# All is Good

**The Increasing Trend of Negative Energy Pricing and Renewable Energy Curtailments in California – Is This a Problem or an Expected Outcome of a Rationally Functioning Market?**

Prepared by: Ziad Alaywan P.E & Nicole Ramos

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There has been a lot of discussion regarding renewable energy curtailments, and some believe it's a big problem. I dug deeper and, as you'll read, curtailments and negative pricing are not as big of an issue as some may think but somehow it gets a lot of attention.

California has experienced a significant increase in the number of hours when energy prices turn negative, a trend most prominently observed during the first six months of the year when demand is low. It is exacerbated when hydroelectric generation must release water as the snow melts during spring just as days are getting longer and solar starts producing more.

The electricity market isn't unique in yielding negative prices that result in energy suppliers paying to produce electricity. Take for instance the Christmas tree market. If I want to buy a Christmas tree before December 25, it will cost over $100 (unless I buy a Charlie Brown Christmas tree). But what if I wait until December 26 to buy a Christmas tree? I can have my pick of any tree on the lot for free[1]. Sometimes the lot owner might even pay me to haul away a truckload of trees. The quality of the tree hasn't changed between December 24 and December 26. But timing has changed the market conditions and thus the value of the product[2].

Similarly, in the wholesale energy business, timing affects the market value of energy products. Suppliers respond to the market and elect, rather than be forced to pay to generate during certain hours of the year. In fact, as you see below and in the summary report below the electricity market is behaving rationally and the overall volume and value of renewable energy curtailment is a small fraction of the wholesale electricity sold and consumed.

In 2023, the total CAISO estimated wholesale cost of serving load in 2023 was about $14.5 billion or about $65/MWh for 223 TWh of customer load served by the CAISO. This represents a 32 percent decrease from about $95/MWh or $21.6 billion for 230 TWh in 2022 (2023-CAISO annual-report, Page 86). Since 2024 similar numbers are not publicly available, we assume that in 2024 the amount of load served and the wholesale cost are similar to 2023.

**What are curtailments?** When the system is experiencing oversupply, CAISO turns to the market to provide an economic signal to reduce generation. Suppliers will bid a price $/MWh and an MW quantity into the CAISO market. If supplier 1 (S1) bids 50 MW at negative $26/MWh and supplier 2 (S2) bids 50 MW at positive$20/MWh and the CAISO is buying 50 MW for a given hour, then S1 is marginal because the CAISO, as a rational buyer, would elect to buy the lowest cost product. S1 sets the energy clearing price for the entire system. In this case, it is negative $26/MWh,

- S1's bid at negative $26/MWh sets the energy clearing price. S1 will continue to operate but must pay to produce energy because the energy clearing price is negative.
- S2 will not get awarded, its offer or bid to operate and generate renewable energy is too expensive compared to S1, which is willing to pay to generate. S2 is not permitted to operate and will have to shut down.

[1] There is a practical aspect to this though. I suggested this before, but my family has consistently objected to this sound economic advice.

[2] Other markets experience similar conditions when a product's value changes from positive to $0 or less when there is not enough demand for the product. Grocery stores categorize unsold food as "loss", which then becomes worthless, the value is $0 or less.

The question is whether S2 was forced to curtail its output or chose not to generate energy because the market clearing price was not high enough to satisfy its $20/MWh offer. The CAISO will buy the least expensive energy, in this case purchasing 50 MWh from S1 not only for free but S1 will have to pay 50MWh x $26/MWh =$1,300 to generate. This is a well-functioning market with an outcome based on the supplier's own bid for the CAISO market.

**What is the volume of energy suppliers are paying to generate as with S1?**

| Year | Day Ahead Supplier MWh | Suppliers' Payment to CAISO | Hours Per Year Priced Between $0 to Negative $26/MWh | Hours Per Year Priced Less Than Negative $26/MWh |
|---|---|---|---|---|
| 2023 | 3,700,265 | $23,277,923 | 188 | 0 |
| 2024 | 13,347,076 | $159,883,667 | 575 | 62 |
| QTR 1 2025 | 3,799,606 | $42,651,353 | 161 | 22 |
| **Total** | **21,560,547** | **$226,606,744** | **963** | **84** |

In 2024, suppliers paid the CAISO $160 million to supply 13.3 TWh of energy.

