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CHBC Comments on California Air Resource Board
Carbon Neutrality: Scenarios for Deep Decarbonization Workshop

August 29, 2019

The California Hydrogen Business Council (CHBC)[1] appreciates the opportunity to provide comments to the California Air Resource Board (CARB) Workshop on Carbon Neutrality: Scenarios for Deep Decarbonization held on August 15, 2019. CHBC is supportive of CARB's carbon neutrality efforts to help achieve California's GHG emissions reduction targets by bridging the gap between existing mid-century deep decarbonization goals and achievement of statewide carbon neutrality by 2045.

The CHBC strongly supports CARB's efforts to evaluate multiple pathways to deep decarbonization and to maximize synergy between currently distinct energy sectors and industries in California. California must chart the roadmap to deep decarbonization in a balanced way by developing strategic and tactical innovative energy approaches that involve a portfolio mix of low and zero-carbon energy resources that can best achieve the state's climate and energy-related goals, including various priorities related to environmental issues, wildfires, safety, reliability, and affordability.

Role of Renewable and Zero Carbon Hydrogen[2] in Deep Decarbonization

As discussed during the workshop with various stakeholders, including the Energy Futures Initiative (EFI), E3 and the California Institute of Technology, renewable or zero-carbon hydrogen can play a critical role in California's decarbonization efforts. To achieve deep decarbonization in California's energy sector, hydrogen will need to be produced from renewable sources, like water electrolysis using renewable (carbon-free) electricity, renewable gas from landfills and diary feedstocks, and/or from natural-gas steam reforming using carbon capture and storage.

Hydrogen produced from the above pathways can be used in several applications, including: seasonal or bulk energy storage applications in the power sector to accommodate the integration of intermittent and variable energy sources; as an energy carrier to decarbonize the transportation sector; as a fuel source for residential and commercial heating; or blending with natural gas for

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[1] The views expressed in these comments are those of the CHBC, and do not necessarily reflect the views of all of the individual CHBC member companies. CHBC Members are listed here: https://www.californiahydrogen.org/aboutus/chbc-members/

[2] Renewable Hydrogen: Hydrogen produced through electrolysis using renewable electricity or reformation of methane derived from renewable feedstocks such as organic material.
Zero Carbon hydrogen: Hydrogen produced through processes that emit no net carbon to the atmosphere including processes with no carbon emissions and those whose carbon emissions are captured (also called Carbon-Neutral or Zero-Net-Carbon)

end-use fuel applications in residential, commercial, industrial sectors; and as a process feedstock for industries such as chemicals, refining, steel manufacturing, food processing, etc.

A 2018 report by McKinsey & Company highlights the important role that hydrogen can play in the industrial sector and in cross-sector decarbonization efforts.[3] Hydrogen is one of essentially three options for achieving deep decarbonization of the industrial sector, along with use of biomass and carbon capture and storage. The optimal solution, the report finds, ultimately depends on local factors, including biomass availability, technical and political viability of carbon sequestration, and the price of low-carbon electricity. At renewable electricity prices below $15-50/MWh, which is within range of new solar and wind projects today, the report finds that renewable hydrogen is a lower cost solution than carbon capture and sequestration is for decarbonizing a range of industrial sectors. The report also notes that decarbonization of industry can lower the costs of transitioning to zero carbon electricity, and that planning and incentives for both should go hand-in-hand.

California should prioritize the development and use of hydrogen–produced from low- or zero-carbon feedstocks–which can play a significant role in facilitating deep decarbonizing of "difficult to eliminate" emission sectors (as presented during the workshop)[4], including load following electricity, industrial, shipping, aviation and long-distance road transport. Multiple cross-sectoral pathways for hydrogen implemented elsewhere globally (as discussed below), can be adopted in California to help achieve the state's carbon neutrality goals.

As CARB discussed the European Union's effort (during the workshop)[5] to develop a strategic long-term vision for a climate-neutral economy by 2050, CHBC would also like to highlight that the recent European Commission's report (2018)[6] on a climate neutral economy examined several pathways including eight scenarios to greenhouse gas neutrality for the European Union. They found that the only way to achieve deep decarbonization of 90+% greenhouse gas emissions below 1990 levels by 2050 was to aggressively pursue a diversified approach that neither focuses on just electrification nor gaseous fuels alone, but rather both, along with efficiency and waste management, and that net carbon neutrality by 2050 and net negativity thereafter (as California's Executive Order B-55-18 calls for) would require additional carbon capture or management of land sinks.

