IEc

# DELPHI PANEL ROUND 2 SUMMARY REPORT – RENEWABLE ENERGY GENERATION

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prepared for:

California Energy Commission

Renewable Energy Generation Delphi Panel Experts

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**TABLE OF CONTENTS**

# 1 | INTRODUCTION AND METHODOLOGY

IEc convened a Delphi Panel to seek expert insight on the potential market uptake of technologies and systems funded by EPIC's renewable generation and grid integration grants. This is a key component of forecasting the potential environmental and health benefits of these grants, and one that is best suited to a structured expert consultation. IEc will use technology-specific market uptake estimates developed through this panel to estimate renewable energy generation over time in California associated with this subset of EPIC grants. IEc will subsequently estimate future greenhouse gas (GHG) reductions, air emission reductions, and avoided health impacts from renewable generation deployment and fuel switching. IEc is undertaking a parallel effort focused on EPIC's grants designed to advance building energy efficiency technologies and systems. These resulting benefit estimates will allow CEC to better communicate the value of EPIC's grant investments in these two key research areas.

This document summarizes the input of 11 Delphi Panel experts from the renewable energy generation panel's second round of interviews.[1] We begin by presenting an overview of each technology, including clarifications on questions about the technologies that arose during the Round 1 interviews. We then provide a general summary of the experts' market uptake projections for energy storage (utility-scale and behind-the-meter) and the EPIC-supported technologies. Then, this report presents the projections provided by each expert, for each technology, in five-year increments from 2020 through 2045. Experts provided projections on several quantities: (1) installed capacity and average duration of energy storage, (2) installed capacity for 14 EPIC-supported technologies, and (3) observed capacity factors for eight sub-groups of renewable energy technologies.[2]

Expert projections are summarized in two ways:

1. **Graphics** that chart each expert's estimates of installed capacity and observed capacity factor. These graphics also show the estimated annual amount of energy generated by each technology (or delivered, for energy storage) at each five-year increment, calculated by combining expert projections of installed capacity and observed capacity factors (or average duration, for energy storage). Each graphic includes the mean and median estimate across experts.

   To put the annual energy generated in context, a note will be included in the graphics of energy generated in 2045 in the Round 2 Summary Report that compares the mean estimate for that

[1] To maintain confidentiality, this memo uses letters rather than names to refer to Delphi Panel experts (e.g., Expert A).

[2] Experts reported estimates for observed capacity factors, which account for the actual energy generated relative to the installed capacity. This value may be significantly less than the capacity factor that could be achieved by each technology under ideal circumstances.

technology to a projection of 2045 statewide electricity demand per CEC's February 2020 Utility-Scale Renewable Energy Research Roadmap.[3]

2. **Tables** that consolidate the estimates of all experts in each five-year increment with a small trend line graphic and a summary of the rationale provided by each expert, as well as the mean and median estimate across experts.

[3] Schwartz, Harrison and Brueske, Sabine. 2020. *Utility-Scale Renewable Energy Generation Technology Roadmap.* https://efiling.energy.ca.gov/GetDocument.aspx?tn=231956&DocumentContentId=63818. CEC-300-17-005.

# 2 | TECHNOLOGY OVERVIEW

The technologies funded by EPIC and included in this Panel are described below. Experts were asked to consider market uptake of energy storage and 14 EPIC-supported technologies. As shown in **Exhibit 1**, the 14 EPIC-supported technologies are organized into five groups and eight sub-groups based on type of renewable energy.

### EXHIBIT 1. SUMMARY OF RGI GRANTS BY TYPE OF RENEWABLE ENERGY

| RENEWABLE ENERGY TYPE | SUB-TYPE | TECHNOLOGY |
|---|---|---|
| Photovoltaics (PV) | Solar Tracking | Air-based solar tracking system |
| | | Mechanical solar tracking system for sloped and rolling terrain |
| | Solar Cells | Self-tracking concentrator PV (CPV) |
| | | Silicon PV with copper electrodes |
| Concentrated Solar Power (CSP) | | Sulfur thermal energy storage (TES) |
| | | Solar collectors on plastic supports |
| Biomass | MSW | Gasification of refuse-derived biomass |
| | | Food waste co-digestion with sludge from wastewater treatment plants |
| | Dairy Waste | Anaerobic digestion of dairy manure |
| | Forest Residue | Gasification of forest residue using a rotary gasifier |
| | | Gasification of forest residue using a portable gasifier |
| Geothermal | Conventional | Load-following operation of geothermal power plants |
| | | Lithium recovery from geothermal brine |
| Wind | Pre-2000 Turbines | Remotely dispatchable pre-2000 wind turbines |

Below we describe each of the technologies considered by the Delphi Panel in more detail, including energy storage. During Round 1 interviews, several questions arose on technologies, prompting us to provide clarifications on certain technology descriptions. We included those clarifications in the descriptions below (these are highlighted in *italics*); we asked experts to consider these updated descriptions in refining their market estimates during the Round 2 interviews.

1. **Energy storage**: For the State to maximize the potential of existing renewables and enable greater penetration of renewables on California's electric grid, energy storage (both utility-scale and behind-the-meter) will play a role in ensuring reliability while minimizing curtailment of such variable resources. The amount of energy storage deployed on the grid each year influences the market uptake potential for EPIC-supported technologies.

*Expert projections for utility-scale storage should consider all forms of energy storage, not just batteries.*

*Expert projections for behind-the-meter storage should consider all forms of residential, commercial, and industrial distributed storage, whether or not they are exclusively customer-owned. This category can include installations that are dispatchable by the utility through a cost-sharing arrangement with the customer.*

2. **Air-based solar tracking system**: Sunfolding, Inc. is working to commercialize a simpler, air-powered tracker using high-volume, low-cost manufacturing. The air-powered tracker developed by Sunfolding has only three components, rather than the 21 components in traditional trackers. The simpler single-axis tracker will reduce the levelized cost of energy (LCOE) by making solar power plants easier to design, faster to install, and smoother to operate.
3. **Mechanical solar tracking system for sloped and rolling terrain**: Under a 2015 SunShot award, Nevados Engineering designed and built a pilot of a single-axis "all-terrain tracking" (ATT) system that can fit on sloped and rolling terrain. The EPIC project allowed Nevados to create software that can provide accurate generation estimates, develop a new control system ("All Terrain Controls" or ATC) for operating on non-flat terrain, modify the design, and test improvements to the tracking system to enhance performance and prepare the system for production.
4. **Self-tracking concentrator PV (CPV)**: Current silicon PV modules have low efficiency, converting only about 16 to 20 percent of the sun's power into electricity. CPV has long promised higher efficiency and more cost-effective solar energy generation, but cost and complexity has prevented them from achieving significant market installations. This project researched the potential to develop a low-cost self-tracking CPV consisting of a thin layer of fluids that passively responds to the changing solar angle.
5. **Silicon PV with copper electrodes**: Ninety-eight percent of all PV cells manufactured worldwide use silver for metallization. Copper (Cu), with its conductive properties and at one-eighth the cost of silver, is an attractive alternative. However, implementation of Cu patterning on silicon is currently cost-prohibitive. Sunpreme, Inc. researched and developed a lower-cost Cu patterning method for solar PV cells using technologies from printed circuit board manufacturing.

   *This technology could be compatible with other emerging PV technologies such as bifacial and perovskite cells.*

6. **Concentrated Solar Power (CSP) with sulfur thermal energy storage (TES)**: This project researched and developed a thermal storage system using elemental sulfur as a storage medium to replace existing thermal energy storage technologies, such as molten salts, for utility-scale applications. Elemental sulfur is an ideal thermal storage medium because it is abundantly available in nature at a very low cost, is chemically stable over a wide temperature range and has a moderate heat capacity to store high-grade thermal energy.
7. **CSP with solar collectors on plastic supports**: The dominant materials used in CSP construction to mount and aim glass mirrors are steel and concrete, which, while durable, are expensive. To lower the cost of CSP, Hyperlight Energy developed a solar reflector with flat glass mirror slats mounted on water-borne, extruded plastic tubes connected to an actuator, which controls the alignment of the mirrors and tracks the sun through the day. Hyperlight Energy received funding for two related research and development efforts: (1) refining the manufacturing and

installation process for the reflector components and (2) optimizing the receiver subsystem to improve thermal efficiency.

8. **Gasification of refuse-derived biomass**: Taylor Energy designed, constructed and tested a pilot-scale modular shockwave gasification technology that uses pulse detonation to intensify the gasification of refuse-derived biomass (RDB) recovered from municipal solid waste (MSW). The project offers opportunities to improve the economics and thus enable the development of community-scale bioenergy generation facilities in California.

9. **Food waste co-digestion with sludge from wastewater treatment plant**: This project developed and tested strategies to reduce the cost of co-digestion at wastewater treatment plants (WWTPs) by adding food waste and restaurant fats, oil, and grease (FOG). Specifically, the project developed a two-step process to lower the cost of food waste pre-processing at waste management facilities and then a strategy to lower the mass of dewatered cake solids. The project offers opportunities to increase the diversion of food waste from landfills, recover digester gas as a renewable energy source and reduce greenhouse gas emissions.

   *The technical potential for electricity generation from wastewater sludge in California is estimated to be 125 MW. However, because this technology combines the recoverable energy from both wastewater sludge and food waste/FOG, co-digestion has a higher technical potential than wastewater treatment alone. The grantee estimates roughly 200 MW of potential electricity generation from co-digestion.*

10. **Anaerobic digestion of dairy manure**: Dairies use large quantities of both electricity and natural gas for their operations. According to the California Air Resources Board (CARB), dairies account for about 60 percent of greenhouse gas emissions from the agricultural sector. California Bioenergy LLC conducted a set of studies to examine the performance of digesters in California. The project consisted of three digester projects similar in size (4,000-6,000 cows), housing type (free stalls), and digester type (covered lagoons). The projects operated for a period of 12 months from which data on performance and technical characteristics was compiled using the digester Supervisory Control and Data Acquisition (SCADA) data collection system, onsite collection of gas and liquid samples, and laboratory analysis. The project team then quantified the biomethane available per cow at California dairies, the expected electrical production from that biomethane, and the total statewide potential for the technology.

11. **Rotary gasification of forest residue**: Forest biomass consists of woody residue, e.g. dead or dying trees. If not collected, these materials present a serious wildfire risk, but forest bioenergy projects could provide communities with a business strategy to fund collection, transportation, and management of forest residues. Existing community-scale biomass gasification systems in California, however, use downdraft gasifiers, which require complex, multi-step cleanup systems to remove tar and particulate matter. The project team developed a new approach called rotary gasification, based on a common approach to thermal processing called torrefaction. Combined with a thermal oil heater and an organic Rankine cycle (ORC) generator, system maintenance cost and downtime were minimal, and the system met emissions targets when combined with the rotary gasifier.

    *According to the grantee, capacity factor for organic Rankine cycle systems tends to be relatively high (80-90%) for existing installations, primarily in Europe.*

12. **Portable gasification of forest residue**: This project designed, tested, and demonstrated a standardized, portable modular biomass gasification electrical generator (“Powertainer”). A

portable gasifier for forest residue offers opportunities to generate electricity and reduce greenhouse gas emissions for commercial and institutional parties that are responsible for forest thinning, which typically rely on expensive prescribed burns to manage forest biomass that otherwise present a serious wildfire risk.

13. **Load-following operation of conventional geothermal**: While The Geysers plants are already being used for load following in CAISO real-time markets, the current nominal ramp rate limit is 2-4 MW/minute; operational data indicate that much faster ramp rates are possible. To increase flexible generating capabilities of geothermal facilities at The Geysers, this project defined the existing operating limits of The Geysers geothermal resources, developed and tested upgrades to the steamfield and power equipment to support more reliable cyclic operations and expansion of operating limits, and developed an integrated numerical framework for the optimal control of a steamfield under economic curtailment.

    *Expert projections should include deployment of load following operation for both new and existing installations. The existing fleet of conventional geothermal in California is 2.7 GW.*

14. **Conventional geothermal with lithium recovery from geothermal brine**: Demand for lithium is increasing due to the growth in markets for lithium-ion batteries used in portable devices, electric vehicles, and grid storage applications. This project developed a low-cost process for the rapid and selective extraction of lithium from geothermal brines using two technologies: (a) a new selective high capacity absorbent and (b) a solid-phase extraction process.

    *Expert projections should include deployment of load following operation for both new and existing installations. The existing fleet of conventional geothermal in California is 2.7 GW.*

15. **Remotely dispatchable pre-2000 wind turbines**: California is home to several thousand legacy wind turbines installed in the 1980s and 1990s with low generating capacities (below 300 kw per turbines). The control systems on pre-2000 turbines are rudimentary. As a result, turbines remain online during periods of oversupply, contributing to grid instability and continuing to generate even when the price of electricity is negative. During periods without wind, the turbines remain energized, costing owners up to $100,000 per year. This project developed and tested a prototype of a remote communication and control system that would allow the turbines to respond to grid operations, thereby allowing the turbines to continue to produce low-carbon electricity without incurring high costs.

    *In considering the potential market for this technology, experts should keep in mind that there are between 4,000 to 6,000 pre-2000 turbines in California. According to the grantee, the total reported generation capacity for these turbines is at least 565 MW. There are additional turbines, however, for which generating capacity data are not reported.*

# 3 | DELPHI PANEL SUMMARY

The Delphi Panel asked experts to consider the scale and timing of market uptake for energy storage and each of the 14 EPIC-supported technologies. Overall, market uptake estimates and rationales provided for the estimates were highly variable across experts, though the range of variability narrowed between Round 1 and Round 2. Estimated installed capacity for the same technology in 2045 ranged from 15,000 to 60,000 MW for the largest variation and 0 to 100 MW for the smallest.[4]

A common measure of the amount of variation or dispersion of a set of values is the standard deviation. A decrease in the standard deviation between Round 1 and Round 2 indicates greater convergence in the panelists' estimates (an increase in the standard deviation indicates greater divergence). The change in standard deviations between Round 1 and Round 2 installed capacity (MW) estimates saw a >1% decrease in standard deviation (i.e., convergence) between Round 1 and 2 for 69 estimates, while 2 estimates saw a >1% increase in standard deviation (i.e., divergence). A quarter of the estimates (25) had a change in standard deviation of 1% or less. The percent change in standard deviation ranged from -78% to 20%; the average percent decrease was 32%, and the average percent increase was 14%. Standard deviations across technologies also generally increased for estimates in later years. **Exhibit 1** presents the change in standard deviation between Round 1 and Round 2 market uptake estimates.

### EXHIBIT 1. PERCENT CHANGE IN STANDARD DEVIATION OF INSTALLED CAPACITY (MW) ESTIMATES

| | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 |
|---|---|---|---|---|---|---|
| Utility scale storage | 0% | 0% | -4% | -4% | -6% | -11% |
| BTM storage | 20% | 0% | -2% | -3% | -5% | -10% |
| Air-based solar trackers | -65% | -44% | -23% | -20% | -17% | -10% |
| Mechanical solar trackers for sloped/rolling terrain | -50% | -30% | -45% | -37% | -29% | -22% |
| Self-tracking concentrator PV | -60% | -52% | -60% | -60% | -60% | -60% |
| Silicon PV with copper electrodes | 0% | -4% | -43% | -1% | -50% | -70% |
| CSP with sulfur thermal energy storage | 0% | 0% | -78% | -78% | -73% | -69% |
| Solar collectors on plastic supports | 0% | 0% | 0% | 0% | 0% | 0% |
| Gasification of refuse-derived biomass | -66% | -21% | -9% | -19% | -17% | -65% |
| Food waste co-digestion with wastewater sludge | 8% | 0% | -7% | -49% | -33% | -2% |
| Anaerobic digestion of dairy manure | -2% | -2% | -5% | 0% | 0% | -1% |
| Rotary gasification of forest residue | 0% | -46% | -54% | -57% | -66% | -67% |
| Portable gasification of forest residue | 0% | 0% | -1% | 0% | -1% | -1% |
| Conventional geothermal with load following | -2% | -5% | -10% | -20% | -20% | -19% |
| Conventional geothermal with lithium recovery | 0% | 0% | -1% | -1% | -2% | -2% |
| Remotely dispatchable pre-2000 wind turbines | -49% | -51% | -48% | -47% | -48% | -51% |

[4] The largest variation refers to utility-scale energy storage; the largest variation among the 14 EPIC-supported technologies ranged from 500 to 25,000 MW. Experts offered estimates for all technologies; the exception is behind-the-meter storage, for which two experts declined to offer an estimate indicating that the technology category was outside their area of expertise.

Capacity factor projections experienced less change between Round 1 and Round 2; the majority of estimates (36 of 48) saw a change in standard deviation between Round 1 and Round 2 of 1% or less. Twelve estimates saw a >1% decrease in standard deviation between Round 1 and 2, while no estimates saw a >1% increase in standard deviation. **Exhibit 2** below presents the change in standard deviation between Round 1 and Round 2 capacity factor estimates.

### EXHIBIT 2. PERCENT CHANGE IN STANDARD DEVIATION OF CAPACITY FACTOR ESTIMATES

| | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 |
|---|---|---|---|---|---|---|
| Utility scale storage (hrs) | 0 | 0 | 0 | 0 | 0 | 0 |
| BTM storage (hrs) | 0 | 0 | 0 | 0 | 0 | 0 |
| Solar tracking | 0% | 0% | -1% | -1% | -1% | -1% |
| Solar PV | 0% | 0% | 0% | 0% | 0% | 0% |
| Concentrated solar power | 0% | 0% | 0% | 0% | 0% | 0% |
| Municipal and solid waste | 0% | 0% | 0% | 0% | 0% | 0% |
| Dairy waste | 0% | -1% | -1% | 0% | 0% | 0% |
| Forest waste | 0% | -1% | -1% | -2% | -2% | -3% |
| Conventional geothermal | 0% | -1% | -1% | -2% | -2% | -2% |
| Remotely dispatchable pre-2000 wind turbines | 0% | 0% | 0% | -6% | -6% | -6% |

Experts generally agreed that California will have tens of thousands of MW of **Utility-Scale Energy Storage** by 2045. The market for **Behind-the-Meter Energy Storage** is also expected to grow significantly, although it will be a fraction of the overall storage market.

There are a few technologies that experts generally agree are *likely* to be deployed widely, including **Air-based Solar Trackers** and, to a lesser degree, **Mechanical Solar Trackers, Conventional Geothermal with Load Following, and Conventional Geothermal with Lithium Recovery**.

Experts largely agreed on several technologies that were *unlikely* to achieve substantial market deployment. These technologies include the **Self-tracking Concentrator PV (CPV)**, **Silicon PV with Copper Electrodes**, **CSP with Sulfur Thermal Energy Storage**, **CSP Solar Collectors on Plastic Supports** and **Remotely Dispatchable Pre-2000 Wind Turbines**.

While expert projections for bioenergy technologies are relatively small – on the order of 100 to 300 MW by the year 2045 for **Gasification of Refuse-Derived Biomass**, **Food Waste Co-digestion**, **Anaerobic Digestion**, and **Rotary Gasification of Forest Residue** – a number of experts expressed support for EPIC's investment in these technologies, noting that the primary value of these technologies is waste management and also reductions in greenhouse gas emissions. Experts further described energy generation as a secondary byproduct of these projects, which in some cases, serves as a means of making these types of projects financially viable.

Results changed as experts considered the market uptake assessments of their peers in Round 2; this often served to narrow the range and did not substantially affect average estimates for most of the EPIC-supported technologies. Of the 14 EPIC-supported technologies, the average installed capacity estimates for 2045 changed substantially (i.e., by more than 40 percent) for six technologies: **Self-tracking CPV, Silicon PV with Copper Electrodes**, **CSP with Sulfur Thermal Energy Storage**, **Gasification of Refuse-Derived Biomass, Rotary Gasification of Forest Residue** and **Remotely Dispatchable Pre-2000 Wind Turbines;** 2045 estimates *decreased* by 59.8%, 40.6%, 54.5%, 43.7%, 54.0% and 49.9%, respectively.

**Exhibit 3** provides a more detailed summary of the Delphi Panel results for energy storage and each of the 14 EPIC-supported technologies reviewed by experts.

