Our Path to 24/7 Renewable Energy by 2025

Jan Pepper(✉), Greg Miller, Siobhan Doherty, Sara Maatta, and Mehdi Shahriari

Peninsula Clean Energy Authority, Redwood City, CA 94061, USA
jpepper@peninsulacleanenergy.com

Abstract. Peninsula Clean Energy, the official power provider for California's San Mateo County, has an unprecedented goal in the utility sector of providing all of our customers with 24/7 renewable electricity by 2025. This white paper is the first in a two-part series and outlines our 24/7 renewable energy vision, why it is critical to tackling climate change, our progress to date and how we are planning to achieve this trendsetting goal reliably and cost-effectively. Accomplishing this goal would be one of the most consequential actions we can take to mitigate our rapidly changing climate. This can provide affordable, reliable and clean power to customers throughout our incredibly diverse service territory - which stretches from industrial and blue-collar South San Francisco and East Palo Alto, affluent and influential Menlo Park and Atherton, senior communities in coastal Half Moon Bay and, starting in 2022, the city of Los Banos in central California's Merced County. Just as important, it can serve as a model for others to more broadly implement 24/7 renewable power, especially as part of efforts to shut down fossil-fuel power plants in disadvantaged communities and convert to pollution-free renewable alternatives.

Keywords: Renewable energy · Time-coincident · 24/7 · Decarbonize · Carbon-free

1 Why we are Pursuing 24/7 Renewable Power

Since our inception, Peninsula Clean Energy has pushed the boundaries in clean energy procurement and deployment to significantly reduce greenhouse gas (GHG) emissions. In 2016, we set an unprecedented goal for a California load serving entity at the time: to procure 100% renewable energy. However, we knew this goal in and of itself was not sufficient to drive the long-run transformation needed to achieve a fully decarbonized grid. So, we decided to push the boundaries even further. In 2017, we adopted a goal to deliver 100% renewable energy on a 24/7 basis by 2025, matching our renewable energy supply with our load every hour of every day to reduce our demand signal for fossil fuels from the grid [1].

From the beginning, we also committed to affordable pricing and have maintained prices consistently below those of Pacific Gas & Electric (PG&E). We believe this is important for widespread consumer adoption of clean energy. This is because, even though research indicates that nearly half of Americans say they are willing to pay more

A. K. Ghosh and C. Rixham (Eds.): ASES SOLAR 2022, SPE, pp. 36–48, 2022.
https://doi.org/10.1007/978-3-031-08786-8_4

for clean electricity, we have found that only a very small percentage of our customers choose to do so [2].

Peninsula Clean Energy was already delivering 50% renewable energy to our first customers in 2016, 14 years ahead of California's goal of 50% renewable by 2030. In 2021, we procured 100% renewable or carbon-free power for all our nearly 300,000 customers. We have done this while building a financially strong organization, with two investment grade credit ratings, and providing this cleaner electricity at a consistently lower price than what our customers would pay at PG&E rates, savings our customers over $90 million to date, and demonstrating that we can reduce GHG emissions and save consumers money at the same time.

This is the cornerstone of the challenge we set for ourselves: How to cost-effectively deliver 100% renewable energy on a 24/7 basis by 2025. Because our load profile is similar in shape to the system-wide load profile in the state, we believe that achieving this goal would demonstrate that this approach is scalable state-wide. If we can achieve this goal, we can provide a model for other load serving entities to follow and accelerate further reductions of GHG emissions in the electricity supply.

The need to do this is urgent, a fact recognized by many since we set our goal in 2017. The following year, Google described its vision of a 24/7 carbon-free goal for their data centers and campuses, and in 2020 set a goal to achieve this by 2030 [3, 4]. Cities such as Los Angeles, Sacramento, and Des Moines have now set similar goals, and researchers at RMI (formerly Rocky Mountain Institute) and Princeton have begun studying the trend [5–9]. Earlier this year, the United Nations started building a global coalition for 24/7 carbon-free energy [10]. Our goal still remains the most ambitious in terms of its timeline and commitment to renewable energy.