Specifically, the first five scenarios in the report focus on impacts of specific technology pathways, varying in the intensity of application of electrification, hydrogen, electrolytic fuels, end user energy efficiency, as well as the role of a circular economy, as actions to reduce emissions. The study found all of these can likely achieve 80% greenhouse gas reductions below

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[3] de Pee et al (2018) Decarbonization of industrial sectors: the next frontier, McKinsey & Company, June.
https://www.bloomberg.com/news/articles/2019-08-21/cost-of-hydrogen-from-renewables-to-plummet-next-decade-bnef
[4] https://ww3.arb.ca.gov/cc/scopingplan/meetings/081519/caltech_cn_scenarios_aug2019.pdf, slide 3.
[5] https://ww3.arb.ca.gov/cc/scopingplan/meetings/081519/carb_cn_scenarios_aug2019.pdf, slide 5.
[6] https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/2050-long-term-strategy

1990 levels, but none can achieve deeper decarbonization. To reduce emissions at least 90% below 1990 levels, all five pathways must be aggressively pursued in combination (the sixth pathway). To achieve net carbon neutrality followed by net carbon negativity, however, the seventh and eighth pathways studied add to the combination scenario either negative emissions technology in the form of bioenergy combined with carbon capture and storage, or reliance on a circular economy, change in consumer choices that are less carbon intensive, and strengthening the land use sink to reduce the need for negative emissions technologies.

CHBC recommends that CARB look closely at fact and science-based examples like the European Commission has and develop a diversified approach that includes multiple pathways to decarbonization, including electrification and a wide range of renewable gases, such as renewable hydrogen and its derivatives.

Japan is also aiming to be the world leader in decarbonizing by becoming a hydrogen-based society and is adopting a multi-pronged strategy for realizing this vision.[7] Showcasing this ambition, the 2020 Olympics in Japan aims to run entirely on hydrogen. A report prepared for Japan by the International Energy Agency declares: "*This is a critical year for hydrogen. It is enjoying unprecedented momentum around the world and could finally be set on a path to fulfil its longstanding potential as a clean energy solution. To seize this opportunity, governments and companies need to be taking ambitious and real- world actions now*."[8] The E3 report included in the workshop risks sending California on the opposite pathway of inaction.

In China, the "father" of China's electric vehicle industry and vice chairman of China's national advisory body for policy making, Wan Gang, who convinced Chinese leaders twenty years ago to adopt battery electric vehicle technology, is now saying the country should be looking into "establishing a hydrogen society" and is seeking to have China to similarly become a global leader in developing hydrogen technology.[9]

The South Korean government has a US$2.33 billion public-private investment plan to accelerate hydrogen fuel cell infrastructure, manufacturing capabilities and technology development for transportation and stationary applications.[10]

Hydrogen is also on the Australian national agenda. The nation's Chief Scientist states that the country's "vision is a future in which hydrogen provides economic benefits to Australia through export revenue and new industries and jobs, supports the transition to low emissions energy across electricity, heating, transport and industry, improves energy system resilience and increases

[7] https://www.meti.go.jp/english/press/2017/pdf/1226_003a.pdf
[8] P. 1, *The Future of* Hydrogen, *Seizing Today's Opportunities, Executive Summary and Recommendations,* IEA, June 2019 https://webstore.iea.org/download/summary/2803?fileName=English-Future-Hydrogen-ES.pdf
[9] https://www.supplychainbrain.com/articles/29843-chinas-father-of-electric-cars-says-hydrogen-is-the-future
[10] p. 56, *Hydrogen for Australia's Future,* Hydrogen Strategy Group (Chaired by Australia Chief Scientist, Dr. Alan Finkel); August 2018

consumer choice."[11] By 2030, it is estimated that the Australian hydrogen industry could be worth over a billion dollars and provide 2,800 jobs.[12] A 2017 study by the Australian Gas Infrastructure Group, with input from Deloitte, compared electrification to hydrogen conversion pathway to decarbonizing the state of Victoria's gas consumption found that although costs of long-term hydrogen storage need to be better understood, modeling showed that the hydrogen conversion pathway would cost about 40% less than the full electrification pathway, largely because of the flexibility of electrolysis to meet gas demand, lower long-term requirement for electricity storage though batteries or hydro, and lower network upgrade costs because of the use of the existing gas infrastructure.[13]

