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Can Storage Close the Gap in California's Decarbonization Plan?

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Executive Summary

- Our previous studies of California's decarbonization plan have shown that, to maintain a reliable electric grid, the state will be burning almost as much natural gas in 2045 as it does now. We have applied an hour-by-hour model to examine to what extent increased storage can reduce the use of fossil fuel.
- To achieve significant reductions in fossil fuel use, both battery storage and solar installations to charge the batteries must be expanded. To achieve a 90% reduction in natural gas use, storage must be doubled in size compared to what the state is currently planning. Solar facilities must be tripled.
- Vast amounts of land are required for this augmented solar capacity. The cost of the plan is greatly increased. Together, these make this an utterly impractical solution for the state. Replacing much of the solar, wind, and storage with nuclear power plants will produce a grid which is more affordable and protective of California's environment.

Introduction

- Last year, we analyzed California's renewable-based decarbonization plan and found that, in the target year of 2045, the electric grid, far from being emission-free, would be burning 81% as much natural gas as it is now. Though large amounts of solar and wind are added to the current mix, they are unable to reliably meet the projected demand.
- Advocates of renewable energy − solar and wind − acknowledge that those sources of emission-free power are not always available. They are intermittent, dependent upon the weather, the time of day, and the season. However, they suggest this limitation can be overcome by using battery storage to capture and hold their output for use at a later time when it will be needed.
- This report examines this premise using an hour-by-hour simulation of California's plan.
- We find that seeking to close this gap requires not only a large expansion in the storage included projected in California's plan, but an even larger overbuild in solar installations as well.

Background

- The **California Energy Commission** is examining whether storage can reduce the burning of natural gas in California's projected decarbonized electric grid. Storage might be able to provide dispatchable power to fill gaps left by variable renewables like solar and wind.
- Several years ago, the Commission published a study prepared by Energy and Environmental Economics, Inc. (E3) and Form Energy, Inc., suggesting that the use of long-duration storage could successfully reduce the use of natural gas in California's decarbonization plan. Their report claimed that "LDES [long duration energy storage] could cost- effectively support bulk grid decarbonization and environmental justice."
- Studies we conducted previously for New York showed that storage cannot eliminate the need for clean firm, dispatchable resources. We found that any attempt to install sufficient storage, along with essential electric generation resources using intermittent renewables, becomes so expensive as to render such an approach impractical.

Storage is not an energy source. It requires charging by real physical sources of energy.

- It is too often forgotten that storage is not an energy source. It must be charged, or filled up, by an actual source of power. In the case of California's current decarbonization plan, this additional output must come from the solar and wind sources themselves since large additions of nuclear, hydro, or natural gas are not permitted. In other words, to provide the extra energy needed to charge the batteries. solar and wind must be **overbuilt** beyond the scale required simply to meet the grid's demand when they are operating.
- Solar and wind already require a degree of overbuilding so they can provide useful power on a cloudy day or in low wind conditions. However, the requirement that they charge batteries or other storage media for later use requires a further extent of overbuilding, beyond that needed to meet the immediate demand for power.

How we estimated the additional storage needed to displace the burning of natural gas.

- Natural gas is burned whenever other sources are unable to meet the electric demand on the grid. In the state's plan, gas fills the gap between demand and zero-emission supply.
- In this report, we examine whether adding more battery storage can reduce or eliminate the need to burn natural gas. (We refer to this as battery storage since this is the only form of storage which is sufficiently scalable upward at the present time. Other forms include pumped (water) storage, compressed air storage.)
- We use the computer model we applied earlier to study California's plans for decarbonization. In the previous study, we referred to the model as the CACI model, developed by two engineers who ran the Center for Academic Collaboration Initiatives. However, the Center no longer exists, so we have renamed it the **Hourly ELectric Grid Analysis**, or **HELGA**, model.

How HELGA computes the need for gas

- In the HELGA model, the contribution of each energy source on the grid is estimated for each hour of the year. The output of nuclear, hydro, solar, and wind is computed using their projected capacities (gigawatts, or GW) in 2045. Electric generation from solar and wind is estimated from the output of these sources during each hour in 2023, scaled up to their capacities in 2045. Imports, too, are scaled up from their contributions in 2023.
- All these sources are assumed to be fixed and non-dispatchable; that is, their outputs do not depend upon the demand on the grid. The dispatchable sources – those that are responsive to demand – are battery storage and gas combustion. The batteries are charged using the excess output from grid-connected solar and wind; that is, their output, beyond that needed to meet the immediate demand, is used to charge the batteries. Once charged, the batteries provide as much energy as they contain, less any losses in the charge/discharge process (about 15% for current Li-ion batteries).
- Whatever demand remains on the grid that is not met by the batteries is supplied by gas-fired generation. That is, gas fills the gap between demand and supply.

California claims its current plan decarbonizes the grid.

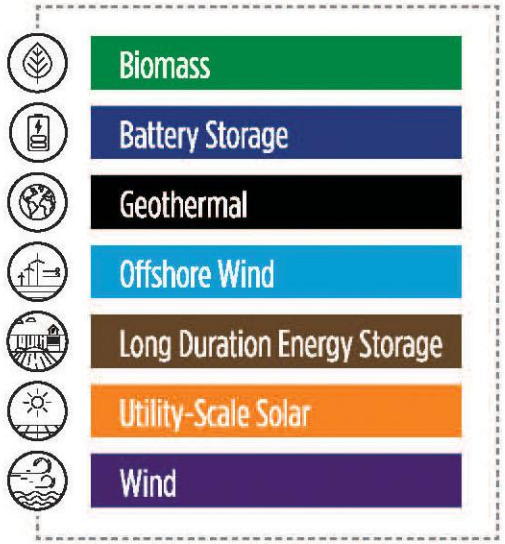
California's current plan, which we refer to as the SB 100 Core scenario, is displayed in a report issued by the Governor. It features greatly expanded solar, a modestly-expanded wind resource, and much expanded battery storage. It does not show the continued burning of gas and claims, falsely, that this plan will produce 100% clean electricity by 2045.

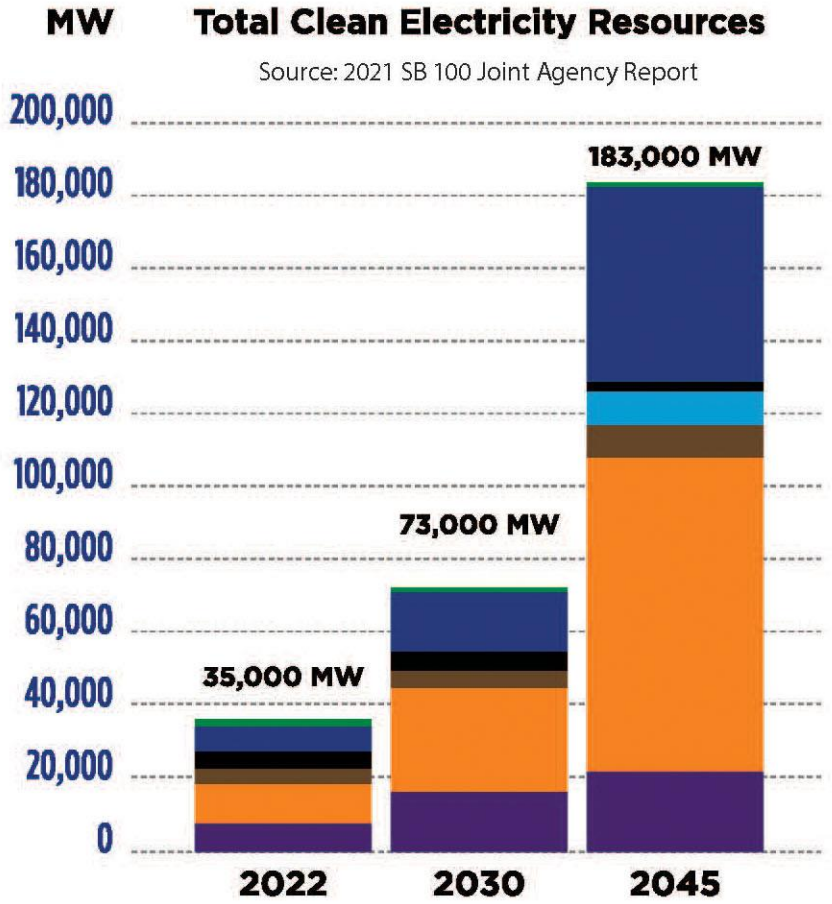
To provide 100% clean electricity by 2045,

California will build an unprecedented amount of new utility-scale clean energy resources

Totals represent new and existing resources. The 2021 SB 100 Joint Agency Report projects the need for 148,000 MW of new resources by 2045.