**EXHIBIT 3. SUMMARY OF ROUND 2 RESULTS BY TECHNOLOGY**

| TECHNOLOGY | SUMMARY OF ROUND 2 RESULTS |
|---|---|
| Storage: Utility-scale | Experts generally agree that the amount of installed storage will increase steadily through 2045, but with a wide range of final installed capacity (15-60 GW), and none reaching the extent of storage needed to meet SB-100 targets (85 GW), according to the Utility-Scale Research Roadmap. Experts also agree that storage is important in a high-renewables grid, while several noted other solutions like energy efficiency or participation in energy imbalance market to take advantage of different system conditions.<br><br>Duration estimates increase somewhat, especially in later years, to roughly 8 hours in 2045. |
| Storage: Behind-the-Meter (BTM) | BTM and distributed storage will be a smaller market than utility-scale, with the average estimate of 11.7 GW by 2045. Experts agree that batteries will be higher cost for smaller installations, although costs will come down over time. Factors driving installations include: the need for backup power for homes and businesses, and the opportunity to shave peak demand. There is disagreement among experts over the extent to which BTM storage will be driven by residential or C&I customers.<br><br>Duration estimates increase somewhat over time, especially from 2020 through 2035, but are lower than utility-scale storage duration throughout. Average duration estimate is 5 hours in 2045. |
| PV: Air-based Trackers | Average estimate is 11.4 GW by 2045. Experts generally agree that the tracker's simplicity to install and maintain is promising. Many experts think the cost is competitive or can be reduced to be competitive.<br><br>Experts note the prevalence of tracking systems for new solar installations in CA, but differ on how much solar will be installed, and on whether the air-based tracker can work on sloped terrain. Several experts predict widespread adoption of the air-based tracker if the technology is produced at scale, but others doubt air-based trackers can capture significant market share from incumbent/rival technologies. |
| PV: Mechanical Trackers | Average estimate is 4 GW by 2045 (median: 1.5 GW). Several experts see a small market for trackers geared toward sloped/rolling terrain in CA; others see potential for increased adoption as flat land becomes scarcer and the tracking technology for sloped terrain improves. Experts cite uncertainties around the early stage of development, accuracy and cost, and note competition with existing trackers. |
| PV: Self-tracking CPV | Average estimate is 14 MW by 2045, although the median estimate is 0 MW by 2045. Most experts (10 of 11) indicate that the technology is not and will not be cost-competitive. Some experts further note the small potential market (rooftops), early stage of the technology, and higher risks than competing solar options. |
| PV: Copper electrodes | Average estimate is 6.5 GW by 2045, although the median estimate is 600 MW by 2045. Many experts agree that the technology is promising, especially if the technology could be compatible with trackers or fixed-tilt installations, along with other emerging PV technologies such as bifacial and perovskite cells. However, experts generally project zero to little market uptake because the company was unable to secure investment and stopped working on the project.<br><br>Several experts suggest that another company could, if given access to the IP, develop and bring the technology to maturity. Some of these same experts project zero or limited market uptake given what has transpired to date, while four experts project widespread uptake. A few experts predict limited uptake due to the time required to scale the technology coupled with the belief |

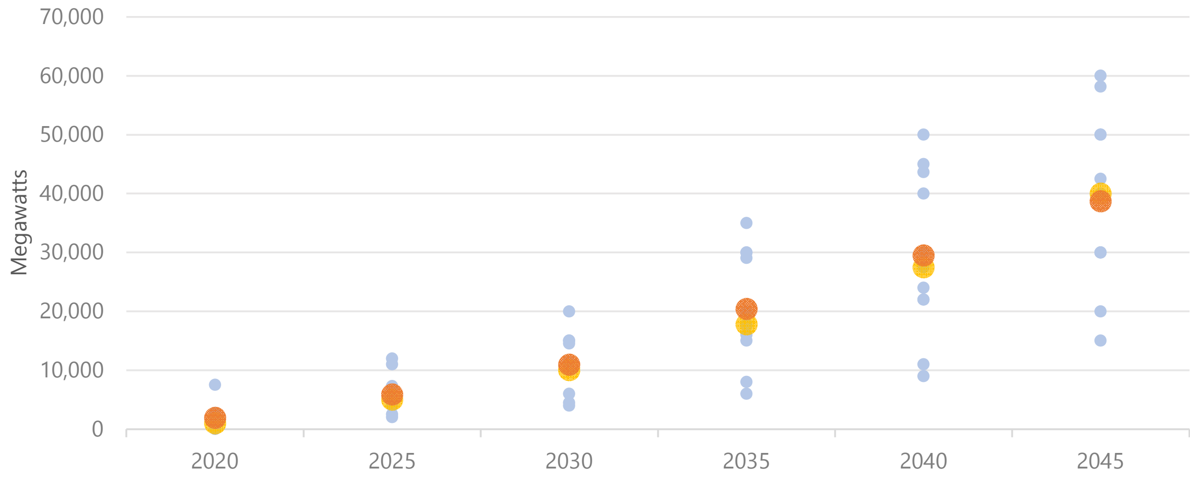
| TECHNOLOGY | SUMMARY OF ROUND 2 RESULTS |
|---|---|
| | that other technologies will surpass it in the future. Competition with existing incumbents is also noted as a barrier to larger-scale deployment. |
| CSP with sulfur TES | A majority of experts project zero installed capacity for CSP with sulfur TES. Concerns include cost relative to PV/battery installations and inherent challenges to CSP, such as siting and environmental issues. Projections by several experts are driven by skepticism that CSP has a viable future in California due to high cost, strict siting requirements, and the mixed performance of past project installations. |
| CSP solar collectors with plastic supports | A majority of experts project zero installed capacity for CSP solar collectors on plastic supports. Consensus is that there may be a strong niche for this technology in low-temperature applications but not in electricity generation. Similar to sulfur TES, projections by several experts are driven by skepticism that CSP has a viable future in California. |
| Gasification of refuse-derived biomass | Average estimate is 151 MW by 2045. Experts generally describe the project as a waste management project where energy production is a by-product. Experts cite high cost and feedstock availability as barriers to larger scale deployment. |
| Food waste co-digestion | Average estimate is 134 MW by 2045. Experts describe the project as a small niche technology with deployment driven largely by the value of co-benefits (e.g., waste management and reduction of greenhouse gas emissions) rather than the value of energy production. Experts cite high cost and feedstock availability as barriers to larger scale deployment. |
| Anaerobic digestion of dairy manure | Average estimate is 103 MW by 2045, as compared to a stated technical potential of 198 MW. Experts generally describe the project as a promising strategy to reduce methane, especially assuming that restrictions on methane emissions are forthcoming. Some experts, however, express concerns about the ability of cattle operations to obtain needed financing. |
| Rotary gasification of forest residue | Average estimate is 78 MW by 2045. Market uptake projections are mixed with some experts projecting very little deployment (0 to 5 MW) by 2045, and other experts indicating some deployment is possible due to the secondary benefits associated with fuels management. Experts cite uncertainty with the availability of feedstock driven by location and transportation costs, uncertainty of the size and stability of the biochar market, and potential environmental permitting and interconnection challenges. |
| Portable gasification of forest residue | Average estimate is 19 MW by 2045. Experts cite uncertainty with the availability of feedstock driven by location and transportation costs, uncertainty of the size and stability of the biochar market, and potential environmental permitting and interconnection challenges. Multiple experts indicate that the technology is still relatively immature and additional development and testing is needed. |
| Conventional geothermal with load following | Estimates for geothermal with load following increase slowly to an average of 2.4 GW in 2045. Experts generally agree that if incentives such as ancillary service revenues are in place, then there will be retrofits to existing geothermal installations to increase flexible dispatch capabilities. |
| Conventional geothermal with lithium recovery | A majority of experts estimate installed capacity for geothermal with lithium recovery of 1 GW or less by 2045, with an average estimate of 1.4 GW by 2045. Many experts note uncertainty regarding further technology development as an additional limiting factor. |
| Remotely dispatchable pre-2000 wind turbines | Average estimate is 54 MW by 2045. Due to the age of these turbines (a minimum age of 20 years), most experts thought that decommissioning and replacing these older turbines would be more valuable than retrofitting these existing turbines to be remotely dispatchable. With that said, most experts predict some short-term value for this technology that could result in the retrofit of a subset of turbines installed in the late 1990s. |

## 4 | EXPERT PROJECTIONS BY TECHNOLOGY

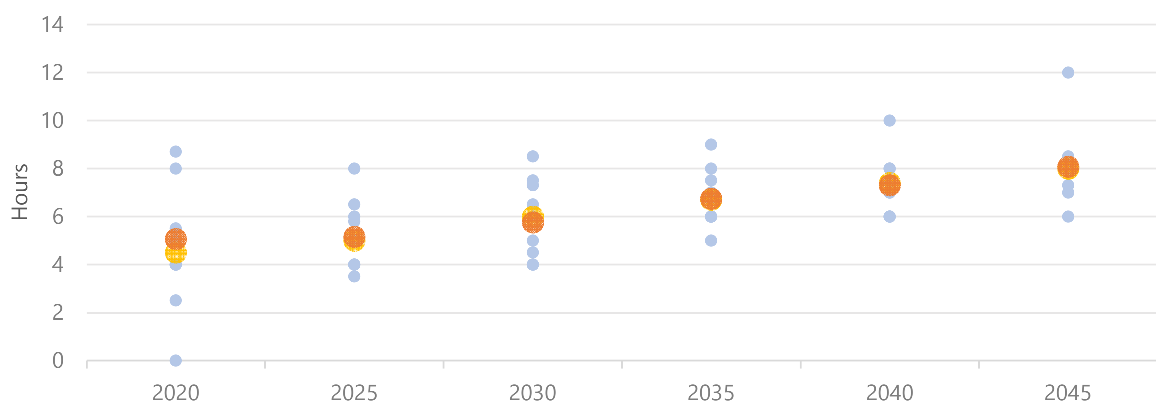
This section contains the graphics and tables that consolidate the year-by-year estimates across experts; when experts provided a range, the tables and graphics rely on the mid-point of the expert's stated range. The tables also include a small trend line graphic and a summary of the rationale provided by each expert. These graphics and tables also present the mean and median estimate across experts in each year.

- In the graphics, the mean and median estimate are presented in orange and yellow, respectively.
- In the tables, the mean and median estimate for each year are presented in **bold** at the top of each table. Data are highlighted if they are the lowest (yellow) or highest (green) estimate for each year.

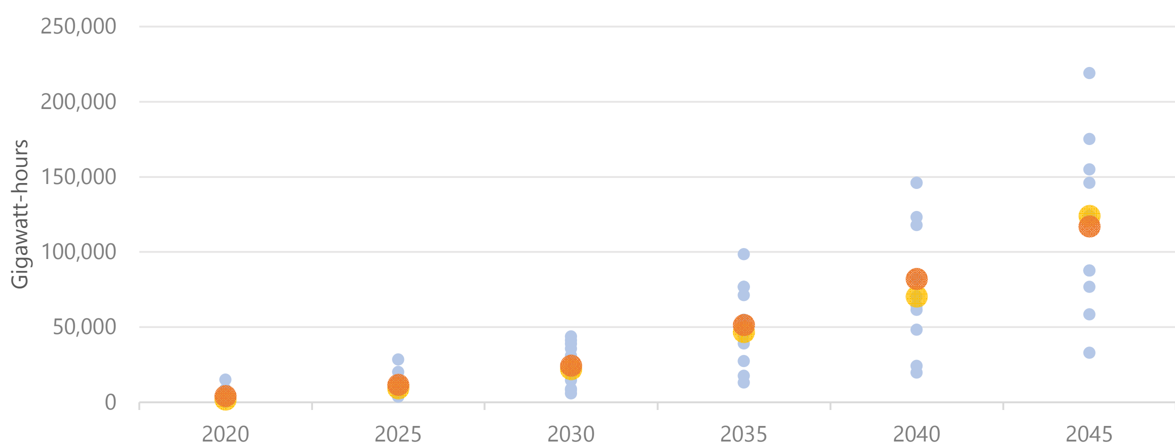
Estimates of installed capacity for utility-scale energy storage in California




Estimates of average duration for utility-scale energy storage in California

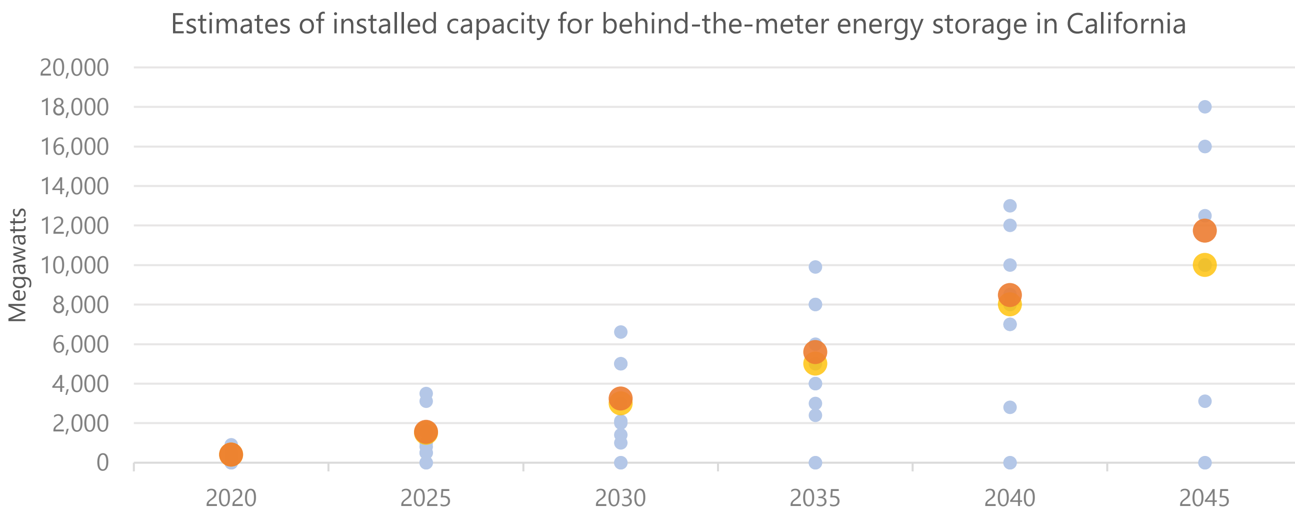


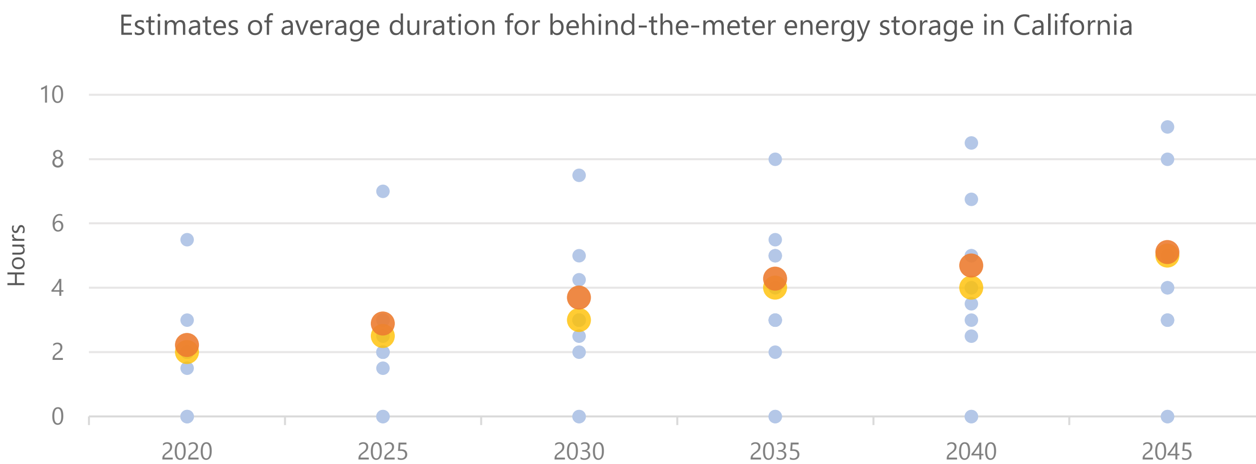

Calculated estimates of annual energy delivered for utility-scale energy storage in California, assuming 1 cycle per day

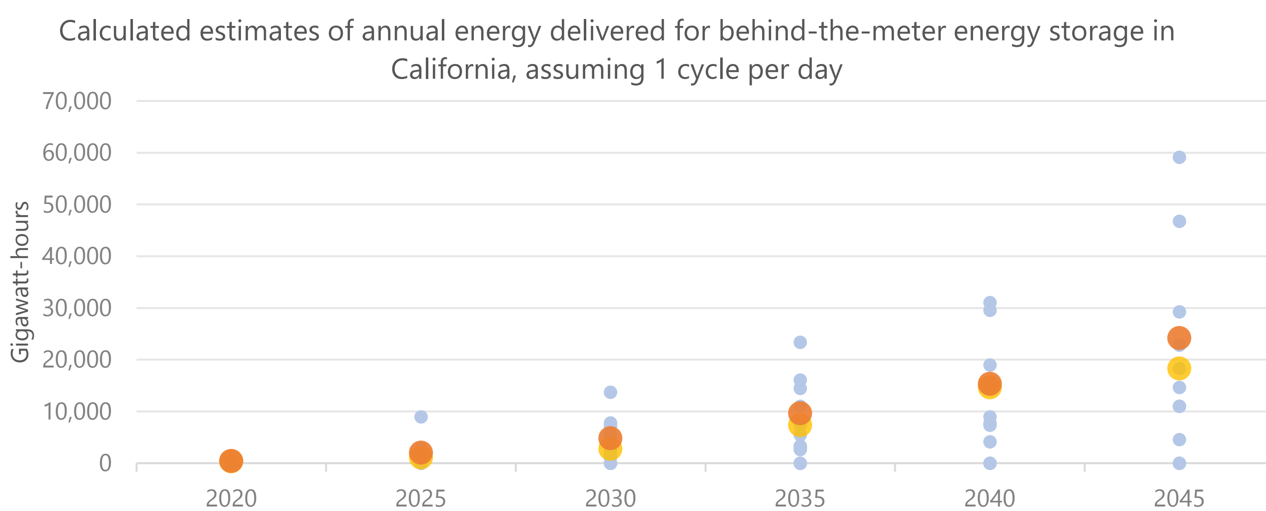



Estimates of annual energy delivered are calculated by combining expert estimates of installed capacity and average duration in each five-year increment.

## ENERGY STORAGE




Estimates of annual energy delivered are calculated by combining expert estimates of installed capacity and average duration in each five-year increment.

The mean estimate across experts is in orange and the median estimate is in yellow.

## ENERGY STORAGE

### Installed Capacity (MW): Utility-Scale Storage and Duration (hrs)

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Mean | 1,907 | 5,863 | 10,948 | 20,398 | 29,465 | 38,697 | | **Mean Installed Capacity (MW)** |
| Median | 1,000 | 5,000 | 10,000 | 17,800 | 27,500 | 40,000 | | **Median Installed Capacity (MW)** |
| *Mean* | ***4.5*** | ***5.0*** | ***6.0*** | ***6.7*** | ***7.4*** | ***8.0*** | | ***Mean Storage Duration (hours)*** |
| *Median* | ***5.1*** | ***5.2*** | ***5.8*** | ***6.7*** | ***7.3*** | ***8.1*** | | ***Median Storage Duration (hours)*** |
| Expert A | 2,000 | 4,000 | 6,000 | 8,000 | 11,000 | 20,000 | | · Significant retention of gas capacity and continued strong interconnections with neighboring states including in battery integration and wind.<br>· 4 hrs is expected today, accelerates after 2030 as integration won't get difficult until renewables are substantially higher. |
| Expert B | 500 | 2,500 | 4,000 | 6,000 | 9,000 | 15,000 | | · Energy and frequency regulation revenue streams are uncertain.<br>· Other technologies provide 4+ hours of energy including during peak hours; however, pumped storage will come into play when grid is saturated with renewables. The need for load shifting will require longer duration storage. |
| Expert C | 2,724 | 7,289 | 14,531 | 29,075 | 43,618 | 58,162 | | · Battery needs at least 4 hrs to qualify for the resource adequacy credit. Most of them are just 4 hours today, but going forward we need longer duration.<br>· Middle of the range of the 4 studies. Could change if we bring in out of state wind or offshore wind. |
| Expert D | 1,000 | 5,000 | 10,000 | 15,000 | 22,000 | 30,000 | | · Used values from the SCE study because it was recent, included economy wide GHG emissions, and included BTM storage estimates.<br>· Value of short-term batteries will become saturated, requiring longer duration batteries. Technology will improve to provide longer duration at reasonable cost. |
| Expert E | 850 | 11,000 | 20,000 | 35,000 | 50,000 | 60,000 | | · Somewhere in between the studies provided. Assumes CA does not join a western RTO or develop grid-forming inverter technology. |
| Expert F | 7,500 | 12,000 | 15,000 | 20,000 | 30,000 | 40,000 | | · Uptake driven by falling costs of large-scale storage and aggressive customer adoption of renewables to increase resiliency and mitigate climate change. |
| Expert G | 1,000 | 5,000 | 10,000 | 16,000 | 22,000 | 30,000 | | · Higher renewables (esp. solar PV) will require a lot of storage to avoid extreme duck curve losses, but energy efficiency will reduce load and demand response will partially offset the need for storage. |
| Expert H | 2,000 | 4,000 | 10,000 | 30,000 | 40,000 | 50,000 | | · Accelerating installations driven by CA's RE targets and shift away from firm capacity toward variable renewable generation, which increases need for storage, particularly long duration storage.<br>· Includes today's pumped hydro, with no significant expansion.<br>· Batteries: shorter duration storage in near term; over time, need for longer duration storage will drive storage development. |

Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

## ENERGY STORAGE

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Expert I | N.R. | 7,000 | 15,000 | 30,000 | 45,000 | 50,000 | | · Includes more than just batteries—pumped hydro, solar thermal, etc. Batteries will come online sooner in CA than in the rest of the country. · Duration will increase due to economics of a high renewables grid and improved battery technology. |
| Expert J | 1,000 | 2,000 | 4,500 | 17,500 | 27,500 | 42,500 | | · Two scenarios for 2045: 1) 25-30 GW by 2045 with 4-6 hour duration based on capacity value of renewable variable generation (which declines as system peak occurs later in the day), with remainder made up by storage. 2) 35 GW more (60GW total) if natural gas units retire after 2030. Also lower battery prices beat natural gas units by 2030. If filling in for gas units, storage duration will increase to ensure night long operation. |
| Expert K | 500 | 4,700 | 11,400 | 17,800 | 24,000 | 30,000 | | · Project utility-scale PV deployment, then assume how much of that would be paired with a battery and the battery:PV capacity ratio. Add simple estimates on deployment of standalone utility-scale battery capacity, gradually increasing until 2025, then assume a constant deployment of ~300 MW per year. Assume hybrid PV plants deploy at ~3x the rate of standalone storage. |

**Installed Capacity (MW): Behind-the-Meter Storage and Duration (hrs)**

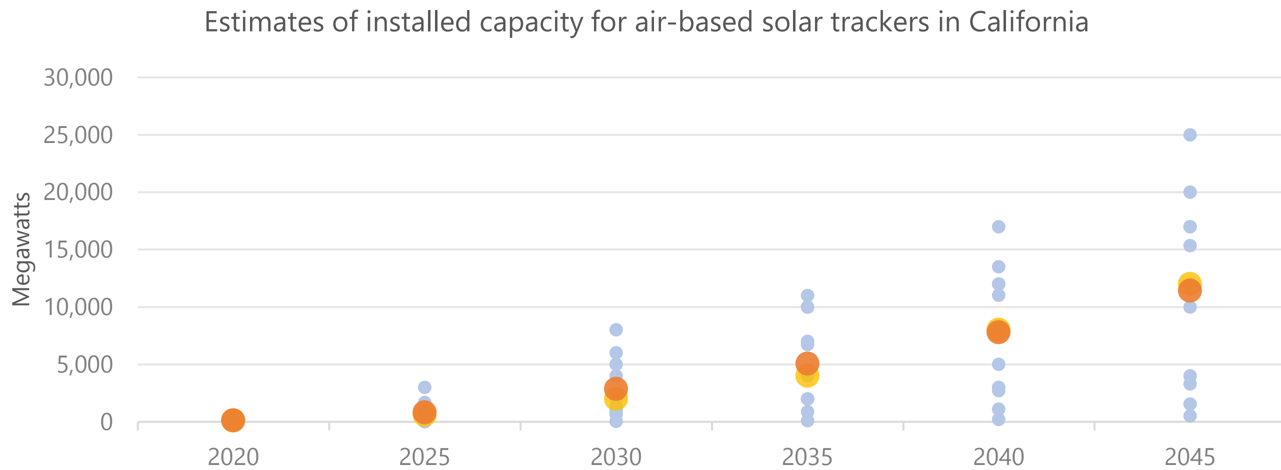
| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Mean | 402 | 1,556 | 3,233 | 5,589 | 8,478 | 11,733 | | Mean Installed Capacity (MW) |
| Median | 400 | 1,500 | 3,000 | 5,000 | 8,000 | 10,000 | | Median Installed Capacity (MW) |
| *Mean* | *2.2* | *2.9* | *3.7* | *4.3* | *4.7* | *5.1* | | *Mean Storage Duration (hours)* |
| *Median* | *2.0* | *2.5* | *3.0* | *4.0* | *4.0* | *5.0* | | *Median Storage Duration (hours)* |
| Expert A | N.R. | N.R. | N.R. | N.R. | N.R. | N.R. | | · Not area of expertise - smaller than utility-scale because of cost. |
| Expert B | N.R. | N.R. | N.R. | N.R. | N.R. | N.R. | | · Not area of expertise. |
| Expert C | 900 | 1,500 | 2,100 | 2,400 | 2,800 | 3,100 | | · Used CEC forecasts (IEPR) and then increased by ~20% to account for the entire state. Difficult to forecast load without direct access to BTM PV numbers. · Duration goes up as batteries become cheaper and more desirable. |
| Expert D | 300 | 1,600 | 3,000 | 5,000 | 7,000 | 10,000 | | · Used the BTM estimates from the SCE study. · Most BTM customers (residential and commercial) will use shorter duration batteries for backup power and have less incentive to invest in longer duration batteries. Customers will likely use other technologies, like a backup generator, for longer duration backup power. |

