PENINSULA CLEAN ENERGY



ACHIEVING 24/7 RENEWABLE ENERGY BY 2025

By Jan Pepper, Greg Miller, Sara Maatta and Mehdi Shahriari

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Contents

Contact Us

info@PenCleanEnergy.com

PenCleanEnergy.com

650-260-0005

2075 Woodside Rd
Redwood City, CA 94061

ON THE COVER
The cover image is a composite showing wind energy (courtesy of Leeward Renewable Energy), solar energy, and electricity storage.

1 Executive summary

Peninsula Clean Energy is leading the charge to fight climate change by radically transforming the electricity sector. We have one of the most aggressive renewable energy goals in the world: Providing our 310,000 residential, commercial, and industrial customers with renewable energy on an hourly basis by 2025.

Over the last two years, we have built, tested, and leveraged a new 24/7 clean energy procurement modeling tool, MATCH (Matching Around-The-Clock Hourly energy), to answer the critical questions: What is the optimal 24/7 renewable energy portfolio, how much will it cost, what are the emissions reduction benefits, and what are the impacts to the broader energy system?

24/7 renewable energy can be achieved at cost-competitive rates, while achieving the expected benefits of reducing emissions, and providing wider benefits to the grid.

Our MATCH modeling shows that 24/7 renewable energy can be achieved at cost-competitive rates, while achieving the expected benefits of reducing emissions, and providing wider benefits to the grid. That includes reductions in long run emissions by building new supplies and storage that will displace methane gas generation.

Specifically, our MATCH modeling finds that providing 100% renewable energy implemented on an approximately 99% time-coincident basis achieves the ideal balance of being cost competitive, reducing portfolio risk, and reducing emissions. Time-coincident or 24/7 renewable energy means matching customer demand with renewable energy supply in the same hour.

The cost of 24/7 renewable energy varies depending on how perfectly supply and demand are matched. We find that a “sweet spot” goal of providing 100% renewable energy on a 99% time-coincident basis results in only a 2% cost increase relative to our baseline, while achieving critical emission reductions and providing other benefits to the grid.

Our model also found there are diminishing returns in trying to match the last 1% of customer demand, with a 10% increase in portfolio cost needed to go from 99% time-coincident to 100% time-coincident.

While there are some benefits in matching that last 1% of customer demand, 100% time-coincident hourly matching will likely not have zero carbon intensity due to trace emissions from beneficial geothermal supplies.

The optimal 24/7 renewable energy portfolios are characterized by significant excess supply, especially at the higher levels of hourly matching. Excess supply is necessary to ensure that customer demand is met by renewable energy, even in the hardest-to-serve times like cloudy, windless days. Seasonal storage could help to reduce excess supply, but no cost-effective seasonal storage is yet available.

There are wider grid benefits that result from our 24/7 renewable energy portfolios, including reducing the system net peak demand and improving the system ramp. Our 24/7 portfolios are also estimated to result in some renewable curtailment which could reach up to about 3% of our renewable supply under certain market conditions.

Over the next decade, as demand-side resources become more prevalent for load shaping and shifting, they will become a critical part of our 24/7 renewable portfolio.

We also expect emerging technologies such as offshore wind and non-lithium storage to mature and play a significant role in our portfolio in later years. As we continue to study and implement 24/7 renewable energy, we will explore how to operate a 24/7 portfolio. Specifically, we are interested in evaluating how to best operate our portfolio to optimize cost, grid impacts, and emissions reductions.

We are confident that these results and the release of our new MATCH modeling tool can guide Peninsula Clean Energy's path toward 100% renewable energy on a 99% time-coincident basis in 2025 and inspire and empower other California Community Choice Aggregators, load serving entities and utilities, and clean energy buyers in their efforts to achieve 100% clean energy around the clock.

2 Our 24/7 renewable goal

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 to procure 100% renewable energy by 2025. 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. Peninsula Clean Energy was already delivering 50% renewable energy to our first customers in 2016, 11 years ahead of California's goal to be about 50% renewable by 2027. In 2021, we procured 100% renewable or carbon-free power** for all our 310,000 residential, commercial, and industrial customer accounts, serving a population of about 810,000 people. We have done this while building a financially strong organization and providing cleaner electricity at consistently lower prices than what our customers would pay at Pacific Gas & Electric (PG&E) rates, 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.

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. By achieving 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 and on the electric grid.

In general, renewable energy goals are implemented on an annual basis, often through a state-mandated Renewable Portfolio Standard (RPS). Energy providers ensure that enough renewable energy is generated over the course of a single year to match a specified percentage of customer demand in that same year. In California the most economical way to achieve this type of annual renewable goal is to use solar energy, which is abundant during the day, but nonexistent overnight. Annual renewable goals incentivize building a lot of solar farms and help to displace the need for energy from fossil fuels when the sun is shining. Annual renewable goals are an important first step in the transformation of an energy system away from fossil fuels.

Annual renewable goals, however, still rely on fossil fuel energy when the sun is not shining, or when the wind is not blowing. In many hours of the year, an annual renewable portfolio will supply much more energy than customer demand in that same hour. And in many other hours of the year, the portfolio will not supply enough renewable energy to meet customer demand. Over the course of a year, those hours of over-supply and under-supply average out to provide the same amount of renewable energy as there is customer demand. In the hours where renewable supply is insufficient to meet customer demand, generic energy from the system is used to serve

* In this paper, we interchangeably use the terms "24/7 renewable energy," "time-coincident renewable energy," or "hourly matching renewable energy." All these terms refer to the same concept of matching customer demand with renewable supply that is generated in the same hour when the demand occurs.

** "Renewable" energy refers to resources that qualify under the California Renewable Portfolio Standard, which generally includes solar, wind, geothermal, biomass, biogas, and small hydro, however, Peninsula Clean Energy's Board of Directors has voted not to procure energy from biomass resources. "Carbon-Free" energy generally means energy from resources that do not emit greenhouse gases, and typically refers to large hydroelectric and nuclear resources, however, Peninsula Clean Energy's Board of Directors has voted not to accept energy from nuclear resources.

customer demand. The generic energy is typically from fossil fuel generation, which, in California, is mainly from methane gas.* Thus, a portfolio built around an annual renewable goal still sends a market signal that fossil fuel energy is needed in many hours of the year.

To reduce emissions and fight climate change, we urgently need to transform our energy system. Our first white paper published in December 2021[1] explained why we believe the next phase of the energy transformation requires a 24/7 approach.

With a 24/7 renewable energy goal, customer demand in every hour of the year is matched by renewable supply that is generated or dispatched from storage in that same hour. A 24/7 renewable energy portfolio made up of new, additional resources sends a market signal that fossil fuel energy is not needed to serve customer demand. This white paper provides the detailed answers to these questions: 1) what a 24/7 renewable energy portfolio looks like; 2) how much 24/7 renewable energy will cost; and 3) what benefits 24/7 renewable energy will provide to our customers and the larger community.

* Methane gas is also marketed as “natural gas”.

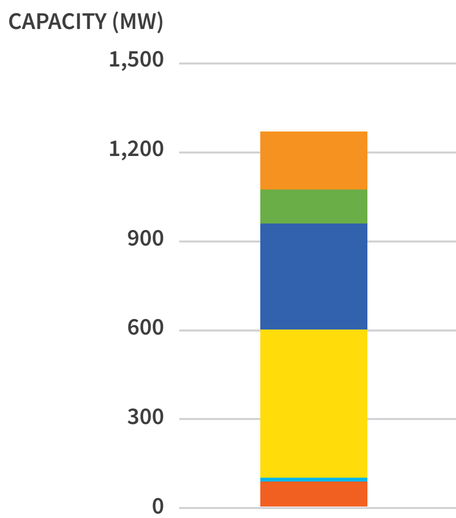
3 Where are we today and where are we going?

Peninsula Clean Energy serves the residential, commercial, and industrial customers in the County of San Mateo and the City of Los Banos in Merced County. Our annual load in 2025 is projected to be about 3,700 gigawatt hours (GWh). We have signed contracts with renewable energy and storage projects for over 1 gigawatt (GW) of capacity. We have contracted with a diverse mix of resources, including solar, wind, small hydroelectric, and geothermal (Figure 1). Based on contracts signed to date, we are currently on track to be 71% renewable on a 24/7 basis by 2025, and we are actively working to procure the remaining 29% by that year.

As discussed in the previous section, an annual renewable goal still relies on fossil fuel generators to serve load when supply of renewable energy is not sufficient. This supply of fossil fuel energy will result in greenhouse gas (GHG) emissions. As an example, while in 2021 our portfolio had 5 lbs of CO_2e* per megawatt-hour (lbs/MWh) on an annual basis, it had 222 lbs/MWh on an hourly basis. For comparison, the California utility average emissions intensity (measured on an annual basis) in 2021 was 456 lbs/MWh.

Figure 1. Our Current Portfolio

Bundled renewable energy contracts signed to date (as of January 2023) plus equivalent capacity of short-term renewables needed to reach 100% renewable energy on an annual basis. The Current Portfolio shown throughout this white paper includes all of our contracts for resources that will be online by 2026. It assumes we will replace all of the large hydroelectric resources that served load in 2021 with renewable resources by 2025.



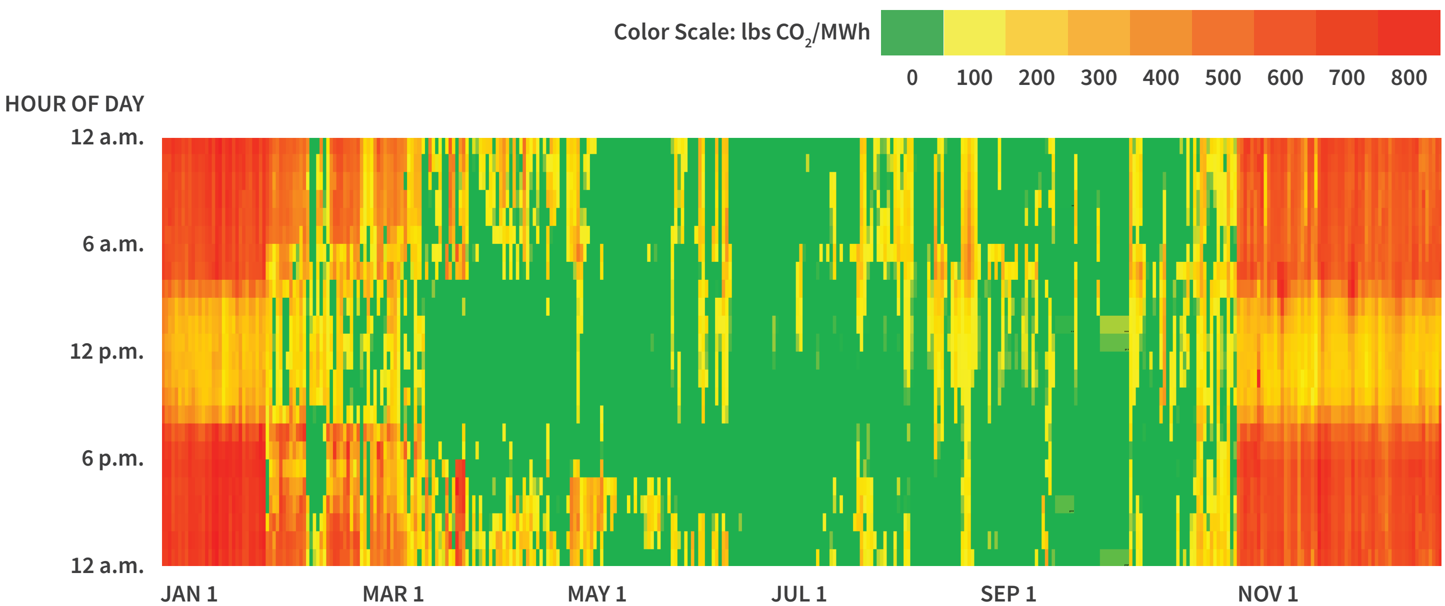
	CURRENT PORTFOLIO (MW)
Short-term renewables capacity	196
Storage	116
Onshore wind	358
Solar	502
Small hydro	12
Geothermal	84
TOTAL	1,268

* Pounds of carbon dioxide equivalent. Throughout this paper we use CO_2 and CO_2e interchangeably.

The heatmap in Figure 2 shows the hourly average carbon intensity of Peninsula Clean Energy's delivered electricity for every hour of the year in 2021. This heatmap considers 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 California Public Utilities Commission (CPUC) Clean System Power Calculator to estimate the hourly generation. The emissions intensity of our portfolio was much higher in winter months when we had limited supply from solar resources.

