CLEAN AIR TASK FORCE

September 19, 2019

California Energy Commission
California Public Utilities Commission,
California Air Resources Board

Re: SB 100 Joint Agency Report: Charting a Path to a 100% Clean Energy Future, Docket No. 19-SB-100

Dear Chair Hochschild, Chair Nichols and Commissioner Randolph:

Thank you for the opportunity to comment on the September 5th, 2019 Joint Agency Workshop on the above-referenced Senate Bill 100 Report.

SB 100 is a pace-setting, model piece of legislation that embodies a critical principle for deep decarbonization of power grids: technology-inclusiveness and creating more options. By allowing for and enabling a variety of zero carbon technologies to meet power supply beyond the requirement of 60% renewable energy, SB 100 reflects best practice thinking from the analytic community on an affordable zero carbon energy transition. The technology-inclusive SB 100 approach has been copied by five other states – Washington State, New Mexico, Nevada, New York, Colorado – and is being considered in several others.

The central theme of our comments is that the joint agency report on implementing SB 100 should remain firmly rooted in the principle of technology-inclusiveness and optionality, and explore ways to make diverse options real in the mid-century time frame and after.

1. The SB 100 report should remain rooted in the key principles of technology inclusiveness and optionality

a. *Diversity and optionality increases affordability*

The importance of technology inclusivity and optionality has been emphasized in a wealth of literature in recent years. A recent meta-study of 40 deep grid decarbonization studies concluded that retaining firm zero carbon energy – whether nuclear, fossil with complete carbon capture, or firm renewables such as advanced geothermal – is likely to reduce the cost of decarbonization substantially, as compared with relying on variable renewable sources such as wind, hydroelectric power and solar energy.[1] A typical recent detailed analysis of the role of firm energy in a Northeast and Southern electric system, for

[1] Jenkins, Jesse D., Max Luke, and Samuel Thernstrom. "Getting to Zero-carbon Emissions in the Electric Power Sector." *Joule* 2.12 (2018): 2498-2510. (Link here)

example, found a dramatic cost difference between 100% clean electric systems that harness wind, solar, and firm resources and those that rely solely on wind and sun.[2] (See Figure 1 below)

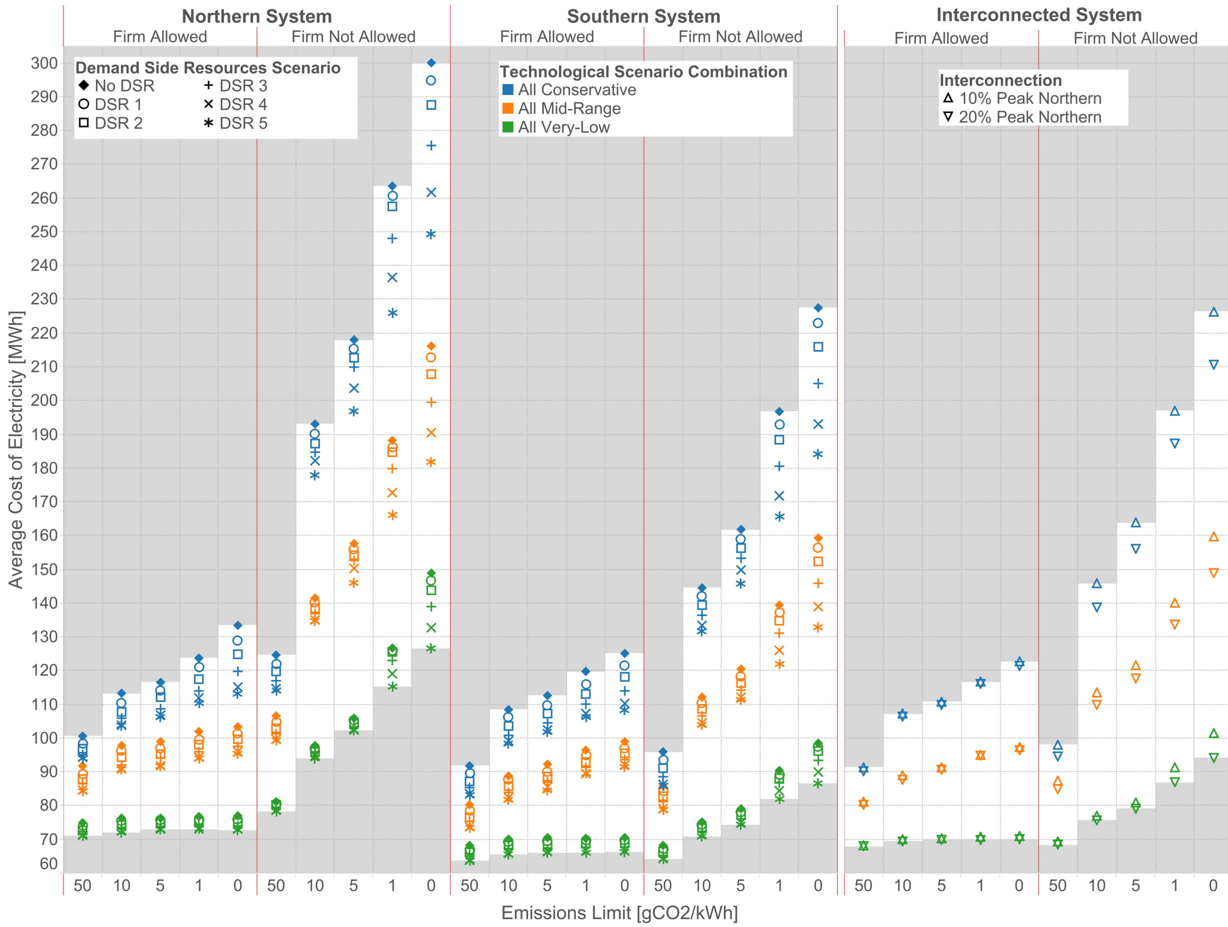


Figure 1: Costs of achieving zero-carbon grids are much higher where firm resources are not allowed and only wind, solar and storage are permitted. Used by permission from Sepulveda, Nestor A., et al. "The role of firm low-carbon electricity resources in deep decarbonization of power generation." *Joule* 2.11 (2018): 2403-2420

