September 14th, 2020

Re: Achieving Carbon Neutrality in California: A Report by E3

Lawrence Livermore National Laboratory (LLNL) appreciates the opportunity to comment on the draft report by E3 on achieving carbon neutrality in California, presented at the public workshop by the California Air Resources Board on August 19th, 2020.

We commend E3 for this draft report, which clearly outlines the challenges, scale and pace of action required to meet the State's 2045 carbon neutrality goal. We believe that the conclusions of E3's report are entirely consistent with those of our own study ("Getting to Neutral – Options for Negative Carbon Emissions in California"), released earlier this year. Both reports point out that dramatic transformation of the State's energy system will be required, and that in addition we will need to find ways to capture carbon dioxide from large point sources and also to remove it from the atmosphere.

In these brief comments, we wish to highlight a few point that underline the consistency and complementary nature of E3's and our analyses, and to point to some areas of future work and collaboration that we believe would be of great benefit to the State.

Pathways analyses and bottom-up technological analyses are complementary

E3's model and analyses highlights very clearly the challenge inherent in meeting California's 2045 carbon neutrality goal, the level of ambition that is required across sectors and subsectors to get there, and the inherent tradeoffs. Essentially, E3's analysis spells out what certain technologies and mitigation measures would need to amount to in order to meet the climate goal.

Our analysis on negative emissions instead used a bottom-up approach that examined whether the suite of technological options available for achieving negative emissions in California (i.e. removing CO2 from the atmosphere) could be scaled up to achieve a given level of removal (CDR).

The two approaches complement each other perfectly, and we see great value in performing the scenario analysis laid out in E3's report using a more comprehensive, informed and robust set of technological assumptions that are constructed from the bottom up, exploit the full gamut of options available to the state, and are consistent with policies and measures that the State has in place or could feasibly implement. This would serve to present policy makers with distinct choices rather than just highlighting interrelations and tradeoffs between measures and technologies.

More uniform assumptions across studies would shed additional light on the best path to carbon neutrality

We see value in comparing and harmonizing inputs and assumptions between E3's approach and that followed by LLNL and partners in *Getting to Neutral*. For example, E3's study excludes natural and working lands as well as carbon dioxide removal from its scope. Our study did consider both of these, but took a more generic view on what level of reductions could be achieved across other sectors. A marriage of the two approaches would best enable to State to assess options and risks.

On a more detailed level, E3 used more conservative assumptions on waste biomass availability and its cost than our study did. We believe that a closer look on this and other topics would be beneficial.

Carbon dioxide removal is needed across all scenarios

E3's analysis points out that, even under very ambitious assumptions for carbon mitigation across sectors, some degree of CDR will be needed in order to achieve the 2045 neutrality goal. This is an important finding that underscores the need to ensure both the deployment of carbon capture and removal technologies, and to develop large-scale geologic carbon storage in California.

No one can say with certainty how much each measure and sector can deliver by 2045. Some of E3's scenarios rely on extremely ambitious assumptions, such as almost the entirety of new vehicle sales being zero-emission 15 years from now, a radical transformation of what appliances and climate control technologies people use in homes and commercial buildings, and more.

While our best efforts must go to achieving such emission reductions, it is plainly evident from past experience that success is not guaranteed. The risk of undershooting on mitigation must be reduced by taking timely steps to ensure that CDR can also contribute meaningfully towards the 2045 goal.

Over-reliance on any technology or approach is risky and more costly

We also strongly agree with E3's conclusion that no single approach or family of measures should be selected as the preferred approach to achieving carbon neutrality. Diversity in approaches and measures decreases the risk of coming up short on emission reductions or removal, and the most prudent risk mitigation strategy is one that enables the largest possible number of contributing approaches without relying on extremely ambitious levels of achievement in any one approach.

In that regard, we point out that the traffic light depiction in Fig. 2 of E3's draft report should show similar climate change mitigation risk for both the Zero Carbon Energy scenario and the

High CDR scenario. The likelihood of failure to achieve the necessary reductions is captured in the technology adoption and implementation risk category. We see the adoption and implementation risk of deploying a high degree of CDR as similar to deploying extraordinarily high degrees of several other solutions simultaneously – the E3 report captures that. Regarding climate change mitigation risk, if the CDR portfolio comprises mainly technological CDR as opposed to relying heavily on storage in natural systems that is potentially reversible, then we do not perceive a high degree of climate change mitigation risk: the technologies to remove and store carbon permanently are well understood and tested.

Respectfully submitted,

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