Figure 2. 2021 hourly average emissions intensity heatmap

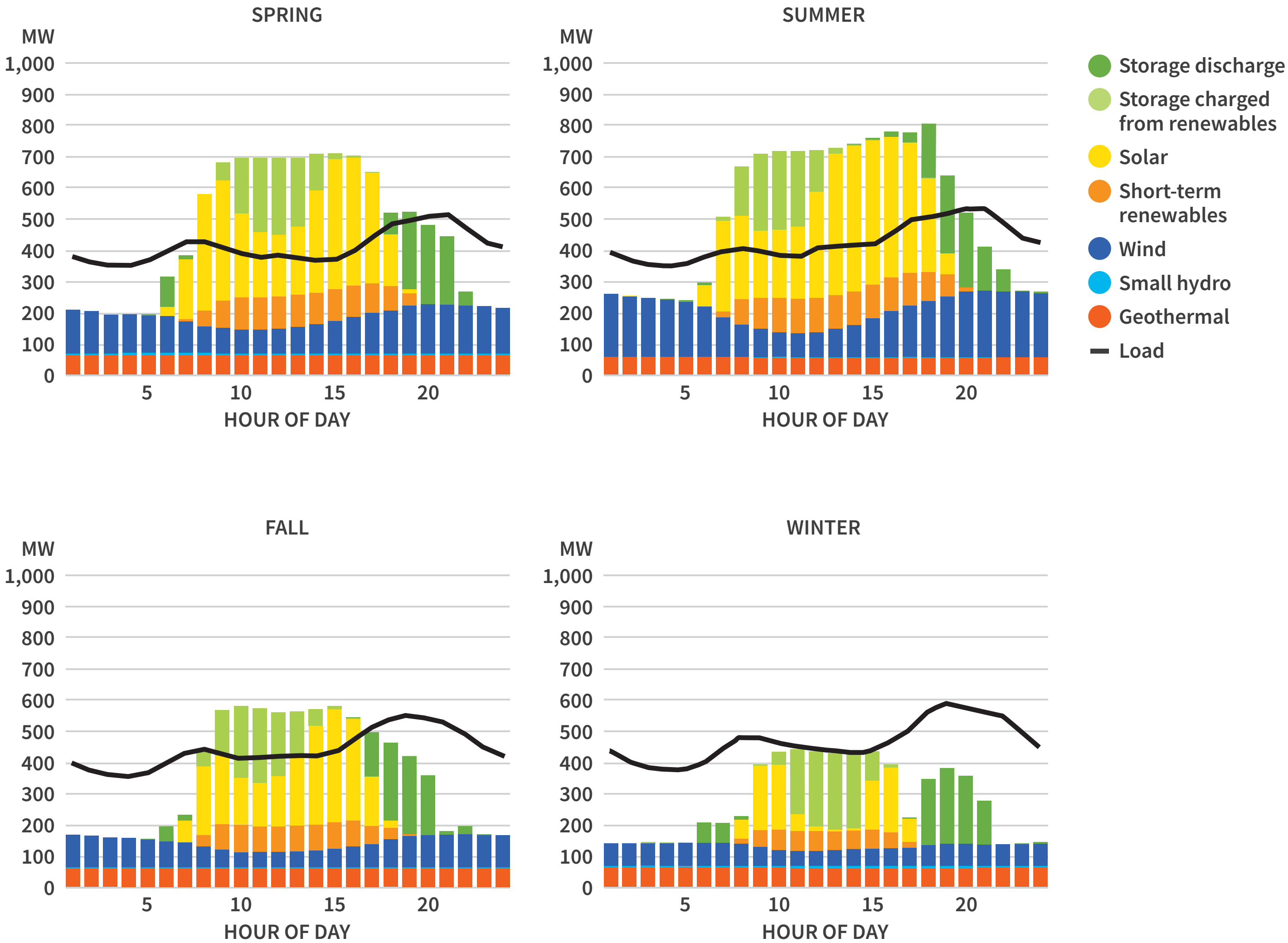
Hour-by-hour emissions intensity for 2021. This heatmap considers our use of grid energy. Peninsula Clean Energy's average hour-by-hour emissions intensity for 2021 was 222 lbs CO_2/MWh (compared to 5 lbs CO_2 /MWh on an annual basis).



Prior to developing our more sophisticated modeling to determine the best way to reach 24/7 by 2025, we used placeholder contracts in our portfolio to estimate our power supply resources and costs in 2025. The placeholders in our current portfolio assume that we will be 100% renewable on an annual basis in 2025 by layering in short-term renewable energy contracts. These placeholder contracts have not been executed and are used for budgeting and planning purposes only. Figure 3 shows the current contracts we have signed, as well as the placeholder short-term contracts needed in order to reach 100% renewable energy on an annual basis in 2025. This "supply stack" is shown for the four seasons of the year, in order to illustrate the variation in supply over the course of a year. When an annual renewable accounting basis is used, excess renewable supply in the spring and summer is "credited" for lower renewable supply in the fall and winter.

Figure 3. Seasonal supply stack and load for our Current Portfolio in 2025

The supply stack consists of contracts signed to date plus placeholder short-term renewables to provide the renewable energy needed to achieve a 100% renewable goal on an annual basis. Open position* can be observed in overnight hours in all seasons while excess supply occurs mainly during solar hours in spring and summer.



* Open position occurs when supply is lower than demand.

4 Modeling approach

Over the last two years, we have built, tested, and leveraged a new 24/7 clean energy procurement modeling tool that is helping us understand our path to achieving our goals. We hope that our results and the release of our new modeling tool can help other California Community Choice Aggregators (CCAs), other load serving entities and utilities, and clean energy buyers to join us in this journey to help the state and the country achieve 100% clean energy, around the clock.

To understand the best way to achieve 24/7 renewable energy, we asked the following key questions:

- What are the incremental resources we should add to our portfolio to meet our procurement targets? (Results in section 5.1)
- How much excess supply does the optimal portfolio have? (Results in section 5.1.1)
- What are the hardest hours to serve with time-coincident procurement? (Results in section 5.1.2)
- How expensive is time-coincident procurement? (Results in section 5.2)
- How does time-coincident procurement impact the risk of our portfolio? (Results in section 5.2.2)
- What emissions benefits may result from time-coincident procurement? (Results in section 5.3 and section 5.4)
- How does our 24/7 renewable energy procurement impact the larger California grid? (Results in section 5.5)
- Is it possible to achieve time-coincident procurement with no excess supply? Can we reduce the risk of our portfolios by limiting excess supply? Is it worth the increase in cost? (Results in section 5.6)
- How will the real-time operation of our portfolio compare to our planning targets? (Results in section 5.7)
- How sensitive are our results to market conditions? (Results section 5.8)

4.1 Renewable energy scenarios

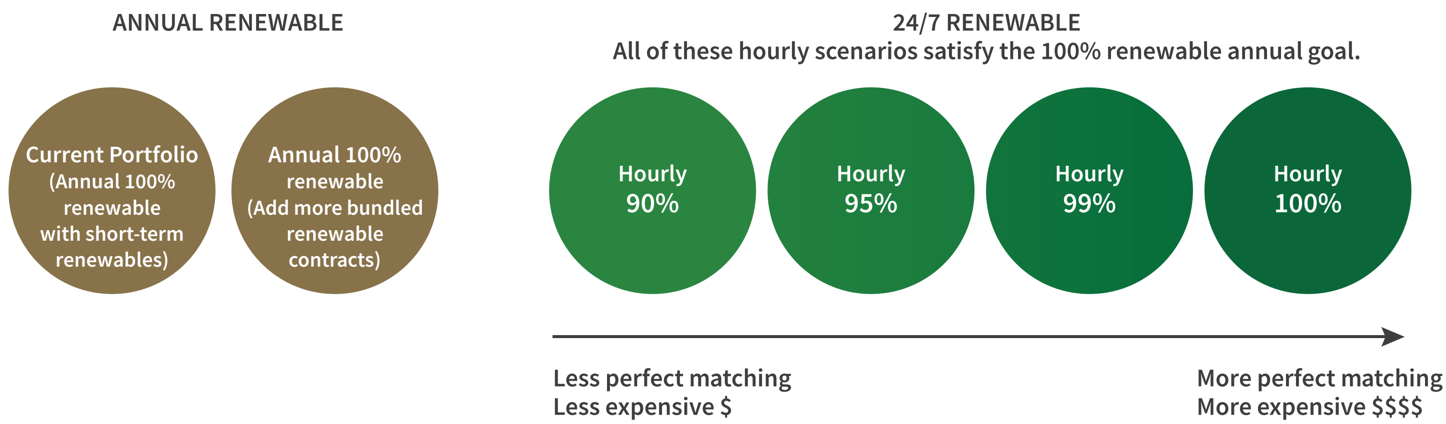
Procuring 100% renewable energy can be implemented in a range of ways. In Figure 4, we summarize the different possible implementations of 100% renewable energy that we evaluated for this white paper, including annual renewable procurement, and 24/7 renewable procurement approaches.

For annual renewable procurement, we explored two scenarios: Current Portfolio and Annual 100%. In this white paper, the term "Current Portfolio" refers to our signed contracts to date, plus placeholder short-term contracts that will deliver 100% renewable energy on an annual basis as shown in Figure 3. Our Current Portfolio is not 24/7 renewable. The Annual 100% scenario includes our signed renewable energy contracts to date, plus additional bundled renewable energy contracts required to deliver 100% renewable energy on an annual basis. The Annual 100% portfolio is not 24/7 renewable.

The other approach to 100% renewable energy implementation is based on a 24/7 matching of renewable energy supply and demand. A 24/7 approach matches renewable supply in each hour with the customer demand in the same hour and can also be referred to as time-coincident renewable energy (because load and renewable supply coincide in time), or as hourly renewable energy matching.

We investigated the trade-offs of implementing 24/7 renewable energy with more perfect and less perfect hourly matching. Specifically, we considered implementing 24/7 renewable energy that matches 100% of demand in each hour with renewable supply, as well as less perfect matching, such as portfolios that, on average, match 99% of demand in each hour with renewable supply, or 95%, or 90%. As we will show, it is more expensive to do more perfect hourly matching, but there are additional benefits to more perfect matching in terms of emissions reductions and grid benefits. The critical question is whether the incremental benefit of more perfect hourly matching is worth the incremental cost.

Figure 4. Different implementations of renewable energy procurement
Potential ways to implement renewable energy procurements: Annual and 24/7 renewable.



4.2 Modeling tools

The analysis presented in this paper was conducted using a new modeling tool that Peninsula Clean Energy developed to identify the lowest-cost portfolio of contracted renewable energy and energy storage resources that could match our customer demand on a 24/7 basis. This new model, which we are calling the MATCH (Matching Around-the-Clock Hourly energy) model, is based on the software architecture of an existing, open-source power system planning model called SWITCH[2], but has been substantially redesigned to meet the needs of modeling time-coincident renewable power portfolios for entities like Peninsula Clean Energy. The MATCH model is a portfolio and dispatch optimization model that determines the least cost portfolio of resources that will meet specified targets. The major cost categories considered in the MATCH model include: resource contract cost, market revenue for generation, market cost of serving load, Resource Adequacy (RA) costs (for capacity-only contracts), Renewable Energy Certificate (REC) costs (for index-plus contracts), and a cost premium for hedge contracts for any load not matched by bundled renewable energy contracts. Our modeling considers the out-of-pocket costs to our customers and does not include any socialized costs or externalities. More information on the MATCH model is available in Appendix 1.

One of the limitations of the MATCH model is that it is deterministic, meaning that it is not able to represent future uncertainty very well. A deterministic model assumes one set of assumptions and results in one set of outputs. To evaluate uncertainty and risk in the modeled portfolios, we used the outputs from MATCH as inputs into Ascend Analytics' PowerSimm software, which is a stochastic analysis tool. A stochastic analysis tool allows us to analyze the portfolios in the face of uncertainty about future prices and weather patterns, and the associated impacts to load, supply, and ultimately, cost.

4.3 Caveats for these results

The results presented in this paper are specific to Peninsula Clean Energy and may not be necessarily generalizable to other entities in California or elsewhere. As discussed in Section 3, our Current Portfolio of contracted renewable resources is projected to meet 71% of our load on a time-coincident basis in 2025. Thus, the MATCH model is choosing resources to meet the remaining 29% of our load. The marginal cost of achieving a 24/7 portfolio for an entity starting with a different supply portfolio may be significantly different from our results.

Additionally, because our load is primarily located in a moderate coastal climate which does not require much air conditioning in the summer, our load tends to be anti-correlated with seasonal solar supply, which is atypical of many communities in California. However, upcoming academic research based on the MATCH model will present results that should be more generalizable to other load serving entities in the state.

Our modeling has focused on a single planning year, 2025. However, many of the resources we plan to procure in pursuit of our time-coincident goal will be under long-term contracts.[3] We are internally evaluating the long-term implications of these projects. The results presented in this white paper represent the expected performance of our portfolio in 2025, but that performance will change over time as market conditions evolve and more renewable resources are built in California.

In addition, these results are based on the projects that are assumed to be available to Peninsula Clean Energy by 2025. Several factors have contributed to delays in construction of renewable projects, including long-term impacts of the coronavirus pandemic, supply chain issues, the war in Ukraine, and inflation and high commodity prices. These factors have limited the pool of projects available to Peninsula Clean Energy by 2025. Further, limited capacity from wind and geothermal resources in California have changed the structure of 24/7 portfolios, resulting in higher amounts of solar and storage resources to meet the last few percentages of customers' demand. Specifically, the Hourly 100% scenario, which needs a much larger capacity of resources, has been significantly impacted by the aforementioned factors. We believe that under different market conditions (such as the Optimistic Case shown in section 5.8), higher time-coincident scenarios could be more favorable than the results presented in this paper.

4.3.1 Demand-side resources

We believe that demand-side resources such as load shaping, load shifting, and demand-response are critical components of a 24/7 strategy. However, demand-side resources are in early stages of deployment and data on how these resources perform is not yet readily available. Moreover, the scale of potential demand-side resources expected to be online by 2025 is relatively small compared to utility scale supply resources. For these reasons, our current analysis does not assume any significant contribution from demand-side resources.

We expect demand-side resources to continue to mature and become an important part of our 24/7 portfolio beyond 2025. We have recently launched demand-side programs (such as managed charging for electric vehicles) that should help to provide the performance data we need to model the contribution of these resources. We will continue to evaluate the role of demand-side resources and support their deployment in our communities.

4.4 Market conditions

Market conditions are always changing, and our results are based on specific snapshots of the market. The contract costs that we pay developers for different renewable resources are impacted by the capital costs for building new projects and the expenses for operating those projects. Changing market conditions also affect the forecasts of future energy prices and the pace at which new projects will be built.

We evaluated two scenarios reflecting the change in market conditions over the last year. One scenario, the “Optimistic Case”, reflects market conditions at the end of 2021. The second scenario, the “Conservative Case”, reflects the market disruptions that occurred in 2022 which resulted in increasing contract prices and wholesale energy prices. These disruptions included the war in Ukraine, supply chain disruptions, uncertainty regarding solar tariffs, interest rate increases, and high inflation and commodity prices. Most recently, the passage of the Inflation Reduction Act is expected to help alleviate some of these market conditions and may help restore the market conditions of late 2021. We have performed sensitivity analyses of our results to market conditions and present a subset of those results in section 5.8. We plan to continuously refresh our analysis to incorporate the most up-to-date market conditions.