In addition, California also expects new capacity from energy efficiency, customer solar and demand response.





https://www.gov.ca.gov/wp-content/uploads/2023/05/CAEnergyTransitionPlan.pdf

Solar and battery storage dominate the SB 100 Core plan, but they are not enough to decarbonize the grid.

- The California Energy Commission estimates that California had 22 GW of solar capacity and 6 GW of wind, with about 16 GW of battery storage at the end of 2024.)
- There is currently 40 GW of gas capacity on the grid. It generated 86,480 GWh in 2024.
- In the SB 100 Core plan, the largest source of new emission-free generation in 2045 is 82 GW of utility-based, non-residential solar. Also, 20 GW of wind are available. This is supplemented by 52 GW of battery storage which supplies power to the grid when the sun is not shining, provided the batteries have been charged before the sun went down.
- HELGA estimates that gas-fired capacity has to be increased to 52 GW and produces75,015 GWh in 2045 in order fill the gap left by the other sources.

In SB 100 Core, gas-fired generation fills the gap between electric demand and emission-free supply.

- In our HELGA modeling of California's decarbonization plan, we focus on the SB 100 Core scenario, the principal plan explored in the 2021 SB100 Joint Agency Report.
- We find that, by 2045, when the grid was supposed to be decarbonized, gas consumption has been reduced by only 19%. Gas continues to carry nearly 18% of the load, filling the gap between electric demand and what the renewables would be capable of supplying.

Electricity Generation
SB100 Core
2045

Energy Source	Capacity (MW)	Output (GWh/yr)	Capacity Factor (%)	% Load
Existing Nuclear	1,042	7,734	84.7%	1.8%
New Nuclear	0	0	0.0%	0.0%
Large & NW Hydro	17,366	30,918	20.3%	7.3%
Other Renewables	5,770	14,061	27.8%	3.3%
Rooftop Solar	36,000	71,984	22.8%	16.9%
Utility Solar	82,000	151,363	21.1%	35.6%
Land-based Wind	12,217	38,496	36.0%	9.1%
Offshore Wind	8,215	33,525	46.6%	7.9%
Battery Discharge*	52,329	61,025	13.3%	14.4%
Gas	52,000	75,015	16.5%	17.7%
Imports		1,736		0.4%
Load		424,832		100.0%

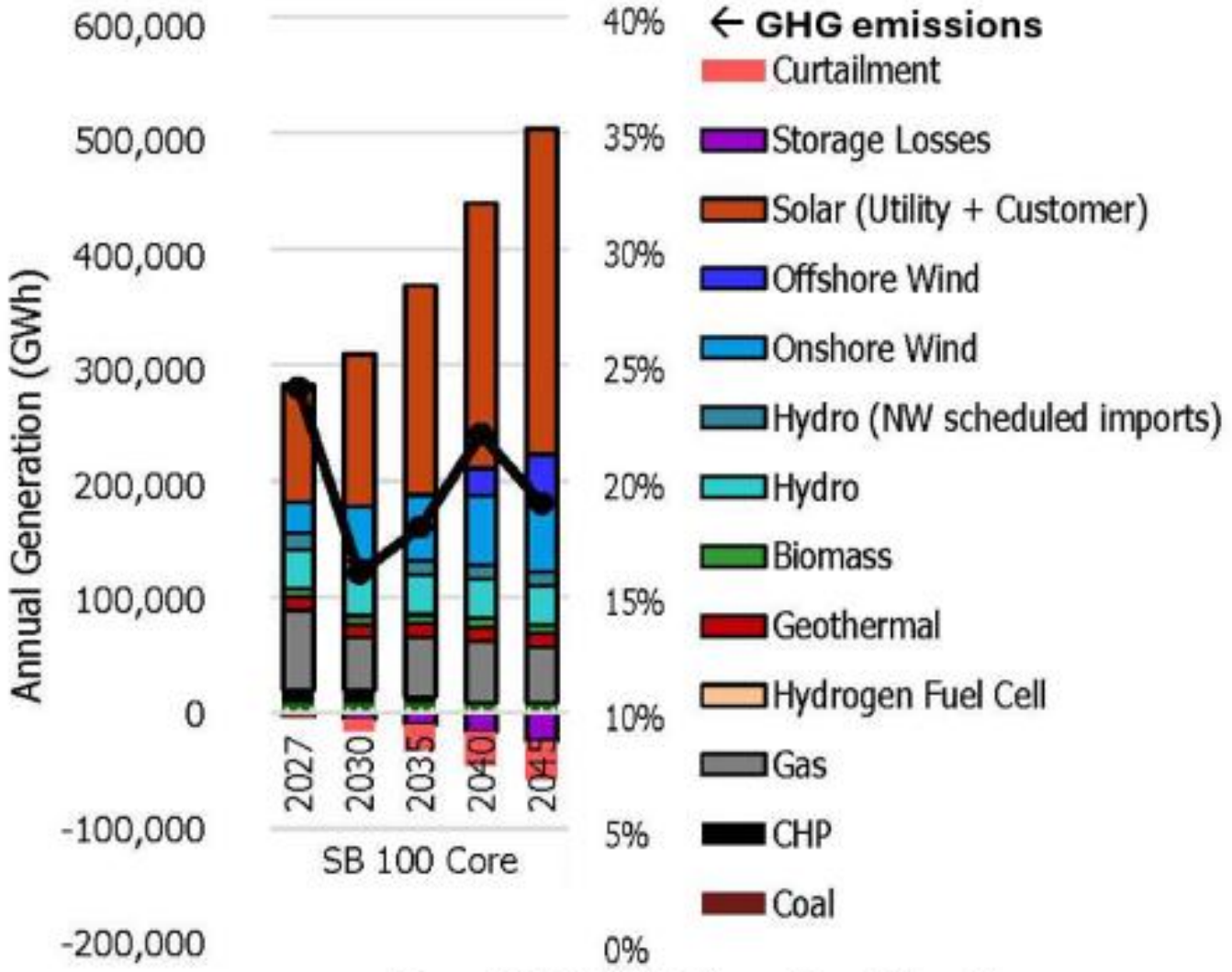
* Battery charging included in solar and wind generation.

The state also needs gas-fired generation in the SB 100 Core scenario.

- The state found continuing burning of gas in their SB 100 Core scenario, but they did not disclose this in their reporting on the plan.
- However, this graph, showing continued gas combustion and GHG emissions in 2045, appears in the official report on the plan.