A recent analysis by Bloomberg New Energy Finance reinforces the opportunities and role for hydrogen, finding that "Hydrogen's plunging price boosts (its) role as (a) climate solution."[14] The BNEF analysis suggests that renewable hydrogen costs may fall to as low as $1.40/kg by 2030, or about 45-80 percent below current levels. A recent presentation by UC Irvine's Advanced Power and Energy Program summarizing the results of a renewable hydrogen study sponsored by the California Energy Commission forecasts that renewable hydrogen will be cost-competitive as a vehicle fuel on a per mile basis by the mid-2020s with continued support from existing policies, such as the LCFS.[15] Just as its policies have done for bringing down costs for renewable power, electric cars, and other technologies with global impacts, California should lead on supporting development of renewable and low carbon hydrogen to accelerate the deployment of this important global solution to climate change.

Role of Renewable and Zero Carbon Hydrogen in Long Duration Bulk Storage

CHBC agrees with E3's assessment on the impact of high renewables integration in a low-carbon future[16] that will require some form of very long duration storage and believes that long duration and bulk energy storage falls on the critical path towards achieving deep decarbonization.

The rapid rise of solar and wind generation has created challenges with managing the electric power system. The self-generation sector alone (behind the meter-photovoltaics) is expected to increase its generation capacity from 28,000 GWh (2019) to 52,000 GWh (2030), an increase of 85% in self-generation capacity from the current levels[17] (see chart below). Utility scale renewables (front of the meter) and doubling of energy efficiency measures in the future can further cause significant challenges to manage the over-supply of electricity on the grid during peak hours. Solar and wind production frequently exceeds electrical demand with limited ability

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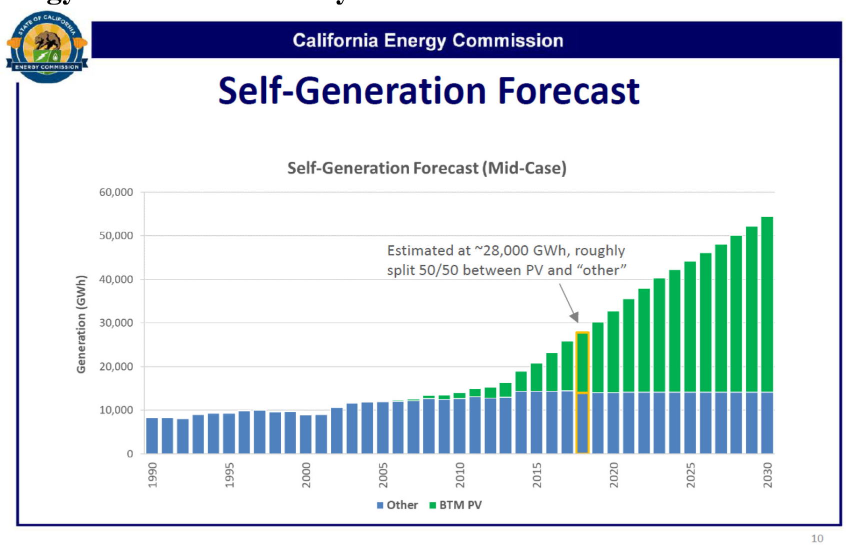
[11] p. i, ibid.
[12] p. 12, Ibid.
[13] Ibid, p. 30
[14] https://www.bloomberg.com/news/articles/2019-08-21/cost-of-hydrogen-from-renewables-to-plummet-next-decade-bnef
[15] https://ww2.energy.ca.gov/altfuels/2017-HYD-01/documents/
[16] https://ww3.arb.ca.gov/cc/scopingplan/meetings/081519/e3_cn_scenarios_aug2019.pdf, slide 7
[17] IEPR Commissioner Workshop on 2019 Preliminary California Energy Demand Electricity and Natural Gas Demand Forecast, slide 10, Self-Generation Forecast, CEC Workshop Presentation