5 Results: How we get to 24/7 renewable energy

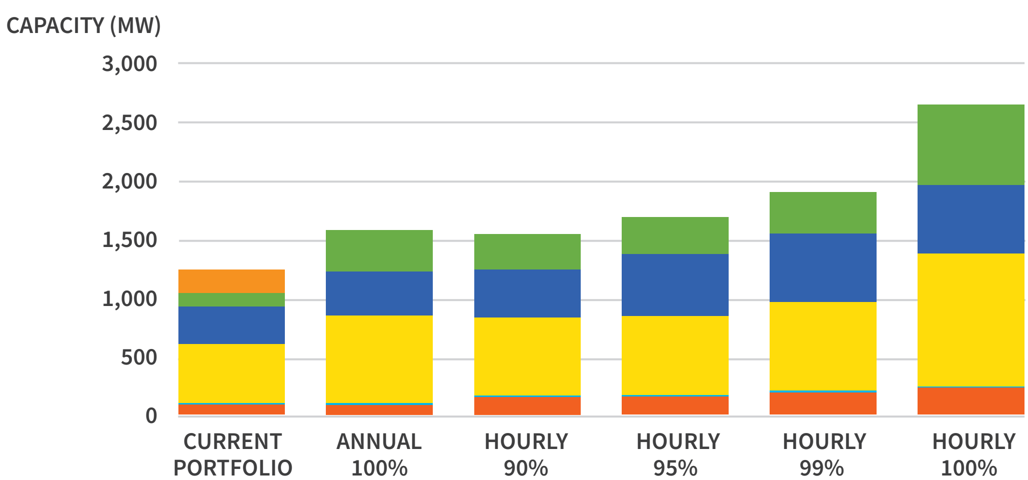
We are pleased to share our results which show that Peninsula Clean Energy can achieve 24/7 renewable energy by 2025 in a cost-effective manner, rapidly reducing emissions, improving grid operations, and providing a blueprint for others to follow in transforming the energy system.

5.1 Portfolio structure

Achieving 24/7 renewable energy requires a diverse portfolio of solar, wind, geothermal, small hydro, storage, and shaped products. The best resource mix for a 24/7 renewable portfolio depends on the amount of hourly matching: at higher levels of matching, we see more storage and geothermal resources in the optimal portfolio.

As described in Section 3, we have already contracted for over 1 gigawatt (GW) of renewable and storage resources. To achieve the 24/7 goal, we will procure up to an additional 1.5 GW of renewable and storage resources depending on the level of hourly matching we pursue. We have found that the portfolio structure is sensitive to market conditions, but that these general trends are consistent across a range of potential market conditions. In general, the capacity required to serve load on an hourly basis increases with higher time-coincident targets. Also, more capacity from firm (i.e. geothermal) and flexible (i.e. storage) resources are needed as the time-coincident target increases.

Figure 5. Portfolios for annual and 24/7 renewable energy implementations in 2025
Total portfolio capacity (nameplate MW) selected by the MATCH model for each scenario. The Annual 100% and Hourly scenarios include the current portfolio contracted capacity.



	CURRENT PORTFOLIO	ANNUAL 100%	HOURLY 90%	HOURLY 95%	HOURLY 99%	HOURLY 100%
Short-term renewables capacity	196	–	–	–	–	–
Storage	116	350	306	311	351	681
Onshore wind	358	378	408	530	586	586
Solar	502	743	660	671	751	1,127
Small hydro	12	16	16	16	16	12
Geothermal	84	84	149	149	187	227
TOTAL	1,268	1,571	1,539	1,677	1,891	2,634

5.1.1 Excess supply

A 24/7 renewable portfolio will have excess supply in many hours. However, unlike in an annual renewable portfolio, a 24/7 renewable portfolio will have no hours or very few hours where there is not enough supply to meet demand. Thus, 24/7 renewable portfolios have net excess supply when averaged over an entire year, while annual-matched portfolios are designed to have no net excess supply when averaged over an entire year.

On cloudy, calm days of the year, we need to have enough renewable energy to serve customer demand. A portfolio that can serve those hardest-to-serve periods will have significant excess supply on sunny, windy days.

Our modeling shows that in the current range of market conditions we evaluated, 24/7 renewable portfolios with excess supply are the least-cost way to achieve 24/7 renewable energy. On cloudy, calm days of the year, we need to have enough wind, solar, and geothermal energy, and enough storage, to serve customer demand. A portfolio that can serve those hardest-to-serve periods will have significant excess supply on sunny, windy days.

The amount of excess supply depends on the relative costs and availability of different resources. If storage were significantly cheaper, the optimal 24/7 portfolio would have more storage and less excess supply. Or, if more firm resources (such as geothermal) were available, the portfolio would substitute geothermal capacity for solar capacity and excess supply would decrease. Our results show the optimal portfolio assuming summer 2022 conditions (the Conservative Case). Even under the Optimistic Case (discussed in section 5.8) the portfolios showed similar, although slightly reduced, trends of excess supply.

In general, our results indicate that excess supply of renewable energy increases with higher time-coincident targets. Matching the last 1% of demand requires procuring 34% more supply. That is, for our load of approximately 3,700 GWh per year, in order to serve the last 37 GWh of demand, we must procure an additional 1,300 GWh of supply. We will further discuss the challenges and benefits of limiting excess supply in section 5.6.

Table 1. Annual Volumetric Energy. Values above 100% show excess energy required to meet load on an hourly basis.

SCENARIO	% ANNUAL VOLUMETRIC ENERGY
CURRENT PORTFOLIO	100%
ANNUAL 100%	102%
HOURLY 90%	114%
HOURLY 95%	126%
HOURLY 99%	146%
HOURLY 100%	180%

5.1.2 Hourly performance of portfolios

In this section, we dive deeper into the hourly performance of the annual and hourly matching scenarios to better understand how these portfolios differ in terms of day-to-day operation.

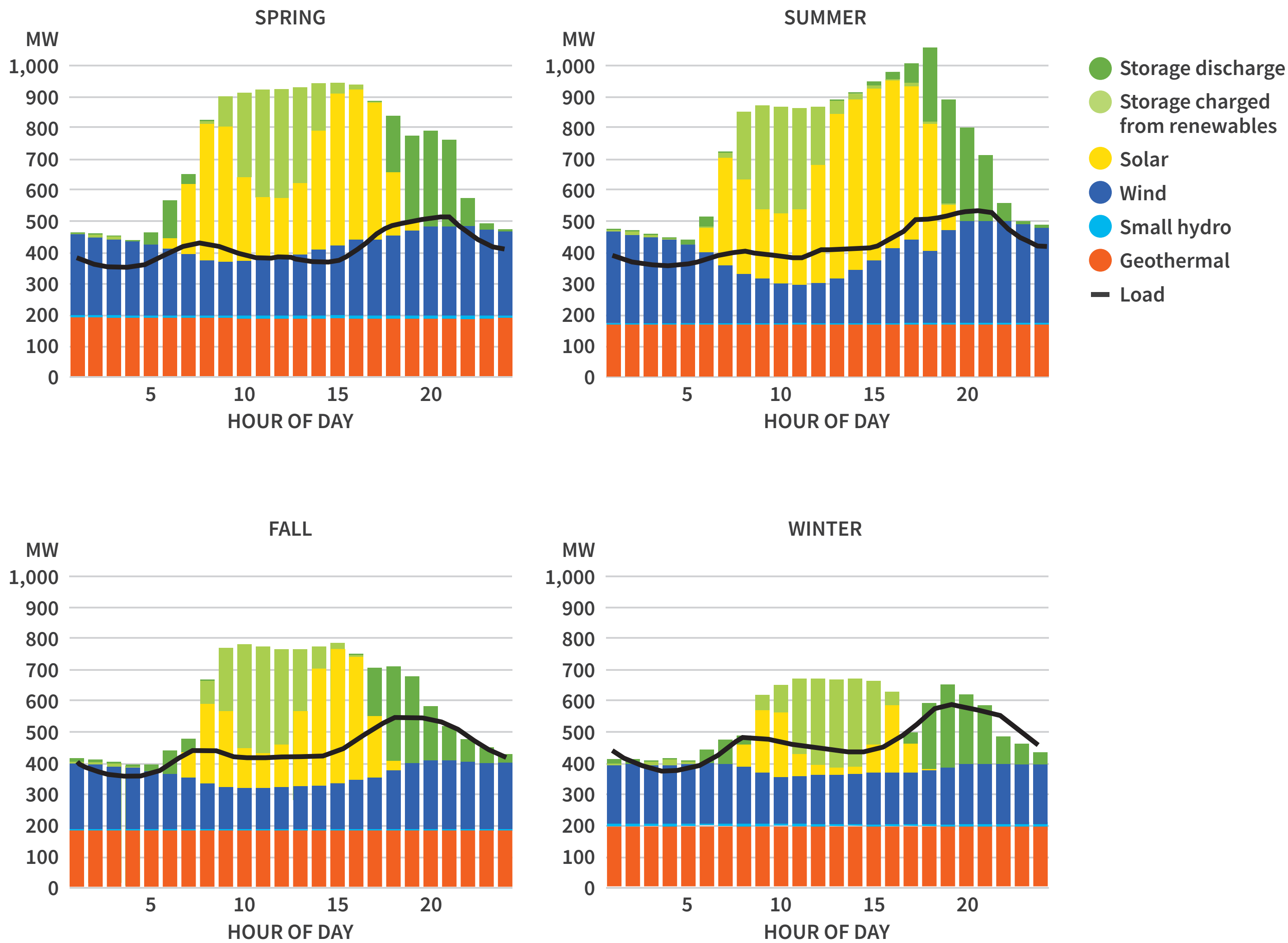
Figure 6 shows the seasonal supply stack and load under the Annual 100% scenario. While on an annual basis, this portfolio generates enough renewable energy to match our customers' demand, when we consider an hourly framework, the portfolio falls short of serving load in many hours. On average, this portfolio achieves a 79% hourly matching of load and renewable energy supply.

Figure 6. Seasonal supply stack for the Annual 100% scenario in 2025
The supply stack consists of contracts signed to date plus new bundled renewable contracts to provide the renewable energy needed to achieve a 100% renewable goal on an annual basis. Open position can be observed in overnight hours in all seasons while excess supply occurs mainly during solar hours in Spring and Summer.

Figure 7 shows the seasonal supply stack and load under the Hourly 99% scenario. The Hourly 99% portfolio provides more than 100% renewable energy on an annual basis, and 99% time-coincident renewable energy. In the Hourly 99% scenario, 1% of load in the year is not matched with time-coincident renewable supply. We find the Hourly 99% scenario to be a cost-optimal implementation of 24/7 and focus some of our discussions on that scenario.

Figure 7. Seasonal supply stack for the Hourly 99% scenario in 2025

The supply stack consists of contracts signed to date plus new bundled renewable contracts to provide the renewable energy needed to achieve 100% renewable energy on a 99% time-coincident basis. Open position can be observed in overnight hours in the winter, with excess supply occurring mainly during solar hours in spring, summer, and fall.



The Seasonal supply stacks for Hourly 90%, 95% and 100% scenarios are included in Appendix 2.

5.1.2.1 Hardest hours to serve load with renewable energy

The hardest hours to serve are the winter overnight hours. Our portfolios rely on solar and storage to supply a significant portion of our load, and in the winter, there is markedly less solar supply. We will seek to contract with resources that have higher winter supply to complement our solar resources.

Our findings of the hardest hours to serve are notably different from the current California grid system operations, where the hardest hours to serve are late summer evening peak loads using methane gas resources. However, as more communities move towards 24/7 renewable energy, winter — not summer — will become the most challenging time of the year to supply reliable renewable energy. This also suggests that one of the more challenging energy uses to electrify will be winter heating load.

5.1.2.2 Hours with significant excess supply of renewable energy

Our results indicate that our supply of renewable energy generates the highest level of excess energy in the spring and summer months. Hours during the middle of the day, when solar supply is high, are in general the hours with the largest amount of excess renewable energy supply. During spring, lower levels of customer demand lead to even more excess supply. Excess supply during these seasons increases the risk of our portfolios due to lower wholesale energy prices during the middle of the day hours in this season when solar and hydro supplies tend to be high.

5.2 24/7 renewable energy is cost-competitive

Our most exciting result is that 24/7 renewable energy can be achieved at practically the same cost as an annual renewable energy goal, with only a 2% cost increase to achieve 99% time-coincident matching.

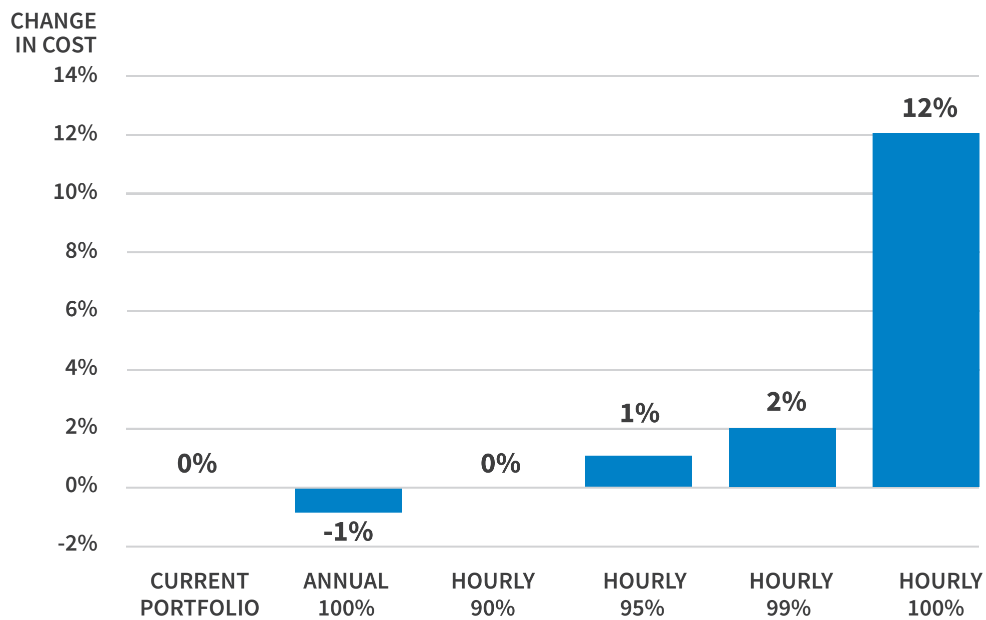
Our most exciting result is that 24/7 renewable energy can be achieved at practically the same cost as an annual renewable energy goal, with only a 2% cost increase to achieve 99% time-coincident matching. Annual renewable energy can lead to a lower cost because it is compatible with procuring low-cost solar power; however, as discussed above, annual matching still relies on system power, mostly from methane gas, and sends a market signal that methane gas generators are needed.

Hourly matching for 24/7 renewable energy requires procuring more diverse resources and can have a higher cost than annual matching. However, hourly matching drastically reduces reliance on system power from methane gas and sends a market signal that methane gas is not needed. Our modeling shows that based on market conditions in summer 2022 (Conservative Case), the cost of hourly matching ranges from about the same as our current portfolio to about 12% higher than our current portfolio.

