Grid to Market

EE379K/EE394V
Smart Grid & Residential Electricity from a Market Perspective

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Lecture Outline

Smart grid from a market perspective

Pricing: day-ahead and real-time

Seasonal and time-of-day influences on pricing

Economics of renewables

Residential

Methodology Notes

Unless explicitly stated otherwise –

- All wholesale market examples are from ERCOT
- Presented data are owned and copyrighted by Grid to Market LLC
- Underlying wholesale market data used by Grid to Market to develop presented information are from ERCOT
- Graphics and analytics are from system-wide (load, generation) and bus average (price) data
- Averages are simple averages rather than weighted averages

The data in the homework questions are representative data drawn from actual market data.

Smart Grid
from a Market Perspective

Smart Grid Real-time Info *enables*

Sophisticated real-time power management

Introduction of sophisticated ***price signals*** – both real-time and future

Electric wholesale markets can now operate in a fashion similar to stock exchanges

Key Market Participant Categories

In ERCOT, most utilities are not vertically integrated

Buyers of wholesale power

- Retail utilities (private, coop, public)
- Re-sellers / arbitragers

Sellers of wholesale power

- Generation owners (power plants, wind, solar)
- Re-sellers / arbitragers

Buyer questions include

How much electricity do I need to buy tomorrow and into the future?

Is it more advantageous to buy in –

- day-ahead market?
- real-time market?

If I lock in supply through a power-purchase agreement, how much should I pay?

Seller questions include

Producers

- Is building more generation capacity a good investment?
- Should I shut down any of my existing capacity?

Re-sellers

- Is it profitable to buy some electricity on the day-ahead market and re-sell it tomorrow on the real-time market?

Pricing:
Day-ahead and Real-time

General pricing structure

Prices are per megawatt hour (MWh)

Prices are set for each electrical bus (or a specified group of electrical buses)

Two types of wholesale pricing

Day-ahead

- Price per MWh for each hour of day
- Entire day of hourly prices published typically around midday the day before

Real-time

- Price per MWh for each 5-minute interval
- Updated every 5 minutes to show latest 5-minute interval along with indicative prices for next 55 minutes

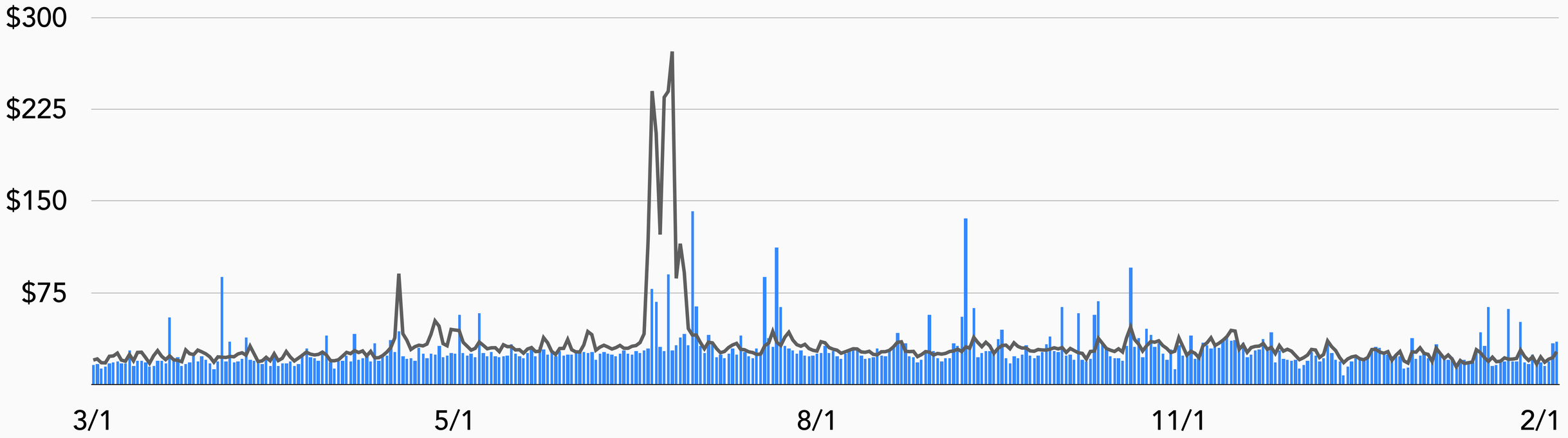
2018-19 Day-ahead Market

Avg. price per hour $32.14

Daily simple average price per hour (March 1, 2018 - Feb. 28, 2019):
Day-ahead Market