2021 SB 100 Joint Agency Report

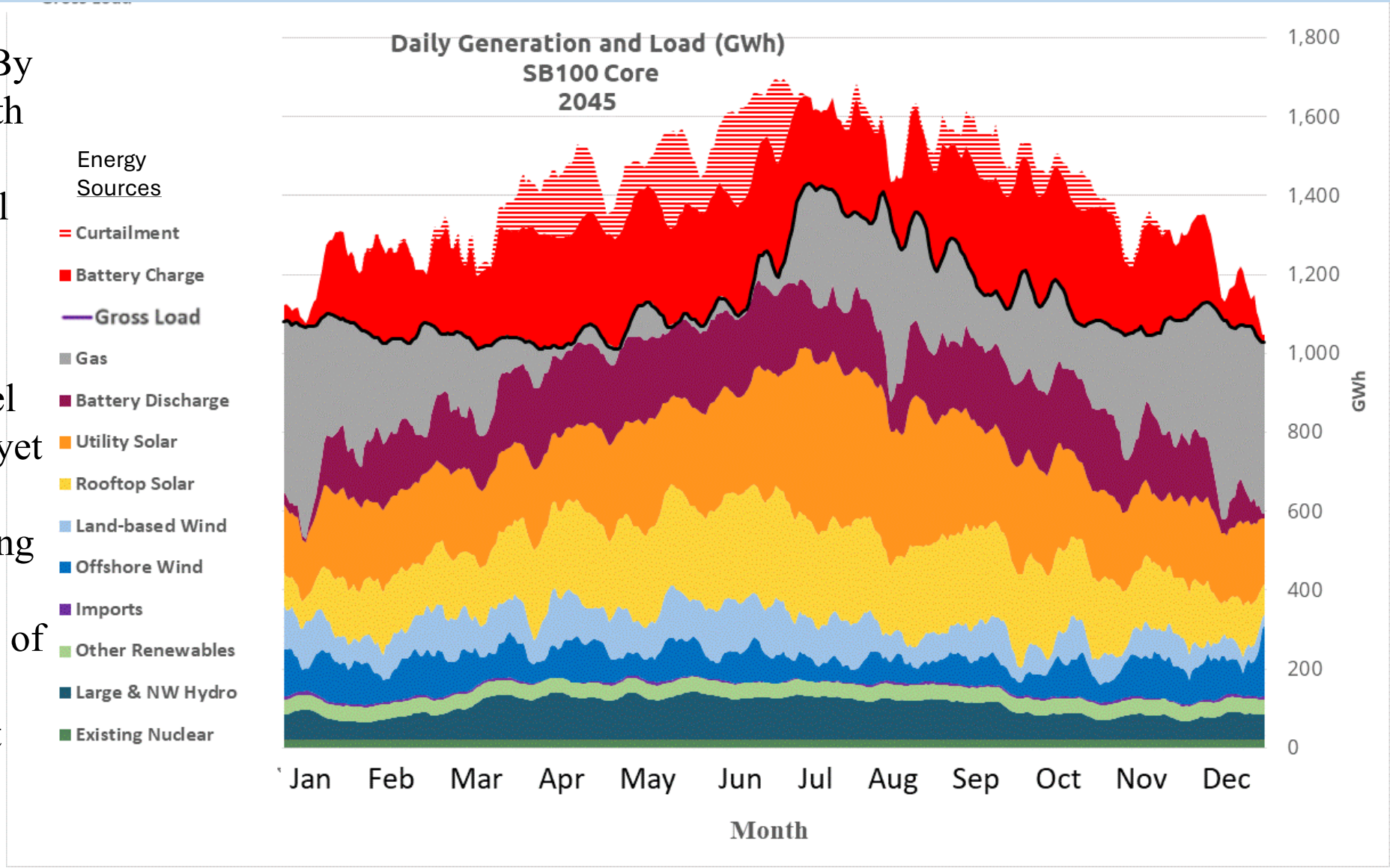
Achieving 100 Percent Clean Electricity in California: An Initial Assessment



Source: 2021 SB 100 Joint Agency Report, Figure 29

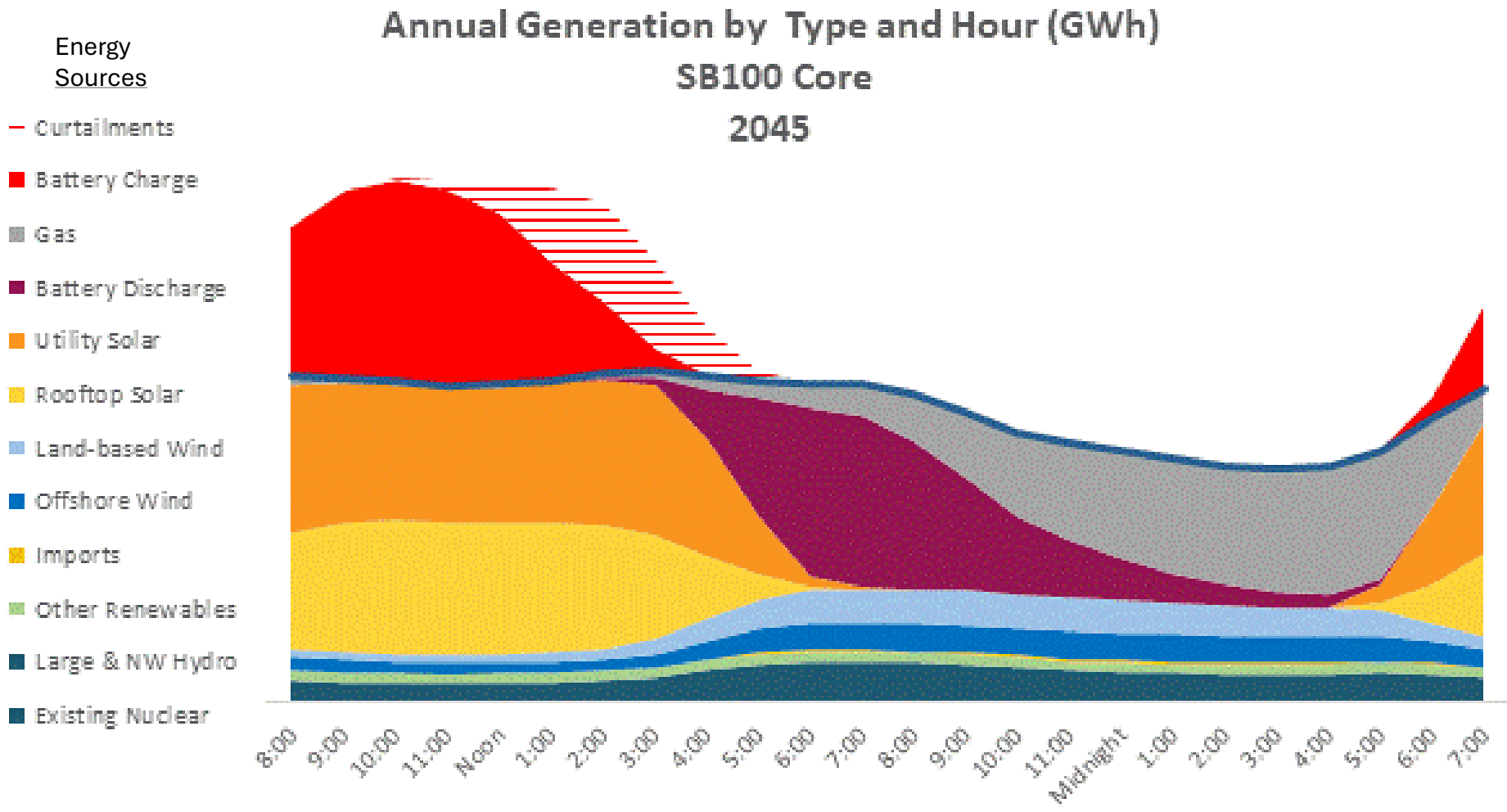
Gas will be burned throughout the year in 2045.

Here is what HELGA found. By 2045, solar output is large, with wind much smaller. Batteries play a large role but cannot fill the gap between supply and demand. SB 100 allows the burning of gas to cover transmission losses. Our model excludes transmission losses, yet we find that, in 2045, California's grid will be burning nearly as much gas (shown in gray) as it is now. A great deal of excess power is produced and stored in batteries, but it is not enough to avoid extensive burning of gas.



Gas is burned through much of the day and evening.