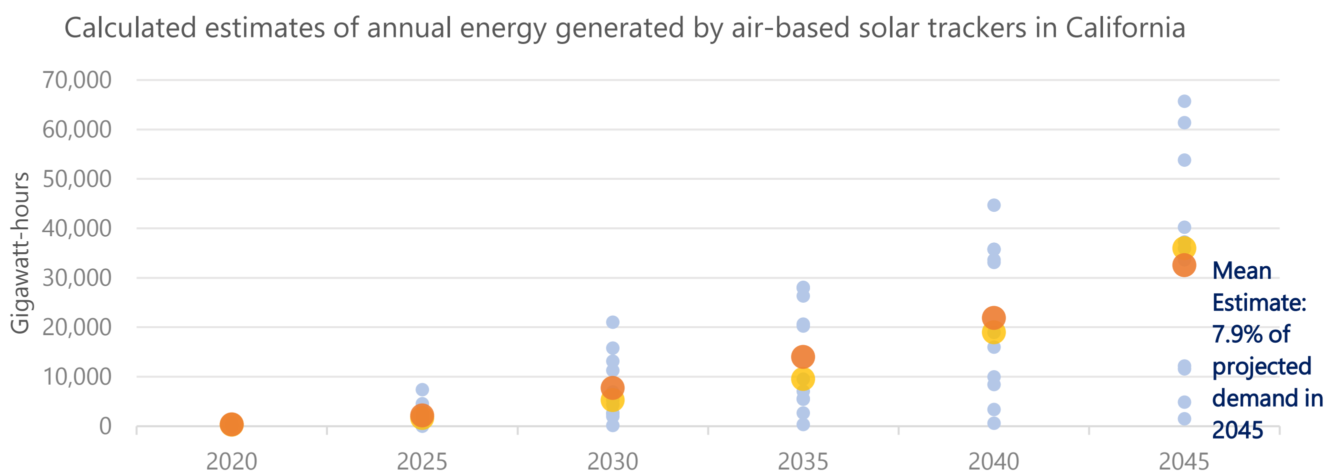
Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

## ENERGY STORAGE

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Expert E | 320 | 800 | 1,400 | 3,000 | 7,000 | 10,000 | | · The fires in CA are a big driver, considering drought and concerns over energy security. The pandemic also drives down electricity demand.<br>· Pretty conservative estimates; overly focus on residential. |
| Expert F | 500 | 3,500 | 5,000 | 8,000 | 10,000 | 18,000 | | · BTM storage driven by: (a) ROI – ability for customers to mitigate TOU charges and (b) resiliency and need for short-term, disaster backup power. |
| Expert G | 500 | 1,500 | 3,000 | 6,000 | 8,000 | 10,000 | | · Similar to utility-scale but PV and storage will both be more expensive at this level. |
| Expert H | 500 | 500 | 2,000 | 4,000 | 8,000 | 10,000 | | · Significant growth in BTM storage for C&I customers to meet their sustainability goals (matching hourly demand with renewables) and reliability requirements.<br>· BTM energy storage will grow in parallel with solar, but will not realize economies of scale required to achieve longer duration storage. |
| Expert I | 0 | 1,000 | 5,000 | 8,000 | 12,000 | 16,000 | | · Projection reflects distributed storage rather than just BTM. Assumes that policy will enable greater deployment of distributed storage (includes car batteries, fleets, pumped hydro, etc.). Deployment driven by customer demand for backup power during blackouts but will also be increasingly dispatchable by the utility.<br>· Cost-sharing will incentivize longer duration BTM resources at commercial sites. Can also strengthen the grid in remote areas. |
| Expert J | 400 | 500 | 1,000 | 4,000 | 8,500 | 12,500 | | · BTM solar size (inverter size) may be a limiting factor.<br>· Saving on peak demand charges is another driver. Peak demand shaving capacity may be 5-10 GW. Combined, the "union set" is about 10-15 GW of installed BTM storage capacity by 2045.<br>· After 2030 the rate of adoption may increase as natural gas units retire or become less cost competitive with storage. |
| Expert K | 200 | 3,100 | 6,600 | 9,900 | 13,000 | 16,000 | | · Assume 50% of projected distributed PV market installs a battery as part of system, and battery is sized at 90% of the PV system capacity. Assume average residential to non-residential BTM deployment of 3.6:1.<br>· Projections reflect increasing value of BTM as battery costs come down, shifts in rate design, growing interest in backup/resilience and greater availability of "package deals" (e.g., software controls, integrated inverter/battery combos). |

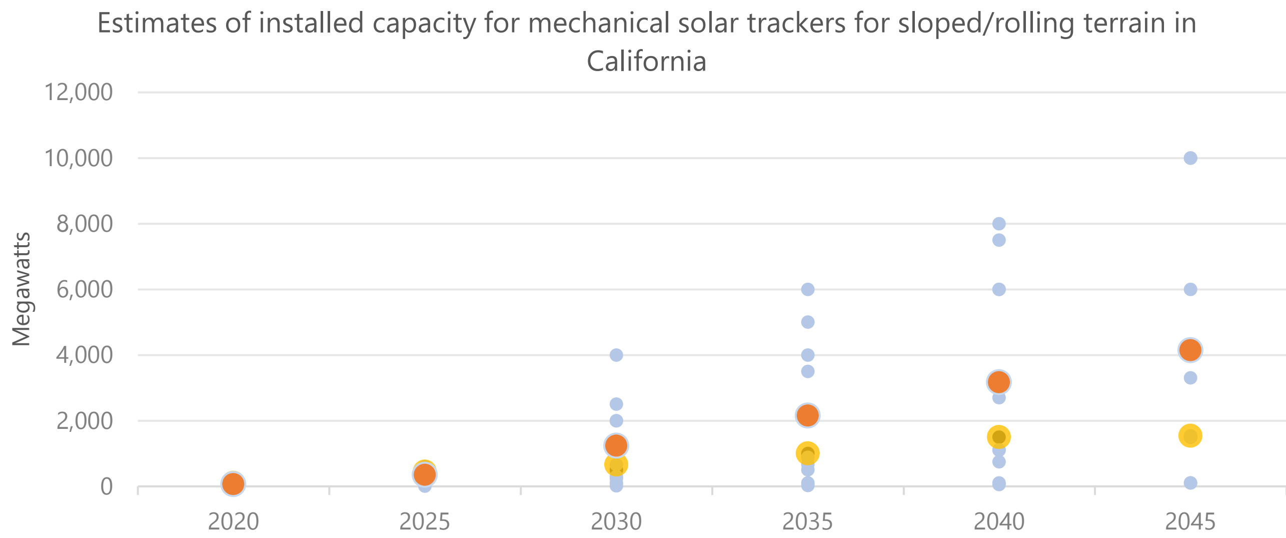
Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

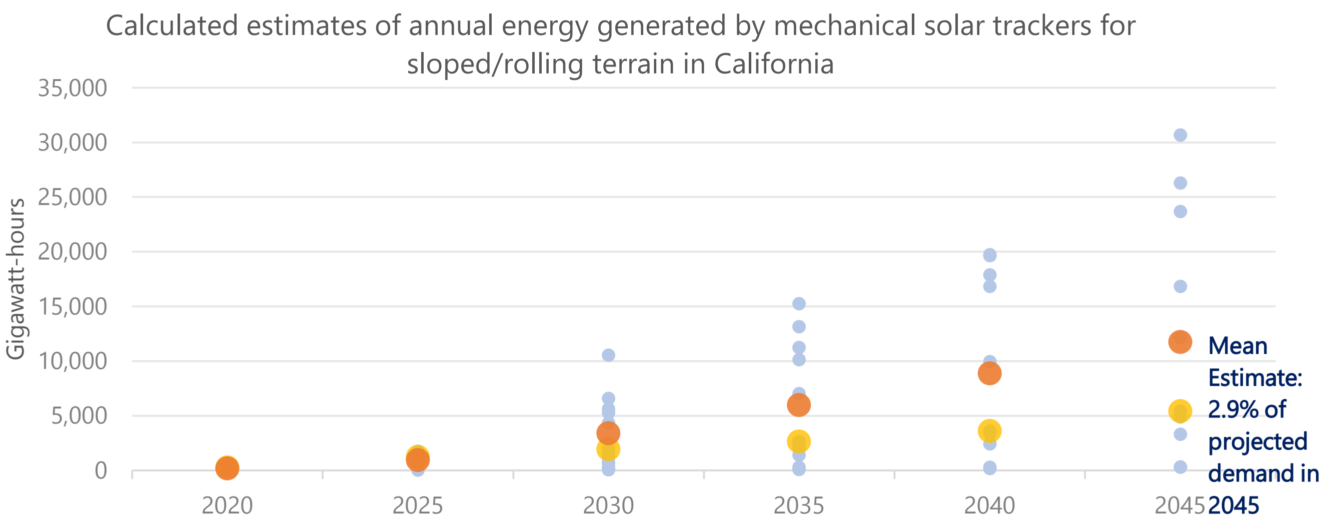



Estimates of annual energy generated are calculated by combining expert estimates of installed capacity and observed capacity factors in each five-year increment.

The mean estimate across experts is in orange and the median estimate is in yellow.

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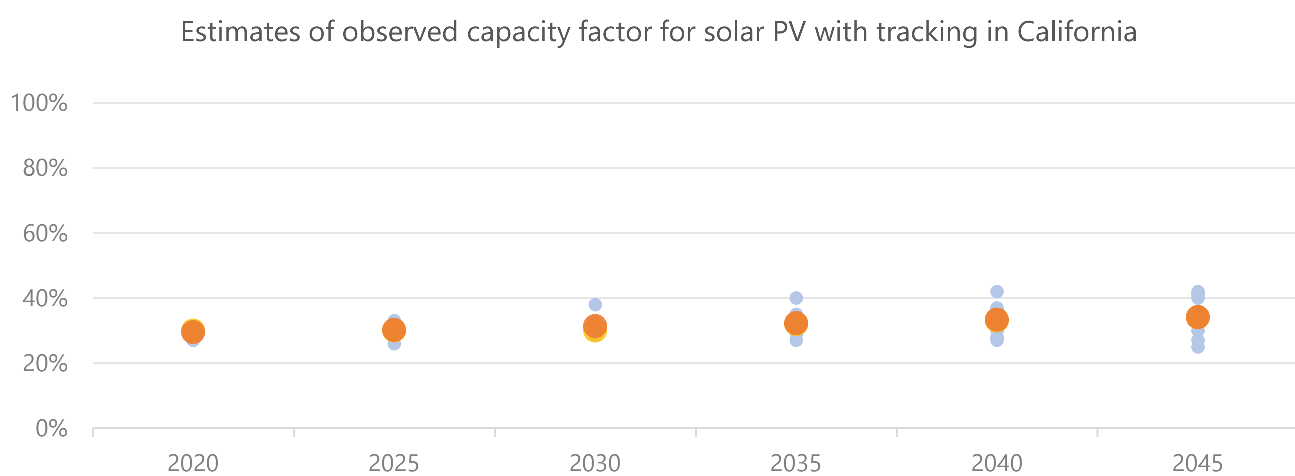
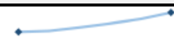



The mean estimate across experts is in orange and the median estimate is in yellow.

## PHOTOVOLTAICS: SOLAR TRACKING

### Installed Capacity (MW): Air-based solar trackers

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| **Mean** | **111** | **828** | **2,855** | **5,063** | **7,776** | **11,426** |  | |
| **Median** | **100** | **600** | **2,000** | **4,000** | **8,000** | **12,000** |  | |
| Expert A | 100 | 1,000 | 8,000 | 11,000 | 13,500 | 17,000 |  | · Air-based trackers and mechanical trackers for sloped terrain represent a small amount of the utility-scale PV market in the coming 5-10 years, but combined they will take almost 50% of the total market by 2045 (i.e., 45% of 60,000 MW), 2045 share of installations is likely higher for the air-based tracker than the mechanical tracker. |
| Expert B | 150 | 800 | 2,000 | 4,000 | 8,000 | 17,000 |  | · Solar will be installed regardless of the tracker. Technology is promising. Reducing cost is more achievable than inventing a new technology, but O&M costs (maintenance frequency) are unknown. |
| Expert C | 50 | 1,668 | 2,399 | 6,715 | 11,031 | 15,347 |  | · Use IRP results from 38 MMT RSP for new solar procurement (only for CAISO area of study, but I believe RESOLVE overstates solar) and assume these trackers are 20% of new procurement.<br>· Cost-effective and cost-competitive, uses land more efficiently, no limits as to what terrain it can be used on. Already has production capability, so should be able to ramp up in a couple years. |
| Expert D | 300 | 3,000 | 6,000 | 10,000 | 12,000 | 12,000 |  | · 100% of the utility-scale solar systems installed in California in 2018 had a tracking system.<br>· 3 components vs. 21 components in traditional trackers reduces installation and maintenance costs. Air-based trackers will replace traditional mechanical trackers over time. However, by 2035 there will likely be newer, better technology. |
| Expert E | 0 | 500 | 1,000 | 2,000 | 3,000 | 4,000 |  | · Appeals to solar companies because it is a simpler system. O&M costs would decrease compared to current tracking systems. If technology can include compressed air-based storage, it may increase the value of the technology.<br>· Assumes Sunfolding gets 50% market share by 2025. |
| Expert F | 220 | 440 | 660 | 880 | 1,100 | 1,540 |  | · While both technologies are promising from a technical perspective, it is difficult for new technologies to unseat existing incumbents. Access to capital is a big barrier, but recognition for Sunfolding and interest from other investors in the last year is promising. Assume both technologies can capture 2% of the 10-15 GW/year utility-scale solar market from NEXTracker and Array Tech. |
| Expert G | 100 | 600 | 4,000 | 7,000 | 12,000 | 20,000 |  | · A simpler tracking system provides more solar conversion per unit area without too much additional cost. |

Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

## PHOTOVOLTAICS: SOLAR TRACKING

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Expert H | 0 | 1 | 50 | 100 | 200 | 500 | | · Assumes 65 GW of solar by 2045 to meet CA's renewables target; half is utility-scale, and half of that is on flat land.<br>· Assumes air-based system can only be used on flat land and will capture 5% market share by 2045.<br>· Attractive due to simpler and less costly O&M. But competes with existing commercially viable trackers on flat land. |
| Expert I | 0 | 0 | 5,000 | 10,000 | 17,000 | 25,000 | | · Assumes 50% penetration in a 50 GW market by 2045.<br>· If this technology performs as indicated - i.e., simpler system with a very small cost increase, and becomes commercially available, wide installation is likely. |
| Expert J | 200 | 500 | 1,000 | 2,000 | 5,000 | 10,000 | | · Pros: different technology with lower cost. Might be easier to have compressed air-based storage, which may provide more value streams.<br>· Cons: Potential additional software costs for monitoring irradiance and optimizing tilt for different terrain; unclear if resilient to severe weather and strong winds; uncertainty around communication medium and infrastructure. |
| Expert K | 100 | 600 | 1,300 | 2,000 | 2,700 | 3,300 | | · Existing tracker market is competitive and companies are innovating on their own. Assume technology will be able to capture 10% market share by 2025 and through 2045, which may not be sustainable, and technology may not capture benefits of bifacial modules as the market shifts to more fully bifacial. |

**Installed Capacity (MW): Mechanical solar trackers for sloped/rolling terrain**

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Mean | 65 | 346 | 1,237 | 2,152 | 3,164 | 4,143 | | |
| Median | 100 | 440 | 660 | 1,000 | 1,500 | 1,540 | | |
| Expert A | 100 | 500 | 4,000 | 6,000 | 8,000 | 10,000 | | · Air-based trackers and mechanical trackers for sloped terrain represent a small amount of the utility-scale PV market in the coming 5-10 years, but combined they will take almost 50% of the total market by 2045 (i.e. 45% of 60,000MW). 2045 share of installations is slightly lower for mechanical trackers due to the cost and complexities associated with this technology. |
| Expert B | 0 | 200 | 500 | 1,000 | 1,500 | 1,500 | | · Sloped and rolling terrain is a very niche market.<br>· Accuracy of tracking on steep terrain is uncertain.<br>· Limited cost reduction from learning by doing given limited steep/mountainous terrain in CA. |

Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

## PHOTOVOLTAICS: SOLAR TRACKING

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Expert C | 0 | 167 | 240 | 672 | 1,103 | 1,535 | | · Assume 2% of new procurement. Tech doesn't make much sense - only works on a small subset of sloped and rolling terrain when facing in certain directions, while air-based solar trackers can also be mounted horizontally or on slopes. |
| Expert D | 100 | 500 | 2,000 | 4,000 | 6,000 | 6,000 | | · Will allow solar PV with tracking at additional sites without flat terrain. Assumes this will be an increasing percentage of all sites over the years. |
| Expert E | 0 | 100 | 100 | 100 | 100 | 100 | | · Cool idea but the technology is further behind. Not convinced it would go further than advanced R&D. |
| Expert F | 220 | 440 | 660 | 880 | 1,100 | 1,540 | | · While both technologies are promising from a technical perspective, it is difficult for new technologies to unseat existing incumbents. Access to capital is a big barrier, but recognition for Sunfolding and interest from other investors in the last year is promising. Assume both technologies can capture 2% of the 10-15 GW/year utility-scale solar market from NEXTracker and Array Tech. |
| Expert G | 100 | 600 | 2,000 | 3,500 | 6,000 | 10,000 | | · Opens up areas that are currently not usable, though there are limits on how steep the slope can be. |
| Expert H | 0 | 1 | 10 | 20 | 50 | 100 | | · Growth possible as flat land becomes scarcer and tracker technology improves. But lack of detailed cost estimates and known technical issues (e.g. shading) raise skepticism of grantee's projections. |
| Expert I | 0 | 500 | 2,500 | 5,000 | 7,500 | 10,000 | | · Assumes 25% penetration in a 50 GW market by 2045.<br>· Not having to grade land for rural installations is an advantage. If technology becomes commercially available, wide installation is likely, though somewhat limited by site availability. |
| Expert J | 100 | 200 | 300 | 500 | 750 | 1,500 | | · Competing with state-of-the-art and heavily adopted trackers such as NEXTracker's NX Gemini and NX Horizon product. NEXTracker seems to work for bifacial panels and seems resilient to weather conditions – not mentioned for the grantee's technology. Methods to improve seem similar to NEXTracker's.<br>· Unclear how this well-accepted technology will differentiate itself. If cost competitive, then may have an opportunity. |
| Expert K | 100 | 600 | 1,300 | 2,000 | 2,700 | 3,300 | | · Existing tracker market is competitive and companies are innovating on their own. Assume technology will be able to capture 10% market share by 2025 and through 2045, which may not be sustainable, and technology may not capture benefits of bifacial modules as the market shifts to more fully bifacial. |

**Capacity Factor**

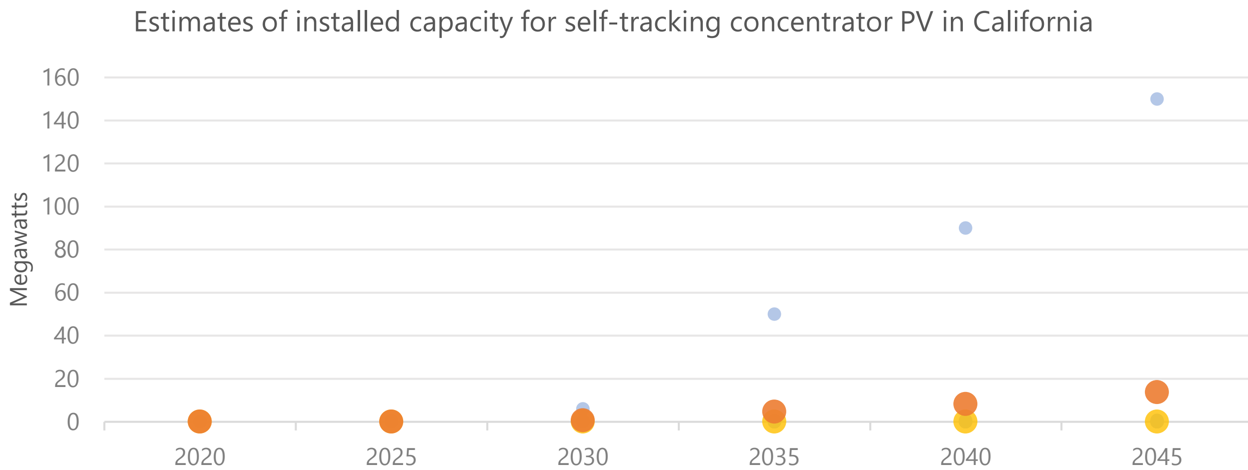
| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Mean | 30% | 30% | 31% | 32% | 33% | 34% | | |

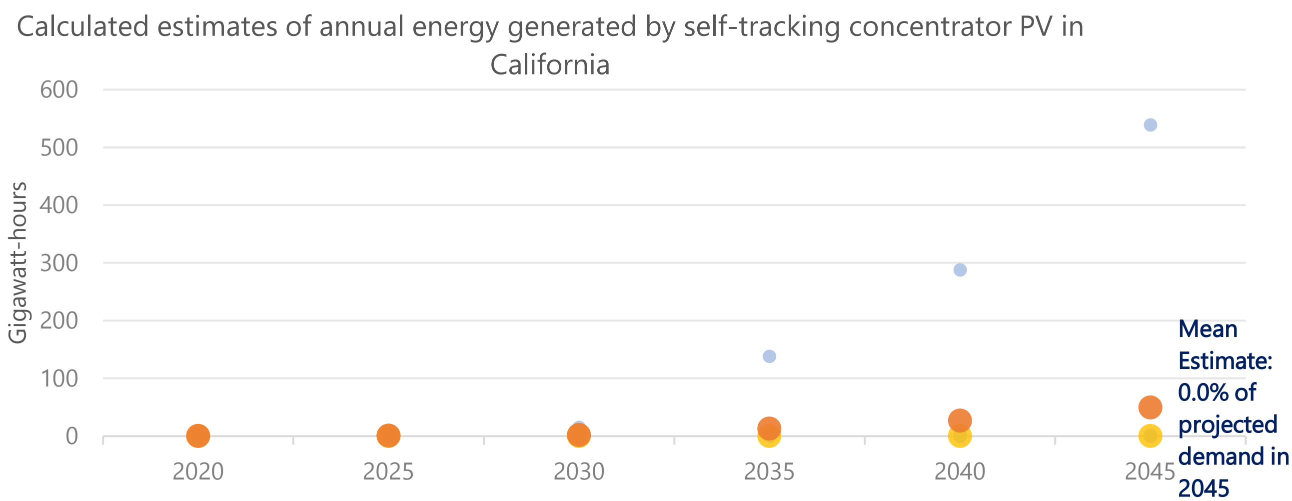
Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