2018-19 Real-time Market

Avg. price per hour $27.92

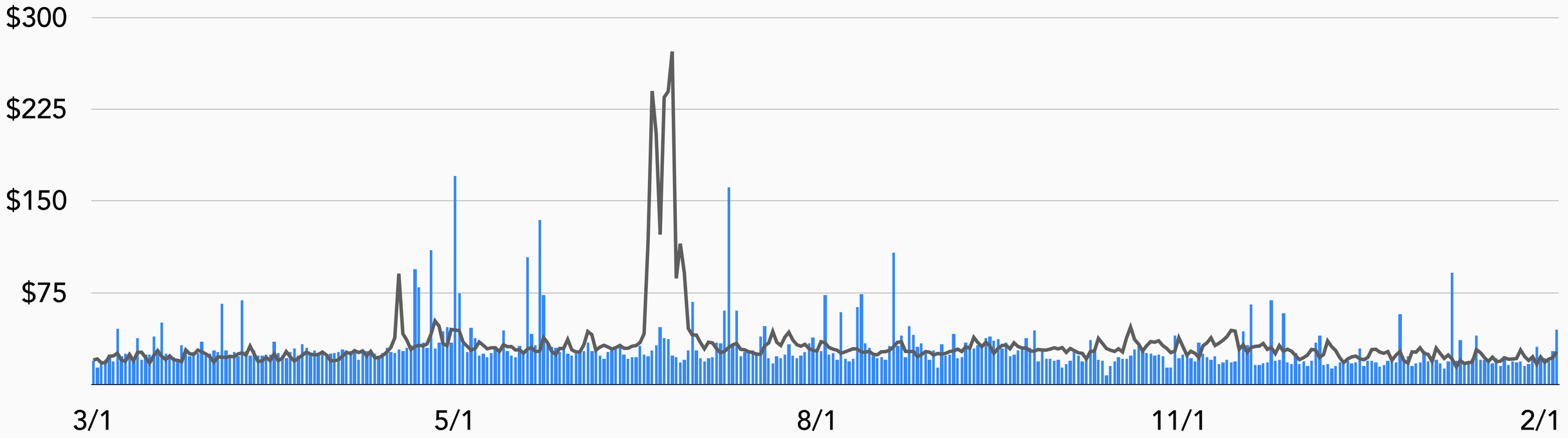


Daily simple average settlement point price per hour (March 1, 2018 - Feb. 28, 2019)

Real-time Market compared to **Day-ahead Market**

2018-19 Real-time Market

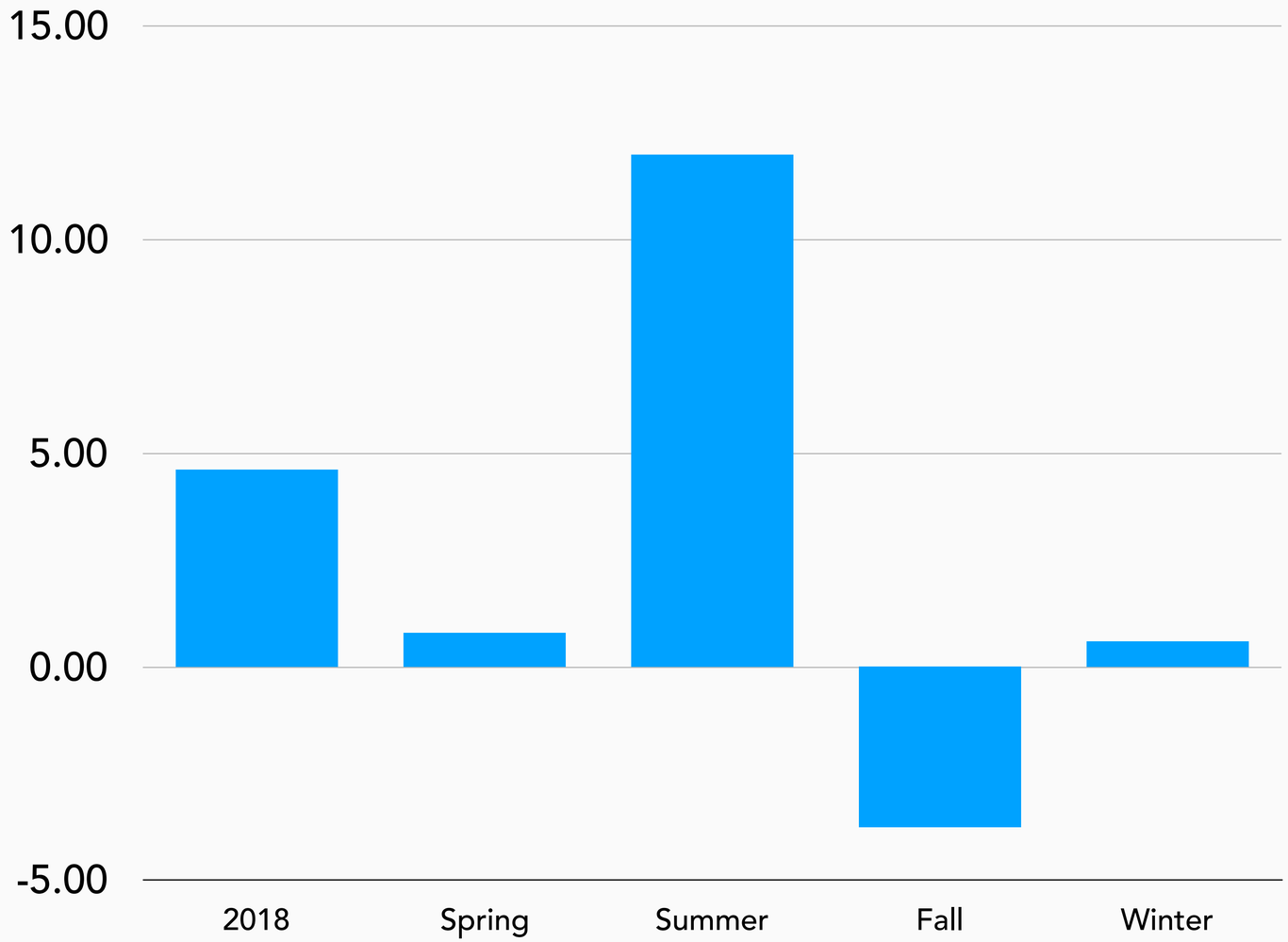
Avg. price per MWh $30.33



Daily weighted average price per megawatt hour (March 1, 2018 - Feb. 28, 2019)
Real-time Market compared to **Day-ahead Market** (simple average price per hour)

