) facilities (Figure 3). These sites are attractive because the region is rich with agricultural waste and known for subsurface carbon storage potential. Each site is an idled biomass power plant that offers valuable infrastructure such as biomass collection and fuel handling, steam turbine, electric generator and electrical interconnect, boiler feedwater systems, and additional balance of plant systems.

The nearly 360 acres of land provided by these sites can be partially made available to CALDAC. All three sites are surrounded by agricultural and farmlands, offering significant space for CALDAC expansion if needed or potential renewable energy deployment. The BiCRS plants could provide up to 35 MWe carbon-negative energy to CALDAC and will offer subsurface storage for the >1 MTY CO_2 removed from air. Note that the CES is pursuing the planning, engineering, design and construction activities to develop the three BiCRS plants with independent funding; only CES's hub related planning and integration activities will be supported in the proposed effort. Details on each site are provided below:

- The Delano plant is located in northern Kern County, just south of the City of Delano. It is next to State Highway 99 and a nearby railroad, offering easy access for biomass delivery and any process offtakes. When operating as a base-load biomass power plant, the 118-acre site processed approximately 400,000 tonnes per year (TPY) of biomass material from farms in Kern and Tulare Counties. Once converted to a BiCRS facility, the plant will capture and permanently store approximately 700,000 TPY of CO_2 and produce up to 15 MWe of carbon-negative electricity for use by CALDAC. Detailed subsurface site characterization is underway, with plans to develop and submit a Class VI UIC permit application to EPA mid-2023. Surface engineering design is ongoing, with a focus on long-lead systems engineering and permit development. The Delano BiCRS facility is expected to be operational in 2026.
- The Mendota plant is located on the northwest side of Fresno County, surrounded by agricultural land to the north, south, and east, and the City of Mendota on the west. The site occupies approximately 80 acres east of Interstate 5, accessible by State Highway 33, with railroad access nearby. Once converted to a BiCRS facility, the plant will capture and permanently store approximately 350,000 TPY of CO_2 and produce up to 5 MWe of carbon-negative electricity for use by CALDAC. Front-end surface engineering for the BiCRS plant has been completed. A Class VI permit application was submitted to EPA in February, 2020, and went through detailed technical review with EPA Region 9. In April 2022, CES withdrew the application and is now considering joint development of the Mendota and Madera sites.
- The Madera plant is located in western Madera county, near the Fresno county line, and only 8 miles from the Mendota site. Sitting on 160 acres of land, it is the largest of the three considered sites. When operating as a base-load biomass power plant, the plant processed approximately 200,000 TPY of biomass, but is suitable for expansion up to 400,000 TPY (same as Delano). Due to the proximity to the Mendota site, CES is considering joint development of the two sites. The detailed surface engineering and subsurface work from the Mendota BiCRS project translates directly to the Madera site. The joint Mendota-

Madera project can be in permitting this year, 2023, and is expected to be online approximately 6 months after the Delano BiCRS project.

Detailed planning will be conducted in the feasibility study to develop an optimized plan for utilizing the three facilities in the initial and final buildout of a DAC Hub.

Figure 3: Top - Aerial Photograph of Delano Biomass Power Plant at Peak Operation (facility is idle today). Middle - Aerial Photograph of Mendota Plant. Bottom - Aerial Photograph of the Madera Site When Operating as Base-Load Biomass Power Plan.

DAC AND CO_2 CONVERSION TECHNOLOGIES UNDER CONSIDERATION

As envisioned, the CALDAC hub would integrate multiple DAC technologies alongside additional CO_2 removal technologies and CO_2 to products systems. This integrated vision approach takes advantage of synergies across technologies, supports economic diversity, and reduces risks.

DAC Technologies

The four DAC technology partners currently included in CALDAC represent a distinct set of important direct air capture approaches and each is committed to the community-centered approach of this feasibility study. The DAC technology partners are:

- ***Mosaic (Solid Sorbent Approach, Current TRL: 5)***
  Mosaic, a division of Baker Hughes, has developed a long-lived material with high capacity for CO_2 sorption under dilute conditions, and has been confirming its operating parameters since 2016. Mosaic's amine functionalized sorbent is a derivative of the M_2(*m*-dobpdc) metal-organic framework (MOF) initially developed at UC Berkeley and Lawrence Berkeley National Laboratory, now tuned for dilute CO_2 removal. MOFs are a class of highly porous, crystalline solids that function as ultra-high capacity sponges for gases because the pore surfaces afford a large number of adsorption sites for gas molecules. By changing the chemical properties of these adsorption sites, MOFs can be designed to selectively capture only specific gases from a complex mixture. The chemical tunability and large surface area allow MOFs to outperform other gas separation technologies including distillation and absorption. The specific amine-MOF material class developed by Mosaic provides flexible material design, but more importantly displays a step-shaped CO_2 adsorption isotherm because of the cooperative adsorption mechanism unique to this class. The resulting step-shaped isotherm contrasts sharply against the more gradual increase in CO_2 loading characteristic of traditional solid sorbent materials, making Mosaic's technology advantageous in terms of process efficiency, materials durability, and cost. Other advantages include Mosaic's amine-functionalized MOF-based adsorbent material selectively captures CO_2 with higher efficiency and lower costs; and the cooperative-binding technology allows the CO_2-loaded materials to be regenerated using only moderate temperature or pressure changes, substantially increasing energy efficiency and decreasing costs.

  Mosaic has developed patent-pending manufacturing techniques to make these adsorbents cost-effectively. The materials have been tested since 2016 at a laboratory scale. Following lab-scale testing, Mosaic has been operating a 1 TPY TRL5 prototype in its facility in Alameda, California since March 2022 to validate all performance characteristics. At present, Mosaic is completing the final design and assembly of a larger scale system which will be deployed in Houston, Texas in 2023.

- ***Capture6 (Liquid DAC and Carbon Mineralization Approach, Current TRL: 6)***
  Capture6 is a project development public benefit corporation that has developed a DAC and mineralization process for permanent and irreversible carbon dioxide removal. Saline water such as desalination plant brine effluent, sea water or saline groundwater (brine) is split into sodium hydroxide and hydrochloric acid via electrodialysis bipolar membranes. The

sodium hydroxide reacts with carbon dioxide in an air contactor system to produce sodium carbonate, for either storage or utilization. If needed, carbon dioxide can be regenerated. Of the salt water input, up to 70% can be output as fresh water for further use (Figure 4). The process can be adjusted to produce green hydrogen and chlorine using electrolysis from the salt water input. The individual technologies involved in the process are TRL 6-9, although the integration is novel and process patents are pending. Capture6 will break ground on a demonstration facility in Palmdale CA in 2023. Capture6 has brought together industrial partners to build facilities, including a collaboration with the global corporation Veolia Water Technologies and Solutions, and was recently nominated for the EarthShot Prize. Capture6 has a global pipeline of facilities in development and is headquartered in Berkeley, CA and Rotorua, New Zealand.

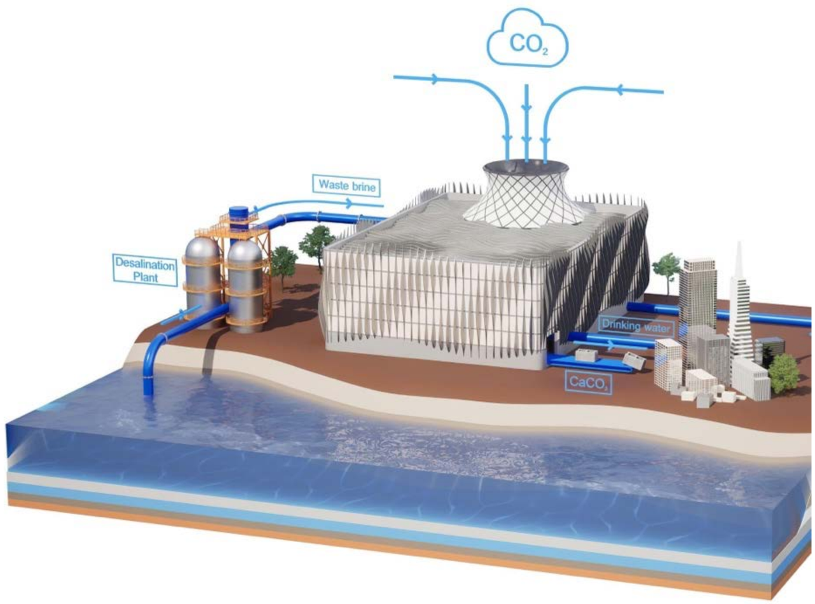


Figure 4: Capture6 Direct Air Capture Solution. This illustration shows a hypothetical scenario where sea water desalination brine is used as the water source. The technology also works with other produced waters (such as brine extracted from the CO_2 storage reservoir to provide storage space).

- ***Origen (Carbon Mineralization Approach, Current TRL: 4)***
  Origen has a path to giga-tonne scale carbon removal by unlocking the power of lime. Lime is a product of limestone, and naturally reacts with CO_2 to remove it from ambient air; however, the production of lime releases more carbon than lime can currently remove. Origen's core technology combines two proven industrial processes - oxy combustion and flash calcination - to create lime that is purpose-built for carbon removal, while sequestering high purity CO_2 emissions for permanent storage (Figure 5). When Origen's decarbonized lime is contacted with ambient air, a process that can be sped up with Origen's partners and that Origen is exploring through R&D, it becomes limestone and can be looped through the process again. With cheap, and widely available inputs utilized in trusted industrial processes, Origen has a direct path to scalable, low-cost carbon removal. In 2022, Origen and contactor partner, 8 Rivers, won pre-purchased removal credits from the Frontier fund. Origen is currently commissioning a pilot in the UK with ~1,000 TPY removal capacity, alongside its strategic partner in the lime industry. The pilot is scheduled to deliver first carbon removals with 8 Rivers in 2024.

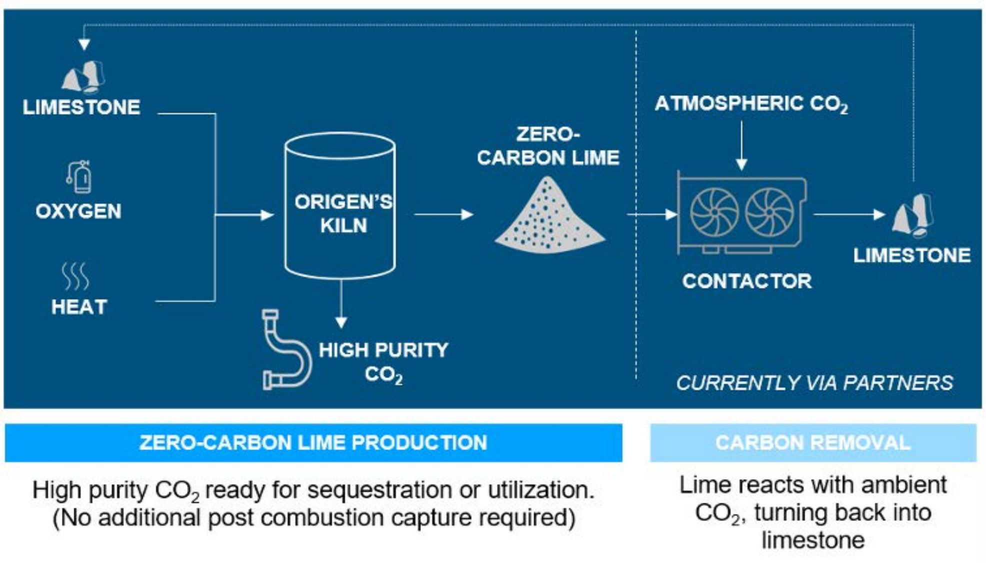


Figure 5: Origen's DAC technology.

