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Berkeley Lab EPIC 4 Investment Plan - Research Concept Proposal Comments

Attached.

Thank you!

Berkeley Lab

Additional submitted attachment is included below.

BERKELEY LAB
Bringing Science Solutions to the World

July 2, 2021

Chair David Hochschild
Vice Chair Janea Scott
California Energy Commission
1516 Ninth Street
Sacramento, CA 95814

RE: Lawrence Berkeley National Laboratory Recommendations for the Development of the EPIC 4 Investment Plan - Research Concept Proposals

Thank you for the opportunity to provide comments on the EPIC 4 Investment Plan. Lawrence Berkeley National Laboratory (Berkeley Lab) appreciates the opportunity to submit the enclosed research concept proposals in connection with the Commission's work to develop a 2021-2025 EPIC Investment Plan that advances grid decarbonization, safety, reliability, affordability, sustainability and equity.

Berkeley Lab agrees that the pathways identified in the 2021 SB 100 Joint Agency Report (SB 100 Report) for 100 percent clean electricity are vital to achieving the State's energy and climate goals and with the Commission's focus on the research and development opportunities being considered in the current workshop series. The SB 100 Report envisions a tripling of the build rates for solar and wind resources and an eightfold increase in battery storage build rates, while continuing to evaluate resources such as offshore wind, long-duration energy storage, green hydrogen and demand flexibility. Observing that diversity in energy resources and technologies can enhance affordability, reliability and equity, Berkeley Lab appreciates staff's invitation at the June 14 Workshop to consider additional research concepts that offer significant potential to decarbonize in a manner that lowers costs, improves performance and advances equity.

In addition to research and development in areas such as flexible load management, building decarbonization, green hydrogen, and energy storage, Berkeley Lab recommends that the Energy Commission consider the following technical areas towards additional energy resources that could contribute significantly to the pathways for decarbonization and meeting the state's clean electricity goals.

- **Negative Emission Technologies**
- **Carbon Capture and Geological Sequestration**
- **Biomass/bio-based Technologies**
- **Geothermal Technologies**
- **Water Treatment and Desalination Technologies**
- **Federal Cost Share**

Specific recommendations are discussed in more detail as follows.

Negative Emission Technologies

Description of proposed concept

Achieving carbon neutrality in California will require rapid and widespread deployment of Negative Emission Technologies (NETs) to remove or sequester anthropogenic carbon dioxide and other greenhouse gases from the climate system (IPCC SR15). The required target by the year 2100 is ~10-20 Gt CO_2e/year, which represents 25-50% of current annual emissions. Yet, the current largest facilities for carbon capture attain only 0.1% of this target.

To meet California's net zero GHG goal in 2045, a large quantity of negative emissions appears to be required, with the exact amount (e.g. 56-106 MMt CO_2 in 2045 commensurate with 80-87% GHG reduction) dependent on the success and pace of decarbonization across all sectors, in particular transportation, industry, and agriculture. To achieve the 40% reduction target in 2030 (as set by SB 32 in 2018), an increase of four times the annual rate of reduction is needed, from the 2006-2018 annual average of 1.0 to 4.1 percent. If the reduction rate of 4.1 percent is extended to 2045, this would still leave 139 Mt CO_2e that would need to be removed through negative emissions or GHG sinks.

A recent survey of carbon mitigation pathways for California suggests that 20-30% of current CO_2 emissions levels (~125 MtCO_2eq) will remain unmitigated by 2045 (Baker et al. 2020) Given that CO_2 capture from industry alone (comprising 24% of the state's emissions) would not be enough to meet the 125 MTCO_2e target, and that emissions from electricity are steadily declining, there is a need for CO_2 capture from pathways that go beyond traditional concepts of CO_2 CCS at power plants and refineries. As such, biological pathways for CO_2 capture and DAC for negative emissions may be required.

Description of technological advancement and breakthrough

Negative emission technologies, while promising, have not yet been demonstrated at scale. Even if they were readily available today, they would still be subject to delays in construction from permitting and environmental reviews. Several promising NETs, such as direct air capture and terrestrial and geological carbon removal, lack scalable implementations and scientifically defensible upper bounds on their potential (NASEM, 2019).