This graph shows the electric generation for each hour of the day in 2045, totalled over the entire year. Solar dominates for a third of the day, but batteries and the burning of natural gas are what keeps the lights on for the rest of the day and night. When the day is overcast or rainy, the batteries will not be charged, and only the burning of gas will avoid rolling blackouts.



How much storage and additional power will we need to reduce or eliminate gas-fired generation?

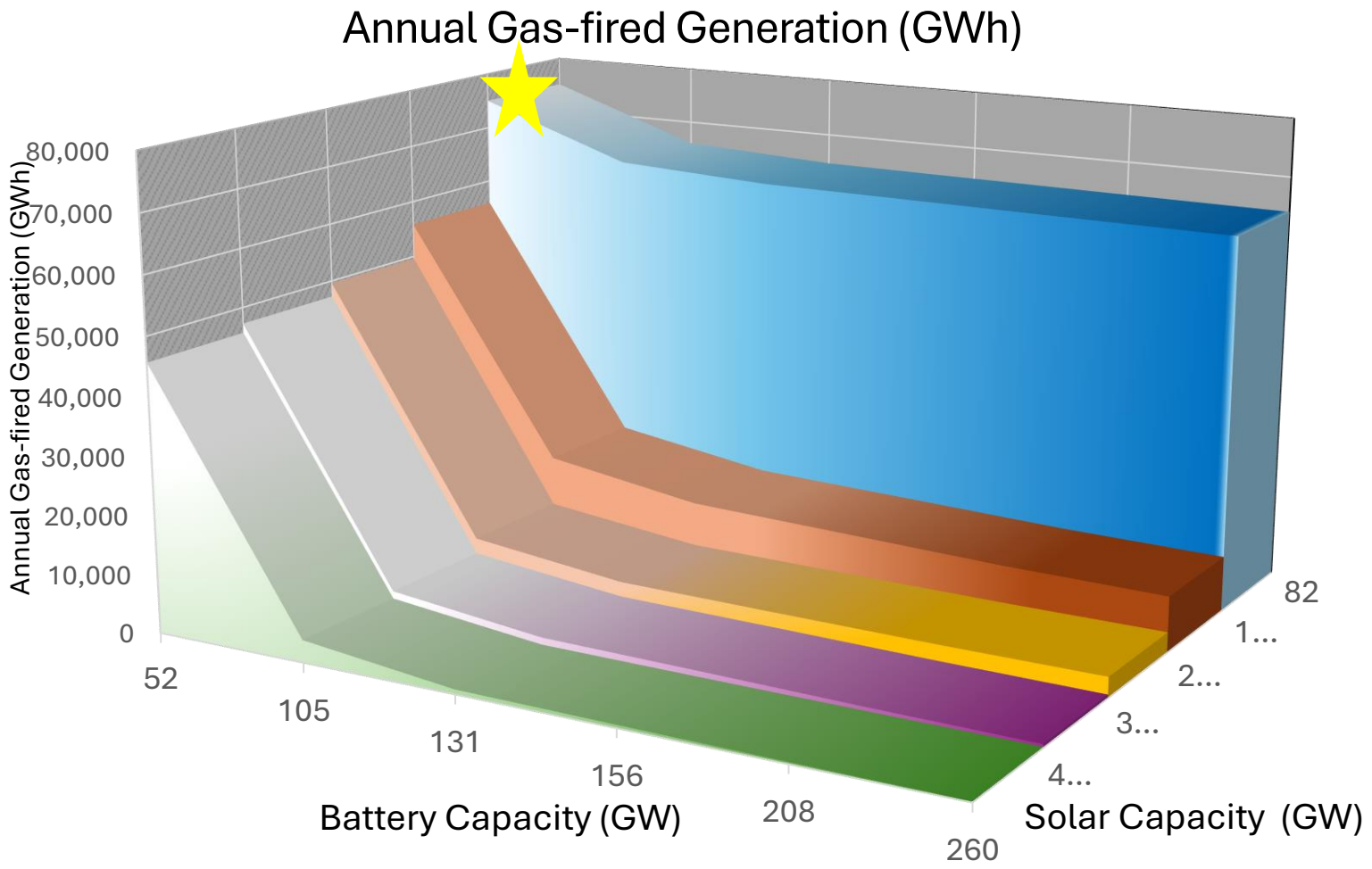
- To answer this question, we start with the current SB 100 Core scenario. We then add storage, along with more solar power to charge it, to see how much of each has to be added to achieve various levels of reduction in gas consumption.
- We do not consider adding more wind power because of the limited number of available, high-quality wind sites beyond those used in the SB 100 Core plan.
- We run HELGA dozens of times with difference combinations of storage and solar. For each possible level of storage and solar installation, HELGA calculates the amount of gas combustion needed to meet the remaining demand and keep the lights on.

Reducing the burning of gas – fossil fuel – renewable sources must be greatly overbuilt .

- In the literature on the use of storage in renewable-focused electric grids, there is little emphasis on the mechanisms that charge the storage, or on the need for overbuilding – excess generating capacity – to charge the storage. There is much discussion of the use of storage to shift consumption from mid-day, when solar output is greatest but demand is low, to the evenings when demand is greatest. There is no discussion of the necessity to continue providing power throughout the night into the early morning, or on days when the sky is overcast and wind is in doldrums (the “dunkelflaute” condition).
- In California’s case, we will be adding more solar power, which will provide excess power beyond what the grid requires to meet the immediate demand. This excess can then charge the batteries so they can be discharged in the evening or on the next cloudy or windless day.

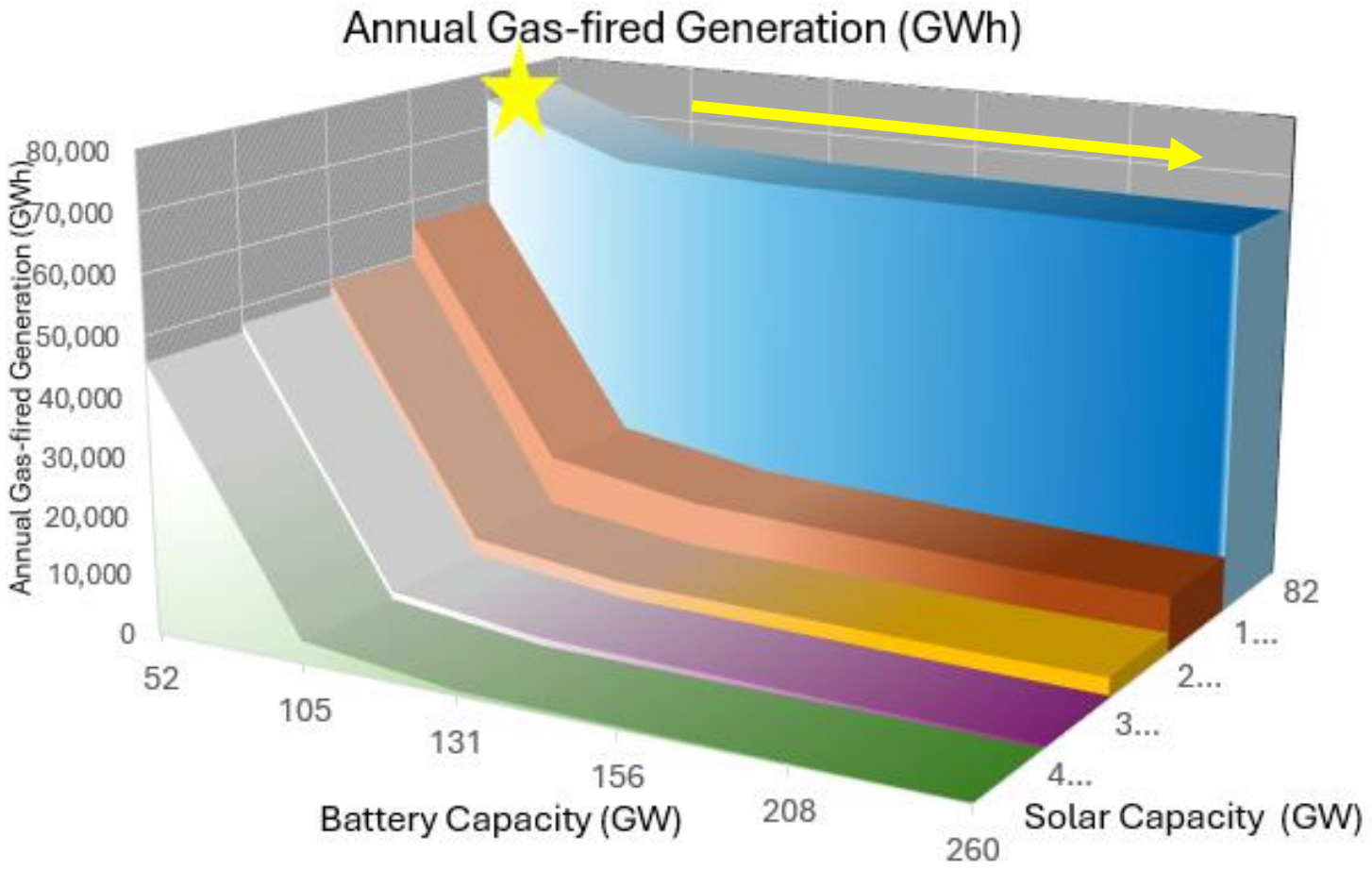
Gas generation can be reduced if increased solar and battery capacities are available.