This white paper introduces Peninsula Clean Energy's vision for 24/7 renewable energy, our progress to date, and at a high level how we are planning to achieve it by 2025. This paper will be followed in the next few months with a report containing the results of our modeling, including details about the expected costs and resource mix required to achieve this unprecedented goal.

2 Renewable Energy vs. Carbon-Free Energy

Renewable energy is produced from resources that are naturally replenished as they are used, while carbon-free energy is produced from resources that do not emit greenhouse gases into the atmosphere. Many resources are both renewable and carbon-free (such as wind and solar), some resources are renewable but not carbon-free (such as biomass), and others are carbon-free but not renewable (such as nuclear). In our case, when we talk about renewable energy, we are using the definitions set by California's Renewables Portfolio Standard [11]. As we develop our mix of resources to meet our goal, we will consider renewable baseload resources such as geothermal and biogas, which may emit small amounts of carbon but generate electricity on a continuous basis in all hours of the day (Table 1).

Table 1. Comparison of resources to meet 24/7 renewable goal

Supply resource	Renewable	Carbon-free	Baseload	Median emissions factor[a] ($lbCO_2e/MWh$)
Solar PV	X	X		0
Wind (Onshore and Offshore)	X	X		0
Geothermal	X	Certain types	X	126
Small Hydroelectric (<30 MW)	X	X		0
Biogas	X		X	8
Wave/Tidal	X	X		0
Biomass	X		X	52
Large Hydroelectric		X	X	0
Nuclear		X	X	0

[a]Peninsula Clean Energy's currently contracted geothermal resource has an emissions factor of 79 lbCO2e/MWh

3 What is 24/7 Procurement and Why is it Important?

To better understand what it means for Peninsula Clean Energy to deliver renewable energy to our customers, it is first necessary to explain generally how the electric grid works. In physical terms, the electric grid is a system of wires that transmits and distributes electricity throughout the state, connecting our customers with the renewable energy generators under contract with us. As an analogy, it can be helpful to think of the electricity grid as a river. Just as streams and tributaries add their water flow to larger rivers, power plants throughout California add their energy to the electricity grid. Just as downstream customers can draw water from the river to use in their homes and businesses, our customers consume energy from the grid. The key point of this analogy is that just as it is impossible to track the source of a single molecule of water drawn from a river, it is similarly impossible to track exactly where each electron you consume comes from.

The electricity that we deliver to customers is therefore tracked based on contractual terms, rather than physical terms. We know how much metered energy our contracted generators deliver to the grid, and we make sure that it is the same amount of metered energy that our customers use. While in contractual terms we currently deliver a specific mix of renewable and carbon-free electricity to our consumers, the physics of the power grid means that everyone consumes a mix of electrons from both the carbon-free and fossil-based resources that deliver energy to the grid.

In addition, the timescale that we use to track our contractual renewable energy deliveries matters. California's current regulatory standards for procuring and reporting clean electricity, such as the Renewables Portfolio Standard and Power Source Disclosure program [12], are tracked on an annual basis. We count how many megawatt-hours

(MWh) of electricity our contracted generators produce in a year and match that to the number of MWh that our customers consume in a year. This annual accounting framework is how we are required to report our procurement to the state and report in our Power Content Label sent to our customers [13].

However, this annual accounting standard ignores whether our contracted generators produce electricity at the same time our customers use it. At certain hours, our contracts generate less clean energy than our customers are using. During those times, we must rely on generic grid electricity (most of which in California comes from methane gas[1] power plants) to make up the difference. In other hours, our contracts generate more clean energy than our customers use. Under the current standards, we can "credit" this excess clean generation to the hours when we rely on fossil-based grid energy and net out our grid energy use on an annual basis. While the excess renewable generation we contribute to the grid in some hours generally displaces fossil generation, we continue to send a demand signal for fossil-based energy in those hours when our clean energy contracts do not match the timing of our customers' energy demand (Fig. 1).