to store this surplus energy optimally.[18] In the absence of a comprehensive energy storage solution, the California Independent System Operator (CAISO) curtails these renewable sources, resulting in missed opportunities to utilize these valuable renewable energy resources. The excess electricity can be used to produce and store renewable hydrogen via electrolysis[19] in a cost-effective manner as a long duration bulk storage resource and can be used across multiple sectors as part of a cross-sectoral decarbonization strategy, from power generation, transportation, heating, and commercial and industrial end use applications.

Self-Generation Forecast, IEPR Commissioner Workshop on 2019 Preliminary California Energy Demand Electricity and Natural Gas Demand Forecast [20]



In 2015, the CAISO curtailed more than 187 GWh of solar and wind generation.[21] In 2016, the curtailment rose to more than 308 GWh. In 2017, California curtailment rose again to 380 GWh of solar and wind generation. The curtailment rates have increased ever since as shown in the table below.[22]

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[18] *Impacts of Renewable Energy on Grid Operations,* California Independent System Operator (May 2017), at available at https://www.caiso.com/Documents/CurtailmentFastFacts.pdf

[19] The electrolysis process uses renewable electricity to split water (H_2O) into hydrogen (H_2) and oxygen (O_2)

[20] https://www.energy.ca.gov/2019_energypolicy/documents/#08152019

[21] http://www.caiso.com/informed/Pages/ManagingOversupply.aspx

[22] Data shown in the table is based on CAISO's oversupply data published as of 8/7/2019, http://www.caiso.com/informed/Pages/ManagingOversupply.aspx

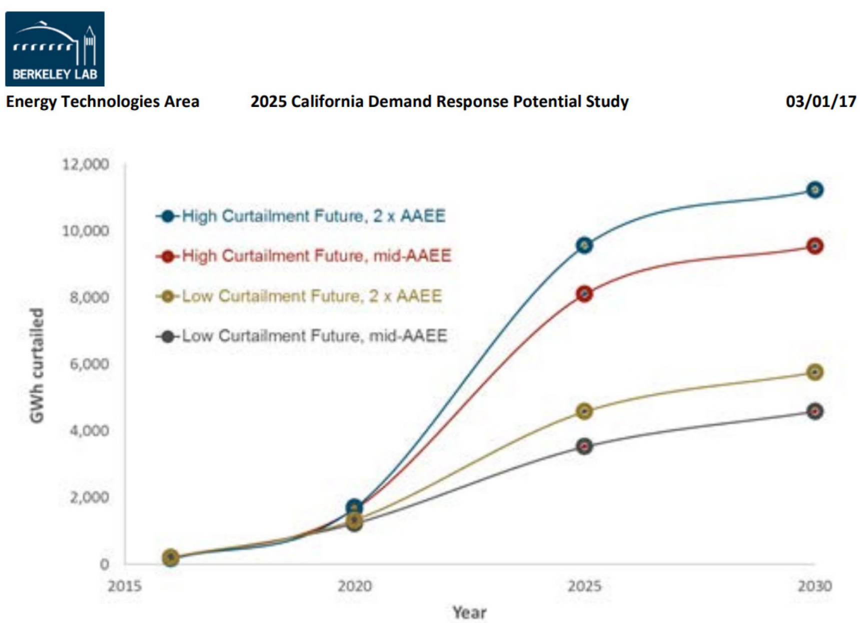
CAISO wind and solar curtailments by year

Year	GWh
2015	188
2016	308
2017	401
2018	461
2019 (until June 1)	679

As of June 1, 2019, the renewable curtailment levels stood at a staggering 679 GWh (with an estimated 34% renewable energy penetration in California as of 2018)[23]. From an energy equivalency perspective, 679 GWh of zero carbon electricity is equivalent to offsetting approximately 480,000 metric tons of CO_2e (according to the EPA GHG equivalency estimates[24]), or equivalent to producing 12.5 million kilograms of zero carbon hydrogen.[25]

The 2025 California Demand Response Potential Study (Lawrence Berkley National Lab, 2017) for the California Public Utility Commission (CPUC) shows curtailment levels more than 10,000 GWh at 50% renewable penetration rates by 2030 with doubling of energy efficiency measures (see chart below).