Seasonal and time-of-day influences on pricing

	Day-ahead	Real-time	Premium ($)
2018	**32.95**	**28.33**	**4.62**
Spring 2018	23.44	22.61	0.82
Summer	42.79	30.79	12.01
Fall	29.35	33.11	-3.76
Winter 18-19	26.81	26.22	0.59

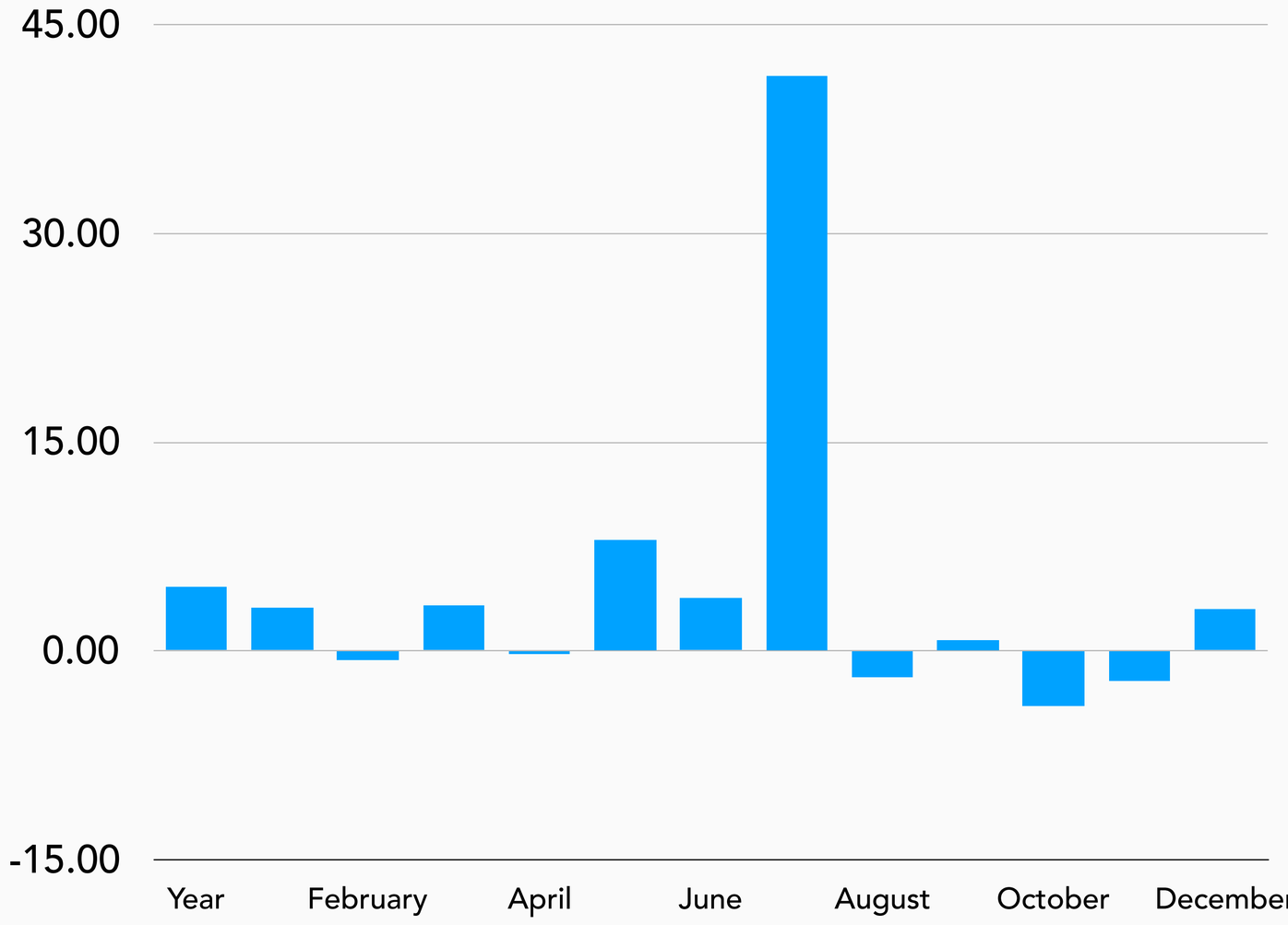


Price premium by ERCOT seasons (2018-19)

Premiums are calculated by subtracting the real-time price from the day-ahead price. Therefore, if a premium is positive, the day-ahead price was higher than the real-time price for that interval.