Analysis performed by CATF suggests that similar patterns apply to California. The fundamental dynamic driving the need for firm energy in California, as in much of the Northern hemisphere, is ***seasonal variability***. Wind and sun do not just vary on ***daily*** cycles; they vary substantially over ***weekly*** and ***monthly*** periods.

[2] Sepulveda, Nestor A., et al. "The role of firm low-carbon electricity resources in deep decarbonization of power generation." *Joule* 2.11 (2018): 2403-2420. ("Across all cases, the least-cost strategy to decarbonize electricity includes one or more firm low-carbon resources. Without these resources, electricity costs rise rapidly as $CO_2$ limits approach zero. Batteries and demand flexibility do not substitute for firm resources. Improving the capabilities and spurring adoption of firm low-carbon technologies are key research and policy goals.") (Link here).

This seasonal effect can be seen in California for wind in Figures 2-3 below, illustrating smoothed, daily-average production[3] for onshore wind and solar photovoltaics:

**Smoothed Daily Average Wind Production in CAISO, 2018 (MW)**

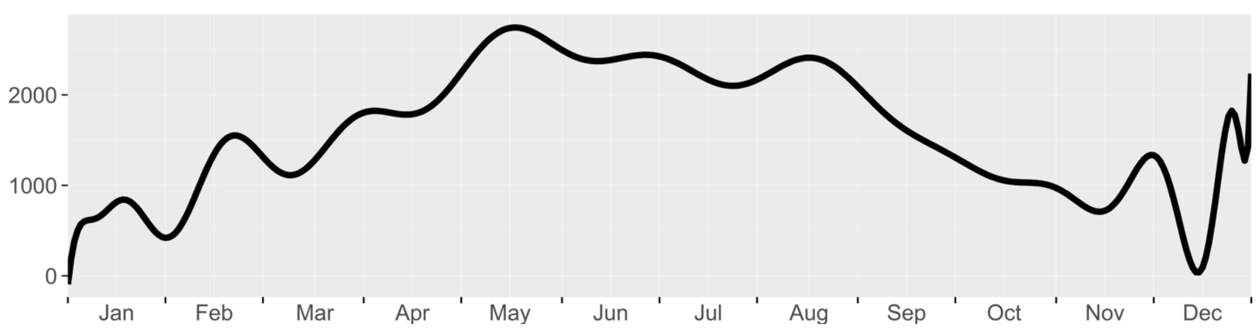


Figure 2

**Smoothed Daily Average Solar Production in CAISO, 2018 (MW)**

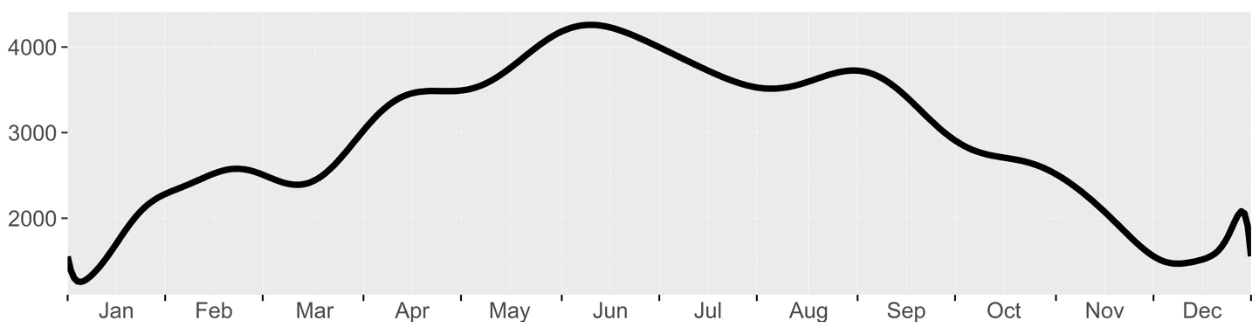


Figure 3

We see a variation in output of 300% or more between seasons.

What happens when we combine wind and solar output to equal 100% of California electric demand on an annual basis, and contrast it to actual demand in each day, week and month? Assuming that we have a 50% wind/50% sun system, we get a pattern like Figure 4 below:

[3] This daily average smoothing conceals more significant variability *within* the day.