**What is the volume of energy suppliers' bids that are not "in the money" and are paying to generate as with S2?**

- S2's renewable generation bid was higher than the energy clearing price of negative $26/MWh and was not able to generate. We label these intentional economic out-of-the-money bids as curtailments.
- In 2024, generation curtailments were 3,423,377 MWh, which was a 29% increase from 2,659,526 MWh of renewable generation curtailed in 2023.
  - In 2024, the 3.4 TWh generation curtailments, although voluntary, represent 1.4 % of the CAISO's annual load.
  - The potential CAISO market revenue of suppliers such as S2 at $15/MWh (the average energy price during solar hours which I used as a proxy for market value) results in approximately $50 million, which is 0.35% of the wholesale energy cost. The $50 million number is conservative and may be a lot lower.

What's the big picture? In my mind, these numbers are small compared to the benefits of renewables.

**Who Benefits?**

S1 produces energy but must pay to produce. Load Serving Entities (LSE) collect, through the CAISO, all the payments from generators that pay to generate although S1 is not totally in the red as there are other bilateral revenue streams outside of the CAISO markets. For instance, there may be power purchase agreements between LSE and S1 for Renewable Energy Credits (RECS) and other payments such as Resource Adequacy (RA) that S1 may collect.

Some may say that S2 is stuck with a curtailment and others may call it "not in the money". Whatever the case may be, suppliers such as S2 do not receive or pay the CAISO. However, depending on their bilateral contract with the LSE, they may collect a payment from the LSE to be curtailed.

In 2022, CAISO collected $23 million or 0.15% of CAISO's wholesale energy cost and is 1.6% of the CAISO load.

In 2023, CAISO collected $159 million or 1% of CAISO's wholesale energy cost and is 5.8% of the CAISO load. This is quite an increase and is much more interesting than curtailment.

In QTR1 2025, we already surpassed all of 2023 when suppliers paid CAISO $42 million to generate 3.7 TWh.

To provide some context, the 2023 bid recovery payment from CAISO to gas-fired generation was $289 million. So, these negative price payments by renewable energy suppliers or curtailment are not as big as many may think!

What does all this mean? Markets work! Suppliers such S1 are bidding into the CAISO market and CAISO has the tools to balance the system. CAISO receives these payments and allocates them to LSEs. Negative prices are an effective way to manage the grid, and revenue goes to the LSEs. Whether the LSE passes these savings to the retail customers is another chapter and is much more complicated.

Suppliers such as S2 are not "in the money" or curtailed by choice and are a small fraction of the entire market.

# Summary Report

As you will see in this report, Load Serving Entities (LSE's) and exporters of energy appear to be the winners when suppliers pay to generate[3] after receiving approximately $226 million in 2023, 2024 and QTR1 2025. Suppliers are the losers because of a drop in energy revenue when they pay $226 million to generate electricity. The CAISO is financially neutral but must do more work to continuously balance the system through market signals.