- ***AirMyne (Liquid Solvent Approach, Current TRL: 4)***
  In AirMyne's patent-pending system, high-efficiency electric fans bring atmospheric air into contact with a solution chemistry that captures carbon dioxide from air by adsorbing it onto the process fluid. The chemistry is recyclable & reusable, and leverages existing supply chains. The captured carbon dioxide is then passed through a steam-heated zone at moderate temperature followed by a purifying step to release pure carbon dioxide. The pure carbon dioxide is compressed for geological sequestration or use as a feedstock in manufacturing processes. The whole system is designed to run on electricity and steam, resulting in a drop-in, low-cost process design & operation. AirMyne is based in Berkeley, CA and employs leading experts in industrial process engineering, mechanical engineering, chemical engineering, prototyping, automation & robotics, sensing, as well as computation and simulation. Since the company's founding in February 2022, AirMyne has demonstrated its capture process at kg/day scale in their 11th prototype. They have filed multiple patents & are hard at work building a fully-automated TRL 5 prototype in preparation for pilot-scale deployment.

In addition to these four core technology partners on the project team, CALDAC has discussed potential partnerships with other DAC companies that value the community-centered approach being taken in this feasibility study (e.g., Heirloom, see support letter). The project team will work with these and other technology providers during the feasibility study to explore additional partnerships.

CO_2 to Products Technologies

One critical aspect of this feasibility study phase for CALDAC is to assess, design, and then build and deploy integrated technologies capable of efficiently converting the CO_2 captured from DAC and converting into products. Turning CO_2 into long-lived, carbon-negative goods and services will create a more carbon-efficient economy, while obtaining economic benefits at the local, state, and national level. These conversion technologies will benefit from the co-produced syngas, hydrogen, heat and electricity that the site will provide. First among these benefits is the creation of new industries within the United States, guided by ongoing technology development based on fundamental and ground-breaking scientific studies. CO_2 and water can be converted into long-lived and high-performance materials for buildings and infrastructure (structural materials, binders and strengtheners for concrete, fibers and composites, and polymers); biofuels (e.g., sustainable aviation fuels); specialty chemicals; and high -value products like the carbon composites used in efficient new vehicles and airframes. CALDAC will co-host a carbon-to-products facility at one or more of its proposed sites. Two CO_2 to products technology partners are currently included in the proposal, both focusing on conversion to building materials. In addition, CALDAC will invite other technology providers with innovative concepts for biological or chemical transformation of CO_2 to products that will be screened in terms of performance targets for yield, rate, cost, energy intensity, carbon intensity, and scalability.

Conversion to Building Materials

- ***Blue Planet (Current TRL: 6-7)***
  Blue Planet's technology combines carbon dioxide with calcium sourced from waste to manufacture synthetic limestone aggregate that permanently and safely sequesters CO_2. The aggregate is then used to produce low-embodied carbon or carbon negative concrete. Each tonne of Blue Planet's aggregate permanently mineralizes 440 kg of CO_2, preventing it from ever leaking or accumulating in the atmosphere. The process is Geomimetic®, meaning that it mimics the earth's natural process of creating rock. The feedstock, referred to as "geomass", can be a range of materials: demolished/returned concrete, cement kiln dust, steel slag, fly ash, and bauxite residue. Blue Planet's process can use dilute CO_2 from any source, at any concentration, and turn it into valuable building materials to enable carbon capture at a profit. The CO_2 does not need to be purified or liquified which has been demonstrated on gas streams containing as little as 5% CO_2. Based in Los Gatos, California, Blue Planet is building its first commercial production facility to use its patented carbon mineralization technology in Pittsburg, CA. The facility will capture CO_2 from the neighboring Los Medanos Energy Center and will be delivering carbon negative aggregate to projects in the Bay Area. The only inputs are CO_2 and waste concrete – the CO_2 capture solution is refreshed by exposure to fresh geomass so chemical consumption is negligible and there is no process waste.

- ***CarbonBuilt (Current TRL: 8)***
  CarbonBuilt is an XPRIZE-winning company that enables the production of ultra-low-carbon concrete products, starting with concrete masonry units (CMU), with no impact on price, performance, or ongoing plant operations. CarbonBuilt's technology reduces the carbon footprint of CMUs by 70% to over 100% through both avoided emissions and permanent carbon removal. A single production line retrofitted with CarbonBuilt's technology can permanently mineralize about 500-1000 TPY of CO_2. CarbonBuilt works with existing concrete product producers to: 1) develop low-cost, locally-sourced concrete mix designs that dramatically reduce or eliminate cement, replacing it with calcium-rich, mostly-waste materials; and 2) retrofit their plants to accommodate CarbonBuilt's CO_2-curing process,

which mineralizes atmospheric CO_2 into the concrete. CMUs produced using CarbonBuilt technology meet the same ASTM standards as traditional blocks.

In addition the measurable, verifiable, and permanent carbon removal, CarbonBuilt's process has several co-benefits: 1) Reduced or zero cement content avoids several TPY of CO_2 emissions per production line; 2) Replacing steam curing with CO_2 curing saves tens of thousands of gallons of freshwater per production line per year and reduces or eliminates onsite natural gas combustion necessary to produce steam; and 3) Reduced raw material costs and increased demand for ultra-low-carbon concrete increases revenue for concrete product producers, enabling them to grow their business and create high quality jobs. CarbonBuilt is based in Los Angeles, CA and works with concrete product producers across the country. They are currently completing the retrofit of their first commercial plant (Blair Block, near Birmingham, AL) and preparing for similar retrofits in other locations.

Testbed for Other CO_2 to Products Technologies

In addition to above two partners, CALDAC will invite low- to mid-TRL technology partners (e.g., Kiverdi, Cemvita, 12, Gingko, Lanzatech) to catalyze development and deployment of other innovative concepts for selective, efficient, scalable conversion processes, such as hybrid biological and chemical conversion approaches. We envision the integration of breakthrough hybrid chemical and biological processes with economical carbon management practices, including advanced materials (e.g., graphene, conductive polymers) and chemicals (e.g., aromatics, hydrocarbons, monomers) from CO_2 by processes such as coupling reducing equivalents (electrons) with the high selectivity of synthetic biology transformations. As results from these nascent technologies are generated, they will be fed into the techno-economic and life cycle analysis (TEA and LCA) teams that will then identify the most promising routes to develop further. This includes evaluating all of the assessed CO_2 to products technologies in terms of performance targets for yield, rate, cost, energy intensity, carbon intensity, and scalability.

Associated Carbon Removal Technologies

In addition to the technologies listed above, this feasibility study will explore the potential inclusion of two additional carbon removal technologies: BiCRS and enhanced soil carbon sequestration. The carbon removed by these technologies is in addition to the CO_2 captured through the DAC technologies in the initial buildout (> 50,000 TPY) and final buildout (> 1 million TPY) of CALDAC. Per FOA definition, the BiCRS and soil carbon sequestration parts of CALDAC are not eligible to receive funding from this grant opportunity. However, the BiCRS technology provider CES serves as a host for and as a clean energy provider to the proposed DAC hub, and as such will receive limited funding for the hub planning and integration work scope.

- ***BiCRS Technology***

  We will assess the technical and social feasibility of co-locating the hub with three BiCRS plants that are currently in development in the region by our project partner Clean Energy Systems (CES). Their CNE (Carbon-Negative Energy) BiCRS process starts by gasifying waste biomass fuels to produce a synthesis gas, or "syngas" (Figure 6). Nearly pure oxygen is generated by an air separation system and fed to CES' oxy-fuel power block with the bio-syngas. The flexible system makes use of biomass waste such as agricultural and forestry residues; there is no need to plant and harvest new crops to serve as field sources. The power block produces electricity and/or steam as well as CO_2 and excess water. Greater than 99% of the carbon from the process (as well as any possible impurities in the CO_2 stream) is captured for CO_2 utilization and/or permanent storage. No flue gas is released from the facility.

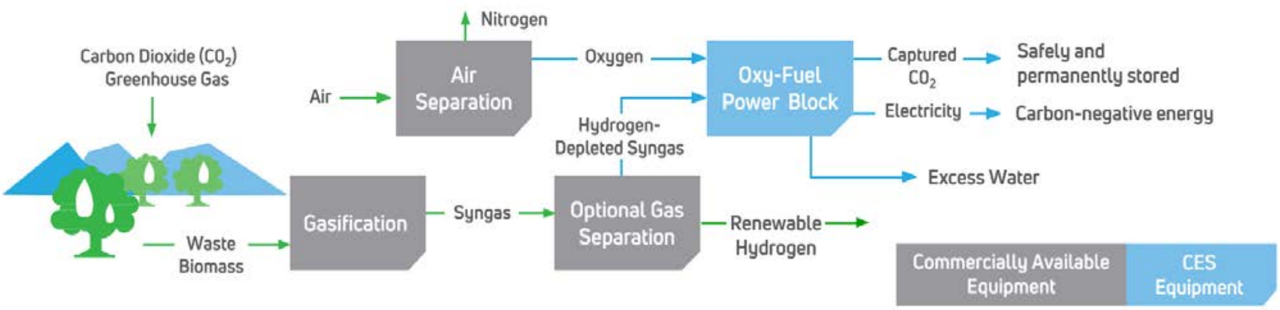


Figure 6: Simplified Schematic of CES' BiCRS Process

By using fuel that consumes carbon dioxide (CO_2) over its lifetime and safely and permanently storing captured CO_2, the process results in net-negative carbon emissions, effectively removing the greenhouse gas from the atmosphere. In addition to helping achieve California's ambitious climate goals (e.g, the California law that requires 100% of the State's electricity to come from carbon-free resources by 2045), the clean use of agricultural and forestry waste in the region would eliminate an important source of criteria pollutants and thereby improve local air quality. This would also lead to the reduction and possible elimination of open field burning of agricultural wastes, alleviating waste management issues and use of forestry biomass as feedstock addresses the tree mortality and wildfire crisis in the State. The revitalization and complete retrofit of existing, idle biomass facilities supports economic growth and jobs in the region. BiCRS specifically excludes organic waste streams such as biosolids, refuse derived feedstocks, food waste and fossil waste, or circular feedstock such as petcoke, heavy resid or plastics.

- ***Enhanced Soil Carbon Sequestration on Working Lands***
  CALDAC will partner with a UC Davis led consortium (the California Working Lands Innovation Center, or WLIC). WLIC explores the potential for carbon removal based on enhanced mineral weathering in working and fallowed lands in California's agricultural regions (see support letter). Enhanced mineral weathering (EMW) accelerates the natural weathering process by incorporating finely ground silicate rock, such as olivine or basalt, into agricultural soils. The large surface area of the rock dust speeds up chemical reactions that lead to the removal of CO_2 from the atmosphere and to geologic time-scale C storage as stable carbonate minerals in the soil. Theoretical estimates of sequestration potential suggest optimal rock types and particle sizes, including natural rocks quarried near the City of Ione, CA, could result in the removal of up to 0.2-0.8 tons of CO_2 per ton of rock dissolved.

Fallowed land will play an increasing role in nature-based climate change solutions. Current estimates from the Public Policy Institute of California indicate that up to 900,000 acres of farmland will be fallowed in the San Joaquin Valley by 2040 due to reduced water availability. The UC Davis led consortium will test and document the ability of enhanced mineral weathering alone and “stacked” with organic amendments such as composts, food-processing waste, crop residues, to sequester organic and inorganic C. The approach is multidirectional with experimentation on a number of demonstration test beds, modeling, policy analysis, and economic assessments and capitalizes on additional benefits of securing food and water, and reclaiming acidified lands. UC Davis and CALDAC envision co-location of one or more EMW demonstration test beds near the hub sites to explore EMW in greenhouses with CO_2 added for potential crop production benefit (either by enriching the air with CO_2 or adding it to the irrigation water). Co-location with CALDAC sites may also have the co-benefit of using water produced by certain DAC technologies for fallowed land irrigation.