Meeting the grand challenge of successfully and economically removing CO_2 from the climate system via NETs will require developing novel systems engineering approaches for capturing, handling, and converting atmospheric and biologically sourced CO_2 into biofuels, bioproducts, and biomaterials; and to develop new technologies to securely transport and store captured CO_2 in shallow soils and the deeper subsurface. Examples of relevant technologies needed to advance negative emissions science and technologies include metal-organic frameworks (MOFs) to capture diffuse carbon from the atmosphere; bioenergy with carbon capture and storage (BECCS); thermal reactors for adsorbents and hydrogen fuels; approaches to store carbon in soils and deeper geological systems; biomanufacturing to transform carbon into products; and energy systems life-cycle analysis and engineering.

Anticipated outcomes

Developing negative emission technologies immediately is an urgent priority for several reasons: to contribute to the 2045 goal and beyond (SB 100 Report)), to provide needed diversity and optionality of technologies in the state's portfolio, to provide greater margin to any undercounting of emissions in the current inventory, to provide margin to increasing emissions from wildfires or other climate risks such as prolonged drought, to prepare for the potential imperative for still tighter emission reduction requirements in the future, and to provide adequate lead time for new technology introduction and adoption, which can take several decades.

The electricity sector could contribute an estimated 15 to 43 MtCO_2eq negative emissions annually (Breunig et al. 2019; LLNL 2019 Report) from bioenergy with carbon capture and storage (BECCs), but to reach these levels of negative emissions would require major scaling up of this technology.

Biomass gasification with carbon capture and storage (a leading form of BECCS) represents a leading candidate for a potentially large-scale carbon negative technology with up to 43Mt CO_2/year potential for annual negative emissions [LLNL 2020], utilizing biomass gasification of solid biomass such as forest biomass, low moisture agricultural residues, and dry municipal solid waste. Identifying early on where distributed sources of CO_2 capture may occur, such as at gasification facilities, is critical for helping guide investments on CO_2 transportation by rail, truck, or pipeline when CO_2 utilization is not viable.

The state should ensure that NETs do not present any greater risks or negative impacts to under-resourced communities, that opportunities could be identified for economic development or redevelopment in the case of lost jobs in the fossil fuels industry, and that community voices from impacted areas should be sought out and heard.

Quantitative or qualitative metrics

Technology readiness levels (TRLs) are one metric or indicator for the state to track technology readiness of various options. Cost per ton of CO_2 saved would be another key economic metric with a rough target of $100/ton CO_2 captured with current near-term costs at closer to $250-300/ton captured.

For example, TRLs are high for biomass gasification to power (TRL 9) but lower TRL levels for biomass gasification to power with carbon capture and storage (TRL 4-7).   Producing power and hydrogen (H2) for transportation by BECCS-BG is attractive since this pathway can take advantage of the high value of low carbon fuel standard (LCFS) credits, but this technology is at lower TRL readiness (TRL 5-6) with at least one project proposed in Central California (Clean Energy Systems). A negative carbon electricity sector with BECCS is a technical option but must deal with logistic, transport, and cost issues as well as demonstrate large scale carbon storage.

As of 2018, California has 101 large point sources (>100,000 tpa) emitting 81 Mtpa CO_2 and 28 very large point sources (>1,000,000 tpa) emitting 54 Mtpa CO_2. These values only include CO_2 and do not include other GHG emissions. Substantial quantities of CO_2 could potentially be captured at these facilities (EPA FLIGHT Tool; http://ghgdata.epa.gov/ghgp). Several emerging capture technologies could also be deployed in this market that offer higher capture efficiency than conventional MEA based capture, to offer “deep CCS”. These include post-combustion ionic liquids, membrane dense inorganic separation for either H2 or CO_2, and pre-combustion low temperature separation(Bui et al. 2018).

Viable pathways for organic waste management and biofuels production by 2040 include biomass anaerobic digestion (including wastewater treatment facilities) (TRL 7-9), gasification

(TRL 7), pyrolysis (TRL 4-6), and torrefaction (TRL 8). Demonstrating their integration with the energy sector and with CO_2 capture, transport, and sequestration is urgently needed.