2018	Day-ahead	Real-time	Premium ($)
Year	**32.95**	**28.33**	**4.62**
January	33.54	30.44	3.10
February	21.85	22.53	-0.68
March	22.56	19.31	3.25
April	23.14	23.35	-0.21
May	34.01	26.06	7.95
June	29.97	26.20	3.77
July	78.86	37.52	41.34
August	31.66	33.52	-1.85
September	27.18	26.38	0.80
October	29.96	33.93	-3.97
November	30.63	32.83	-2.19
December	30.27	27.22	3.05

Price premium by month

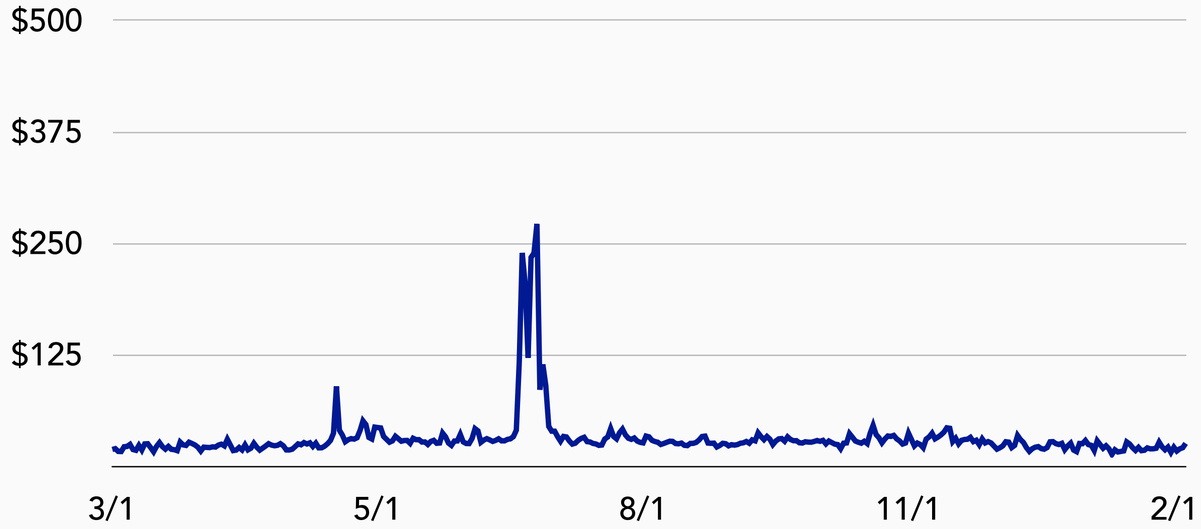


Segment markets by time of day

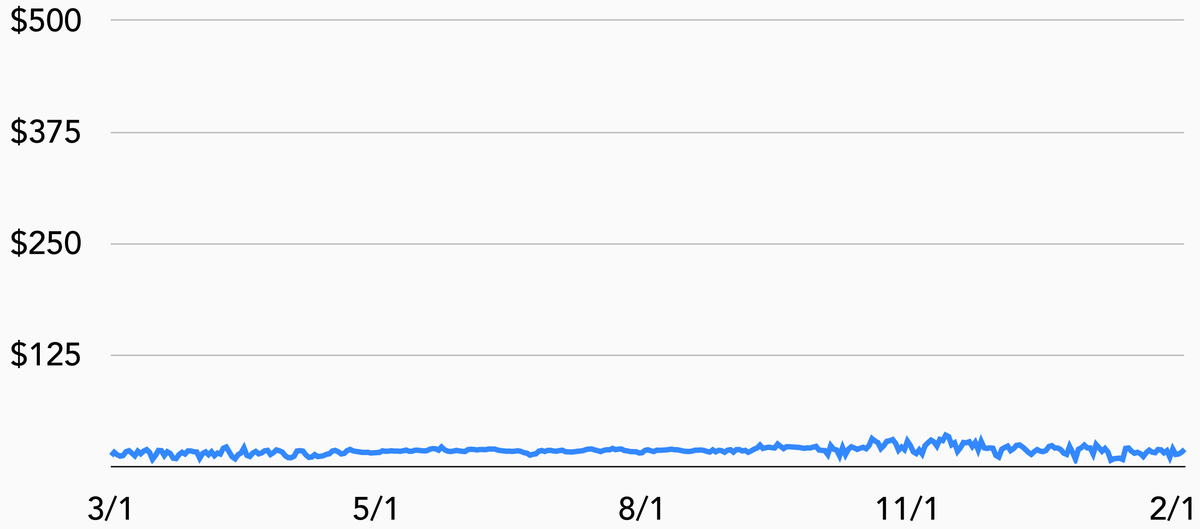
Night	11 pm - 6 am
Morning Peak	6 am - 9 am
Mid-morning	9 am - 12 pm
Early afternoon	12 pm - 3 pm
Afternoon Peak	3 pm - 7 pm
Evening	7 pm - 11 pm