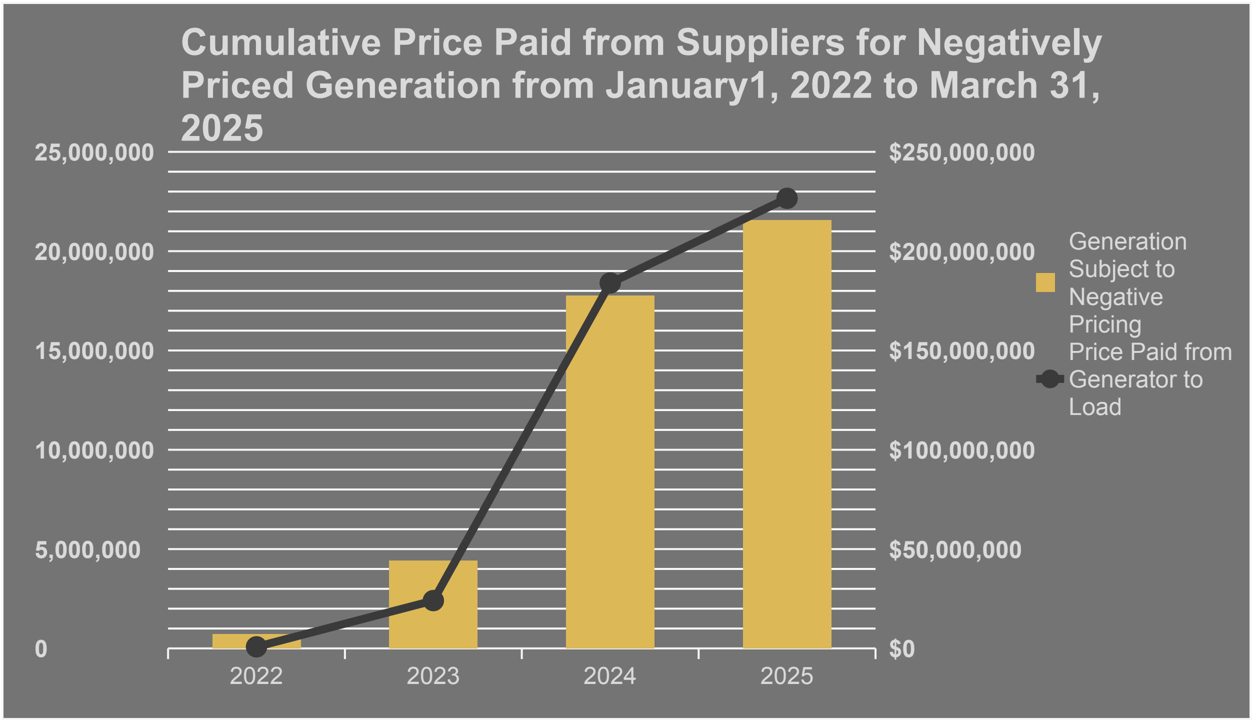
However, energy payments are just one part of a supplier's revenue stream. California regulations require LSEs to meet specific percentages of their load with zero-emission sources. To verify compliance, LSEs must procure Renewable Energy Credits (RECs) from suppliers. Additionally, LSEs are mandated to secure enough generation capacity to meet reliability standards, leading to a third revenue source for suppliers known as Resource Adequacy (RA).

Most suppliers structure long-term contracts that bundle three payments: compensation for energy delivered, RECs, and RA capacity. This allows the generator to earn revenue even during negative pricing periods because, in some cases, LSEs are willing to pay for the generators to produce energy during negatively priced periods since they would have to purchase RECs and RA capacity if they chose to curtail the energy. However, because PPA contracts, including REC and RA contracts, are typically bilateral and confidential, it is difficult to determine whether suppliers can remain profitable when energy prices dip below zero. From ZGlobal's perspective, the combined value of RECs and RA payments may not always offset the financial losses incurred from negative energy prices, especially as these events become more frequent and negative pricing is driven lower.

Quantifying the total amount that generators have effectively paid to keep producing during negatively priced hours is challenging. Each generator is assigned a unique pricing node (PNode), where locational marginal prices (LMPs) reflect not only the energy price but also congestion and transmission losses. To simplify this analysis, this report focuses on the universal energy component of the LMP across the California Independent System Operator (CAISO) market. It highlights the year-over-year increase in negatively priced energy hours from 2022 to QTR1 2025, with particular attention to seasonal trends that contribute to this growing phenomenon.

## Summary of Findings: Breaking Down the Increase of Negative Energy Pricing Over Time

In the CAISO balancing area, negative energy pricing has become more frequent over time, especially during the spring months. The quantity of negatively priced hours has been steadily increasing from 2022 to 2025, driven by rising renewable generation and seasonal factors. The chart below shows an illustration of the cumulative total of generation in CAISO, including imports, which were subjected to negative energy pricing for the period and the associated cost of energy.