RESOURCE REQUIREMENTS AND AVAILABILITY

Energy Supply and Energy Storage

An important planning task is to develop optimal pathways that provide affordable low-carbon energy to the hub. Early estimates for the 50,000 TPY initial DAC capacity range from 20 to 22 MWe which may be reduced to 5-10 MWe if high efficiency performance can be achieved. Up to 400 MWe may be required for the final buildout of 1 million TPY, reducible to 200 MWe or even 100 MWe if high efficiency performance is achieved. Drying and compressing 1 million TPY of CO_2 for pipeline transport and subsurface storage adds another 30-50 MWe, while saline groundwater pumping may add roughly 3 MWe. For the purpose of this proposal, these estimates assume that Mosaic and Capture6 are the anchor technologies, thus need to be revised when the final DAC technology portfolio is defined during the feasibility study. The energy required for CO_2 to products conversion will need to be added, but can only be estimated when the capacity of these facilities has been designed during the feasibility study.

CALDAC will explore the technical and social feasibility of satisfying the initial 50,000 TPY energy requirements with combined power and heat from the carbon-negative BiCRS plants, which are hosted on the same site, allowing for a local solution. The final buildout to > 1 million TPY will require a significant amount of additional power to the hub (approximately between 200 to 450 MWe), which greatly exceeds what the BiCRS plants can provide. This energy demand needs to be put into the context of the astonishing progress California has made and continues to make in building clean energy resources. The state has transformed its electricity generation portfolio and now receives roughly sixty percent of its electricity from carbon-free resources. Future goals — including 90 percent zero-carbon electricity by 2035 and 100 percent zero-carbon electricity by 2045 — ensure that an aggressive buildout will continue and in fact needs to accelerate. The SB 100 Joint Agency Report identified up to 170 GWe of new clean energy resources needed to reach the state's goals (California Energy Commission, 2021). And according to the California Air Resources Board, at least five GWe of utility-scale solar facilities must be built annually for more than 20 years (California Air Resources Board, 2022), on top of other clean energy sources such as wind, geothermal, or hydrogen.

Given this projected rapid expansion of California's clean electricity generation capacity, we expect that the required energy for CALDAC's final buildout capacity will be achievable with renewable energy at affordable cost, either by integration into the grid or via dedicated renewable energy facilities powering the hub. While the proposed feasibility study will take a look at multiple energy pathways, we anticipate that it will be most cost effective to use solar for the majority of the supplied energy. CALDAC will partner with Berkshire Hathaway Energies (BHE) to explore the use of solar and possible wind energy for the hub. BHE owns the 550 MWe Topaz solar power plant, one of the world's largest solar farms located in California about 80 miles west of the Delano site (see support letter).

In California's energy market, solar electricity can be available during the day for about 2 cents/kWh. In addition, power curtailment is frequently needed today as the intermittent cycle of solar generation leads to excess electricity on the grid during peak production. Given California's mandated zero-carbon energy future, this need for curtailment is likely to increase exponentially in the next decades. For example, the California Independent System Operator (CAISO) curtailed 1.5 million MWh of utility-scale solar in 2020, representing 5% of total production. CALDAC plans to fully tap into this opportunity space - cheap or even curtailed renewable energy during the day - by aggressive deployment of energy storage technologies.

We will explore multiple energy storage technologies in the feasibility study (e.g., battery packs, compressed air, etc.). One of CALDAC's project partners, California-based Rondo, has developed the Rondo Heat Battery, which stores intermittent electricity supply as high temperature heat in refractory bricks and delivers back continuous, high-temperature heat as steam, hot water, hot air, and electricity (Figure 7). Rondo Energy uses proven, durable materials such as high-alumina refractory bricks and off-the-shelf resistance heaters to capture electricity from intermittent sources such as solar PV and wind and store it as heat. This would allow the CALDAC to exclusively utilize low-cost heat and electricity with 20-30% capacity factor electrical supply. Charged to full 24-hour capacity within a few hours, the Rondo Heat Battery can be configured to deliver energy to a wide variety of DAC technologies as either steam or hot air, as well as providing 24x7 renewable electricity when operated as a combined heat and power unit.

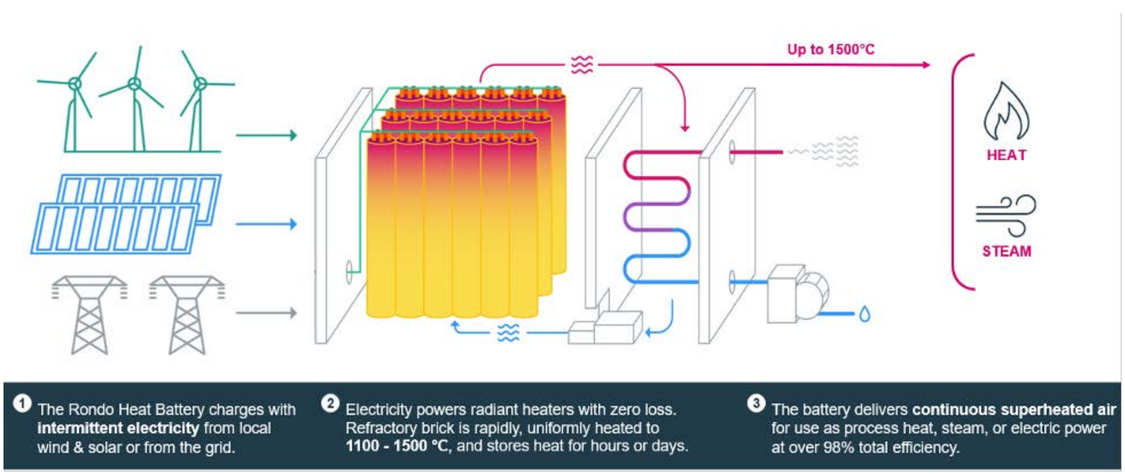


Figure 7: Concept of Rondo Energy heat battery technology to store intermittent renewable electricity to provide 24x7 power or steam to DAC Hub.

CALDAC will also evaluate green hydrogen (H2) as an alternative or complementary pathway to powering the hub, and will do so in partnership with ARCHES (Alliance for Renewable Clean Hydrogen Energy Systems), California's public-private hydrogen (H2) hub consortium to accelerate the development and deployment of clean renewable H2 projects and infrastructure (see support letter). ARCHES is currently developing a major proposal to establish a regional hydrogen hub in California that will include the Central Valley. Tapping into a $8B appropriation in the Bipartisan Infrastructure Law (BIL) to support four or more such hubs, ARCHES (if awarded) would create a network of clean H2 producers, consumers, and infrastructure across the State to deliver clean H2 at a cost of $2/kg by 2026 and $1/kg by 2031. CALDAC is also partnering with Bloom Energy, a major fuel cell company, to convert hydrogen into low carbon heat and power for DAC and CO_2-to-products plants (see support letter).

Land Requirements and Availability

Based on literature data and estimates received from CALDAC's four technology partners, the land requirements for DAC installation at the 1 million TPY scale range widely, between 6-100-acres for solvents, 150-1250 acres for sorbents, and 20-100 acres for mineralization, not including land for enhanced mineral weathering. These large ranges reflect the wide range of possible capture rates, but generally less than 5% of land footprint is dedicated to air contactors and regeneration equipment, with the rest of land dedicated to ballpark aerial mixing, processing equipment and safety margin requirements. Based on this range, we expect that the DAC facilities installed at full capacity can be housed on the three BiCRS sites. Whether these sites will also be able to situate other DAC infrastructure, such as the CO_2 to products facilities, is an open question at this time. More detailed layout planning will be conducted during the feasibility study.

Geologic Storage Options, Available Capacity, and Transportation Needs

The three BiCRS sites overlie a deep stack of sedimentary strata that provide considerable capacity to store CO_2:

- CO_2 captured at the Delano site will be sequestered in sandstones of the Olcese or the Vedder Formation. The primary seal is the combined Macoma/McClure/Fruitvale shale, with a 2,000 ft (600 m) thickness whose base is 6,500 ft (2.0 km) deep. Net cumulative production of gas, oil, and water from the Vedder Formation as of 2010 was 700 million reservoir barrels (100 million reservoir cubic meters), which is equivalent to about 70 million tonnes of CO_2. Including the saline reservoir portion of these sands, the sequestration capacity of these formations is much larger.
- Sandstones of the Cretaceous Moreno and Panoche Formations below the Moreno shale provide stacked sequestration capacity below the Mendota and Madera sites, which are only 8 miles (13 km) apart from each other. The Madera site is within the Moffat Ranch Gas field where the base of the Moreno shale is about 5,500 ft (1.7 km) deep. At the Mendota site the base of the Moreno shale is about 8,500 ft (2.6 km) deep. The Gill Ranch Gas field is 6 miles (9 km) to the east-northeast where some of the Cretaceous depleted gas sands have been converted to gas storage. Both sites have 1,000 to 1,500 ft (300 to 450 m) net sand in the Cretaceous below the Moreno shale. Gas production alone from these sands in the

vicinity of the sites is equivalent to about 10 million tonnes of CO_2. Including the saline reservoir portion of these sands, their sequestration capacity is larger.

Injection wells can be hosted on each of CES's three sites, limiting the need for transportation of CO_2 from the BiCRS and DAC plants to wells. However, the sites will not accommodate the CO_2 footprints resulting at each location and access agreements will be needed to secure contiguous pore space. California's Senate Bill 905 provides regulatory developments to facilitate CO_2 storage and transportation (Sen. Caballero, Sept 2022). The law requires State regulatory agencies to adopt a unified permitting process by January 1, 2025 to facilitate capture, removal, and sequestration projects, which will reduce the permitting risk and time. The law could result in the establishment of unitization rules in the 2026 legislative session. The bill establishes a minimum threshold of access secured to three quarters of the pore space needed for a project to utilize unitization. If adopted these rules will reduce project risk.

ENVIRONMENTAL IMPACTS AND MITIGATION

Understanding the environmental impacts and potential mitigation measures for a DAC hub will be critically important given the high pollution burden in the region. During the feasibility assessment, we will work closely with community groups, residents, and other stakeholders to characterize potential environmental, health and safety hazards associated with CALDAC. Evaluations will consider both the construction and operational phases of CALDAC and will include characterization of potential air quality impacts, mitigation strategies, and community air monitoring requirements (see below). We will also closely examine water needs and potential impacts, including evaluation of the use of unconventional water sources, such as agricultural drainage water, municipal wastewater, brackish water, and possibly brine extracted from the CO_2 storage reservoir. Physical hazards (such as noise) and safety hazards will also be evaluated. The environmental impact assessment will focus on the DAC technologies, as well as CO_2 transport, conversion, and storage components, and supporting infrastructure. Inputs will include data provided by DAC, CO_2 conversion, energy providers and the host site operator.

Activities related to environmental impact assessment and subsequent proposal of mitigation approaches will be directly informed by a Community Oversight Council, through the model described below in Section 2.6 *'Approaches to Achieve Community Acceptance and Ensure Community Benefits.'* Briefly, in the context of environmental impact assessment, this includes the co-production of research questions regarding potential environmental, health, and safety impacts of the DAC and CO_2 conversion technologies as well as respective hub infrastructure. By centering community input in the research question development process, environmental impact assessment activities will aim to support data provision from providers and independent evaluation efforts to comprehensively address community concerns. Results of the environmental impact assessment will be provided to the Community Advisory Council to inform discussions regarding hub design optimization and potential mitigation strategies.

<u>Air Quality</u>

Data on anticipated air emissions will be provided by DAC, CO_2 conversion, energy storage technology providers and the host site operator (CES). Data requested from technology providers will take into account co-produced research questions developed by technical parties and the Community Advisory Council. These data may include construction-based and operational-based emissions, as well as emissions during events associated with routine maintenance operations. Air pollutants of interest may include U.S. EPA-designated criteria air pollutants, criteria air pollutant precursors (e.g., VOCs), hazardous air pollutants, and specific air pollutants associated with DAC technologies (e.g., solid sorbent or liquid solvents) identified by technology providers. Methods used to develop underlying emissions rates or model ambient air concentrations may also be requested.