References

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- Energizing America/Columbia https://www.energypolicy.columbia.edu/energizingamerica
- Carbon180 https://carbon180.org/reports
- LLNL getting to neutral in ca https://www-gs.llnl.gov/content/assets/docs/energy/Getting_to_Neutral.pdf
- Energy Futures 'frontiers of CDR' [don depaolo chaired one of these report series] (carbon dioxide removal) https://energyfuturesinitiative.org/efi-reports

Carbon Capture and Geological Sequestration

Description of proposed concept

This initiative will improve technologies for carbon capture and permanent geologic sequestration (CCS) in California. The goal is to: (a) reduce the cost for carbon capture from large CO_2 point sources associated with zero-emission firm power generation (e.g., natural gas generation with CCS, clean hydrogen production with CCS) or negative-emission firm power generation (biomass conversion to energy with CCS, or BECCS), and (b) ensure that geologic sequestration at can be safely conducted in California's subsurface at the necessary scale. Areas of emphasis could include: (1) Develop and demonstrate new or improved CO_2 capture/separation technologies for zero-carbon firm resources that have less energy penalty and are more cost-effective (such as next-generation sorbent technologies based metal organic frameworks, or MoFs). The focus is mainly on clean firm power generation but may also comprise CCS for industrial decarbonization. (2) Develop improved technologies for ensuring the long-term integrity of CO_2 storage underground, such as methods for site characterization, risk assessment, monitoring of CO_2 migration and leakage, and management of pressure/geomechanics response to large-scale injection. Research will take into account the specific geological, tectonic and regulatory boundary conditions in California. Opportunities to deploy carbon-negative solutions such as BECCS will be of particular interest. (3) Conduct system-level optimization and life-cycle studies that allow for statewide CCS deployment at competitive costs and meaningful scales while minimizing potential impacts on local communities and environments. Such studies should capture the effects of geographic distribution of sinks and sources, as well as their temporal variation on overall environmental benefit and cost. (4) Support at least one carbon capture and sequestration pilot project across the State, preferably a BECCS pilot. The initiative will help a pilot to get off the ground, via financial support (e.g., "X-Price" for first sizable BECCS demonstration in the State) and via regulatory clarification.

Description of technological advancement and breakthrough

The SB 100 Report provides an assessment of and recommendation for various pathways for 100% clean electricity in California. One study scenario (referred to as generic zero-carbon firm resources) suggests the potential importance of cost-competitive zero-carbon firm baseload and/or dispatchable generation, such as natural gas with carbon capture, biomass with CCS, or hydrogen combustion with CCS. According to the models used in the SB 100 Report, generic firm power if available at competitive cost would provide a significant share of total power needed in 2045 (15-20 GW), while decreasing overall capacity needs and reducing the overall need for solar and energy storage. This can lead to significant cost reduction; in fact, the report estimates the inclusion of zero-carbon firm resources such as natural gas with CCS lowers the annual resource cost in 2045 by $2 billion, or roughly 3%. The initiative described here would advance these zero-carbon firm technologies to be cost-competitive, safe, and sustainable such that they can be applied across the state.

The SB100 Report makes the recommendation to continue assessing the role and impacts of emerging technologies that could have significant impact to a 2045 resource mix and total cost. The report specifically mentions work that will “build on the generic zero carbon firm resources included in the study scenario to explore the projected impact of technologies that can achieve specific price milestones...” and goes on to specifically mention hydrogen combustion, gas with CCS and lower-cost geothermal. It should also be noted that the research and development in CCS is well-aligned with federal priorities in particular within the Department of Energy where carbon capture and sequestration is considered a key technology to meet the Nation’s goal of becoming carbon neutral.

Anticipated outcomes

An important quantitative metric for CCS is cost per ton of CO_2 captured and stored underground. A second quantitative metric relates to the storage safety of CO_2 in the subsurface: here a useful metric is the CO_2 containment after a meaningful time period, say percentage of CO_2 remaining in storage after 1000 years (e.g., > 99%).

Quantitative or qualitative metrics

An important quantitative metric for CCS is cost per ton of CO_2 captured and stored underground. A second quantitative metric relates to the storage safety of CO_2 in the subsurface: here a useful metric is the CO_2 containment after a meaningful time period, say percentage of CO_2 remaining in storage after 1000 years (e.g., > 99%).

References

- 2021 SB 100 Joint Agency Report (CEC-200-2021-001), Assessing 100 Percent Clean Electricity in California: An Initial Assessment
- 2020 Lawrence Livermore National Laboratory Report (LLNL-TR-796100), Getting to Neutral, Options for Negative Carbon Emissions in California

Biomass/bio-based Technologies

Description of proposed concept

According to the *Getting to Neutral Report*, California generates approximately 56 million tons of biomass per year from sources such as forest and farms. Catastrophic wildfires or the anaerobic degradation of biomass result in large emissions of short-lived climate pollutants such as black carbon and methane.