This graph displays annual gas-fired generation as a function of battery and solar capacities. The ***star*** denotes gas generation of 75,031 GWh under SB 100 Core conditions with 82 GW of solar capacity and 52 GW of battery capacity available in 2045. As greater amounts of solar and battery capacity are introduced, needed gas generation declines. Detailed numerical results are shown in the Appendix, Table 1.



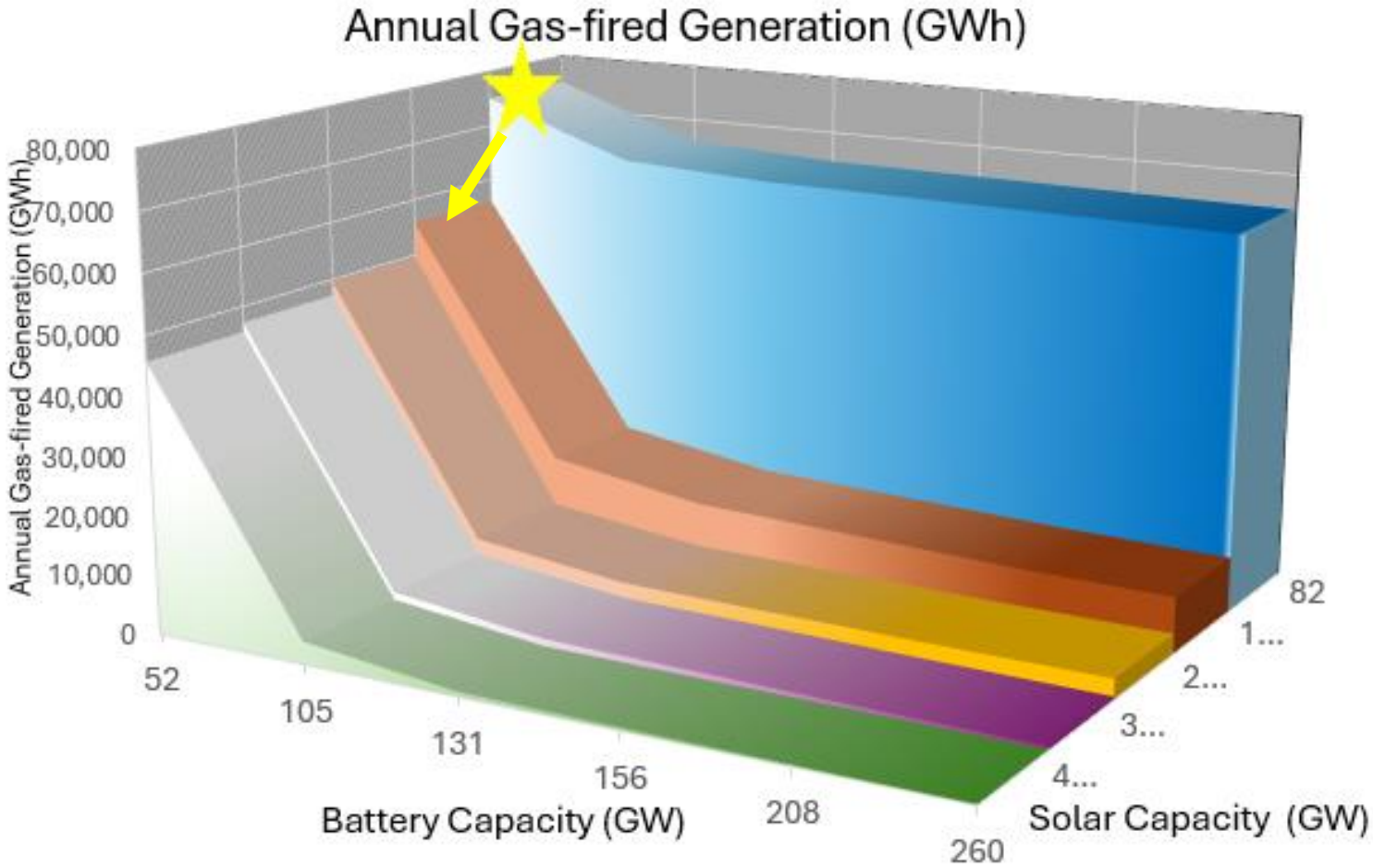
Without additional solar, adding storage has little impact on gas generation.

- First, consider expanding the amount of storage, without adding any solar. If we double the amount of storage to 105 GW, gas generation declines to 66,032 GWh, a 12% reduction. As more storage is added, there is little further reduction in gas use.
- Why is this? With 82 GW of solar, there is not enough excess solar output to fully charge the batteries, so they are of limited usefulness. In fact, on most days, the batteries are not fully charged (See Appendix, Table 2).