This is why a 24/7 renewable energy approach, which matches renewable energy supply with demand on an hour-by-hour basis, is so important for the success of our state and global decarbonization goals. It enables us to help eliminate the demand signal for fossil-based electricity from the grid that our customers' electricity consumption presently provides at the times when our contracted renewable generation does not match our load. Reducing demand for this fossil-based electricity generation means that these generators run less frequently and become less economic to operate, ultimately helping to expedite the retirement of these resources. The 24/7 procurement approach also helps address the state's grid reliability needs, helping to ensure that there is enough renewable capacity on the grid at the times when it is needed, and helping to address the state's renewable integration challenges characterized by the "duck curve" [14].

Although Peninsula Clean Energy is just a small part of the California grid, if we can demonstrate that 24/7 procurement can be achieved practically and cost-effectively, it will create a blueprint for others to follow. If scaled, this collective action to achieve 24/7 goals can ultimately lead to a carbon-free electricity supply for the whole state and beyond.

4 Our Progress to Date

As of 2020, based on the annual accounting standard, Peninsula Clean Energy delivered 52% renewable energy and 47% large hydro to our customers [13]. Our delivered electricity had a GHG emissions intensity of 12 lbCO2e/MWh, compared to the California utility average of 466 lbCO2e/MWh[2].

[1] Methane gas is also marketed as "natural gas".

[2] 12 lb/MWh is a load-weighted average of our "ECOplus" product with a GHG intensity of 13 lb/MWh, and our "ECO100" product, which had a GHG intensity of 0 lb/MWh. The non-zero emission footprint of our portfolio on an annual basis is related to small emissions associated with geothermal and biomass energy sources.

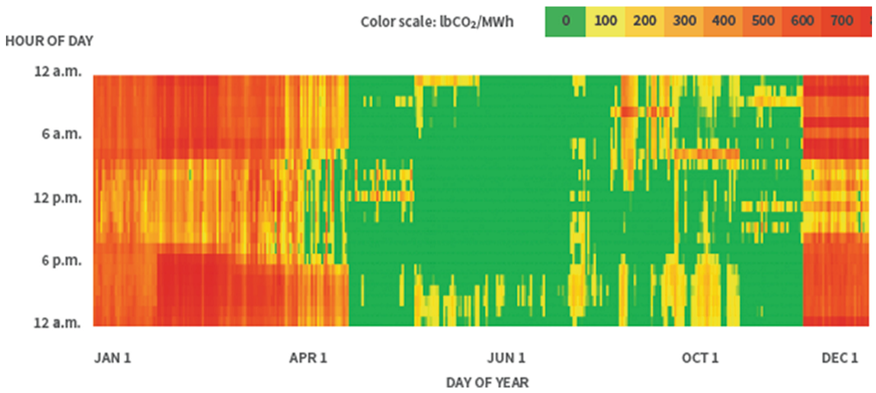

Fig. 1. Hour-by-hour emissions intensity for 2020

This heatmap shows the estimated carbon intensity of Peninsula Clean Energy's delivered electricity for every hour of the year in 2020, considering the emissions intensity from our renewable energy and greenhouse gas-free contracts as well as the use of generic (fossil-based) grid energy. When available, we used the actual hourly generation data from our contracts to develop this heatmap, otherwise, we used the CPUC Clean System Power Calculator to estimate the hourly generation.

Also as of 2020, 47% of our hourly load was matched by contracted renewable energy generated in the same hour. That is slightly lower than our annual renewable percentage (52%) because in some hours our contracted generators produced more renewable energy than we consumed, which we do not count toward meeting our goal. This excess renewable energy is still delivered to the grid. However, although the excess renewable energy offsets emissions from the grid as a whole, it is not being used to offset the emissions from generic grid energy that our customers consume in those hours when consumption exceeds what our contracted renewables produce. Using an hourly, time-coincident accounting method, we estimate that the GHG emission intensity of our delivered electricity was closer to 187 lbCO2/MWh[3] (Table 2).