The development of advanced biopower production systems capable of utilizing forest biomass can support the state's wildfire risk reduction activities and benefit ratepayers by also introducing biopower into the electrical grid and co-products that provide an economic boost for rural and urban populations throughout the state. This includes research into advanced thermochemical, biological, chemical and hybrid biomass conversion technologies capable of handling mixed lignocellulosics and municipal solid waste streams with near zero emissions. Distributed approaches will be emphasized as a complement to ongoing centralized renewable energy production, as well as developing biopower as an integrated complement to solar and wind power generation.

Description of technological advancement and breakthrough

- Ability to handle mixed inputs/feedstocks from a variety of sources
- Ability to fractionate and collect any and all hazardous materials present in the feedstocks and dispose of them safely
- >90% conversion efficiency
- >80% thermal efficiency
- Decrease GHG emissions by 50% relative to conventional biopower state of the art

Anticipated outcomes

- Increased biopower contributions to the state's renewable energy portfolio
- Reduced risk of wildfires
- Decreased GHG and criteria pollutant emissions from wildfires
- Near zero emission technologies
- Affordable, distributed and scalable production of biopower and co-products
- Decrease GHG emissions by 80% relative to conventional biopower state of the art
- Increased resilience and supply of renewable energy and biopower to ratepayers
- Improved health and economic opportunities in rural and historically underserved communities

Quantitative or qualitative metrics

- *>90% conversion efficiency*
- *>80% thermal efficiency*
- *Decrease GHG emissions by 50% relative to conventional biopower state of the art*
- *Decreased risk of catastrophic wildfires through utilization of low-value forest thinnings.*

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Geothermal Technologies

Description of proposed concept

The 2019 US Department of Energy Geovision report noted that “Technology improvements could reduce costs and increase . . . geothermal power generation nearly 26-fold from today, representing 60 gigawatts-electric (GWe) of always-on, flexible electricity-generation capacity by 2050.” California leads the nation in geothermal power generation, and according to a USGS resource assessment, the Imperial Valley contains over 8 GWe of undiscovered hydrothermal systems (Williams et al., 2009). Three of the four geothermal fields in the Imperial Valley (Brawley, East Mesa, and Heber) are considered to be “hidden”, that is, they do not have any surface geothermal expression, such as hot springs, and were discovered accidentally while exploring for oil (Dobson, 2016). The installed capacity of the Salton Sea geothermal field is ~400 MWe; however, a recent study (Kaspereit et al., 2016) suggest that this field could support up to 2.9GWe of sustained geothermal power generation.

We suggest two concepts to help unlock these valuable energy resources of this economically impoverished region by reducing exploration risk and improving project economics. The first concept would be to develop improved geophysical imaging techniques to identify and characterize the subsurface, leading to improved targeting of exploration and production wells. These techniques include the use of fiber optic sensing systems that utilize existing but unused fiber optic networks (known as “dark fiber”) to conduct distributed acoustic sensing (DAS) to characterize faults and fractures in the subsurface that serve as conduits for fluid flow in geothermal systems, and distributed temperature sensing (DTS) to identify shallow thermal anomalies that may help detect undiscovered geothermal systems. Scientists from LBNL, LLNL, UCSD, and Rice University are conducting a pilot study in the Imperial Valley within the Brawley geothermal field using these techniques (https://earthscience.rice.edu/imperial-valley-dark-fiber-project/) – early returns from this work has generated very promising results regarding detection of natural seismic events and imaging of the subsurface (https://www.sandiegouniontribune.com/opinion/commentary/story/2021-06-24/opinion-fiber-opti c-seismometers-earthquakes). Expanding this work to include additional fiber optic lines within the Imperial Valley could help identify other hidden geothermal resources within this region, leading to an expanded deployment of these clean energy resources. This approach could also be integrated into the joint USGS-DOE GeoDAWN initiative, which is being expanded in 2022 to include the Imperial Valley. This joint effort is designed to use Lidar, aeromagnetic, and aeroradiometric survey data collected on a regional scale to identify geothermal and critical mineral resources. Integration of these soon-to-be collected data sets with existing geologic and geophysical data from the Imperial Valley would provide valuable new information on the complex structural geology of this region. Finally, the use of machine learning and joint geophysical inversion methods will allow for more effective integration of disparate datasets into more reliable models of the subsurface geology.