Third-party, independent review of these data are a critical function of this project, as trusted information on environmental, public health, and safety implications of DAC technologies is foundational to community acceptance. As such, these data will be independently reviewed by a subset of Project Team partners (this will include UC Berkeley, LBNL, PSE, World Resources Institute). Independent review will include examination of available data on air emissions associated with DAC technologies in the peer-reviewed literature; evaluation of analytical approaches for developing underlying data (e.g., gas analyses, modeling approaches), and a detailed summary of potential air quality and public health impacts, limitations and remaining data gaps. Depending on data availability for air pollutants of concern, emissions rates may be used to model ambient air pollutant concentrations and evaluate potential health risks and impacts. With recognition of the broader external landscape in which CALDAC will situate, the environmental impact assessment will also include a summary of baseline cumulative (environmental, health and socioeconomic) burdens of communities located nearby the proposed CALDAC locations. Findings from the independent environmental impact assessment of potential air quality impacts can be used to inform exploration of community-focused air monitoring approaches for the build phase and to co-develop a community air monitoring plan with the Community Oversight Council.

Water Management

Two of the four current DAC Technology partners have substantial water needs, and while synergies can be explored between water-consuming and water-producing technologies, careful water management and sustainable water supply practices are essential to prevnent exacerbating water shortage in a drought-stricken region like the San Joaquin Valley. CALDAC imagines a modular optimized approach to circular water management that relies on unconventional water sources, such brackish groundwater, agricultural drainage water or municipal wastewater. The availability of these candidate water sources for DAC processes will be evaluated as to source type, volume, quality and treatability, location, approximate cost at the source, and other special considerations pertaining to each source type. Unconventional water sources will likely need to be selectively treated as required for the different end uses involved in CALDAC. The cost of water delivered will be evaluated as a function of the amount of water required, the degree of treatment of desalination required, and the distance between the water source and the DAC facility. Negative impacts on water quality will be assessed.

Another valuable water source considered by CALDAC is brine extracted from the very reservoirs that CO_2 is injected to. Brine extraction is viewed as a potentially important mitigation measure for CO_2 storage reservoirs with limited capacity or induced seismicity risks (as a result of injection-related pore pressure increases). In California where natural seismicity is ever present and faulting is ubiquitous, the need for brine extraction from CO_2 storage reservoirs needs to be carefully evaluated. If required, CALDAC would drill an additional brine extraction well to bring deep groundwater up for the purpose of pressure management, and then would selectively treat these waters as feeds for DAC and BiCCRS. Note that the produced saline waters from the reservoirs in the San Joaquin Valley are typically quite low in salinity (around 15,000 to 20,000 ppm, less than seawater), thus water treatment and desalination is less arduous than in the case of high-salinity brines. Also, the DAC technologies developed by Capture6 which utilizes high-mineral context waters may be capable of using the San Joaquin Valley brines directly, without much treatment.

CALDAC will partner with NAWI, the National Alliance for Water Innovation (also called DOE's Desal Hub, https://www.nawihub.org/), which is working towards modular water treatment systems for a wide range of unconventional source water (see support letter). Findings from the water research will support Community Advisory Council conversations regarding a community- informed water management plan.

APPROACH TO ACHIEVE COMMUNITY ACCEPTANCE AND ENSURE COMMUNITY BENEFITS

In addition to evaluating the technical feasibility of the DAC hub, we will conduct a social and governance feasibility study to inform hub design and examine community governance and ownership models to advance equity in the region. The San Joaquin Valley experiences high concentrations of poverty and has a long history of pollution. Therefore, development of a carbon removal economy in the region needs to be undertaken in a manner that centers on community benefit and equity. CALDAC will have a governance model that engages local communities and stakeholders as core partners from concept through operation. Within the first nine months of the feasibility study, the project will develop a community-centered ownership model that is tailored to support underserved communities, minimize environmental impacts, and promote workforce development (a hub by the community for the community). To ensure the social feasibility of the planned hub endeavor, several community groups including local environmental justice organizations will join CALDAC as active project team members.

The technical and social/governance feasibility assessments will be connected through stakeholder engagement and information and data sharing. The diverse project team will be co-producing research questions and scenarios related to the social, environmental, and technological implications of a DAC hub in order to ensure that any technological solutions that are on the table and various design structures are fully vetted before deployment to ensure they are socially responsible and in line with community needs and values. In addition, the social and governance feasibility assessment will shape the business model and financial plan and inform go/no-go decisions.

Community Ownership Models

We are working with partner organizations to explore different models of public authority, including a range of community-based public-private partnership models that could best operate a DAC Hub as a public good. During Phase 0a, CALDAC will explore the feasibility of establishing a Public Authority to oversee the operations and financing of a DAC hub. A Public Authority, much like a Port Authority, Transit Authority, or Municipal Utility District would operate the DAC hub as a public good – one that maximizes safety and the strongest environmental standards while minimizing costs. A public authority would ensure that CALDAC is operated as a public good, have access to public financing, operates with data transparency and performance tracking, and takes a long-term outlook. Since the State of California is committed to removing legacy emissions and permanently sequestering them, California is an ideal place to develop this innovative model. Creating a Public Authority in California – with its unique geological sequestration resources and strong environmental standards could serve as a model for the creation of DAC Hubs nationally. This innovative structure will facilitate competitive DAC services and prevent this essential infrastructure from being dominated by a monopoly incumbent industry.

Community Benefits

Delivering real and meaningful benefits to the communities where a DAC hub might be located is a central goal of the CALDAC project. The resulting Community Benefits Plan will address labor and workforce development; diversity, equity, inclusion, and accessibility; and environmental justice. The plan will include analysis and recommendations for orienting governance and management in ways that help to alleviate the region's pollution burdens and environmental vulnerabilities. The goal of this process is to develop a new paradigm and model for community ownership, accountability, transparency, and generational wealth building that centers communities and people as beneficiaries of the energy transition.

The CALDAC governance model will be designed through a collaborative process to maximize community benefits. We will develop a business plan for the DAC hub that includes community and/or public ownership models, revenue streams and sharing models, and collaborative governance structures. In addition to having permanent community representatives on the project team, we will:

- Establish a paid/compensated Community Oversight Council, encompassing stakeholders from various community and interest groups, including representatives from historically disadvantaged and environmental justice community groups.
- Identify and collect community-relevant data that would inform the design process and help to monitor, track and verify social and environmental goals. This could include various climate and resource needs data related to CALDAC (water, energy, and air), as well as data in line with the federal government's Justice40 initiative.
- Establish baseline data and data transparency processes that include timely sharing of project performance data in an easily understandable and regionally-relevant manner with the public.
- Test and verify the effectiveness and possible environmental and social footprint of various innovative technologies that would be included as part of the DAC technology portfolio. We will test the design under community-informed scenarios to assess the environmental, economic, and social impacts of the hub.
- Develop a business plan for the DAC hub that includes innovative ownership models, revenue streams and sharing models, and governance structures that deliver meaningful community benefits, while identifying a risk and profit-sharing process.
- Work with the technical team leads to develop a hub integration plan that describes how public and private entities participate in hub design, development, and operation.

Community Oversight Council

To ensure broad community participation and engagement throughout this project, we will establish a Community Oversight Council that will include stakeholders, residents, and representatives from historically disadvantaged and environmental justice community groups. The council will provide feedback and direction to the project team, help coordinate public engagement activities, and inform key project decision-making points. All members of the Council will be compensated. The data collected and the input provided by the Community Advisory Council will directly inform the feasibility assessment of the hub and design considerations. The design will be tested under various scenarios that would consider the environmental, economic, and social impacts of the hub. We will verify the effectiveness and possible environmental and social footprint of various innovative technologies that would be included as part of the DAC technology portfolio through an inclusive engagement process. We will identify and collect community-relevant data to inform the hub design process and help monitor, track and verify social and environmental goals. We will establish baseline data and data transparency processes through collaboration with community groups. This will include timely sharing of project performance data in an easily understandable and regionally-relevant manner with the public.

Labor and Workforce Development

Through our engagement process, we will work with local businesses and labor representatives to assess and identify potential for jobs and employment opportunities in a DAC hub. Several of the major industries in the southern San Joaquin Valley face pressure under changing climate conditions, which will affect workers and the local economy. The oil and gas industry is a large employer in Kern County, where it is also an important source of revenue to local governments. Agriculture is also an important employer, but faces pressure due to changing climate conditions including drought and increasing temperatures. Therefore, the DAC hub can provide meaningful transition pathways to high quality employment opportunities. We will work with local educational institutions and other partners to identify workforce development opportunities.

Diversity, Equity, Inclusion, and Accessibility

We will partner with community groups, residents, and other stakeholder groups to bring diverse representation into the DAC hub process. We will conduct all outreach in accordance with practices to increase accessibility for all parties. This will include holding meetings at accessible times and locations, ensuring language accessibility, providing compensation to attendees, and providing food and childcare.

To increase accessibility, Carbon180 will provide community capacity building by holding sessions to deliver their carbon removal curriculum designed to support informed community decision making around DAC engagement. The curriculum empowers citizens and communities to make decisions about whether and how they engage with DAC technology. Carbon180 will administer grants to community-based organizations to support staffing, capacity building, and other resources to ensure that they have the staff resources and technical capacity to engage.

Environmental Justice

The Southern San Joaquin Valley has a high concentration of disadvantaged communities, including the highest-ranking census tract in the state, as measured by CalEnviroScreen 4.0. As a result, several state and local programs are working in the region to advance environmental justice plans and projects. To the extent possible, we will leverage these existing environmental justice activities and investments in the region. Recent activities include three Community Air Protection grants to support development of community air monitoring programs and projects in Southwest Fresno (Fresno Co.), Shafter (Kern Co.), and Arvin/Lamont (Kern Co.). The City of Fresno received a $66.5 million grant under the Transformative Climate Communities program that has supported integrated infrastructure and workforce development projects.

SUMMARY OF INNOVATION AND IMPACT

This proposal focuses on the techno-economic feasibility of the DAC Hub in the Central Valley as well as the socio-cultural considerations that are equally important determinants of project success. The innovation and impact of this project are therefore not only related to the expected technological advances but also our novel approach to fully capture the needs and concerns of the community:

- Technical Innovation and Impact: CALDAC involves a strong portfolio of innovative technology providers, involving multiple DAC technologies alongside additional CO_2 removal technologies and CO_2 to products systems. These technology providers have been selected for the innovation and potential impact. As a "connected" hub focused on technology integration, CALDAC seeks to fully benefit from synergistic connections between multiple technologies with regards to CO_2 handling and transportation, power and heat needs, water supply, and shared infrastructure.
- Community and Governance Innovation and Impact: CALDAC will bring technology providers, community groups, and other stakeholders as equal partners to the table to meaningfully engage and inform potential DAC hub design, governance, and, if successful, operation. CALDAC will provide resources to compensate community stakeholders and to augment staff capacity, if desired, at community-based organizations. We hope this model can provide a new paradigm for community leadership in climate for community-led and focused energy transitions.

3. WORKPLAN

PROJECT OBJECTIVES

This project will undertake a comprehensive feasibility assessment of the technical and social and governance feasibility of establishing a Community Alliance for Direct Air Capture (CALDAC) in California. This innovative proposal invites the local community to be the center of DAC hub development. The feasibility assessment will include two intersecting and interconnected elements:

- Development of the DAC Hub structure and assessment of the technical feasibility of the DAC Hub, including technology partners, location, business model, and CO_2 storage/utilization/conversion option(s), and
- Assessment of the social and governance feasibility of an innovative, community-led ownership model and community benefits plan that engages local stakeholders as core partners.

TECHNICAL SCOPE SUMMARY

During Phase 0a, we will assess candidate DAC technologies both individually and as a system to ensure that the DAC hub is anchored in strong technical and technological capacity. This assessment will provide inputs to the Technology Maturation Plan, Life Cycle Assessment, and Technoeconomic Analysis. We will work with our community partners to conduct outreach, engagement, and education on DAC; establish a compensated Community Oversight Council; and develop a set of community-vetted criteria and goals for DAC hub design, development, and operation. These activities will inform preliminary hub design, integration, location, and ownership decisions. Completion of a feasibility assessment that meets both technical <u>and</u> social criteria tasks is a go/no go decision point to advance to Phase 0b.