Table 2. Calculations based on different accounting methods

	Renewable percentage	GHG emissions intensity
Annual accounting method	52%	12 lb CO2e/MWh
Time-coincident accounting method	*47%*	187 lb CO2/MWh

[3] We assigned grid mix electricity a residual mix emissions factor, which we estimated to include a mix of all non- renewable and non-carbon free system CO_2 emissions in each hour as reported by CAISO's "Today's Outlook" dashboard.

Based on contracts signed to date, we are currently on track to be 64% renewable on a time-coincident basis in 2025, and we are actively working to plan and procure the remaining 36% by that year (Fig. 2).

Fig. 2. Seasonal load profile and contracted resources for 2025. For each season of the year 2025, this plot shows the average hourly match between our forecasted load and currently contracted resources, as well as hypothetical energy storage dispatch. This puts us on track to be 64% renewable on a time-coincident basis in 2025 if we were to take no further actions.

Starting in 2020, we began developing a novel 24/7 portfolio planning model to identify the most cost-effective portfolio of renewable energy and energy storage resources that can meet our goal. The results of this modeling will be shared in the second part of this white paper, to be published in early 2022. We have also convened an advisory group of external experts from industry and academia, with whom we meet regularly to review our approach.

5 Overview of 24/7 Strategies

Meeting our 24/7 renewable energy target will require a combination of supply-side and demand-side strategies that together can help match supply and demand around the clock. On the supply side, we plan to procure a diverse portfolio of resources that most closely match our load and utilize energy storage to shift excess generation to the times when we need it.

On the demand side, we can use load shaping and load shifting to better match the timing of our energy demand to the times when renewables are more available. By evaluating these strategies together, we can design a portfolio that most cost-effectively allows us to meet this goal.

5.1 Diversify Our Generation Portfolio

The first strategy is to procure energy from a diverse set of generation resources. Each type of resource—wind, solar, geothermal, or small hydro—produces energy at different times of day and in different seasons. We will also pursue geographic diversity. Wind resources have different power production profiles depending on location. Emerging technologies, such as offshore wind, may have distinct generation profiles that fill a gap left by existing, proven resources and technologies. The challenge of this strategy is finding the right combination of resources that together can generate electricity at the times when we need it and at the lowest cost. Even with a diverse portfolio, it would be nearly impossible to exactly match our generation with our load in every hour of the year. There will be some hours or seasons when we will have more supply than we need, and other hours or times of years when we may fall short. This is why this first strategy is only part of the solution to achieving a 24/7 match (Fig. 3).

5.2 Use Storage to Fill the Gaps

The second strategy is to leverage energy storage to help shift excess renewable generation to the times when there is not enough generation to meet our load. In California, most storage is charged midday and stored energy is discharged in the evenings as solar production decreases and power is most needed (Fig. 4). As resources and load profiles change over time, storage systems provide significant flexibility to charge and discharge at times when it is most needed.

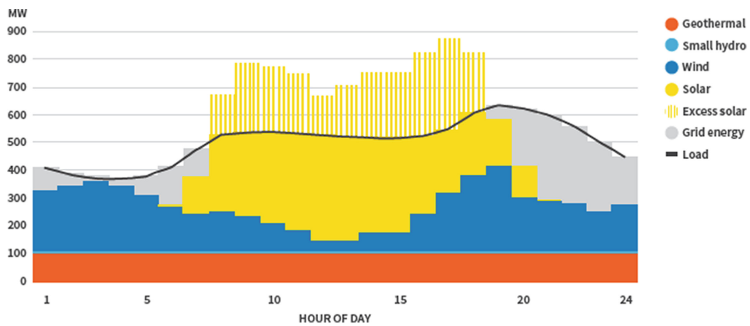

Fig. 3. Diversify renewable portfolio. A hypothetical day demonstrating a mix of renewable resources being used to try and match hourly load. In some hours, there is excess solar generation, and in other hours, this example load is still relying on generic grid energy.