The cost of hourly matching depends on how closely load and supply are matched. Lower levels of matching, such as 90% of load matched with supply generated in the same hour, results in lower costs. Higher levels of matching result in higher costs, with matching the last 1% of demand increasing cost by 10%. Costs increase at higher levels of matching because higher levels of hourly matching require more storage and excess supply to match the hardest-to-serve hours. As discussed further in Section 5.2.1, our expected cost of energy makes certain assumptions about our ability to resell any excess supply in our portfolio.

Figure 8 shows the expected cost of energy, showing that 99% hourly matching results in only a 2% increase from our Current Portfolio.

Figure 8. Cost of time-coincident renewable energy procurement in 2025
This figure shows the difference in expected cost of energy relative to the current portfolio. The expected cost assumes we can resell 75% of any excess RA and RECs.



5.2.1 Resale value of excess RECs and RA

As discussed in section 5.1, time-coincident renewable energy procurement will result in having excess supply of renewable energy in our portfolio. This excess supply is needed in the portfolio to meet customer demand on an hourly basis even on the hardest to serve days. This excess supply will create excess of certain attributes in our portfolio: 1) Renewable Energy Certificates (RECs) and 2) Resource Adequacy (RA) Capacity.

To quantify the true cost of time-coincident renewable energy procurement, we need to account for the resale value of any excess RECs and RA that result from the excess supply built for hourly matching of supply and demand. While in the short term the value of these attributes is more certain, there is higher uncertainty around the value and demand for these attributes in the long term. We expect that over the long term, the value and demand for these attributes might decrease as more entities move toward higher renewable targets. However, we have found it difficult to quantify a value for these attributes in the long term. In this white paper, we assume we can resell 75% of the excess RECs and RA in our portfolios. Table 2 shows different variations of model results based on the value of excess RECs and RA.

Table 2. Variations of Model Results based on excess RA/REC value.

VARIATION	NOTES
COST OF ENERGY WITHOUT RESALE	Cost of energy without any resale of excess RECs and RA
COST OF ENERGY WITH RESALE	Cost of energy with full (100%) resale of all excess RECs and RA
EXPECTED COST OF ENERGY (DEFAULT ASSUMPTION)	Cost of energy with 75% resale of excess RECs and RA

Different variations of the ability to resell excess RECs and RA changes the cost of the portfolio. Table 3 shows how much our cost of energy could change based on how much of our excess RECs and RA we can resell (our expected cost of energy assumes we can resell 75%). In the best case we can resell 100% of all excess RECs and RA, but in the worst case we cannot resell any of our excess RECs and RA. For example, in the Hourly 99% scenario, if we can resell all excess RECs and RA, then our cost of energy could be 3% less than the Expected Cost of Energy. If we cannot sell any of the excess RECs and RA, however, then our cost of energy could increase by 7% compared to our Expected Cost of Energy.

Table 3. Expected cost of energy (with 75% resale), and cost of energy with and without resale, compared to our Current Portfolio cost. Our Current Portfolio has negligible excess RECs or RA.

SCENARIO	EXPECTED COST OF ENERGY (75% RESALE), RELATIVE TO CURRENT PORTFOLIO	COST OF ENERGY WITHOUT RESALE, RELATIVE TO CURRENT PORTFOLIO	COST OF ENERGY WITH 100% RESALE, RELATIVE TO CURRENT PORTFOLIO
CURRENT PORTFOLIO	0%	0%	0%
100% ANNUAL	-1%	0%	-1%
90% HOURLY	0%	+2%	-1%
95% HOURLY	+1%	+5%	0%
99% HOURLY	+2%	+9%	-1%
100% HOURLY	+12%	+27%	7%

5.2.2 Risk of different renewable energy procurement approaches

While the above results from MATCH (a deterministic model) represent the expected cost of our portfolio, our cost of energy in real time operation could be lower or higher due to the uncertainty around wholesale market prices. Variability in load and renewable supply could also impact our cost of energy but at smaller magnitudes compared to the variability and volatility in the market prices. The uncertainty around market prices would result in a range of likely outcomes for our cost of energy. We used a stochastic model (PowerSimm, developed by Ascend Analytics) to evaluate the uncertainty around our results and to better understand the risk associated with our renewable energy procurement.

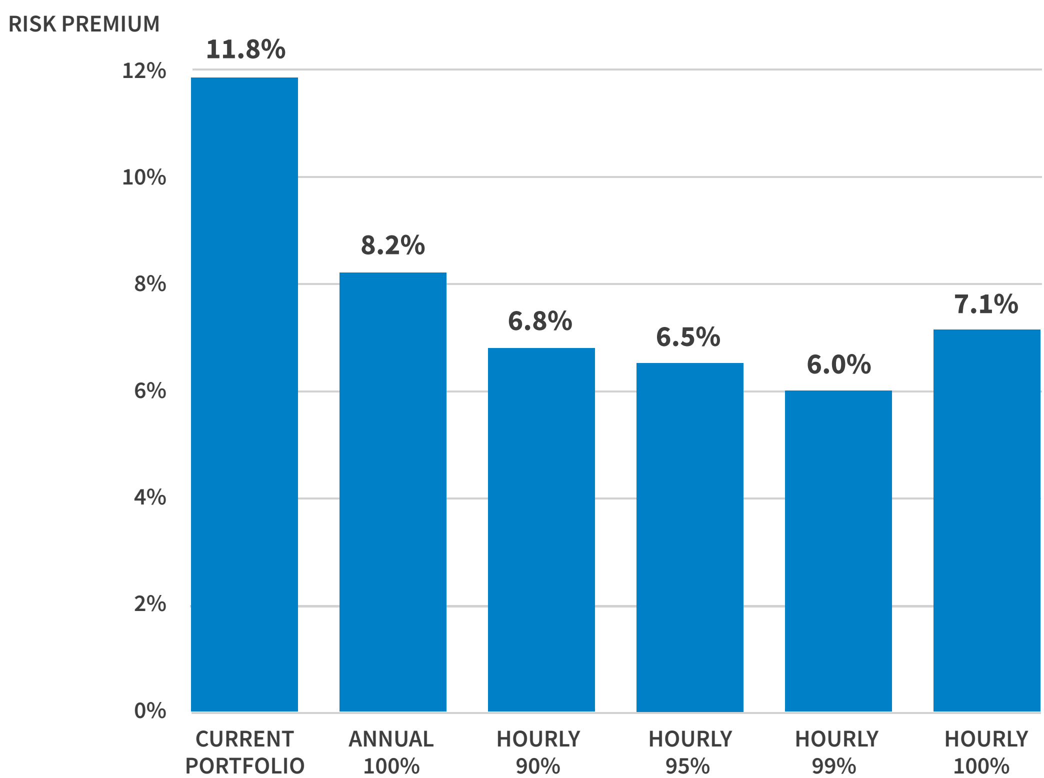
Risk premium
The risk premium is calculated as the difference between the 95th percentile simulated cost and the 50th percentile (median) cost.

To quantify the uncertainty around the cost of our portfolio, we use a metric called the risk premium, which is a measure of the potential for cost increase in the worst-case scenario and represents the highest probable additional cost of our portfolio above the median cost. We express the risk premium as a percent of the expected portfolio cost.

In general, 24/7 renewable energy procurement reduces the risk of our portfolio compared to an annual approach (see Figure 9). Hourly matching between 90% and 99% levels are a "sweet spot" for minimizing risk. Higher levels of hourly matching, such as 100% hourly matching, increase the risk of our portfolio due to excess supply and increased market exposure.

We find that the optimal implementation for 24/7 renewable energy is to match 99% of load with renewable supply generated in the same hour. At 99% hourly matching, costs are 2% higher than our current portfolio, portfolio risk is reduced, and a wide range of emissions and grid benefits are achieved (as we will discuss in the next few sections).

Figure 9. Risk Premium for different types of renewable energy implementation in 2025
Risk Premium is shown as a percent of average cost of energy. For example, for the Hourly 99% scenario, under the worst conditions, our cost of energy could increase by 6% relative to the normal (average) conditions.



These financial results are incredibly exciting. Peninsula Clean Energy already delivers cleaner energy to our customers at generation rates 5% below those of the service

By implementing 24/7 renewable energy at a 99% hourly matching basis, we can continue to offer our customers energy that is less expensive than PG&E, saving our customers millions of dollars per year.

territory's investor-owned utility, PG&E. By implementing 24/7 renewable energy at a 99% hourly matching basis, we can continue to offer our customers energy that is less expensive than PG&E, saving our customers millions of dollars per year, and delivering energy that is far cleaner than PG&E and that provides additional benefits to the overall California electricity grid.

5.3 24/7 renewable energy reduces long-run emissions

Our primary goal in pursuing 24/7 renewable energy is to rapidly reduce greenhouse gas emissions associated with electricity generation and fight climate change. As expected, our modeling indicates significant long-run emissions benefits of 24/7 renewable energy, for two primary reasons.

The first reason is that 24/7 renewable energy reduces long-run emissions from the dirtiest power plants. The methane gas power plants that generate during the evening peak tend to be the least efficient, dirtiest power plants in the system. By providing renewable energy during the evening peak hours, we can turn off the worst emitters. In contrast, annual renewable portfolios tend to provide supply primarily during solar hours, when less dirty methane generators are more likely to be operating. Annual renewable portfolios contribute to turning off methane gas generators, but they are turning off the more efficient plants that tend to run during the middle of the day. Annual renewable portfolios typically cannot provide renewable supply in the evening peak hours, and so cannot help turn off the dirtiest methane gas generators.

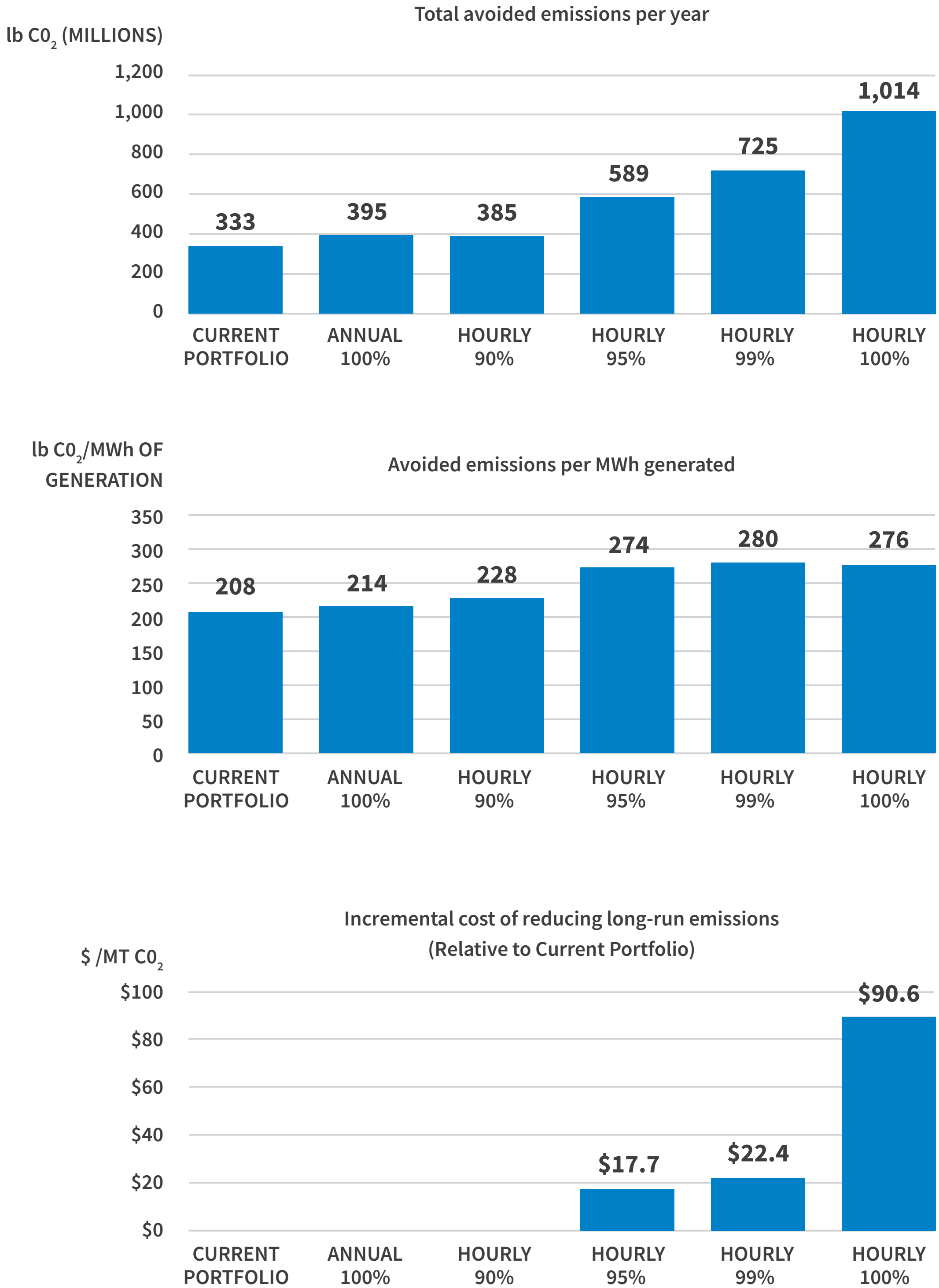
By providing renewable energy during the evening peak hours, we can turn off the least efficient, dirtiest power plants in the system.

The second reason is that 24/7 renewable portfolios tend to have larger amounts of excess supplies that displace additional long-run methane gas generation relative to annual renewable portfolios. The 24/7 renewable energy portfolios have excess energy from solar and wind in many hours of the year, even after fully charging all storage and serving all load in that hour. This net excess energy is still delivered to the grid and helps to turn off additional methane gas generators. In contrast, annual matching results in little or no excess energy (on an annual average basis) and so cannot displace as much methane gas generation.

Our results demonstrate that 24/7 renewable energy will reduce emissions, and the emissions reductions increase at higher levels of hourly matching. We find that there are diminishing returns in trying to match the last 1% of load. The sweet spot for reducing emissions at a reasonable cost occurs when we match 99% of load in every hour with renewable supply. At 99% hourly matching, we can reduce 725 million lbs CO_2e per year at only a 2% cost premium relative to our current portfolio as shown in Figure 10.