Day-ahead Market by time class

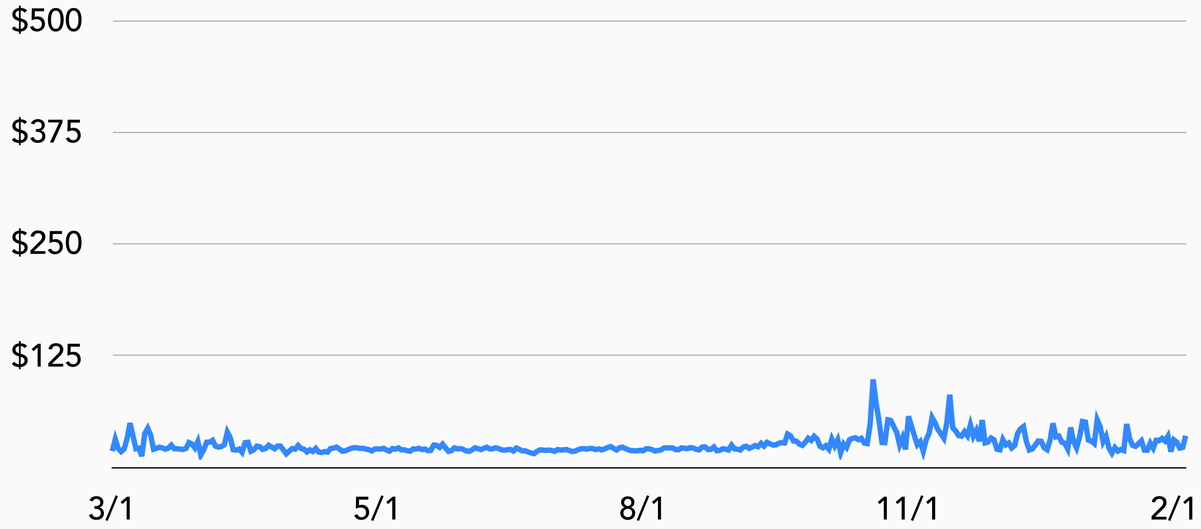
Mar 1, 2018 - Feb. 28, 2019



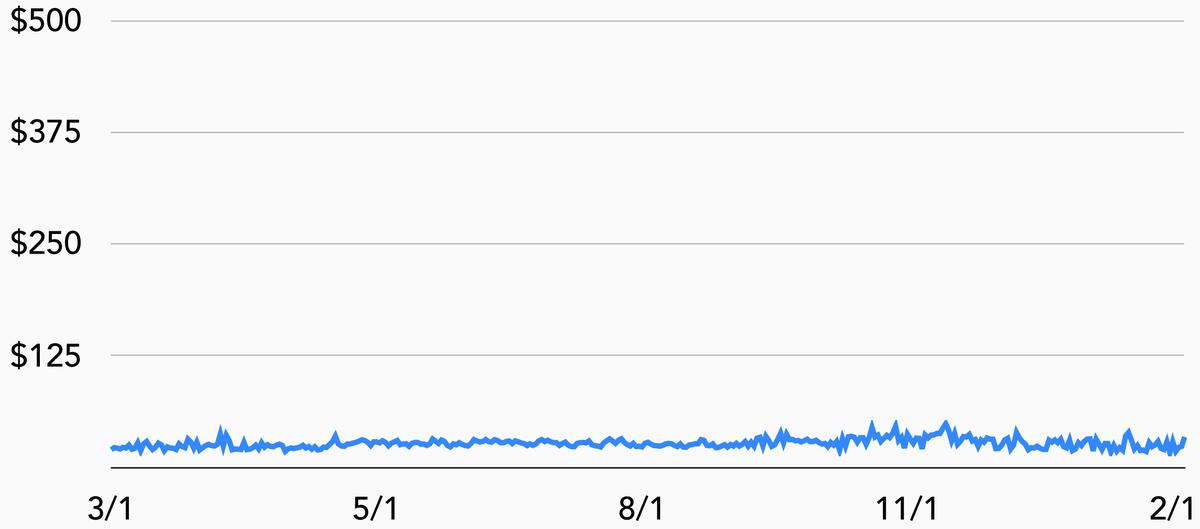
All Day avg. price per hour $ 32.14



Night avg. price $ 18.90

