Turning Down the Gas in California

The Role of Natural Gas in the State's Clean Electricity Future

Technical Appendix

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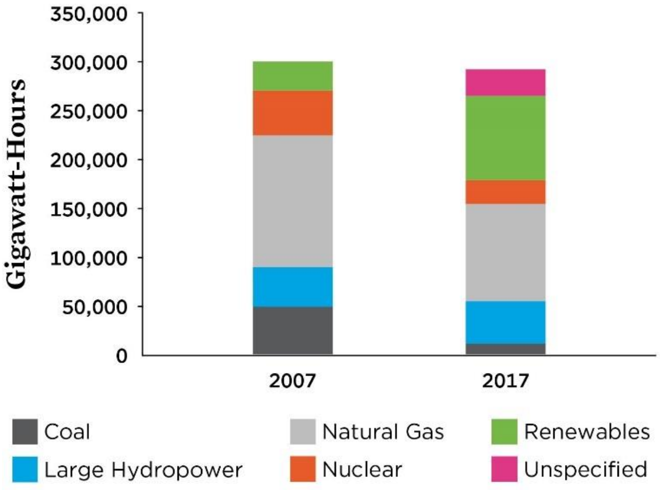
[EXECUTIVE SUMMARY]

California has firmly established itself as a global clean energy leader by advancing new technologies and "clean tech" jobs while reducing global warming emissions, diversifying its fuel mix, and growing its economy to become the fifth largest in the world. Driving these efforts are California's law to reduce emissions throughout its economy to 40 percent below 1990 levels by 2030 (California Legislature 2016) and its longer-term goal to reduce emissions to 80 percent below 1990 levels by 2050 (Schwarzenegger 2005).

To transition to a safer and cleaner electricity system and meet California's ambitious climate goals, the state must use less fossil fuel and instead rely on cleaner sources of energy that do not emit global warming gases. In the electricity sector, this transition means using less electricity produced by natural gas–fired power plants and more from renewable sources such as solar, wind, geothermal, low-carbon biomass, and biogas. In the transportation sector, this transition means replacing vehicles currently running on gasoline and diesel with vehicles powered by renewable electricity, which will also significantly reduce criteria air pollutants that cause cancer and chronic respiratory diseases. In the residential sector, this transition means using affordable renewable electricity to heat homes and buildings that currently depend on natural gas for these needs.

In the past decade, California has made significant investments in renewable electricity generation. In 2017, renewables comprised 29 percent of the state's electricity mix (CEC 2018) (Figure ES-1). Most utilities in the state are on track to meet—and even exceed—the current requirement to serve 50 percent of electricity demand from renewables by 2030 (California Legislature 2015). But California still relies on natural gas–fired generation to meet a substantial portion of its electricity needs: in 2017, natural gas made up 33 percent of the state's electricity mix (CEC 2018).

FIGURE ES-1. **California Electricity Mix, 2007 and 2017**



Renewable energy generation in California has increased significantly since 2007, but natural gas remains a key component of the state's electricity supply.

Note: "Unspecified" sources of power include spot market purchases, wholesale power purchases, and purchases from pools of electricity for which the original source cannot be determined.

SOURCE: CEC 2018.

Because natural gas–fired power plants supply a substantial portion of California's current electricity demand and support grid reliability, natural gas generation will be needed through at least 2030 as cleaner energy sources and other grid reliability technologies come online. But for California to realize the benefits of its clean energy transition and achieve its global warming emissions targets, it needs to reduce its dependence on natural gas electricity generation significantly. This transition should prioritize reducing natural gas generation in communities most negatively affected by the pollution resulting from burning fossil fuels and by the social, economic, and health burdens associated with global warming.

Methodology

The purpose of this report is to present modeling results that shed light on the transition away from natural gas generation in California's electricity system. To understand what an orderly and equitable transition away from natural gas generation in California might look like, the Union of Concerned Scientists (UCS) analyzed the operations of the 89 natural gas simple cycle "peaker" plants and combined cycle gas turbine (CCGT) plants located in the territory of the California Independent System Operator (CAISO), the grid operator that manages the electricity flow for about 80 percent of the state.

For this analysis, UCS used GridPath, a grid analytics platform capable of several types of power system modeling approaches. Here, we used GridPath in capacity-expansion mode to identify cost-effective deployment of new system resources and retirement of existing infrastructure to meet load, reliability, and policy goals for the CAISO power system in four planning years: 2018, 2022, 2026, and 2030. (For more information regarding GridPath, see the appendix.)

Our analysis used the public data available from the 2017–2018 cycle of the California Public Utilities Commission (CPUC) Integrated Resource Plan (IRP), a long-term energy planning process required by statute to determine what investments are needed in the electricity sector to meet the state's 2030 global warming emission reduction goals (California Public Utilities Code 2015a). A high-level summary of the GridPath model setup and input data is provided in the appendix.

This analysis has three major objectives:

1. **Identify economic drivers of natural gas plant retirements**: GridPath optimizes retirements over the entire study period (i.e., with "perfect foresight"), economically retiring individual natural gas plants when they are no longer valuable to the CAISO system. The model also incorporates local capacity requirements (LCR)—generation to provide power in specific locations during grid emergencies—in order to understand their effect on retirements.[1]
2. **Estimate the quantity, location, and timing of natural gas plant economic retirements**: GridPath models the operations of individual gas plants in four investment periods—2018, 2022, 2026, 2030—making it possible to identify where and when economic retirements will occur within the CAISO system.
3. **Measure future changes in operations for natural gas plants not being retired**: GridPath measures the change in generation, capacity factor, and starts/stops for each gas plant.

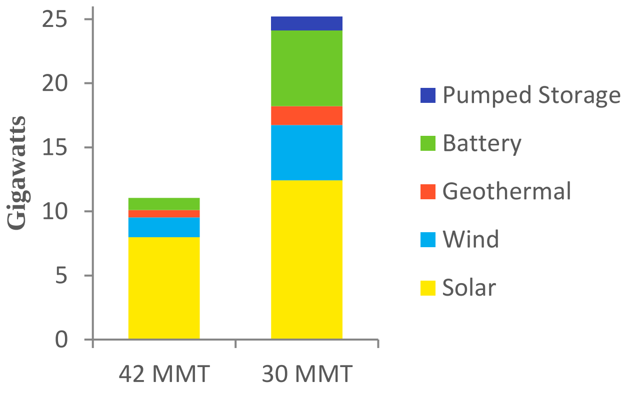
Using GridPath, we ran six pairs of scenarios. Each pair consisted of a scenario that capped statewide electricity-sector global warming emissions in 2030 at 42 million metric tons (MMT) of carbon dioxide (CO_2) equivalent and one that capped emissions at 30 MMT CO_2 equivalent. These carbon caps are identical to the caps used in the CPUC IRP. All 12 scenarios in the UCS analysis incorporated a natural gas fleet that was modeled at the individual plant level, but the scenarios varied the ability of natural gas plants to be retired and the way in which LCR constraints were enforced.

Only one of the six pairs of scenarios did not allow natural gas plants to be retired. Of the remaining scenarios that did allow natural gas plant retirements, one pair did not enforce LCR constraints, one pair enforced LCR constraints but allowed only existing resources to satisfy the constraints, and the other three pairs enforced LCR constraints and allowed new natural gas or energy storage to satisfy the constraints. Each of the three pairs of scenarios that allowed new resources to satisfy LCR had a different minimum battery duration requirement; we tested a four-hour, six-hour, and eight-hour minimum battery duration. A summary of the scenarios can be found in Table ES-1.

New Capacity Investments

In all but one of the scenarios we ran, no new natural gas capacity is needed to meet energy and grid reliability needs by 2030 (Figure ES-2).[2] In the "42 MMT, Enforce LCR, Allow New Resources, 4h" scenario, GridPath selects approximately 8.0 gigawatts (GW) solar, 1.5 GW wind, 1.0 GW batteries (with an average duration of about one hour), and 0.6 GW geothermal by 2030. In the "30 MMT, Enforce LCR, Allow New Resources, 4h" scenario, GridPath selects approximately 12.4 GW solar, 4.3 GW wind, 5.9 GW batteries (with an

FIGURE ES-2. **New Capacity Investments by 2030**



Our analysis indicates that no new natural gas capacity is needed to meet 2030 energy or grid reliability needs.

Note: Figure assumes scenarios with LCR enforced and four-hour batteries allowed for LCR. These capacity build-outs are representative of the build-out for any scenario with the same carbon cap. GridPath had the option to add new biomass, peaker, and CCGT capacity, but did not select any.

average duration of about four hours), 1.5 GW geothermal, and 1.1 GW pumped hydro (with an average duration of about 12 hours) by 2030. Because the carbon cap is the primary driver of new capacity selected by GridPath, the results presented for this pair of scenarios are representative of any scenario with the same carbon cap, regardless of whether natural gas plant retirements are allowed or how LCR is met.

Local Capacity Requirements Prevent Natural Gas Plant Retirements

To understand the effects of LCR on natural gas plant retirements, we ran scenarios with and without LCR constraints and compared the results. LCR is very important for ensuring grid reliability, and UCS did not conduct this comparison to suggest that LCR should be reduced or removed. This comparison is merely meant to shed light on the drivers keeping natural gas plants from being retired. A summary of how much natural gas capacity is retired in each scenario can be found in Table ES-2.

TABLE ES-1. **Summary of Scenarios**

Scenario Name	Carbon Cap	Allow Retirements?	Enforce LCR?	Allow New Resources to Contribute to LCR?	Minimum Battery Duration for LCR Credit
42 MMT, No Retirements	42 MMT	No	No	No	N/A
30 MMT, No Retirements	30 MMT	No	No	No	N/A
42 MMT, No LCR	42 MMT	Yes	No	No	N/A
30 MMT, No LCR	30 MMT	Yes	No	No	N/A
42 MMT, Enforce LCR, Existing Resources Only	42 MMT	Yes	Yes	No	N/A
30 MMT, Enforce LCR, Existing Resources Only	30 MMT	Yes	Yes	No	N/A
42 MMT, Enforce LCR, Allow New Resources, 4h	42 MMT	Yes	Yes	Yes	4 hours
30 MMT, Enforce LCR, Allow New Resources, 4h	30 MMT	Yes	Yes	Yes	4 hours
42 MMT, Enforce LCR, Allow New Resources, 6h	42 MMT	Yes	Yes	Yes	6 hours
30 MMT, Enforce LCR, Allow New Resources, 6h	30 MMT	Yes	Yes	Yes	6 hours
42 MMT, Enforce LCR, Allow New Resources, 8h	42 MMT	Yes	Yes	Yes	8 hours
30 MMT, Enforce LCR, Allow New Resources, 8h	30 MMT	Yes	Yes	Yes	8 hours

In the 12 scenarios, we varied the carbon cap, the ability of natural gas plants to retire, the enforcement of LCR constraints, and the battery duration required in order to meet LCR.

TABLE ES-2. **Percent of Capacity Retired by 2030 with and without LCR**

Carbon Cap	Plant Type	Scenario		
		No LCR		**Enforce LCR**
42 MMT	**CCGT**	20%	***Enforce LCR*** ⇨	23%
	Peaker	57%		24%
30 MMT	**CCGT**	32%		25%
	Peaker	100%		24%

Enforcing LCR prevents a significant quantity of natural gas plant generation capacity from being retired.

Note: Table shows results from the "No LCR" and "Enforce LCR, Existing Resources Only" scenarios.

In the "42 MMT, No LCR" scenario, 20 percent of CCGT capacity and 57 percent of peaker capacity is retired by 2030. When LCR is enforced in the "42 MMT, Enforce LCR, Existing Resources Only" scenario, 23 percent of CCGT capacity and 24 percent of peaker capacity is retired by 2030. Thus, enforcing LCR constraints prevents one-third of CAISO peaker capacity from being retired because those peakers must remain on the system to provide local capacity. Since more peaker capacity remains on the system when LCR constraints are enforced, this allows a little more CCGT capacity to be retired in the "42 MMT, Enforce LCR, Existing Resources Only" scenario.

In the "30 MMT, No LCR" scenario, 32 percent of CCGT capacity and 100 percent of peaker capacity is retired by 2030. When LCR constraints are enforced in the "30 MMT, Enforce LCR, Existing Resources Only" scenario, only 25 percent of CCGT capacity and 24 percent of peaker capacity is retired. In this case, enforcing LCR constraints prevents 76 percent of CAISO peaker capacity and 7 percent of CAISO CCGT capacity from being retired.

Our results suggest that LCR constraints have a significant effect on the number of natural gas plant retirements, particularly peaker retirements. Enforcing LCR constraints limits peaker retirements to 24 percent of peaker fleet capacity regardless of the carbon cap; when LCR is not enforced, an additional one-third to three-quarters of peaker capacity is retired, depending on the carbon cap. This indicates that one-quarter of the peaker fleet does not provide essential local capacity value, while the other three-quarters of the peaker fleet does have locational value, which forces those plants to remain on the system.

Meeting Local Capacity Requirements with Batteries Accelerates Natural Gas Plant Retirements

We ran three additional pairs of scenarios under the 42 MMT and 30 MMT carbon caps in which certain new resources (natural gas plants and battery storage) were allowed to satisfy LCR: "Enforce LCR, Allow New Resources." Each of the three pairs of scenarios had a different minimum battery duration required to contribute to LCR; we tested a four-hour, six-hour, and eight-hour minimum battery duration. A summary of how much natural gas capacity is retired in each scenario can be found in Table ES-3.

Allowing new resources to satisfy LCR has no effect on gas plant retirements in the 42 MMT scenarios. This is because batteries with a duration of four hours or more, which would be able to satisfy LCR, are not economical under the 42 MMT carbon cap so the model does not select them. In these scenarios, new battery capacity that is selected by the model has an average duration of approximately one hour, so these batteries cannot satisfy the LCR constraints.

In the 30 MMT scenarios, allowing new resources to satisfy LCR has a substantial effect on the quantity of gas plant capacity retirement, and the minimum battery duration required to satisfy LCR plays a crucial role in determining the number of natural gas plants that are economically retired. Under the 30 MMT carbon cap, the model selects batteries with an average duration of 4.1 hours, and these batteries are used for shifting energy over several hours. In the "30 MMT, Enforce LCR, Allow New Resources, 4h" scenario, four-hour batteries are already being built, and the addition of LCR as another revenue stream results in the strategic placement of the four-hour batteries to maximize their LCR value. As a result, allowing new four-hour batteries to satisfy LCR leads to the retirement of 30 percent of CCGT capacity and 87 percent of peaker capacity. This is a significant increase in peaker capacity retirement compared to the "30 MMT, Enforce LCR, Existing Resources Only" scenario (with peaker capacity retirement at only 24 percent). However, as the battery duration required to satisfy LCR is increased, fewer natural gas plants, particularly peakers, are retired. In the "30 MMT, Enforce LCR, Allow New Resources, 6h" scenario, peaker capacity retirement drops to 34 percent. In the "30 MMT, Enforce LCR, Allow New Resources, 8h" scenario, both peaker capacity and CCGT capacity retirements drop down to 24 percent. In this scenario, the model does not build any batteries with a duration long enough to satisfy LCR, so no additional natural gas plants are retired.

TABLE ES-3. **Percent of Capacity Retired by 2030 with and without Allowing New Resources to Satisfy LCR**

Carbon Cap	Plant Type	Scenario				
		Existing Resources Only		Allow New Resources, 4h	Allow New Resources, 6h	Allow New Resources, 8h
42 MMT	**CCGT**	23%	***Allow New Resources for LCR*** ⟹	23%	23%	23%
	Peaker	24%		24%	24%	24%
30 MMT	**CCGT**	25%		30%	30%	24%
	Peaker	24%		87%	34%	24%

Allowing new resources to satisfy LCR enables more natural gas capacity to be retired in the 30 MMT scenarios with a four-hour or six-hour minimum battery duration requirement.

Note: Table shows results from the “Enforce LCR, Existing Resources Only” and “Enforce LCR, Allow New Resources” scenarios.

In summary, the battery duration required for LCR is a key factor in determining the quantity of natural gas generation capacity that can be retired by 2030 under a 30 MMT carbon cap. On one end of the spectrum, nearly the entire peaker fleet can be retired by 2030 if four-hour batteries can satisfy LCR, but on the other end, only a quarter of peaker generation capacity can be retired if eight-hour batteries are required for LCR.

At Least One-Quarter of Natural Gas Plant Capacity Can Be Retired by 2030

To understand the natural gas plant retirements that are likely to occur by 2030, we focus on the results from one pair of scenarios, “Enforce LCR, Allow New Resources, 4h,” under both the 42 MMT and 30 MMT carbon caps. We focus on these two scenarios because four-hour duration batteries are currently allowed to satisfy LCR, so this pair of scenarios represents current policy. Therefore, the results of these two scenarios are our best estimate of the quantity, location, and timing of natural gas plant retirements likely to occur by 2030.

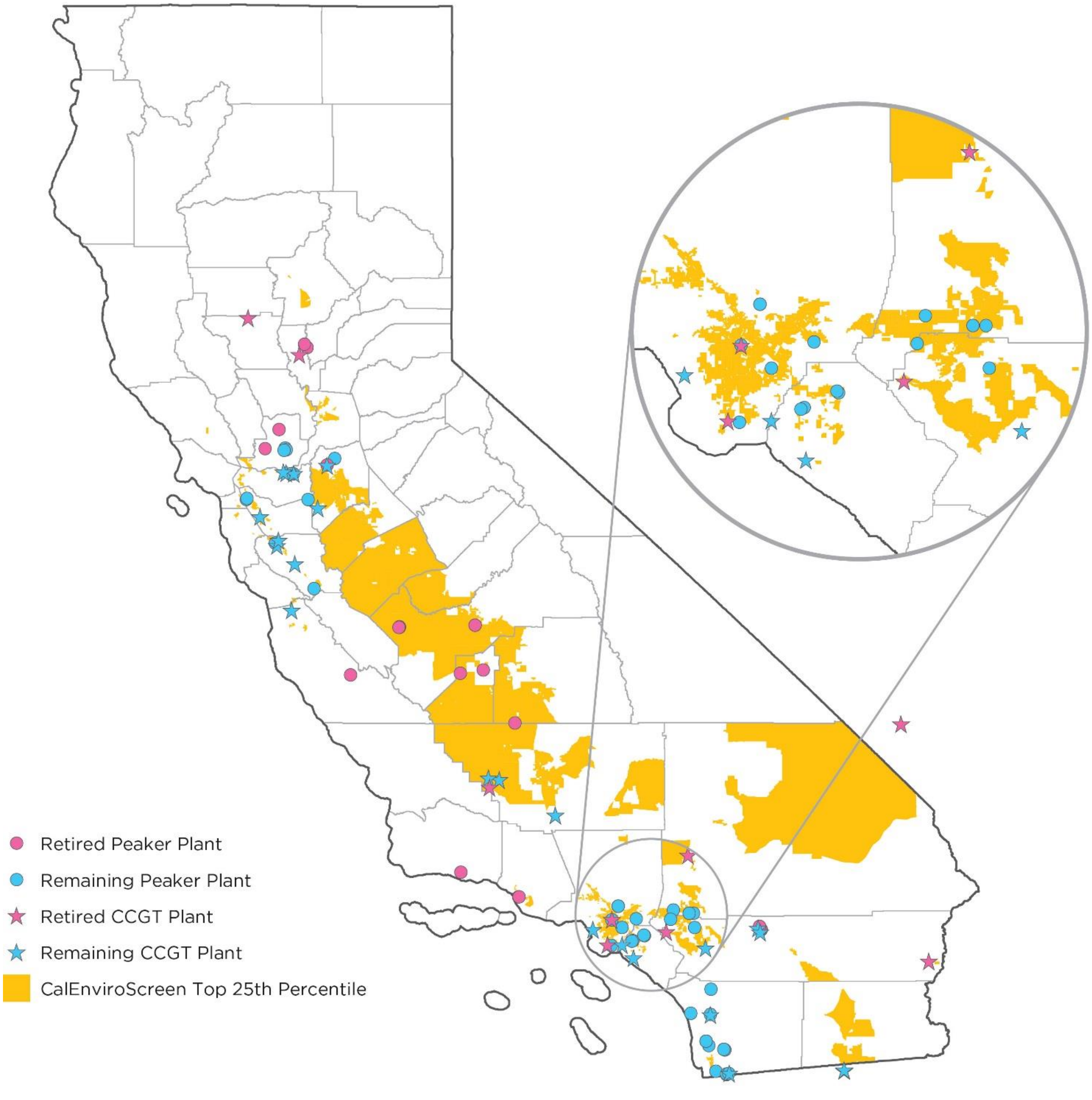
Under the 42 MMT carbon cap, 23 percent of CCGT capacity and 24 percent of peaker capacity is retired by 2030. This equates to 28 of the 89 natural gas plants modeled in the CAISO territory being retired without affecting grid reliability (Figure ES-3). Twelve of the 28 retired plants are located in CalEnviroScreen top 25th percentile census tracts, which the CPUC considers “disadvantaged communities.”

Under the 30 MMT carbon cap, 30 percent of CCGT capacity and 87 percent of peaker capacity—a total of 56 of the 89 plants currently operating in the CAISO territory—are retired by 2030 without negatively affecting grid reliability (Figure ES-4). Of the 56 natural gas plants that are retired, 23 are located in CalEnviroScreen top 25th percentile census tracts, or disadvantaged communities.

These results indicate that, depending on the carbon cap, as many as 23 natural gas plants located in disadvantaged communities can be retired by 2030. These retirements will likely have a positive impact on these communities, where air pollution is often persistent and emissions from natural gas plants contribute to that pollution.