To better understand the tradeoffs of pursuing higher levels of hourly matching, we calculate the incremental cost of reducing CO_2 emissions. The incremental cost of reducing emissions can be interpreted as the equivalent "carbon price" that would make reducing those emissions cost-neutral, if Peninsula Clean Energy's use of grid energy and marginal emissions from renewable resources was subject to a carbon price. (Currently, we do not directly pay any carbon price associated with our use of grid energy.) The incremental cost to reduce emissions significantly increases if we want to pursue a 100% matching of load and supply. With the 99% matching scenario, we will continue to save our customers money relative to PG&E's prices, while delivering these remarkable emissions benefits to our customers and to society as a whole.

Figure 10. Impact of renewable energy procurement on emissions in 2025
Carbon emissions avoided by each portfolio on an absolute (top panel) and per MWh generated (middle panel) basis. Incremental cost above Current Portfolio costs to reduce emissions beyond Current Portfolio (bottom panel).



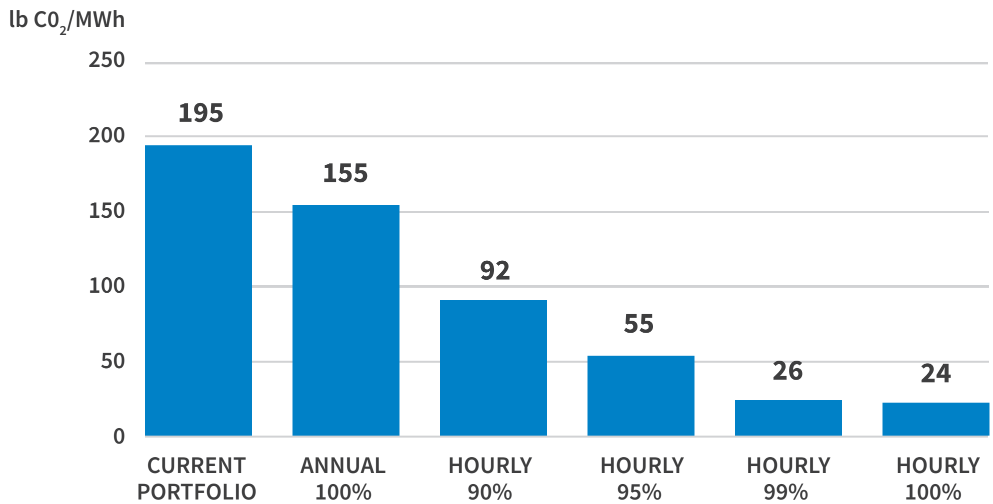
5.4 24/7 renewable energy results in a lower carbon intensity of delivered electricity

In addition to reducing long-run emissions, 24/7 renewable energy also decreases the carbon intensity of our electricity supply, when calculated according to a 24/7 accounting standard. We calculate the hourly carbon emissions associated with our use of grid energy for each hour, without crediting ourselves for excess supply in hours where we have excess supply after we charge our storage. We also include any trace emissions from our renewable resources such as geothermal.

Higher levels of hourly matching result in lower carbon intensity, however, even at 100% matching, there remains a small, non-zero carbon intensity, due to trace emissions from some of the geothermal resources in our portfolio (see Figure 11).

Figure 11. Carbon intensity of delivered electricity in 2025

The hourly average carbon intensity of delivered electricity decreases as the goal approaches 100% time-coincident. Because the 100% time-coincident portfolio relies on geothermal, which emits small amounts of CO_2, the emissions intensity never gets completely to zero.



Carbon intensity vs. avoided emissions

The carbon intensity metric differs from the avoided emissions metric. Avoided emissions is an estimate of how much our procurement would reduce total system emissions, while carbon intensity describes the share of total system emissions that our customers are responsible for.

Annual renewable energy goals have higher carbon intensity when calculated using the 24/7 accounting method.* The heat map in Figure 12 shows the hourly average carbon intensity of delivered energy from the Annual 100% portfolio. Annual renewable portfolios tend to have sufficient supply during solar hours, and insufficient supply during evening and overnight hours, which can be seen by the yellow and orange areas in this heat map.

The 24/7 renewable energy goal, illustrated by the heatmap for the Hourly 99% scenario in Figure 13, has much better hourly load matching, with very low emissions intensity. A 24/7 renewable portfolio relies very little on generic grid energy, instead matching renewable supply to demand in each hour. In the case of an Hourly 99% scenario, there are a handful of hours in the fall and winter where the portfolio is expected to use generic grid energy. The heatmaps for other Hourly scenarios are shown in Appendix 2.

* While 24/7 renewable portfolios have smaller carbon intensities than annual renewable portfolios, communities that are not yet 100% renewable on an annual basis can significantly reduce their carbon intensity by increasing their annual renewable goal.

Figure 12. Hourly average emissions intensity heatmap for the Annual 100% scenario in 2025
The hourly carbon intensity of the 100% annual portfolio identified by MATCH. The average hour-by-hour emissions intensity is 155 lbs/MWh.

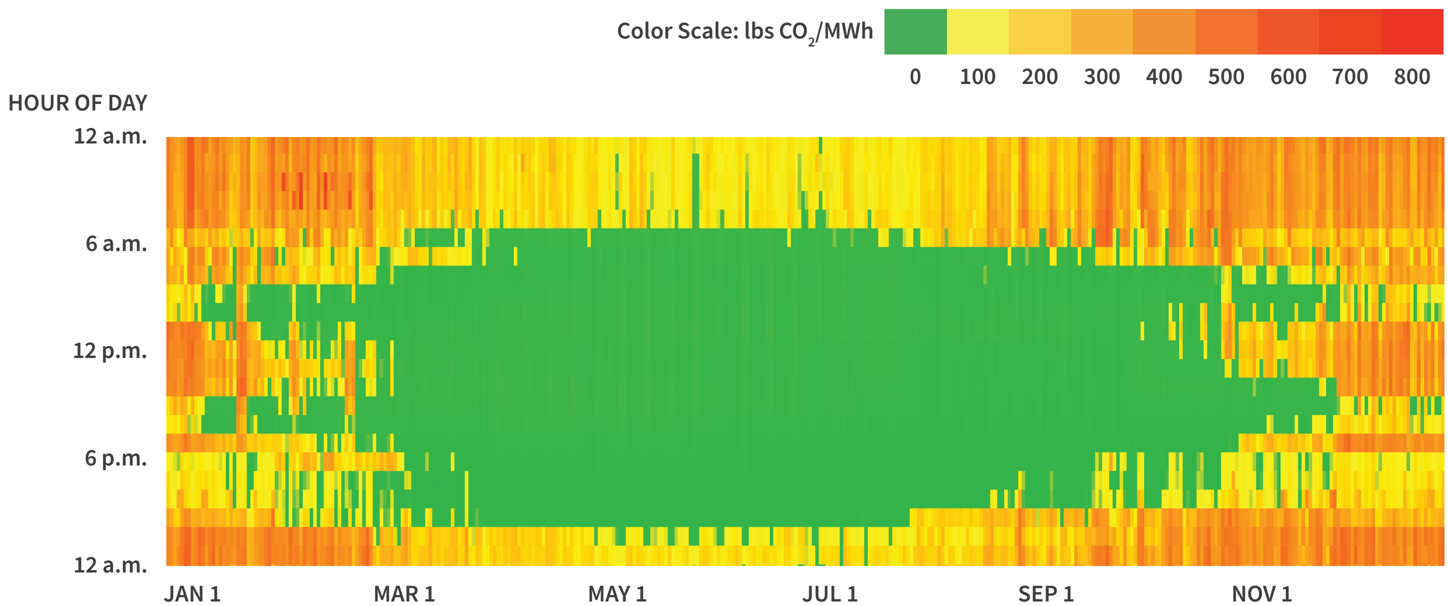
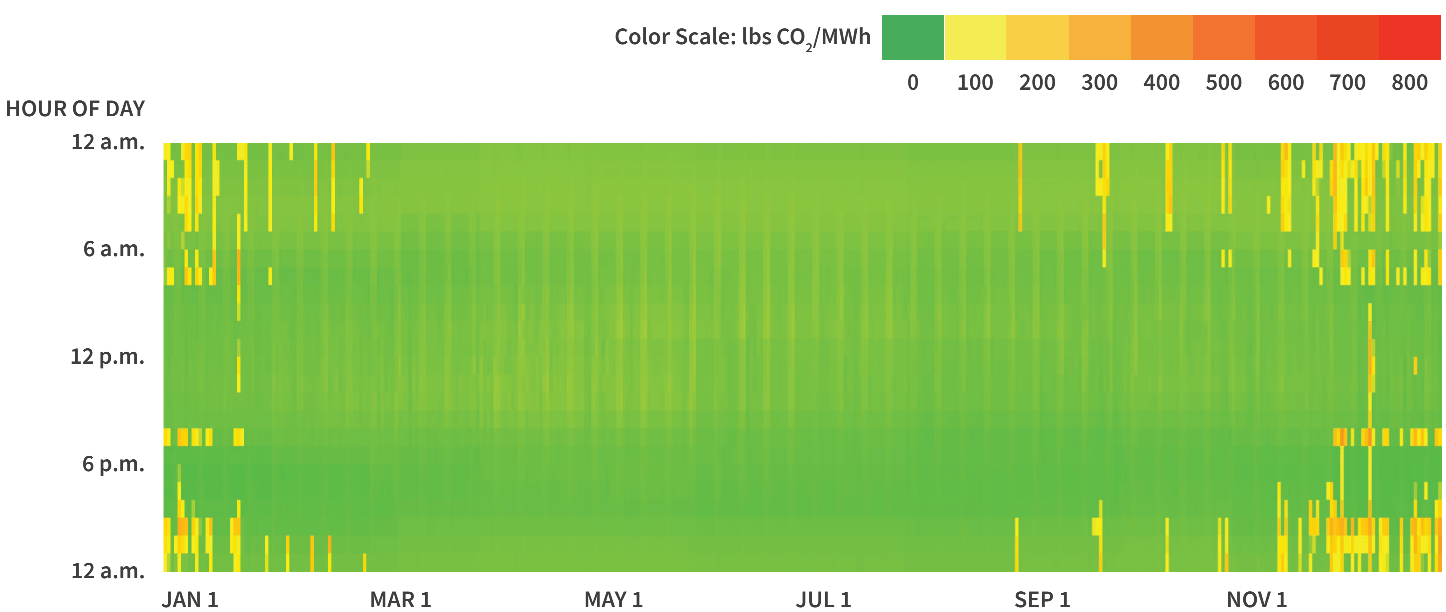


Figure 13. Hourly average emissions intensity heatmap for the Hourly 99% scenario in 2025
The hourly carbon intensity of the 99% time-coincident portfolio identified by MATCH. The average hour-by-hour emissions intensity is 26 lbs/MWh.



5.5 Time-coincident procurement results in greater grid benefits

In addition to reducing emissions, 24/7 renewable energy improves the operations and reliability of the state's electricity grid. The California Independent System Operator (CAISO) has identified three challenges[4] for grid operations as renewable energy increases: the net peak demand, the system ramp, and curtailment.

5.5.1 Net peak demand

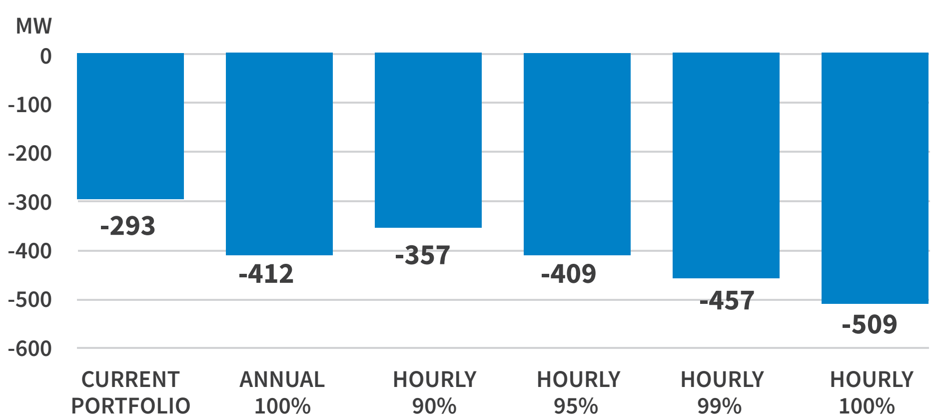
Net demand is defined by CAISO as total system demand minus wind and solar supply. The highest level of net demand in each day is called the net peak demand. Net peak demand has traditionally represented the peak demand that must be met using methane gas generation. Reducing the net peak demand helps reduce the amount of methane gas required by the grid. We believe that as more renewables and storage are added to the grid, the net peak demand should be defined as demand minus all renewables and storage (not just wind and solar) to better represent the actual need for methane gas generation. In Figure 14 we show the impact of the new (additional) resources in our portfolio on the net peak demand assuming all of our new renewable resources and our new storage resources, can contribute.

Annual matching can help reduce the net peak demand slightly, because some solar energy is available during the peak hours in the summer, however much of the supply in an annual renewable portfolio is unavailable during the evening peak, and an annual renewable portfolio tends not to help reduce the net peak demand very much.

The 24/7 renewable portfolios reduce the net peak demand more significantly, increasing as the amount of hourly matching increases. This means that we have a net benefit to the grid during peak hours: we eliminate the need for methane gas to meet our peak load.

Figure 14. Portfolio impact on CAISO net peak demand in 2025

The average daily change in the CAISO system net peak demand resulting from each portfolio. A larger reduction in the peak is better. Peninsula Clean Energy's average coincident load during the CAISO net peak demand is 500 to 600 MW.