During Phase 0b, we will continue to support co-creation of the hub design and development with technology partners and the Community Oversight Council. Based on the hub design developed in Phase 0a, we will continue the technical feasibility assessment for scaling the hub capacity from initially at least 50,000 TPY to at least 1 million TPY. This scaling will be completed and evaluated alongside community-developed performance criteria. In Phase 0b, we will work with the Community Oversight Council to co-produce the Community Benefits Plan. The Plan will be developed through robust engagement with labor, local government, environmental justice, and other stakeholders. The community vision, goals, and values for the DAC hub developed in Phase 0a will be the foundation of the CBP. We will work with the hub owner(s) to develop a business and financial plan that delivers community benefits in alignment with the community vision, goals, and criteria for a regional DAC hub.

WORK BREAKDOWN STRUCTURE

The work breakdown structure for the CALDAC feasibility study is shown below, with tasks and sub-tasks down to two levels. Task 1 is Project Management and Planning, Tasks 2 through 7 are in Phase 0a (BP1), Tasks 8 through 11 are in Phase 0b (BP2).

Task 1	**Project Management and Planning**
1.1	Project Management Plan
1.2	Business Plan
1.3	Financial Plan
1.4	Technology Maturation Plan
1.5	Community Benefits Plan

Phase 0a - BP1

Task #	**Description**
2	**Hub Design and Development**
2.1	Assessment of DAC Technologies
2.2	Assessment of CO2 to Products Technologies
2.3	Community Guided Project Design
3	**Hub Resources and Analysis**
3.1	Preliminary DAC Hub Design
3.2	Energy: Sources of Electricty and Thermal Energy
3.3	Water Management: Requirements and Availability
3.4	CO2 Purification
3.5	Hub Layout and Land Use
3.6	Host Site Modifications
3.7	Integration and Hub Design: Connections and Synergies
3.8	Preliminary Life Cycle Analysis
3.9	Geologic Storage Options and Available Capacity
4	**Environment, Health and Safety**
4.1	Environment and Health and Safety Risk Analysis
4.2	Safety, Security, and Regulatory Requirements
5	**Community Partnerships and Benefits**
5.1	Community Outreach and Engagement
5.2	Carbon Removal Curriculum
5.3	Community Workshops
5.4	Establish Community Oversight Council
5.5	Develop Community, Vision and Goals for Hub
6	**Hub Ownership**
6.1	Review of Possible Ownership Structures
6.2	Identify Hub Owner(s)
7	**Phase 0 Topical Report and Decision Point Prep.**

Phase 0b - BP2

Task #	**Description**
8	**Technology Description and Scale-up Potential**
9	**Finalize DAC Hub Concept**
9.1	Final DAC Hub Design
9.2	Resource Planning: Energy, Water, Land Use, Transport and Integration
9.3	Preliminary Life Cycle Analysis
9.4	Integrated DAC System pre-FEED Study
9.5	Hub Balance-of-Plant Conceptual Design
9.6	Geologic Storage Options and Available Capacity
9.7	Business Development and Financial Plan
10	**Environment, Health and Safety**
10.1	Environment and Health and Safety Risk Analysis
10.2	Safety, Security and Regulatory Requirements
11	**Community Partnerships and Benefits**
11.1	Community and Labor Engagement
11.2	Energy and Environmental Justice
11.3	Workforce Development

WORKPLAN AND TASK DESCRIPTION (PHASE 0a)

Task 2.0 – Hub Design and Development (LBNL, EPRI, UCB, Technology Providers)

Subtask 2.1 – Assessment of DAC Technologies (LBNL, EPRI, Technology Providers)

We will work with each DAC technology to collect or estimate inputs for the Technology Maturity Plan, Life Cycle Assessment, and Technoeconomic Analysis. We will request that companies provide state-point data, details, updates on technology developments, and any available process flow diagrams or schematics. We will start the assessment with our four partner companies: Mosaic, Capture6, Origen, and AirMyne. The assessment will include descriptions of technology state of development and scale, which is essential for understanding design flexibility, scaling uncertainty when extrapolating data, and for determining appropriate technology performance milestones. The project team will also work with other DAC technology providers during the pre-feasibility study to see whether participation in the hub might be considered. Once an inventory is developed for the DAC technologies, LBNL and EPRI will verify the inventory to ensure it provides detail at relevant operating conditions to conduct subsequent process modeling, and environmental and economic assessments.

Subtask 2.2 – Assessment of CO_2 to Products Technologies (LBNL, Technology Providers)

As in Subtask 2.1, we will gather or estimate inputs for the Technology Maturity Plan, Life Cycle Assessment, and Technoeconomic Analysis from each CO_2 to Products technology: Blue Planet and Carbon Built. LBNL will compile information in an inventory and conduct analysis to ensure each technology has a complete energy and mass balance for relevant deployment scales, with an eye towards integrated operations that maximize heat, hydrogen, power and mass transport efficiency and cost within the DAC Hub physical infrastructure. Additional technologies will be assessed as they become available thanks to the modular testbed approach used by the hub. Such an approach can quickly adapt to screening new technologies that are ready for testing and evaluation in a skid-like workflow at scale with integrated data collection and analysis. The project team will also work with other CO_2 to Products technology providers during the pre-feasibility study to see whether participation in the hub might be considered. Once an inventory is developed for the CO_2 to products technologies, LBNL will verify the inventory to ensure it provides detail at relevant operating conditions to conduct subsequent process modeling, and environmental and economic assessments.

Subtask 2.3 – Community Guided Project Design (UCB, LBNL, EPRI)

We will work with the CALDAC Community Oversight Council (see Task 5.3) and technology providers to prepare scenarios for the DAC Hub design. We will evaluate these scenarios against the performance objectives of the solicitation (i.e., minimum capacity of at least 50,000 tonnes CO_2 annually captured from the atmosphere (50,000 TPY) for the pre-FEED study to be completed in Phase 0b) and community vision, goals, and criteria of hub design. We will produce data tables with preliminary estimates for the operations of the hub. We will prioritize scenarios according to synergy between hub performance goals, TRLs, and community priorities. Based on this process, we will select anchoring technologies going forward that will serve as the initial baseline for the development of the CALDAC Technology Maturation Plan.

Inputs to guide hub designs which will be evaluated in Task 3 will be derived from the community engagement process. Inputs may include targets for financial performance, water consumption, or annual volumes of stored CO_2. Many possible hub configurations may emerge from the anchor and alternative technologies evaluated in Tasks 2.3 and 2.4, and only hub designs that can meet the Project Design Basis, which reflect the needs of the hub owner and community, will be explored in the feasibility study.

Task 3.0 – Hub Resources and Analysis (EPRI, LBNL, AECOM, UCB, CES, Fresno State, Rondo, Technology Providers)

Subtask 3.1 – Preliminary DAC Hub Design (UCB, LBNL, EPRI, AECOM)

We will develop a preliminary hub design that conforms to community developed vision, goals, and criteria (developed in Task 5.0 and associated subtasks). Selected DAC Hub technologies and CO_2 to Products technologies identified in Task 2.0 will provide the starting point for assessment of resource requirements (i.e., energy, land, water, etc.). These preliminary DAC hub designs will be shaped at first based on individual technology data tables and the overall Project Design Basis, and advanced as process modeling and simulation efforts offer more robust data on equipment requirements, operation cycles, and material and energy storage and consumption.

Subtask 3.2 – Energy: Sources of Electricity and Thermal Energy (UCB, Rondo)

Based upon the energy usage of selected technologies, we will calculate the amount of clean electricity sources needed to support an initial buildout of 50,000 TPY. Evaluation of electricity sources will be informed by the Community Oversight Council (developed in Subtask 5.4). The evaluation will include consideration of BiCRS, renewable electricity generation, and energy storage. We will prepare a detailed planning and optimization study of renewable power and heat sources for initial capacity. The BiCRS plants that are co-hosting the DAC Hub will provide roughly enough power and heat to satisfy the initial removal capacity of at least 50,000 TPY. We will also consider the delivery of power, heat, syngas, water to the CO_2 to Products facilities in order to maximize energy and carbon capture/conversion efficiency. This task will be directly informed by the process modeling and simulation efforts that may start with individual technologies but will ultimately evolve to capture synergistic effects of colocation that could influence energy needs.

Subtask 3.3 – Water Management: Requirements and Availability (Fresno State, LBNL, UCB)

The team will develop information regarding unconventional water sources located in the southern San Joaquin Valley that may be available for use with the three sites and related processes requiring water. Given drought considerations, CALDAC will prioritize modular optimized approach to circular water management that relies on unconventional water sources. Potential sources of water include, but not limited to surface waters available for agricultural and domestic uses; agricultural drainage waters; dairy wash waters; food processing facilities such as wineries, tomato paste, cheese, and juice plants; fresh produce processing plants; municipal wastewater treatment plants; groundwater having domestic and agricultural users; petroleum industry-produced water; and brackish water in groundwater aquifers. Based upon information received regarding technology water usage and quality needs, we will evaluate the availability candidate water sources according to: (1) source type, (2) volume, (3) quality and treatability, (4) location, (5) estimated cost at the source and transport costs, and (6) other special considerations including treatment pertaining to each source type. Importantly, the cost delivered to a DAC process is a function of the amount of water required and the distance between the water source and the DAC facility. We will also explore secondary usage or disposal of wastewater from DAC facilities.

Subtask 3.4 – CO_2 Purification (AECOM)

We will assess CO_2 purification options for an initial buildout of 50,000 TPY. In an ideal situation, CO_2 produced by different DAC technology providers will be combined into a single stream to minimize redundant equipment and cost. The choice of purification technologies will be dictated by produced CO_2 purity as well as the purity needed for downstream operations (e.g., geologic sequestration). Options include simple dehydration and compression to cryogenic distillation. For the 50,000 TPY feasibility study, priority will be placed on preengineered, turnkey systems rather than greenfield design, but system optimization with other Balance of Plant (BOP) equipment will be explored.

Subtask 3.5 – Hub Layout and Land Use (AECOM, EPRI)

Preliminary design for the 50,000 TPY hub layout will consider optimal locations for centralized equipment (e.g., CO_2 purification), air flow, CO_2 depletion, CO_2 conversion, energy and water/wastewater flow, and interdependencies between DAC providers. Hub activities that require transportation of material into or out of the hub will be located to minimize localized impacts. The hub's footprint will also be minimized while retaining maneuverability throughout the site for operation and maintenance activities and to adhere to engineering best practices and regional codes and requirements.

Subtask 3.6 – Host Site Modifications (CES, AECOM)

Several opportunities exist for hub cost reduction by leveraging existing infrastructure and equipment at the host sites. The objective of this task is to identify such opportunities, as well as characterize the cost and timeline for necessary modifications. Modifications may range from changes to the CO_2 pipelines and injection site, to relocation of biomass onsite to accommodate DAC air contactor distribution, to adjustments to existing and new safety and utility requirements.

Subtask 3.7 – Integration and Hub Design: Connections and Synergies (LBNL, AECOM, EPRI)

We will identify opportunities for shared equipment, synergistic thermal and material flows, and overall hub optimization following the initial development of a hub design, and as new DAC and CO_2-to-products technologies are identified. We will develop process flow diagrams for each technology according to the company informed guidance and state tables for a feasible capture scale, and then scaled based on the individual technology's potential contribution to meeting the hub CO_2 capture capacity requirements as well as the Project Design Basis. Following this first assessment, opportunities for technology integration will be carefully evaluated. Each opportunity may come with an advantage at either the technology or hub level, and tradeoffs must be weighed accordingly. In some cases, decisions may be simple and rational engineering choices that lower risk of unexpected shutdowns. In other cases, there may be a tradeoff among profitability, energy, land and water efficiency, sharing transportation equipment and CO_2 processing equipment, minimizing socio-environmental impacts, flexibility and redundancy.

Subtask 3.8 – Preliminary Life Cycle Analysis (EPRI, LBNL, AECOM, Technology Providers)

The team will conduct a preliminary life cycle analysis (LCA) of the DAC Hub at the initial capacity (at least 50,000 TPY CO_2) and final capacity (at least 1 M TPY CO_2) in accordance with Appendix D of the FOA. Analyses of the energy and material inputs and outputs from each process will be integrated, resulting in a high-level carbon balance of all components, processes, and co-products derived from CO_2 not stored underground.