The timing of natural gas plant retirements depends on the carbon cap. In the 42 MMT carbon cap scenario, all the CCGT and peaker retirements happen in 2018. In contrast, in the 30 MMT carbon cap scenario, most of the CCGT capacity retirements and one-third of peaker capacity retirements occur in 2018. The remaining CCGT capacity retirements and the remaining two-thirds of peaker capacity retirements occur in 2030. Despite low peaker utilization under the 30 MMT carbon cap, the planning reserve margin prevents most of the peakers from being retired until 2030, when the rapid deployment of multihour batteries and pumped hydropower, which contribute to LCR and the planning reserve margin, allows nearly all the peakers to be retired.

FIGURE ES-3. **Natural Gas Plant Retirements by 2030, 42 MMT Scenario**

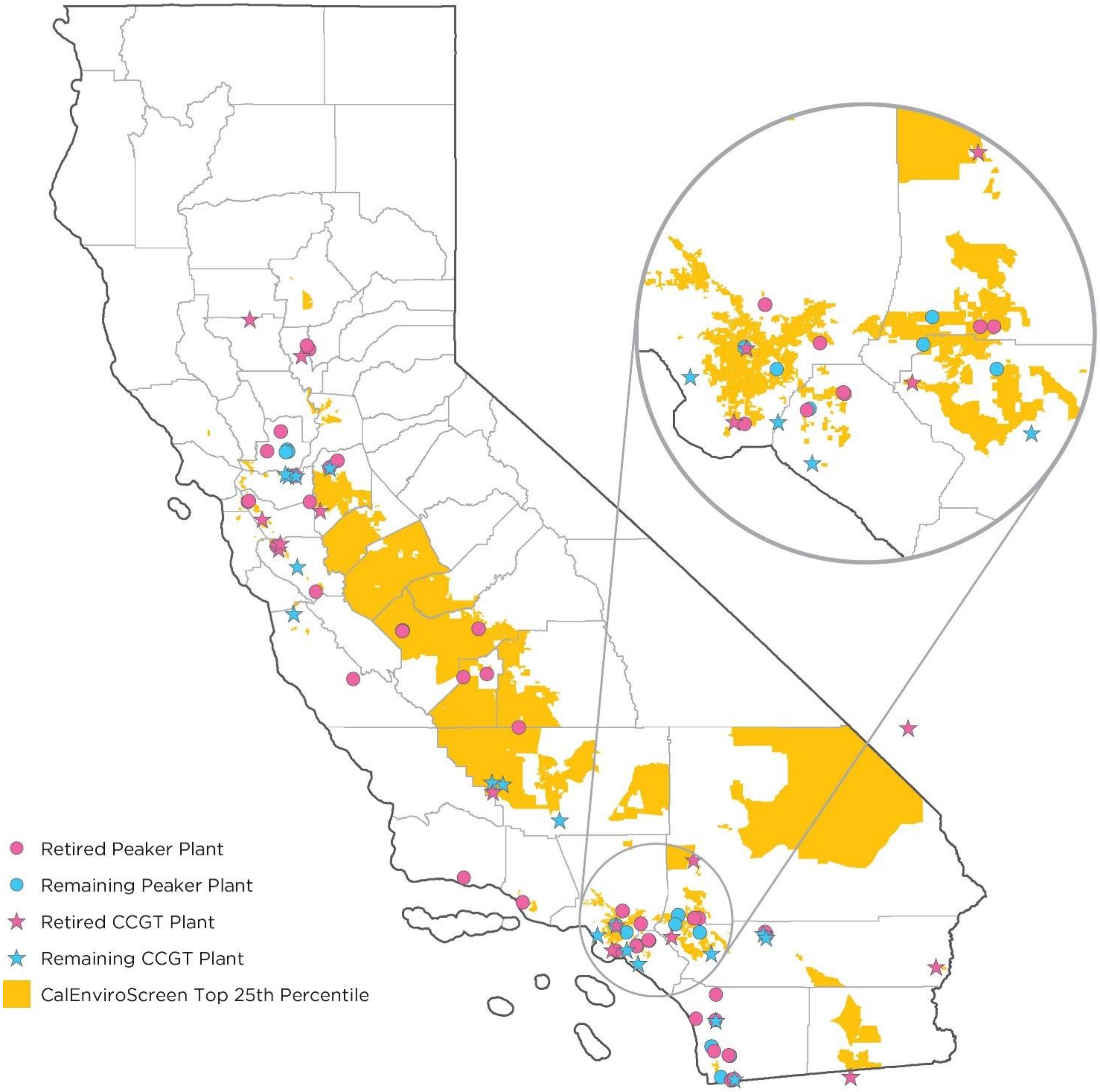


Twenty-eight natural gas plants in the CAISO territory could be retired while still meeting energy and reliability requirements. Twelve of the plants that could be retired are located in communities, shown in orange, that are disproportionately burdened by air pollution.

Note: Figure assumes a 42 MMT scenario with LCR enforced and four-hour batteries allowed for LCR. Orange shading indicates the top 25th percentile of California census tracts that are disproportionately burdened by, and vulnerable to, multiple sources of pollution according to CalEnviroScreen, an environmental, health, and socioeconomic mapping tool. Plants shown outside of state boundaries are plants that supply electricity to the CAISO grid.

SOURCES: OEHHA 2017 (CALENVIROSCREEN 3.0); UCS ANALYSIS.

FIGURE ES-4. **Natural Gas Plant Retirements by 2030, 30 MMT Scenario**



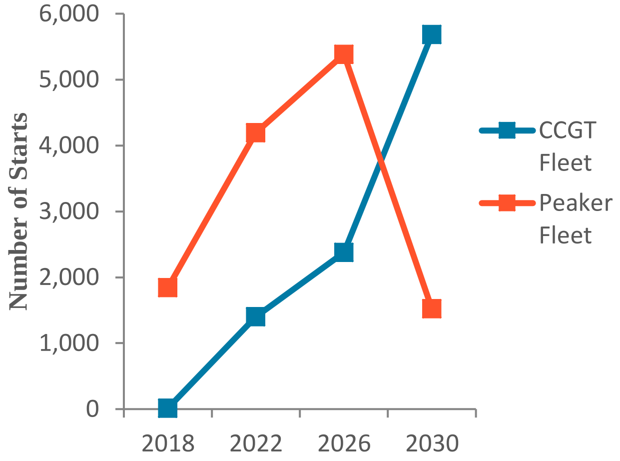
Fifty-six natural gas plants in the CAISO territory could be retired while still meeting energy and reliability requirements. Twenty-three of the plants that could be retired are located in communities, shown in orange, that are disproportionately burdened by air pollution.

Note: Figure assumes a 30 MMT scenario with LCR enforced and four-hour batteries allowed for LCR. Orange shading indicates the top 25th percentile of California census tracts that are disproportionately burdened by, and vulnerable to, multiple sources of pollution according to CalEnviroScreen, an environmental, health, and socioeconomic mapping tool. Plants shown outside of state boundaries are plants that supply electricity to the CAISO grid.

SOURCES: OEHHA 2017 (CALENVIROSCREEN 3.0); UCS ANALYSIS.

Regardless of the carbon cap, approximately one-quarter of both CCGT and peaker capacity is retired immediately in 2018. This indicates that those plants are not necessary for energy or reliability, and the lowest-cost way to manage the grid may be to retire those plants to avoid paying the fixed costs associated with keeping them operational.

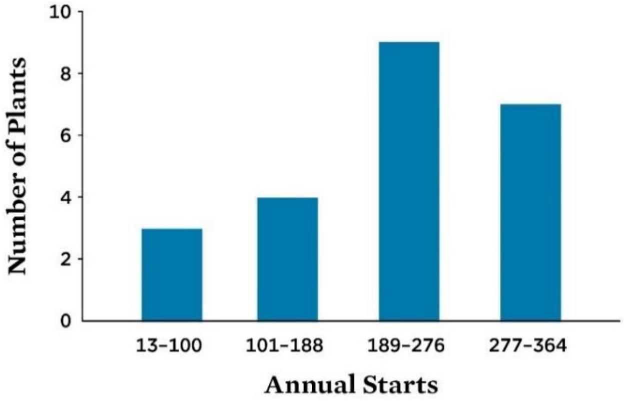
FIGURE ES-5. **Annual Gas Plant Starts**



Both CCGTs and peakers start up much more frequently over the duration of the study.

Note: Figure assumes a 42 MMT scenario with LCR enforced and four-hour batteries allowed for LCR.

FIGURE ES-6. **Frequency of CCGT Starts in 2030**



Under a 42 MMT scenario, many combined-cycle natural gas plants will start and stop much more frequently in 2030 compared with today. Some plants will go from close to zero starts today (i.e., nonstop generation) to starting once nearly every day of the year.

Note: Figure assumes a 42 MMT scenario with LCR enforced and four-hour batteries allowed for LCR.

Natural Gas Plants Will Start and Stop Much More Frequently by 2030

In the “42 MMT, Enforce LCR, Allow New Resources, 4h” scenario, natural gas generation overall decreases by 4.2 terawatt-hours (TWh), or 8 percent, between 2018 and 2030 as more renewable generation capacity is installed. However, our results do not indicate that the retirement of natural gas generation capacity is a significant driver in further reducing natural gas energy generation. This is because plants retired in the model would have had a very low capacity factor and lost generation from one gas plant is generally compensated for by an increase in generation from another gas plant or imported electricity.

Over the course of the study period, many peakers and CCGTs start and stop significantly more than in 2018. The system-level trends for the “42 MMT, Enforce LCR, Allow New Resources, 4h” scenario are shown in Figure ES-5, which displays the total number of annual starts for both the peaker fleet and the CCGT fleet. Overall, the number of peaker and CCGT starts increases in 2022 and in 2026. This increase is a result of two factors: the rapid deployment of renewables by 2022 and steady load growth. The rapid deployment of renewables, particularly solar, forces many natural gas plants to turn off completely during the day then turn back on later to meet the evening net load peak. However, by 2030, a sudden switch occurs as the number of peaker starts drops sharply and the number of CCGT starts increases rapidly (Figure ES-5). This is because the 42 MMT carbon cap becomes the driving force behind decreasing peaker usage by 2030, and more-efficient CCGTs begin to play the role that less-efficient, but more flexible, peakers once fulfilled.

We also examined how changes in fleet operations manifest at the individual plant level. Figure ES-6 shows the distributions of CCGT starts in 2030. The CCGT fleet stops and starts close to zero times in 2018, but by 2030, 16 of the 23 nonretired CCGT plants start up more than 200 times per year (Figure ES-6).

This dramatic increase in peaker starts until 2026 and the increase in CCGT starts through 2030 could have a negative effect on air quality in communities near these plants. The amount of NO_x emissions resulting from starting up a natural gas plant can be as much as 30 times that from the same plant running at steady state for one hour (Birdsall et al. 2016; Lew et al. 2013). With a significant number of peakers and CCGTs starting up at least every other day, overall NO_x emissions from natural gas power plant generation may increase dramatically in California, potentially having a negative effect on air quality, and in turn, on the health of people living in communities near these plants.

Conclusion

California is on track to supply substantially more electricity needs with renewable energy generation, which will reduce global warming emissions and provide new clean resources to power the state's electricity needs, including the growing electric vehicle market. But natural gas–fired power plants still supply a substantial portion of energy and reliability needs for the grid, and California must take steps to reduce its dependence on natural gas generation if it is to realize the benefits of its clean energy transition.

Our analysis finds that no additional natural gas generation capacity is needed to keep the CAISO grid reliable even if California adds significant amounts of renewables to its electricity mix to meet its 2030 global warming emissions target. Indeed, UCS analysis indicates that at least a quarter of the state's existing natural gas generation capacity could be taken offline today, depending on what carbon cap is assumed and how LCR is met.

However, as natural gas generation declines overall, failure to invest further in nonfossil fuel grid flexibility technologies could lead to individual natural gas power plants cycling on and off much more frequently to meet evening energy needs, which may result in increased NO_x emissions from these plants. In addition, the need to fulfill LCR could prevent the retirement of some gas plants. Additional analysis is required to understand how more frequent stopping and starting of natural gas plants will affect air quality and the health of communities living near these plants. Future analysis should also consider how changes in air pollution associated with electricity generation may be offset by pollution reduction associated with vehicle electrification. To ensure an orderly and equitable transition away from natural gas generation, California needs to understand and plan better for natural gas plant retirements and changes in operations that will occur between now and 2030. UCS makes the following recommendations:

Energy planning activities should identify where natural gas plants can be retired. As California reduces dependence on natural gas generation, electricity providers, energy agencies, and grid operators need to know which natural gas plants may be critical for maintaining electricity system reliability and which are not. Keeping excess natural gas generation capacity on the system could impose unnecessary costs on electricity customers and may make it more difficult for California to meet its global warming emissions reduction goals. In addition, not having a clear understanding of the gas plant capacity most valuable to the electricity system may result in natural gas plants being retired prematurely.

Electricity providers, energy agencies, and grid operators should work together to calculate criteria air pollution emissions associated with increased natural gas plant cycling from individual power plants, and future procurement should minimize air pollution from gas plants. Our analysis indicates that both peakers and CCGTs will start and stop much more frequently between now and 2030. More analysis is therefore needed to understand better how increased natural gas plant cycling at the plant-specific level may affect emissions and air quality, especially in disadvantaged communities in California. More locational information on emissions from future gas plant cycling and potential implications for air quality can help electricity providers target nonfossil investments in certain areas to reduce the cycling of gas plants most likely to have a negative effect on local air quality.

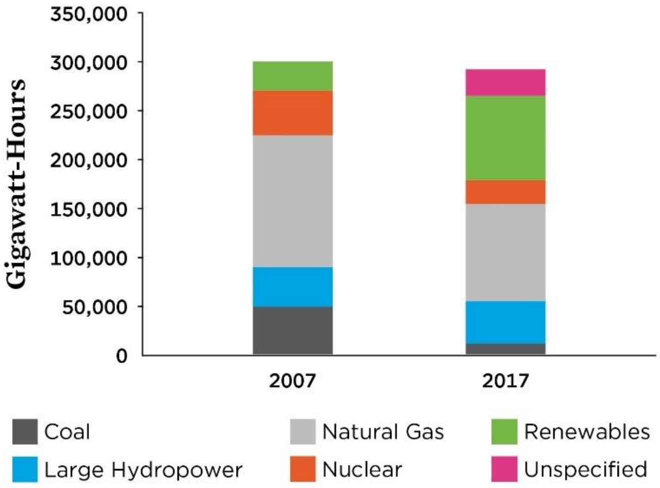
Electricity providers should invest in nonfossil sources of energy and grid flexibility and strategically site these resources so they can fulfill LCR. Shifting more evening electricity demand to daytime hours, investing in energy storage, and diversifying the portfolio of renewable energy resources can all help reduce the state's reliance on natural gas generation and the need to cycle in-state gas plants. In addition, allowing California grid operators greater access to generation resources outside the state will help reduce the need to cycle in-state gas plants. Also, our modeling indicates that when flexible nonfossil resources, such as energy storage, are located in areas where they can fulfill LCR, more peaker power plants can be retired. Electricity providers should be encouraged to invest in nonfossil resources in strategic locations to fulfill LCR and consider transmission upgrades to reduce/eliminate LCR in certain locations. This will be especially important in situations where gas plants that are essential to reliability will require major retrofits or contract payments that did not result from a competitive solicitation in order to continue fulfilling LCR.

California has firmly established itself as a global clean energy leader by advancing new technologies and "clean tech" jobs while reducing global warming emissions, diversifying its fuel mix, and growing its economy to become the fifth largest in the world. Driving these efforts are California's law to reduce emissions throughout its economy to 40 percent below 1990 levels by 2030 (California Legislature 2016) and its longer-term goal to reduce emissions to 80 percent below 1990 levels by 2050 (Schwarzenegger 2005).

To transition to a safer and cleaner electricity system and meet California's ambitious climate goals, the state must use less fossil fuel and instead rely on cleaner sources of energy that do not emit global warming gases. In the electricity sector, this transition means using less electricity produced by natural gas–fired power plants and more from renewable sources such as solar, wind, geothermal, low-carbon biomass, and biogas. In the transportation sector, this transition means replacing vehicles currently running on gasoline and diesel with vehicles powered by renewable electricity, which will also significantly reduce criteria air pollutants that cause cancer and chronic respiratory diseases. In the residential sector, this transition means using affordable renewable electricity to heat homes and buildings that currently depend on natural gas for these needs.

In the past decade, California has made significant investments in renewable electricity generation. In 2017, renewables comprised 29 percent of the state's electricity mix (CEC 2018) (Figure 1). Most utilities in the state are on track to meet—and even exceed—the current requirement to serve 50 percent of electricity demand from renewables by 2030 (California Legislature 2015). But California still relies on natural gas–fired generation to meet a substantial portion of its electricity needs: in 2017, natural gas made up 33 percent of the state's electricity mix (CEC 2018).

FIGURE 1. **California Electricity Mix, 2007 and 2017**



Renewable energy generation in California has increased significantly since 2007, but natural gas remains a key component of the state's electricity supply.

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SOURCE: CEC 2018.

The Current Role of Natural Gas Plants in California's Electricity System

There are nearly 200 utility-scale natural gas–fired power plants in California; together, they provide approximately 39 GW of generation capacity to the grid (S&P Global 2018). Almost all these plants are either simple cycle "peaker" plants or CCGT plants. Peakers are more flexible but less efficient than CCGTs.

Natural gas–fired power plants' flexibility has been useful for California's electricity grid operators, who must always match electricity supply and demand. Natural gas can be stored, which means power plant operators can control when a plant generates electricity. In contrast, weather patterns determine wind and solar generation, so electricity supplied by them varies over the course of the day and season. Operators can ramp both peakers and CCGTs up and down in a relatively short amount of time, which helps keep supply matched to demand as solar and wind generation fluctuates. In addition, natural gas plants have historically provided many grid reliability services. These services include fast response to a grid operator's signal to restore electricity supply as well as "local capacity," or generation to provide power in specific locations in emergencies, such as when a major power plant fails and electricity cannot be imported from outside the local area.[1]

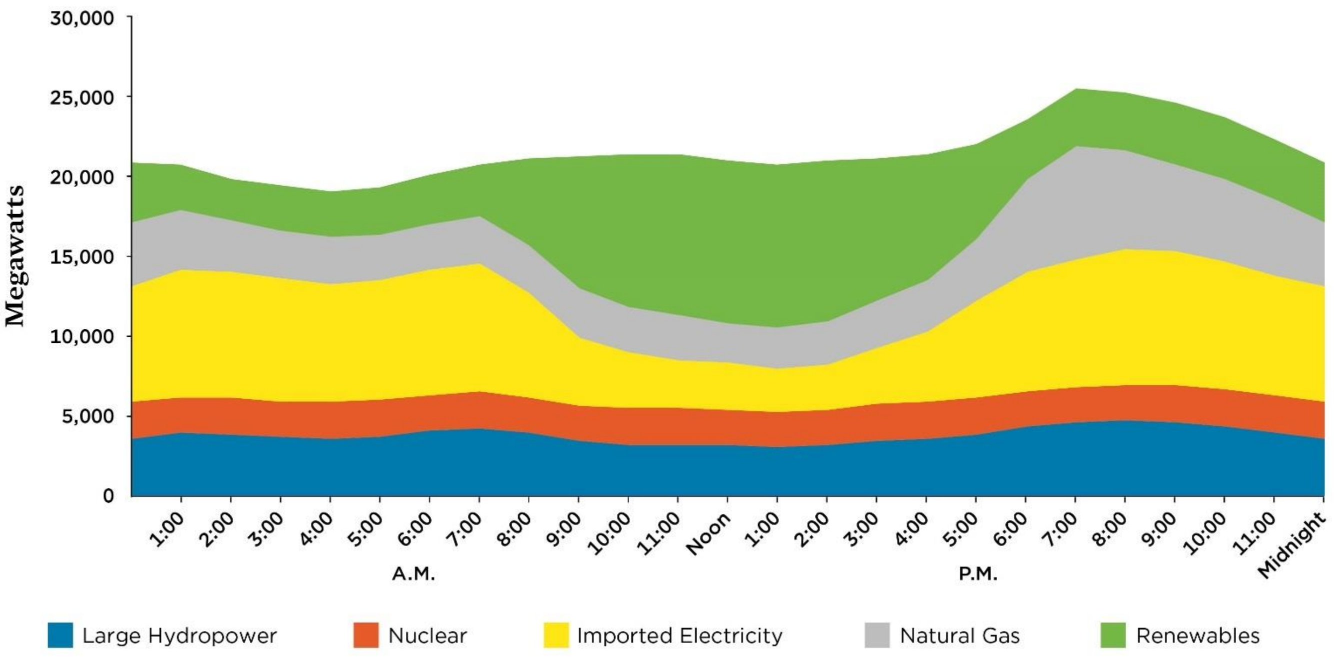
The Changing Role of Natural Gas in California's Electricity System

Because natural gas–fired power plants supply a substantial portion of California's current electricity demand and support grid reliability, natural gas generation will be needed through at least 2030 as cleaner energy sources and other grid reliability technologies come online. But for California to realize the benefits of its clean energy transition and achieve its global warming emissions targets, it needs to reduce its dependence on natural gas electricity generation significantly. This transition should prioritize reducing natural gas generation in communities most negatively affected by the pollution resulting from burning fossil fuels and by the social, economic, and health burdens associated with global warming.

Solar photovoltaics' low cost and availability mean they will make up a significant percentage of new renewable energy resources in California. As solar generation supplies more daytime electricity demand, natural gas will supply less. In many cases, gas plants will be turned off during the day. This shift will provide substantial global warming emissions reduction benefits.