## PHOTOVOLTAICS: SOLAR TRACKING

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| **Median** | **30%** | **30%** | **30%** | **32%** | **33%** | **34%** | | |
| Expert A | 30% | 30% | 30% | 29% | 28% | 27% | | · Increasing solar on the grid and meeting CA renewables targets will lead to more curtailment. These technologies decrease cost and do not necessarily improve CF. |
| Expert B | 30% | 30% | 30% | 27% | 27% | 25% | | · 30% is reasonable to maintain until the market saturates the daytime hours. This will reduce CF unless storage makes economic sense. |
| Expert C | 30% | 31% | 33% | 35% | 37% | 40% | | · Most important factor is technology, then curtailment (most renewable generation is solar). Either we deploy a lot of batteries or diversify the portfolio (geothermal, offshore or out-of-state wind) to increase CF. 40% CF is achievable with wind improvement. |
| Expert D | 27% | 28% | 30% | 32% | 32% | 32% | | · <30% near term due to economic curtailments and lower electricity demand. As market expands in Energy Imbalance Market (western states + Canada), need to curtail in CAISO will be reduced. Other mitigants and technology will also improve, and storage and electrification of loads in the building and EV sectors will catch up. |
| Expert E | 30% | 30% | 30% | 31% | 32% | 33% | | · Degradation of modules over time would be offset by new solar cell technologies and semiconductor materials. Technological improvements will increase CF over time. Estimates do not take into account curtailment which is harder to predict at this time. |
| Expert F | 31% | 32% | 33% | 34% | 35% | 36% | | · Steady improvements in CF driven by technology improvements including bifacial cells, better tracking accuracy, glass coatings, and cell optical surface improvement. Larger modules, but substantial increases limited by need to keep down cost per watt or per watt-hr. |
| Expert G | 30% | 31% | 32% | 33% | 34% | 35% | | · Small improvements in efficiency at scale seem likely. |
| Expert H | 30% | 31% | 31% | 32% | 33% | 34% | | · Slight increase in CF due to increased efficiencies in solar and additional storage, partly offset by more solar on non-flat terrain. |
| Expert I | 30% | 30% | 30% | 30% | 30% | 30% | | · No change in single-axis tracking. Reduced maintenance and forced outages may be offset with difficulties of rural installations, e.g. more debris. |
| Expert J | 27% | 26% | 29% | 32% | 37% | 41% | | · If tracker can facilitate bifacial modules, CF will increase.<br>· With increased storage and transmission planning, CF may increase (depends on size of storage, transmission, or hybrid projects; and load growth). |
| Expert K | 30% | 33% | 38% | 40% | 42% | 42% | | · Net effect of: (a) increases due to bifacial modules and pairing of bifacial modules with DC-coupled batteries and (b) decreases due to solar curtailment, as CA already has a large installed PV base. |

Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

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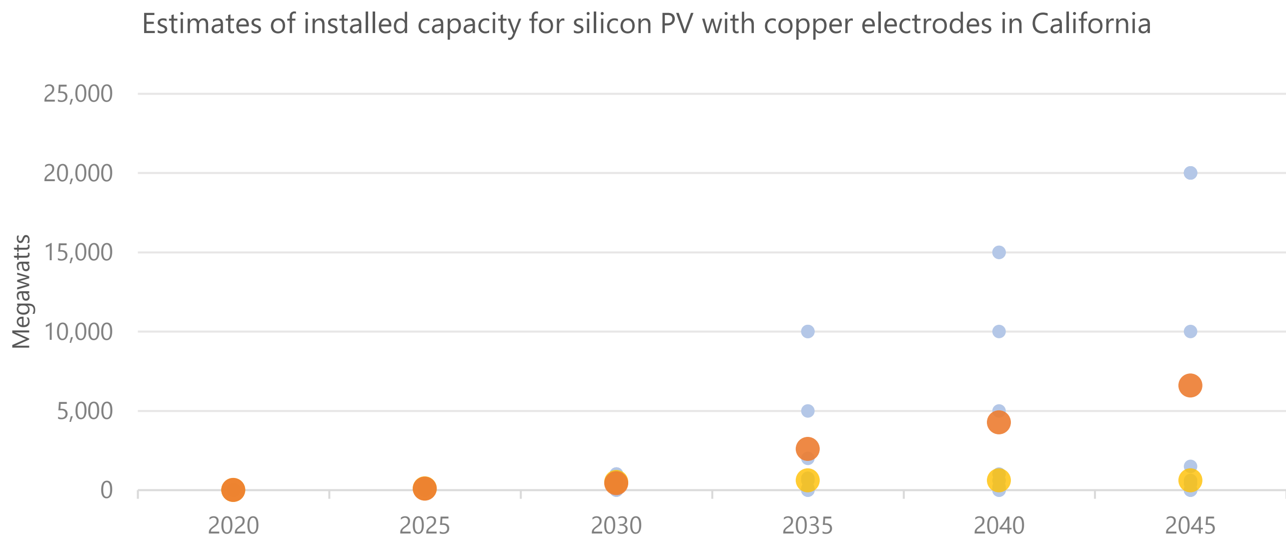


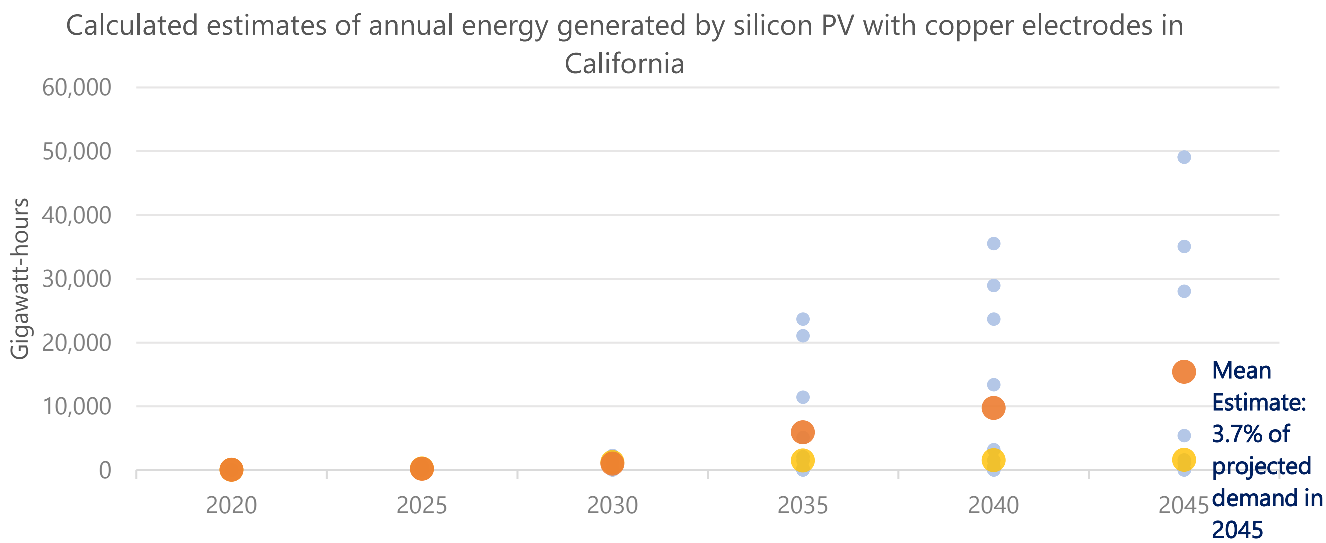


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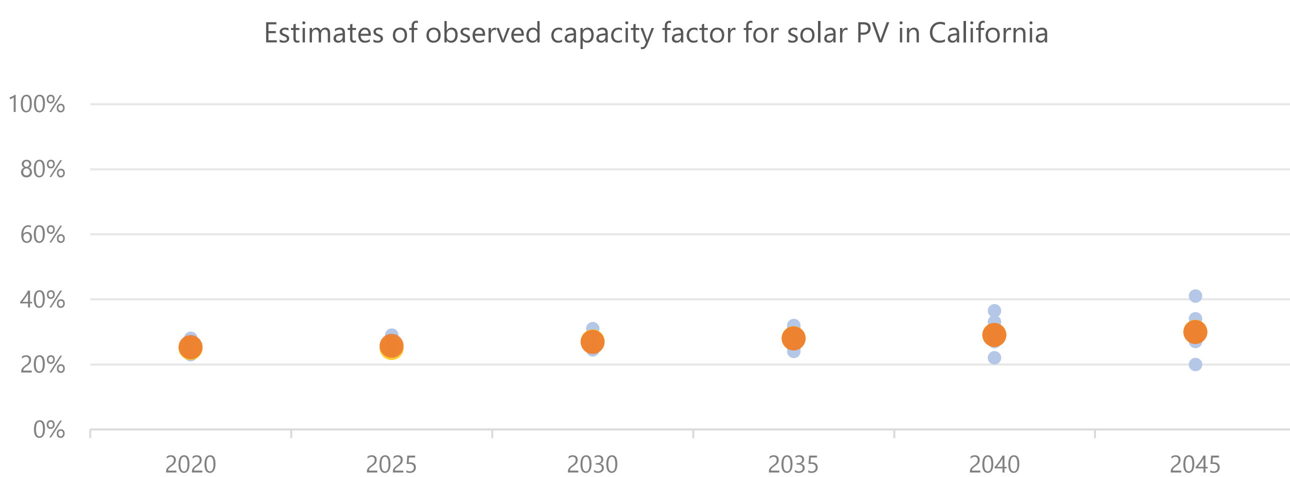



The mean estimate across experts is in orange and the median estimate is in yellow.

# PHOTOVOLTAICS: SOLAR PV CELLS

**Installed Capacity (MW): Self-tracking concentrator PV**

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Mean | 0 | 0 | 1 | 5 | 8 | 14 | | |
| Median | 0 | 0 | 0 | 0 | 0 | 0 | | |
| Expert A | 0 | 0 | 0 | 0 | 0 | 0 | | · There does not seem to be a pathway to reducing cost. The incremental performance of this technology does not justify the cost premium. Growth in the PV market will be competitive, primarily driven by declining cost. |
| Expert B | 0 | 0 | 0 | 0 | 0 | 0 | | · Costs twice as much as existing technologies; will never be able to compete. |
| Expert C | 0 | 0 | 0 | 0 | 0 | 0 | | · Technology is early stage and unproven at this time; not nearly mature enough to be commercialized. There are other PV technologies that can make them more effective and efficient in the meantime. |
| Expert D | 0 | 0 | 0 | 0 | 0 | 0 | | · Too expensive; unlikely to be cost-competitive. |
| Expert E | 0 | 0 | 0 | 0 | 0 | 0 | | · Solar PV cost and performance has improved dramatically over such a short period of time, leaving CPV in the dust. |
| Expert F | 0 | 0 | 0 | 0 | 0 | 0 | | · Seems like a good idea but cost and complexity impede commercialization. |
| Expert G | 0 | 0 | 0 | 0 | 0 | 0 | | · Unlikely that the non-competitive position of this technology will improve. |
| Expert H | 0 | 0 | 0 | 0 | 0 | 0 | | · Not cost-competitive. If deployed, would be in a niche BTM capacity. |
| Expert I | 0 | 0 | 0 | 0 | 0 | 1 | | · The technology did not achieve projected cost targets. In addition, market uptake will be limited by the small-scale application proposed. |
| Expert J | 0 | 1 | 6 | 50 | 90 | 150 | | · As technology is targeted toward distributed PV, market size is relatively small, uncertainty whether tracking and concentrators can be demonstrated for rooftop applications, cost and risk of killing birds or animals.<br>· Technology is a big risk, but giving it a slight chance. |
| Expert K | 0 | 1 | 1 | 1 | 1 | 1 | | · Projections reflect only a few demonstration sites. PV modules are a commodity and the residential sector is unlikely to take a risk on a new technology with limited benefits compared to current PV. Tariffs are phasing out, likely before this technology reaches commercial scale, increasing the cost differential. Lastly, community solar reduces the urgency of space-constrained sites. |

Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

# PHOTOVOLTAICS: SOLAR PV CELLS

## Installed Capacity (MW): Silicon PV with copper electrodes

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Mean | 0 | 77 | 423 | 2,586 | 4,255 | 6,591 | | |
| Median | 0 | 100 | 500 | 600 | 600 | 600 | | |
| Expert A | 0 | 100 | 1,000 | 10,000 | 15,000 | 20,000 | | · Technology seems promising and compatible with either trackers or fixed-tilt installations. Potential to capture one-third of the overall PV market in 2045. |
| Expert B | 0 | 0 | 0 | 0 | 0 | 0 | | · Not cost-competitive, investors not interested, and grantee stopped working on the project in April 2019. The PV market is better developed and there is room to further reduce PV costs. |
| Expert C | 0 | 0 | 0 | 0 | 0 | 0 | | · Technology is early stage and unproven at this time, and there are other PV technologies that can make them more effective and efficient. |
| Expert D | 0 | 300 | 600 | 600 | 600 | 600 | | · Project unable to get financing for 300MW/yr factory. After 2030, other innovations could make this obsolete before manufacturing facilities adopt it. Modules will have higher efficiency, lower degradation, and lower cost ($0.022/W) than silver paste, but difficult to compete with lower costs of imported modules. |
| Expert E | 0 | 100 | 1,000 | 5,000 | 10,000 | 20,000 | | · Technology is promising - in particular, technology's compatibility with both trackers or fixed-tilt installations as well as with bifacial modules and perovskites. |
| Expert F | 0 | 0 | 0 | 0 | 0 | 0 | | · While copper electrodes is a great idea, significant momentum would be needed to displace the incumbent silver paste technology. |
| Expert G | 0 | 100 | 1,000 | 10,000 | 15,000 | 20,000 | | · Potential for technology to maintain competitive position if EPIC has access to the IP. Competitive advantages include lower cost of copper compared to silver, lower degradation and compatibility with both trackers and fixed-tilt installations. |
| Expert H | 0 | 0 | 0 | 0 | 0 | 0 | | · Unable to secure investor commitment. But technology has potential and could be resurrected if others take up the IP and are able to raise capital. |
| Expert I | 0 | 100 | 500 | 2,000 | 5,000 | 10,000 | | · Promising due to lower cost and lower degradation. Copper will always be cheaper than silver, and PV industry's dependence on silver is a major weakness.<br>· While the company looks weak, potential if EPIC has access to the IP and can move this forward. Assumes 10 years to develop technology, 10 years to further lower costs, 10 years to achieve wide adoption. |
| Expert J | 1 | 150 | 500 | 750 | 1,000 | 1,500 | | · High impact potential- applicable to utility scale PV, but company seems to have hit a development roadblock. Technology could achieve greater success if it partners with a more mature company like SunPower. Success also depends on ability to alleviate risks associated with reliability and production costs. |
| Expert K | 0 | 1 | 50 | 100 | 200 | 400 | | · PV cell and module architecture is changing rapidly - copper deposition not better than bifacial or half-cut cells. Cost is a more important driver of deployment than efficiency. If technology is compatible with bifacial and perovskites, higher chance of being developed by another company. |

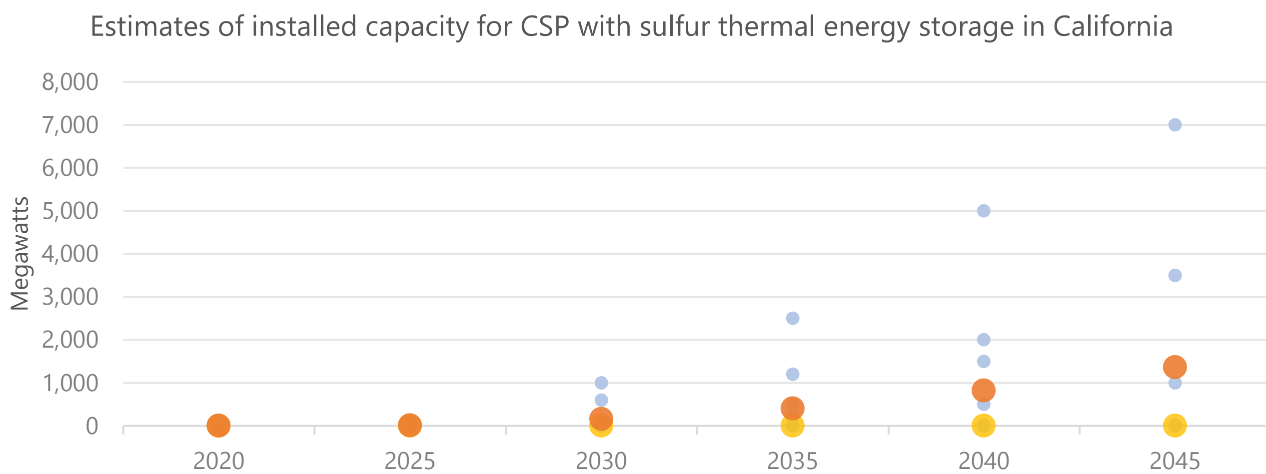
Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

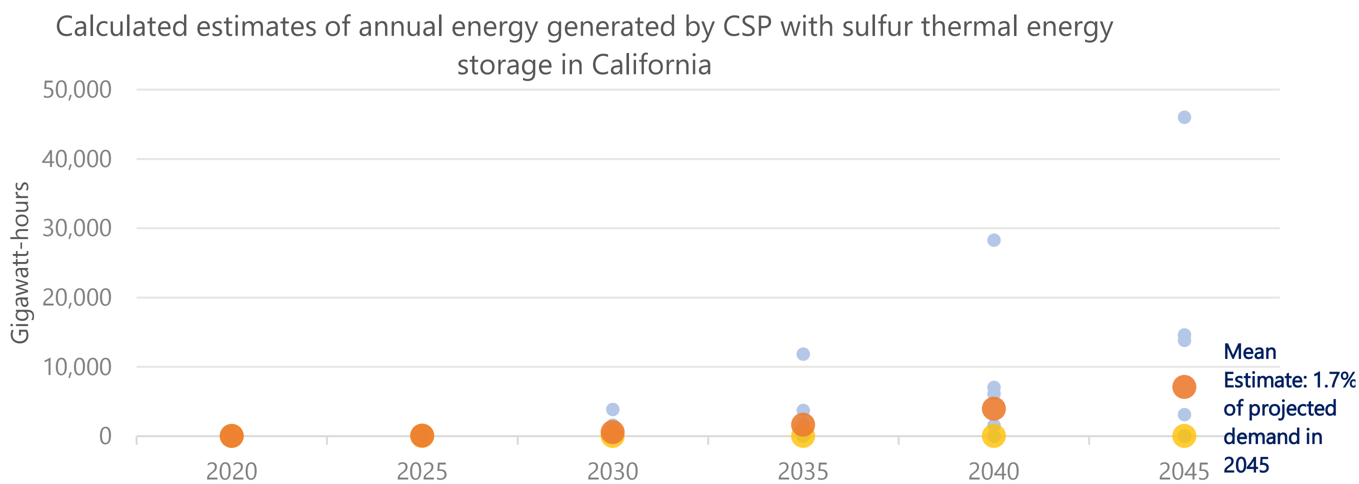
## PHOTOVOLTAICS: SOLAR PV CELLS

### Capacity Factor

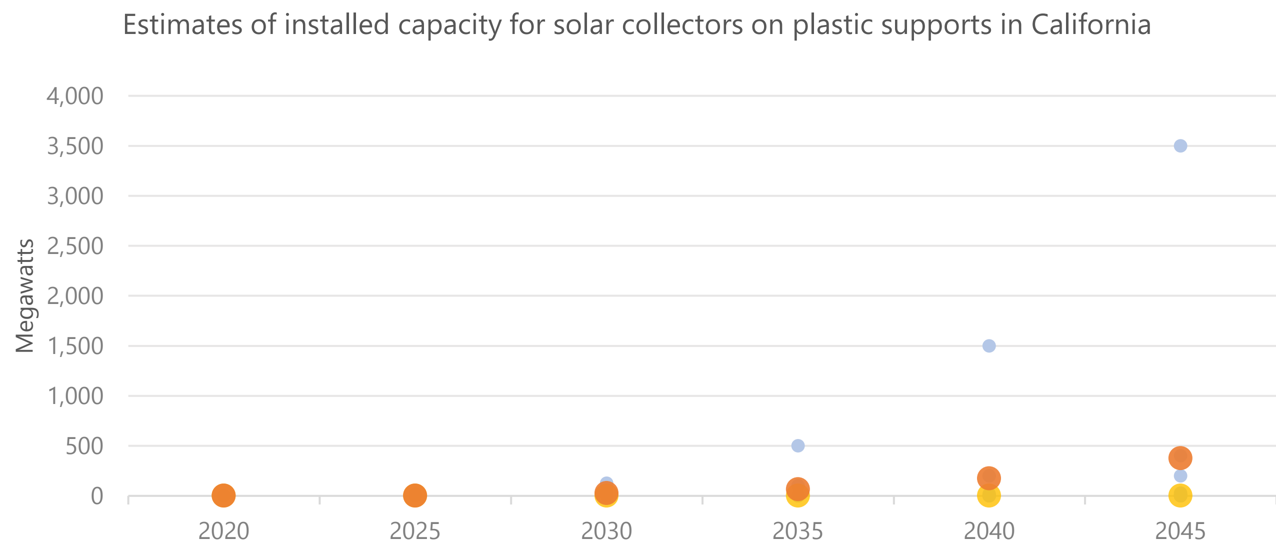
| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| **Mean** | **25%** | **26%** | **27%** | **28%** | **29%** | **30%** | | |
| **Median** | **25%** | **25%** | **27%** | **28%** | **29%** | **30%** | | |
| Expert A | 26% | 26% | 25% | 24% | 22% | 20% | | · Improvements in O&M will improve performance for the coming 5-10 years, but CF will drop off because fixed-tilt is vulnerable to curtailment in peak hours of solar output. |
| Expert B | 25% | 25% | 25% | 25% | 27% | 27% | | · Picked the mid-range based on improvements in PV cells.<br>· CF increases over time as existing panels in large installations degrade and are replaced with more efficient panels. |
| Expert C | 28% | 29% | 31% | 32% | 33% | 34% | | · No tracking systems; increase due to technology improvement of the PV board. |
| Expert D | 23% | 25% | 27% | 28% | 29% | 30% | | · Lower near-term due to economic curtailments and lower electricity demand, until storage, larger Energy Imbalance Market, and electrification of loads in building and transportation sectors catch up. 2020 estimate is informed by EIA which shows CF of 21.9% in March 2020 compared to 24.2% in March 2019. |
| Expert E | 25% | 25% | 25% | 26% | 27% | 28% | | · Degradation of modules over time would be offset by new solar cell technologies and semiconductor materials. Incremental CF improvements beginning in 2035 due to technology advancements. |
| Expert F | 25% | 26% | 27% | 28% | 29% | 30% | | · New glass coatings and bifacial cells can improve the capacity factor as well as optical design of the cell surface. |
| Expert G | 25% | 25% | 26% | 27% | 27% | 28% | | · Slow increase driven by evolutionary technology improvements. |
| Expert H | 25% | 25% | 26% | 27% | 28% | 29% | | · CF will improve somewhat due to technology efficiencies, increasing storage, and social factors (e.g. working from home); but curtailment will remain an issue. |
| Expert I | 25% | 26% | 28% | 29% | 31% | 32% | | · Steady increase due to improved tracking and cell technology. |
| Expert J | 27% | 26% | 29% | 32% | 37% | 41% | | · Increased CF due to possible penetration of bifacial panels, with trackers; and cost reduction in PV/increased PV penetration. After 2030, energy storage and transmission planning will improve CF further (esp. if storage is built to make hybrid PV plants). Includes scaled applications, not just BTM storage. |
| Expert K | 25% | 25% | 28% | 30% | 30% | 30% | | · Increases in CF over time due to DC-coupled battery storage. Since residential PV is not subject to curtailment and won't benefit much from bifacial modules, curtailment is not a driving factor of CF. Module efficiency is also not a factor- the more efficient the module, the fewer modules are needed to reach a given amount of capacity. |

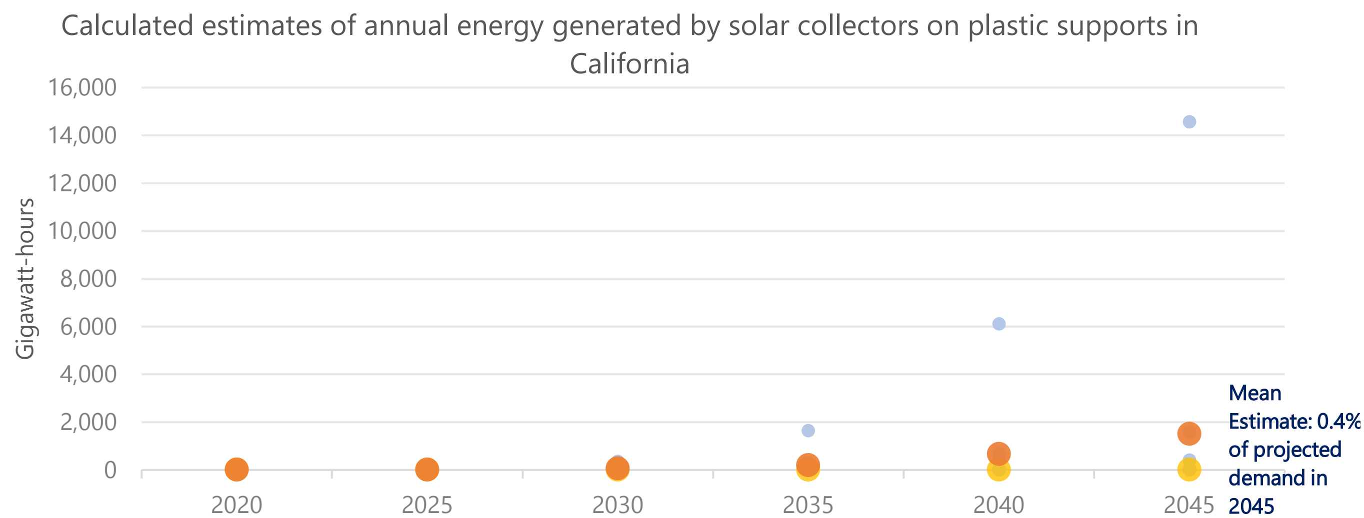
Data are highlighted if they are the lowest (yellow) or highest (green) for each year.