Most storage today is capable of shifting energy between hours of a day or days in a week. As part of our storage strategy, we are evaluating both short duration and long-duration energy storage that is capable of filling unexpected renewable production gaps in our portfolio.

Our specific storage dispatch strategy will involve responding not only to matching our net load, but also to wholesale electricity price signals. This ensures that our energy storage will not only be working to meet Peninsula Clean Energy's needs, but also

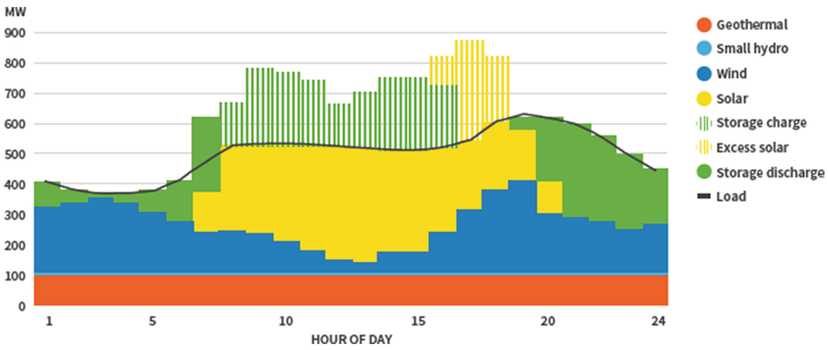

Fig. 4. Use storage to shift renewable energy timing. By adding storage to the hypothetical example, some of the excess solar generation in the middle of the day can be stored and discharged in the evening and early morning to reduce reliance on generic grid energy.

the needs of the broader electric grid. This strategy also helps maximize the economic benefits of energy storage, keeping costs low for our customers.

5.3 Shape and Shift Load

The final strategy involves approaching the challenge from the opposite direction: If it is challenging to match supply to load, how can we better match our load to the available supply of renewable energy? This demand-side approach involves both shaping and shifting our load (Fig. 5).

Load shaping refers to actions that permanently modify the shape of our load profile, such as transportation and building electrification, energy efficiency, and time-of-use electricity rates. For example, setting high commercial rates during the peak hours of the day will lead businesses to modify their energy use to minimize their energy bill.

Load shifting, in contrast, refers to shifting load between hours of a single day in response to specific signals, and may be useful to help respond to shorter-term intermittency of renewable resources. For example, customers with smart thermostats could shift their heating and cooling to match the availability of renewable resources each day.

The challenge of this strategy is these demand-side resources are often distributed, take time to develop, and represent a relatively small portion of our overall load. As opposed to signing a contract for a single 200 MW solar farm, which may help match up to half of our midday load, demand-side resources may only affect single-digit percentages of our load. The largest opportunities for load shaping may come from strategically shaping the charging of the increasing number of electric vehicles on the road (for example, through encouraging mid-day workplace charging rather than overnight at-home charging), as well as the electrification of our homes and buildings as we transition away from methane gas.