During this period, CAISO has experienced an overall increase in renewable energy capacity, particularly solar, which coupled with generation from hydroelectric plants during the spring (in moderate to above average hydro years) has produced a year-over-year increase in curtailment and negative prices. The surplus of energy during peak renewable generation months has outpaced demand, contributing to a greater number of negatively priced hours. When negative prices occur, suppliers, subject to their contractual agreement, can stop generating energy or curtail their output[4] or keep generating electricity and pay for the ability to generate. Below is a summary of the total amount paid by suppliers to CAISO and the total amount of energy supplied at negative prices.

| Year | Supplier MWh | Suppliers' Payment to CAISO | Day Ahead Hours Per Year Priced Between $0 to Negative $26/MWh | Day Ahead Hours Per Year Priced Less Than Negative $26/MWh |
|---|---|---|---|---|
| 2023 | 3,700,265 | $23,277,923 | 188 | 0 |
| 2024 | 13,347,076 | $159,883,667 | 575 | 62 |
| Q1 2025 | 3,799,606 | $42,651,353 | 161 | 22 |
| **Total** | **21,560,547** | **$226,606,744** | **963** | **84** |

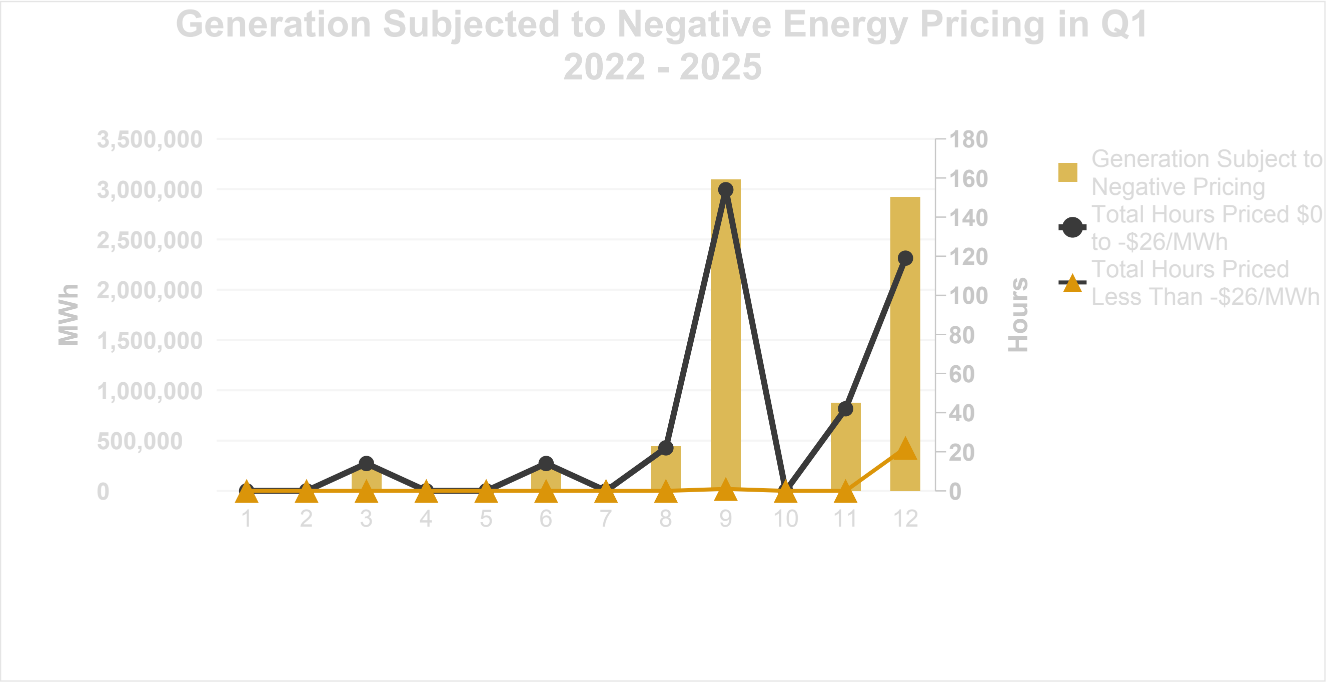
| | Generation Subjected to Negative Pricing | Total Hours Priced $0 to Negative $26/MWh | Total Hours Priced < Negative $26/MWh |
|---|---|---|---|

[4]In 2024, 3,423,377 MWh of renewable generation was curtailed, which was an increase from 2,659,526 MWh or renewable generation curtailed in 2023.