Estimates of annual energy generated are calculated by combining expert estimates of installed capacity and observed capacity factors in each five-year increment.

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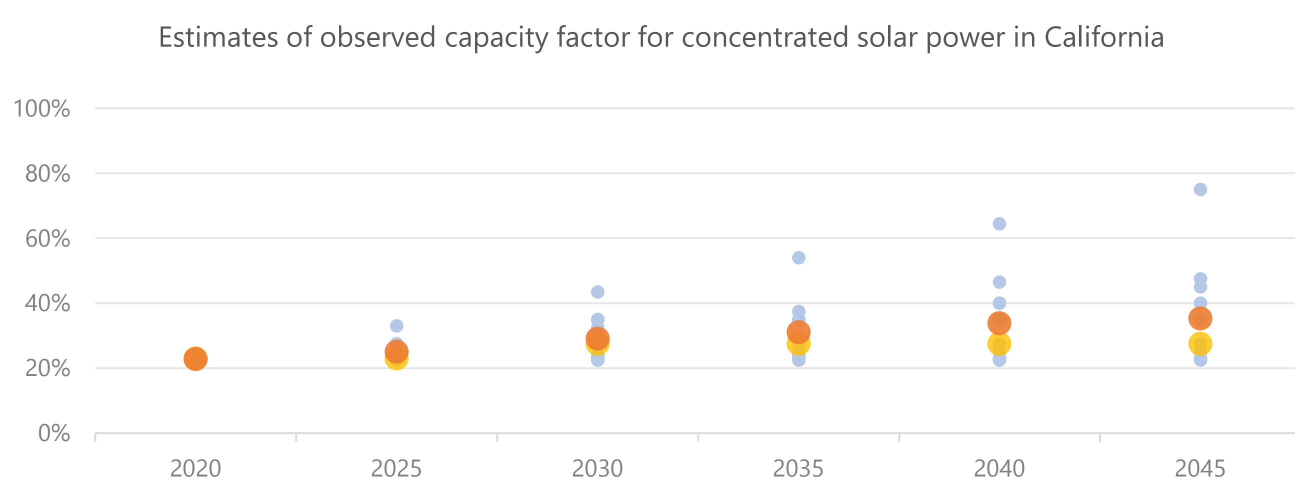



The mean estimate across experts is in orange and the median estimate is in yellow.

# CONCENTRATING SOLAR POWER

**Installed Capacity (MW): CSP with sulfur thermal energy storage**

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Mean | 0 | 10 | 162 | 401 | 820 | 1,365 | | |
| Median | 0 | 0 | 0 | 0 | 0 | 0 | | |
| Expert A | 0 | 5 | 50 | 200 | 500 | 1,000 | | · Seems expensive; will struggle to compete. But consistent with curtailment, will be more valuable as we get to high renewables penetration in 2040/2045. |
| Expert B | 0 | 0 | 0 | 0 | 0 | 0 | | · Cannot compete with existing PV on the market – PV is easier, simpler, and cheaper. |
| Expert C | 0 | 0 | 600 | 1,200 | 2,000 | 3,500 | | · Size and siting concerns for CSP, but this could be a solution going forward. If we're going to build CSP, this is the technology we'll go to. Operationally, CSP also makes more sense than co-located PV and battery. |
| Expert D | 0 | 0 | 0 | 0 | 0 | 0 | | · LCOE is too high compared to alternatives such as solar PV. Lack of suitable sites is also an issue. |
| Expert E | 0 | 0 | 0 | 0 | 0 | 0 | | · Cost of PVs is still coming down – cost gap for CSP will stay the same or even widen. Some bigger tower systems didn't go well, which reduces confidence. |
| Expert F | 0 | 0 | 0 | 0 | 0 | 0 | | · Of the ~80GW of PV installed in the US, only 2% is CSP. Has been around since 1980 but hasn't gained traction due to its complexity and cost. |
| Expert G | 0 | 1 | 3 | 8 | 15 | 20 | | · This is attractive for a niche market with limited geographic area or use cases. |
| Expert H | 0 | 0 | 0 | 0 | 0 | 0 | | · Slow market entry and low adoption due to inherent challenges with CSP, e.g. environmental footprint. Not a "breakthrough" technology, but may find a niche outside of power systems. Most useful for CHP applications, but CA already on track to meet CHP targets. |
| Expert I | 0 | 100 | 1,000 | 2,500 | 5,000 | 7,000 | | · CSP is expensive and usable land is limited, but solar and storage combined may be cost effective compared to PV and batteries. If transmission constraints in more remote areas are resolved, the storage could be very useful, more so than the electricity generation. Assumes that the 90 MW project in fact meets the DOE SunShot target of $50/MWh. |
| Expert J | 0 | 4 | 125 | 500 | 1,500 | 3,500 | | · CSP will need more time to take off due to higher costs. Potential to decrease storage cost by up to 50%. After 2030, when natural gas and other base load plants retire, CSP has a better chance (if cost comes down) and could help supply load. Issues to be addressed: wildlife impacts; high temperature testing; efficiency at higher temperatures. |
| Expert K | 0 | 0 | 0 | 0 | 0 | 0 | | · While elemental sulfur is superior to molten salt, the 0.2 c/kWh reduction is lost in the noise when compared to the total LCOE of CSP. CSP does not have a viable future due to the stigma associated with past projects, strict siting requirements in CA, and competition from existing low-cost PV and storage. |

Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

# CONCENTRATING SOLAR POWER

## Installed Capacity (MW): Solar collectors on plastic supports

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Mean | 0 | 2 | 25 | 65 | 174 | 375 | | |
| Median | 0 | 0 | 0 | 0 | 0 | 0 | | |
| Expert A | 0 | 0 | 0 | 0 | 0 | 0 | | · Too complex compared to the alternatives (sulfur thermal and existing CSP). |
| Expert B | 0 | 0 | 100 | 100 | 200 | 200 | | · Potential uptake if cost can be justified and technology is attractive for industrial CHP applications.<br>· Initial market uptake in 2030 due to RPS requirement – provides enough time for the market to prepare and policies to form. |
| Expert C | 0 | 20 | 50 | 100 | 200 | 400 | | · This is just for low temperature food processing plants, not for high temp, larger scale electricity generation. Not sure how strong the plastic is and how long it will last; mirror alignment is important, so will be small-scale. |
| Expert D | 0 | 0 | 0 | 0 | 0 | 0 | | · Plastic tubes are still unproven. HTP commercialization might be proceeding with municipal sewage waste as the beachhead market; they were awarded a DOE grant to deploy a large HTP system in the San Francisco Bay Area. Would not be economic absent DOE funds. |
| Expert E | 0 | 0 | 0 | 0 | 0 | 0 | | · Cost of PVs is still coming down – cost gap for CSP will stay the same, or even widen. Some bigger tower systems didn't go well, which reduces confidence. |
| Expert F | 0 | 0 | 0 | 0 | 0 | 0 | | · Of the ~80 GW of PV installed in the US, only 2% is CSP – hard to envision more growth. It's been around since 1980 but hasn't gained traction because of its complexity and cost. |
| Expert G | 0 | 1 | 3 | 10 | 18 | 25 | | · This is attractive for a niche market with limited geographic area or use cases. |
| Expert H | 0 | 0 | 0 | 1 | 1 | 2 | | · As above, does not overcome inherent challenges with CSP, but may be able to carve out a niche. |
| Expert I | 0 | 0 | 0 | 0 | 0 | 0 | | · Potential exists for process heat and agriculture but technology is not suitable for electricity generation. |
| Expert J | 0 | 4 | 125 | 500 | 1,500 | 3,500 | | · High impact - reduces cost. May have impact after 2030, esp. with nuclear plant retirements. But needs more testing and reliability data. Seems to indicate lower cost walls (thin walls) – can it withstand high temperature storage heat? |
| Expert K | 0 | 0 | 0 | 0 | 0 | 0 | | · Near-term target application seems to be food processing and/or industrial heat, which might be suitable small scale. With competition from PV and batteries, hard to see this reaching commercial deployment for power generation. The two companies also seem to have gone their separate ways. |

Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

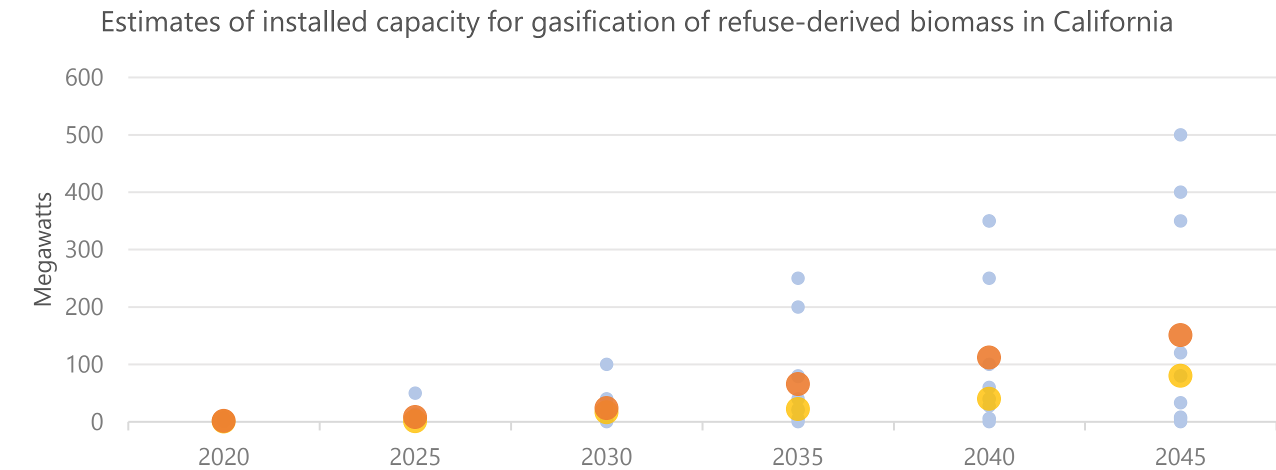
# CONCENTRATING SOLAR POWER

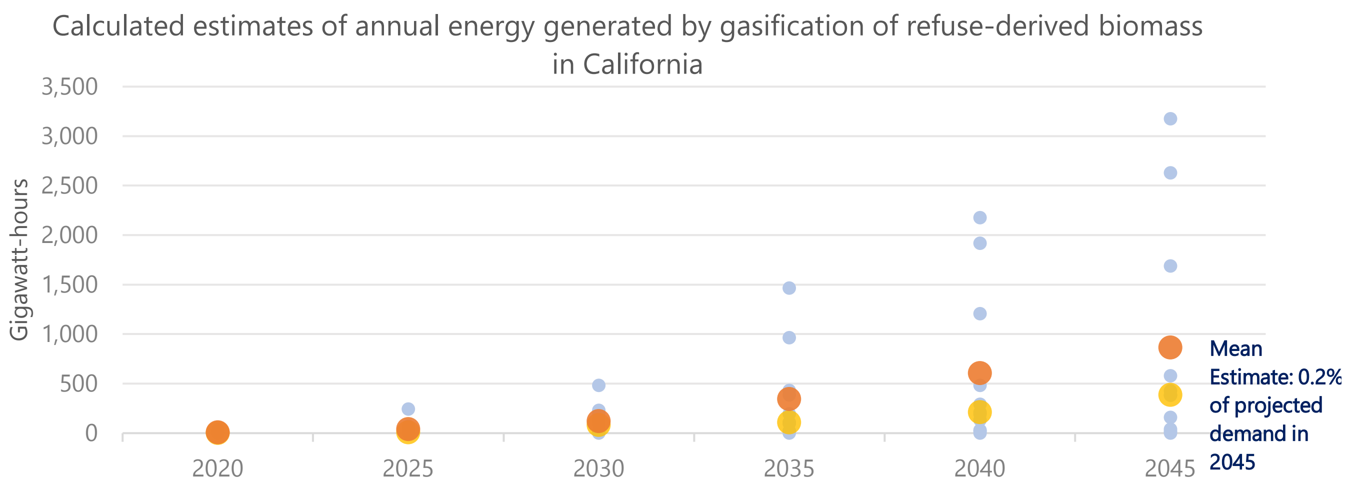
## Capacity Factor

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| **Mean** | **23%** | **25%** | **29%** | **31%** | **34%** | **35%** | | |
| **Median** | **23%** | **23%** | **28%** | **28%** | **28%** | **28%** | | |
| Expert A | 23% | 25% | 35% | 35% | 35% | 35% | | · More expensive than PV; can only succeed if it can achieve higher CF. Projections are based on assumption that new builds in 2035 and forward will achieve this. |
| Expert B | 23% | 23% | 23% | 23% | 23% | 23% | | · Current CF seems reasonable. |
| Expert C | 23% | 25% | 30% | 35% | 40% | 45% | | · Sulfur TES kicks in 2030. Curtailment is not a huge issue, since TES is on-site. |
| Expert D | 23% | 23% | 23% | 23% | 23% | 23% | | · Do not see much changing for the three existing CSP sites. |
| Expert E | 23% | 23% | 35% | 35% | 40% | 40% | | · 22-23% is low based on a small sample where some projects didn't perform very well. If there are any CSP projects after 2030, capacity factor might be better. |
| Expert F | 23% | 23% | 23% | 23% | 23% | 23% | | · No change as I don't think there will be more systems deployed commercially. |
| Expert G | 23% | 23% | 24% | 24% | 25% | 25% | | · Slow efficiency improvements likely with greater experience, but with less attractive sites over time. |
| Expert H | 23% | 23% | 24% | 25% | 25% | 25% | | · CSP provides firm dispatchable power; CF could potentially be much higher. Estimates tempered by transmission constraints and uncertainties about extent of wind and solar deployment. |
| Expert I | 23% | 33% | 44% | 54% | 65% | 75% | | · CF is low for parabolic troughs with single-axis tracking and no storage. As CSP shifts to power tower designs, it will operate more as baseload with higher CF. |
| Expert J | 23% | 28% | 33% | 38% | 47% | 48% | | · Improvement in CSP storage technology.<br>· High temperature applications, which may have lower losses and better heat retention. |
| Expert K | 23% | 28% | 28% | 28% | 28% | 28% | | · Slight increase by 2025 due to Ivanpah eventually ramping up to its projected potential but stays flat thereafter due to lack of further CSP deployment in CA. |

Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

## BIOENERGY: MUNICIPAL AND SOLID WASTE

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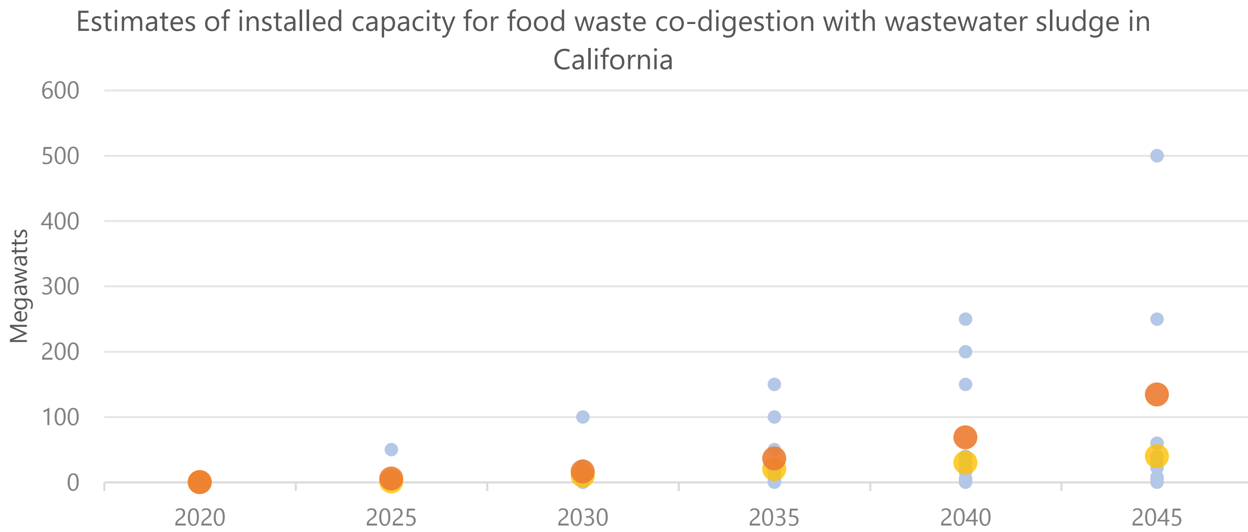


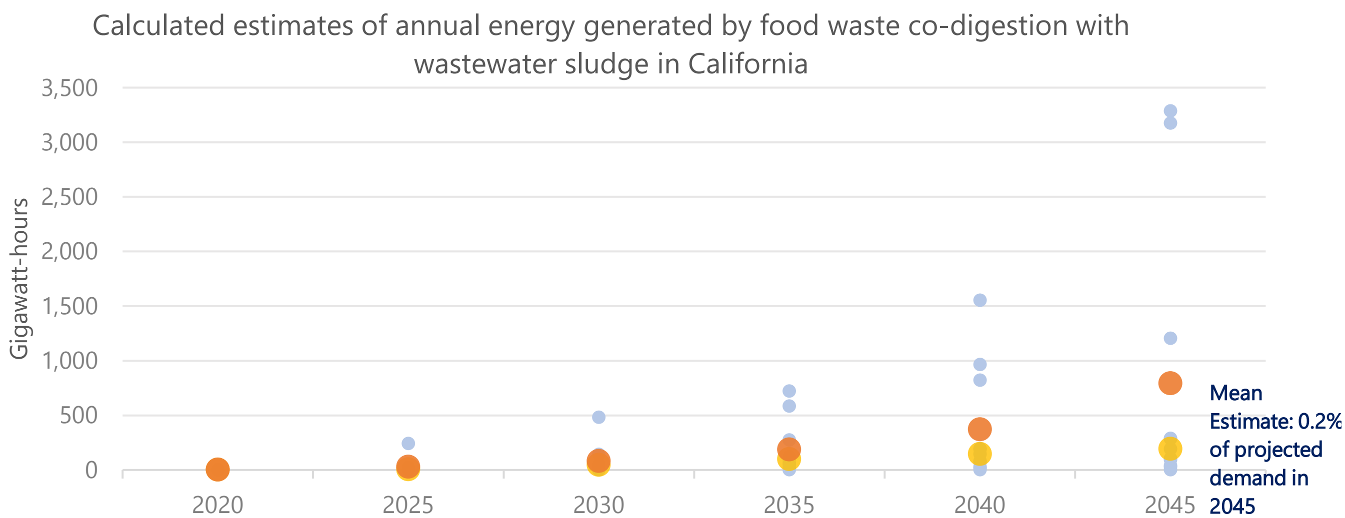


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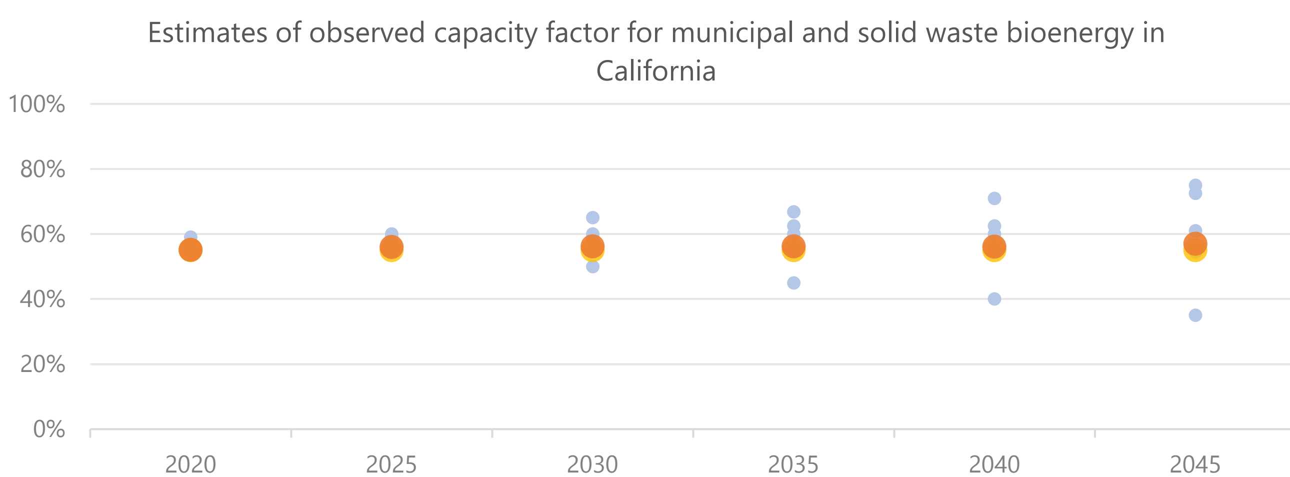



The mean estimate across experts is in orange and the median estimate is in yellow.