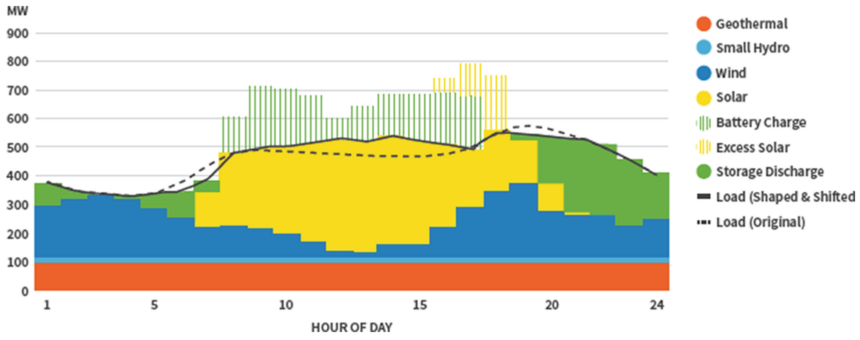

Fig. 5. Shape and shift load to match renewable availability. Using demand-side resources can help further align load with the timing of renewables to reduce the need for as much storage.

6 Challenges in Meeting 24/7 Renewable Energy

As we blaze a trail toward achieving 24/7 renewable energy, we have uncovered both technical and policy barriers that require creativity and innovation to overcome. While these make the process more challenging, we are confident we can address these and help reduce these barriers for others who follow.

6.1 Technical Challenges

Seasonal Mismatches Between Renewable Energy and Load. Even with all three of our strategies working in tandem, there are likely to be mismatches in supply and demand at certain times. The largest mismatches between renewable supply and demand are likely seasonal in nature. For example, because solar energy is more available in the summer, if we procure enough solar to match our wintertime demand, we would have a large amount of excess solar generation in the summer.

We can partially address this challenge by procuring non-solar resources such as wind and geothermal. We could also sell the excess solar to another entity that has a need for more summer resources. Storage may also be able to help address this in the future, however at this time, most seasonal storage technologies are immature or not widely available.

Implications of Forecasting Limitations. There are also likely to be mismatches between load and supply due to errors in our forecasts. Peninsula Clean Energy prepares forecasts on an hourly basis for how much electricity our customers are likely to consume (plus any distribution losses that occur to deliver the electricity), as well as how much generation our resources are likely to produce.[4] However, our actual demand and generation in each hour of the year is often going to differ from our forecasts (Fig. 6).

[4] Our goal currently seeks to match our generation to our loss-adjusted load, which includes retail sales plus distribution losses, but not transmission system losses. We are interested in better understanding how we could consider dynamic and locational transmission losses in our approach.

Years ahead of when power is actually consumed, Peninsula Clean Energy produces a long-term forecast of our hourly load to try to match generation procurement with the anticipated need. Both our demand forecasts and generation forecasts are based on historical data, models, and future assumptions. Our estimates improve as we get closer to the real-time hour. However, climate change is making long-term forecasting even more difficult by introducing more extreme and unprecedented weather events, as well as worsening climate-driven disasters such as wildfires that introduce unpredictable factors affecting both our supply and load.

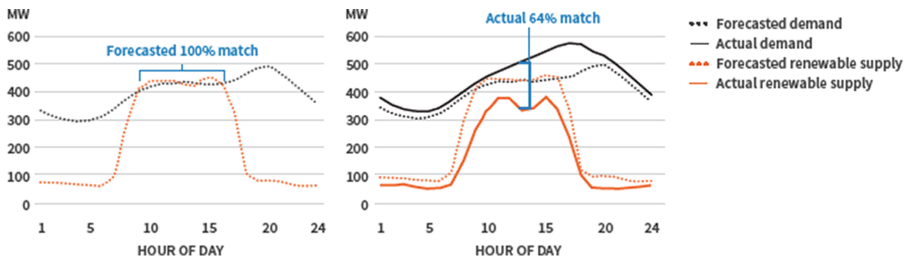

Fig. 6. Forecasted vs. actual supply and demand – October 2, 2020. An example showing how our actual renewable supply and demand on October 2, 2020, differed from our forecasts for that day.

Uncertainty Surrounding Demand-Side Resources. Making effective use of demand-side resources requires us to plan for and understand when and how these resources would perform, and how much it would cost to deploy them. At this time, we have limited information about these characteristics for load in our territory, which makes it challenging for us to model demand-side resources and understand how big a role they might play in our 24/7 strategy.