However, as the sun sets, solar generation decreases (Figure 2). Unless cleaner alternatives—such as other renewable generation technologies, energy storage, and load shifting or increased energy efficiency that reduce evening electricity demand—are substituted, gas plants already operating will ramp up generation and other gas plants will be turned back on to meet evening demand. A natural gas plant starting up can produce as much as 30 times more NOx emissions than it will after it has been running for a few hours (Birdsall et al. 2016; Lew et al. 2013). This increase in natural gas plant starts could have a negative effect on air quality and especially on the communities living near these plants. In addition, gas plants in certain locations on the grid must

FIGURE 2. **Hourly Electricity Generation in the CAISO, by Fuel (March 4, 2018)**



Renewable energy generation, primarily from solar, can meet much of California's electricity needs during daytime hours, allowing natural gas to supply less.

Note: Generation data represent real-time generation from the California Independent System Operator (CAISO).

SOURCE: CAISO 2018.

remain available to be turned on to meet LCR in order to keep the grid reliable during power plant or transmission line failures, unless cleaner resources or transmission upgrades can serve this need.

Planning for a Low-Carbon Future

In 2015, California passed a law, Senate Bill 350 (California Legislature 2015), requiring electricity providers in the state to conduct long-term energy planning to ensure global warming emissions in the electricity sector are consistent with the statewide goal to reduce emissions 40 percent below 1990 levels by 2030 (California Legislature 2016). This long-term energy planning, or IRP, is overseen by the CPUC for all load-serving entities (LSEs) under its jurisdiction and by the California Energy Commission (CEC) for all publicly owned utilities (California Public Utilities Code 2015a; California Public Utilities Code 2015b). In 2016 and 2017, as part of the IRP process, the CPUC conducted an analysis of grid operations in the territory controlled by the CAISO under a range of scenarios to understand the investments necessary to maintain grid reliability and meet California’s 2030 global warming emissions goals. The CPUC’s analysis used the Renewable Energy Solutions (RESOLVE) model, “a resource investment model that identifies optimal long-term generation and transmission investments in an electric system, subject to reliability, technical, and policy constraints” (E3 2018). Ultimately, the CPUC’s modeling was used to develop a Reference System Plan, intended to serve as a blueprint for individual LSE IRPs (CPUC 2017a). The Reference System Plan will be revised by the CPUC every two years, and it is intended to guide biennial IRP planning for individual electricity providers. However, the modeling that produced the Reference System Plan has several limitations, the most consequential being that the RESOLVE model did not have the ability to retire natural gas plants if it is economical to do so (E3 2017a, p.17). As a result, the Reference System Plan assumed that all the natural gas generation capacity that exists today (aside from the plants that have already announced retirement dates) would still be available in 2030. UCS believes that assuming natural gas power plants will remain online through 2030 is not prudent and may result in the CPUC overestimating the role that natural gas generation will play in California's future electricity mix. This limitation in the RESOLVE model prevents a deeper analysis of the gas plant attributes that will have the most value to the grid in 2030 and the gas plant attributes that can be most cost-effectively replaced by cleaner resources.

Study Design and Modeling Methodology

Research Objectives

The purpose of this report is to present modeling results that shed light on the transition away from natural gas generation in California's electricity system. To understand what an orderly and equitable transition away from natural gas generation in California might look like, UCS analyzed the operations of 89 natural gas CCGTs and peakers located in the territory of the CAISO, the grid operator that manages the electricity flow for about 80 percent of the state. This analysis has three major objectives:

1. Identify economic drivers of natural gas plant retirements.
2. Estimate the quantity, location, and timing of natural gas plant economic retirements.
3. Measure future changes in operations for natural gas plants not being retired.

Modeling Methodology

Because the RESOLVE model lacks functionality needed for this study, we chose to use the GridPath platform. GridPath is a grid analytics platform capable of several types of power system modeling approaches. Here, we used GridPath in capacity-expansion mode to identify cost-effective deployment of new system resources and retirement of existing infrastructure while meeting load, reliability, and policy goals for the CAISO power system. (For more information regarding GridPath, see the appendix.)

Our GridPath analysis used the public data available from the 2017–2018 cycle of the CPUC IRP proceeding (E3 2017a). These data were developed as inputs to the RESOLVE model to create the Reference System Plan as well as a wide range of sensitivity scenarios. A high-level summary of the GridPath model setup and input data can be found below, and further details can be found in the appendix.

- We modeled the CAISO as a single zone interconnected with five other zones: three within California (BANC, IID, and LADWP) and two external zones (the Pacific Northwest and the Southwest).
- We modeled the period between 2018 and 2030. Like RESOLVE, GridPath makes investment (and retirement) decisions at four points in time during that period: 2018, 2022, 2026, and 2030. We used the same 37 independent days used in RESOLVE to simulate hourly operations.
- We used the final load profile that was used to create the Reference System Plan. The CAISO load incorporates a series of demand-side modifiers. The modifiers include assumptions about electric vehicle adoption, building electrification, behind-the-meter PV, energy efficiency, and the impact of time-of-use rates.
- We used the existing generation portfolio from RESOLVE, and we provided the same new resource options to GridPath as used in RESOLVE.
- We modeled several reserve types for the CAISO load zone, including frequency response, regulation up, regulation down, load following up, load following down, and spinning reserves. The reserve constraints applied to every hour in the simulations.
- We included a resource adequacy constraint in the CAISO, requiring sufficient capacity to meet a 15 percent planning reserve margin.

Our GridPath analysis adheres to the RESOLVE 2018 Reference System Plan modeling—in terms of both functionality and input data—as closely as possible, while adding three additional features:

1. **Ability to retire natural gas plants economically**: GridPath optimizes retirements over the entire study period (i.e., with "perfect foresight"). Therefore, the model retires a plant only if that plant is uneconomic in the current period and over the remainder of the study period.
2. **Ability to model individual natural gas plants**: For this study, we disaggregated the two CCGT and two peaker "fleets" used in RESOLVE to the individual plant level. Gas fleet disaggregation was necessary to model natural gas plant retirements accurately because retirements are based on plants' individual characteristics. We disaggregated the gas fleet to the plant level based on the CAISO generator list provided with the RESOLVE inputs and used to create the gas "fleets" (E3 2017b).
3. **Enforcement of LCR**: GridPath also enforces LCR, which is designed to ensure sufficient electricity generation in specific locations during emergencies, such as when a major power plant fails and electricity cannot be imported from outside the local area. We modeled LCR because it is also necessary for accurately modeling retirements. LCR is an important aspect of grid reliability, and we enforced LCR constraints in our modeling to prevent excess retirements in certain locations, because such retirements would jeopardize reliability. The LCR values used in this study were calculated from values in the CAISO's 2018 Local Capacity Technical Report (CAISO 2017a) and the CAISO's 2016–2017 Transmission Plan (CAISO 2017b).

This analysis also has the following limitations. First, like RESOLVE, GridPath simulates operations over 37 representative days of the year. Consequently, GridPath's operations results may not be as exact as a simulation that models all 8,760 hours in a year. For instance, when assessing the number of stops/starts of a natural gas plant, GridPath only quantifies intraday starts because the 37 days are not connected in any way; thus, our results likely underestimate the number of stops/starts because they only include intraday starts and not interday starts. Second, the retirement results in this analysis reflect general system trends only. Even though we show individual plant retirements, those results are illustrative only, and additional production-cost and power-flow modeling are required to determine exactly which plants should be kept on the CAISO system and which plants can be retired. In addition, GridPath, like RESOLVE, assumes no transmission constraints within the CAISO zone. The presence of transmission constraints within the CAISO may impact the ability of natural gas capacity to be retired. Third, we analyzed the degree to which natural gas plant capacity could be retired economically in GridPath under different carbon caps; we used the same input data for every scenario, and we did not run any "sensitivities" to measure the impacts of, for example, higher levels of electric vehicle penetration or alternative fuel price forecasts on natural gas plant retirements.

A summary of the data inputs used in GridPath, as well as further details on GridPath's additional functionality, can be found in the appendix of this report. An extensive description of the IRP input data is available in Attachment B of the Reference System Plan (E3 2017a).

Scenarios

Using GridPath, we ran six pairs of scenarios. Each pair consisted of a scenario that capped electricity-sector global warming emissions in 2030 at 42 MMT of CO_2 equivalent and one that capped emissions at 30 MMT of CO_2 equivalent. We used these two emissions caps because they are the caps used in the "Core Policy Cases" in the CPUC Reference System Plan modeling (CPUC 2017a). All 12 scenarios in the analysis incorporated a natural gas fleet that was disaggregated to the individual plant level, but the scenarios varied the ability of natural gas plants to be retired and the way in which LCR constraints were enforced.

The first pair of scenarios, "No Retirements," did not allow any natural gas plant retirements. These scenarios were run for two purposes: to ensure the GridPath results reasonably matched the RESOLVE results and to gather baseline results for gas plant operations. The only difference between the two "No Retirements" scenarios in GridPath and the CPUC Reference System Plan scenarios is that the gas fleet was disaggregated to the plant level in the GridPath modeling, so we expected nearly identical results—which is precisely what we observed. The results from these scenarios are not discussed further in this report, except that they are referenced later in order to understand future changes in natural gas plant operations.

The second pair of scenarios, "No LCR," allowed natural gas plants (both CCGTs and peakers) to be retired if it was economical to do so. LCR constraints were not enforced in these scenarios, so plants were retired even if those retirements led to a lack of local capacity.

The third pair of scenarios, "Enforce LCR, Existing Resources Only," allowed natural gas plants to be retired and enforced LCR constraints. In these scenarios, LCR could only be satisfied by existing capacity—new capacity chosen by GridPath was not counted towards LCR constraints. These scenarios were run so that they could be compared to the "No LCR" scenarios in order to determine the effect of LCR constraints on natural gas plant retirements.

Last, we ran three pairs of scenarios, "Enforce LCR, Allow New Resources." All six of these scenarios allowed natural gas plants to be retired, and they also allowed existing resources as well as certain new resources (natural gas and batteries) to satisfy LCR constraints. We varied the minimum battery duration required to satisfy LCR constraints in each of the three pairs, testing a four-hour, six-hour, and eight-hour minimum battery duration. These scenarios were run so that they could be compared to the "Enforce LCR, Existing Resources Only" scenarios in order to understand the role that new resources could play in satisfying LCR constraints and the resulting effect on natural gas plant retirements. These scenarios are named based on the minimum battery duration required to satisfy LCR; for instance, the "30 MMT, Enforce LCR, Allow New Resources, 6h" scenario incorporates a six-hour minimum battery duration required to satisfy LCR.

TABLE 1. **Summary of Scenarios**

Scenario Name	Carbon Cap	Allow Retirements?	Enforce LCR?	Allow New Resources to Contribute to LCR?	Minimum Battery Duration for LCR Credit
42 MMT, No Retirements	42 MMT	No	No	No	N/A
30 MMT, No Retirements	30 MMT	No	No	No	N/A
42 MMT, No LCR	42 MMT	Yes	No	No	N/A
30 MMT, No LCR	30 MMT	Yes	No	No	N/A
42 MMT, Enforce LCR, Existing Resources Only	42 MMT	Yes	Yes	No	N/A
30 MMT, Enforce LCR, Existing Resources Only	30 MMT	Yes	Yes	No	N/A
42 MMT, Enforce LCR, Allow New Resources, 4h	42 MMT	Yes	Yes	Yes	4 hours
30 MMT, Enforce LCR, Allow New Resources, 4h	30 MMT	Yes	Yes	Yes	4 hours
42 MMT, Enforce LCR, Allow New Resources, 6h	42 MMT	Yes	Yes	Yes	6 hours
30 MMT, Enforce LCR, Allow New Resources, 6h	30 MMT	Yes	Yes	Yes	6 hours
42 MMT, Enforce LCR, Allow New Resources, 8h	42 MMT	Yes	Yes	Yes	8 hours
30 MMT, Enforce LCR, Allow New Resources, 8h	30 MMT	Yes	Yes	Yes	8 hours

In the 12 scenarios, we varied the carbon cap, the ability of natural gas plants to retire, the enforcement of LCR constraints, and the battery duration required in order to meet LCR.

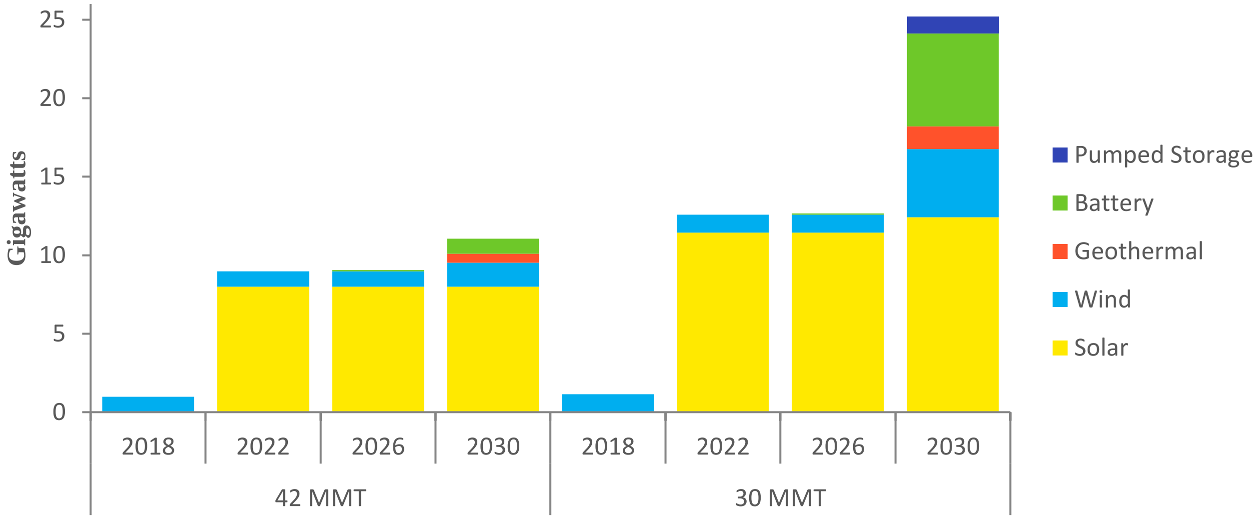
New and Retired Capacity

Figure 3 shows new capacity added in the "Enforce LCR, Allow New Resources, 4h" scenarios. The carbon cap is the primary driver of new capacity selected by GridPath, so the results presented for this pair of scenarios are representative of any other scenario with the same carbon cap. Allowing retirements and enforcing LCR constraints does not have a significant impact on the resources selected by GridPath. Last, while GridPath does have the option to build new natural gas capacity, the model does not select any new natural gas capacity in any scenario but one.[2]

In the "42 MMT, Enforce LCR, Allow New Resources, 4h" scenario, GridPath selects approximately 8.0 GW solar, 1.5 GW wind, 1.0 GW batteries (with an average duration of about one hour), and 0.6 GW geothermal by 2030. The model builds these new resources at different times. To take advantage of expiring tax credits, 1.0 GW of wind is selected in 2018 and all 8.0 GW of solar is selected in 2022; nearly all the remainder is added in 2030 (Figure 3).

In the "30 MMT, Enforce LCR, Allow New Resources, 4h" scenario, GridPath selects approximately 12.4 GW solar, 4.3 GW wind, 5.9 GW batteries (with an average duration of about four hours), 1.5 GW geothermal, and 1.1 GW pumped hydro (with an average duration of about 12 hours) by 2030. In this case as well, the model selects these resources at different times. To take

FIGURE 3. **New Capacity in Each Investment Period**



Our analysis indicates that no new natural gas capacity is needed to meet 2030 energy or grid reliability needs.

Note: Figure shows cumulative results from "Enforce LCR, Allow New Resources, 4h" scenarios. These capacity buildouts are representative of the buildout for any scenario with the same carbon cap. GridPath had the option to add new biomass, peaker, and CCGT capacity, but selected none.

advantage of expiring tax credits, 1.1 GW of wind is selected in 2018 and 11.4 GW of solar is selected in 2022; nearly all the remainder is added in 2030 (Figure 3).

Finally, the natural gas plant retirement results for all 10 scenarios in which retirements were allowed are shown below in Table 2. These results and their implications are discussed in depth in the sections that follow, but the complete set of retirement results are included here for reference.

TABLE 2. **Complete Retirement Results**

Scenario Name	Status	CCGT Capacity (MW)				Peaker Capacity (MW)			
		2018	**2022**	**2026**	**2030**	**2018**	**2022**	**2026**	**2030**
42 MMT, No LCR	**Retired**	3,171	3,171	3,171	3,284	3,674	3,544	3,544	3,982
	Remaining	11,975	13,259	13,259	13,147	3,291	3,389	3,389	2,951
30 MMT, No LCR	**Retired**	4,421	4,421	4,421	5,212	2,520	2,390	2,390	6,932
	Remaining	10,726	12,010	12,010	11,218	4,444	4,542	4,542	0
42 MMT, Enforce LCR, Existing Resources Only	**Retired**	3,788	3,788	3,788	3,788	1,666	1,666	1,666	1,666
	Remaining	11,359	12,643	12,643	12,643	5,298	5,266	5,266	5,266
30 MMT, Enforce LCR, Existing Resources Only	**Retired**	4,028	4,028	4,028	4,028	1,668	1,668	1,668	1,668
	Remaining	11,118	12,402	12,402	12,402	5,297	5,265	5,265	5,265
42 MMT, Enforce LCR, Allow New Resources, 4h	**Retired**	3,810	3,810	3,810	3,810	1,666	1,666	1,666	1,666
	Remaining	11,336	12,620	12,620	12,620	5,298	5,266	5,266	5,266
30 MMT, Enforce LCR, Allow New Resources, 4h	**Retired**	4,120	4,220	4,220	4,919	1,937	1,937	1,937	6,049
	Remaining	11,026	12,211	12,211	11,512	5,027	4,995	4,995	883
42 MMT, Enforce LCR, Allow New Resources, 6h	**Retired**	3,841	3,841	3,841	3,841	1,666	1,666	1,666	1,666
	Remaining	11,305	12,589	12,589	12,589	5,298	5,266	5,266	5,266
30 MMT, Enforce LCR, Allow New Resources, 6h	**Retired**	4,149	4,249	4,249	4,877	1,908	1,908	1,908	2,362
	Remaining	10,997	12,182	12,182	11,554	5,057	5,025	5,025	4,571
42 MMT, Enforce LCR, Allow New Resources, 8h	**Retired**	3,841	3,841	3,841	3,841	1,666	1,666	1,666	1,666
	Remaining	11,305	12,589	12,589	12,589	5,298	5,266	5,266	5,266
30 MMT, Enforce LCR, Allow New Resources, 8h	**Retired**	4,023	4,023	4,023	4,023	1,668	1,668	1,668	1,668
	Remaining	11,124	12,408	12,408	12,408	5,297	5,265	5,265	5,265

Retirement results for all 10 scenarios that allowed retirements. Displays retired and remaining capacity (cumulative) for both CCGTs and peakers in each of the four investment periods.

Note: Table reflects only the economic retirements chosen by the model in each scenario; planned retirements are not included in retired capacity values.

Drivers of Natural Gas Plant Retirements

What Effect Does Meeting LCR Have on Natural Gas Plant Retirements?

To understand the effects of LCR on natural gas plant retirements, we ran scenarios with and without LCR constraints and compared the results. LCR is very important for ensuring grid reliability, and UCS did not conduct this comparison to suggest that LCR should be reduced or removed. This comparison is merely meant to shed light on the drivers keeping natural gas plants from being retired. This subsection first examines the impact of LCR on the *quantity* of natural gas plant retirements; then we illustrate the impact of LCR on *which* natural gas plants are retired.

THE EFFECT OF LCR ON THE QUANTITY OF GAS PLANT RETIREMENTS

In the “42 MMT, No LCR” scenario, 20 percent of CCGT capacity and 57 percent of peaker capacity is retired by 2030. When LCR is enforced in the “42 MMT, Enforce LCR, Existing Resources Only” scenario, 23 percent of CCGT capacity and 24 percent of peaker capacity is retired by 2030 (Table 3). Thus, enforcing LCR constraints prevents one-third of CAISO peaker capacity from being retired because those peakers must remain on the system to provide local capacity. Since more peaker capacity remains on the system when LCR constraints are enforced, this allows a little more CCGT capacity to be retired in the “42 MMT, Enforce LCR, Existing Resources Only” scenario.

In the “30 MMT, No LCR” scenario, 32 percent of CCGT capacity and 100 percent of peaker capacity is retired by 2030. When LCR constraints are enforced in the “30 MMT, Enforce LCR, Existing Resources Only” scenario, only 25 percent of CCGT capacity and 24 percent of peaker capacity is retired (Table 3). In this case, enforcing LCR constraints prevents 76 percent of CAISO peaker capacity and roughly 7 percent of CAISO CCGT capacity from being retired.

TABLE 3. **Percent of Capacity Retired by 2030 with and without LCR**

Carbon Cap	Plant Type	Scenario		
		No LCR		**Enforce LCR**
42 MMT	**CCGT**	20%	***Enforce LCR*** ⟹	23%
	Peaker	57%		24%
30 MMT	**CCGT**	32%		25%
	Peaker	100%		24%

Enforcing LCR prevents a significant quantity of natural gas plant generation capacity from being retired.