Base Curtailments by year (2025 Demand Response Study, LBNL, 2017, p. 3-8)



[23] https://www.energy.ca.gov/sites/default/files/2019-06/renewable_highlights.pdf
[24] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator
[25] Assuming 54 kWh/kg of hydrogen energy conversion ratio at 61% electrolyzer efficiency.

As the Renewable Portfolio Standard (RPS) requirements climb to 100% penetration in the future, one can project these curtailments to grow exponentially, yielding significantly less GHG emission reductions than anticipated, and potentially leaving California in a disadvantaged position paying for expensive partial solutions and over-procuring renewable electric resources with diminishing returns.[26] Integrating hydrogen produced from excess electricity (using electrolysis) is a scalable and comprehensive energy storage solution that can play a vital role in supporting the growth of the RPS by optimizing and synchronizing California's energy resources and providing a much needed linkage between variable renewable electric resources, seasonal energy storage, and dispatchable electric generation. Enabling this hydrogen technology in California will help remediate time-of-day and seasonal energy imbalances between supply of power from renewable sources and its demand. While short-term balancing of electricity is likely to utilize technologies such as demand-side management and batteries, long-term storage options will be required to optimize California's electric system under a growing RPS. NREL states: "*Initial cost analysis indicates that hydrogen systems could be competitive with battery systems for energy storage and could be a viable alternative to pumped storage hydro and CAES at locations where these latter two technologies are not favorable*."[27]

With regard to comparison to pumped hydro and compressed air energy storage (CAES), CEC Staff has acknowledged that pumped hydro and CAES are restricted in terms of project location due to their site-specific nature, and that best sites may not be within areas where they are needed.[28] Electrolytic hydrogen storage, in contrast, has many options for siting because of its flexibility – e.g., it can connect to the electric grid for large-scale storage, operate on a smaller scale at industrial facilities that use hydrogen, co-locate with a wind or solar farm to maximize their generation capacity and reduce the need for transmission upgrades, blend renewable gas into the vast existing gas system, or power one of the state's baseload gas plants. A study conducted by McKinsey & Company found that converting renewable power into hydrogen via electrolysis followed by salt cavern hydrogen storage and use of combined cycle power plant conversion back to electricity was cheaper than pumped hydro storage. The findings showed that with a round trip efficiency of 40% and capital costs of $1000/kW, this pathway has a lower levelized cost of electricity than pumped hydro storage, the current lowest cost energy storage solution.[29]

This is not to say that different storage technologies are mutually exclusive, as they can be combined in complementary ways. Indeed a 1000 MW project combining clean hydrogen storage, compressed air, and flow batteries is currently under development in Utah.[30]

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[26] See *2025 California Demand Response Potential Study*, Lawrence Berkeley National Laboratory, 2017, http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442452698.

[27] http://www.nrel.gov/docs/fy16osti/64764.pdf

[28] CEC Staff Paper on *Bulk Energy Storage for California:* http://www.energy.ca.gov/2016publications/CEC-200-2016-006/CEC-200-2016-006.pdf

[29] McKinsey & Company, "Commercialisation of Energy Storage in Europe," Fuel Cell and Hydrogen Joint Undertaking, European Commission, March, 2015.