# BIOENERGY: MUNICIPAL AND SOLID WASTE

**Installed Capacity (MW): Gasification of refuse-derived biomass**

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| **Mean** | **1** | **8** | **24** | **65** | **112** | **151** | | |
| **Median** | **0** | **1** | **17** | **22** | **40** | **80** | | |
| Expert A | 2 | 5 | 5 | 5 | 5 | 5 | | · In the long-term, cost and complexity of this technology will make it less attractive than food waste co-digestion and other MSW technologies. |
| Expert B | 0 | 1 | 3 | 4 | 6 | 8 | | · Very niche market. Some increase since the early 2000s, but no breakthrough. And costly - generates electricity as a byproduct of a waste management project; requires local government/other customer to buy in. |
| Expert C | 0 | 0 | 0 | 0 | 0 | 0 | | · Can't develop large-scale since feedstock is limited. Cost becomes an issue small-scale. In the IRP process, CEC doesn't see any incremental change for bioenergy from today, at best it's emission neutral. Doesn't justify the cost - better to just put a solar panel on the same site. |
| Expert D | 0 | 10 | 30 | 40 | 60 | 80 | | · Not expecting much uptake for community-scale refuse plants due to costs and NIMBY concerns, but other drivers reducing emissions will increase deployment. |
| Expert E | 0 | 0 | 5 | 20 | 40 | 80 | | · Assume they can build their first full-scale project by 2030, but future deployment will face community buy-in and funding challenges. Technology would need to monetize co-benefits like fuels management. |
| Expert F | 6 | 11 | 17 | 22 | 28 | 33 | | · Technology sounds promising, especially assuming sufficient feedstock availability, but no generating costs or ROI were provided so it is difficult to project significant deployment over the next two decades. |
| Expert G | 0 | 50 | 100 | 200 | 250 | 350 | | · Attractive niche technology combining energy production and waste disposal, but with limited feedstock inputs. |
| Expert H | 0 | 0 | 2 | 20 | 40 | 80 | | · One demonstration-scale installation in 2030; medium-sized installation(s) added by 2035; and two full community-scale installations by 2045.<br>· Limited by challenges with community buy-in and funding. |
| Expert I | 0 | 0 | 40 | 250 | 350 | 400 | | · Small potential for MSW (<2 GW), but deployment is driven by further restrictions on GHG emissions, esp. methane. Likelihood of deployment increases if technology can be offered as a 'turnkey' service and financing is available. |
| Expert J | 7 | 13 | 21 | 79 | 350 | 500 | | · Cost reduction is impressive ($3-4K/kW), but possible competition with distributed solar. Unclear if utilities will invest or feedstock is reliable. Needs to be demonstrated for larger systems. |
| Expert K | 0 | 0 | 40 | 80 | 100 | 120 | | · Assumes a 40 MW demonstration project in 2030 and 2035 and a few smaller projects in 2040 and 2045. Projections in 2040 and 2045 may also represent a de-rating of earlier projects over time. The value of these technologies should also consider co-benefits like fuels management. |

Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

## BIOENERGY: MUNICIPAL AND SOLID WASTE

### Installed Capacity (MW): Food waste co-digestion with wastewater sludge

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Mean | 0 | 6 | 16 | 36 | 69 | 134 | | |
| Median | 0 | 1 | 10 | 20 | 30 | 40 | | |
| Expert A | 0 | 5 | 10 | 15 | 20 | 30 | | · More viable than gasification of refuse-derived biomass due to secondary benefits like reducing tipping fees, esp. when coupled with a strong carbon policy. |
| Expert B | 0 | 1 | 3 | 4 | 6 | 8 | | · Very niche market. Some increase since the early 2000s, but no breakthrough.<br>· Costly. Generates electricity as a byproduct of a waste management project. Requires local government/other customer to buy in. |
| Expert C | 0 | 0 | 0 | 0 | 0 | 0 | | · Can't develop large-scale since feedstock is limited. Cost becomes an issue small-scale. In the IRP process, CEC doesn't see any incremental change for bioenergy from today, at best it's emission neutral. Doesn't justify the cost - better to just put a solar panel on the same site. |
| Expert D | 0 | 0 | 10 | 25 | 40 | 60 | | · Food waste preprocessing and co-digestion not economically attractive, but co-benefits (e.g. complying with methane restrictions) will result in some deployment. |
| Expert E | 0 | 0 | 10 | 25 | 40 | 60 | | · Assumes half of market adoption potential (125 MW) by 2045. |
| Expert F | 1 | 2 | 6 | 11 | 17 | 22 | | · Sounds promising, but with COVID-19 shutdown of restaurants and schools, the necessary feedstock may not be available for the technology to achieve greater scales. That said, there is another value of a more circular (closed loop) economy. |
| Expert G | 0 | 50 | 100 | 150 | 200 | 250 | | · Attractive niche technology combining energy production and waste disposal, but with limited feedstock inputs. |
| Expert H | 0 | 0 | 0 | 1 | 3 | 5 | | · Economics are unclear. Seems it would only work for a few very large wastewater treatment plants. |
| Expert I | 0 | 2 | 25 | 100 | 250 | 500 | | · Small potential for MSW (<2 GW), but the real benefit is reduction of emissions, not electricity generation.<br>· Deployment driven by further restrictions on GHG emissions, particularly methane. Will take time to ramp up. Likelihood of deployment increased if technology can be offered as a 'turnkey' service and financing is available. |
| Expert J | 1 | 2 | 5 | 50 | 150 | 500 | | · Promising, seems like low hanging fruit. Max potential 1 GW: assume gas production improves 50-60% + existing max. potential of wastewater treatment-based energy 700 MW. Needs a lot of coordination with WWTPs and ensuring the plant doesn't introduce new contaminants with food waste co-digestion. |
| Expert K | 0 | 0 | 10 | 20 | 30 | 40 | | · Assumes 10 MW pilot project(s) by 2030, with another 10 MW added every five years through 2045. Because the 125 MW generation potential is very small, deployment driven by co-benefits rather than the value of power generation. |

Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

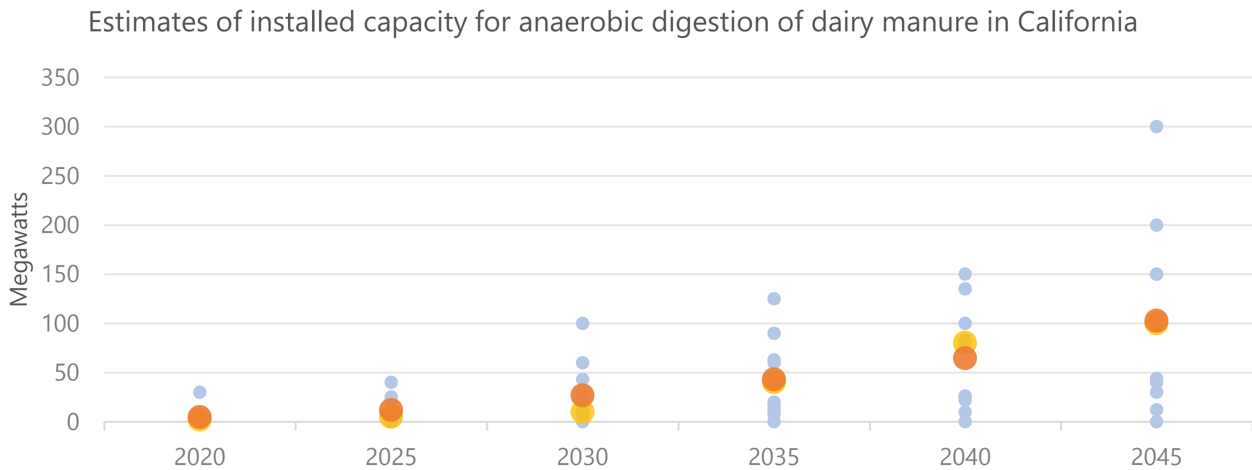
## BIOENERGY: MUNICIPAL AND SOLID WASTE

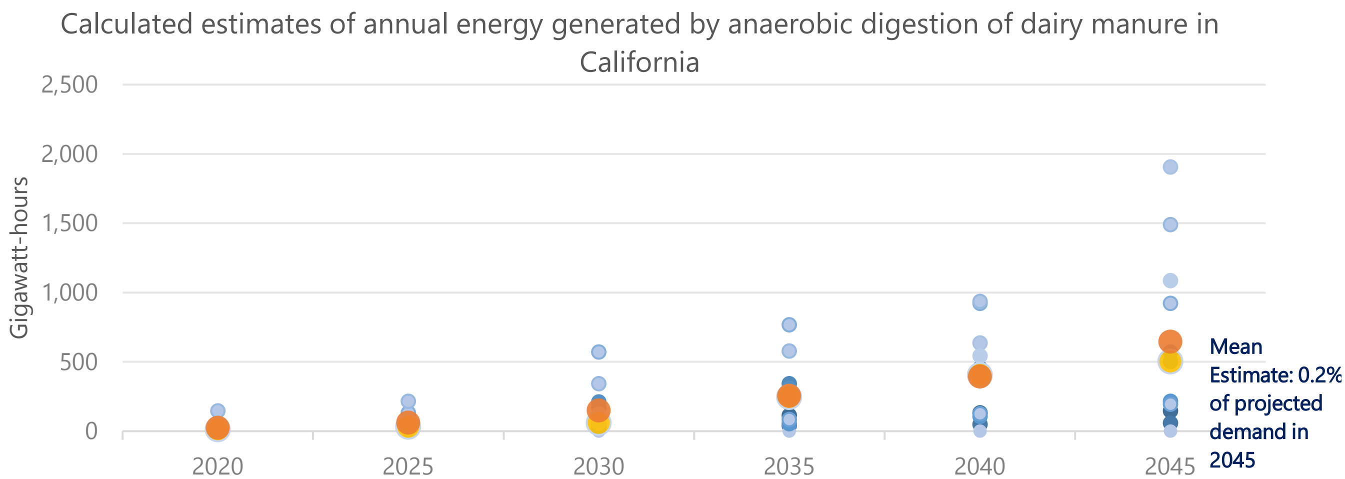
### Capacity Factor

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Mean | 55% | 56% | 56% | 56% | 56% | 57% | | |
| Median | 55% | 55% | 55% | 55% | 55% | 55% | | |
| Expert A | 55% | 55% | 50% | 45% | 40% | 35% | | · As we get to 2045 these plants will turn down their output in the middle of the day when we have solar generation. |
| Expert B | 55% | 55% | 55% | 55% | 55% | 55% | | · Midpoint of current CF seems reasonable. |
| Expert C | 55% | 55% | 55% | 55% | 55% | 55% | | · No new installations. |
| Expert D | 55% | 55% | 55% | 55% | 55% | 55% | | · Capacity factors should remain relatively constant. |
| Expert E | 55% | 55% | 55% | 55% | 55% | 55% | | · Assume no change, not because of the technology but because of limits on feedstock. |
| Expert F | 55% | 55% | 55% | 55% | 55% | 55% | | · Will likely stay in the same range as existing installations are operating at a very high CF compared to other generating technologies. |
| Expert G | 55% | 55% | 55% | 55% | 55% | 55% | | · No improvements anticipated. |
| Expert H | 59% | 59% | 59% | 60% | 60% | 61% | | · If barriers to entry are overcome, MSW bioenergy can provide a steady supply of firm energy capacity. But uncertainties about economics and fluctuations in input streams need to be managed. |
| Expert I | 55% | 59% | 65% | 67% | 71% | 75% | | · Capacity factor will increase if the technology can be commercialized and the feedstock issues can be resolved. |
| Expert J | 55% | 60% | 60% | 63% | 63% | 73% | | · Typically, though biopower technology has higher CF (~60-80%), this is not realized. After 2030 (with more renewables and retirement of base load units), biopower contribution may increase and hence the CF increase. |
| Expert K | 55% | 55% | 55% | 55% | 55% | 55% | | · Technologies appear to be working at their current maximum capacity. |

Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

## BIOENERGY: DAIRY WASTE

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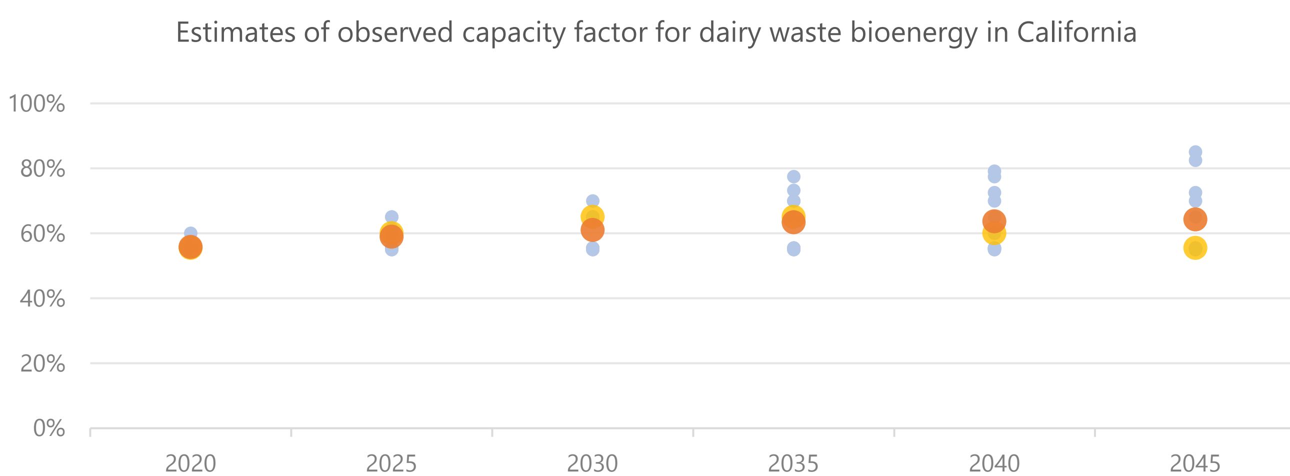



The mean estimate across experts is in orange and the median estimate is in yellow.

## BIOENERGY: DAIRY WASTE

Installed Capacity (MW): Anaerobic digestion of dairy manure

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| **Mean** | **5** | **12** | **27** | **43** | **65** | **103** | | |
| **Median** | **2** | **5** | **10** | **40** | **80** | **100** | | |
| Expert A | 2 | 5 | 10 | 20 | 25 | 30 | | · Potential for slow and steady growth based on continued investment in these facilities, including on-site usage for load reduction. But there is competition for the fuel – injecting it into the natural gas grid or heating/industrial gas uses. |
| Expert B | 2 | 4 | 6 | 8 | 10 | 12 | | · CA's Low Carbon Fuel Standard might support market adoption.<br>· May not be economical if only generating electricity revenue; more economically attractive to feed renewable natural gas into the pipeline. |
| Expert C | 0 | 0 | 0 | 0 | 0 | 0 | | · Size limit – has to be built on-site at the dairy farm. Hard to justify the cost. |
| Expert D | 5 | 10 | 30 | 60 | 80 | 100 | | · Will take time to develop; estimate 30% of technical potential by 2035.<br>· 2045 deployment reflects 50% of potential. Main driver of deployment in out years will be dairies complying with regulations to reduce methane emissions (SB 1383) while keeping costs down, given fewer options and more incentives. |
| Expert E | 3 | 23 | 43 | 63 | 83 | 103 | | · Assumes half of technical potential is reached by 2045.<br>· These will all be distributed projects. The economics are not sufficient for utility-scale installation. |
| Expert F | 1 | 3 | 6 | 11 | 22 | 44 | | · Adoption will be difficult for farmers until the agricultural economy recovers from COVID. The food and dairy supply will need to be stabilized, and the capital needed for 6-7 year payback may be difficult to finance. Technology is promising, however, especially when considering available feedstock. |
| Expert G | 1 | 5 | 10 | 17 | 26 | 40 | | · Attractive niche technology combining energy production with waste disposal. Makes sense economically but is difficult institutionally. |
| Expert H | 3 | 25 | 100 | 125 | 150 | 150 | | · Drivers include air quality concerns, climate pollution concerns, and turning a liability into a revenue stream for farmers. Assumes no change in extent of high-density cattle operations; not viable for smaller farms. |
| Expert I | 30 | 40 | 60 | 90 | 135 | 200 | | · EPIC project demos can help kickstart the market. Adoption will grow if dairies are legally required to reduce GHG emissions or if a market develops for turnkey service providers. Greater potential if adopted by non-dairy animal facilities. |
| Expert J | 1 | 3 | 10 | 40 | 100 | 300 | | · Promising- methane reduction can be achieved and also CHP with chilling system. Different construction of lagoon (double walled with lesser parasitic loss) and demand response (using the thermal energy) is promising. |
| Expert K | 5 | 10 | 20 | 40 | 80 | 150 | | · As the paybacks are reasonably good and the co-benefits can be substantial, projections assume gradual scale-up to 75% of stated potential by 2045. |

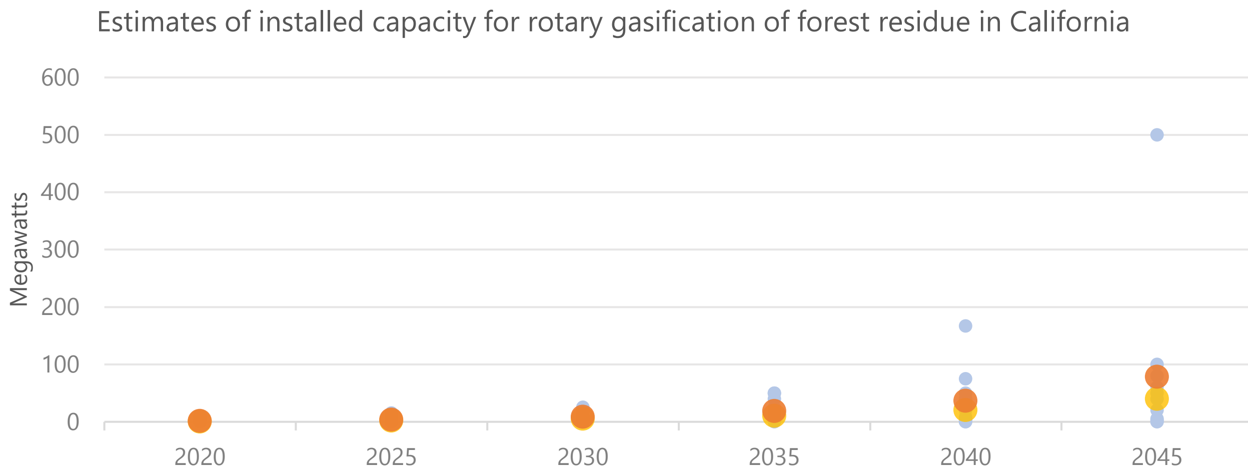
Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

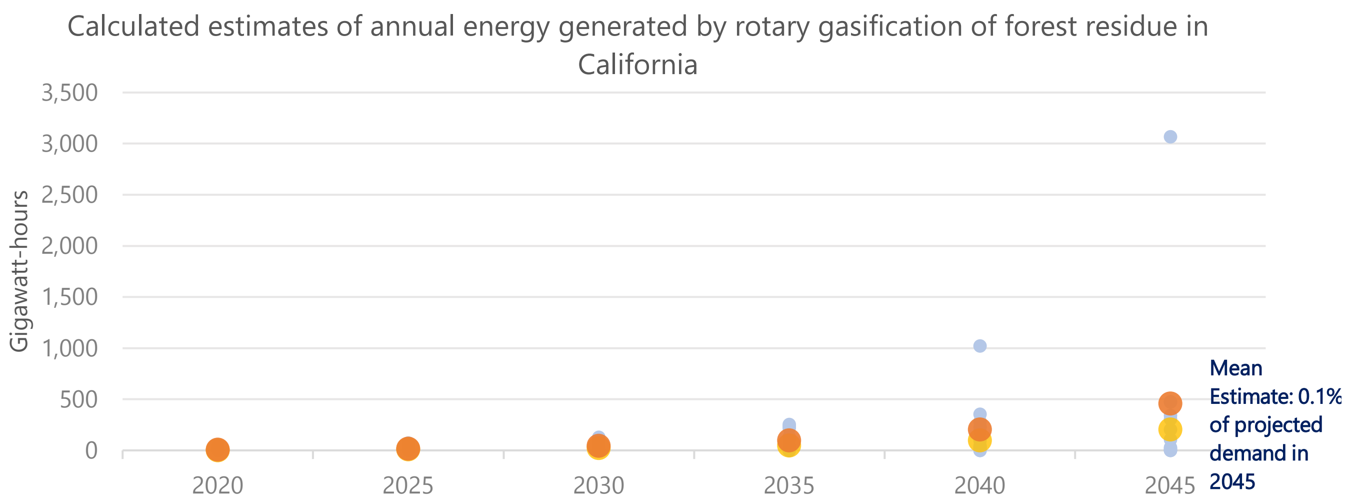
# BIOENERGY: DAIRY WASTE

## Capacity Factor

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Mean | 56% | 59% | 61% | 63% | 64% | 64% | | |
| Median | 56% | 60% | 65% | 65% | 60% | 56% | | |
| Expert A | 60% | 65% | 65% | 65% | 60% | 55% | | · Room for performance improvements in near-term. But to 2045, projects may be curtailed or reduce their input. Fuel is valuable, especially with competition between sectors. |
| Expert B | 55% | 55% | 55% | 55% | 55% | 55% | | · Midpoint of current CF seems reasonable. |
| Expert C | 56% | 56% | 56% | 56% | 56% | 56% | | · No new installations. |
| Expert D | 55% | 60% | 65% | 65% | 65% | 65% | | · The dairy digester systems averaged 84% CF or better. Observed CF would improve from the current 55% as more, higher CF generators are installed. |
| Expert E | 56% | 56% | 56% | 56% | 56% | 56% | | · No change; assume midpoint of historical range. |
| Expert F | 56% | 56% | 56% | 56% | 56% | 56% | | · Will likely stay in the same range as existing installations are operating at a very high CF compared to other generating technologies. |
| Expert G | 55% | 55% | 55% | 55% | 55% | 55% | | · No improvement anticipated. |
| Expert H | 56% | 60% | 65% | 70% | 70% | 70% | | · Source of firm capacity, tempered by constraints on transmission lines to rural areas, and uncertainties about feedstock and minimum sizes of cattle facilities. |
| Expert I | 56% | 61% | 65% | 73% | 79% | 85% | | · Capacity factor will increase if the technology can be commercialized. |
| Expert J | 56% | 65% | 65% | 70% | 73% | 73% | | · Improved CF when connected with CHP and Demand Response.<br>· Double-walled lagoon seems to have less parasitic losses, and the integrated CHP will lower in-house/local demand. |
| Expert K | 56% | 60% | 70% | 78% | 78% | 83% | | · Demonstration project seems to be running at higher CFs than observed in the recent past (e.g., 80-90%). These projects will pull up the overall average over time as more capacity of similar type is deployed. |

Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

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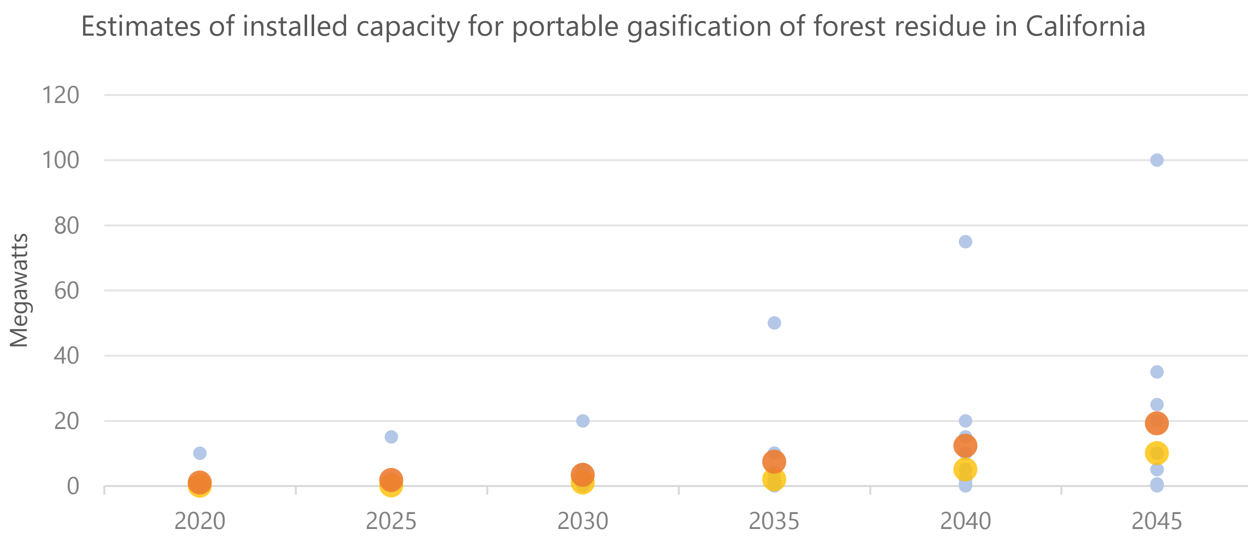


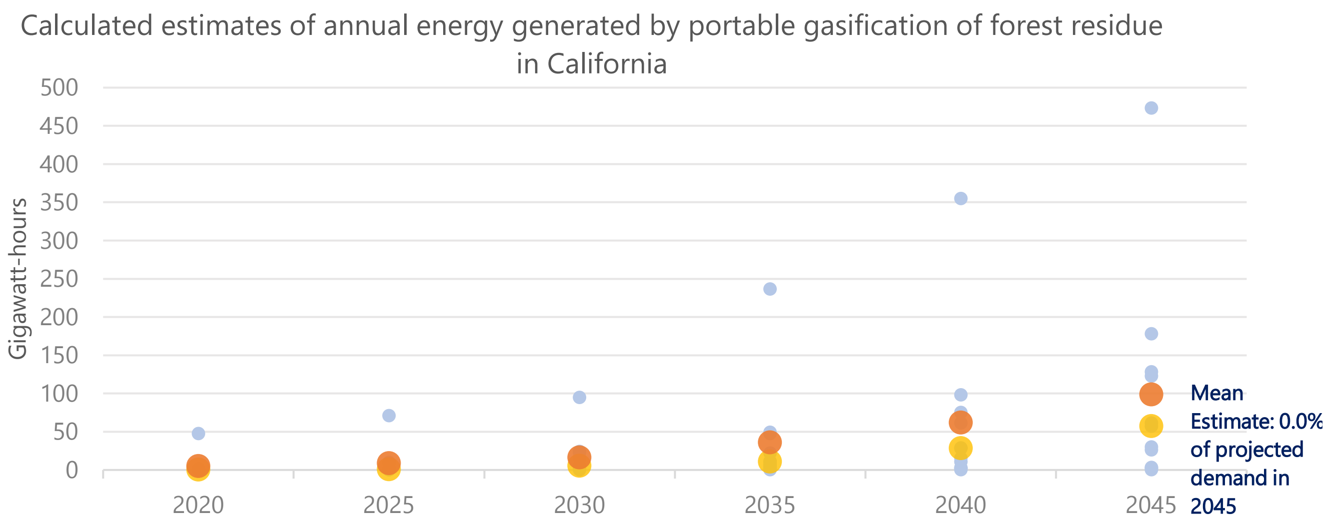


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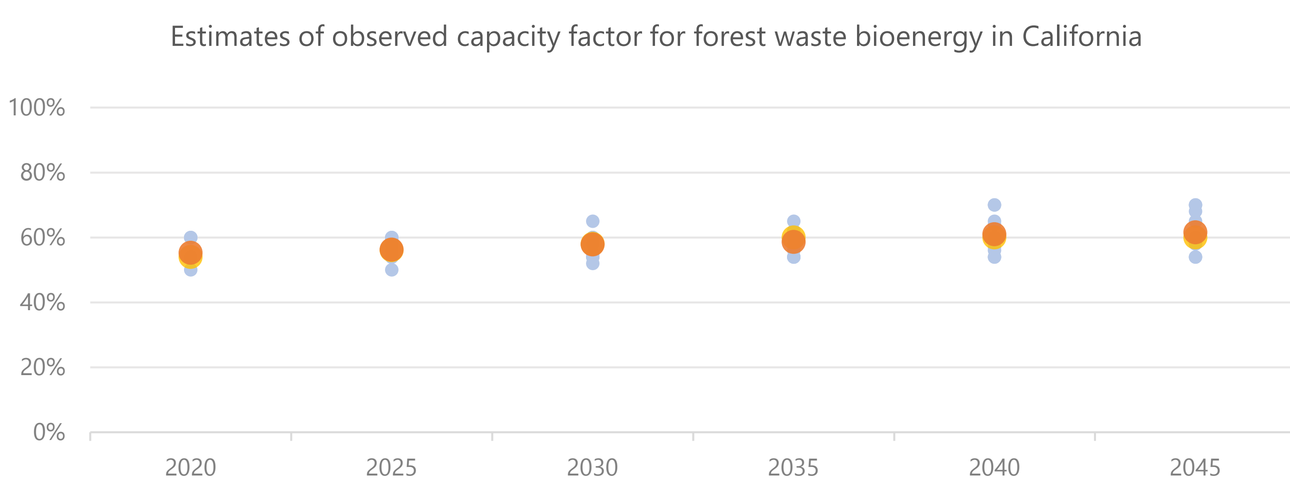


The mean estimate across experts is in orange and the median estimate is in yellow.

## BIOENERGY: FOREST WASTE

### Installed Capacity (MW): Rotary gasification of forest residue

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| **Mean** | **1** | **3** | **9** | **19** | **36** | **78** | | |
| **Median** | **0** | **2** | **5** | **10** | **20** | **40** | | |
| Expert A | 0 | 1 | 4 | 6 | 8 | 20 | | · Torrefaction is well understood. Rotary gasification is lower risk and simpler than portable gasifier approach. |
| Expert B | 3 | 3 | 4 | 4 | 5 | 5 | | · Projection includes planned demonstration capacity. Electricity generation is a byproduct of forestry waste management; with wildfires, interest in managing forests could grow. Biochar market is small; tipping fees and transport costs could exceed revenues from electricity and biochar sales.<br>· Demand depends on stakeholders outside electric utilities. |
| Expert C | 0 | 0 | 0 | 0 | 0 | 0 | | · CA's high env. standards and cost makes this noncompetitive with other renewables. No additional GHG emission reduction from existing biomass plants. |
| Expert D | 3 | 10 | 25 | 40 | 50 | 80 | | · LCOE for new system ~$242/MWh, assuming no revenue from biochar co-product, but LCOE is highly dependent on the price of biochar and could be lower, even negative, at higher biochar prices. Assume capacity factor of 81%, and heat rate 26,656 Btu/kWh. Environmental permitting and interconnection issues remain unresolved. Transportation costs of fuel could limit deployment. |
| Expert E | 0 | 0 | 0 | 0 | 0 | 0 | | · Cost is high and experience with biomass has been mixed. There is a lot of public opposition to biomass. There is a lot of uncertainty for this technology. Future deployment driven by co-benefits would likely require incentives. |
| Expert F | 10 | 15 | 20 | 50 | 75 | 100 | | · Technology is promising; deployment depends on permitting and verifying Europe data. A challenge is potential disruption of feedstock delivery and production driven partly by feedstock location and transportation costs. |
| Expert G | 0 | 2 | 5 | 10 | 20 | 40 | | · Attractive niche technology combining energy production, waste disposal and forest management/fire suppression. Biochar can be redeposited into topsoil for agriculture. |
| Expert H | 0 | 3 | 3 | 3 | 3 | 3 | | · No additional deployment. Growth requires active development of forest management incentives. Significant uncertainty around the biochar market. |
| Expert I | 0 | 0 | 10 | 24 | 40 | 60 | | · Has potential, but is limited by feedstock availability and transport costs. |
| Expert J | 0 | 1 | 17 | 50 | 167 | 500 | | · Reduces wildfire risk, but transportation and processing costs seem high; biofuel competition. Future deployment depends on biochar market and feedstock availability. |
| Expert K | 0 | 3 | 9 | 18 | 30 | 50 | | · Even though expensive, managing forest/ag residue is important for CA, so co-benefits warrant some deployment. European experience is a plus. Assume an initial pilot online by 2025, and then accelerated adoption thereafter. |

Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

## BIOENERGY: FOREST WASTE

**Installed Capacity (MW): Portable gasification of forest residue**

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| **Mean** | **1** | **2** | **3** | **7** | **12** | **19** | | |
| **Median** | **0** | **0** | **1** | **2** | **5** | **10** | | |
| Expert A | 0 | 0 | 1 | 2 | 2 | 5 | | · Seems risky, but if LCOE targets are hit it could be very successful. |
| Expert B | 0 | 0 | 0 | 0 | 0 | 1 | | · Electricity generation is a byproduct of forestry waste management. With wildfires, interests in managing forests could grow. Permitting could be difficult, but perhaps manageable. Demand depends on stakeholders outside electric utilities. |
| Expert C | 0 | 0 | 5 | 10 | 15 | 25 | | · Portable, but siting limitation and immature technology delay deployment. |
| Expert D | 0 | 2 | 3 | 4 | 5 | 5 | | · Powertainer design: estimated installed cost of $111,000/unit; if meets the target of 150 kW, this translates to $1,270/kW. Projected LCOE $117/MWh once system is commercialized and producing 7,560 GWh annually at a 60% CF. Unclear where the mobile unit would connect to the grid. Larger, stationary resources seem more viable than the portable gasifier. |
| Expert E | 0 | 0 | 0 | 0 | 0 | 0 | | · Cost is high and experience with biomass has been mixed. There is a lot of public opposition to biomass. |
| Expert F | 10 | 15 | 20 | 50 | 75 | 100 | | · Technology is promising, but biochar is the limiting factor. Trees will not be grown specifically for biochar production, so biochar will need to be “gathered"-may have secondary benefit of culling forests and reducing fire hazards. |
| Expert G | 0 | 2 | 5 | 10 | 20 | 35 | | · Attractive niche technology combining energy production, waste disposal and forest management/fire suppression. Brings processing capacity to where the residues are. |
| Expert H | 0 | 0 | 0 | 1 | 1 | 1 | | · Growth potential due to cost improvements and portability of the technology. But seems early stage; potential pitfalls around scalability and mass production. |
| Expert I | 0 | 0 | 1 | 2 | 5 | 10 | | · Some deployment possible-could be used to power parks or resorts, or coupled with batteries. Hard to see widely grid-integrated given the difficulty of interconnecting. Not particularly reliable for electricity, main objective is managing the fuels. |
| Expert J | 0 | 0 | 1 | 1 | 3 | 10 | | · Assumes up to 100 plants, 150 kW each (15MW). Modular units, with reliable forest residue supply, is attractive. But lower potential, as tested for small facilities. Competition from distributed solar and biofuels. Low capacity factor - biofuels may be a better option. Needs reliability testing. |
| Expert K | 0 | 0 | 1 | 1 | 10 | 20 | | · Even though expensive, the co-benefits likely warrant some deployment. Current small, modular scale, but presuming success, modest deployment is possible. |

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## BIOENERGY: FOREST WASTE

### Capacity Factor

*According to the grantee, capacity factor for organic Rankine cycle systems tends to be relatively high (80-90%) for existing installations, primarily in Europe.*

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Mean | 55% | 56% | 58% | 59% | 61% | 62% | | |
| Median | 54% | 56% | 58% | 60% | 60% | 60% | | |
| Expert A | 60% | 60% | 60% | 60% | 60% | 60% | | · Assume constant level of performance, but utilization factor largely driven by secondary markets, so CF could go up if there a lot more trimmings available.<br>· Reflects higher CFs achieved by projects in Europe. |
| Expert B | 60% | 60% | 60% | 60% | 60% | 60% | | · Stays on once it is fired up. But portable gasifier unlikely to be grid connected. |
| Expert C | 54% | 54% | 55% | 56% | 57% | 59% | | · Slight increase due to technology improvement. |
| Expert D | 54% | 56% | 58% | 62% | 64% | 68% | | · New utility-scale units report capacity factors of ~80%.<br>· Reflects higher CFs achieved by projects in Europe. |
| Expert E | 54% | 54% | 54% | 54% | 54% | 54% | | · No change. Ideally with gasification you should get better efficiency, but experience is lacking. |
| Expert F | 54% | 54% | 54% | 54% | 54% | 54% | | · CF will likely stay in the same range as existing installations but potential for further increase if biochar density and burn temperatures are improved over time. |
| Expert G | 50% | 50% | 52% | 54% | 56% | 58% | | · Modest improvement expected as learning expands, especially in materials handling. |
| Expert H | 60% | 60% | 60% | 60% | 60% | 60% | | · Held CF steady due to uncertainties around consistency of feedback availability and future directions for forest management in CA. |
| Expert I | 54% | 59% | 60% | 62% | 65% | 65% | | · Capacity factor will increase if the technology can be commercialized. Feedstock availability will continue to be a challenge. |
| Expert J | 54% | 54% | 58% | 58% | 70% | 70% | | · With decrease in base load units after 2030, biopower can be utilized more. Rotary gasifier might increase CF after 2030 if penetration increases. The portable gasifier has a lower CF (~60%), reducing overall CF estimates. |
| Expert K | 54% | 58% | 65% | 65% | 70% | 70% | | · Modest increase in capacity factor over time as new technology with higher CFs penetrates the market. |

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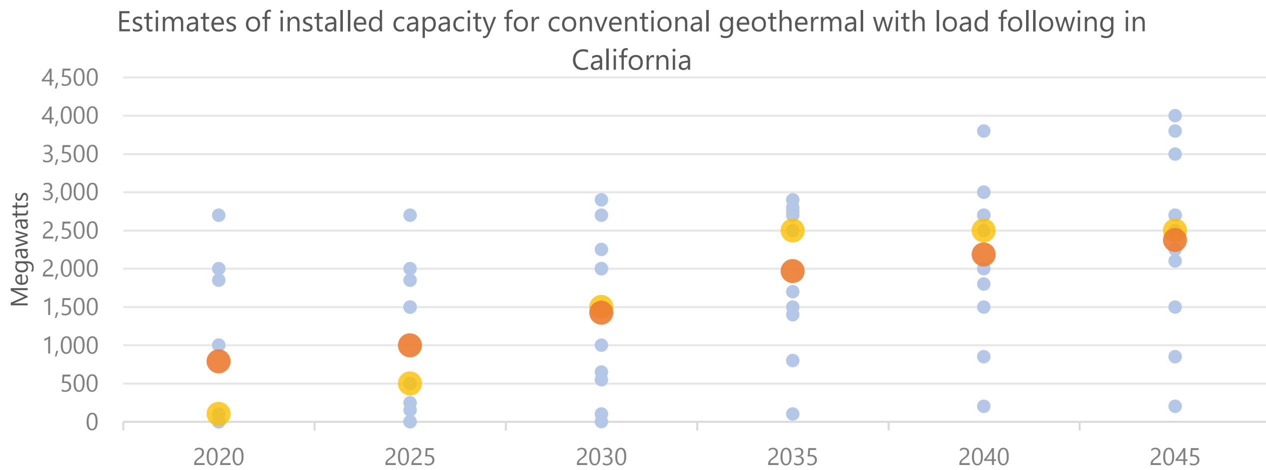
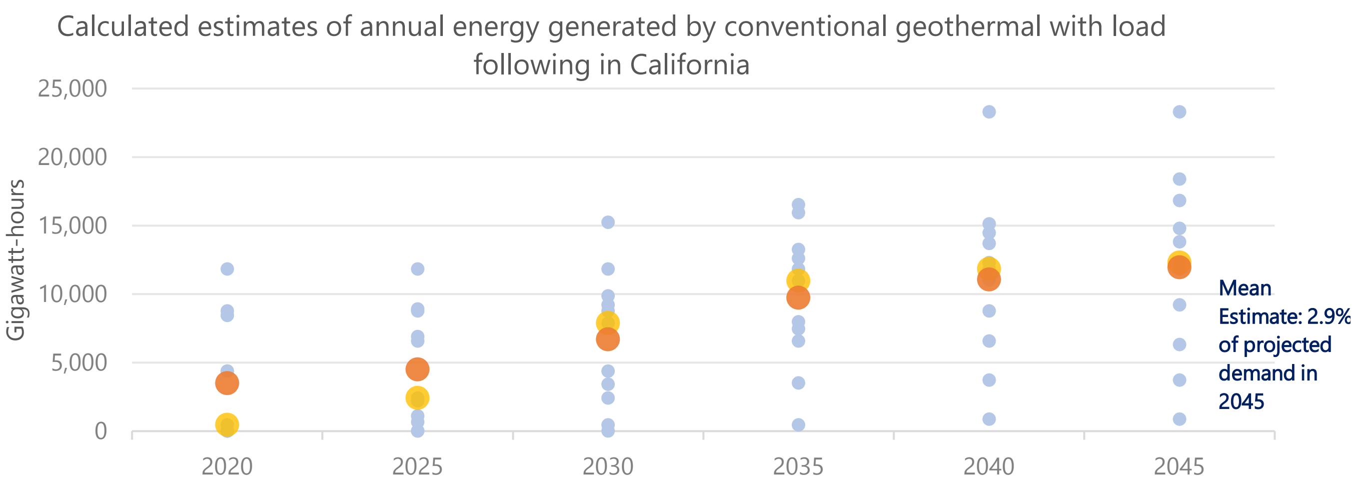
## GEOTHERMAL

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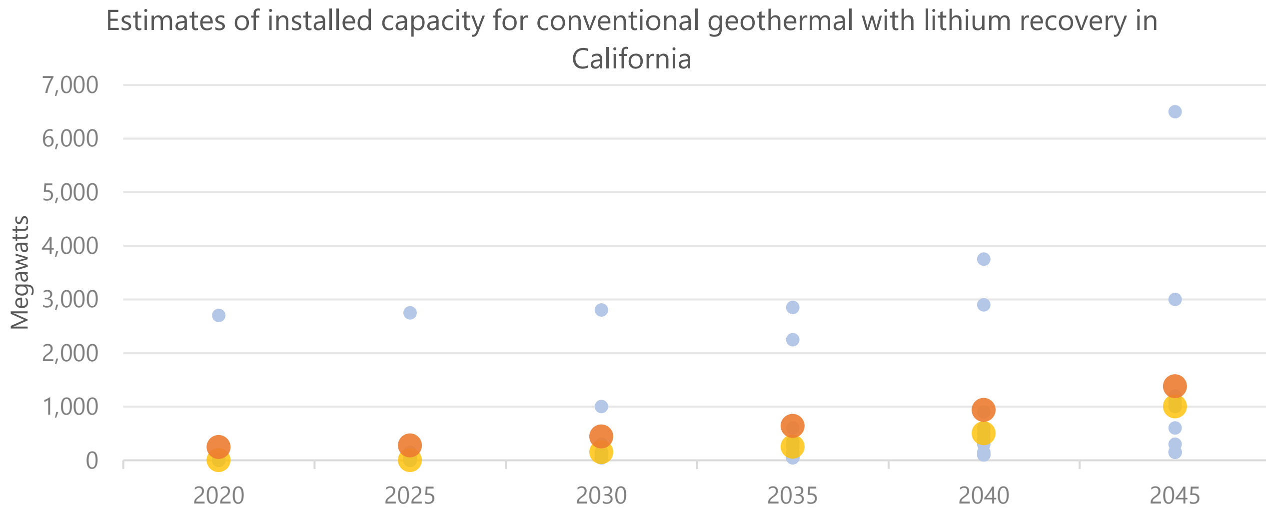
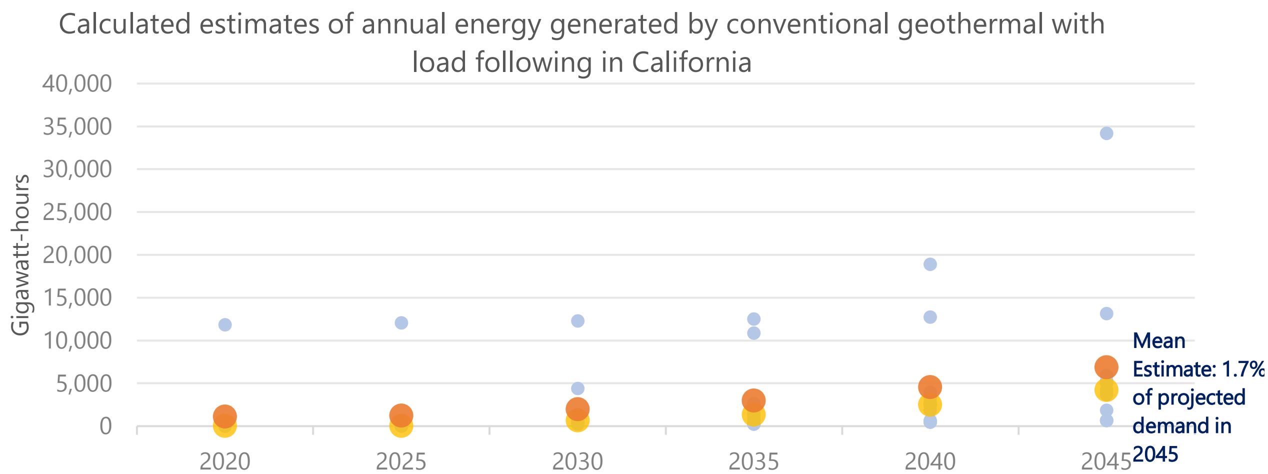
The mean estimate across experts is in orange and the median estimate is in yellow.