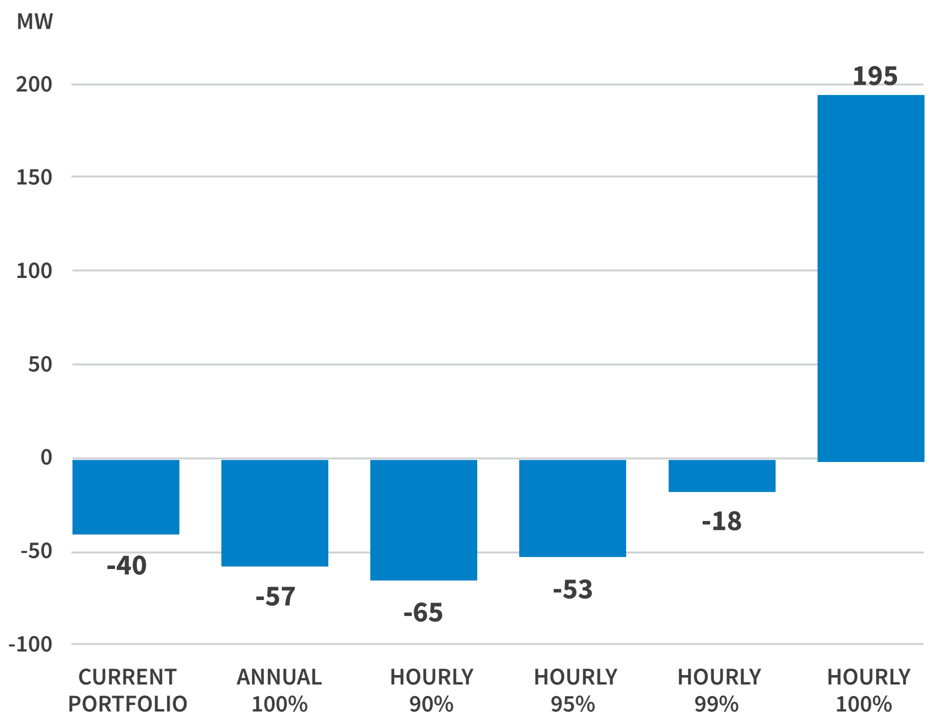


5.5.2 System ramp

The system ramp occurs when renewable energy becomes unavailable and methane gas generation is needed to quickly come online to meet demand. The system ramp happens practically every day when the sun sets and solar power becomes unavailable, but when demand is still high and often increasing as people begin their evening activities. The bigger the system ramp, the more unstable and vulnerable the grid becomes. Minimizing the system ramp has both emissions and reliability benefits. Our hourly matched portfolios, except for the Hourly 100% Portfolio, help to decrease the ramp. Figure 15 shows the impact of the new (additional) resources in our portfolios on the system ramp, assuming all new renewables and storage can contribute.*

Most portfolios tend to help grid operations by reducing the system ramp. Our modeling shows that the Hourly 90% portfolio provides the most improvement for the system ramp, while the Hourly 100% portfolio, which adds significant amounts of solar resources to the grid, tends to worsen the ramp. Our preferred 24/7 renewable energy portfolio, the Hourly 99% portfolio, will help to decrease the ramp slightly, providing emissions and reliability benefits to the entire grid (Figure 15).

Figure 15. Portfolio impact on magnitude of CAISO daily ramping needs in 2025
The change in the magnitude of the CAISO system ramping needs due to our new (additional) renewable and storage resources, as defined by the change in the average daily maximum 3 hour ramp averaged over a single year. A larger reduction in these ramping needs is better.



* Like the net demand peak, CAISO currently calculates the ramp considering only the benefits of wind and solar. However, we think including all renewables and storage is a more realistic measure of the decreased market signal for methane gas generation.

5.5.3 Curtailment

Curtailment occurs when there is more renewable supply available than the grid, or the market, can accept. As more renewables are added to the grid, the potential for curtailment increases. The more diverse the resource mix and geographic distribution, the less likely curtailment becomes. As 24/7 renewable portfolios tend to have excess supply, they can be more subject to curtailment, especially when the resource mix is less diverse.

Curtailment can have a range of effects on an energy supply portfolio. Curtailment often occurs because market signals indicate that there is excess supply on the grid. In those cases, it is economically advantageous to respond to the market signals and curtail, or decrease production from, resources. However, depending on the contract structure of the resource, Peninsula Clean Energy may need to compensate the contracted resource regardless of curtailment.

Curtailment can contribute to grid flexibility and reliability by creating excess renewable supply on the grid.[5] In the future, more of this curtailed supply could be tapped with growing electrical loads or energy storage, or by relieving transmission bottlenecks that would allow this energy to flow where it can be used. In our Conservative Case (summer 2022 market conditions), we did not see much curtailment in our portfolio due to several factors such as higher forecasted wholesale energy prices and higher resource contract costs. The former decreases the frequency of negative wholesale energy prices and the latter makes operating under negative energy prices more economical compared to building new resources. However, in the Optimistic Case that we studied, we did see some curtailment of the modeled portfolios. In Table 4, we have shown annual renewable energy curtailment results from our Optimistic Case (Late 2021 market conditions). While, the curtailed renewable energy MWhs increase with higher levels of hourly matching, curtailment as a percent of total renewable supply does not change with higher levels of hourly matching.

Table 4. Average annual curtailment of Peninsula Clean Energy's portfolio, expressed as a percentage of total renewable supply, assuming Optimistic Case market conditions. (Conservative Case market conditions result in very little modeled curtailment.)

SCENARIO	CURTAILMENT (% OF TOTAL RENEWABLE SUPPLY)
CURRENT PORTFOLIO	3.7%
ANNUAL 100%	1.8%
HOURLY 90%	2.8%
HOURLY 95%	3.1%
HOURLY 99%	3.0%
HOURLY 100%	2.8%

5.6 Potential tradeoffs of reducing excess supply

We studied the potential tradeoffs of reducing excess supply in our portfolios. We found that reducing excess supply increases the portfolio costs significantly, while only decreasing the risk slightly. The cost increase of reducing excess supply far outweighs the risk reduction benefits. Therefore, we find that excess supply is a key feature of a 24/7 portfolio. That said, we will continue to seek economical resources that are a better match for our load patterns to try to reduce the excess supply where we can.

We also found that, given the resources available in the market and our load profile, it was technically infeasible to reduce excess supply below a certain amount. For example, in the Hourly 100% scenario, it was infeasible to reduce excess supply below about 30%. Similar trends were observed when we analyzed excess supply in the Optimistic Case (market conditions as of the end of 2021). We conclude that excess supply is a necessary aspect of a time-coincident renewable portfolio in the range of likely market conditions in California today.

Our findings have implications for future grid planning. As more entities procure 24/7 renewable energy, excess supply on the grid will increase. Excess supply on the grid can be handled in a variety of ways, including exporting renewable energy to neighboring grids via interties, storing excess renewable energy in utility scale storage, partnering with other load serving entities whose demand profile complements ours, or curtailing the excess renewable energy. We are seeking partners who can use the excess renewable supply in our portfolio.

5.7 In real-time operations, our portfolio will perform differently than our planning target

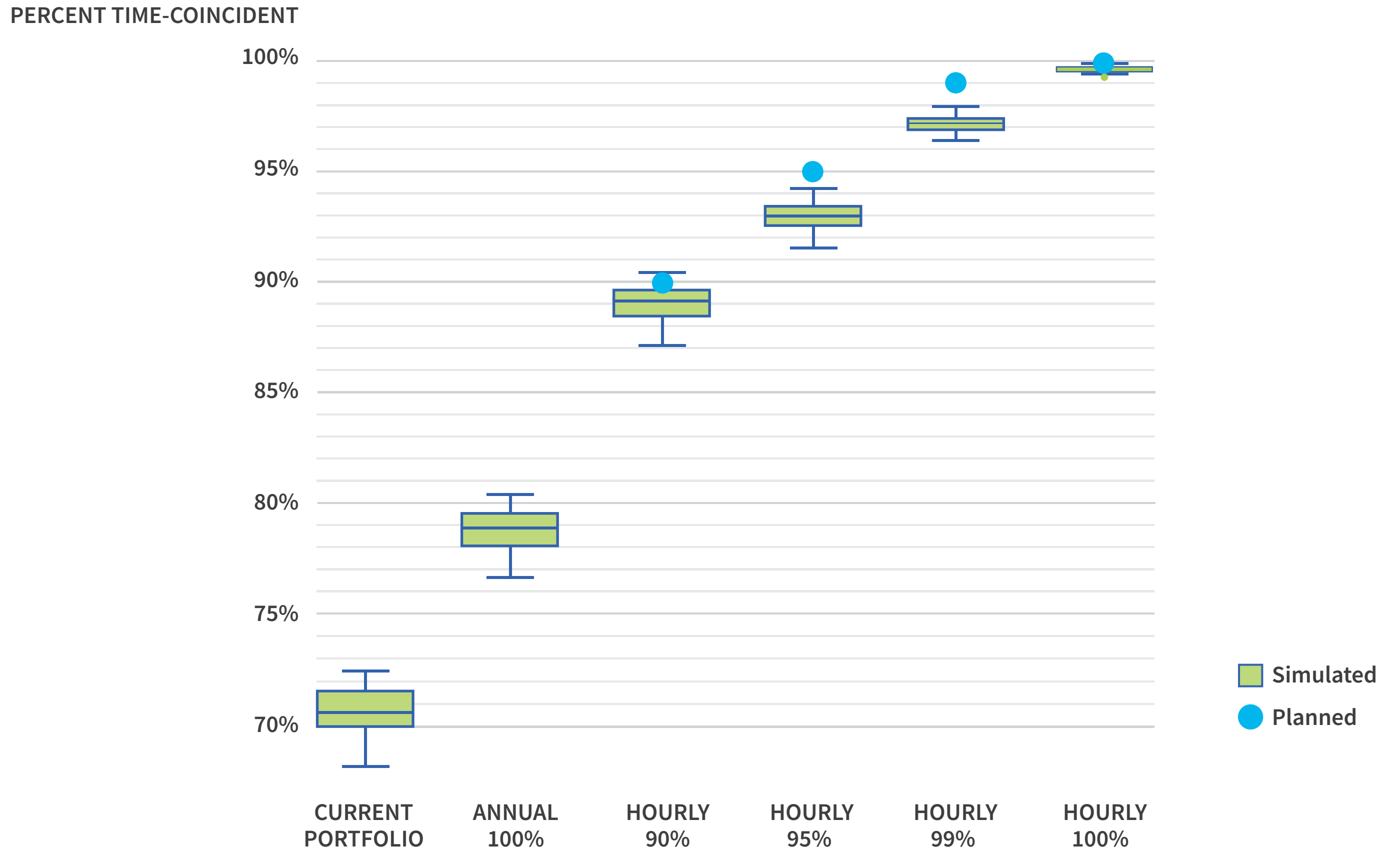
We expect the real-time operations of our portfolio to differ from the modeling assumptions: this is always the case with modeling. We evaluated that potential difference with a stochastic analysis using the PowerSimm software developed by Ascend Analytics.

The stochastic analysis suggests that in real-time operations, we will have lower hourly matching by about 1% to 3%. For example, if we target 99% hourly matching for our 24/7 renewable portfolio, in real-time operations we may only achieve 96% to 98% hourly matching.

The difference is due to the real-time variability of renewable supply and load. Our portfolio is optimized around deterministic planning assumptions of how load and renewable supply varies by each hour. However, the actual load and renewable supply patterns will certainly be different from our planning assumptions and will lead to slightly less perfect matching of our demand with our renewable supply.

As we move to higher levels of hourly matching for a 24/7 renewable portfolio, the range of likely outcomes becomes smaller and closer to our planning target due to the greater amount of excess supply in our portfolio. However, even in the Hourly 100% scenario, our real time operations still do not reach our planning target.

Figure 16. Real-time performance of time-coincident portfolios in 2025
When simulating each portfolio using stochastic analysis, we found that the actual time-coincident performance (represented by the green box plots) was a few percent lower than the planning target for each goal (represented by the blue circles).



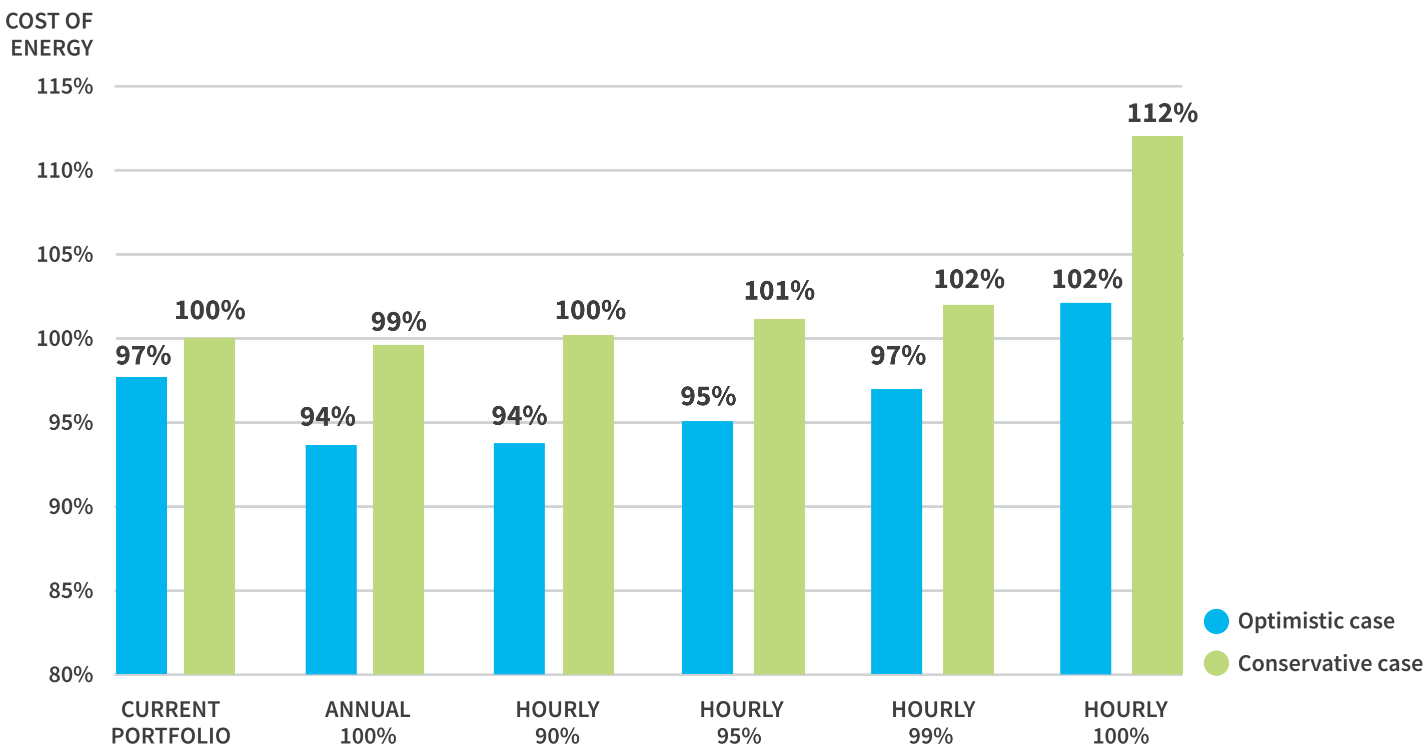
5.8 Time-coincident renewable procurement is economically feasible under a range of market conditions

The ideal 24/7 renewable portfolio changes as market conditions change, and market conditions are always changing, meaning that any results will be outdated by the time they are published. The major results we present in this white paper are consistent with the market conditions present in the summer of 2022 prior to the passage of the Inflation Reduction Act (IRA). We believe that summer 2022 (prior to the IRA) represents a Conservative Case in evaluating the cost of implementing 24/7 renewable energy, due to various market disruptions that have driven up renewable energy prices, including supply chain disruptions, tariff investigations, inflation, high commodity prices, supply scarcity, and rising interest rates.