6.2 Policy Barriers and Solutions for Tracking and Reporting 24/7 Clean Energy

As mentioned previously, California requires procuring and reporting renewable energy on an annual rather than hourly basis. The Western Renewable Energy Generation Information System (WREGIS), the organization responsible for tracking renewable energy in California, currently issues monthly renewable energy certificates (RECs).[5] WREGIS has recently contracted with M-RETS, which has established a process for tracking renewable energy on an hourly basis which, once fully implemented by WREGIS, should allow us to communicate about our progress and report the time-coincident renewable content of electricity to our customers. Fortunately, these issues are also being actively discussed by policymakers in Sacramento [15].

[5] A renewable energy certificate (REC) is issued by WREGIS for every megawatt-hour of metered renewable energy generated and reported into this system.

7 Phased Approach to Delivering 24/7 Renewable Energy

Peninsula Clean Energy plans to take a phased approach to meeting its 24/7 goal. The first phase, which aligns with our 2025 target, is to procure 24/7 renewable energy from proven technologies based on our forecasted hourly load and generation. This recognizes that in real time our actual renewable generation may not perfectly align with our actual load due to forecast errors. However, because we are part of a larger power system with a centralized balancing authority who can draw on systemwide resources to balance supply and demand, these relatively small mismatches due to forecast error may be more efficiently managed by the balancing authority than they would be by us.

Once we meet our 2025 goal of matching supply and demand on a forecasted basis, the second phase is to evaluate the costs and benefits of more closely matching our load and generation on a real-time basis. This will require improving our real-time data pipelines with PG&E, the California ISO, and our generation projects. We will need to develop more sophisticated portfolio management and dispatch tools. We will also need to continue to scale our demand-side flexibility resources and make room in our supply portfolio for emerging technologies that may better match our load shape than currently available resources.

8 Next Steps Toward Our Goal

Peninsula Clean Energy expects to complete a first round of modeling of our 24/7 portfolio in early 2022. We plan to release the results of this modeling in a follow-up white paper to be published mid-2022. This modeling will take a rigorous approach to exploring some of the more complex questions about our 24/7 procurement approach: How much will it cost to achieve? What types of resources will be needed to match our load? How can this approach help address grid reliability challenges? What are the short-run and long-run emission impacts of pursuing this goal? How should storage and demand flexibility be dispatched to balance grid needs, emission impacts, and 24/7 balancing?

After publishing the second part of our paper, we plan to release the modeling tool itself. Others can use it to evaluate their own 24/7 goals and hopefully join us in this journey to accelerate the decarbonization of the electric grid.

Appendix: About Peninsula Clean Energy

Peninsula Clean Energy is a Community Choice Aggregator (CCA) and the official electricity provider for San Mateo County and all twenty of its towns and cities, located just south of San Francisco, California. In April 2022, Peninsula Clean Energy has started providing electricity service to the city of Los Banos in California's Central Valley. Founded in 2016 with a mission to reduce greenhouse gas emissions, Peninsula Clean Energy now serves a population of approximately 800,000 people with annual retail load totaling approximately 3,500 GWh. As a community-led, not-for-profit agency, Peninsula Clean Energy makes significant investments in our communities to expand access to sustainable and affordable energy solutions.

As a CCA, Peninsula Clean Energy is responsible for planning for and securing commitments from a diverse portfolio of energy-generating resources to reliably serve the electric energy requirements of its customers over the near-, mid-, and long-term horizons. The energy which Peninsula Clean Energy procures is delivered on power lines and infrastructure managed by Pacific Gas & Electric, the investor-owned utility which serves much of Northern California. Peninsula Clean Energy is a locally controlled Joint Powers Authority and is governed by a Board of Directors consisting of elected officials from each of the jurisdictions to which we supply energy.