The second concept is to extract valuable dissolved minerals present in the highly saline geothermal brines from the Salton Sea geothermal field as a means of providing ancillary economic value to these resources, thus improving the economics of geothermal development, and also providing improved domestic resource security for these critical materials. The Commission has provided strong leadership to develop these lithium brines, which represent about 1/3 of the current world annual production, and could yield up to over a million tons of lithium, making it a world-class resource. The Lithium Valley Commission is currently examining how the state, Imperial County, local communities, industry, and the scientific research community can work together to ensure that this resource is used in an equitable and environmentally sound manner. Additional research on direct lithium extraction technologies from geothermal brines (Stringfellow and Dobson, 2021) is needed to make this vision a reality.

Description of technological advancement and breakthrough

While it remains an abundant resource in California, geothermal energy has often been viewed as uncompetitive with respect to other renewable energy sources such as wind and solar because of its higher cost. Geothermal does provide ancillary benefits over these intermittent energy sources because it is available 24/7. The SB100 report noted that “The 2020 ATB update, which was released after modeling for this report was underway, however, included a 30 percent reduction in geothermal cost projects, based on the Department of Energy Geovision Report. This cost-reduction projection places the geothermal LCOE below the LCOE of the generic zero-carbon firm resources modeled in these scenarios. As significant generic zero-carbon firm capacity was selected in the study scenario, it is likely that geothermal would be selected to a much greater extent should the updated cost data be used.” Thus, the abundant undeveloped geothermal resources in the Imperial Valley could potentially meet the zero-carbon firm generation needs of the state, and offset the need for procuring excess generation capacity for wind and solar as well as large energy storage systems (Bartsz and Thomsen, 2020).

The proposed concepts described above would help reduce resource risk factors that contribute to the higher cost of geothermal power. The improved geophysical imaging techniques would result in identification of additional undiscovered resources within the Imperial Valley – these methods could be applied to improve exploration for geothermal resources in other parts of the state and beyond. These methods would also lead to improved success rates for exploration, confirmation, production, and injection wells, resulting in significant cost reductions for geothermal projects. Finally, hybrid development of geothermal power along with mineral recovery from geothermal brines would lead to improved economics for geothermal projects at the Salton Sea geothermal field, and would also help accelerate the clean energy transition in California by providing a clean domestic source of lithium, a key component for electrification of the transportation sector and would facilitate sufficient battery storage to address the temporal mismatch between power generation and consumption. The SB100 report noted "Coproduction of lithium from geothermal brine may also provide additional revenue streams, effectively lowering the cost of geothermal power, and will be evaluated by the Blue-Ribbon Commission on Lithium Extraction in California."

Anticipated outcomes

The anticipated outcomes for improved geothermal exploration methods applied to identify new geothermal resources within the Imperial Valley would be a significant reduction in exploration risk. One of the factors that makes geothermal less cost competitive than wind and solar is the resource risk. Nearly 40% of the cost of a geothermal project is associated with geothermal exploration and resource confirmation, and greenfield exploration success rates are on the order of 20-25% (Wall and Dobson, 2016). Improved subsurface imaging technologies should lead to more effective well targeting of permeable fractures, leading to a reduced number of failed wells and lower exploration and development costs. Additionally, using produced geothermal brines for both power generation and mineral extraction could dramatically improve project economics, leading to a significant expansion of geothermal development in the Imperial Valley. Developing these technologies and subsequently implementing these new approaches could lead to a doubling of the deployment of geothermal resources within California over the next 10-15 years.

Quantitative or qualitative metrics

The metrics associated with geothermal imaging technologies could include identification of new hidden resources and improved imaging of subsurface structures compared to current methods, which would ultimately result in improved geothermal well success rates. Improved methods for direct extraction of lithium from geothermal brines could be evaluated by lower costs for extraction and more efficient extraction rates.

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Water Treatment and Desalination Technologies

Description of proposed concept

Diminishing snowpack, stressed groundwater reserves and intensifying drought are placing unprecedented stresses on California water supplies. With the Commission's support, California is developing new technologies to enable a more climate resilient water future, including desalination and water treatment technologies to enable broader reuse and use of impaired sources, as well as localized treatment which could reduce energy needed for long-distance water conveyance. With every year, desalination will make up an increasing fraction of the total water supply for the State of California. Because current desalination technologies are energy intensive and not easily modulated for demand response, this trend could result in increased grid stress and cost to California ratepayers.