We also evaluated market conditions consistent with the turn of the year from 2021 to 2022, which we believe represent an Optimistic Case for 24/7 renewable energy, and how we expect the market will respond to the passage of the IRA. The cost to achieve 24/7 renewable energy in the optimistic market conditions is notably lower in every scenario we studied.

Our results indicate that based on the Conservative Case (summer 2022 market conditions), in all scenarios our cost of energy is higher than in the Optimistic Case (Late 2021 market conditions). The results (Figure 17) show that the cost of energy for the time-coincident scenarios under the Conservative Case increased by 5% to 10% relative to the Optimistic Case, while the cost of energy for our Current Portfolio increased by 3%. These results indicate that time-coincident procurement is cost-competitive in the Conservative Case and could become even more competitive under more favorable market conditions.

Figure 17. Expected cost of energy under different market conditions in 2025
Comparison of expected cost of energy under different market conditions. Costs are relative to the cost of energy for Current Portfolio under Conservative Case. Values above 100% represent higher costs relative to the cost of energy for Current Portfolio under Conservative Case and values below 100% represent lower costs relative to the cost of energy for Current Portfolio under Conservative Case. For example, cost of energy for the Hourly 99% scenario under the Conservative Case is 2% higher than the cost of energy for Current Portfolio under Conservative Case.



Even in the Conservative Case, 24/7 renewable energy portfolios are cost-competitive up to and including 99% hourly matching. In the Optimistic Case, 24/7 renewable energy up to and including 99% hourly matching has even lower costs than our current portfolio for 2025. If actual market conditions come to resemble the Optimistic Case, we can deliver 24/7 renewable energy to our customers while providing them additional savings of millions of dollars.

6 Peninsula Clean Energy's strategy to provide time-coincident renewable energy to our customers

Our modeling shows providing 100% renewable energy on a 99% time-coincident basis can be feasible and cost competitive and will deliver a wide array of benefits to our customers and to society as a whole.

The benefits of 24/7 renewable energy increase with more perfect matching, but so do the costs. The last 1% of demand can be very expensive to match with time-coincident renewable supply, and the incremental benefits of matching the last 1% of demand may not be worth the significant cost. This finding of diminishing returns at very high levels of 24/7 renewable matching is consistent with findings by others who have studied 24/7 renewables.[6, 7, 8]

At 99% hourly matching, we can still save our customers millions of dollars per year relative to PG&E, all while delivering cleaner energy.

We believe the sweet spot for 24/7 renewable energy is to provide 100% renewable energy on a 99% time-coincident basis, i.e., to match 99% of load with renewable supply generated in the same hour. At 99% hourly matching, we can still save our customers millions of dollars per year relative to PG&E, all while delivering cleaner energy. And this is what we will do. This is a groundbreaking result that shows that we can "green the grid" without increasing – and likely decreasing – customer costs. A cleaner electricity future is possible for everyone without expensive cost increases.

Over the next decade, as demand side resources become more prevalent for load shaping and shifting, they could become a lower cost resource to match this last 1% of load. We also expect emerging technologies such as offshore wind and non-lithium storage to mature and play a significant role in our portfolio in later years. As we continue to study and implement 24/7 renewable energy, we will explore how best to operate a 24/7 portfolio. Specifically, we are interested in evaluating how to operate our portfolio to optimize cost, grid impacts, and emissions reductions.

We hope that our efforts will inspire and encourage other utilities and communities to join us in revolutionizing our energy system, transforming it into what it must become: fully powered by renewable energy each and every hour of the day. In particular, we hope that our open-source MATCH software will enable other communities to determine the optimal way to pursue 24/7 renewable energy specific to their individual needs.

We must collectively take bold and immediate steps to turn off fossil fuel generation, reduce emissions, and fight climate change. Join us now on the path forward toward a cleaner, greener energy future.

Appendix

Appendix 1: The MATCH (Matching Around-The-Clock Hourly energy) model

The MATCH (Matching Around-The-Clock Hourly energy) model is based on the software architecture of an existing, open-source power system planning model called SWITCH, but has been substantially redesigned by Peninsula Clean Energy staff to meet the needs of modeling time-coincident renewable power portfolios for entities like Peninsula Clean Energy. The MATCH model is a portfolio and dispatch optimization model that determines the least cost portfolio of resources that will meet specified renewable targets. MATCH includes several customized features that make it better suited for our use:

- MATCH is available free and open-source, and was designed to be used by analysts who are comfortable using Excel and running simple Python code in Jupyter notebooks.
- MATCH allows users to identify an optimal portfolio to meet multiple types of clean energy procurement goals, including annual procurement targets, time-coincident targets (such as 24/7 matching goals), and emissions-based procurement goals (such as incorporating a carbon price in the objective function).
- MATCH optimizes the cost of a clean energy portfolio based on power purchase agreement (PPA) contract costs and wholesale market revenues, rather than generator capital and operations and maintenance (O&M) costs, making it more applicable for use by CCAs and voluntary clean energy buyers who are mainly procuring power from renewable and clean energy developers and operators, rather than large utilities that are building and operating their own power plants.
- MATCH can automatically simulate hourly wind and solar generation profiles using NREL's System Advisor Model[9], ensuring the impacts of weather-based correlation between the generation of different resources and decreasing the effort and complexity of inputting customized generation profiles for each modeled generation resource.
- MATCH economically dispatches generators and energy storage resources (including hybrid resources) on an hourly basis, for every hour of the year, to meet the specified procurement target. MATCH can also be configured to co-optimize dispatch for economics and load matching, and to incorporate carbon pricing in the objective function. In CAISO, marginal emissions are well correlated with nodal prices, and dispatch to hourly nodal pricing is a reasonable proxy for dispatch to reduce marginal emissions.
- Model outputs are summarized in interactive, visual reports which include information about the resource portfolio and its cost, dispatch, and impacts.

The MATCH model requires the user to provide a solver package. Many free solver packages are available online, or users can purchase commercial solver software for faster model convergence.

The MATCH model can be configured in many ways, and the results depend heavily on the inputs used and the configurations. The following tables (Table A1 and Table A2) summarize the major assumptions and inputs considered in our modeling.

Table A1. Overview of the inputs, outputs, and modules included in the MATCH model. Italicized terms indicate that they are optional

MAJOR INPUTS	MODULES	OUTPUTS
Procurement target (for example: annual renewable targets, time-coincident renewable targets, cost and emissions co-optimization, etc.) Hourly load data Nodal Locational Marginal Prices Resource characteristics and PPA costs Resource adequacy requirements*	Generator build & dispatch Supply & demand balancing (clean energy target, system power, excess supply) Wholesale pricing* Energy storage* Resource adequacy* Emissions optimization	Portfolio composition Portfolio cost Delivered power content Delivered carbon intensity Generator dispatch profiles Grid impacts Marginal emission impacts

* Indicates optional input or module

Table A2. Details of the MATCH model as implemented by Peninsula Clean Energy for the modeling results contained in this white paper

TOPIC	APPROACH
COSTS CONSIDERED	The model minimizes the total annual cost of an energy portfolio, which in our case includes: • PPA contract costs • Wholesale generation revenues and energy storage arbitrage at each project pricing node • Wholesale cost of electric demand • Cost of meeting any resource adequacy requirements • Cost premium of hedge contracts for any load not matched by bundled renewable energy contracts • Cost of economic curtailment of renewable generators Notably, our objective function assumed no resale of RECs and RA. Resale assumptions are post-processed into the results. In addition to these optimized costs, a user can specify fixed costs to be included in the final outputs.
RENEWABLE TARGETS	We ran scenarios that targeted 100% renewable on an annual basis, and 90%, 95%, 99% and 100% time-coincident goals. The results of each scenario were compared to each other and to Peninsula Clean Energy's Current Portfolio, which includes executed contracts as well as placeholder short-term renewable contracts to provide 100% renewable energy on an annual basis. We do not count any "grid-mix" renewables toward meeting any of these goals. All targets must be met by short-, medium-, and long-term contracted renewable generation that is selected by the model as part of the optimal portfolio.

TOPIC	APPROACH
LOAD	The load that the model is matching represents our forecasted hourly loss-adjusted load for all Peninsula Clean Energy customers in San Mateo County and the City of Los Banos in 2025. Loss-adjusted load is the sum of our retail (metered) load plus distribution system losses (estimated at around 6.5%), and represents what PCE must pay for load in the wholesale market. In MATCH, our load forecast is modeled as a Month-Hour-Day of Week average load.
GENERATION TECHNOLOGIES ASSESSED	We include both established and emerging technologies located around California and adjacent states for the model to consider, including: • Utility-scale solar PV, including solar + storage projects • Onshore wind • Geothermal • Run-of-river hydro • Biogas • Solar thermal Specific project characteristics and prices are informed by both actual projects that responded to recent RFOs issued by PCE, as well as various government and industry reports. Offshore wind is not assumed to be available in 2025, but will likely be available by 2030.
STORAGE TECHNOLOGIES ASSESSED	We assess both standalone energy storage and hybrid energy storage (paired with a renewable generator) projects. We model both short-duration (≤ 4 hours) and long-duration (≥8 hours) standalone storage from multiple technologies, including lithium ion batteries, chemical batteries, compressed air or steam storage, pumped storage hydro, and gravity storage.
RENEWABLE PROFILES	For solar and wind resources, we simulate generation profiles using NREL's System Advisor Model (SAM), based on the project location and system design. To avoid optimizing our portfolio based on a single year of weather data, our generation profiles represent expected generation based on an average of three different years of weather patterns. For all other resources (for example, geothermal and small hydro resources) we manually enter an 8760 profile representing the hourly forecast generation.
WHOLESALE MARKET PRICES	We use forecasted day-ahead hourly nodal prices at each generator Pnode and at the settlement node for our load (the PG&E default load aggregation point). We used Ascend Analytics forecasts of hourly nodal prices in 2025 for the evaluation presented in this white paper.
RESOURCE ADEQUACY	We expect resource adequacy rules in California to change significantly over the next few years, with the implementation of 24-hour RA, but with little clarity about what these rules will look like yet, we use the current RA rules to model RA costs and procurement constraints. We assign a qualifying capacity value to each generation and storage resource, and calculate our net resource adequacy position based on our forecast RA obligation for system and flexible RA in 2025. The model has the option of procuring unbundled RA from the market at our current estimate of market prices.

TOPIC	APPROACH
STORAGE DISPATCH	Storage assets are dispatched to maximize wholesale price arbitrage revenue while balancing generation and load, assuming perfect foresight across the whole year. We model roundtrip efficiency losses and hourly leakage (self-discharge) losses and consider cycling constraints. Hybrid energy storage is required to charge only from the paired generator, and combined discharge and generator dispatch must be less than the project's interconnection limit (which is usually the nameplate capacity of the generation resource). Standalone energy storage charges from the grid but is required to charge only when there is renewable energy being generated by the portfolio. This charging restriction on stand-alone storage is done to simplify accounting and ensure that all discharged storage energy can be considered "renewable" (on an accounting basis). Storage is first dispatched to meet the hourly renewable matching target, if any, and once that target is achieved, storage is allowed to discharge whenever it is economically advantageous.
EXCESS SUPPLY	The model allows for excess supply (defined as any generation that exceeds load and storage charging in each hour). We assume that any excess supply is still delivered to the grid, but this generation does not count toward our time-coincident goal. However, we must still pay the PPA contract price for this generation, and we will receive the wholesale market revenue.
ECONOMIC CURTAILMENT	Variable generators such as wind and solar may be economically curtailed by the model, which means that the model chooses not to dispatch some portion of available variable generation. Depending on the contract structure, we may still have to pay the PPA contract cost for curtailed energy, but we do not earn any wholesale market revenues. Curtailment is modeled to happen when wholesale prices are negative, but the model can choose to not curtail when prices are negative if the energy is needed to meet the specified renewable target.
DELIVERED CARBON INTENSITY AND GRID EMISSIONS	The carbon intensity of delivered electricity is based on direct carbon emissions from selected resources (such as from geothermal or biogas) and based on the carbon intensity of any system power that is used to meet load in each hour. For system power, we calculate an hourly-average residual mix emissions factor based on the carbon intensity of all emitting generators in CAISO, as forecasted by NREL's Cambium model.[10] We do not credit ourselves for grid-mix renewable or carbon-free energy. In California, we believe all renewable and carbon-free energy is fully claimed by other offtakers and is not part of the residual grid-mix energy.
LONG-RUN EMISSIONS IMPACT	The long-run emissions impact of our portfolio is estimated using month-hour average Long Run Marginal Emission Rates forecasted by NREL's Cambium model. Only generators and storage resources that will be newly built as a result of our procurement are considered to have an additional impact on long-run emissions.

Peninsula Clean Energy provides the MATCH model as open-source software for other communities and energy managers to transition to 24/7 renewable energy. Instructions for how to download and use the model can be found on GitHub at https://github.com/pencleanenergy. While in theory the model can be flexibly used by any type of energy buyer in any location, certain modules and functionalities have been specifically designed and tested for the context of Community Choice Aggregators in California. Over time, however, the model may be expanded to work for additional users. New features can be requested or bugs reported via the model's GitHub site. Peninsula Clean Energy is releasing the MATCH model under a AGPLv3 license[11], which is an open source license that allows others to use and make contributions to the MATCH model.

Appendix 2: Additional figures for Hourly 90%, 95%, and 100% scenarios

Figure A1. Seasonal supply stack for the Hourly 90% scenario in 2025

The supply stack consists of contracts signed to date plus new bundled renewable contracts to provide the renewable energy needed to achieve 100% renewable energy on a 90% time-coincident basis. Open position can be observed in overnight hours in the winter, spring, and fall, with excess supply occurring mainly during solar hours in spring and summer.