| | | | |
|---|---|---|---|
| 2022 | 713,600 | 39 | 0 |
| Qtr1 | 227,795 | 14 | 0 |
| Qtr2 | 485,805 | 25 | 0 |
| Qtr3 | 0 | 0 | 0 |
| Qtr4 | 0 | 0 | 0 |
| 2023 | 3,700,265 | 188 | 0 |
| Qtr1 | 234,450 | 14 | 0 |
| Qtr2 | 3,405,095 | 171 | 0 |
| Qtr3 | 0 | 0 | 0 |
| Qtr4 | 60,720 | 3 | 0 |
| 2024 | 13,347,076 | 575 | 62 |
| Qtr1 | 3,541,012 | 176 | 1 |
| Qtr2 | 9,346,599 | 380 | 61 |
| Qtr3 | 331,349 | 13 | 0 |
| Qtr4 | 128,116 | 6 | 0 |
| 2025 | 876,062 | 42 | 0 |
| Qtr1 | 876,062 | 42 | 0 |
| Grand Total | 18,637,003 | 844 | 62 |

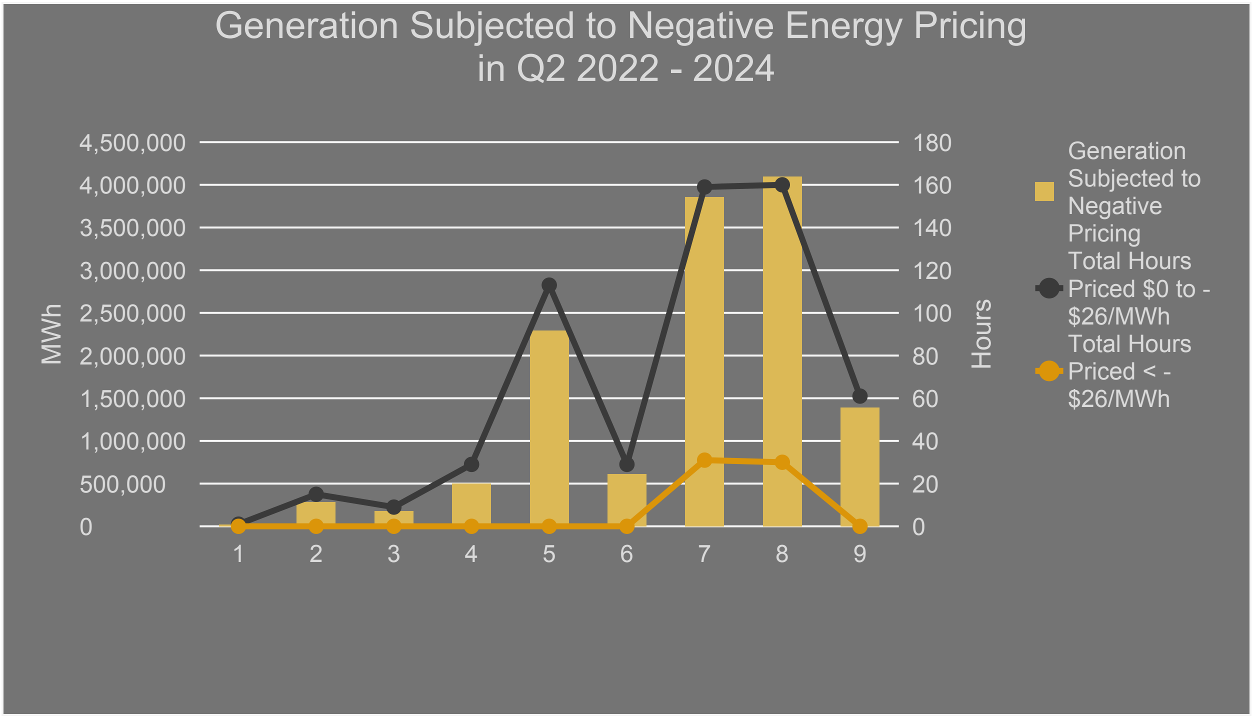
As renewable capacity grows, negative pricing becomes more frequent in the first and second quarters each year. By 2023, this issue extended to the fourth quarter, and, by 2024, negative pricing was also recorded in the third quarter, further emphasizing the increasing trend of negative pricing across all quarters.