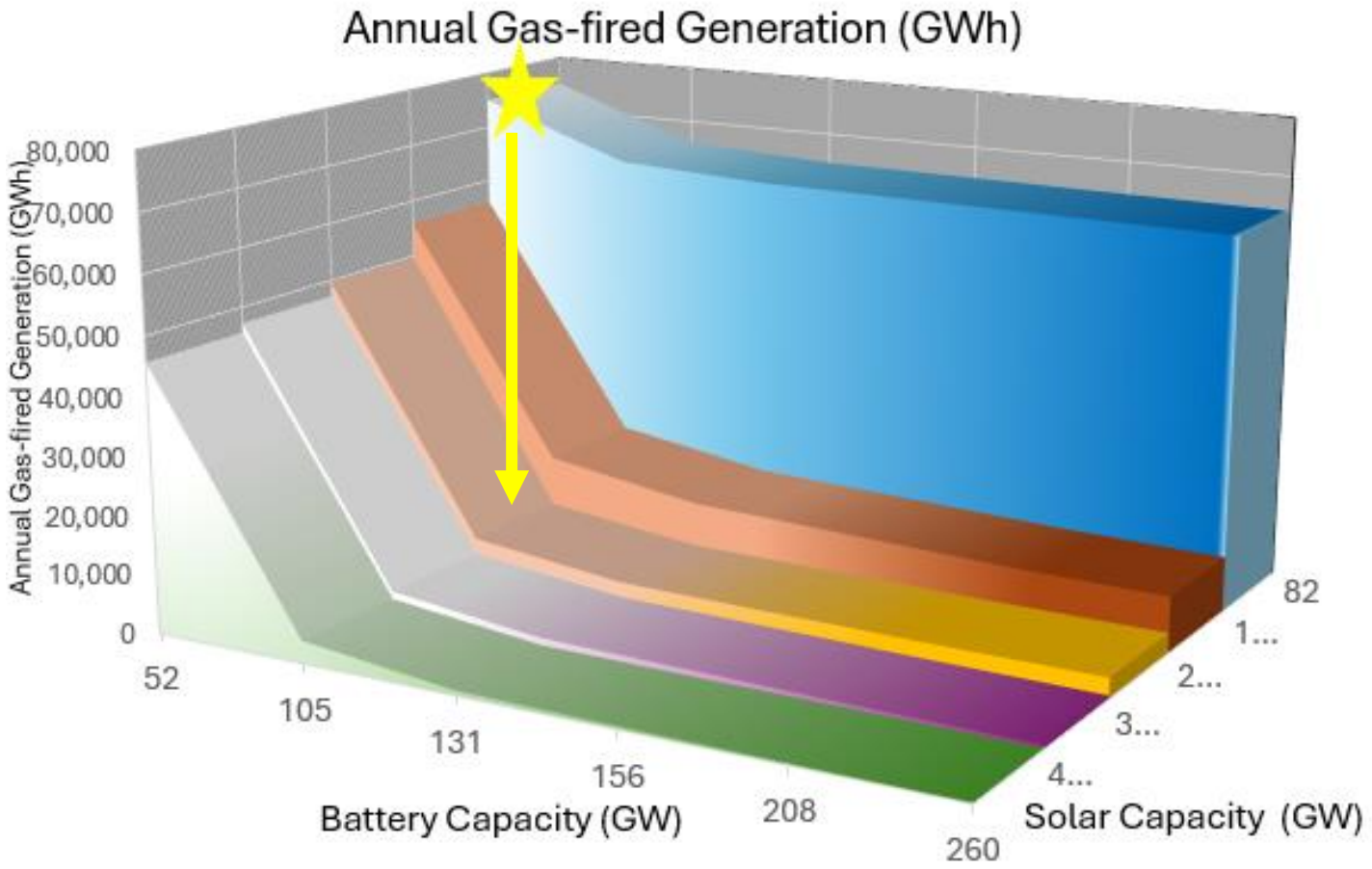
If solar is doubled without adding storage, gas generation is reduced by 26%.

With solar capacity doubled, gas generation is reduced to 55,681 GWh, a reduction of 26%. There are only 31 days when the batteries are not fully charged, so the existing battery capacity becomes more useful.



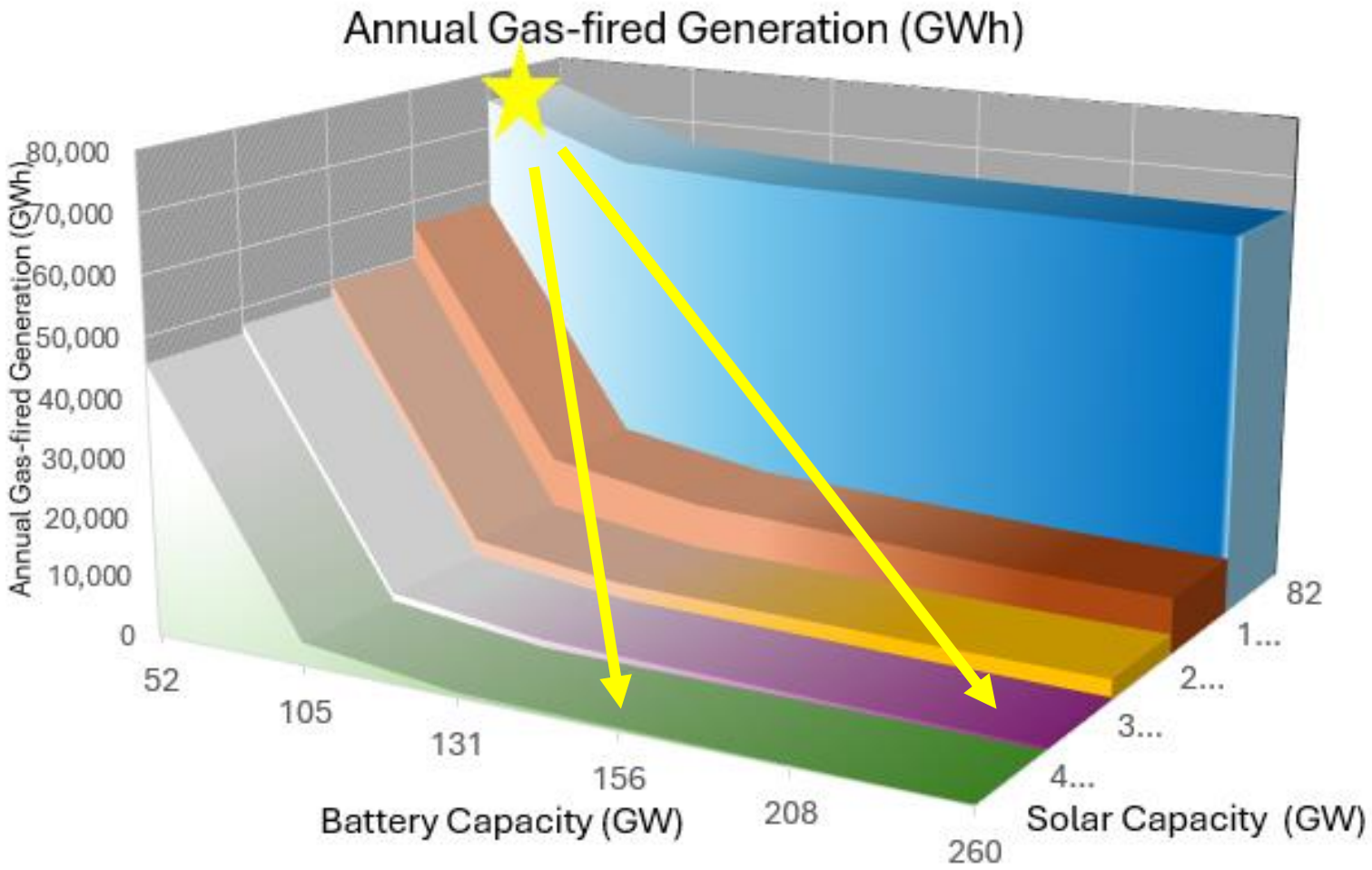
If we want to reduce gas generation by 90%, we must double the battery storage and triple the solar capacity.

Doubling battery storage to 105 GW and tripling the solar capacity to 246 GW reduces gas generation to 7,729 GWh, a 90% reduction from SB 100 Core's value. Still, gas remains essential and is burned on 89 days through the year, mostly overnight (see Table 3).



If we want to reduce gas generation by 99%, we must increase solar or battery storage five-fold.