The team will follow NETL CO_2U LCA guidance for developing an LCA for each component technology and will construct an attributional LCA inventory based on energy and material inputs from anchor DAC technologies and CO_2 disposal pathways, including components such as pipelines and underground storage. We will estimate direct and indirect greenhouse gas emissions and criteria air pollutants based on the operation of systems, and the source of plausible local energy and feedstocks, using emission factors reported in the CA-GREET model and literature. Sensitivity analysis based on factors such as carbon intensities of electricity and heat sources will be considered to understand the range of expected outcomes, and will be refined as the sources of energy and feedstocks are known. All results will be normalized to a functional unit of 1 kg of CO_2 removed from the atmosphere and permanently stored. Major uncertainties stemming from the DAC technologies, the manufacturing of novel materials, and their hub-level integration will be discussed in a summary report.

Subtask 3.9 – Geologic Storage Options and Available Capacity (LBNL, CES, AECOM)

Historic oil and gas exploration and production has identified widespread contingent storage resources in the area of each potential CALDAC site. The three BiCRS sites have credible plans for development of subsurface storage that will offer additional capacity for the >1 M TPY CO_2 removed from air. Detailed subsurface site characterization is underway for the Delano site, with plans to develop and submit a Class VI UIC permit application mid-2023. CES is considering joint storage development for the Mendota and Madera sites, using a 2020 Class VI permit application as the starting point. Working with CES and other potential storage providers, the CALDAC team will assess the planned storage locations and will monitor progress towards development, characterization, and permitting activities, relative to the capacity needed for a minimum of 12 years of DAC Hub operation.

The team will also review potential obstacles to storage development and provide mitigation plans. For example, pore space ownership in the vicinity of each site is fragmented relative to the size of prospective CO_2 footprints resulting from storage. One of the three sites is also in the vicinity of residences. Due to these factors, the team will identify a suite of potential locations for storing the CO_2 from each site that provide options meeting community preferences expressed in the Project Design Basis developed in Subtask 2.3 and gaining pore space access. The team will generate and elicit community perspective on each location, including transportation of CO_2. The team will open pore space access discussions with the owners of each location. Based on the results, the team will work with the site hosts to optimize storage locations for CALDAC. The team will consider existence of legacy wells as a secondary factor in down selection.

Task 4.0 – Environment, Health and Safety (LBNL, PSE, Fresno State AECOM, UCB)

Subtask 4.1 – Environmental Health and Safety Risk Analysis (PSE, Fresno State, LBNL, UCB)

4.1.1 – Air (PSE)

We will assess risks from air emissions based on data on all potential or incidental air emissions provided by DAC, CO_2 to products, energy supply and storage providers, and the host site operator (CES). We may also request methods used to develop underlying emissions rates, estimate magnitude of emissions, and/or model ambient air concentrations. A subset of the Project Team will independently review data via approaches outlined in Technical Volume (see 'Environmental Impacts and Mitigation - Air Quality'). We will assess potential hazards to human health and the environment for the air pollutants identified by technology providers and the host site operator, including associated transformation and degradation byproducts We will compile chemical-specific physical, chemical and toxicological properties (e.g., volatility, flammability, explosivity, corrosivity, biodegradation and bioaccumulation potential, acute and chronic toxicity) and associated environmental and/or health-based guidance values from publicly available state, federal, and international screening and authoritative databases and the peer-reviewed literature. We will examine similar substances or class of substances for any air pollutants lacking information on potential health effects or ecotoxicity shall be evaluated. Depending on data availability, emissions rates may be used to model ambient air pollutant concentrations and evaluate potential health risks and impacts. Findings from the independent review of potential air quality risks and impacts can be used to inform exploration of community-focused air monitoring approaches for the build phase and to co-develop a community air monitoring plan with the Community Oversight Council.

4.1.2 – Water (Fresno State, UCB, LBNL)

The availability of water resources for the proposed technologies will be evaluated in Subtask 3.3. This task will work closely with that effort but will focus on any potential changes, deleterious or positive, impacts on water quality resulting from DAC Hub activities. The rerouting and repurposing of water resources could potentially have positive benefits for water quality by providing a use for lower quality waste waters. However, any change in water resource utilization needs to be examined at a system level. In addition, we will evaluate potential water quality impacts of all DAC Hub activities, e.g., potential impacts to groundwater from geologic carbon storage activities, any effluent or waste waters that need disposal, changing utilization of groundwater (fresh and brackish). The impacts will be assessed in the context of regional water quality but will also focus specifically on domestic and municipal wells and water sources in the vicinity of the Hub site(s).

4.1.3 – Other Risks (LBNL, PSE)

Air and water impacts are expected to be the most likely concerns associated with the Hub development. However, in conjunction with our community partners we will also assess other potential negative or positive environmental impacts of the proposed project including impacts on traffic, noise, light pollution, or local wildlife.

Subtask 4.2 – Safety, Security, and Regulatory Requirements (AECOM, UCB)

The larger and more established participants in CALDAC (i.e., UCB, LBNL, EPRI, AECOM) have an established safety culture and history which can be readily communicated and adapted to the unique requirements of the Hub. These larger entities can help guide the newer organizations, leading by example to assist the development of a safety culture and security standards for the technology providers. The site, as is typical of any industrial facility, will have controlled access. AECOM has experience with both physical protection and cybersecurity of sensitive sites, construction sites, and operating facilities that will be adapted for the host site facility. Permit applications will not be sought during the feasibility study, but the team will develop a list of the permits required as well as the applicable regulatory standards. Contact with the relevant regulatory agencies will be initiated where feasible. Priority will be given to requirements that have lengthy review and approval processes and those that require input from aligned community groups.

Task 5.0 – Community Partnership and Benefits (UCB, LBNL, Project 2030, Data for Progress, Carbon180, Valley Onward, CSU Bakersfield)

Subtask 5.1 – Community Outreach and Engagement (Data for Progress, Carbon180, UCB, LBNL, CSU Bakersfield)

We aim to have community groups as thought partners in this feasibility effort. Carbon180 in consultation with LBNL, will administer grants to community-based organizations to support staffing, capacity building, and other resources to ensure that they have the staff resources and technical capacity to engage. Valley Onward will support community outreach and engagement with labor and workforce agencies throughout the project. We will conduct a series of roundtables and convenings to engage residents, stakeholders, and community organizations in DAC hub design. We will conduct roundtables at locations and times that are conducive to broad participation. We will provide compensation for participants and other services (e.g., food, childcare) to increase accessibility.

Subtask 5.2 – Carbon Removal Curriculum (Carbon180)

To increase accessibility for community members and community-based organizations to engage in the DAC process, Carbon180 will host sessions to deliver their carbon dioxide removal curriculum. The curriculum is designed to support informed community decision making around DAC engagement. The curriculum empowers citizens and communities to make decisions about whether and how they engage with DAC technology, including hub development.

Subtask 5.3 – Establish Community Oversight Council (Carbon180, UCB, LBNL, Data for Progress, Valley Onward, Project 2030)

We will establish a Community Oversight Council that includes representatives of community-based organizations, environmental justice organizations, labor and workforce representatives, and residents. UC Berkeley will work with local organizations to develop a facilitation and convening strategy for the Council. All members of the council will be compensated for their participation. We will facilitate meetings between the Oversight Council, technology providers, and site owner(s) to develop a shared set of criteria for hub design, development, and performance.

Subtask 5.4 – Develop Community Vision and Goals for Hub (UCB, LBNL, Valley Onward)

The Community Oversight Council will work with technology providers, UC Berkeley, and LBNL to develop a community vision and goals for a DAC Hub. These criteria will be used to guide the feasibility assessment and design principles. We will identify and collect community-relevant data to inform the design process and to monitor, track and verify social and environmental goals. This could include various climate and resource needs data related to CALDAC (water, energy, and air), as well as data in line with the federal government's Justice40 initiative. We will establish baseline data and data transparency processes to ensure timely sharing of project performance data in an easily understandable and regionally-relevant manner with the public. We will also test and verify the effectiveness and possible environmental and social footprint of technologies that could be included as part of the DAC technology portfolio (included in Task 2 and associated subtasks).

Task 6.0 – Hub Ownership (UCB, LBNL, Data for Progress, Project 2030, Carbon180, Valley Onward)

Subtask 6.1 – Review of Possible Ownership Structures (Project2030, UCB)

We will prepare a literature review of public, community, and cooperative hub ownership models that include a comparison of the characteristics of different ownership models, including enabling legal and regulatory actions. We will explore the feasibility and legal and regulatory steps needed to establish a Public Authority to oversee the business model, operations and financing of a DAC hub. A Public Authority would operate the DAC hub as a public good – one that maximizes safety and the strongest environmental standards while minimizing costs.

Subtask 6.2 – Identify Hub Owner(s) (UCB, LBNL)

Based on the review of ownership models, engagement with technology providers, site owner(s), and the Community Oversight Council, we will select an ownership model and identify a hub owner or owners. We will also identify needed steps to establish an ownership structure in Phase 0b, including any transitional or intermediate steps. We will evaluate ownership models for alignment with community vision, goals, and criteria.

Task 7.0 – Phase 0a Topical Report and Decision Point Preparation (UCB, LBNL)

The team will prepare and submit a "Decision Point Application" directly to the DOE Project Officer and the DOE Contract Specialist no later than forty-five (45) days prior to the end of Phase 0a – Pre- Feasibility. In addition, a Topical Report documenting the results of work completed to date will be submitted as a separate document along with the Decision Point Application. The Decision Point Application shall include the following information:

- Report on progress towards meeting the objectives of the project
- DAC and CO_2 conversion Technology Maturation Plans
- Preliminary Life Cycle Analysis
- CBP Development Proposal (CBPDP)
- A detailed budget and supporting justification for the upcoming Phase 0b – Feasibility.
- Plans for the conduct of the project during the upcoming scope of work.

WORKPLAN AND TASK DESCRIPTION (PHASE 0b)

Task 8.0 – Technology Description and Scale-Up Potential (EPRI, LBNL, Technology Providers)

This task will be a continuation and further maturation of the efforts conducted in Task 2, but with a shift in emphasis on conducting scale-up feasibility and design scenarios to at least 1 M TPY for the DAC hub for all selected DAC and CO_2 to products technologies that pass through the Go/No-Go process in Phase 0a. This will include evaluating the community-based priorities and perspectives around the deployment of these technologies at the scale of the hub to be built and operated. The assessment will also include descriptions of technology state of development and scale, which is essential for understanding design flexibility, scaling uncertainty when extrapolating data, and for determining appropriate technology performance milestones. Once an inventory is developed for the DAC and CO_2 to products technologies, LBNL and EPRI will conduct additional analysis to verify inputs and ensure the inventory and technologies are described with enough detail at relevant operating conditions to conduct subsequent process modeling, and environmental and economic assessments. We will produce data tables with the next round of estimates for the operations of the hub. Prioritization of those designs and related technologies that maximize the synergy between hub performance goals, TRLs, and community priorities will be used to rank the different scenarios evaluated. Based on this process, we will select the final anchoring technologies going forward that will serve as the foundational engineering design basis for the hub and the finalization of the CALDAC Technology Maturation Plan.

Task 9.0 - Finalize DAC Hub Concept (UCB, LBNL, EPRI, AECOM, Fresno State, CES, Rondo, Technology Providers)

Subtask 9.1 – Final DAC Hub Design (UCB, LBNL, EPRI, AECOM)

We will develop a final DAC hub design for a capture capacity of at least 1 M TPY. The design will be informed by the knowledge gained through the development and technical and community vetting of hub designs at the 50,000 TPY scale, the life cycle assessment, technology maturity plans for each technology, and technoeconomic analysis. This will include qualitative information, such as the effects of scale up on the host site and local communities. We will evaluate additional effects of scale identified in the Balance of Plant. This could include the potential change in technology contribution to capture and opportunities for system integration or improved ancillary equipment performance that are possible at a larger scale. We will work with the Community Oversight Council to assess final hub design and evaluate options relative to community goals, vision, and criteria, with emphasis on concerns resulting from operation at a larger scale. The hub design will include guidance on the implication of scale that is specific to the region of study, that may extend beyond a 1 M TPY capacity. This will provide the basis for analysis of resource requirements (i.e., energy, land, water, etc.) and energy source(s) for the selected DAC technology(ies), as well as CO_2 to Product technologies.