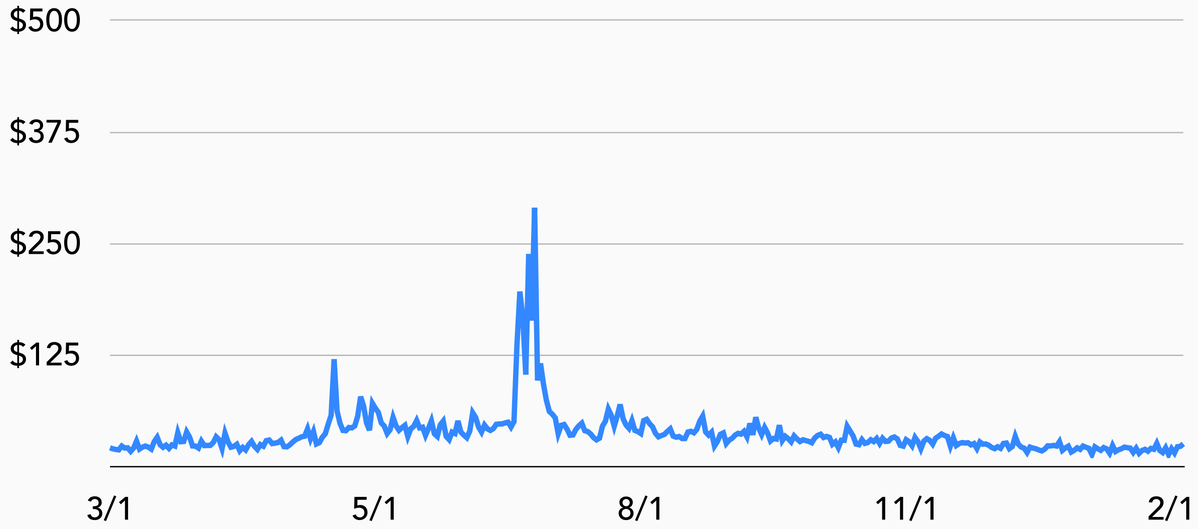


Morning peak avg. price $ 25.83

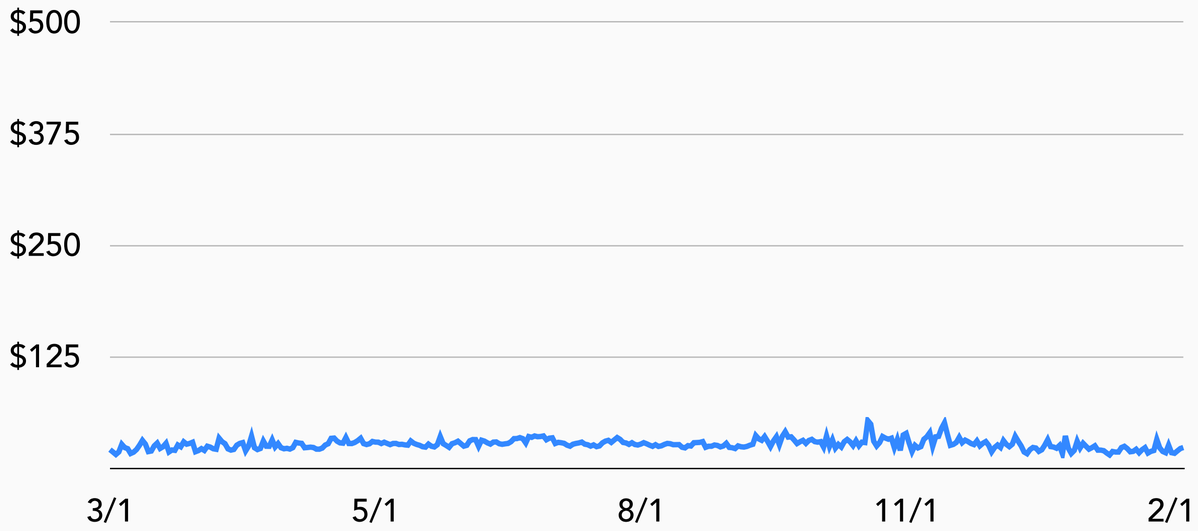


Mid-morning avg. price $ 26.94

Real-time Market by time class (*cont'd*)