**Smoothed Daily Load & Renewable Energy Generation, Mixed Renewable Scenario (MW)**

Scenario definition: 2018 wind and solar generation scale to each meet 50% of total 2018 CAISO load

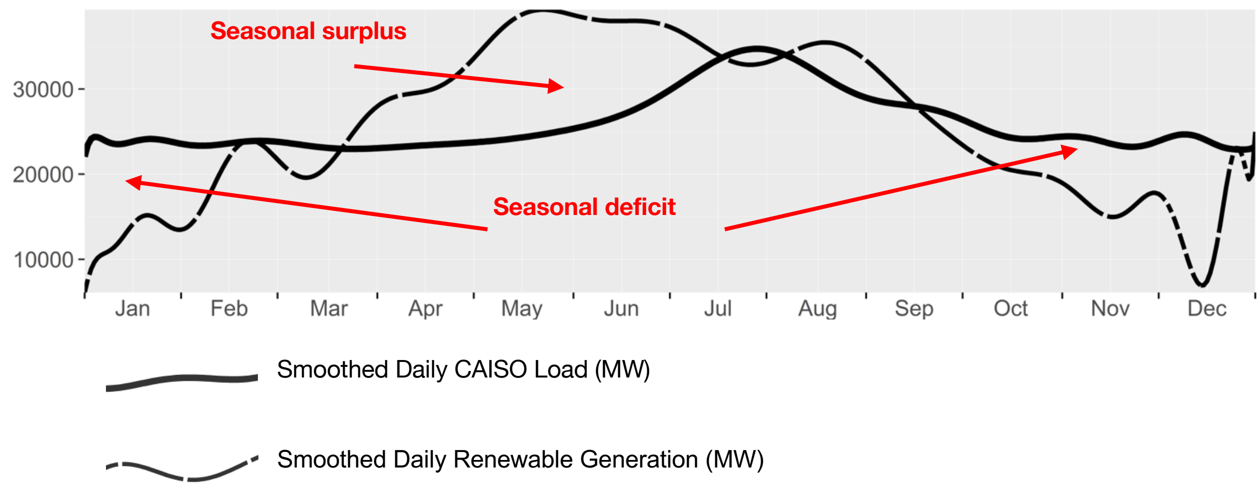


Figure 4

There are multiple weeks of average surplus above demand during the summer months but substantial deficits September through February.

The consequence of this seasonal variation is that, even when California procures enough wind and solar output to meet total electricity demand on an ***annual average*** basis, ***roughly 27% of hours of the year cannot be served by wind and sun.*** This is shown in the "heat map" below, Figure 5, in which yellow, orange and red hours are unserved by variable wind and sun:

**Percent of Hourly Load Served, Mixed 100% Wind and Solar Scenario**


Figure 5

In theory, we could use battery storage to harvest surpluses and use them in deficit periods. But this is where cost comes in. The sheer amount of storage that must be built to capture maximum surplus, and then utilized infrequently, becomes cost prohibitive, even at very low storage costs.

In Figure 6, we see that the accumulated surplus during the year equals 35,946,633 MWh, or roughly 14% of California's annual electric usage. To contain that much energy at peak storage time, you would need a storage system equivalent in instantaneous capacity larger than the generating capacity of the entire US electric grid.

**Daily Renewable Energy Generation Surpluses and Deficits, Mixed Renewable Scenario**

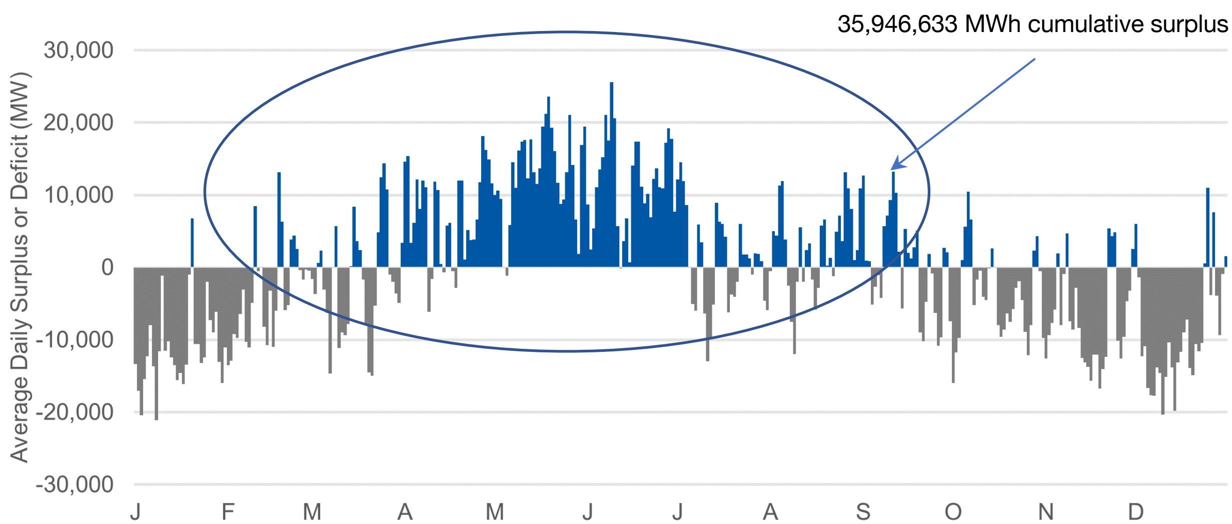


Figure 6: California surplus and deficit patterns under a 100% renewable energy scenario.

That much capacity will incur a very large capital expense. The US Department of Energy estimates the current cost of grid scale energy storage to be just under $500/kwh of capacity.[4] Let us assume we drop that cost by roughly 85% to $80/kwh. The total cost of such a battery storage system would be ***$2.9 trillion,*** or more than California's annual GDP of $2.7 trillion.

But that in some way understates the problem, because this storage capacity would be used at a very low rate – about 1% of capacity in an average year. That is because only a small amount of the storage capacity would be used regularly to balance daily variations in solar and wind output. Most of the storage capacity would need to be built to store peak seasonal surplus and thus only cycle seasonally. That means large capacity divided by little use, resulting in very large per unit costs for stored energy.