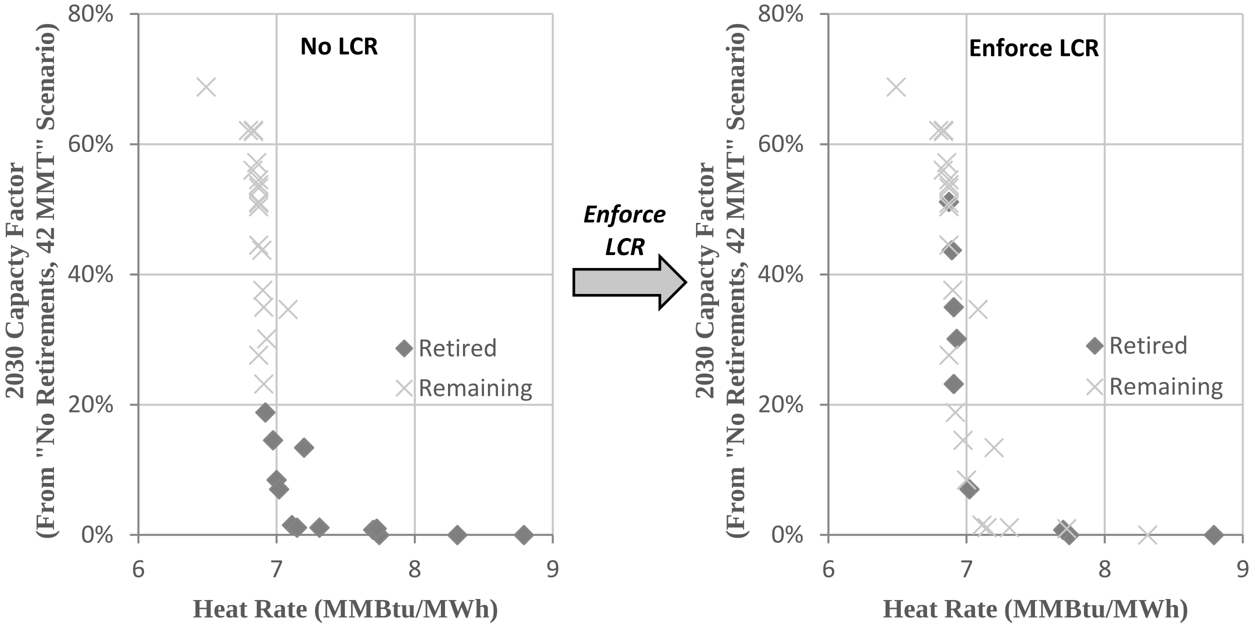
Note: Table shows results from the “No LCR” and “Enforce LCR, Existing Resources Only” scenarios.

Our results suggest that LCR constraints have a significant effect on the number of natural gas plant retirements, particularly peaker retirements. Enforcing LCR constraints limits peaker retirements to 24 percent of peaker fleet capacity regardless of the carbon cap; but when LCR is not enforced, an additional one-third to three-quarters of peaker capacity is retired, depending on the carbon cap. This indicates that one-quarter of the peaker fleet does not provide essential local capacity value, while the other three-quarters of the peaker fleet does have locational value, which forces those plants to remain on the system in 2030.

THE EFFECT OF LCR ON WHICH GAS PLANTS ARE RETIRED

In addition to examining LCR’s effect on the quantity of retirements, we also examined the effect of LCR on *which* natural gas plants are retired in each scenario. In the comparison shown here, we only show CCGT retirements in

FIGURE 4. **Effect of LCR on Retired and Remaining CCGTs**



The plant heat rate, which determines the plant capacity factor, is no longer the primary driver of retirements when LCR is enforced. Less-efficient plants are retained to satisfy LCR while more-efficient plants are retired.

Note: Figure shows results from the “42 MMT, No LCR” and “42 MMT, Enforce LCR, Existing Resources Only” scenarios. Each marker represents a single plant. The capacity factor shown here is the capacity factor for each plant from the “42 MMT, No Retirements” scenario; this can be thought of as the capacity factor that a CCGT would have if it did not retire.

the 42 MMT scenarios for “No LCR” and “Enforce LCR, Existing Resources Only.” However, similar trends hold for peakers in the 42 MMT scenarios and for both plant types in the 30 MMT scenarios.

When LCR constraints are not enforced (“42 MMT, No LCR” scenario), the main factor driving CCGT retirements is the plant heat rate, which largely determines the plant capacity factor. The capacity factor retirement threshold for CCGTs is approximately 20 percent—plants with a capacity factor below this level are retired by 2030 (Figure 4). While the plant heat rate is the primary factor influencing the plant capacity factor, other operational characteristics (e.g., minimum stable level and start-up cost) also influence the plant capacity factor and affect which plants are retired. These other operational characteristics are particularly consequential for CCGTs with a heat rate close to seven million British thermal units per megawatt-hour (MMBtu/MWh).

When LCR constraints are enforced (“42 MMT, Enforce LCR, Existing Resources Only” scenario), the plant heat rate is no longer the primary determinant of CCGT retirements. In this scenario, more-efficient CCGTs are retired and less-efficient CCGTs are retained (Figure 4). The less-efficient CCGTs that remain on the system are not retired because they are located in areas with LCR constraints. In this way, enforcing LCR constraints not only affects the number of plants that are retired, but also affects which plants are retired, resulting in less-efficient plants staying on the system to satisfy LCR constraints.

What Effect Does Allowing New Resources to Satisfy LCR Have on Natural Gas Plant Retirements?

To understand further the effect of LCR on natural gas plant retirements, we ran three additional pairs of scenarios, “Enforce LCR, Allow New Resources,” in which certain new resources (natural gas plants and battery storage) were allowed to satisfy LCR. Each of the three pairs of scenarios had a different minimum battery duration required to contribute to LCR; we tested a four-hour, six-hour, and eight-hour minimum battery duration. In all these scenarios, the model could still choose to build batteries with any duration, but batteries with a duration shorter than the minimum battery duration in that scenario did not count towards LCR. By comparing the “Enforce LCR, Allow New Resources” scenarios to the “Enforce LCR, Existing Resources Only” scenarios, we can begin to understand the role that new resources could play in replacing services provided by existing natural gas plants and the resulting impact on gas plant retirements.

In all the “42 MMT, Enforce LCR, Allow New Resources” scenarios, the ability of new resources to satisfy LCR has no effect on gas plant retirements (Table 4). While one gigawatt of new battery capacity is selected by the model in each of the four 42 MMT scenarios displayed in Table 4, this new capacity has an average duration of approximately one hour, and these batteries are used primarily to provide reserves. Since this new battery capacity has a duration of only one hour, these batteries cannot satisfy LCR. Batteries with a duration of four hours or more, which would be able to satisfy LCR, are not economical under the 42 MMT carbon cap. The addition of LCR as a value stream is not sufficient to justify the investment in four-hour batteries, so natural gas plants remain on the system to meet the LCR constraints at the least cost. Because no new gas capacity is built in the “42 MMT, Enforce LCR, Allow New Resources” scenarios, and because the duration of the battery storage selected by the model in these scenarios is not long enough to satisfy LCR, natural gas plant retirements remain unchanged.

In the “30 MMT, Enforce LCR, Allow New Resources” scenarios, allowing new resources to satisfy LCR has a substantial effect on the quantity of gas plant retirements, and the minimum battery duration required to satisfy LCR plays a crucial role in determining the number of natural gas plants that are economically retired (Table 4). In the “30 MMT, Enforce LCR, Existing Resources Only” scenario, long-duration batteries are already cost-effective. The model selects batteries with an average duration of 4.1 hours, and these batteries are used for energy shifting over several hours. In the “30 MMT, Enforce LCR, Allow New Resources, 4h” scenario, four-hour batteries are already being built, and the addition of LCR as another revenue stream results in the strategic placement of the four-hour batteries to maximize their LCR value. As a result, allowing new four-hour batteries to satisfy LCR leads to the retirement of 30 percent of CCGT capacity and 87 percent of peaker capacity (Table 4). This is a significant increase in peaker capacity retirement compared to the “30 MMT, Enforce LCR, Existing Resources Only” scenario (with peaker capacity retirement at only 24 percent). However, as the battery duration required to satisfy LCR is increased, fewer natural gas plants, particularly peakers, are retired. In the “30 MMT, Enforce LCR, Allow New Resources, 6h” scenario, peaker capacity retirement drops sharply to 34 percent (Table 4). In this case, some six-hour batteries are built to satisfy LCR even though these batteries have a longer duration than is optimal for system-level energy balancing. Last, in the “30 MMT, Enforce LCR, Allow New Resources, 8h” scenario, both peaker capacity and CCGT capacity retirements drop to 24 percent (Table 4). In this

TABLE 4. **Percent of Capacity Retired by 2030 with and without Allowing New Resources to Satisfy LCR**

Carbon Cap	Plant Type	Scenario				
		Existing Resources Only		Allow New Resources, 4h	Allow New Resources, 6h	Allow New Resources, 8h
42 MMT	**CCGT**	23%	***Allow New Resources for LCR*** ⟹	23%	23%	23%
	Peaker	24%		24%	24%	24%
30 MMT	**CCGT**	25%		30%	30%	24%
	Peaker	24%		87%	34%	24%

Allowing new resources to satisfy LCR enables more natural gas capacity to be retired in the 30 MMT scenarios with a four-hour or six-hour minimum battery duration requirement.

Note: Table shows results from the “Enforce LCR, Existing Resources Only” and “Enforce LCR, Allow New Resources” scenarios.

scenario, the model does not build any batteries with a duration long enough to satisfy LCR, so no additional natural gas plants are retired.

In summary, the battery duration required for LCR is a key factor in determining the quantity of natural gas generation capacity that can be retired by 2030 under a 30 MMT carbon cap. On one end of the spectrum, nearly the entire peaker fleet can be retired by 2030 if four-hour batteries can satisfy LCR, but on the other end, only a quarter of peaker generation capacity can be retired if eight-hour batteries are required for LCR.

A note: We did not allow partial LCR credit for batteries with a duration shorter than the LCR minimum requirement (which was varied in the “Enforce LCR, Allow New Resources” scenarios). However, it may be reasonable to assign partial credit to these batteries, since, for instance, the IRP modeling conducted by the CPUC using RESOLVE allowed batteries with a duration of less than four hours to contribute a derated amount to the system planning reserve margin (E3 2017a). A similar approach may be reasonable in the context of LCR. Last, we also did not allow new renewables to contribute to LCR (existing renewables did contribute their CAISO-established net qualifying capacity), but some may be able to do so.

Natural Gas Plant Retirements by 2030

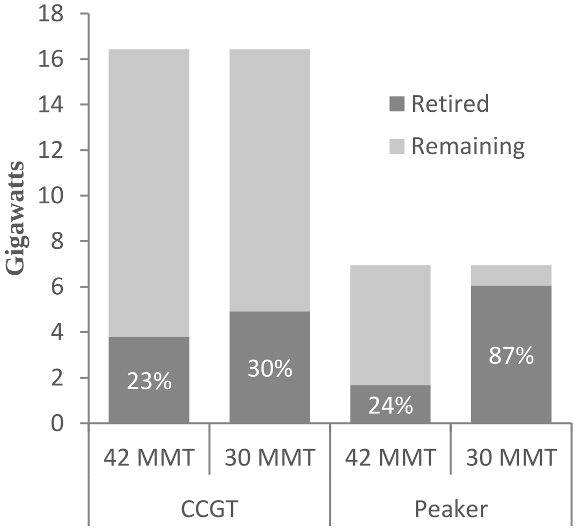
In this section, we report the quantity, location, and timing of natural gas plant retirements by 2030. Throughout this section, we focus on one pair of scenarios, "Enforce LCR, Allow New Resources, 4h," comparing the results that occur under both the 42 MMT and 30 MMT carbon caps. We focus on this pair of scenarios because four-hour batteries are currently allowed to satisfy LCR requirements, so this pair of scenarios represents current policy. Therefore, we home in on the results from these two scenarios to develop our best estimate of the quantity, location, and timing of natural gas plant retirements likely to occur by 2030.

How Much Natural Gas Plant Capacity Can Be Retired by 2030?

In the "42 MMT, Enforce LCR, Allow New Resources, 4h" scenario, 23 percent of CCGT capacity and 24 percent of peaker capacity is retired by 2030 (Figure 5). In contrast, in the "30 MMT, Enforce LCR, Allow New Resources, 4h" scenario, 30 percent of CCGT capacity and 87 percent of peaker capacity is retired by 2030 (Figure 5). The driving force behind this very large difference in retirements (particularly in peaker retirements) is the carbon cap, which affects the duration of the batteries built in each of these scenarios. The roughly one gigawatt of new batteries selected in the 42 MMT scenario have an average duration of approximately one hour. These short-duration batteries, which are used mostly to provide reserves, cannot satisfy LCR constraints. As a result, no additional natural gas generation capacity retires under the 42 MMT carbon cap. In the 30 MMT scenario, GridPath selects nearly six gigawatts of batteries with an average duration of 4.1 hours—a duration long enough to satisfy LCR. These batteries are then strategically placed in LCR zones to allow a significant amount of natural gas plant capacity to be retired. Interestingly, under the 30 MMT carbon cap, peakers have a fleet-wide capacity factor of only 0.2 percent in 2030; however, the 13 percent of peaker capacity that is not retired by 2030 must remain on the system in order to satisfy the LCR constraints.

In summary, a lower carbon cap is the impetus for building longer-duration batteries, and these batteries are then able to satisfy LCR constraints, which in turn allows additional natural gas plant capacity (particularly peaker capacity) to be retired.

FIGURE 5. **Retired and Remaining Natural Gas Plant Capacity by 2030**



Depending on the carbon cap, anywhere from 23 to 30 percent of CCGT capacity and 24 to 87 percent of peaker capacity can be retired by 2030.

Note: Figure shows results from "Enforce LCR, Allow New Resources, 4h" scenarios.

Where Do Natural Gas Plant Retirements Occur?

In the "42 MMT, Enforce LCR, Allow New Resources, 4h" scenario, UCS found that 23 percent of the CCGT generation capacity and 24 percent of the peaker capacity—a total of 28 of the 89 plants currently operating in the CAISO territory—are retired in 2018 without negatively affecting grid reliability. Furthermore, of the 28 natural gas plants that are retired in this scenario, 12 are located in CalEnviroScreen top 25th percentile census tracts, which the CPUC considers "disadvantaged communities" (CPUC 2018) (Figure 6).

In the "30 MMT, Enforce LCR, Allow New Resources, 4h" scenario, UCS found that 30 percent of CCGT capacity and 87 percent of peaker capacity—a total of 56 of the 89 plants currently operating in the CAISO territory—are retired by 2030 without negatively affecting grid reliability. Of the 56 natural gas plants that are retired, 23 are located in CalEnviroScreen top 25th percentile census tracts (Figure 7).

In summary, these results indicate that, depending on the carbon cap, as many as 23 natural gas plants located in disadvantaged communities can be retired by 2030. These retirements will likely have a positive effect on these communities, where air pollution is often persistent and emissions from natural gas plants contribute to that pollution.

When Do Natural Gas Plant Retirements Occur?

The timing of natural gas plant retirements depends on the carbon cap. In the "42 MMT, Enforce LCR, Allow New Resources, 4h" scenario, all of the CCGT and peaker retirements happen in 2018 (Table 5). In contrast, in the "30 MMT, Enforce LCR, Allow New Resources, 4h" scenario, most of the CCGT capacity retirements and one-third of peaker capacity retirements occur in 2018. The remaining CCGT capacity retirements and the remaining two-thirds of peaker capacity retirements occur in 2030 (Table 5). Despite low peaker utilization under the 30 MMT carbon cap, the planning reserve margin prevents most of the peakers from being retired until 2030, when the rapid deployment of multihour batteries and pumped hydro (see Figure 3), which contribute to LCR and the planning reserve margin, allows nearly all the peakers to be retired.

Regardless of the carbon cap, approximately one-quarter of both CCGT and peaker capacity are retired immediately in 2018. This indicates that those plants are not necessary for energy or reliability, and the lowest-cost way to manage the grid may be to retire those plants to avoid paying the fixed costs associated with keeping them operational.

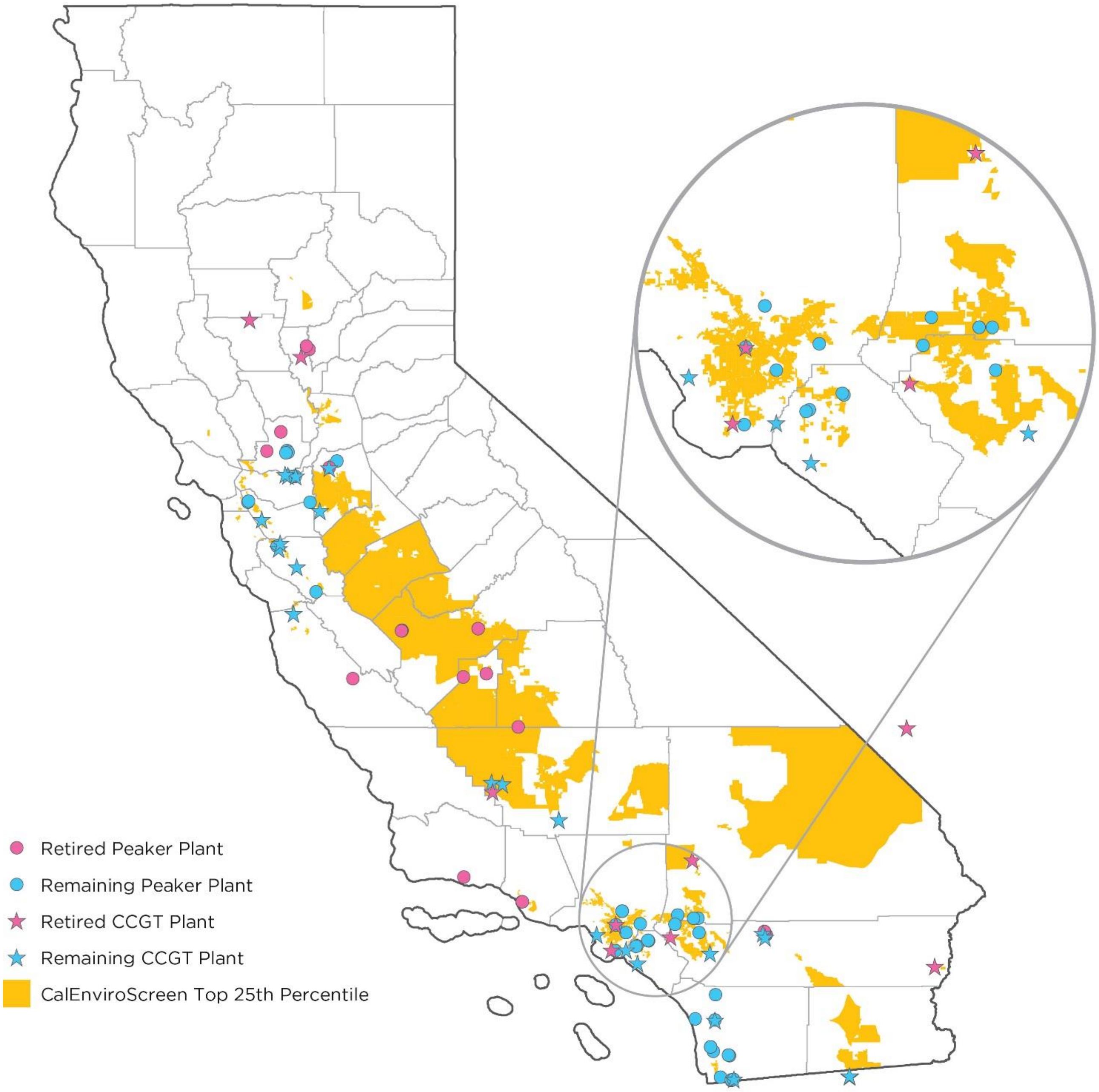
TABLE 5. **Natural Gas Plant Retirements in Each Investment Period**

Carbon Cap	Percentage of CCGT Capacity Retired				Percentage of Peaker Capacity Retired			
	2018	**2022**	**2026**	**2030**	**2018**	**2022**	**2026**	**2030**
42 MMT	25%	23%	23%	23%	24%	24%	24%	24%
30 MMT	27%	26%	26%	30%	28%	28%	28%	87%

Under the 42 MMT carbon cap, all retirements occur in the first investment period, 2018. Under the 30 MMT carbon cap, most CCGT retirements occur in 2018, and most peaker retirements occur in the last investment period, 2030.

Note: Figure shows results from the "Enforce LCR, Allow New Resources, 4h" scenarios. Percentage of capacity retired is cumulative. Percentage of retired CCGT capacity goes down between 2018 and 2022 because total CCGT capacity increases as planned CCGT capacity becomes operational between 2018 and 2022. This new capacity is included as a model input; GridPath does not select it.