Early afternoon avg. price $ 37.30

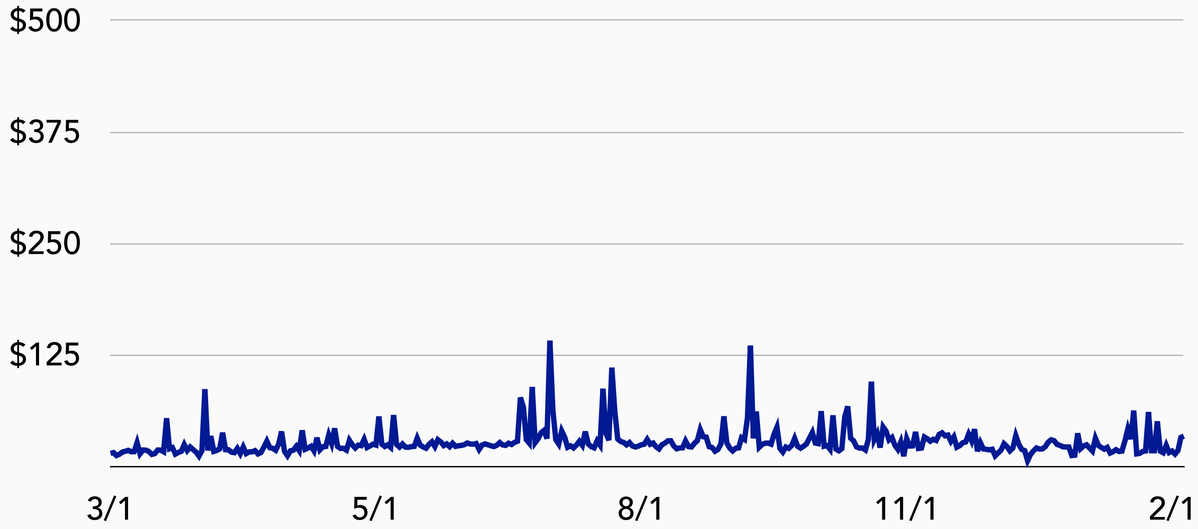


Evening avg. price $ 27.88

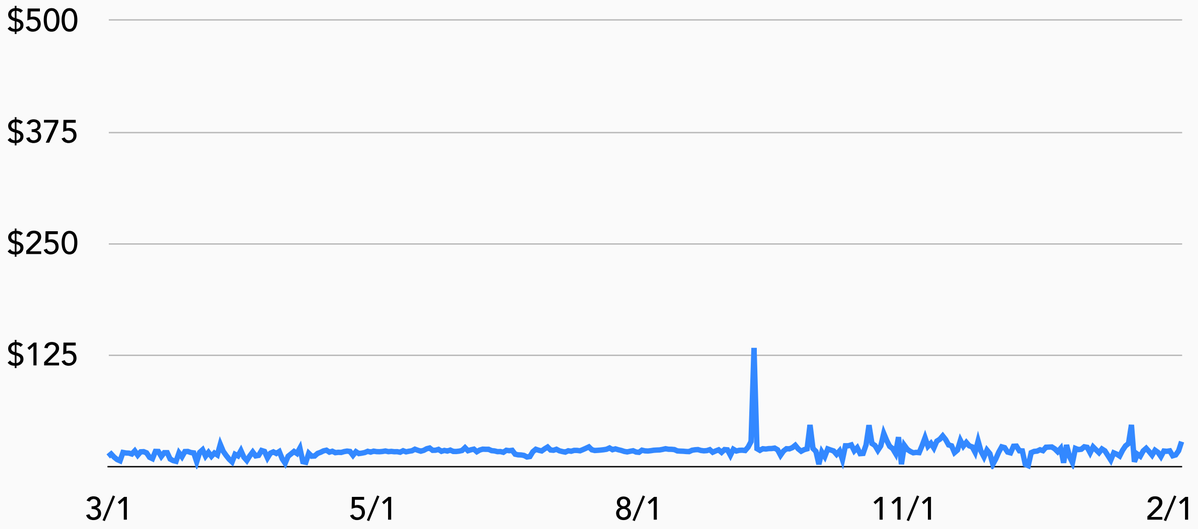
Afternoon peak avg. price $ 64.32

Real-time Market by time class

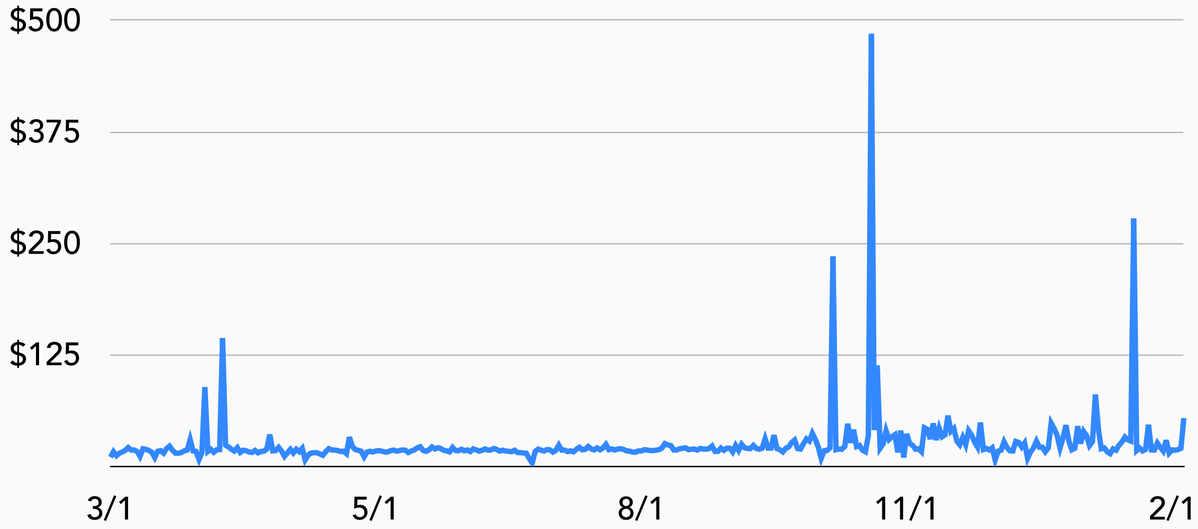
Mar 1, 2018 - Feb. 28, 2019