Negative energy prices have been observed in the first quarter of each year since 2022, which is typically the period when hydroelectric plants are operating at their peak due to snowmelt. During this time, the combination of high hydroelectric output and low energy demand led to an oversupply of electricity.



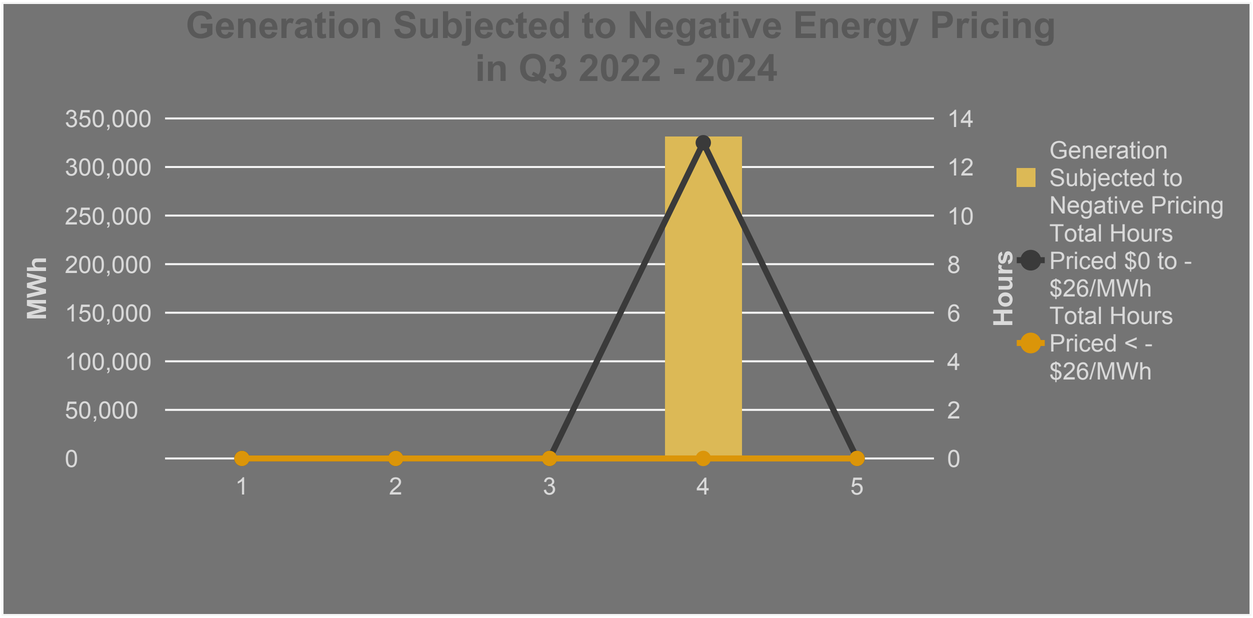
Since 2022, there have been 7,802,864 MWh of generation subjected to negative-energy pricing as low as negative $26.08/MWh over a total of 388 hours. In 2022 and 2023, negative prices were observed in QTR1 only in March, but in 2024 we saw negative prices stretch into February as well. In March 2025, we saw less generation subjected to negative prices than in 2024, but there was a higher overall number of hours when prices dipped below negative $26.

QTR2 has historically been the period with the most pronounced negative pricing events, driven by the high generation of hydroelectric and solar power during the spring as the combination of spring snowmelt and strong solar generation result in an oversupply of energy.