FIGURE 6. **Natural Gas Plant Retirements by 2030, 42 MMT Scenario**

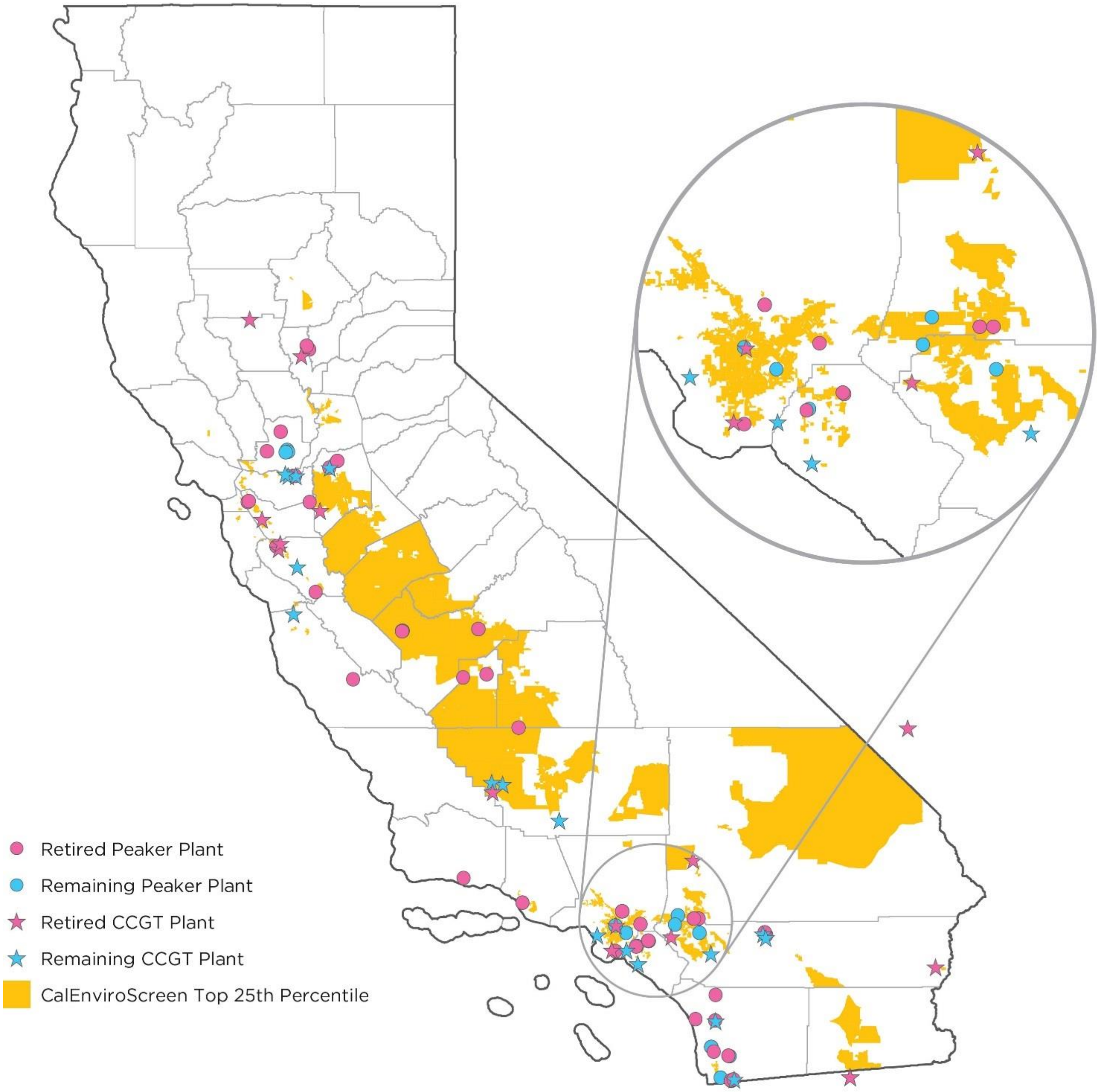


Twenty-eight natural gas plants in the CAISO territory could be retired while still meeting energy and reliability requirements. Twelve of the plants that could be retired are located in communities, shown in orange, that are disproportionately burdened by air pollution.

Note: Figure shows results from the "42 MMT, Enforce LCR, Allow New Resources, 4h" scenario. Orange shading indicates the top 25th percentile of California census tracts that are disproportionately burdened by, and vulnerable to, multiple sources of pollution according to CalEnviroScreen, an environmental, health, and socioeconomic mapping tool. Plants shown outside of state boundaries are plants that supply electricity to the CAISO grid.

SOURCES: OEHHA 2017 (CALENVIROSCREEN 3.0); UCS ANALYSIS.

FIGURE 7. **Natural Gas Plant Retirements by 2030, 30 MMT Scenario**



Fifty-six natural gas plants in the CAISO territory could be retired while still meeting energy and reliability requirements. Twenty-three of the plants that could be retired are located in communities, shown in orange, that are disproportionately burdened by air pollution.

Note: Figure shows results from the "30 MMT, Enforce LCR, Allow New Resources, 4h" scenario. Orange shading indicates the top 25th percentile of California census tracts that are disproportionately burdened by, and vulnerable to, multiple sources of pollution according to CalEnviroScreen, an environmental, health, and socioeconomic mapping tool. Plants shown outside of state boundaries are plants that supply electricity to the CAISO grid.

SOURCES: OEHHA 2017 (CALENVIROSCREEN 3.0); UCS ANALYSIS.

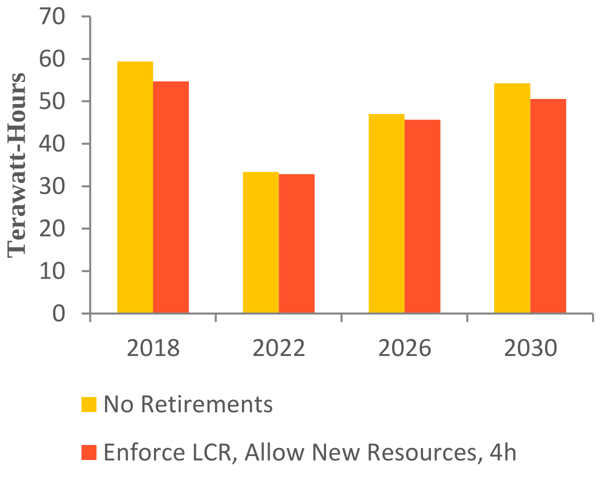
The Changing Dynamics of Natural Gas Plant Operations

In this section, we illustrate the ways in which natural gas plant operations may change in the coming decade. We examine changes in natural gas plant generation, capacity factors, and starts/stops. Throughout this section, we continue to focus on one pair of scenarios, "Enforce LCR with New Resources, 4h," because these scenarios represent current policy.

Do Gas Plant Retirements Result in Less Natural Gas Generation?

In the "42 MMT, Enforce LCR, Allow New Resources, 4h" scenario, natural gas generation overall decreases by 4.2 TWh, or 8 percent, between 2018 and 2030 as more renewable generation capacity is installed. This reduction in generation results in reduced global warming emissions. However, our results do not indicate that the retirement of natural gas generation capacity is a significant driver in further reducing natural gas energy generation. Figure 8 shows a comparison between the "42 MMT, No Retirements" scenario, and the "42 MMT, Enforce LCR, Allow New Resources, 4h" scenario. This figure shows that when natural gas plant retirements are allowed, annual energy from natural gas generation does decrease, but only by a few percentage points. There are a few reasons why natural gas generation does not decrease more dramatically. First, some of the plants that are retired would have had low capacity factors if they were not retired (Figure 4), so they would not have generated much electricity anyway. Second, most of the reduction in generation resulting from retiring CCGT plants is compensated for by a combination of increased peaker generation and increased imports. Ultimately, other factors determine the level of natural gas generation, and natural gas plant retirements have only a small effect on the amount of energy produced annually by natural gas generation.

FIGURE 8. **Annual Energy from Natural Gas Generation, 42 MMT Scenarios**



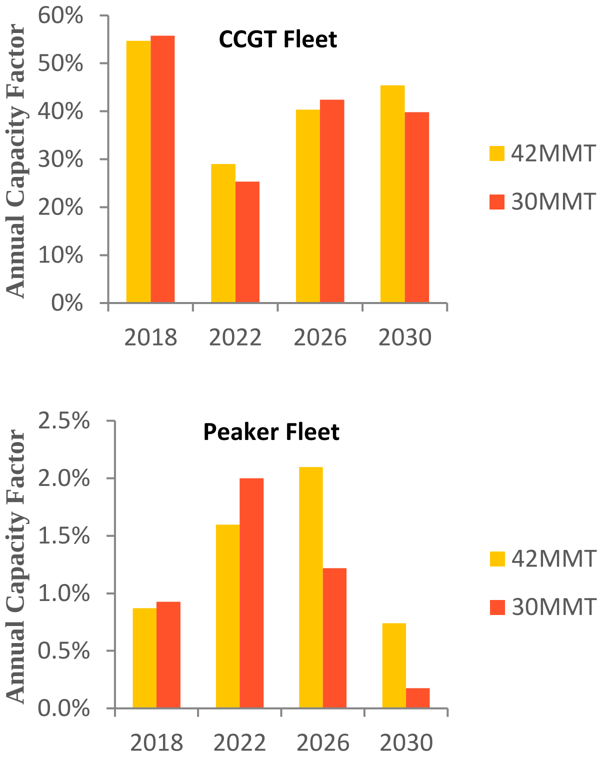
Regardless of whether natural gas plants are retired, energy from natural gas generation is relatively unaffected.

Note: Figure shows annual energy from natural gas generation (both CCGTs and peakers) from the "42 MMT, No Retirements" and "42 MMT, Enforce LCR, Allow New Resources, 4h" scenarios.

How Do Natural Gas Plant Capacity Factors Change over Time?

Over the study period, natural gas plant capacity factors change significantly under both the 42 MMT and 30 MMT carbon caps in the "Enforce LCR, Allow New Resources, 4h" scenarios. In addition, the CCGT fleet capacity factor and the peaker fleet capacity factor display very different trends over time.

FIGURE 9. **Gas Fleet Capacity Factors in Each Investment Period**



The general trend in the CCGT fleet capacity factor is the same regardless of the carbon cap. However, the trend in the peaker fleet capacity factor varies based on the carbon cap.

Note: Figure shows results from "Enforce LCR, Allow New Resources, 4h" scenarios. The capacity factor calculation includes retired capacity.

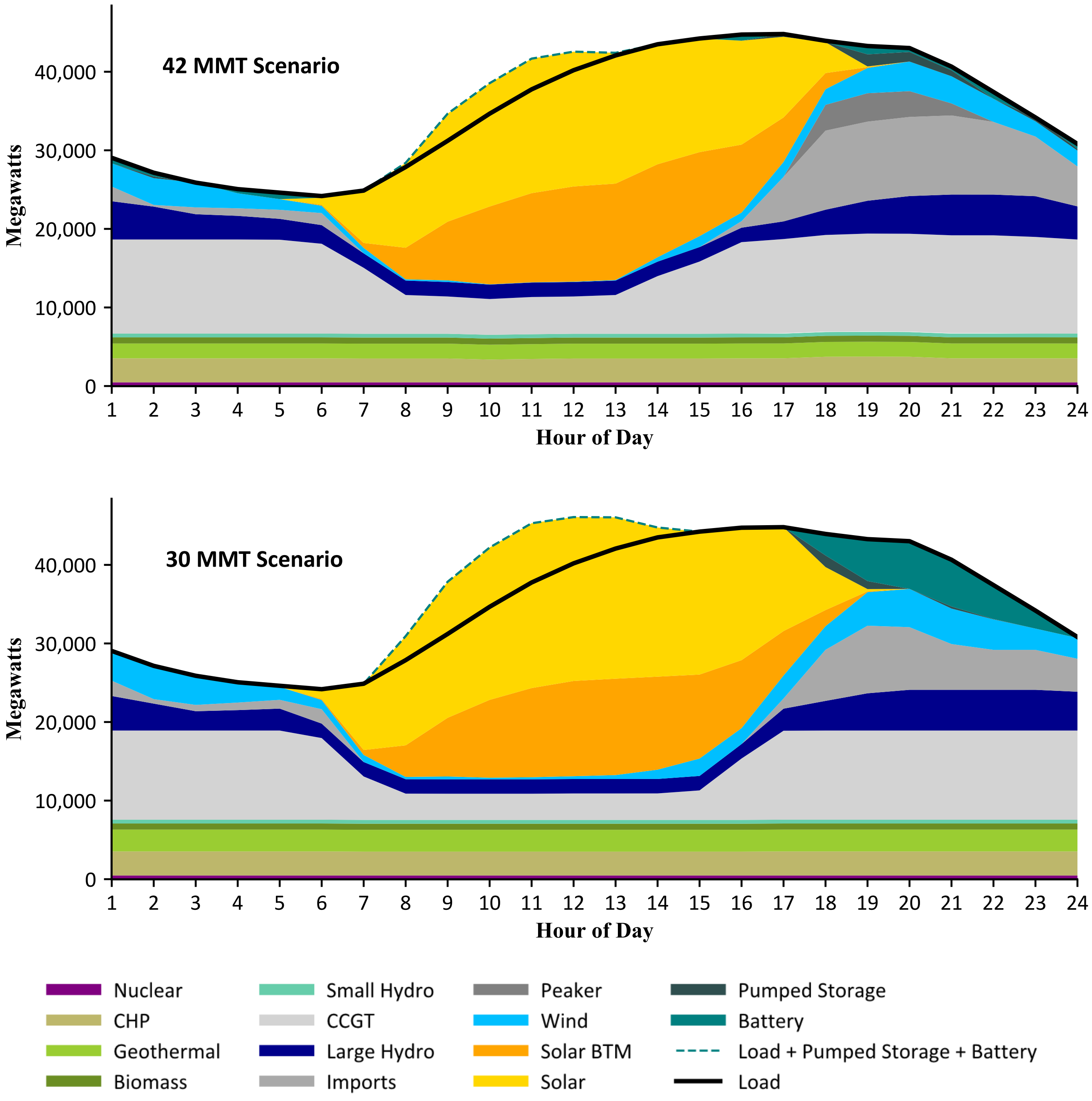
The CCGT fleet capacity factor is at its highest level in 2018, and it drops to its lowest level in the study period by 2022 (Figure 9). This sudden drop is a result of the rapid deployment of renewable generation, particularly solar (see Figure 3), in 2022 to take advantage of tax credits before they expire. Nevertheless, the CCGT fleet capacity factor rebounds by 2026 (Figure 9) due to the planned closure of the Diablo Canyon nuclear power plant in 2025. Finally, the CCGT fleet capacity factor does not change much between 2026 and 2030. Interestingly, this overall pattern applies to both "Enforce LCR, Allow New Resources, 4h" scenarios regardless of the carbon cap (Figure 9).

The peaker fleet capacity factor demonstrates a different pattern from the CCGT fleet capacity factor. First, the peaker fleet capacity factor is very low throughout the study period—almost always less than 2 percent. The peaker fleet capacity factor starts out relatively low in 2018, then increases dramatically by 2022 (Figure 9). This increase is likely due to some load growth and the rapid deployment of intermittent renewables by 2022 (see Figure 3), forcing peakers to run more often to smooth out increased renewable generation. Then in 2026, the peaker fleet capacity factor diverges depending on the carbon cap. The 30 MMT scenario results in a steady decrease in the peaker fleet capacity factor in 2026 and 2030, arriving at a peaker fleet capacity factor of 0.2 percent by 2030 (Figure 9). However, under the less stringent carbon cap in the 42 MMT scenario, the peaker fleet capacity factor continues to increase in 2026. In the 42 MMT scenario, the peaker fleet capacity factor is not substantially reduced until 2030, when it drops back below 1 percent (Figure 9).

By 2030, these trends in the CCGT and peaker fleet capacity factors are evident in CAISO system dispatch. Figure 10 shows the hourly dispatch on a peak load day in 2030 in both the 42 MMT and 30 MMT scenarios. The major difference between the two scenarios is in how the evening ramp is met. In the 42 MMT scenario, CCGTs, imports, and peakers play the largest role in meeting the evening ramp, with pumped storage and batteries playing only a small role. However, in the 30 MMT scenario, CCGTs, imports, and batteries are the most important resources for meeting the evening ramp. In this scenario, peakers play no role at all, imports play a smaller role than in the 42 MMT scenario, and CCGTs begin ramping up a few hours later (due to sufficient solar generation until the early evening) until they reach peak generation levels roughly equivalent to those in the 42 MMT scenario. Thus, the dispatch plots in Figure 10 reflect the system-level trends in gas plant capacity factors: CCGTs play a major role in meeting the peak evening load in both scenarios, but peakers play no role at all in the 30 MMT scenario.

From this analysis it's clear that, even with the additional gas plant retirements in the 30 MMT scenario, evening peak loads can still be met through a combination of CCGTs, imports, and day-time solar energy stored in long-duration batteries.

FIGURE 10. **CAISO System Hourly Dispatch on Peak Load Day in 2030**



CCGTs play a major role in meeting the peak evening load in both scenarios, but peakers play no role at all in the 30 MMT scenario.

Note: Figure shows results for RESOLVE day 15 in 2030 from "Enforce LCR, Allow New Resources, 4h" scenarios. RESOLVE day 15 has the highest load of all 37 RESOLVE days.

How Does the Number of Natural Gas Plant Starts Change over Time?

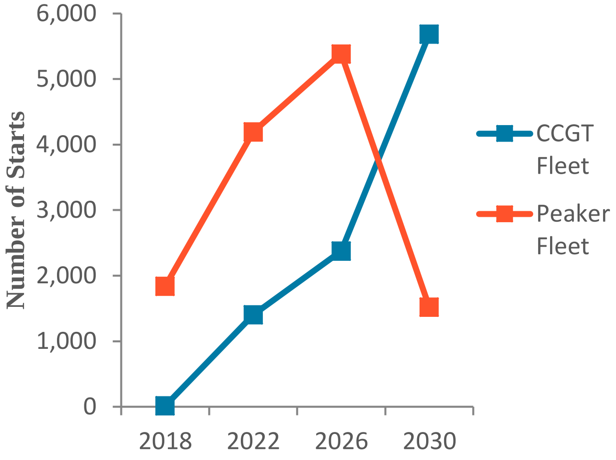
During the study period, many peakers and CCGTs undergo drastic changes in the number of times they stop and start. The system-level trends for the "42 MMT, Enforce LCR, Allow New Resources, 4h" scenario are shown in Figure 11, which displays the total number of annual starts for both the peaker fleet and the CCGT fleet. Overall, the number of peaker and CCGT starts increases in 2022 and in 2026. This increase is a result of two factors: the rapid deployment of renewables by 2022 and steady load growth. The rapid deployment of renewables, particularly solar, forces many natural gas plants to turn off completely during the day then turn back on later to meet the evening net load peak. However, by 2030, a sudden switch occurs as the number of peaker starts drops sharply and the number of CCGT starts increases rapidly (Figure 11). This is because the 42 MMT carbon cap becomes the driving force behind decreasing peaker usage by 2030 and more-efficient CCGTs begin to play the role that less-efficient, but more flexible, peakers once fulfilled.

In addition to examining changes in the total number of starts for the peaker and CCGT fleets, we examined how these changes in fleet operations manifest themselves at the individual plant level. To provide better understanding of individual plant start-up frequency, Figure 12 shows the distributions of CCGT starts in 2030. The CCGT fleet goes through a dramatic shift over the study duration: the fleet stops and starts close to zero times in 2018, but 16 of the 23 nonretired CCGT plants start up more than 200 times in 2030 (Figure 12).

The dramatic increase in peaker starts until 2026 and the increase in CCGT starts through 2030 could have a negative effect on air quality in communities near these plants. As discussed earlier, NO_x emissions resulting from starting up a natural gas plant can be as much as 30 times the amount of NO_x emissions resulting from the same plant running at steady state for one hour (Birdsall et al. 2016; Lew et al. 2013). With a significant number of peakers and CCGTs starting up at least every other day, overall NO_x emissions from natural gas power plant generation may increase dramatically in California, potentially having a negative effect on air quality, and in turn, the health of people living in communities near these plants.

More research is needed to understand better the extent of future increased natural gas plant cycling and its effect on total emissions and air quality. GridPath has several limitations that prevent a more detailed analysis of these topics. First, GridPath does not model CO_2 emissions from plant start-up events. Because peakers are generally smaller in

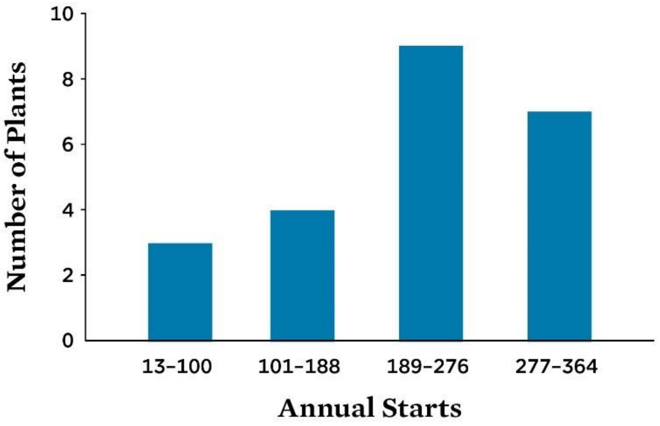
FIGURE 11. **Annual Gas Plant Starts**



Both CCGTs and peakers start up much more frequently over the duration of the study.

Note: Figure shows results from the "42 MMT, Enforce LCR, Allow New Resources, 4h" scenario. Because peakers generally have a smaller capacity than CCGTs and start-up emissions are proportional to plant capacity, the emissions resulting from peaker and CCGT starts are not equivalent. The average CCGT start produces more emissions than the average peaker start.

FIGURE 12. **Frequency of CCGT Starts in 2030**



Under a 42 MMT scenario, many combined-cycle natural gas plants will start and stop much more frequently in 2030 compared with today. Some plants will go from close to zero starts today (i.e., nonstop generation) to starting once nearly every day of the year.

Note: Figure shows results from the "42 MMT, Enforce LCR, Allow New Resources, 4h" scenario.

terms of generation capacity than CCGTs, peakers use less fuel and have lower overall CO_2 emissions when starting up. Given this fact, the drastic shift from peaker starts to CCGT starts that occurs between 2026 and 2030 in this study (see Figure 11) may be unrealistic because a potentially large amount of CCGT start-up CO_2 emissions are unaccounted for and may have a significant effect on the optimal solution that meets the carbon cap. Second, GridPath does not model NO_x emissions from plant start-up events, so it is difficult to determine the extent to which increased plant cycling will result in increased NO_x emissions. Third, GridPath does not differentiate between hot, warm, and cold starts, and the type of start significantly affects start-up costs and emissions. Fourth, even if GridPath did quantify NO_x emissions from plant start-up events, determining the effect of increased NO_x emissions on air quality in the communities near these plants is not a straightforward task. Plant characteristics, atmospheric conditions, and NO_x emissions from other sources must all be considered when analyzing the effect of increased cycling on air quality in nearby communities.