Description of technological advancement and breakthrough

New technologies are needed to move desalination and water treatment from an inflexible, energy-intensive process into a nimble, distributed and sustainable process. Specifically:

1. Novel control systems and system architectures are needed to better automate desalination and water treatment unit processes and systems. Such control systems would allow desalination and water treatment plants in California to quickly adjust water production in response to grid demands, or rapidly expand water production during periods of energy abundance.
2. Simulation software that accurately estimates the performance of water treatment unit processes and systems is needed to enable treatment plant designers and consulting engineers to explore a greater range of design space for new treatment facilities and retrofits and enable energy optimization of such systems. Presently, no such software is available, requiring that engineers adopt conservative and often energy sub-optimal designs for new facilities.
3. Improved desalination membranes and energy-optimized membrane modules would allow for immediate retrofit of current desalination plants - reducing energy loads and increasing water production.
4. New water treatment technologies and materials that enabled precision separation of contaminants would dramatically reduce the cost and energy associated with wastewater treatment and pollutant mitigation. Present water treatment technologies are non-discriminating, and remove both problematic and benign solutes. This results in excess energy use and, in some cases, requires more energy and cost to "remineralize" water that has been treated. Precision separations technologies would enable water

treatment for problematic pollutants such as hexavalent chrome, PFAS and arsenic at each wellhead, dramatically lowering the cost (and embedded carbon) of treatment and avoiding the need to build large-scale centralized treatment facilities.

Anticipated outcomes

The development of some or all of these technologies would represent a breakthrough for water supply in California and result in dramatically lower and more flexible energy use from the water sector:

- Water treatment plants could rapidly adjust production in response to grid demands - providing a balancing load during periods of rapid energy supply change
- Water wells could provide fit-for-purpose treatment, avoiding the cost and energy associated with gathering water into large scale centralized treatment facilities.
- Accurate design software and predictive models of water treatment facilities would enable engineers and municipal planners to rapidly design and optimize new water treatment facilities, greatly lowering the time required to bring new facilities on-line and enabling these facilities to be inherently more energy efficient.
- Distributed systems may offer affordable water treatment to communities underserved by current technologies and methods.

Quantitative or qualitative metrics

Energy-efficiency performance for new water treatment and desalination systems can be easily obtained and benchmarked to current facilities. All water treatment facilities have detailed energy use tracking and accounting, as energy is a principal operating expense for these facilities. Modeling software could also allow the energy performance of existing facilities to be benchmarked against a “theoretical optimum” allowing operators and managers to identify key processes where energy is being most inefficiently used.

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Federal Cost Share

In our overview comments provided on June 21, Berkeley Lab urged the Commission to continue to offer cost share funding to applicants that apply for and receive awards under eligible federal Funding Opportunity Announcements (FOA) that advance key state objectives.

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Given the growth in federal clean energy research investments and the close alignment of state and federal clean energy objectives, continuation of the EPIC cost share program offers California a strong opportunity to leverage federal resources and significantly magnify the impact of limited state research dollars, accelerate achievement of California clean energy and decarbonization goals, and build state technology leadership in key sectors.

The Commission's GFO 18-902, Cost Share for Federal Funding Opportunities for Energy Research, Development, and Demonstration, and its predecessor initiatives, have played a critical role in enabling California to successfully compete for large federal clean energy research investments, often attracting multiple federal dollars for each state match dollar invested. As one example, the Commission's 2019 $3 million EPIC cost share commitment played an important role in enabling the Berkeley Lab-led research consortium, the National Alliance for Water Innovation, to win a $100 million U.S. Department of Energy investment to develop new water desalination technologies that will significantly reduce the energy intensity required to supply and treat water. Further, the Public Utilities Commission noted the example of a $3 million CEC grant in helping the Joint Bioenergy Institute win a $100 million federal funding award to develop low-carbon biofuels and bioproducts, an award that demonstrated the successful conversion of California woody biomass to low-carbon fuels.

Berkeley Lab appreciates the Commission's consideration of these research concepts and would be pleased to provide further information on any of these topics as needed.

Sincerely,

Alecia Ward
Leader, Program and Business Development
Energy Technologies Area
award@lbl.gov

Jim Hawley
Director, State and External Relations
jchawley@lbl.gov