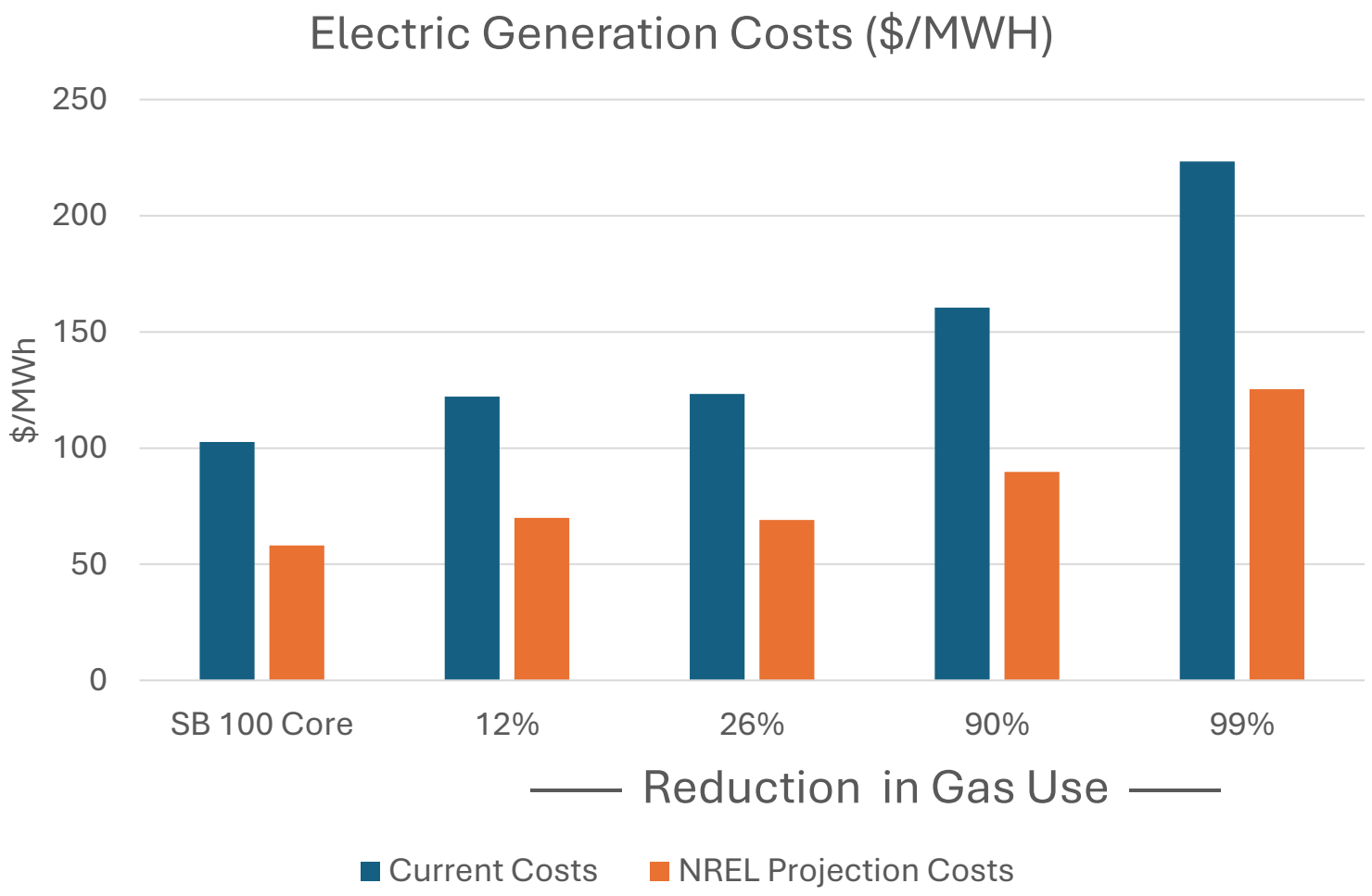
Even a five-fold expansion of both solar and battery storage will not reduce emissions to zero (see Table 1).



Reducing gas-fired generation through increased storage and solar capacity greatly increases cost.

Here are the estimated costs in 2045 of the various scenarios for reducing gas generation. For source cost assumptions, we use Moderate costs in NREL's 2024 Annual Technology Baseline, which assumes a reduction of about 50% from current renewable costs.

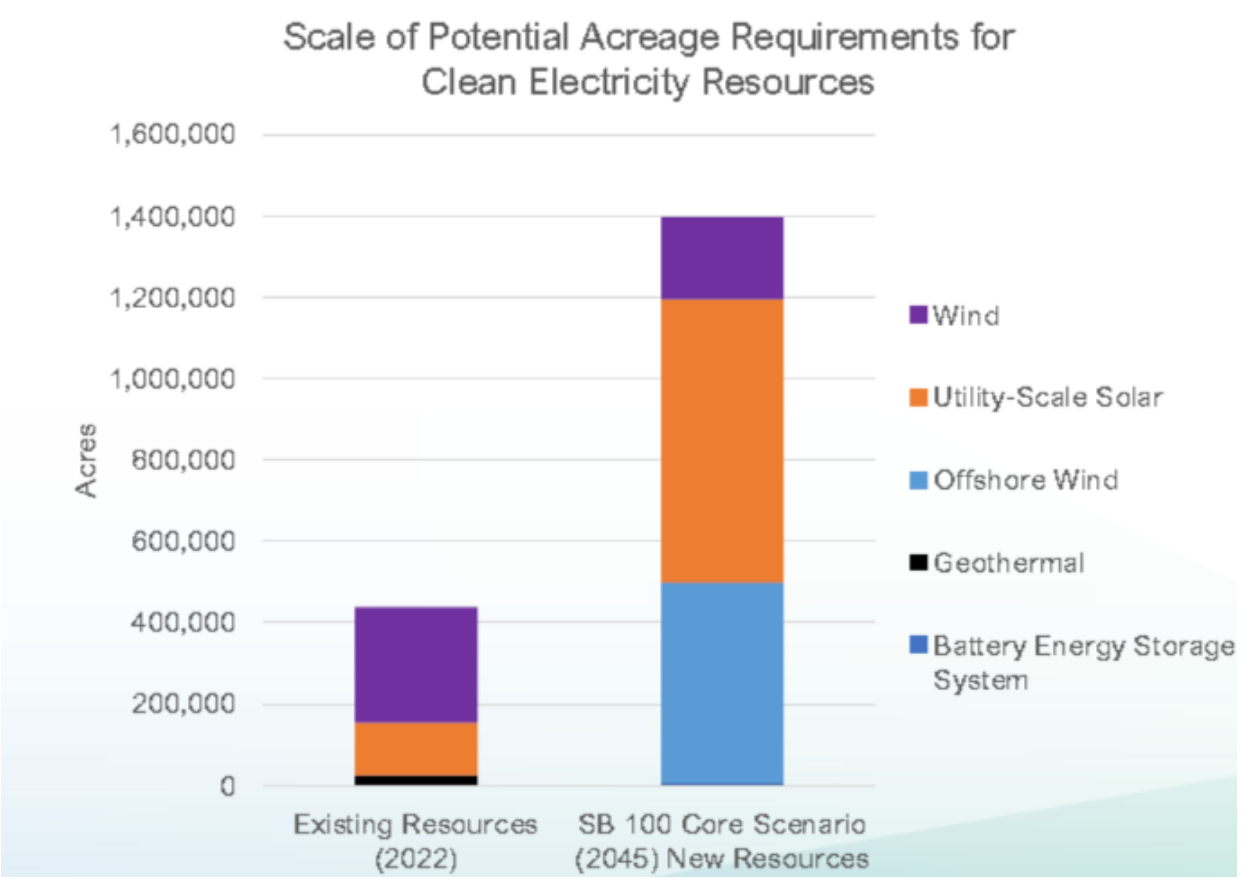
Note: This does not include the cost of additional transmission required for these distributed resources.



Perhaps even greater than the economic impact of added solar and storage would be their land use impacts.

- "[The wind and solar requirements of the SB 100 Core plan] would cover at least 850 square miles, an area larger than the city of Los Angeles, and 18 times the footprint of the city of San Francisco." (California Air Resources Board staff)
- The solar facilities needed to reduce gas use by 90% would occupy an additional area of 1,700 square miles.