[CONCLUSION]

California Needs a Long-Term Plan for Turning Down the Gas

California is on track to supply substantially more electricity needs with renewable energy generation, which will reduce global warming emissions and provide new clean resources to power the state's electricity needs, including the growing electric vehicle market. But natural gas–fired power plants still supply a substantial portion of energy and reliability needs for the grid, and California must take steps to reduce its dependence on natural gas generation if it is to realize the benefits of its clean energy transition.

Our analysis finds that no additional natural gas generation capacity is needed to keep the CAISO grid reliable even if California adds significant amounts of renewables to its electricity mix to meet its 2030 global warming emissions target. Indeed, UCS analysis indicates that as much as a quarter of the state's existing natural gas generation capacity could be taken offline today. In the UCS 30 MMT scenarios, much more natural gas plant capacity, particularly peakers, retires by 2030, but only if LCR is satisfied by other resources (e.g., long-duration battery storage).

However, as natural gas generation declines overall, failure to invest further in nonfossil fuel grid flexibility technologies could lead to individual natural gas power plants cycling on and off much more frequently to meet evening energy needs, which may result in increased NO_x emissions from these plants. In addition, the need to fulfill LCR could prevent the retirement of some gas plants. More analysis is required to understand how stopping and starting natural gas plants more frequently will affect air quality and the health of communities living near these plants. Future analysis should also consider how changes in air pollution associated with electricity generation may be offset by pollution reduction associated with vehicle electrification. To ensure an orderly and equitable transition away from natural gas generation, California needs to understand and plan better for natural gas plant retirements and changes in operations that will occur between now and 2030. UCS makes the following recommendations:

Energy planning activities should identify where natural gas plants can be retired. As California reduces dependence on natural gas generation, electricity providers, energy agencies, and grid operators need to know which natural gas plants may be critical for maintaining electricity system reliability and which are not. Keeping excess natural gas generation capacity on the system could impose unnecessary costs on electricity customers and may make it more difficult for California to meet its global warming emissions reduction goals. In addition, not having a clear understanding of the gas plant capacity most valuable to the electricity system may result in natural gas plants being retired prematurely.

Electricity providers, energy agencies, and grid operators should work together to calculate criteria air pollution emissions associated with increased natural gas plant cycling from individual power plants, and future procurement should minimize air pollution from gas plants. Our analysis indicates that both peakers and CCGTs will start and stop much more frequently between now and 2030. For the 2017–2018 IRP, the CPUC conducted some postprocessing analysis of the RESOLVE outputs to estimate the number of start-ups that occurred for each type of generation capacity for each of the scenarios run for the Reference System Plan (CPUC 2017b). But the CPUC's modeling did not calculate the number of unit start-ups associated with individual plants in the natural gas fleet, making it impossible to understand fully the impact of increased natural gas plant cycling on localized NO_x emissions and air quality (CPUC 2017a). The CPUC has a statutory obligation to ensure IRPs "minimize localized air pollutants and other greenhouse gas emissions, with early priority on disadvantaged communities" (California Public Utilities Code 2015a), and start-up events from natural gas plants generally emit much more NO_x than steady-state operations (Birdsall et al. 2016; Lew et al. 2013). More analysis is therefore needed to understand better how increased natural gas plant cycling at the plant-specific level may affect emissions and air quality, especially in disadvantaged communities in California. More locational information on emissions from future gas plant cycling and potential implications for air quality can help electricity providers target nonfossil investments in certain areas to reduce the cycling of gas plants most likely to have a negative effect on local air quality.

Electricity providers should invest in nonfossil sources of energy and grid flexibility, and electricity providers should strategically site these resources so they can fulfill LCR. Shifting more evening electricity demand to daytime hours, investing in energy storage, and diversifying the portfolio of renewable energy resources can all help reduce the state's reliance on natural gas generation and the need to cycle in-state gas plants. In addition, allowing California grid operators greater access to generation resources outside the state will help reduce the need to cycle in-state gas plants. Also, our modeling indicates that when flexible nonfossil resources, such as energy storage, are located in areas where they can fulfill LCR, more peaker power plants can be retired. Electricity providers should be encouraged to invest in nonfossil resources in strategic locations to fulfill LCR and consider transmission upgrades to reduce/eliminate LCR in certain locations. This will be especially important in situations where gas plants will require major retrofits or contract payments that did not result from a competitive solicitation in order to continue fulfilling LCR.

[ENDNOTES]

[1] For more on LCR, see *www.caiso.com/informed/Pages/StakeholderProcesses/LocalCapacityRequirementsProcess.aspx*.

[2] The only scenario with new natural gas capacity is the “42 MMT, Enforce LCR, Allow New Resources, 8h” scenario, in which 81 megawatts (MW) of CCGT capacity is added in 2026. This new gas capacity is added due to a local capacity shortfall in the San Diego-IV area; however, this shortfall is an artifact of the input data. The list of resources available to meet LCR that is used in GridPath implies a local capacity shortfall in the San Diego-IV area in 2026, but the list of resources available to meet LCR that is used in the CAISO’s 2016–2017 Transmission Plan indicates no shortfall in 2026 at all (CAISO 2017b). Since the CAISO has determined there will be no local capacity shortfall in the San Diego-IV area in 2026, this new gas capacity is likely not necessary in this scenario.

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[APPENDIX]

Modeling Details

GridPath Platform

GridPath is a grid analytics platform developed by Blue Marble Analytics, LLC. The platform is capable of several types of power system modeling approaches, including multistage production-cost simulation, long-term capacity expansion, and price-based asset valuation. GridPath can simulate the operations of the power system, capturing the capabilities of and constraints on generation, storage, and transmission resources to understand grid integration and flexibility needs. The platform can also be used to identify cost-effective deployment of conventional and renewable generation as well as storage, transmission lines, and demand response.

GridPath has a flexible temporal and spatial resolution, and it is designed for fast and easy application to different regions and systems. Each generation, storage, and transmission resource can be modeled with a user-specified level of detail. The platform can also optionally capture the effects of forecast error, provision of ancillary grid services, interconnection, and policies such as a renewables portfolio standard (RPS) or a carbon cap on operations and the optimal resource portfolio.

For more information on GridPath, please visit *https://www.gridpath.io*.

Input Data

For the analysis described here, we used the public data available from the 2017–2018 cycle of the CPUC IRP proceeding (E3 2017a). These data were developed as inputs to the RESOLVE model, which was used to create the 2018 Reference System Plan as well a wide range of sensitivity scenarios. We attempt to adhere to the RESOLVE Reference System Plan modeling—in terms of both functionality and input data—as closely as possible. Below, we provide a summary of the data inputs ported to GridPath from RESOLVE. We include a high-level description only, not the detailed inputs. An extensive description of the RESOLVE input data is available in Attachment B of the 2018 Reference System Plan (E3 2017a).

ZONES AND TRANSMISSION

We modeled the CAISO as a single zone interconnected with five other zones: three within California (BANC, IID, and LADWP) and two external zones (the Pacific Northwest and the Southwest). The transmission topology and transfer limits are the same as in RESOLVE. We also included a constraint on simultaneous net exports from the CAISO, using the “Mid” scenario (5,000 MW of net exports allowed by 2030) and hurdle rates for transfers between zones.

TEMPORAL RESOLUTION

We modeled the period between 2018 and 2030. Like RESOLVE, GridPath makes investment decisions at four points in time during that period: 2018, 2022, 2026, and 2030. GridPath also makes retirement decisions at those times. We modeled the same 37 independent days used in RESOLVE, weighted to represent load and resource availability conditions over a full calendar year. Operational decisions were made at an hourly resolution on each day. The 37 days were selected from the historical meteorological record and assigned weights to reflect the distribution of load, renewable resource availability, and hydro conditions. Like in RESOLVE, each modeled investment year has an assigned weight, based on the fraction of the entire study period it represents and a discount rate.

CAISO LOAD FORECAST AND LOAD PROFILES

The final load profile used in this study was the same as that used to create the 2018 Reference System Plan. The total annual consumption and normalized profiles for each component were incorporated into the load profile. The baseline consumption is equal to the CEC's 2016 Integrated Energy Policy Report total "baseline" forecast minus non-PV self-generation. The CAISO load is based on this baseline consumption with a series of demand-side modifiers. The modifiers include assumptions about electric vehicle adoption, building electrification, behind-the-meter PV, energy efficiency, and the impact of time-of-use rates. Transmission and distribution losses were assumed to be 7.33 percent.

CAISO EXISTING AND PLANNED RESOURCES

We used the existing conventional generation portfolio from RESOLVE (based on the preliminary 2017 CAISO Net Qualifying Capacity (NQC) List), which can be found on the "CONV_CAISO_Gen_List" tab of the RESOLVE user interface (E3 2017b). Like RESOLVE, we input aggregated "fleets" of generators for the following resource categories: CHP, CAISO_ST, and CAISO_Reciprocating_Engine. For units classified into the remaining four "fleets"—CAISO_CCGT1, CAISO_CCGT2, CAISO_Peaker1, CAISO_Peaker2—we used a higher-resolution, plant-level aggregation instead, which is described in more detail below.

CAISO CANDIDATE RESOURCES AND COSTS

GridPath used the same new resource investment options as RESOLVE, including the same costs and performance assumptions. Like RESOLVE, GridPath picked from a range of renewable resources that represent aggregations of individual sites, grouped to several geographic areas that each include several Competitive Renewable Energy Zones (E3 2017a). We used the Desert Renewable Energy Conservation Plan/San Joaquin Valley environmental screen to limit potential at each candidate renewable resource. Like RESOLVE, we modeled the transmission zones for each California renewable resource along with the zone's existing transmission capability, i.e., the amount of new resource capacity that can be added while receiving full capacity deliverability status. Beyond that, the model could choose to install resources either as energy-only—up to a certain capacity limit—or to incur an additional transmission cost for full deliverability. The out-of-state resource options we used correspond to the "Existing Tx Only" scenario setting (2,000 MW of wind) in RESOLVE. For each wind and solar resource, we used the normalized generation profiles in the REN_Profiles tab of the RESOLVE user interface (E3 2017b).

Candidate natural gas resources included advanced CCGTs, aero combustion turbines, and reciprocating engines. The model could also pick storage resources. Like in RESOLVE, the duration of storage was endogenously determined based on the storage technology's power and energy cost structure. Pumped storage was limited to 2,000 MW of new deployment in 2022 and 4,000 MW thereafter and was required to have at least 12 hours of duration. Lithium-ion or flow battery storage were other options available to the model with unlimited potential.

CAISO RESERVES

We modeled several reserve types for the CAISO load zone including frequency response, regulation up, regulation down, load following up, load following down, and spinning reserves. Like in RESOLVE, the frequency response requirement was 770 MW, half of which had to be provided by thermal or storage resources while the rest could be provided by hydro; the frequency-response provision from thermal generators was limited to 8 percent of committed capacity. The regulation requirement, both up and down, was set to 1 percent of hourly load, the spinning reserves requirement was 3 percent of hourly load, and the load-following up and down requirements were the same as in the IRP inputs (based on subhourly modeling of a 50 percent RPS). These reserve products could be provided by thermal generation, limited by their 10-minute ramp rate, and by hydro and storage resources limited by their available headroom or footroom. Battery and pumped hydro resources were also required to have sufficient energy available in storage or room left in the "reservoir" to store energy. Like RESOLVE, we also allowed CAISO wind and solar resources to provide load-following down, but we modeled this explicitly for each resource in GridPath (i.e., resources incurred curtailment within the hour when providing downward reserves) rather than via the "Reflex Surface" in RESOLVE.

CAISO SYSTEM RESOURCE ADEQUACY

Like in RESOLVE, we included a resource adequacy constraint in the CAISO requiring sufficient capacity to meet a 15 percent planning reserve margin. The requirement was reduced by the CAISO import capability after adjustment for the CAISO share of Hoover and Palo Verde, which were modeled as if located inside the CAISO.

CAISO conventional thermal and hydro resources contributed a fraction of their capacity based on the CAISO NQC list. Baseload renewable resources (geothermal, biomass, and small hydro) were assumed to contribute their full capacity to the planning reserve margin. We also included the contribution of variable renewable resources like wind and solar via a piecewise linear effective load carrying capability (ELCC) surface developed in the IRP proceeding. The ELCC surface expresses the total capacity contribution of the portfolio of wind and solar resources as a function of the penetration of each of those two resources. Energy storage with at least four hours of duration received full capacity credit based on its power rating; storage with a shorter duration could contribute an amount of capacity derated proportionately relative to a four-hour resource (e.g., a two-hour device could contribute 2/4, or half, of its power capacity).

CAISO RPS

We included a constraint enforcing a 50 percent RPS in the CAISO by 2030. However, the CAISO carbon cap requires that more renewables be built than required by the RPS, so the RPS constraint is not binding in any of the scenarios.

CAISO GREENHOUSE GAS POLICY

Like in RESOLVE, we modeled a constraint on greenhouse gas emissions produced within or imported into the CAISO. The constraint was set by first multiplying the California statewide caps of 42 MMT and 30 MMT respectively by 81 percent to arrive at the CAISO cap. This cap was then adjusted by 2.8 MMT to account for specified imports into the CAISO that may have a lower carbon content than the intensity assumed for unspecified imports. The assumed carbon intensity of imports was 0.428 metric tons per MWh.

FUEL PRICES

We used the “Mid” fuel price forecast from the 2018 IRP Reference System Plan inputs. Natural gas prices are highest in California, and higher in the Southwest than in the Northwest. We also applied a carbon price adder to fuel used in California as well as to imports into California.

OTHER REGIONS

For the five other zones modeled, we used the load profiles and resource mixes assumed in the IRP inputs.

GridPath Additional Functionality

Our GridPath analysis adheres to the RESOLVE Reference System Plan modeling—in terms of both functionality and input data—as closely as possible, while adding three additional features: gas fleet disaggregation to the individual plant level, the ability to economically retire gas plants, and the enforcement of LCR.

GAS FLEET DISAGGREGATION

For this study, we disaggregated the CAISO resources included in the RESOLVE “CAISO_CCGT1,” “CAISO_CCGT2,” “CAISO_Peaker1,” and “CAISO_Peaker2” fleets to the plant level and modeled each plant’s operating characteristics individually. Table A1 shows the mapping of units in the CAISO generator list (from the CONV_CAISO_Gen_List tab of the RESOLVE user interface [E3 2017b]), RESOLVE fleets, and GridPath plants. Table A2 shows the operating characteristics (e.g., heat rate, minimum stable level, ramp rate) and capacity-contribution characteristics (e.g., NQC fraction, LCR area) of each plant in GridPath (from the CONV_CAISO_Gen_List tab of the RESOLVE user interface [E3 2017b]). We assumed a variable cost of $5.7 per MWh for plants classified into one of the RESOLVE CCGT fleets and $5 per MWh for plants classified into one of the RESOLVE peaker fleets consistent with the IRP assumptions for those fleets. The Mandalay power plant retires in 2020, so it is only available in the 2018 period. The Alamitos, Huntington Beach, and Stanton plants come online in 2020, so they are first available in the 2022 period.

ECONOMIC RETIREMENTS

For this study, we allowed economic retirement of peakers and CCGT plants in each investment period. GridPath optimizes retirements over the entire study period (i.e., with "perfect foresight"). Therefore, the model will retire a plant only if that plant is uneconomic in the current period and over the remainder of the study period. Keeping a plant available requires incurring an annual fixed operations and maintenance (O&M) cost, but the model could also decide to retire a plant, therefore avoiding the need to pay its annual fixed O&M cost. This occurs if the total value of the plant (i.e., system benefit from all value streams including energy, ancillary services, system capacity, local capacity, etc.) is lower than the cost to keep the plant available.

We assumed a fixed O&M cost of $10 per kilowatt-year (kW-yr) for plants classified into one of the RESOLVE CCGT fleets and six dollars per kW-yr for plants classified into one of the RESOLVE peaker fleets based on the data for the "Gas—CCGT" and "Gas—CT-Frame" technologies in the COSTS_Resource_Char tab of the RESOLVE user interface (E3 2017b).

Several plants classified into one of the CCGT and peakers fleets belong to the CAISO "cogeneration" category (see Table A1). We did not allow these plants to retire.

For computational feasibility, the retirement decisions in this study were continuous rather than an integer decision. Only a handful of partial retirements occurred across the scenarios.

LCR

We modeled LCR to ensure sufficient resources were available for local reliability in addition to system-level services. The 2018 requirements are based on the CAISO *2018 Local Capacity Technical Report* (CAISO 2017a). The requirements for 2022, 2026, and 2030 are based on the CAISO *2016–2017 Transmission Plan, Appendix D* (CAISO 2017b). The latter document provides requirements for 2021 and 2026. To get the requirement for 2022, we linearly interpolated between those two numbers. To arrive at a requirement for 2030, we extrapolated to 2030 based on the trend from 2021 to 2026. If the trend was downward, we kept the 2030 requirement the same as the 2026 value. Table A3 shows the resulting requirements for each local capacity area.

The extrapolation to 2030 results in small local capacity shortfalls that year—if no new resources are added—in the Bay Area (103 MW), Kern (101 MW), and San Diego (266 MW). To avoid infeasibilities in scenarios with no new LCR resources allowed, we included a slack variable in the local capacity constraint (in all scenarios) with a cost set an order of magnitude higher than the CAISO net cost of new entry of $154 per kW-yr.

Since we explicitly modeled the local-capacity contribution only of plants categorized into the "CAISO_CCGT1," "CAISO_CCGT2," "CAISO_Peaker1," and "CAISO_Peaker2" fleets, before inputting LCR values into GridPath, we first subtracted the contribution of all

TABLE A3. **LCR Values Used in GridPath**

Local Area Name	2018	2022	2026	2030
Bay Area	5,160	5,302	5,732	6,162
Big Creek-Ventura	2,321	2,424	2,528	2,632
Fresno	2,081	1,223	1,474	1,725
Humboldt	169	169	171	173
Kern	453	162	392	622
LA Basin	7,525	6,965	7,234	7,503
NCNB	634	493	547	601
San Diego-IV	4,032	4,415	4,649	4,883
Sierra	2,113	1,550	1,004	1,004
Stockton	719	426	516	606

LCR values calculated from CAISO studies.

Note: Values shown here represent the total need for each local area before subtracting the contribution from all other resources that are not in the peaker or CCGT fleets.

SOURCES: CAISO 2017A; CAISO 2017B; UCS ANALYSIS.

other resources on the CAISO generator list included with the RESOLVE inputs (CONV_CAISO_Gen_List tab of the RESOLVE user interface [E3 2017b]) from each area’s LCR (if the resource is available in the respective year).