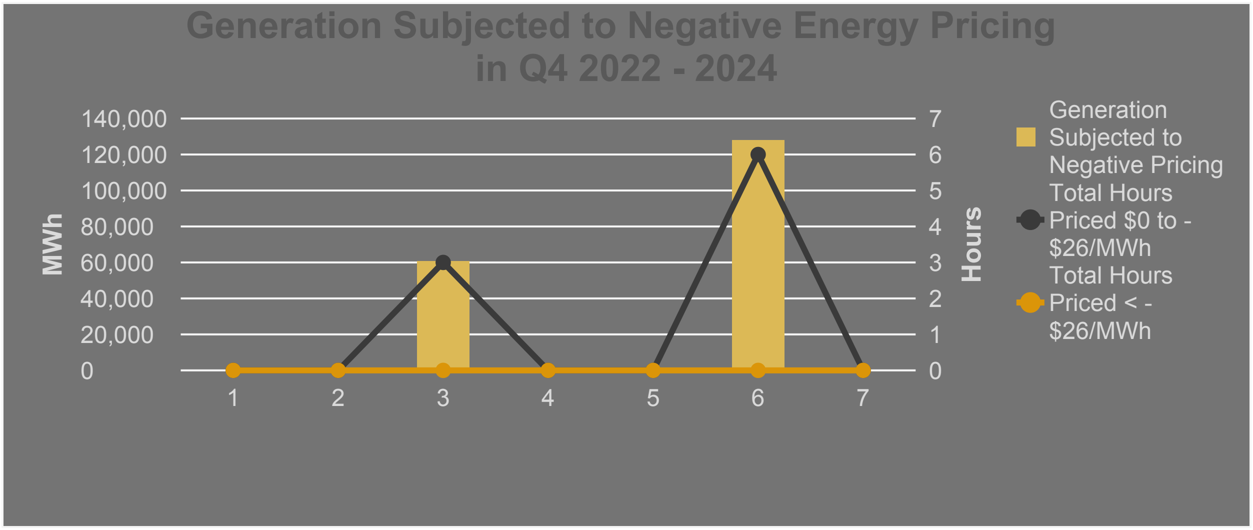

Since 2022, in QTR2 there have been 13,237,499 MWh of generation subjected to negative energy pricing as low as negative $40.99/MWh over a total of 637 hours. As shown in the graph above, negative prices are getting lower as time goes on with prices more frequently dropping below negative $26 per MWh.

While QTR3 typically sees high solar generation during the summer months, the issue of negative pricing was observed in 2024, when the increase in renewable generation and continuing grid imbalances contributed to negative pricing events even in the traditionally high-demand summer period due to milder summer temperatures and high hydro generation.




In 2024, negative pricing was observed over 13 hours in QTR3 with a total of 331,349 MWh of generation being subjected to prices as low as negative $3.17/MWh. This highlights the growing challenges in managing grid supply and demand, even during the summer months when energy consumption typically peaks.

QTR4 of the year saw negative pricing events beginning in 2023, with solar and hydro generation continuing to contribute to the energy surplus. While QTR4 had historically been a period of high demand, it became another point of concern as renewable generation continued to rise and outpace demand.