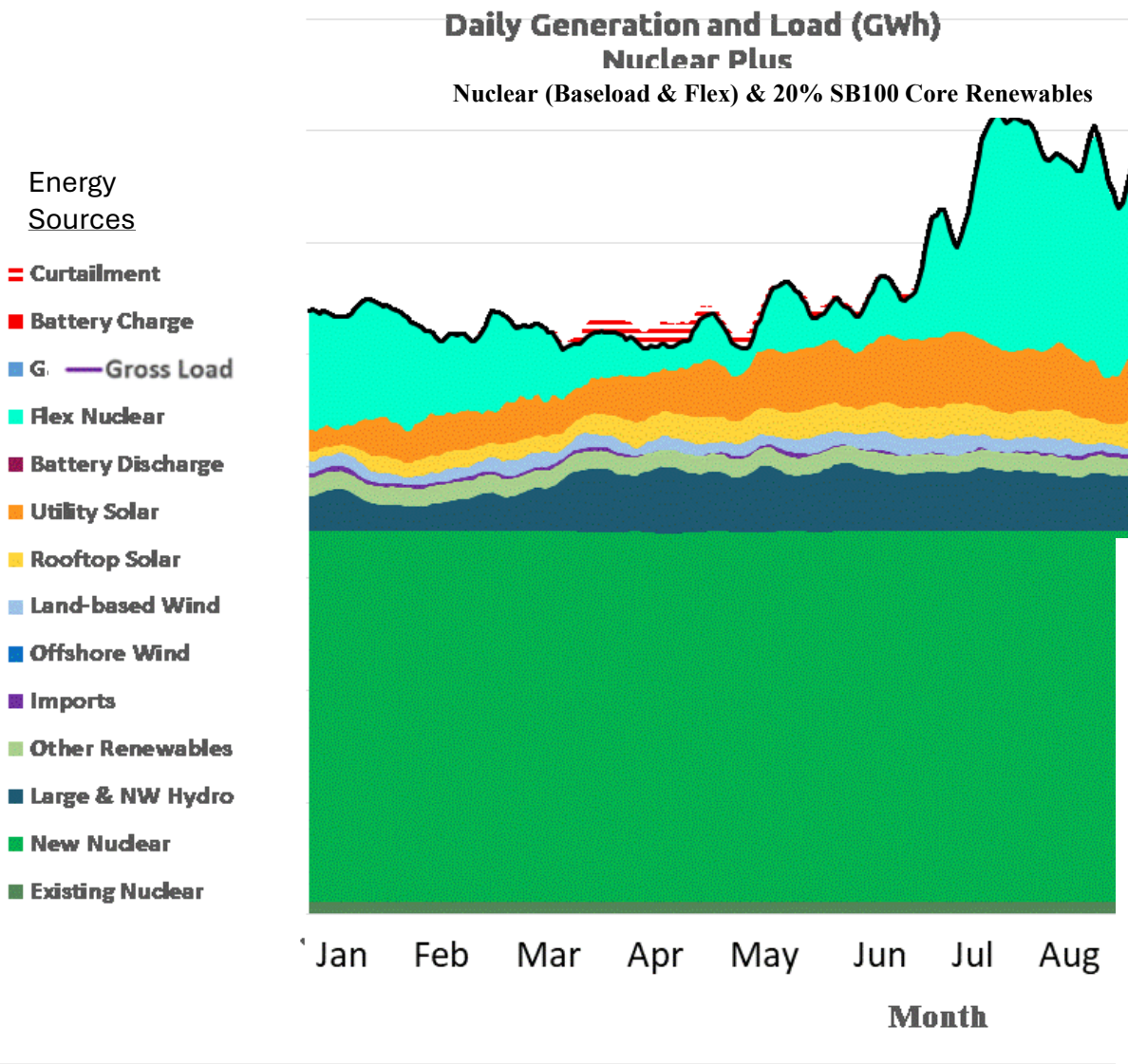
To provide 100% clean electricity by 2045,
the land area and sea space needed for new clean



https://efiling.energy.ca.gov/GetDocument.aspx?tn=254242&DocumentContentId=89603

Nuclear (baseload & flex) with 20% SB100 Core renewables can replace most of the renewables and all of the storage.

There is an alternative to the current all-renewable plan that will cost less and have no emissions. Replace most of the solar, wind, and batteries with a combination of baseload (always-on) nuclear reactors, like that at Diablo Canyon, and add flexible, dispatchable nuclear like Terrapower's Natrium reactor. This approach will be far less destructive to the environment than the vast expansion of solar, wind, and batteries now envisioned.



Electricity Generation
Nuclear (Baseload & Flex) & 20% SB100 Core Renewables
2045

Energy Source	Capacity (MW)	Output (GWh/yr)	Capacity Factor (%)	% Load
Existing Nuclear	1,042	7,734	84.7%	1.9%
New Nuclear	30,000	242,238	92.2%	58.6%
Large & NW Hydro	17,366	30,918	20.3%	7.5%
Other Renewables	4,845	11,807	27.8%	2.9%
Rooftop Solar	7,200	14,397	22.8%	3.5%
Utility Solar	16,000	31,654	22.6%	7.7%
Land-based Wind	2,400	7,481	35.6%	1.8%
Offshore Wind	0	0	0.0%	0.0%
Flex Nuclear	28,000	65,142	26.6%	15.8%
Imports		1,780		0.4%
Load		413,151		100.0%

* Battery charging included in solar and wind generation.

Curtailment	1,978	0.5%
Total Generation Cost ($/MWh)	$ 88.76	

The use of long-duration storage would not change our conclusions.

- We use 4-hour Li-ion batteries in our analysis. Our results would be no different if we used long-duration energy storage (LDES), usually defined as storage which can discharge at full power for more than 10 hours.
- The contribution of storage to the grid depends upon two factors: (1) maximum power (wattage, or energy released per hour), and (2) the total energy (watt-hours) that can be stored. The hourly metric – 4 hours, 10 hours, or 100 hours – is the ratio of these two. Their impact on the grid depends only upon those two separate measures, not their ratio.
- While Li-ion batteries are rated at 4 hours, depending upon how they are connected and used, they can discharge for much longer than that. In our smartphones, they can last for 18 hours and sometimes longer.
- In our modeling, we confirmed that what counts is not the rated hours of the batteries but their peak power (GW) and their total energy capacity (GWh), which can be calculated as the peak power output multiplied by rated hours. Batteries with the same energy capacity yield the same gas generation when operating on the grid, regardless of their rated hours. For instance, gas generation with 246 GW of solar and 52 GW of 8-hour storage has the same impact as with 105 GW of 4-hour storage.
- The real point about long-duration storage is that it has to be less costly than short-duration Li-ion batteries. At present, battery costs are greater than $100 per kwh. Sepulveda et al found that energy capacity costs must be less than $1 per kWh to be a practical asset in decarbonization.

Conclusions

- Adding battery storage, along with solar capacity to charge it, can reduce gas-fired electric generation in a renewable-focused grid.
- Large amounts of both additional battery storage and solar capacity would be needed to achieve even modest reductions in gas-fired generation.
- Added storage and solar capacity would lead to more costly electricity and very significant land use impacts.
- Replacing much of the solar and wind buildup with baseload and flexible nuclear would lead to a less costly, less disruptive grid.
- In short, battery storage not a magic decarbonization bullet. It cannot create an affordable, environmentally-protective, zero-emission grid.

Appendix

Table 1- Gas-fired Generation

Gas-fired Generation (GWh)					
	Battery Capacity (GW)				
Solar (GW)	52	105	156	208	260
82	75,031	66,032	64,490	64,243	64,034
164	55,861	16,285	11,120	10,071	9,512
246	49,597	7,729	4,097	3,681	3,472
328	47,257	5,061	1,517	961	585
410	45,701	3,812	534	325	165

Table 2 - Days Batteries Not Fully Charged

Days Batteries Not Fully Charged					
	Battery Capacity (GW)				
Solar (GW)	52	105	156	208	260
82 GW	172	297	300	303	305
164 GW	31	65	97	104	108
246 GW	10	32	37	39	41
328 GW	5	12	19	20	24
410 GW	2	7	10	12	13

Table 3 - Days Gas Burned

Days Gas Burned					
	Battery Capacity (GW)				
Solar (GW)	52	105	156	208	260
82 GW	362	327	254	252	251
164 GW	357	221	53	43	40
246 GW	317	89	21	18	17
328 GW	315	81	12	6	4
410 GW	315	75	4	3	1