[4] US EIA, "U.S. Battery Storage Market Trends "(May 2018) https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf

The result, depicted in Figure 7 below, shows that the escalating costs of storage per unit output required, as wind and sun percentages become higher, drive very large system cost increases of roughly sevenfold as wind and sun go from 60% to 80% of energy supply, and roughly twenty four times as wind and sun provide all system energy.

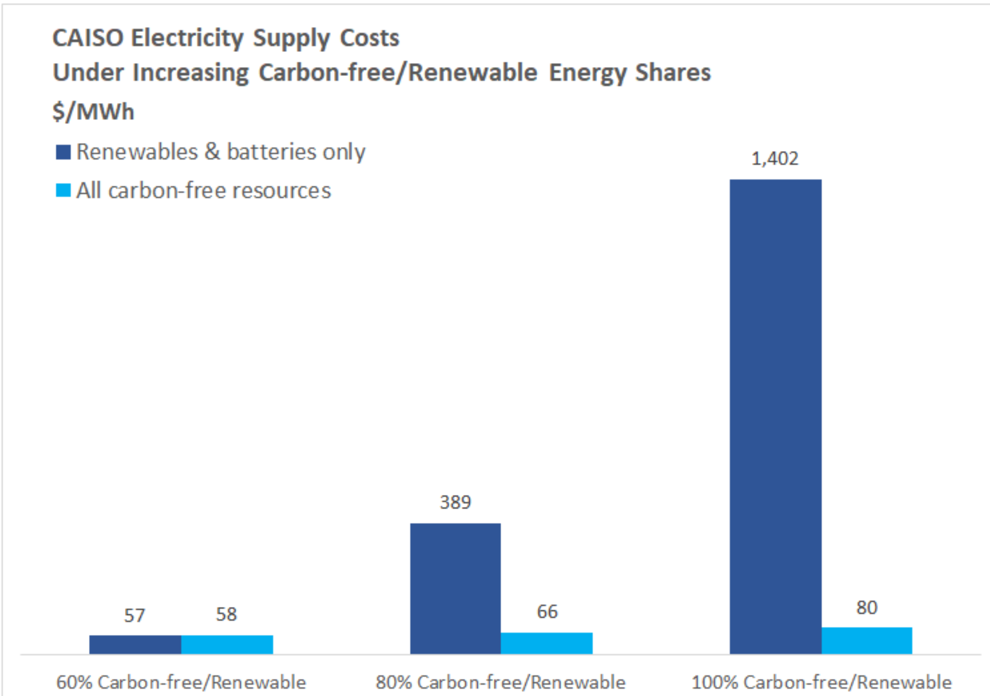


Figure 7. California energy systems costs with increasing shares of wind and solar, versus a mixed system including firm zero-carbon sources. Source: Clean Air Task Force calculated from CAISO data and aggressive assumptions on renewable energy and storage cost reductions.[5]

A similar cost escalation pattern has been seen in national studies, such as a recent one conducted by National Renewable Energy Laboratory analyst Bethany Frew, which also assumed a transcontinental electric grid and optimal demand response mechanisms (see Figure 8 below).

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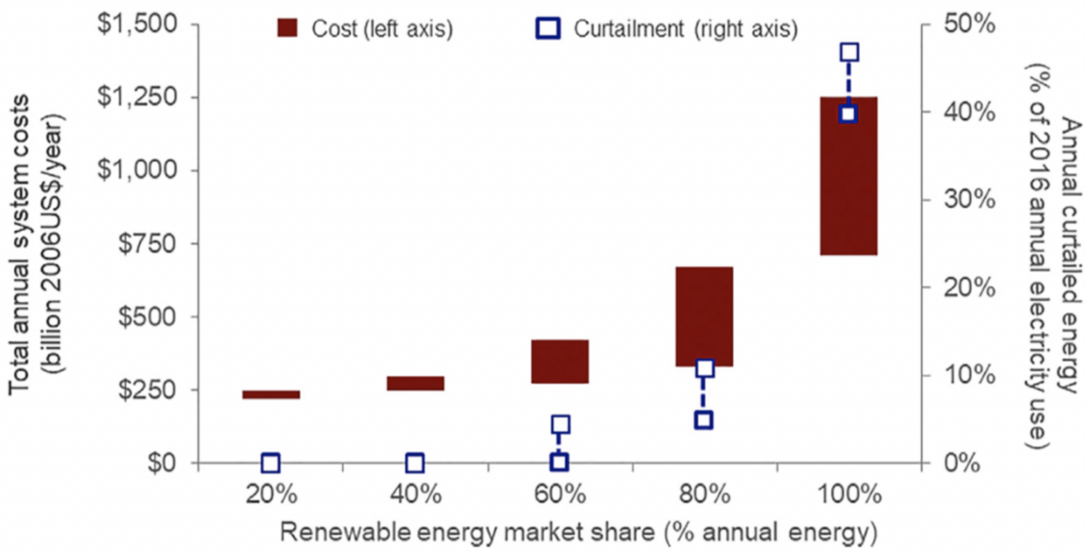
[5] The analysis assumes very aggressive further cost reductions in wind and solar energy compared to current projections by the US Energy Information Administration. Specifically, the analysis assumes that wind costs drop from $1,624 per kw to $1,000/kw and that solar PV drops from $1,969/kw to $700/kw.




Jenkins et al., Getting to Zero Carbon Emissions in the Electric Power Sector, Joule (2018), https://doi.org/ 10.1016/j.joule.2018.11.013, adapted from Frew, Bethany A., Jacobson, M. et al. "Flexibility mechanisms and pathways to a highly renewable US electricity future." *Energy* 101 (2016): 65-78.