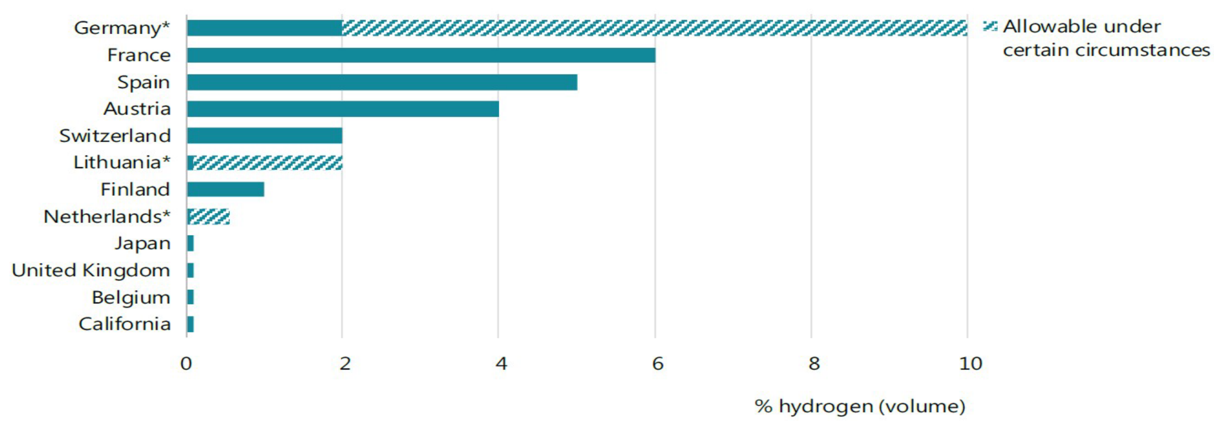
[30] https://amer.mhps.com/world%E2%80%99s-largest-renewable-energy-storage-project-announced-in-utah.html

Hydrogen blending also is key to decarbonizing existing gas system, that can be redeployed from a climate challenge into a climate solution.

The usage of hydrogen-natural gas blends at "safe operating levels" can also assist in meeting California's decarbonization goals cost effectively. Blending hydrogen into the existing natural gas infrastructure can also help avoid the significant upfront capital costs involved in developing new transmission and distribution energy infrastructure. The Energy Futures Initiative (EFI) report titled: "Optionality, Flexibility and Innovation: Pathways for Deep Decarbonization in California," highlights the potential significant role hydrogen can play in decarbonizing power plants and pipelines.[31]

Many European countries including France, Germany, Spain, Austria and Switzerland have adopted hydrogen blending standards with blending percentages ranging between 2 and 10% based on end use application and other technical constraints (see shown below).

Hydrogen blending limits in natural gas networks (IEA, 2019) [32]



* Higher limit for Germany applies if there are no CNG filling stations connected to the network; higher limit for the Netherlands applies to high-calorific gas; higher limit for Lithuania applies when pipeline pressure is greater than 16 bar pressure.

Sources: Dolci et al. (2019), "Incentives and legal barriers for Power-to-Hydrogen pathways: An international snapshot", *International Journal of Hydrogen*; HyLaw (n.d.), *Online Database*; Staffell et al. (2019) "The role of hydrogen and fuel cells in the global energy system", *Energy and Environmental Science*.

In Northern Germany, an increase of hydrogen blends to 20% are being demonstrated.[33]

Conclusion

As E3 pointed out in their presentation at the workshop, California needs at least one "reach

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[31] Energy Futures Initiative. Optionality, Flexibility, & Innovation. Pathways for Deep Decarbonization in California. 2019. Available at: https://energyfuturesinitiative.org/s/EFI_CA_Decarbonization_Full-b3at.pdf

[32] International Energy Agency. Future of Hydrogen Report, Seizing today's opportunities. June 2019. https://webstore.iea.org/the-future-of-hydrogen

[33] https://www.eon.com/en/about-us/media/press-release/2019/hydrogen-levels-in-german-gas-distribution-system-to-be-raised-to-20-percent-for-the-first-time.html

technology" to offset "difficult to electrify" end uses like the industrial end use sectors, heavy duty trucking, long duration bulk storage etc. to help meet the longer-term 2050 GHG goals. Hydrogen can fulfill this role, although it's hardly a "reach technology." Hydrogen has been a major energy carrier in the U.S. and globally for decades, and productively expanding that role to include renewable and low carbon hydrogen to help fight climate change only suffers from policies that disadvantage it compared to other alternatives. If the state were to proactively plan for renewable and low carbon hydrogen to help meet the state's clean energy and climate goals, and provide support, such near-term access to wholesale electricity rates, proper demand and T&D charges, the existing pipeline network for blending at appropriate levels, and research and development programs to advance large scale pilots, California could lead in unlocking this critical global climate solution, just like it has so many times before with other important technologies.

We appreciate CARB's consideration of these points and would be happy to explore them in greater detail, if needed.

Sincerely,

Emanuel Wagner
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