Subtask 9.2 – Resource Planning: Energy, Water, Layout and Land Use (UCB, Fresno State, LBNL, CES, AECOM, EPRI, Rondo)

We will complete resource planning for initial buildout (50,000 TPY) and final buildout (1 M TPY) to feed into BOP for final capacity as described in Task 3.0 and associated Subtasks. In Phase 0b, we will focus attention on the increased electricity and thermal energy demand with a buildout to 1 M TPY. Reliance on intermittent sources will depend on smart grid integration and optimization of supply and demand as well as build-out of energy storage solutions. We will evaluate potential power supply by hydrogen via fuel cell technology and storage via Rondo Heat Battery. We will also continue to evaluate unconventional water sources located in the southern San Joaquin Valley that may be available for use with the three identified carbon dioxide capture sites and related processes requiring water.

Subtask 9.3 – Preliminary Life Cycle Analysis (EPRI, LBNL, AECOM, Technology Providers)

We will continue activities on Life Cycle Analysis begun in Phase 0a. The LCA inventory will be updated for the 1 M TPY scale, and any new life cycle phases associated with the final DAC hub design will be evaluated following Appendix D of the FOA.

Subtask 9.4 – Integrated DAC System pre-FEED Study (i.e., Initial DAC Hub Capacity) (AECOM, EPRI, LBNL, Technology Providers)

The pre-FEED for the initial capacity DAC Hub will include key capital equipment for each DAC technology and shared supporting infrastructures such as heating and cooling, water, CO_2 purification, compression, and transportation. The general design and size of the equipment will be based on heat and material balances, heating and cooling duties, and power requirements provided by anchor DAC partners and key vendors. If partner companies do not have complete process flow diagrams, the analysis will derive these data from theoretical heat and mass transfer calculations. We will conduct process modeling using software such as Aspen. We will normalize key metrics, including capture rates and efficiencies, land use, feedstock consumption, and waste production relative to captured tonnes of CO_2, both for each subcomponent and the entire DAC Hub.

This task will result in: The pre-FEED final report for the initial DAC Hub following the guidance in Appendix L; and the completed relevant Hub Data Tables, which are expected to be for sorbent, solvent- and mineralization-based capture, the synthesis of value-added organics, and the production of inorganic materials. We will combine the results from the pre-FEED with the pre-LCA for a range of electricity and thermal production carbon intensities to calculate the cost of CO_2 abated, and the levelized cost of electricity.

Subtask 9.5 – Hub Balance-of-Plant (BOP) Conceptual Design (UCB, LBNL, EPRI)

We will identify the conceptual design for the mature DAC Hub at its final design capacity based on requirements of the Project Design Basis. This will include identifying and evaluating options for all common systems and utilities including electricity, thermal energy, cooling, water, waste treatment, and CO_2 transportation. To develop a process flow diagram, we will consider plausible scenarios for collocation siting and integration of anchor technologies with each other, with pipelines, water, and CO_2 injection infrastructure. In doing this we will consider heat and mass balances for each process at scale and for the integrated hub at the final capacity DAC Hub. Details on the pipeline and the geologic carbon storage system will be informed by previous and ongoing work conducted by CALDAC’s site host CES and their partners.

Subtask 9.6 – Geologic Storage Options and Available Capacity (LBNL, CES, AECOM)

The team will continue engagement with the pore space owners for each of the storage locations selected in Phase 0a (Subtask 3.9). We will work with CES and potentially other hosts of storage locations associated with each CALDAC site to provide sufficient for 12 years of operation. All work will be conducted with full consideration of parameters and preferences developed by community stakeholders in Subtask 3.9, and the feasibility and magnitude of legacy well corrective actions. For each of these the team will develop preliminary plans for CO_2 monitoring, reporting, and verification. The status of this aspect of storage along with that of each of the other components of a Storage Field Development Plan according to Appendix U of the FOA, including preliminary Authorizations of Expenditures for the proposed project wells in the cost section will be developed and submitted 90 days prior to project completion.

Subtask 9.7 – Business Development and Financial Plan (LBNL, AECOM)

An initial market assessment will estimate the required selling price (RSP) for each CO_2 conversion product derived from anchor DAC technologies. Key material and energy inputs as well as overhead estimations will be based on the developed BOP conceptual design. A plausible range of RSP will be derived from identified uncertainties. Commercial viability for each product will be conducted by assessing its market price and gross market volume at present and in the near future when the proposed DAC Hub can be scaled to 1 M TPY CO_2. We will also assess potential for credits for carbon removal as a revenue generation mechanism.

Task 10.0 – Environment, Health and Safety (LBNL, PSE, Fresno State, AECOM, UCB)

EH&S risk analysis activities under Task 10 will include continuation of activities outlined in Task 4 and will lead to a complete EH&S risk analysis.

Subtask 10.1 – Environmental Health and Safety (EH&S) Risk Analysis (PSE, Fresno State, LBNL, UCB)

EH&S risk analysis activities under Subtask 10.1 will include continuation of activities outlined in Subtask 4.1 and will lead to a completed EH&S risk analysis.

10.1.1 – Air (PSE)

EH&S risk analysis activities focused on air emissions under Subtask 10.1.1 will include continuation of activities outlined in Subtask 4.1.1 and will lead to a completed EH&S risk analysis component focused on air emissions.

10.1.2 – Water (Fresno State, LBNL, UCB)

Activity on water quality impact assessment will continue in the second budget period along the same lines as described in Task 4.1.2. We will conduct more detailed analysis of the most likely potential improvements or negative impacts identified in the first budget period and develop preliminary recommendations for steps that should be considered in a mature design that could maximize (for positive impacts) or minimize these impacts.

10.1.3 – Other Risks (LBNL)

This activity will continue in this budget period during which the finalized list of additional impacts that are worth additional risk assessment and mitigation efforts will be developed.

Subtask 10.2 – Safety, Security, and Regulatory Requirements (AECOM, UCB)

All aspects of Task 4.2 EH&S activities will be progressed as part of Task 10.2. Organization-specific practices will be adapted to activities and plans appropriate for the hub. Together with input from Community partners and with results from Task 10.1, a final EH&S risk analysis will be completed. The project team will also begin development of a permitting roadmap, building upon the list generated in Task 4.2. The roadmap will help the hub team understand not only the technical permitting requirements but also the timeline of submittals, review periods, and ultimately approvals for all of the necessary regulatory documentation.

Task 11.0 – Community Partnership and Benefits (UC Berkeley, Data for Progress, Carbon180, Project 2030, LBNL, Valley Onward, Project2030, CSU Bakersfield)

We will continue working with the Community Oversight Council and other stakeholders to develop a Community Benefits Plan that reflects the community vision, goals, and objectives for a DAC hub. This will include metrics to monitor hub progress and performance, transparency, and accountability systems.

Subtask 11.1 – Community and Labor Engagement (Carbon180, Valley Onward, UC Berkeley, LBNL, Data for Progress, CSU Bakersfield)

We will continue activities started under Task 5 to support ongoing community engagement through the second phase of the project and to implement the plan to develop a Community Benefits Plan in Phase 0b. We will continue to provide education and capacity building opportunities to ensure accessibility for all interested stakeholders. We will partner with local labor organizations and leverage ongoing regional economic development efforts, including the recently-funded Community Economic Resilience Fund collaboratives in the region.

Task 11.2 – Energy and Environmental Justice and Justice40 Initiative (Carbon180, UCB, LBNL, Valley Onward, Data for Progress, Project2030)

The information from the Community Oversight Council, the community vision, goals, and criteria for a DAC hub, and the EH&S Risk analysis will inform community monitoring, data transparency, and accountability systems to ensure the hub does not result in increased environmental burden in the community. These criteria will shape the development of an assessment of community impacts of the hub. We will develop a hub design informed and guided by community-developed criteria. The ownership model, coupled with the Community Benefits Plan, will provide a pathway for implementation.

Task 11.3 – Workforce Development (UCB, Valley Onward)

In partnership with project partner, Valley Onward, the Community Oversight Council, and local labor and workforce partners, we will work with technology providers to understand workforce needs for various hub designs. We will develop a business plan for the DAC hub that includes innovative ownership models, revenue streams and sharing models, and governance structures that deliver meaningful community benefits, while identifying a risk and profit-sharing process. We will work with the technical providers to develop a hub integration plan that describes how public and private entities participate in hub design, development, and operation.

MILESTONE SUMMARY AND GO/NO-GO DECISION POINTS

We have defined four Go/No-go decision points, which are synchronized with the project decision point to proceed beyond Phase 0a. Two of these decision points are associated with the technical feasibility assessment for the hub (GNG2.1, 3.1). The other two decision points are related to the social and governance feasibility of the hub (GNG4.1, 5.1).

Task	Task Title	MS Type	MS Number	Milestone Description	Month	QTR
1	Project Management	Regular	MS1.1	Initiate and implement project management plan	1	Q1
2	Hub Design and Development	Go/No-go	GNG2.1	Preliminary hub design completed with selection of anchoring technologies	8	Q3
3	Hub Resources and Analysis	Go/No-go	GNG3.1	Preliminary LCA completed for initial hub capacity	8	Q3
4	Environment, Health and Safety	Regular	MS4.1	Initial EH&S risk analysis complete	8	Q3
5	Community Partnerships and Benefits	Go-No-go	GNG4.1	Community Oversight Council established and community design criteria identified	8	Q3
6	Hub Ownership	Go/No-Go	GNG5.1	Ownership model developed	8	Q3
7	Phase 0a Topical Report and Decision Point Preparation	Decision Point	DP7.1	"Decision Point Application" submitted to the DOE Project Officer and the DOE Contract Specialist (no later than forty-five (45) days prior to the end of Phase 0a – Pre- Feasibility)	8	Q3
8	Technology Description and Scale-up Potential	Regular	MS8.1	Final hub design completed for full capacity buildout	22	Q8
9	Finalize DAC Hub Concept	Regular	MS9.1	Final hub concept and analysis completed for full capacity buildout	22	Q8
10	Environment, Health and Safety	Regular	MS10.1	Final EH&S risk analysis complete	22	Q8
11	Community Benefits Plan Development	Regular	MS11.1	Final Community Benefits Plan completed.	22	Q8

END OF PROJECT GOAL

The goal of this project is to complete a comprehensive assessment of the technical and social and governance feasibility of establishing a Community Alliance for Direct Air Capture. The resulting feasibility study will include:

- A hub design that is technically feasible and meets community-designed criteria for hub design; environmental, economic, and safety performance; and accountability and transparency
- A hub owner, ownership model, and governance structure that delivers real and measurable community benefits
- Co-produced data, accountability metrics, and structures to guide Phases 1 and 2.

4. TECHNICAL QUALIFICATIONS AND RESOURCES

REGIONAL DAC HUB TEAM DESCRIPTION

UC Berkeley (UCB), project lead, and Lawrence Berkeley National Laboratory (LBNL), co-lead, have assembled an extremely qualified project team with multiple organizations bringing complementary assets and resources to the proposed feasibility study. The team comprises DAC and CO_2 conversion companies (Mosaic, Capture6, Origen, AirMyne, Blue Planet, and CarbonBuilt); academic institutions (UC Berkeley, Fresno State University, Cal State University Bakersfield); energy, engineering and consulting companies (EPRI, AECOM, Rondo); an environmental research institute (PSE Healthy Energy); several non-profits dedicated to equitable energy transition, community engagement and environmental justice (Project 2030, Data for Progress, Carbon180, and Valley Onward); and a BiCRS company as the possible site host (Clean Energy Systems).