Figure A2. Seasonal supply stack for the Hourly 95% scenario in 2025

The supply stack consists of contracts signed to date plus new bundled renewable contracts to provide the renewable energy needed to achieve 100% renewable energy on a 95% time-coincident basis. Open position can be observed in overnight hours in the winter and fall, with excess supply occurring mainly during solar hours in spring and summer.

Figure A3. Seasonal supply stack for the Hourly 100% scenario in 2025

The supply stack consists of contracts signed to date plus new bundled renewable contracts to provide the renewable energy needed to achieve 100% renewable energy on a 100% time-coincident basis. Open position is eliminated, with excess supply occurring mainly during solar hours in spring, summer, and fall.

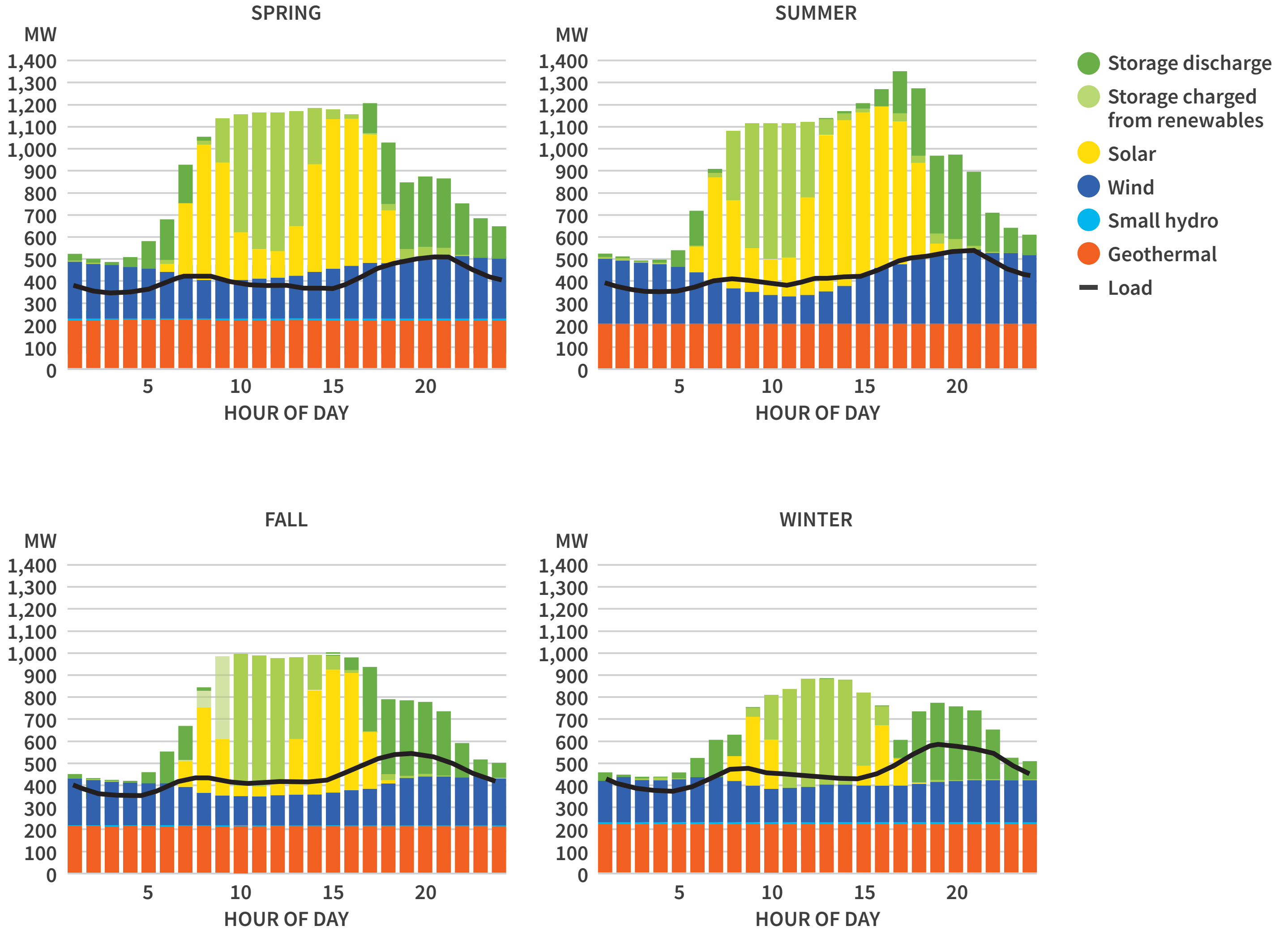


Figure A4. Hourly average emissions intensity heatmap for the Hourly 90% scenario in 2025
The hourly carbon intensity of the 90% time-coincident portfolio identified by MATCH. The average hour-by-hour emissions intensity is 92 lbs/MWh.

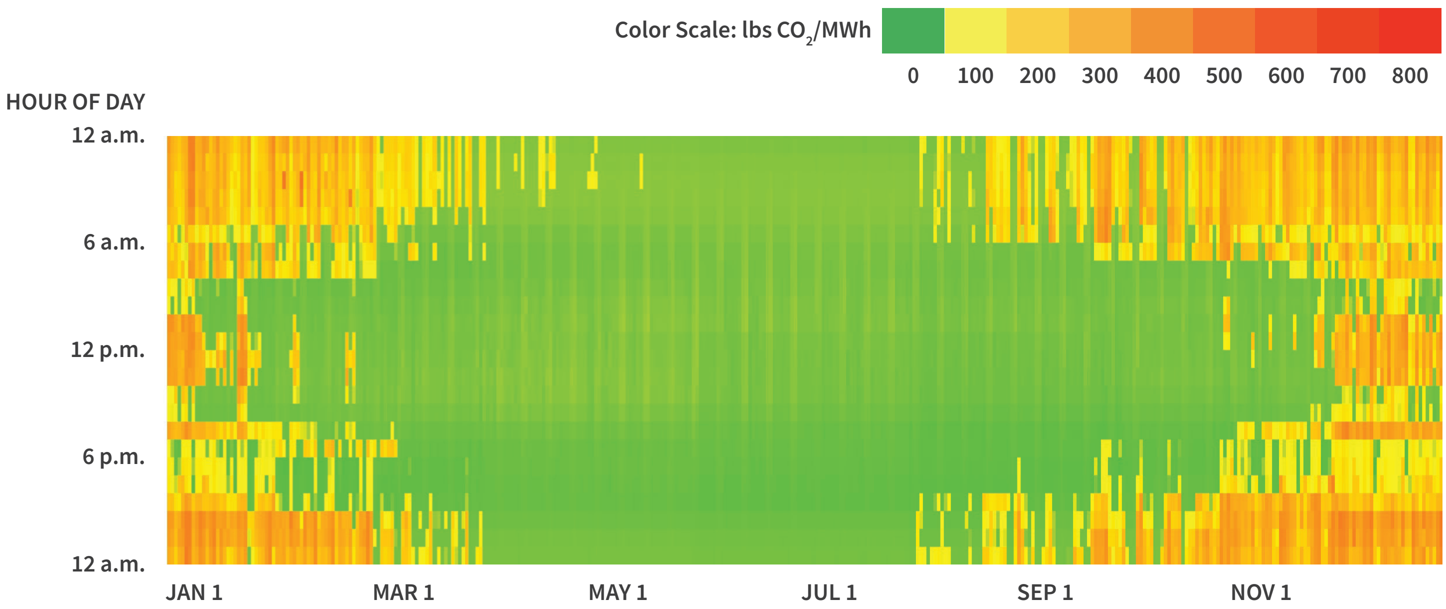


Figure A5. Hourly average emissions intensity heatmap for the Hourly 95% scenario in 2025
The hourly carbon intensity of the 95% time-coincident portfolio identified by MATCH. The average hour-by-hour emissions intensity is 55 lbs/MWh.

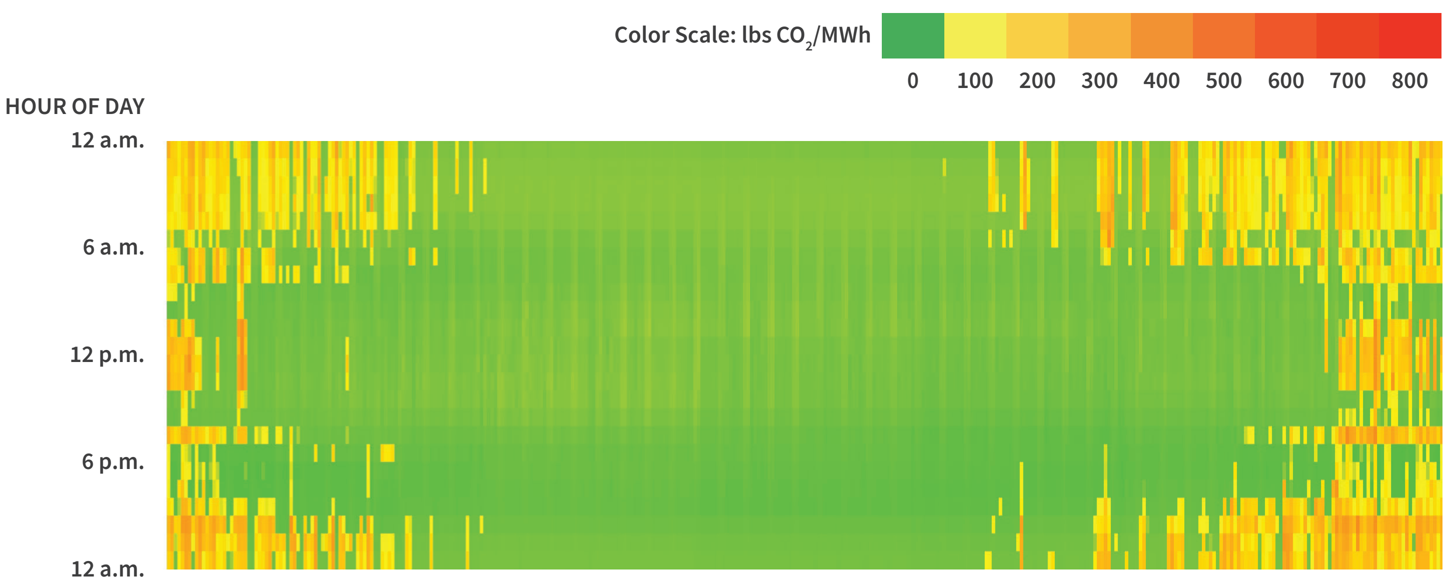
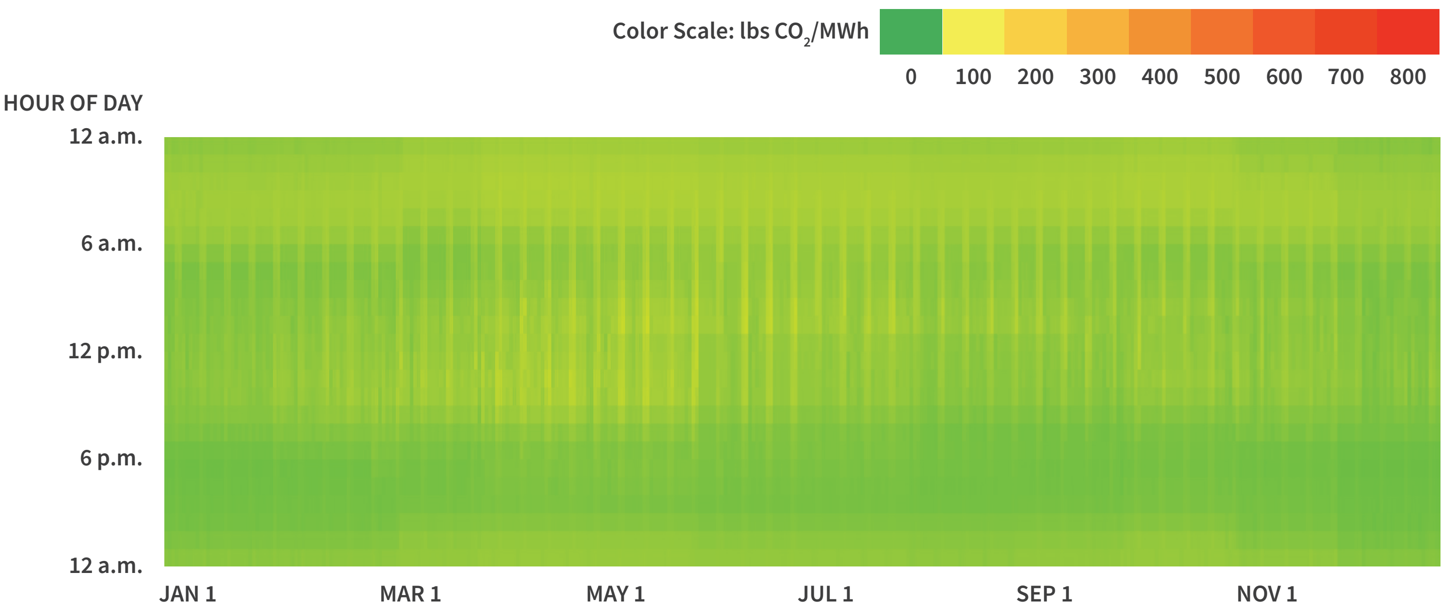


Figure A6. Hourly average emissions intensity heatmap for the Hourly 100% scenario in 2025
The hourly carbon intensity of the 100% time-coincident portfolio identified by MATCH. The average hour-by-hour emissions intensity is 24 lbs/MWh.



Appendix 3: Peninsula Clean Energy's 24/7 external advisory group

Over the past two years, Peninsula Clean Energy has engaged with the following individuals who have agreed to serve as part of our external advisory group for our 24/7 analysis. They have reviewed drafts of our findings and provided valuable input on our approach. We welcome others who are interested in joining us.

- Vince Battaglia, PhD, Lawrence Berkeley National Laboratory
- Sally Benson, PhD, Stanford University
- Lori Bird, World Resources Institute
- Mike Della Penna, Google
- Mark Dyson, RMI
- Nate Hausman, World Resources Institute
- Jesse Jenkins, PhD, Princeton University
- Andy Satchwell, Lawrence Berkeley National Laboratory
- James Sweeney, PhD, Stanford University
- Chaz Teplin, PhD, RMI
- Christine Vangelatos, Zglobal
- Benjamin L Gerber, M-RETS, Inc.

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