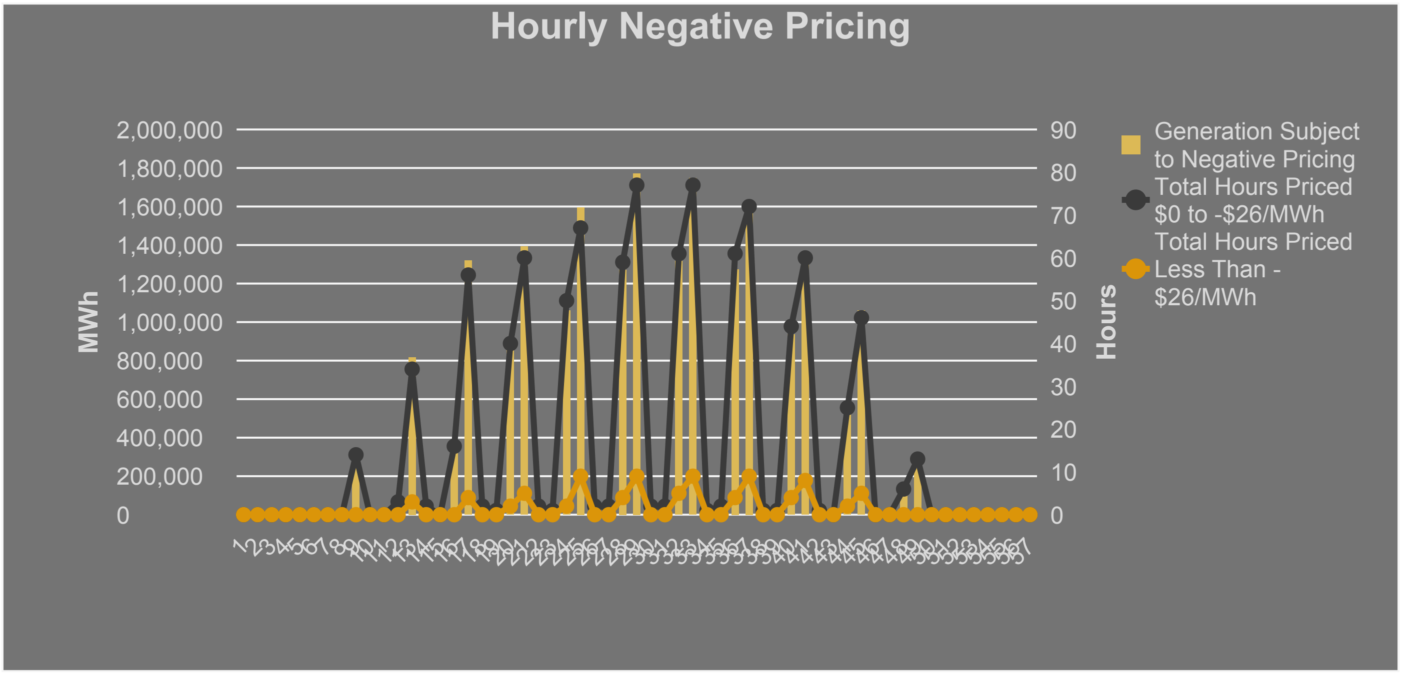



A total of 188,836 MWh was subjected to negative pricing over 9 hours with prices reaching as low as negative $3.93/MWh. This trend in QTR4 reflects broader challenges in grid balancing as renewable energy generation expands, and the capacity to store or distribute energy remains limited.

## How Negative Pricing Follows the "Duck Curve"

The rising number of negatively priced hours in California aligns with the well-known "Duck Curve" issue. The Duck Curve illustrates how solar generation peaks in the middle of the day, often leading to oversupply when energy demand is lower, especially in the spring and early fall.

Negative pricing is most often observed during the hours of peak solar generation, when excess energy floods the grid. As California's solar generation increases, the "duck-shaped" dip in demand occurs when there is a sharp drop in net demand as solar output peaks, followed by a steep increase in demand during the evening when solar generation drops off.




As the state's solar capacity grows, negative pricing during midday hours becomes more frequent, especially when hydro generation is at its highest.

## Looking Forward

Although not necessarily a bad outcome, negative energy pricing in California has been steadily increasing, particularly during the spring months when hydroelectric generation is at its peak. In 2022, negative pricing was largely limited to the first and second quarters. However, by 2023 it had expanded into the fourth quarter, and, in 2024, negatively priced hours were observed across all four quarters. In the first quarter of 2025 alone, California recorded the highest number of negatively priced hours since 2022—a trend that is expected to continue throughout the year.

This growing phenomenon is closely tied to the state's increasing share of renewable energy, particularly the overgeneration of solar and hydroelectric power. Compounding the issue are persistent grid management challenges and limited energy storage capacity. As California advances its transition toward a cleaner grid, addressing the root causes of negative pricing will be critical to ensuring long-term grid stability and operational efficiency.

## Will Battery Storage Offer a Solution?

In our opinion, battery storage is not enough to offer a complete solution. Utility-scale battery storage is progressing rapidly, but not fast enough to fully absorb the entire excess generation during peak solar hours. Some predict that widespread battery deployment will eventually flatten the price differential between solar and non-solar hours. However, we do not anticipate this scenario becoming reality within the next decade—especially if the Diablo Canyon nuclear plant retires. Additionally, much of the current battery development is co-located with new solar projects, further adding solar capacity to the grid rather than providing standalone storage. As a result, it may take time before batteries have a significant impact on mitigating overgeneration.

Interconnection, transmission constraints, and deliverability limitations remain key barriers to the accelerated deployment of storage resources. The core economic case for batteries lies in their ability to store low-cost or negatively priced energy during solar hours and discharge it during evening peaks, ideally at prices lower than those seen before widespread storage adoption.

One particularly telling market dynamic is that many investors are hesitant to pursue standalone storage projects due to uncertainty around future charging costs. There's skepticism that today's low or negative prices will persist over the long term. Nonetheless, we believe that early movers in standalone storage will be best positioned to benefit, while those who take a "wait and see" approach risk missing critical market opportunities.