TABLE A1. **Mapping of CAISO Resources, RESOLVE Fleets, and GridPath Plants**

Source	Resource ID	Local Area	Generator Name	Type (CAISO)	RESOLVE Fleet Type	GridPath Plant
CAISO NQC List	CALPIN_1_AGNEW	Bay Area	Agnews Power Plant	COGENERATION	CAISO_CCGT1	Agnews
CAISO NQC List	COLTON_6_AGUAM1	LA Basin	AGUA MANSA UNIT 1 (CITY OF COLTON)	PEAKER	CAISO_Peaker2	AguaMansa
CAISO NQC List	ALMEGT_1_UNIT 1	Bay Area	ALAMEDA GT UNIT 1	PEAKER	CAISO_Peaker2	Alameda
CAISO NQC List	ALMEGT_1_UNIT 2	Bay Area	ALAMEDA GT UNIT 2	PEAKER	CAISO_Peaker2	Alameda
D.15-11-04	TBD	LA Basin	Alamitos	UNKNOWN	CAISO_CCGT1	Alamitos
CAISO NQC List	ANAHM_7_CT	LA Basin	ANAHEIM COMBUSTION TURBINE	PEAKER	CAISO_Peaker2	Anaheim
CAISO NQC List	BDGRCK_1_UNITS	Kern	BADGER CREEK LIMITED	COGENERATION	CAISO_Peaker1	BadgerCreek
CAISO NQC List	BARRE_6_PEAKER	LA Basin	Barre Peaker	PEAKER	CAISO_Peaker1	Barre
CAISO NQC List	BEARMT_1_UNIT	Kern	Bear Mountain Limited	COGENERATION	CAISO_Peaker2	BearMountain
CAISO NQC List	BUCKBL_2_PL1X3	CAISO System	Blythe Energy Center	THERMAL	CAISO_CCGT2	Blythe
CAISO NQC List	BORDER_6_UNITA1	San Diego-IV	CalPeak Power Border Unit 1	PEAKER	CAISO_Peaker2	Border
CAISO NQC List	ESCNDO_6_UNITB1	San Diego-IV	CalPeak Power Enterprise Unit 1	PEAKER	CAISO_Peaker2	Enterprise
CAISO NQC List	PNOCHE_1_UNITA1	Fresno	CalPeak Power Panoche Unit 1	PEAKER	CAISO_Peaker2	CalPeakPanoche
CAISO NQC List	VACADX_1_UNITA1	CAISO System	CalPeak Power Vaca Dixon Unit 1	PEAKER	CAISO_Peaker2	VacaDixon
CAISO NQC List	ANAHM_2_CANYN1	LA Basin	CANYON POWER PLANT UNIT 1	PEAKER	CAISO_Peaker1	Canyon
CAISO NQC List	ANAHM_2_CANYN2	LA Basin	CANYON POWER PLANT UNIT 2	PEAKER	CAISO_Peaker1	Canyon
CAISO NQC List	ANAHM_2_CANYN3	LA Basin	CANYON POWER PLANT UNIT 3	PEAKER	CAISO_Peaker1	Canyon
CAISO NQC List	ANAHM_2_CANYN4	LA Basin	CANYON POWER PLANT UNIT 4	PEAKER	CAISO_Peaker1	Canyon
CAISO NQC List	LGHTHP_6_ICEGEN	LA Basin	CARSON COGENERATION	COGENERATION	CAISO_CCGT1	Carson
CAISO NQC List	CENTER_6_PEAKER	LA Basin	Center Peaker	PEAKER	CAISO_Peaker1	Center
CAISO NQC List	CENTRY_6_PL1X4	LA Basin	CENTURY GENERATING PLANT (AGGREGATE)	PEAKER	CAISO_Peaker1	Century
CAISO NQC List	CENTRY_6_PL1X4	LA Basin	CENTURY GENERATING PLANT (AGGREGATE)	PEAKER	CAISO_Peaker1	Century

CAISO NQC List	CENTRY_6_PL1X4	LA Basin	CENTURY GENERATING PLANT (AGGREGATE)	PEAKER	CAISO_Peaker1	Century
CAISO NQC List	CENTRY_6_PL1X4	LA Basin	CENTURY GENERATING PLANT (AGGREGATE)	PEAKER	CAISO_Peaker1	Century
CAISO NQC List	CHALK_1_UNIT	CAISO System	CHALK CLIFF LIMITED	COGENERATION	CAISO_Peaker2	ChalkCliff
CAISO NQC List	OTAY_6_PL1X2	San Diego-IV	Chula Vista Energy Center, LLC	PEAKER	CAISO_Peaker2	ChulaVista
CAISO NQC List	CORONS_6_CLRWTR	LA Basin	Clearwater Power Plant	THERMAL	CAISO_CCGT2	Clearwater
CAISO NQC List	COLUSA_2_PL1X3	CAISO System	Colusa Generating Station	THERMAL	CAISO_CCGT1	Colusa
CAISO NQC List	LMBEPK_2_UNITA2	Bay Area	Creed Energy Center, Unit #1	PEAKER	CAISO_Peaker2	Creed
CAISO NQC List	ELCAJN_6_UNITA1	San Diego-IV	Cuyamaca Peak Energy Plant	PEAKER	CAISO_Peaker1	Cuyamaca
CAISO NQC List	DELTA_2_PL1X4	Bay Area	DELTA ENERGY CENTER AGGREGATE	THERMAL	CAISO_CCGT1	Delta
CAISO NQC List	MRCHNT_2_PL1X3	CAISO System	Desert Star Energy Center	THERMAL	CAISO_CCGT1	DesertStar
CAISO NQC List	DUANE_1_PL1X3	Bay Area	DONALD VON RAESFELD POWER PROJECT	THERMAL	CAISO_CCGT2	DonaldVonRaesfeld
CAISO NQC List	DOUBLC_1_UNITS	Kern	DOUBLE "C" LIMITED	COGENERATION	CAISO_Peaker2	DoubleC
CAISO NQC List	DOUBLC_1_UNITS	Kern	DOUBLE "C" LIMITED	COGENERATION	CAISO_Peaker2	DoubleC
CAISO NQC List	DREWS_6_PL1X4	LA Basin	DREWS UNIT AGGREGATE	PEAKER	CAISO_Peaker1	Drews
CAISO NQC List	DREWS_6_PL1X4	LA Basin	DREWS UNIT AGGREGATE	PEAKER	CAISO_Peaker1	Drews
CAISO NQC List	DREWS_6_PL1X4	LA Basin	DREWS UNIT AGGREGATE	PEAKER	CAISO_Peaker1	Drews
CAISO NQC List	DREWS_6_PL1X4	LA Basin	DREWS UNIT AGGREGATE	PEAKER	CAISO_Peaker1	Drews
CAISO NQC List	ELCAJN_7_GT1	San Diego-IV	EL CAJON	PEAKER	CAISO_Peaker2	ElCajonGT
CAISO NQC List	ELCAJN_6_LM6K	San Diego-IV	El Cajon Energy Center	PEAKER	CAISO_Peaker2	ElCajonEC
CAISO NQC List	ELSEGN_2_UN1011	LA Basin	El Segundo Energy Center 5/6	THERMAL	CAISO_CCGT2	ElSegundo
CAISO NQC List	ELSEGN_2_UN2021	LA Basin	El Segundo Energy Center 7/8	THERMAL	CAISO_CCGT1	ElSegundo
CAISO NQC List	ELKHIL_2_PL1X3	CAISO System	ELK HILLS COMBINED CYCLE (AGGREGATE)	THERMAL	CAISO_CCGT1	ElkHills
CAISO NQC List	GOLETA_6_ELLWOD	Big Creek-Ventura	ELLWOOD ENERGY SUPPORT FACILITY	PEAKER	CAISO_Peaker2	Ellwood
D.15-11-041	TBD	San Diego-IV	Encina Gas Peaker	UNKNOWN	CAISO_Peaker1	Carlsbad
CAISO NQC List	ENCINA_7_GT1	San Diego-IV	ENCINA GAS TURBINE UNIT 1	PEAKER	CAISO_Peaker2	Encina
CAISO NQC List	BOGUE_1_UNITA1	Sierra	Feather River Energy Center, Unit #1	PEAKER	CAISO_Peaker1	FeatherRiver
CAISO NQC List	AGRICO_7_UNIT	Fresno	Fresno Cogen	COGENERATION	CAISO_CCGT2	FresnoCogen

CAISO NQC List	AGRICO_6_PL3N5	Fresno	Fresno Peaker	COGENERATION	CAISO_Peaker2	FresnoPeaker
CAISO NQC List	GATWAY_2_PL1X3	Bay Area	GATEWAY GENERATING STATION	THERMAL	CAISO_CCGT1	Gateway
CAISO NQC List	CSCGNR_1_UNIT 1	Bay Area	GIANERA PEAKER UNIT 1	PEAKER	CAISO_Peaker2	Gianera
CAISO NQC List	CSCGNR_1_UNIT 2	Bay Area	GIANERA PEAKER UNIT 2	PEAKER	CAISO_Peaker2	Gianera
CAISO NQC List	GILROY_1_UNIT	Bay Area	GILROY COGEN AGGREGATE	COGENERATION	CAISO_CCGT1	GilroyCogen
CAISO NQC List	GILRPP_1_PL1X2	Bay Area	GILROY ENERGY CENTER UNITS 1&2 AGGREGATE	PEAKER	CAISO_Peaker2	GilroyPeaker
CAISO NQC List	GILRPP_1_PL1X2	Bay Area	GILROY ENERGY CENTER UNITS 1&2 AGGREGATE	PEAKER	CAISO_Peaker2	GilroyPeaker
CAISO NQC List	GILRPP_1_PL3X4	Bay Area	GILROY ENERGY CENTER, UNIT #3	PEAKER	CAISO_Peaker2	GilroyPeaker
CAISO NQC List	GLNARM_7_UNIT 1	LA Basin	GLEN ARM UNIT 1	PEAKER	CAISO_Peaker2	GlenArm12
CAISO NQC List	GLNARM_7_UNIT 2	LA Basin	GLEN ARM UNIT 2	PEAKER	CAISO_Peaker2	GlenArm12
CAISO NQC List	GLNARM_7_UNIT 3	LA Basin	GLEN ARM UNIT 3	PEAKER	CAISO_Peaker1	GlenArm34
CAISO NQC List	GLNARM_7_UNIT 4	LA Basin	GLEN ARM UNIT 4	PEAKER	CAISO_Peaker1	GlenArm34
CAISO Other	TBD	LA Basin	GLENARM UNIT 5	UNKNOWN	CAISO_Peaker2	GlenArm5
CAISO NQC List	LMBEPK_2_UNITA3	Bay Area	Goose Haven Energy Center, Unit #1	PEAKER	CAISO_Peaker2	GooseHaven
CAISO NQC List	ETIWND_6_GRPLND	LA Basin	Grapeland Peaker	PEAKER	CAISO_Peaker1	Grapeland
CAISO NQC List	HENRTA_6_UNITA1	Fresno	GWF HENRIETTA PEAKER PLANT UNIT 1	PEAKER	CAISO_Peaker2	Henrietta
CAISO NQC List	HENRTA_6_UNITA2	Fresno	GWF HENRIETTA PEAKER PLANT UNIT 2	PEAKER	CAISO_Peaker2	Henrietta
CAISO NQC List	VERNON_6_GONZL1	LA Basin	H. Gonzales Unit #1	PEAKER	CAISO_Peaker1	HGonzalez
CAISO NQC List	VERNON_6_GONZL2	LA Basin	H. Gonzales Unit #2	PEAKER	CAISO_Peaker1	HGonzalez
CAISO NQC List	GWFPWR_1_UNITS	Fresno	HANFORD PEAKER PLANT	PEAKER	CAISO_Peaker2	Hanford
CAISO NQC List	GWFPWR_1_UNITS	Fresno	HANFORD PEAKER PLANT	PEAKER	CAISO_Peaker2	Hanford
CAISO NQC List	HARBGN_7_UNITS	LA Basin	HARBOR COGEN COMBINED CYCLE	THERMAL	CAISO_CCGT2	Harbor
CAISO NQC List	HIDSRT_2_UNITS	CAISO System	HIGH DESERT POWER PROJECT AGGREGATE	THERMAL	CAISO_CCGT1	HighDesert
CAISO NQC List	SIERRA_1_UNITS	Kern	HIGH SIERRA LIMITED	COGENERATION	CAISO_Peaker2	HighSierra
CAISO NQC List	SIERRA_1_UNITS	Kern	HIGH SIERRA LIMITED	COGENERATION	CAISO_Peaker2	HighSierra
CAISO NQC List	HINSON_6_LBECH1	LA Basin	HINSON_6_LBECH1	PEAKER	CAISO_Peaker2	LongBeach

CAISO NQC List	HINSON_6_LBECH2	LA Basin	HINSON_6_LBECH2	PEAKER	CAISO_Peaker2	LongBeach
CAISO NQC List	HINSON_6_LBECH3	LA Basin	HINSON_6_LBECH3	PEAKER	CAISO_Peaker2	LongBeach
CAISO NQC List	HINSON_6_LBECH4	LA Basin	HINSON_6_LBECH4	PEAKER	CAISO_Peaker2	LongBeach
D.15-11-04	TBD	LA Basin	Huntington Beach	UNKNOWN	CAISO_CCGT1	HuntingtonBeach
CAISO NQC List	INDIGO_1_UNIT 1	LA Basin	INDIGO PEAKER UNIT 1	PEAKER	CAISO_Peaker2	Indigo1
CAISO NQC List	INDIGO_1_UNIT 2	LA Basin	INDIGO PEAKER UNIT 2	PEAKER	CAISO_Peaker2	Indigo23
CAISO NQC List	INDIGO_1_UNIT 3	LA Basin	INDIGO PEAKER UNIT 3	PEAKER	CAISO_Peaker2	Indigo23
CAISO NQC List	INLDEM_5_UNIT 1	LA Basin	Inland Empire Energy Center, Unit 1	THERMAL	CAISO_CCGT1	InlandEmpire
CAISO NQC List	INLDEM_5_UNIT 2	LA Basin	Inland Empire Energy Center, Unit 2	THERMAL	CAISO_CCGT1	InlandEmpire
CAISO NQC List	KEARNY_7_KY3	San Diego-IV	KEARNY GT3 AGGREGATE	PEAKER	CAISO_Peaker2	Kearny
CAISO NQC List	OMAR_2_UNIT 1	Big Creek-Ventura	KERN RIVER COGENERATION CO. UNIT 1	COGENERATION	CAISO_Peaker1	KernRiver
CAISO NQC List	OMAR_2_UNIT 2	Big Creek-Ventura	KERN RIVER COGENERATION CO. UNIT 2	COGENERATION	CAISO_Peaker1	KernRiver
CAISO NQC List	OMAR_2_UNIT 3	Big Creek-Ventura	KERN RIVER COGENERATION CO. UNIT 3	COGENERATION	CAISO_Peaker1	KernRiver
CAISO NQC List	OMAR_2_UNIT 4	Big Creek-Ventura	KERN RIVER COGENERATION CO. UNIT 4	COGENERATION	CAISO_Peaker1	KernRiver
CAISO NQC List	KNGCTY_6_UNITA1	CAISO System	King City Energy Center, Unit #1	PEAKER	CAISO_Peaker2	KingCity
CAISO NQC List	LAPLMA_2_UNIT 1	CAISO System	La Paloma Generating Plant Unit #1	THERMAL	CAISO_CCGT1	LaPaloma
CAISO NQC List	LAPLMA_2_UNIT 2	CAISO System	La Paloma Generating Plant Unit #2	THERMAL	CAISO_CCGT1	LaPaloma
CAISO NQC List	LAPLMA_2_UNIT 3	CAISO System	La Paloma Generating Plant Unit #3	THERMAL	CAISO_CCGT1	LaPaloma
CAISO NQC List	LAPLMA_2_UNIT 4	CAISO System	LA PALOMA GENERATING PLANT, UNIT #4	THERMAL	CAISO_CCGT1	LaPaloma
CAISO NQC List	LMBEPK_2_UNITA1	Bay Area	Lambie Energy Center, Unit #1	PEAKER	CAISO_Peaker2	Lambie
CAISO NQC List	LARKSP_6_UNIT 1	San Diego-IV	LARKSPUR PEAKER UNIT 1	PEAKER	CAISO_Peaker1	Larkspur
CAISO NQC List	LARKSP_6_UNIT 2	San Diego-IV	LARKSPUR PEAKER UNIT 2	PEAKER	CAISO_Peaker1	Larkspur
CAISO NQC List	LIVOAK_1_UNIT 1	Kern	LIVE OAK LIMITED	COGENERATION	CAISO_Peaker2	LiveOak
CAISO NQC List	LODIEC_2_PL1X2	Sierra	Lodi Energy Center	THERMAL	CAISO_CCGT1	LodiCC
CAISO NQC List	LODI25_2_UNIT 1	Stockton	LODI GAS TURBINE	PEAKER	CAISO_Peaker2	LodiPeaker
CAISO NQC List	STIGCT_2_LODI	Sierra	LODI STIG UNIT	PEAKER	CAISO_Peaker2	LodiSTIG
CAISO NQC List	LECEF_1_UNITS	Bay Area	LOS ESTEROS ENERGY FACILITY AGGREGATE	PEAKER	CAISO_CCGT2	LosEsteros

CAISO NQC List	LMEC_1_PL1X3	Bay Area	Los Medanos Energy Center AGGREGATE	THERMAL	CAISO_CCGT1	LosMedanos
CAISO NQC List	LAROA1_2_UNITA1	San Diego-IV	LR1	THERMAL	CAISO_CCGT2	LaRosita1
CAISO NQC List	LAROA2_2_UNITA1	San Diego-IV	LR2	THERMAL	CAISO_CCGT2	LaRosita2
CAISO NQC List	MALAGA_1_PL1X2	Fresno	Malaga Power Aggregate	THERMAL	CAISO_Peaker1	Malaga1
CAISO NQC List	MALAGA_1_PL1X2	Fresno	Malaga Power Aggregate	THERMAL	CAISO_Peaker1	Malaga2
CAISO NQC List	VERNON_6_MALBRG	LA Basin	Malburg Generating Station	THERMAL	CAISO_CCGT2	Malburg
CAISO NQC List	MNDALY_7_UNIT 3	Big Creek-Ventura	MANDALAY GEN STA. UNIT 3	PEAKER	CAISO_Peaker2	Mandalay
CAISO NQC List	KELSO_2_UNITS	Bay Area	Mariposa Energy	PEAKER	CAISO_Peaker1	Mariposa
CAISO NQC List	KELSO_2_UNITS	Bay Area	Mariposa Energy	PEAKER	CAISO_Peaker1	Mariposa
CAISO NQC List	KELSO_2_UNITS	Bay Area	Mariposa Energy	PEAKER	CAISO_Peaker1	Mariposa
CAISO NQC List	KELSO_2_UNITS	Bay Area	Mariposa Energy	PEAKER	CAISO_Peaker1	Mariposa
CAISO NQC List	COCOPP_2_CTG1	Bay Area	Marsh Landing 1	THERMAL	CAISO_Peaker1	MarshLanding
CAISO NQC List	COCOPP_2_CTG2	Bay Area	Marsh Landing 2	THERMAL	CAISO_Peaker1	MarshLanding
CAISO NQC List	COCOPP_2_CTG3	Bay Area	Marsh Landing 3	THERMAL	CAISO_Peaker1	MarshLanding
CAISO NQC List	COCOPP_2_CTG4	Bay Area	Marsh Landing 4	THERMAL	CAISO_Peaker1	MarshLanding
CAISO NQC List	MNDALY_6_MCGRTH	Big Creek-Ventura	McGrath Beach Peaker	PEAKER	CAISO_Peaker1	McGrath
CAISO NQC List	MKTRCK_1_UNIT 1	CAISO System	MCKITTRICK LIMITED	COGENERATION	CAISO_Peaker2	McKittrick
CAISO NQC List	METEC_2_PL1X3	Bay Area	Metcalf Energy Center	THERMAL	CAISO_CCGT1	Metcalf
CAISO NQC List	PNCHPP_1_PL1X2	Fresno	Midway Peaking Aggregate	PEAKER	CAISO_Peaker2	Midway
CAISO NQC List	PNCHPP_1_PL1X2	Fresno	Midway Peaking Aggregate	PEAKER	CAISO_Peaker2	Midway
CAISO NQC List	SUNSET_2_UNITS	CAISO System	MIDWAY SUNSET COGENERATION PLANT	COGENERATION	CAISO_Peaker1	MidwaySunset
CAISO NQC List	SUNSET_2_UNITS	CAISO System	MIDWAY SUNSET COGENERATION PLANT	COGENERATION	CAISO_Peaker1	MidwaySunset
CAISO NQC List	SUNSET_2_UNITS	CAISO System	MIDWAY SUNSET COGENERATION PLANT	COGENERATION	CAISO_Peaker1	MidwaySunset
CAISO NQC List	MIRLOM_6_PEAKER	LA Basin	Mira Loma Peaker	PEAKER	CAISO_Peaker1	MiraLoma
CAISO NQC List	MRGT_7_UNITS	San Diego-IV	MIRAMAR COMBUSTION TURBINE AGGREGATE	PEAKER	CAISO_Peaker2	MiramarAgg
CAISO NQC List	MRGT_6_MMAREF	San Diego-IV	Miramar Energy Facility	PEAKER	CAISO_Peaker1	Miramar1

CAISO NQC List	MRGT_6_MEF2	San Diego-IV	Miramar Energy Facility II	PEAKER	CAISO_Peaker1	Miramar2
CAISO NQC List	ESCNDO_6_PL1X2	San Diego-IV	MMC Escondido Aggregate	THERMAL	CAISO_Peaker2	MMCEscondido
CAISO NQC List	MOSSLD_2_PSP1	Bay Area	MOSS LANDING POWER BLOCK 1	THERMAL	CAISO_CCGT1	MossLanding
CAISO NQC List	MOSSLD_2_PSP2	Bay Area	MOSS LANDING POWER BLOCK 2	THERMAL	CAISO_CCGT1	MossLanding
CAISO NQC List	SBERDO_2_PSP3	LA Basin	Mountainview Gen Sta. Unit 3	THERMAL	CAISO_CCGT1	Mountainview3
CAISO NQC List	SBERDO_2_PSP4	LA Basin	Mountainview Gen Sta. Unit 4	THERMAL	CAISO_CCGT1	Mountaiview4
CAISO NQC List	OAK C_7_UNIT 1	Bay Area	OAKLAND STATION C GT UNIT 1	PEAKER	CAISO_Peaker2	Oakland
CAISO NQC List	OAK C_7_UNIT 2	Bay Area	OAKLAND STATION C GT UNIT 2	PEAKER	CAISO_Peaker2	Oakland
CAISO NQC List	OAK C_7_UNIT 3	Bay Area	OAKLAND STATION C GT UNIT 3	PEAKER	CAISO_Peaker2	Oakland
CAISO NQC List	OGROVE_6_PL1X2	San Diego-IV	Orange Grove Energy Center	PEAKER	CAISO_Peaker2	OrangeGrove
CAISO NQC List	OGROVE_6_PL1X2	San Diego-IV	Orange Grove Energy Center	PEAKER	CAISO_Peaker2	OrangeGrove
CAISO NQC List	OTMESA_2_PL1X3	San Diego-IV	OTAY MESA ENERGY CENTER	THERMAL	CAISO_CCGT1	OtayMesa
CAISO NQC List	PALOMR_2_PL1X3	San Diego-IV	Palomar Energy Center	THERMAL	CAISO_CCGT1	Palomar
CAISO NQC List	PNCHEG_2_PL1X4	CAISO System	PANOCHE ENERGY CENTER (Aggregated)	PEAKER	CAISO_Peaker1	Panoche
CAISO NQC List	PNCHEG_2_PL1X4	CAISO System	PANOCHE ENERGY CENTER (Aggregated)	PEAKER	CAISO_Peaker1	Panoche
CAISO NQC List	PNCHEG_2_PL1X4	CAISO System	PANOCHE ENERGY CENTER (Aggregated)	PEAKER	CAISO_Peaker1	Panoche
CAISO NQC List	PNCHEG_2_PL1X4	CAISO System	PANOCHE ENERGY CENTER (Aggregated)	PEAKER	CAISO_Peaker1	Panoche
CAISO NQC List	PNOCHE_1_PL1X2	Fresno	Panoche Peaker	PEAKER	CAISO_Peaker2	PanochePeaker
CAISO NQC List	LEBECS_2_UNITS	Big Creek-Ventura	Pastoria Energy Facility	THERMAL	CAISO_CCGT1	Pastoria1
CAISO NQC List	LEBECS_2_UNITS	Big Creek-Ventura	Pastoria Energy Facility	THERMAL	CAISO_CCGT1	Pastoria2
CAISO Other	PIOPIC_2_CTG1	San Diego-IV	Pio Pico Unit 1	UNKNOWN	CAISO_Peaker1	PioPico
CAISO Other	PIOPIC_2_CTG2	San Diego-IV	Pio Pico Unit 2	UNKNOWN	CAISO_Peaker1	PioPico
CAISO Other	PIOPIC_2_CTG3	San Diego-IV	Pio Pico Unit 3	UNKNOWN	CAISO_Peaker1	PioPico
A.14-11-018	TBD	Big Creek-Ventura	Puente Power Project	UNKNOWN	CAISO_Peaker1	Puente
CAISO NQC List	SMPRIP_1_SMPSON	CAISO System	Ripon Cogeneration Unit 1	COGENERATION	CAISO_Peaker1	Ripon
CAISO NQC List	RVSIDE_6_RERCU1	LA Basin	Riverside Energy Res. Ctr Unit 1	COGENERATION	CAISO_Peaker1	Riverside
CAISO NQC List	RVSIDE_6_RERCU2	LA Basin	Riverside Energy Res. Ctr Unit 2	COGENERATION	CAISO_Peaker2	Riverside