## GEOTHERMAL

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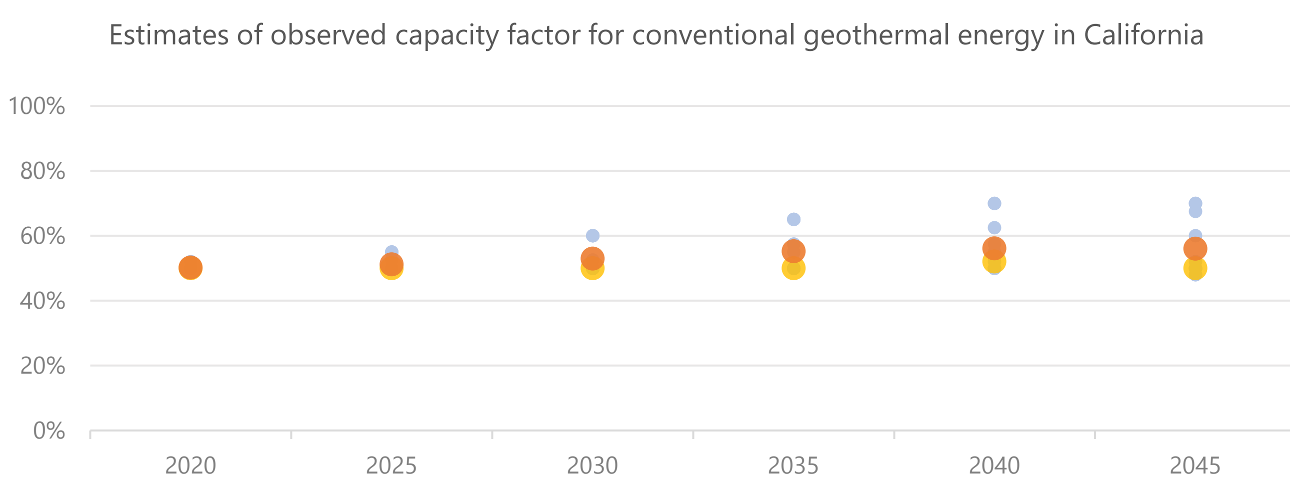



The mean estimate across experts is in orange and the median estimate is in yellow.

## GEOTHERMAL

### Installed Capacity (MW): Conventional geothermal with load following

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| **Mean** | **786** | **995** | **1,423** | **1,968** | **2,186** | **2,373** | | |
| **Median** | **100** | **500** | **1,500** | **2,500** | **2,500** | **2,500** | | |
| Expert A | 100 | 500 | 1,500 | 2,800 | 3,000 | 4,000 | | · Clear CAISO market signals and low price hours from high solar generation will drive adoption. |
| Expert B | 0 | 150 | 650 | 1,400 | 1,800 | 2,250 | | · Load-following alone will not increase geothermal installed capacity or reduce LCOE. Project will improve the ramp rate.<br>· Geothermal capacity additions will help fulfill CA's RPS requirement, after solar (solar will fulfill most of the requirement). |
| Expert C | 1,850 | 1,850 | 2,900 | 2,900 | 3,800 | 3,800 | | · Reliable and effective. Despite higher cost, can compete against solar/battery due to high CF and effectiveness in meeting load in the evening peak net load hours (a portion of the existing geothermal is dispatchable). |
| Expert D | 1,000 | 1,500 | 2,000 | 2,500 | 2,700 | 2,700 | | · Includes new and existing installations - load following will be added to all new conventional geothermal plants.<br>· Deployment will be constrained by cost (including expiration of tax credits in near term), water availability and insufficient transmission to remote sites. |
| Expert E | 0 | 0 | 100 | 100 | 200 | 200 | | · Includes new and existing installations - deployment constrained by cost (including expiration of tax credits in near term), water availability, and transmission. The market is not lucrative enough to support this technology for existing or new geothermal capacity, unless CAISO redesigns its ancillary services markets. |
| Expert F | 2,700 | 2,700 | 2,700 | 2,700 | 2,700 | 2,700 | | · Good candidate for retrofitting the existing 2.7 GW of capacity. |
| Expert G | 0 | 250 | 550 | 800 | 850 | 850 | | · Tough technology development, but with hard work it could play a substantial role. Influenced by Experts D and H. Geothermal could compete with solar/battery, but geothermal is dispatchable. |
| Expert H | 0 | 500 | 1,000 | 1,500 | 1,500 | 1,500 | | · Estimates refer to enhanced load following beyond existing capabilities. Increased flexibility is challenging, but incentives exist to figure it out. More tangible than early-stage technologies; involves changing facility operations to do more ramping than they do now. |
| Expert I | 0 | 0 | 0 | 1,700 | 2,000 | 2,100 | | · The ISO will want to use this, but unclear what economic incentives will be in place for the geothermal plant.<br>· Assuming proper incentives to cut production, the bulk of geothermal will be load following. |

Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

## GEOTHERMAL

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Expert J | 2,000 | 2,000 | 2,250 | 2,750 | 3,000 | 3,500 | | · Increased revenues from ancillary services like flexible ramping product (in CAISO market) and spinning reserves.<br>· Turbine bypass technology may have good steamfield performance, but heat seems wasted. If steamfield can be altered such that heat can be saved, might increase CF and lifetime, though cost may increase for adding advanced controls to alter the steamfield. |
| Expert K | 1,000 | 1,500 | 2,000 | 2,500 | 2,500 | 2,500 | | · The Geysers is already load-following. Assume additional adoption by mostly existing plants but also a few new plants through 2035, but then stagnates as massive battery deployment flattens out the system net load profile through arbitrage, thereby diminishing the value of load-following. |

**Installed Capacity (MW): Conventional geothermal with lithium recovery**

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| **Mean** | **246** | **273** | **441** | **636** | **936** | **1,377** | | |
| **Median** | **0** | **0** | **150** | **250** | **500** | **1,000** | | |
| Expert A | 0 | 5 | 50 | 250 | 500 | 1,000 | | · Technology still needs to be proven, but increasing lithium value will drive much of the new built geothermal to support lithium recovery. |
| Expert B | 0 | 0 | 150 | 150 | 300 | 300 | | · Construction lead time of 4 years; no near-term capacity additions.<br>· Long term capacity additions depend on lithium carbonate demand. If capacity additions (even initially) are driven by lithium demand, cost reduction would make geothermal attractive. But plants built to support lithium recovery are unlikely to feed electricity back to the grid, unless plant is oversized for the operation. |
| Expert C | 0 | 0 | 100 | 100 | 400 | 600 | | · Cost is the hurdle. The technology is not mature yet. |
| Expert D | 0 | 50 | 150 | 300 | 600 | 1,100 | | · Lithium extraction process has payback of ~1 year. This will help make the technology more competitive.<br>· Projections reflect new and existing installations. May not be implemented at all new sites – depends on brine chemistry, lithium concentration at the site, and lithium price. Lithium prices could rise due to need for additional storage and electrification of the transportation sector.<br>· PTCs are expected to expire, so it will be a while before new projects are undertaken. The Current Market Overview states new commercial facilities are targeted for deployment in 2030. |

Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

## GEOTHERMAL

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Expert E | 0 | 0 | 50 | 50 | 150 | 150 | | · Assume relevant to flash and binary plants, not dry steam. Would need substantial government investment to proceed past these low estimates.<br>· Assume load following and lithium recovery could both be adopted at sites where lithium can be recovered (e.g., Salton Sea area). |
| Expert F | 2,700 | 2,750 | 2,800 | 2,850 | 2,900 | 3,000 | | · Lithium recovery has a significant growth trajectory over the next decade. Assume one 50 MW plant can be permitted every 5 years. This technology may need the load flexibility innovation offered by prior grant 14-002. |
| Expert G | 0 | 0 | 50 | 50 | 100 | 150 | | · Tough technology development, but large long-run potential for supplying energy and critical materials. |
| Expert H | 0 | 0 | 50 | 50 | 100 | 150 | | · Unproven, very early stage. Skeptical how quickly can ramp up.<br>· Highly sensitive to lithium market. Recent push to increase domestic production of energy technologies, but unclear if this will affect the supply chain long-term. |
| Expert I | 0 | 0 | 300 | 600 | 900 | 1,200 | | · There is a growing market for lithium, but it is unclear how this compares with regular lithium production.<br>· If the payback is only one year, existing resources should convert to lithium production within 10 years. |
| Expert J | 10 | 150 | 1,000 | 2,250 | 3,750 | 6,500 | | · Pros: Higher impact, as cost recovery. Existing geothermal facilities may benefit. Project 3-10 GW in 2045 - more new plants are possible if economics improve. Assumes enhanced geothermal hits the market after 2030, and if lithium recovery improves costs, there will be more penetration.<br>· Cons: Technical feasibility of exploration is a huge task and requires capital. |
| Expert K | 0 | 50 | 150 | 350 | 600 | 1,000 | | · Estimated payback of just one year seems fantastic (assuming achievable). Demand for lithium spurred by massive battery deployment increases this technology's chance of success. Projections assume single 50 MW prototype by 2025, with scale up thereafter (in concert with IID's 1.7 GW development goal). Presumes lithium resource mostly limited to Salton Sea area. |

**Capacity Factor**

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Mean | 50% | 51% | 53% | 55% | 56% | 56% | | |
| Median | 50% | 50% | 50% | 50% | 52% | 50% | | |
| Expert A | 50% | 55% | 60% | 65% | 55% | 48% | | · Some room for improvement near term with improved O&M practices. Assuming load-following capability is successful, slight decrease in output with more load-following. |

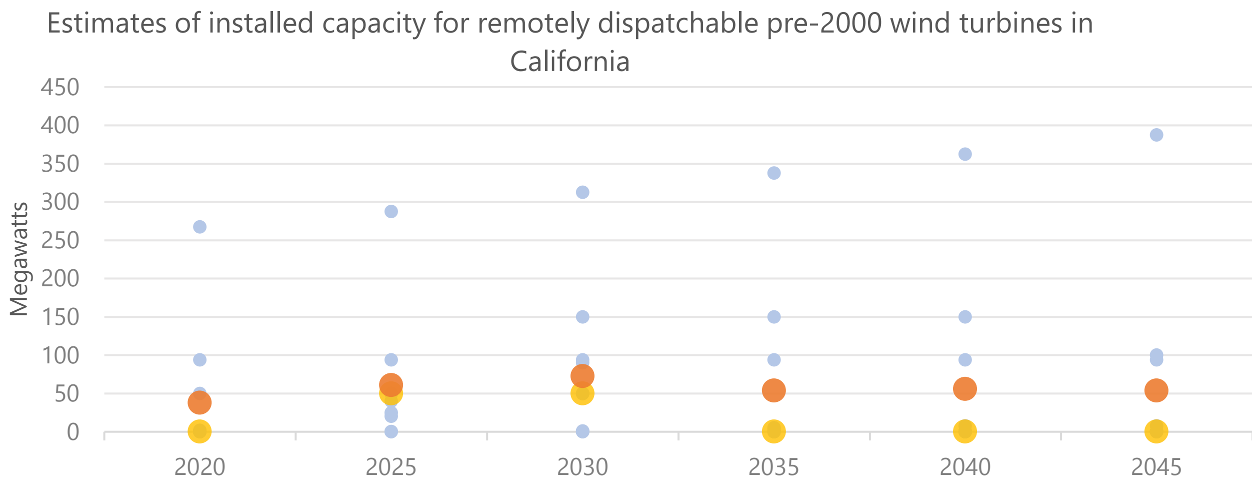
Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

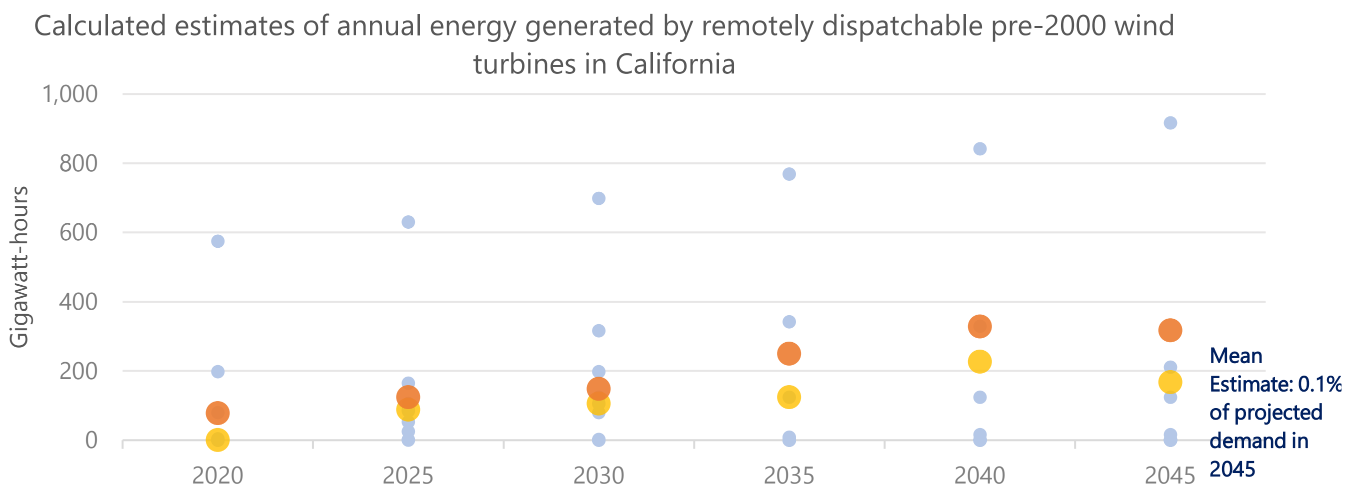
## GEOTHERMAL

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Expert B | 50% | 50% | 60% | 65% | 70% | 70% | | · Will probably come online more often, driving up the observed CF.<br>· Requirements for renewables will peak around 2030, possibly forcing gas units to retire and allowing geothermal to shine. |
| Expert C | 52% | 55% | 60% | 65% | 70% | 70% | | · If we can resolve the issue of transmission constraints, that will reduce curtailment. We will need to make a larger portion dispatchable. Storage will also increase CF.<br>· If we can diversify the portfolio and do a good job in transmission timing, this CF is achievable. |
| Expert D | 50% | 50% | 50% | 50% | 52% | 52% | | · Despite curtailments during the day and new systems largely being load following, CF will increase due to higher capacity factors at night (due to retirement of nuclear and natural gas plants) and co-benefits of lithium production (provides incentive to continue production during the day). |
| Expert E | 50% | 50% | 50% | 50% | 50% | 50% | | · CF will remain constant as load following and lithium recovery focus on flexibility and cogeneration, which will not affect CF. |
| Expert F | 50% | 50% | 50% | 50% | 50% | 50% | | · Technology improvements are aimed at flexibility and cogeneration of a byproduct, not improving technology capacity factors. |
| Expert G | 50% | 50% | 50% | 50% | 50% | 50% | | · Technology improvement will be offset by issues with materials flow and cleanup. |
| Expert H | 50% | 50% | 50% | 50% | 50% | 48% | | · Geothermal is good backup for renewables and a firm resource, but increasing concerns about water stress by mid-century will result in reduced CF in 2045. |
| Expert I | 50% | 50% | 50% | 50% | 50% | 50% | | · Curtailment would bring capacity factor down, but there will also be new transmission. |
| Expert J | 50% | 50% | 50% | 55% | 58% | 60% | | · Pros: Higher impact with cost recovery. More new plants possible if economics improve. When enhanced geothermal hits the market after 2030, and if lithium recovery improves costs, then there will be more penetration.<br>· Cons: Technical feasibility of exploration is a huge task, and will require capital. |
| Expert K | 50% | 53% | 53% | 58% | 63% | 68% | | · Economic curtailment remains a hurdle as long as costs are higher than solar. But as nuclear and natural gas phase out, less curtailment of geothermal (night-time generation will be valued) leads to higher CFs. Co-benefits of lithium production will provide greater incentive to run (or at least keep brine circulating). |

Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

## WIND

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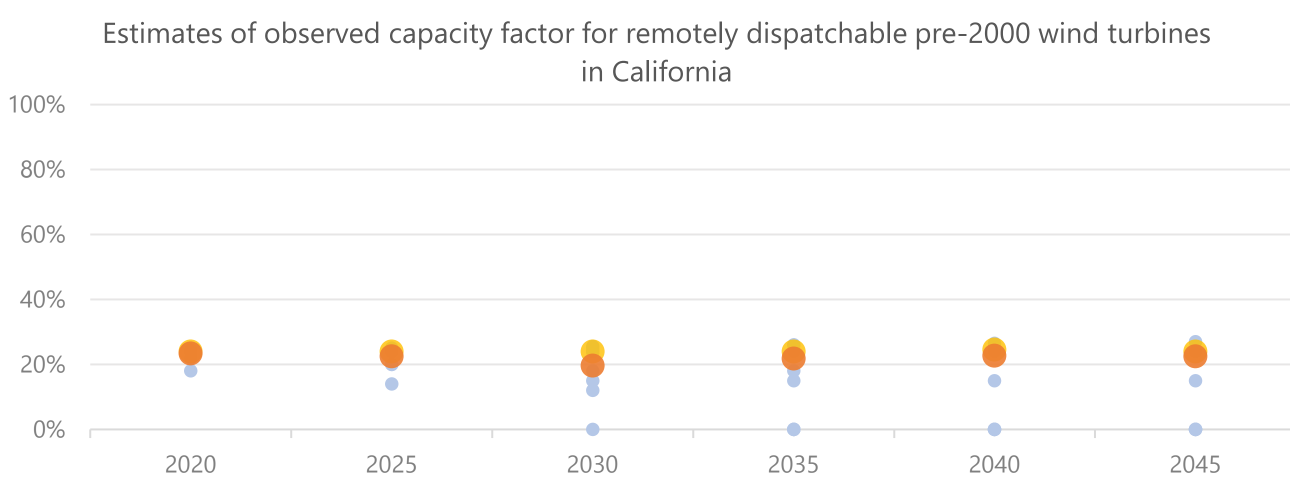


The mean estimate across experts is in orange and the median estimate is in yellow.

## WIND

### Installed Capacity (MW): Remotely dispatchable pre-2000 wind turbines

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| Mean | 38 | 61 | 73 | 54 | 56 | 54 | | |
| Median | 0 | 50 | 50 | 0 | 0 | 0 | | |
| Expert A | 1 | 25 | 0 | 0 | 0 | 0 | | · Low costs/overgeneration challenges will encourage adoption, but variety of models and turbine owners prove a challenge. Old turbines will be repowered with technology that's more cost effective, larger in scale, and has a better CF. |
| Expert B | 94 | 94 | 94 | 94 | 94 | 94 | | · Few wind power plant owners will retrofit existing turbines, some newer turbines might with low estimated capital cost. Turbines will likely be retired or repowered. PTC expiration and flat marginal power price make repowering uneconomical. |
| Expert C | 0 | 0 | 0 | 0 | 0 | 0 | | · Turbines are retiring or soon to be retired - small and inefficient, don't justify cost to install remote devices. Because of siting, more valuable to replace with larger, more efficient turbines and taller towers. Each tower provides <1 MW, but a new one on the same site would be at least 7 MW. |
| Expert D | 2 | 50 | 50 | 5 | 0 | 0 | | · Cost per turbine could be reduced to $100. However, sites for wind in CA are limited- will replace older turbines with more efficient ones. Braking would hasten end-of-life. Other means exist to address negative LMP's. |
| Expert E | 0 | 50 | 150 | 0 | 0 | 0 | | · Oldest turbines will be replaced - the ones installed in mid-1990s will remain until 2030. |
| Expert F | 268 | 288 | 313 | 338 | 363 | 388 | | · Valuable to optimize existing, operating assets. Assume improvement of 30-50% over time. Maintenance issues limit further deployment in out years. |
| Expert G | 0 | 40 | 90 | 150 | 150 | 100 | | · Technology seems advantageous and relatively low cost, though offset by physical and economic depreciation. Near term, technology increases output of existing capacity. Assumes technology is scalable. At some point, however, the advantage becomes harder to maintain relative to age of turbines. |
| Expert H | 0 | 50 | 50 | 0 | 0 | 0 | | · Only relevant to upgraded turbines, but most turbines will be replaced or retired. |
| Expert I | 0 | 50 | 50 | 0 | 0 | 0 | | · Pre-2000 turbines are much less efficient and lower height. Maybe a short-term bump, but older turbines will be replaced with better technology in long-term. |
| Expert J | 0 | 0 | 1 | 3 | 8 | 8 | | · Reduces operating costs (no generation during negative prices or load charges) and grid stability issues. May increase value if tested for flexible generation. But wear and tear due to curtailment/braking may increase cost of flexible operation and lead to energy loss. |
| Expert K | 50 | 20 | 0 | 0 | 0 | 0 | | · Most plants will not do this due to turbines nearing the end of their useful lives and the need to repower (rather than reinvest in old plants). |

Data are highlighted if they are the lowest (yellow) or highest (green) for each year.

## WIND

### Capacity Factor

| Expert | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | Trend | Rationale |
|---|---|---|---|---|---|---|---|---|
| **Mean** | **23%** | **22%** | **20%** | **22%** | **23%** | **23%** | | |
| **Median** | **24%** | **24%** | **24%** | **24%** | **25%** | **24%** | | |
| Expert A | 24% | 24% | 24% | N/A | N/A | N/A | | · O&M practices help for existing turbines, but old, tiny turbines will get less attention, and there might be less room for improvement. |
| Expert B | 24% | 20% | 15% | 15% | 15% | 15% | | · Wind typically generates at night in CA. May be curtailed with more solar + storage projects coming online. |
| Expert C | 24% | 24% | 0% | N/A | N/A | N/A | | · Assumes pre-2000 turbines are all retired after 2025. |
| Expert D | 22% | 20% | 18% | 18% | N/A | N/A | | · Capacity factor will only decrease as turbines age, assuming constant meteorological conditions. Negative prices will occur more frequently in 2020 due to lower demand. Braking would further reduce CF since turbines would not generate with negative forecasted prices. |
| Expert E | 24% | 24% | 24% | N/A | N/A | N/A | | · Less curtailment leads to increase in capacity factor, but with greater dispatchability, capacity factor could go down. Assumes these two offset each other. Pre-2000 wind turbines will ultimately be decommissioned due to age. |
| Expert F | 25% | 25% | 26% | 26% | 27% | 27% | | · Improving a few turbines in critical areas could improve power production. Data will also point out the turbines that need new motors, which will further improve efficiency. |
| Expert G | 24% | 24% | 25% | 26% | 25% | 24% | | · Wear and tear from aging machines, offset by improved control effects. |
| Expert H | 24% | 24% | 24% | N/A | N/A | N/A | | · Holds steady until the turbines are retired. |
| Expert I | 24% | 24% | 24% | N/A | N/A | N/A | | · No change anticipated. |
| Expert J | 24% | 24% | 24% | 24% | 24% | 24% | | · Will reduce CF as it is about curtailing or braking. This technology is meant to decrease the operational cost.<br>· CF could increase if more storage (hybrid plants) added, provided it makes economic sense, but needs further study. |
| Expert K | 18% | 14% | 12% | N/A | N/A | N/A | | · CF trending downward as plants age and curtailment increases. By 2035, none of them will still be operating. |

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