Figure 8: Costs of supplying power in a national study of increasing shares of wind and solar. (Source: see Figure description above).

It has been suggested that these kinds of high cost tails can be avoided by building substantially more wind and solar to meet California's peak demand, and then curtailing wind and solar in times of surplus – thus minimizing the need for storage. However, this does not solve the problem, as Figures 7 and 8 show. In CATF's analysis (Figure 7), very little storage is used at the 80% carbon free grid mark and additional amounts are added only as needed in the movement towards 100% carbon free – yet the cost curve is well on its upward trend. And in Figure 8, one can see that an optimized mix of curtailment and storage still yields a system with substantial curtailment that provides 70-80% of energy from wind and sun rather than 100%, which still incurs steep costs.

None of this analysis is to gainsay a substantial role – likely greater than the statutory SB 100 minimum of 60%, which itself is three times today's share – for renewables such as wind and solar energy in cost-effectively achieving the electric system decarbonization challenge. And it is always possible that technological breakthroughs could occur that would make it possible to increase the percentage of economically affordable wind and solar to much higher levels.[6] But such breakthroughs may not occur. Supporting policies to bring other zero-carbon options to market will provide greater certainty of success.

*b. Diversity and optionality increases the chance of success in low carbon build-out*

Apart from cost, there may be serious issues associated with siting necessary zero carbon infrastructure of any kind. While public concerns over siting nuclear energy plants are historically well-known, and the siting of new gas-fired power plants with carbon capture is not likely to be without controversy, it is also true that very large buildouts of a wind- and solar-dominated system and associated transmission may also face obstacles.

For example, Figure 9 below depicts the amount of zero-carbon energy that would need to be added each year to the California grid to meet the state's mid-century zero-carbon target, compared to various historical addition rates. To achieve these targets on wind and solar alone would require California to deploy those sources at five times the best historic rate, every year for the next 25 years – the equivalent of nearly ten of the world's largest onshore or offshore windfarms ***every year***. In nuclear terms, this would amount to construction of more than one Diablo Canyon size plant (2256 MW) every year. Figure 10 shows similar national figures for various technologies.

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[6] It is sometimes argued that "demand response," that is, the ability to curtail customer load, will alleviate the surplus and deficit problems outlined in this testimony. While this resource can be valuable, it is a question of scale and duration. Today, the California grid operator reports that the system has in place 350 MW of maximum load reduction/demand response — representing less than 1% of peak demand. See California ISO, 2018 Annual Report on Market Issues and Performance, http://www.caiso.com/Documents/2018AnnualReportonMarketIssuesandPerformance.pdf, pp. 29, 42. These agreements are generally understood to require interruptions for a few hours a few times a year. By contrast, as Figure 5 demonstrates, 100% wind and solar scenarios produce power deficits equal to as much as 75% of demand ***over many weeks***. It is not likely that California businesses, industries and consumers would effectively agree to multi-week and seasonal curtailment of demand, or that this would be good for the California economy if they did.

It also may be argued that interconnection of California to other control areas will alleviate the surplus and deficit problem. While greater interconnections can help at the margins, we must assume that other regions will be pursuing similar levels of decarbonization and are likely to adopt similar levels of variable energy. And wind and solar tends to be highly correlated on a daily and weekly across the nation. As a result, even with seamless national interconnection, as is assumed in the study referenced in Figure 8, substantial surplus and deficit problems are experienced at very high levels of wind and solar, with the resulting cost impacts shown in the figure.