CAISO NQC List	RVSIDE_2_RERCU3	LA Basin	Riverside Energy Res. Ctr Unit 3	PEAKER	CAISO_Peaker1	Riverside
CAISO NQC List	RVSIDE_2_RERCU4	LA Basin	Riverside Energy Res. Ctr Unit 4	PEAKER	CAISO_Peaker1	Riverside
CAISO NQC List	RVRVEW_1_UNITA1	Bay Area	Riverview Energy Center (GP Antioch)	PEAKER	CAISO_Peaker2	Riverview
CAISO NQC List	RUSCTY_2_UNITS	Bay Area	Russell City Energy Center	THERMAL	CAISO_CCGT2	Russel
CAISO NQC List	CSCCOG_1_UNIT 1	Bay Area	SANTA CLARA CO-GEN	COGENERATION	CAISO_Peaker1	SantaClara
CAISO NQC List	CSCCOG_1_UNIT 1	Bay Area	SANTA CLARA CO-GEN	COGENERATION	CAISO_Peaker1	SantaClara
CAISO NQC List	SENTNL_2_CTG1	LA Basin	Sentinel Unit 1	THERMAL	CAISO_Peaker1	Sentinel
CAISO NQC List	SENTNL_2_CTG2	LA Basin	Sentinel Unit 2	THERMAL	CAISO_Peaker1	Sentinel
CAISO NQC List	SENTNL_2_CTG3	LA Basin	Sentinel Unit 3	THERMAL	CAISO_Peaker1	Sentinel
CAISO NQC List	SENTNL_2_CTG4	LA Basin	Sentinel Unit 4	THERMAL	CAISO_Peaker1	Sentinel
CAISO NQC List	SENTNL_2_CTG5	LA Basin	Sentinel Unit 5	THERMAL	CAISO_Peaker1	Sentinel
CAISO NQC List	SENTNL_2_CTG6	LA Basin	Sentinel Unit 6	THERMAL	CAISO_Peaker1	Sentinel
CAISO NQC List	SENTNL_2_CTG7	LA Basin	Sentinel Unit 7	THERMAL	CAISO_Peaker1	Sentinel
CAISO NQC List	SENTNL_2_CTG8	LA Basin	Sentinel Unit 8	THERMAL	CAISO_Peaker1	Sentinel
CAISO NQC List	RVSIDE_6_SPRING	LA Basin	SPRINGS GENERATION PROJECT AGGREGATE	PEAKER	CAISO_Peaker1	Springs
CAISO NQC List	RVSIDE_6_SPRING	LA Basin	SPRINGS GENERATION PROJECT AGGREGATE	PEAKER	CAISO_Peaker1	Springs
CAISO NQC List	RVSIDE_6_SPRING	LA Basin	SPRINGS GENERATION PROJECT AGGREGATE	PEAKER	CAISO_Peaker1	Springs
CAISO NQC List	RVSIDE_6_SPRING	LA Basin	SPRINGS GENERATION PROJECT AGGREGATE	PEAKER	CAISO_Peaker1	Springs
D.15-11-04	TBD	LA Basin	Stanton Peaker Facility	UNKNOWN	CAISO_Peaker1	Stanton
CAISO NQC List	SUNRIS_2_PL1X3	CAISO System	Sunrise Power Project AGGREGATE II	THERMAL	CAISO_CCGT1	Sunrise
CAISO NQC List	SUTTER_2_PL1X3	CAISO System	SUTTER POWER PLANT AGGREGATE	PSEUDO TIE	CAISO_CCGT1	Sutter
CAISO NQC List	SYCAMR_2_UNIT 2	Big Creek-Ventura	Sycamore Cogeneration Unit 2	COGENERATION	CAISO_Peaker1	Sycamore
CAISO NQC List	SYCAMR_2_UNIT 4	Big Creek-Ventura	Sycamore Cogeneration Unit 4	COGENERATION	CAISO_Peaker1	Sycamore
CAISO NQC List	TERMEX_2_PL1X3	San Diego-IV	TDM	THERMAL	CAISO_CCGT1	TermoMexi
CAISO NQC List	SCHLTE_1_PL1X3	Stockton	Tracy Combined Cycle Power Plant	PEAKER	CAISO_CCGT2	Tracy
CAISO NQC List	WALCRK_2_CTG1	LA Basin	Walnut Creek Energy Park Unit 1	THERMAL	CAISO_Peaker1	WalnutCreek

CAISO NQC List	WALCRK_2_CTG2	LA Basin	Walnut Creek Energy Park Unit 2	THERMAL	CAISO_Peaker1	WalnutCreek
CAISO NQC List	WALCRK_2_CTG3	LA Basin	Walnut Creek Energy Park Unit 3	THERMAL	CAISO_Peaker1	WalnutCreek
CAISO NQC List	WALCRK_2_CTG4	LA Basin	Walnut Creek Energy Park Unit 4	THERMAL	CAISO_Peaker1	WalnutCreek
CAISO NQC List	WALCRK_2_CTG5	LA Basin	Walnut Creek Energy Park Unit 5	THERMAL	CAISO_Peaker1	WalnutCreek
CAISO NQC List	VESTAL_2_WELLHD	Big Creek-Ventura	Wellhead Power Delano	THERMAL	CAISO_Peaker1	Wellhead
CAISO NQC List	WOLFSK_1_UNITA1	CAISO System	Wolfskill Energy Center, Unit #1	PEAKER	CAISO_Peaker2	Wolfskill
CAISO NQC List	YUBACT_6_UNITA1	Sierra	Yuba City Energy Center (Calpine)	PEAKER	CAISO_Peaker2	YubaCity

SOURCE: E3 2017B.

TABLE A2. **Operating Characteristics and Capacity-Contribution Characteristics of Each GridPath Plant**

GridPath Plant	RESOLVE Fleet Type	Heat Rate at Pmin (MMBtu /MWh)	Heat Rate at Pmax (MMBtu /MWh)	Minimum Stable Level (Fraction of Pmax)	Startup/ Shutdown Cost ($/MW)	Ramp Up/Down Rate (% Pmax/hr)	Unit Size (MW)	Number of Units	Total Capacity (MW)	NQC Fraction	LCR Area
Agnews	CAISO_CCGT1	7.7	7.7	0.99	41.87	41%	28	1	28	1	Bay_Area
AguaMansa	CAISO_Peaker2	13.6	10.7	0.3	16.96	744%	43	1	43	1	LA_Basin
Alameda	CAISO_Peaker2	11.6	10.4	0.45	16.96	630%	25	2	49	0.98	Bay_Area
Alamitos	CAISO_CCGT1	10.2	6.8	0.2	25	60%	640	1	640	1	LA_Basin
Anaheim	CAISO_Peaker2	13.8	12.2	0.45	16.96	325%	43	1	43	0.95	LA_Basin
BadgerCreek	CAISO_Peaker1	8.8	8.8	0.99	54.6	156%	47	1	47	0.93	Kern
Barre	CAISO_Peaker1	10.4	10	0.6	16.96	653%	47	1	47	1	LA_Basin
BearMountain	CAISO_Peaker2	12.1	12	0.99	16.96	250%	47	1	47	0.99	Kern
Blythe	CAISO_CCGT2	7.9	7	0.59	44.66	89%	494	1	494	0.99	CAISO_System

Border	CAISO_Peaker2	11.4	10.3	0.45	54.6	320%	51	1	51	0.94	San_Diego
Enterprise	CAISO_Peaker2	11.4	10.3	0.45	54.6	341%	48	1	48	1	San_Diego
CalPeakPanoche	CAISO_Peaker2	11.5	10.3	0.45	16.96	327%	52	1	52	0.92	Fresno
VacaDixon	CAISO_Peaker2	12.6	10.3	0.3	16.96	330%	51	1	51	0.95	CAISO_System
Canyon	CAISO_Peaker1	13.3	8.9	0.45	16.96	646%	49	4	198	0.99	LA_Basin
Carson	CAISO_CCGT1	7.7	7.7	0.99	41.87	45%	48	1	48	1	LA_Basin
Center	CAISO_Peaker1	10.4	10	0.6	16.96	653%	47	1	47	1	LA_Basin
Century	CAISO_Peaker1	13.4	8.6	0.45	16.96	670%	10	4	41	0.87	LA_Basin
ChalkCliff	CAISO_Peaker2	12.1	12	0.99	16.96	174%	47	1	47	0.97	CAISO_System
ChulaVista	CAISO_Peaker2	17.2	12.9	0.3	16.96	363%	36	1	36	1	San_Diego
Clearwater	CAISO_CCGT2	9.9	8.8	0.45	41.87	306%	28	1	28	1	LA_Basin
Colusa	CAISO_CCGT1	7.3	6.9	0.57	44.79	49%	641	1	641	0.94	CAISO_System
Creed	CAISO_Peaker2	11.5	10.4	0.45	16.96	321%	48	1	48	1	Bay_Area
Cuyamaca	CAISO_Peaker1	17.6	9.6	0.3	5	375%	45	1	45	1	San_Diego
Delta	CAISO_CCGT1	7.2	6.9	0.66	51.37	52%	880	1	880	0.92	Bay_Area
DesertStar	CAISO_CCGT1	7.3	6.9	0.61	46.32	67%	495	1	495	0.85	CAISO_System
DonaldVonRaesfeld	CAISO_CCGT2	8.5	7.7	0.55	41.87	97%	148	1	148	1	Bay_Area
HighSierra	CAISO_Peaker2	11.4	11.3	0.99	16.96	325%	26	2	52	1	Kern
Drews	CAISO_Peaker1	13.4	8.6	0.45	16.96	643%	10	4	41	0.87	LA_Basin
ElCajonGT	CAISO_Peaker2	15.4	12.7	0.48	87.35	1707%	16	1	16	0.98	San_Diego
ElCajonEC	CAISO_Peaker2	11.7	10.4	0.45	54.6	321%	48	1	48	1	San_Diego
ElSegundo	CAISO_CCGT2	7.7	7	0.55	41.87	48%	263	2	527	1	LA_Basin
ElkHills	CAISO_CCGT1	7.3	6.9	0.59	44.75	29%	552	1	552	0.77	CAISO_System

Ellwood	CAISO_Peaker2	18.3	15	0.3	54.6	143%	54	1	54	1	Big_Creek_Ventura
Carlsbad	CAISO_Peaker1	17.6	9.6	0.3	5	97%	500	1	500	1	San_Diego
FeatherRiver	CAISO_Peaker1	13.3	8.9	0.45	16.96	667%	46	1	46	0.97	Sierra
FresnoCogen	CAISO_CCGT2	9.3	8.4	0.55	41.87	16%	51	1	51	1	Fresno
FresnoPeaker	CAISO_Peaker2	11.4	10.4	0.45	16.96	705%	23	1	23	0.88	Fresno
Gateway	CAISO_CCGT1	7.4	6.9	0.54	46.01	47%	563	1	563	0.99	Bay_Area
Gianera	CAISO_Peaker2	11.6	10.4	0.45	16.96	646%	25	2	50	0.97	Bay_Area
GilroyCogen	CAISO_CCGT1	6.9	6.4	0.5	41.87	37%	120	1	120	0.88	Bay_Area
GilroyPeaker	CAISO_Peaker2	16.6	12.9	0.3	16.96	160%	47	3	142	1	Bay_Area
GlenArm12	CAISO_Peaker2	48.9	18.6	0.3	16.96	523%	22	2	44	1	LA_Basin
GlenArm34	CAISO_Peaker1	11.6	9.5	0.3	16.96	169%	44	2	87	1	LA_Basin
GlenArm5	CAISO_Peaker2	18.6	9.7	0.3	11.3	113%	65	1	65	1	LA_Basin
GooseHaven	CAISO_Peaker2	16.6	12.9	0.3	16.96	321%	48	1	48	1	Bay_Area
Grapeland	CAISO_Peaker1	10.4	10	0.45	16.96	653%	46	1	46	1	LA_Basin
Henrietta	CAISO_Peaker2	11.4	10.3	0.45	16.96	163%	50	2	99	0.91	Fresno
HGonzalez	CAISO_Peaker1	8.4	7.9	0.3	16.96	1030%	6	2	12	1	LA_Basin
Hanford	CAISO_Peaker2	11.6	10.4	0.45	16.96	167%	49	2	98	0.86	Fresno
Harbor	CAISO_CCGT2	8.5	7.7	0.55	41.87	55%	109	1	109	0.92	LA_Basin
HighDesert	CAISO_CCGT1	7.4	6.9	0.55	45.8	34%	830	1	830	0.9	CAISO_System
LongBeach	CAISO_Peaker2	13.6	13.1	0.6	16.96	457%	65	4	260	1	LA_Basin
HuntingtonBeach	CAISO_CCGT1	10.2	6.8	0.2	25	60%	644	1	644	1	LA_Basin
Indigo1	CAISO_Peaker2	13.4	12.2	0.45	16.96	356%	44	1	44	0.95	LA_Basin
Indigo23	CAISO_Peaker2	26.4	16.2	0.45	16.96	356%	44	2	88	0.95	LA_Basin
InlandEmpire	CAISO_CCGT1	7	6.5	0.6	45.71	70%	371	2	743	0.9	LA_Basin

Kearny	CAISO_Peaker2	17.6	9.6	0.3	5	318%	61	1	61	1	San_Diego
KernRiver	CAISO_Peaker1	5.7	5.6	0.77	54.6	66%	80	4	319	0.96	Big_Creek_Ventura
KingCity	CAISO_Peaker2	11.6	10.4	0.45	16.96	160%	45	1	45	1	CAISO_System
LaPaloma	CAISO_CCGT1	7.3	6.9	0.64	44.35	151%	259	4	1036	1	CAISO_System
Lambie	CAISO_Peaker2	16.6	12.9	0.3	16.96	962%	48	1	48	1	Bay_Area
Larkspur	CAISO_Peaker1	10.8	9.6	0.45	54.6	356%	47	2	94	0.98	San_Diego
LiveOak	CAISO_Peaker2	11.4	11.3	0.99	16.96	174%	47	1	47	0.94	Kern
LodiCC	CAISO_CCGT1	5.9	7.1	0.45	41.87	48%	303	1	303	0.93	Sierra
LodiPeaker	CAISO_Peaker2	11.6	10.4	0.45	16.96	630%	25	1	25	0.9	Stockton
LosEsteros	CAISO_CCGT2	8.2	7.3	0.5	41.87	47%	294	1	294	1.03	Bay_Area
LosMedanos	CAISO_CCGT1	7.2	6.9	0.66	48.23	81%	561	1	561	0.99	Bay_Area
LaRosita1	CAISO_CCGT2	7.9	7.1	0.55	41.87	15%	180	1	180	0.92	San_Diego
LaRosita2	CAISO_CCGT2	7.9	7.1	0.55	41.87	45%	322	1	322	1	San_Diego
Malaga1	CAISO_Peaker1	10.8	9.7	0.45	16.96	333%	48	1	48	1	Fresno
Malaga2	CAISO_Peaker1	9	8.1	0.45	16.96	333%	48	1	48	1	Fresno
Malburg	CAISO_CCGT2	7.8	7.7	0.61	46.5	85%	134	1	134	1	LA_Basin
Mandalay	CAISO_Peaker2	19.5	15.9	0.3	54.6	92%	130	1	130	1	Big_Creek_Ventura
Mariposa	CAISO_Peaker1	13.3	8.9	0.45	16.96	641%	49	4	196	0.97	Bay_Area
MarshLanding	CAISO_Peaker1	13.3	9.3	0.45	54.6	178%	205	4	820	0.98	Bay_Area
McGrath	CAISO_Peaker1	10.4	10	0.6	16.96	415%	47	1	47	1	Big_Creek_Ventura
McKittrick	CAISO_Peaker2	15.3	15.2	0.99	54.6	276%	47	1	47	0.95	CAISO_System
Metcalf	CAISO_CCGT1	7.3	6.9	0.6	48.77	62%	593	1	593	0.96	Bay_Area
Midway	CAISO_Peaker2	15.1	10.2	0.45	16.96	343%	60	2	120	0.93	Fresno

MidwaySunset	CAISO_Peaker1	5.6	5.6	0.99	54.6	192%	83	3	248	0.95	CAISO_System
MiraLoma	CAISO_Peaker1	10.4	10	0.6	16.96	653%	46	1	46	1	LA_Basin
MiramarAgg	CAISO_Peaker2	17.6	9.6	0.3	5	428%	36	1	36	1	San_Diego
Miramar1	CAISO_Peaker1	10.6	9.6	0.45	54.6	197%	48	1	48	1	San_Diego
Miramar2	CAISO_Peaker1	15.4	9.4	0.45	54.6	323%	48	1	48	1	San_Diego
Mountainview3	CAISO_CCGT1	7.2	6.9	0.53	41.49	41%	525	1	525	0.92	LA_Basin
Mountaiview4	CAISO_CCGT1	7.1	6.8	0.64	50.36	41%	525	1	525	0.92	LA_Basin
Oakland	CAISO_Peaker2	15.8	12.6	0.3	15.9	148%	55	3	165	1	Bay_Area
OrangeGrove	CAISO_Peaker2	26.4	16.2	0.45	54.6	640%	48	2	96	1	San_Diego
OtayMesa	CAISO_CCGT1	7.2	7	0.55	47.25	55%	604	1	604	1	San_Diego
Palomar	CAISO_CCGT1	7.4	6.8	0.53	44.33	39%	575	1	575	0.98	San_Diego
Panoche	CAISO_Peaker1	13.3	9.4	0.45	54.6	370%	100	4	401	0.95	CAISO_System
PanochePeaker	CAISO_Peaker2	11.6	10.4	0.45	16.96	327%	50	1	50	1	Fresno
Pastoria1	CAISO_CCGT1	7.3	6.9	0.63	45.36	85%	400	1	400	0.94	Big_Creek_Ventura
Pastoria2	CAISO_CCGT1	7.3	6.9	0.62	44.46	169%	400	1	400	0.94	Big_Creek_Ventura
PioPico	CAISO_Peaker1	17.6	9.6	0.3	5	237%	103	3	308	1	San_Diego
Ripon	CAISO_Peaker1	3	3.1	0.99	54.6	141%	46	1	46	0.99	CAISO_System
Riverside	CAISO_Peaker1	14.6	9.8	0.45	16.96	653%	49	4	195	0.99	LA_Basin
Riverview	CAISO_Peaker2	11.6	10.4	0.45	16.96	160%	49	1	49	1	Bay_Area
Russel	CAISO_CCGT2	7.2	7.2	0.4	41.87	27%	620	1	620	0.96	Bay_Area
SantaClara	CAISO_Peaker1	5.6	6.7	0.45	16.96	1538%	4	2	7	0.86	Bay_Area
Sentinel	CAISO_Peaker1	13.3	9.4	0.45	54.6	301%	92	8	736	0.99	LA_Basin
Springs	CAISO_Peaker1	13.4	8.6	0.45	16.96	1455%	9	4	36	1	LA_Basin
Stanton	CAISO_Peaker1	17.6	9.6	0.3	5	243%	98	1	98	1	LA_Basin

Sunrise	CAISO_CCGT1	7.4	6.9	0.56	46.51	50%	586	1	586	1	CAISO_System
Sutter	CAISO_CCGT1	7.3	6.9	0.55	49.14	74%	525	1	525	0.95	CAISO_System
Sycamore	CAISO_Peaker1	5.6	5.6	0.99	54.6	51%	85	2	170	1	Big_Creek_Ventura
TermoMexi	CAISO_CCGT1	7.6	6.9	0.55	41.87	22%	625	1	625	0.95	San_Diego
Tracy	CAISO_CCGT2	9.2	8.3	0.55	41.87	44%	332	1	332	0.9	Stockton
WalnutCreek	CAISO_Peaker1	13.3	9.3	0.45	54.6	320%	97	5	483	0.99	LA_Basin
Wellhead	CAISO_Peaker1	13.3	8.9	0.45	16.96	735%	49	1	49	1	Big_Creek_Ventura
Wolfskill	CAISO_Peaker2	11.6	10.4	0.45	16.96	160%	47	1	47	0.98	CAISO_System
YubaCity	CAISO_Peaker2	11.6	10.4	0.45	16.96	321%	46	1	46	1	Sierra
DoubleC	CAISO_Peaker2	11.4	11.3	0.99	16.96	329%	26	2	52	0.99	Kern
LodiSTIG	CAISO_Peaker2	11.6	10.4	0.45	16.96	156%	50	1	50	0.99	Sierra

SOURCE: E3 2017B.