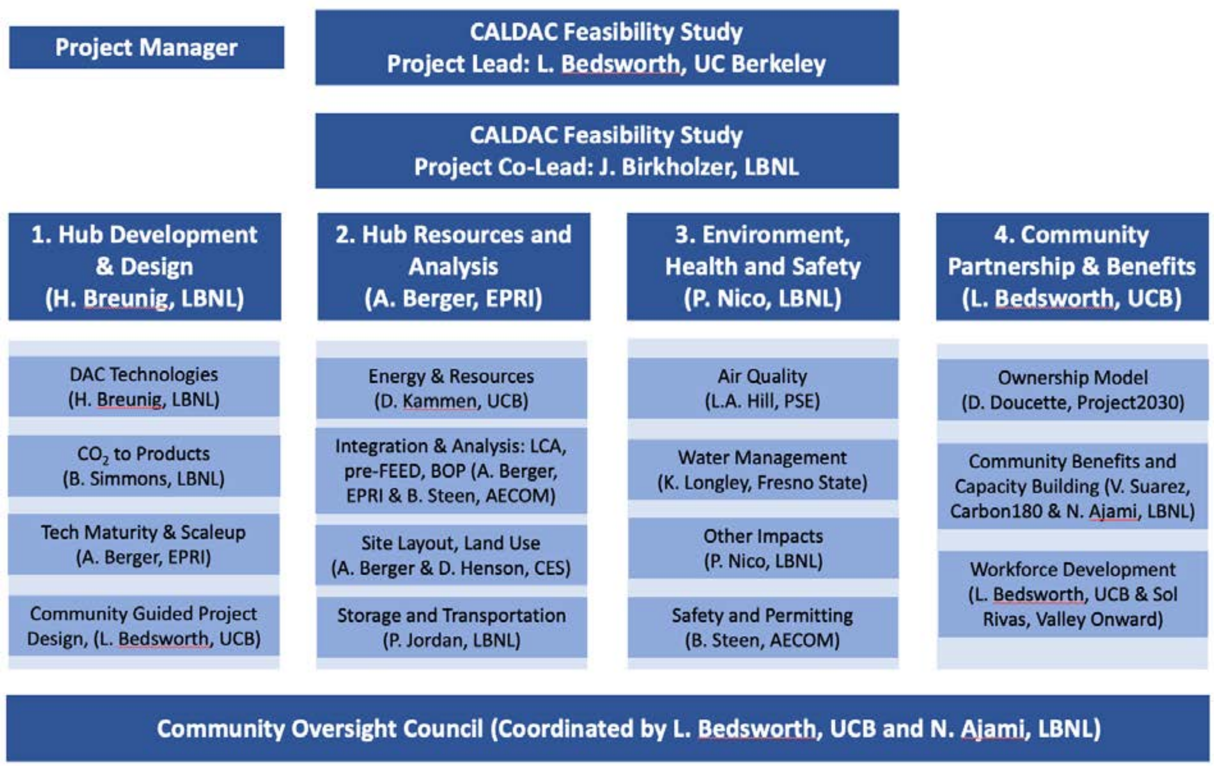
PROJECT LEADERSHIP

The CALDAC feasibility study will be led by UC Berkeley's Center Law, Energy and the Environment (CLEE). CLEE's Executive Director, Louise Bedsworth, will serve as the project lead and principal investigator. UC Berkeley is major research university with an international reputation in clean energy, carbon management, carbon removal, climate resilience, environmental sciences, and community and labor relations. CLEE channels the expertise of the Berkeley Law community – faculty, staff, and students – and the broader technical expertise at UC Berkeley into pragmatic, creative policy solutions to critical environmental and energy challenges. Before joining CLEE, Louise spent nearly a decade working for the State of California, most recently as the Executive Director of the Strategic Growth Council (SGC), a collaborative state department that supports sustainable communities, strong economies, social equity, and environmental stewardship. Before that, she served as the Deputy Director of the Governor's Office of Planning and Research for Governor Jerry Brown. Other key personnel at UCB are Daniel Kammen, an internationally renowned expert on renewable energy and environmental policy, and Ken Alex, the Director of Project Climate at CLEE and former Senior Policy Advisor to Governor Jerry Brown.

As the co-lead, LBNL will support UC Berkeley in the overall leadership of the proposed project and will play a key role contributing to several study areas such as hub design and integration, life cycle assessment, evaluation of CO_2 storage options, environmental impact assessment, and community partnerships. A United States National Laboratory owned by the United States Department of Energy, LBNL delivers scientific breakthroughs over a remarkable range of science, with special focus on research addressing deep decarbonization, climate resilience, environmental quality, health, and economic competitiveness. The Director of LBNL's Energy Geosciences Division (EGD), Jens Birkholzer, will serve as the co-lead of the proposed project. Jens is an internationally recognized expert studying the feasibility and environmental sustainability of a broad portfolio of geo-energy applications, with particular focus on carbon sequestration and removal. Other key personnel at LBNL are Hanna Breunig, who leads the techno-economical life-cycle assessment group; Peter Nico, a Program Lead with expertise in the fate and transport of environmental contaminants as well as soil carbon mineralization; Blake Simmons, Director of the Biological Systems and Engineering Division and a leading expert in biomanufacturing and CO_2 conversion; Newsha Ajami, the Chief Development Officer for Research in the Earth and Environmental Sciences Area and a leading expert in sustainable water resource management; and Preston Jordan, an expert on geological carbon storage including risk assessment and permitting.

PROJECT ORGANIZATION AND ROLES

In this fast-paced multi-institutional project with several interdependent tasks, a carefully crafted organizational structure and effective communication are imperative to achieve tight integration and coordination. The project is organized in four thrust areas with three or more sub-areas (see figure below), each with highly qualified leadership and with defined roles and responsibilities for partner organizations and key personnel. Note that some organizations listed below have already been introduced in Section 2; no further information about these is provided here. For more information on institutions and key personnel that could not be described below for brevity, we refer to the commitment letters and resumes in the attachment.



- Thrust Area 1 comprises assessment of DAC and CO_2 to Product Technologies, monitors their maturity and scaleup potential and will provide the community-guided design of the potential DAC Hub, including selection of anchoring technologies (Tasks 2 and 7 of the SOPO). This area will be led by Hanna Breunig of LBNL. Other key contributors to this thrust are EPRI and AECOM, who will work closely with the technology providers Mosaic, Capture6, Origen, AirMyne, Blue Planet, and CarbonBuilt to incorporate technology information as required. EPRI conducts research and development relating to the generation, delivery, and use of electricity for the benefit of the public. AECOM is a Fortune

500 infrastructure consulting firm, delivering professional services for projects spanning transportation, buildings, water, new energy and the environment, from advisory, planning, design and engineering to program and construction management.

- Thrust Area 2 involves development and analysis of the conceptual design of the hub, and includes the planning of energy sources and other resource requirements (Tasks 3 and 9 of the SOPO). This area will be led by Adam Berger of the Electric Power Research Institute (EPRI), an expert in process modeling, process development, and technology verification of energy conversions and separations processes, including novel separations technologies focusing on carbon capture and storage. Other key contributors to this thrust are UCB, LBNL, AECOM, Rondo, Fresno State University, and the potential site host CES. Fresno State is a public university in Fresno, California, part of the California State University system, and a Hispanic-serving institution.
- Thrust Area 3 is dedicated to the assessment of potential environment, health and safety impacts of the planned hub and planning of mitigation measures (Tasks 4 and 10 of the SOPO). This Area will be led by Peter Nico of LBNL. Other key contributors to this thrust are UCB, PSE Healthy Energy, Fresno State University, and AECOM. PSE Healthy Energy is a nonprofit research institute that studies the way energy production and use may impact public health and the environment.
- Thrust Area 4 includes community partnership and community benefits activities (Tasks 5, 6 and 11 of the SOPO). Louise Bedsworth of UCB will lead this area and other key contributors to this thrust are LBNL, Project 2030, Data for Progress, Carbon180, Valley Onward, and Cal State University Bakersfield (CSUB). Project 2030 is a non-profit dedicated to enabling negative emissions in California by advancing the state’s carbon storage infrastructure. Data for Progress is a progressive think tank and polling firm arming movements with the tools they need to fight for a more equitable future. Carbon180 works with policymakers, entrepreneurs, and peer organizations across the US to design policies that will bring necessary carbon removal solutions to gigaton scale. Valley Onward is a nonprofit dedicated to harnessing and cultivating new leaders in California's Central Valley, in an effort to organize around issues that impact women, people of color, and disinvested communities across. And finally, CSUB has more than 11,000 students in the southern Central Valley, is the only public university within nearly 100 miles, and is designated a Hispanic-serving institution. Additional community partners will be included during the study period.

In order to ensure broad community participation and engagement throughout this project, CALDAC will establish a Community Oversight Council that will include stakeholders, residents, and representatives from historically disadvantaged and environmental justice community groups. The council will provide feedback and direction to the project team across all four thrust areas, help coordinate public engagement activities, and inform key project decision-making points. Louise Bedsworth of UCB and Newsha Ajami of LBNL will serve as coordinators of the Community Oversight Council.

Other key personnel with leadership roles shown in above org chart (and not yet introduced in the text) are Bill Steen of AECOM, a Project Manager and Principal Chemical Engineer with deep experience in FFED studies; David Henson of potential site host Clean Energy Systems who serves as the companies’ Senior Vice President; Lee Ann Hill who is the Director of the

Energy and Health portfolio at PSE Healthy Energy; Karl Longley, an expert in water & wastewater treatment and supply, also former Dean of Engineering and the founding director of the California Water Institute at Fresno State University; Diane Doucette, Co-founder and President of Project 2030; Vanessa Suarez, a Senior Policy Advisor at Carbon180 who works on federal policy across land-based and technological carbon removal with an emphasis on environmental justice; and Sol Rivas, founder and Executive Director of Valley Onward.

The technology companies involved in CALDAC (DAC and CO_2 to Products) are represented on the project team as follows:

- Mosaic: Nathan Gilliland, CEO; Graham Wenz, Director of R&D
- Capture6: Lydia Le Page, Director of Research; Rahul Surana, CTO; Calli Obern, Director of Policy and Stakeholder Engagement
- Origen: Dustin Pool, Chief Commercial Officer; Mira Nagarajan, Manager for Strategy and Commercialization
- AirMyne: Mark Cyffka, co-founder; Sudip Mukhopadhyay, co-founder; Bart Scherpbier, Chief Engineer
- Blue Planet: Laura Berland-Shane, Vice President for Government Affairs; Joshua Johnson, Development Engineer
- CarbonBuilt: Camly Tran, Head of Operations
- Rondo: Julianna Wei, Vice President for Market Deployment; Arvind Menon, Customer Application Manager

For more information, see resumes in the attachment.

Management and Operational Strategies

We will form a multi-institutional leadership team that includes the project lead at UC Berkeley, the co-lead of the project at LBNL, the thrust leads, the sub-area leads, and the coordinators of the Community Oversight Council. For effective integration and coordination, we plan for bi-weekly conference meetings of the leadership team (to be revised as needed). Individual thrusts and sub-areas may have additional calls/meetings on a regular basis. The team will use the following software tools for tracking progress and to develop monthly status dashboards: SMARTSHEET and Microsoft Project.

During Phase 0a of the proposed project, decisions on scientific/technical/governance direction of the hub will be made by the leadership team in consultation with the Community Oversight Council. At the end of Phase 0b, a community based ownership model will be selected for the Hub. If this ownership can be established during Phase 0b, we will explore the role this entity will play in the decision-making during Phase 0b.

The management and operational strategies structure proposed for this project follows best practices for large-scale multi-institutional studies. Both UC Berkeley and LBNL have deep experience executing the complexities of complex multi-institutional and multidisciplinary team efforts. The leadership team and other key personnel are expected to spend less than 100% of their time executing on the feasibility study, with details on planned effort given in the individual budgets. However, UC Berkeley will be supported by a full-time project manager who will track the progress of the task teams, lead reporting to DOE, and manage project communications, sharing, deliverables, etc.