**Illustrative zero-carbon energy deployment to achieve California grid decarbonization target (TWh)**

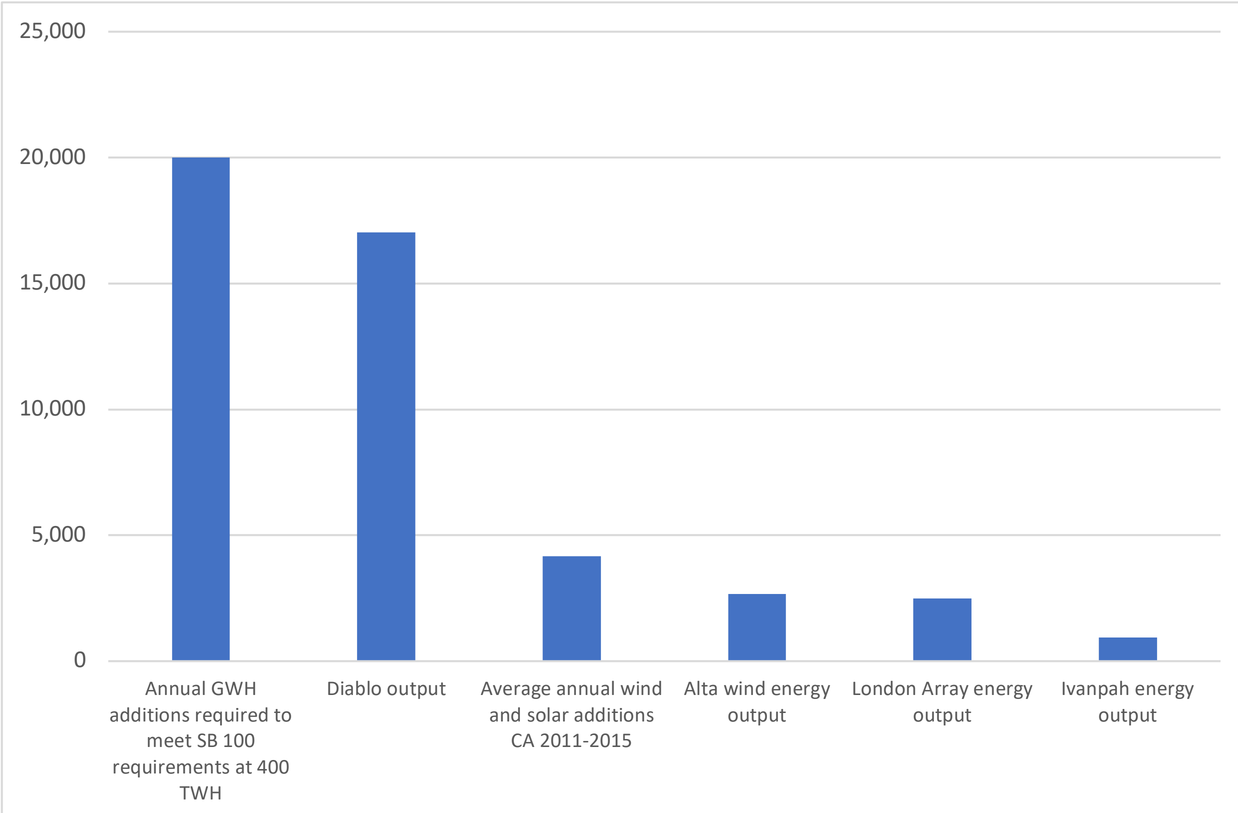


Figure 9: Annual zero-carbon energy deployment rates required to meet California's 2045 zero-carbon grid requirement starting in 2020, assuming increased electrification. It is assumed that all current zero-carbon energy infrastructure would need to be replaced by midcentury. (Source: Clean Air Task Force calculated with historical data from published reports of the California Energy Commission, California PUC)

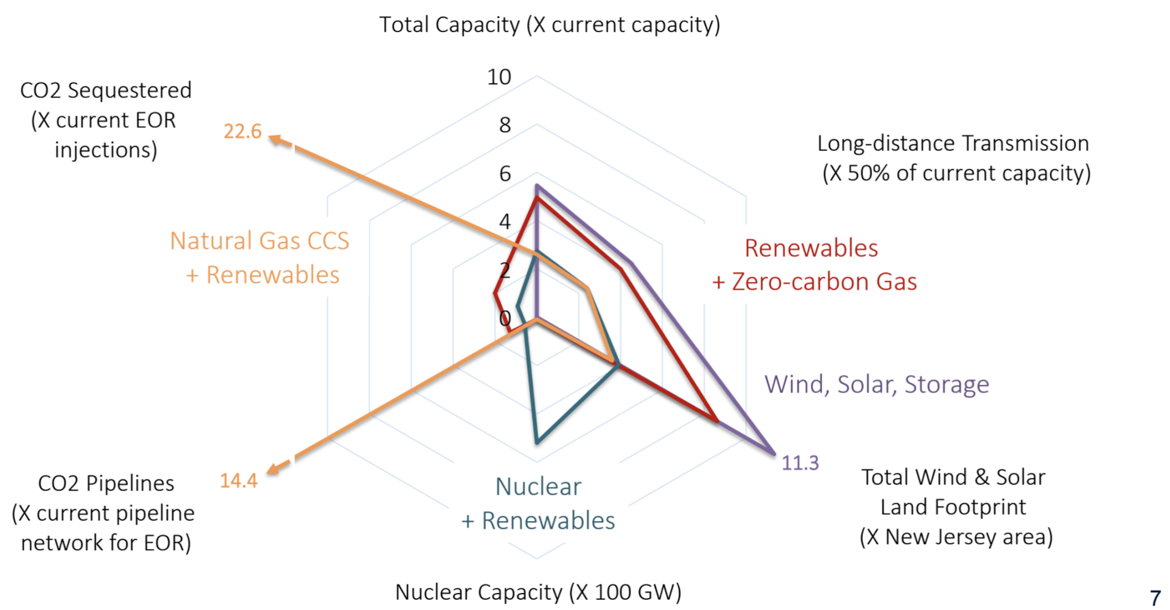


Figure 10: National buildout required for 100% carbon-free electricity, by technology. Source: J. Jenkins, *Critical bottlenecks in decarbonization of the U.S. electricity grid*, Jesse D. Jenkins, PhD, Princeton Rapid Switch Workshop (June 12, 2019), used by permission of author

By any measure, this is blistering and unprecedented pace of energy system buildout. It would be challenging enough to imagine achieving this with all of the available options. The difficulty increases as options are increasingly taken off the table.

The sheer engineering feat required is complicated further by public acceptance issues. Around the nation, and even, or especially, in more environmentally oriented states such as California, there have been substantial battles and delays over siting renewable energy infrastructure and associated transmission.[7] Additional transmission needed to knit together diverse wind, sun and hydro resources are especially dramatic as renewable energy shares increase – requiring as much as a twenty-fold increase in US transmission capacity and interties for very high renewable energy scenarios, according to the National Renewable Energy Laboratory (see Figure 11 below). Just one such transmission line, in New England, has recently consumed roughly a decade of environmental debate, and is still not resolved.[8]

[7] See P. Field, et al, Resolving Land Use and Energy Conflicts (2018); https://www.cbsnews.com/news/new-york-wind-turbines-face-uphill-battle/ ; and https://friendsofmainesmountains.org/?category=Anti-Wind+Groups

[8] https://www.bostonglobe.com/metro/2018/11/22/plans-bring-hydropower-from-canada-cornerstone-state-energy-policy-faces-mounting-obstacles/3j6iBavrm4Libx8QdpX67M/story.html