Appendix: Peninsula Clean Energy's 24/7 External Advisory Group

To date, Peninsula Clean Energy is engaging with the following individuals who have agreed to serve as part of our external advisory group for our 24/7 goal. We look forward to expanding this group and hearing from those who may be interested in joining us on this journey.

- Vince Battaglia, PhD, Lawrence Berkeley National Laboratory
- Mark Dyson, RMI
- Mike Della Penna, Google
- Ben Gerber, M-RETS
- Andy Satchwell, Lawrence Berkeley National Laboratory
- James Sweeney, PhD, Stanford University
- Christine Vangelatos, zGlobal.

References

1. Peninsula Clean Energy: 2018 Integrated Resources Plan, 14 December 2017. https://www.peninsulacleanenergy.com/wp-content/uploads/2018/01/PCE-FINAL-2017-IRP-Updated.pdf
2. Gustafson, A., Goldberg, M., Rosenthal, S., Kotcher, J., Maibach, E., Leiserowitz, A.: Who is willing to pay more for renewable energy? Yale University and George Mason University. Yale Program on Climate Change Communication, New Haven (2019). https://climatecommunication.yale.edu/publications/who-is-willing-to-pay-more-for-renewable-energy/
3. Google: Moving Toward 24x7 Carbon Free Energy at Google Data Centers: Progress and Insights, October 2018. https://storage.googleapis.com/gweb-sustainability.appspot.com/pdf/24x7-carbon-free-energy-data-centers.pdf.
4. Google: Our third decade of climate action: Realizing a carbon-free future, September 2020. https://blog.google/outreach-initiatives/sustainability/our-third-decade-climate-action-realizing-carbon-free-future/
5. Los Angeles Department of Water and Power: LA100: The Los Angeles 100% Renewable Energy Study. https://maps.nrel.gov/la100/#home-1
6. Sacramento Municipal Utility District: 2030 Zero Carbon Plan. https://www.smud.org/-/media/Documents/Corporate/Environmental-Leadership/ZeroCarbon/2030-Zero-Carbon-Plan-Technical-Report.ashx
7. RMI: Clean Power by the Hour: Assessing the Costs and Emissions Impacts of Hourly Carbon-Free Energy Procurement Strategies. https://rmi.org/insight/clean-power-by-the-hour/

8. Iowa Environmental Council: History made as Des Moines adopts 24/7 carbon-free energy resolution, becoming first in nation
9. Manocha, A., Patankar, N., Jenkins, J.D.: System-level Impacts of 24/7 Carbon-free Electricity Procurement, Zero-carbon Energy Systems Research and Optimization Laboratory, Princeton University, Princeton, 16 November 2021. https://acee.princeton.edu/24-7/
10. United Nations: 24/7 Carbon-free Energy Compact. https://www.un.org/en/energy-compacts/page/compact-247-carbon-free-energy
11. Green, L., Crume, C.: Renewables Portfolio Standard Eligibility Guidebook, 9th edn. California Energy Commission, Publication Number: CEC-300-2016-006-ED9-CMF-REV (2017). https://efiling.energy.ca.gov/GetDocument.aspx?tn=217317&DocumentContentId=25796
12. California Energy Commission: 2020 Power Source Disclosure Annual Report Template. https://www.energy.ca.gov/programs-and-topics/programs/power-source-disclosure
13. Peninsula Clean Energy: 2020 Power Content Label. https://www.peninsulacleanenergy.com/wp-content/uploads/2021/09/2020-Power-Content-Label-pdf.pdf
14. California ISO: What the duck curve tells us about managing a green grid (2016). https://www.caiso.com/documents/flexibleresourceshelprenewables_fastfacts.pdf
15. Senator Josh Becker: 24/7 Clean Energy: What it means and why California needs it, 6 October 2021. https://sd13.senate.ca.gov/news/getting-to-zero/october-6-2021/247-clean-energy-what-it-means-and-why-california-needs-it