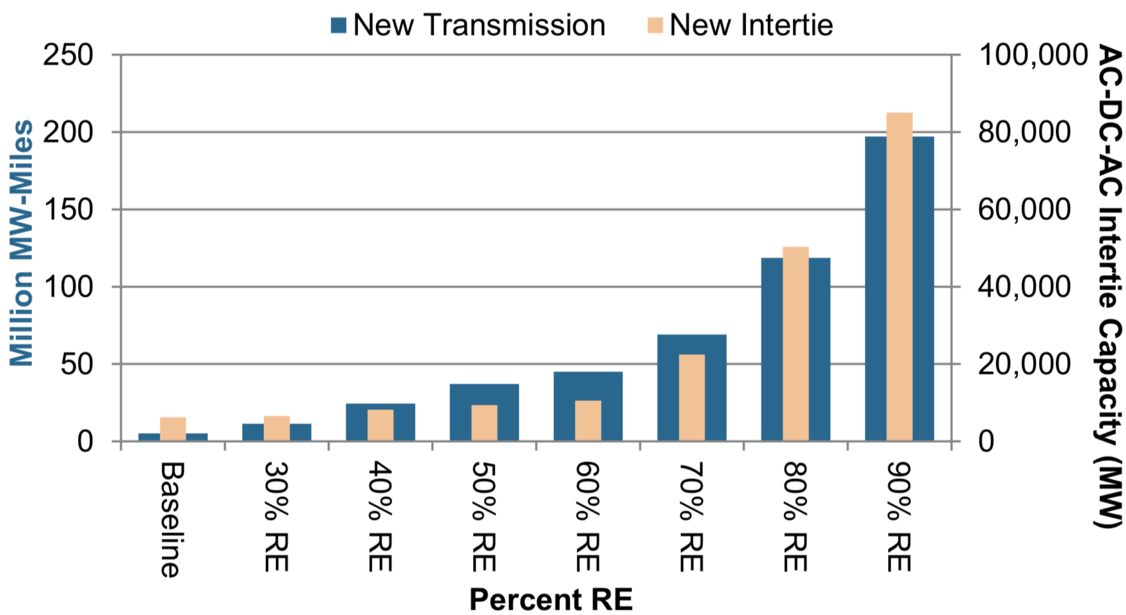


Figure 11: Transmission required for various levels of renewable energy deployment. Source: National Renewable Energy Laboratory, “Renewable Electricity Futures Study,” Executive Summary, p. 26.

*c. Conclusion: Allow and Support Developing Firm Zero-carbon Electricity Options*

A diverse approach provides resiliency to the strategy by proving optionality in case insurmountable hurdles are faced in one pathway. As we have discussed, in addition to cost issues, a large build-out of wind and solar energy capacity, along with the substantial increase in transmission capacity that would be necessary to serve a wind- and sun-dominated system, may well face substantial and well organized opposition which has already emerged around relatively small scale proposals. At present, California law forbids construction of new in-state plants because there exists no federal waste repository. The use of natural gas with carbon capture and careful methane emissions management, although based on well-demonstrated technologies, will likely face challenges from those opposed to the use of any fossil fuels for reasons including local health and environmental effects. The more options we have, the greater will be our chance of success. The joint agency report should explore the opportunity for incentives and other policies to bring additional zero-carbon options to market.

2. <u>The joint agency report should consider potential synergies between technology optionality and innovation in the power sector and the need to decarbonize the non-electric parts of the California energy economy</u>

Executive order B-44-18 commits California to total, economy-wide carbon neutrality by 2045. But electricity represents only 16% of the state greenhouse gas emissions.

Where we cannot replace emitting energy sources with carbon-free electricity, four additional and overlapping energy pathways could be critical and should be addressed in comprehensive climate legislation or enacted as complementary policies:

- Zero-carbon liquid or gaseous fuels that can be used for transport, high temperature industrial heat, and building heat (and to create firm, non-weather-dependent electricity)
- Direct sources of zero-carbon high temperature heat such as supercritical geothermal energy and high temperature nuclear energy
- Industrial processes that do not inherently produce carbon emissions
- Direct carbon capture for otherwise unavoidable industrial carbon emissions

I was honored last year to be part of a group of authors who published an article in *Science* entitled "Net-zero emissions energy systems." [9] The key insight of that article is that it is best to think of a net-zero greenhouse gas emissions energy economy as a ***system*** of complementary and overlapping parts. These parts include zero-carbon electricity, fuels, storage, low-carbon industrial processes, and carbon capture and sequestration from fossil fuel use. A greatly simplified schematic picture of such a system can be seen in Figure 12 below.

Note that there are a variety of interconnections and complementarities between these pathways and potential pathways for carbon-free power sector. For example, zero-carbon liquid or gaseous fuels can be made (a) via electrolysis of water which requires zero-carbon electricity, but also by (b) stripping carbon from responsibly-sourced natural gas through steam reforming and carbon capture and (c) direct chemical conversions using nuclear energy.[10] Likewise, carbon capture is not only useful for directly capturing power and industrial emissions, but also for decarbonizing industrial heat or producing carbon-free hydrogen from natural gas. And zero-carbon fuels, as well as nuclear and carbon capture, as discussed below, can be important enablers of a zero-carbon electric grid in complement to wind, solar and energy storage.

These potential complementarities should be taken into account in the joint agency report.

[9] Davis, Steven J., et al. "Net-zero emissions energy systems." *Science* 360.6396 (2018): eaas9793.

[10] See Clean Air Task Force, "Fuel Without Carbon" (2018), https://www.catf.us/wp-content/uploads/2018/12/Fuels_Without_Carbon.pdf

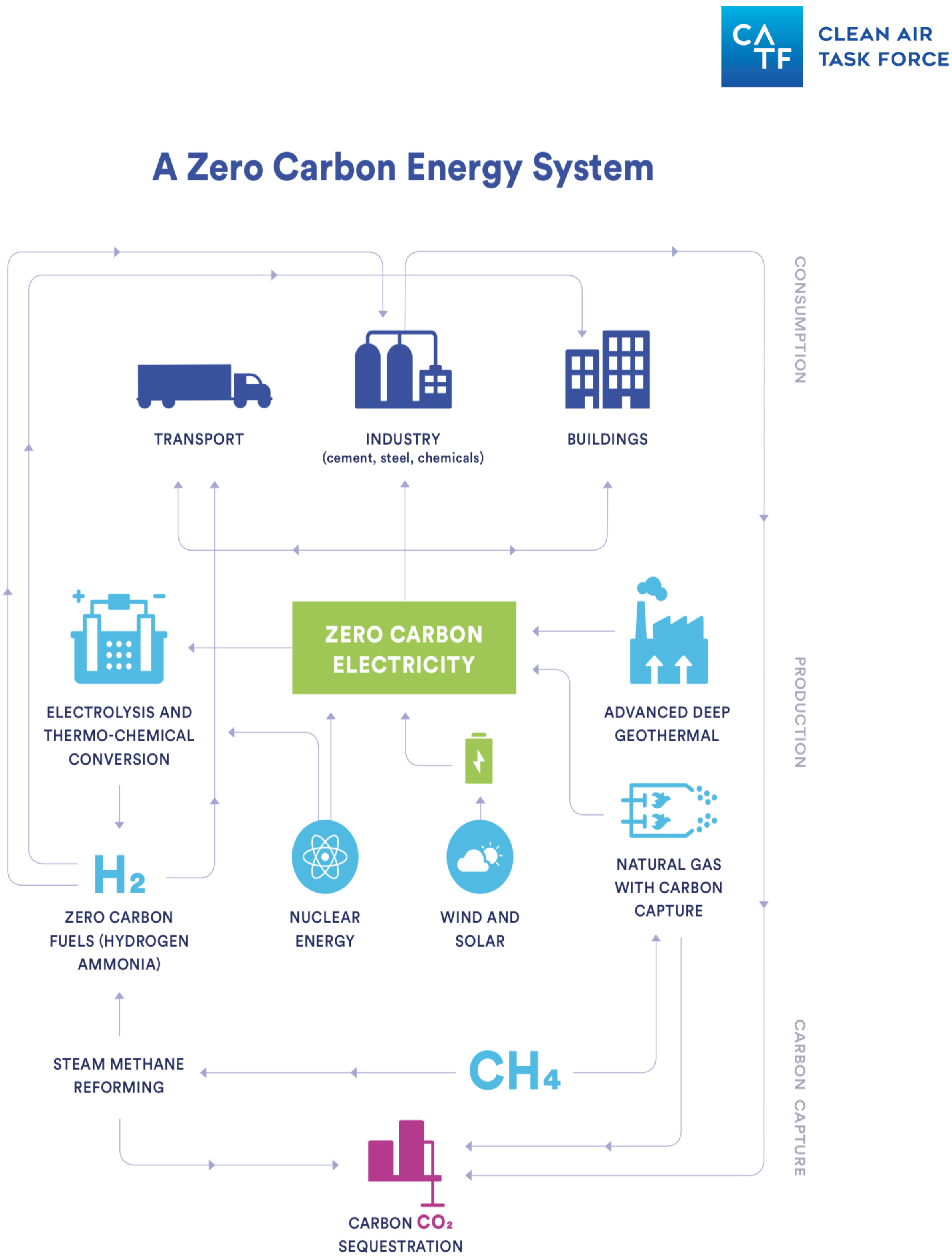


Figure 12: Schematic of a zero-carbon energy system (Source: Clean Air Task Force, 2019)

3. The joint agency report so should explore specific state policies to enhance optionality and technology diversity for the zero carbon grid

California has historically been a world leader in bringing forward low-emission vehicle and power technologies to market through mandates and incentives. Most recently, the CPUC's storage procurement mandate has helped stimulate the national market for energy storage. Similar "market pull" policies should be considered in the joint agency report for zero carbon power technologies, particularly those that have potential application to other energy sectors.

Potential technology candidates for incentives, grants and mandates include:

- Long duration electrical energy storage
- Renewable energy resources physically coupled to long duration storage
- Natural gas generating facilities equipped with carbon capture and sequestration
- Thermal generating units fueled entirely by zero carbon fuels such as hydrogen and ammonia
- Dedicated non-generating facilities that produce zero carbon fuels such as hydrogen and ammonia for use in electric generation facilities
- Advanced dispatchable renewable energy technologies such as deep hot rock geothermal energy
- Nuclear fission or fusion technologies, whether located in or outside of the state, consistent with other laws of the state

Another, more generic approach that could be considered is a requirement for load-serving entities to test the market for zero carbon "firm" energy in specific tranches without specifying technology type. At a minimum, such a solicitation or request for proposals would reveal the range of technologies and price points the private sector is able to offer.

4. Conclusion

CATF once again appreciates the opportunity to file these comments, and stands ready to assist the agencies by providing further information on the ideas contained in this letter. Our local California contact point is Deepika Nagabhushan at 1 (847) 505-4149 or dnagabhushan@catf.us.

Respectfully submitted,

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