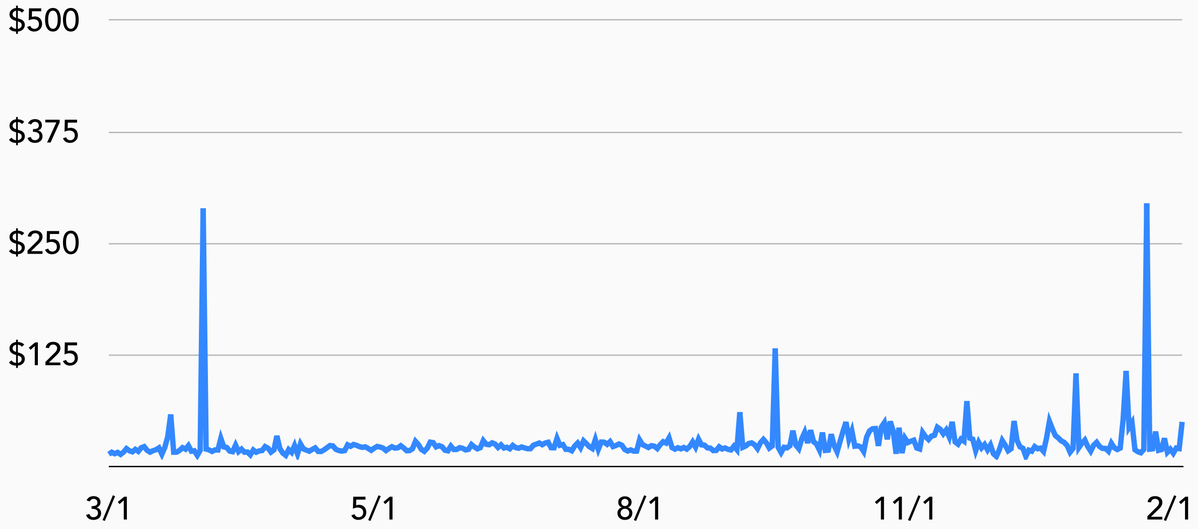
All Day avg. price per hour $ 27.92



Night avg. price $ 18.56



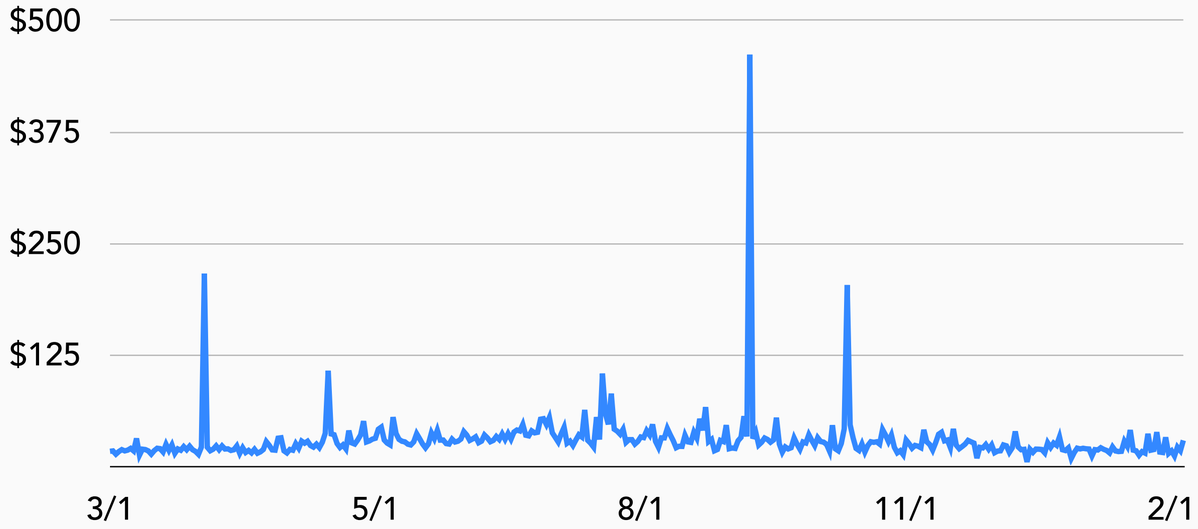
Morning peak avg. price $ 25.65



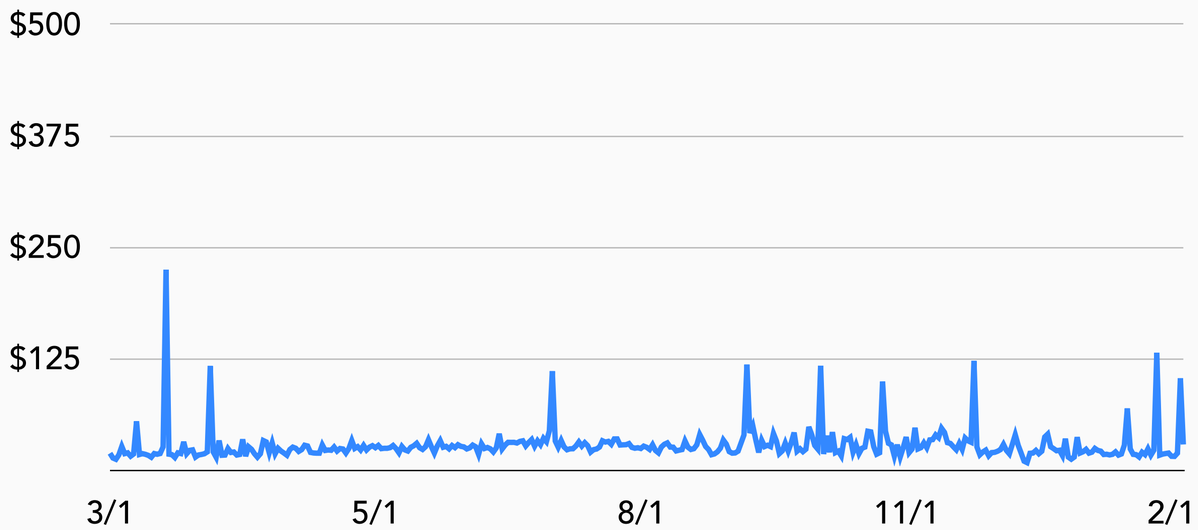
Mid-morning avg. price $ 26.87

Real-time Market by time class (*cont'd*)

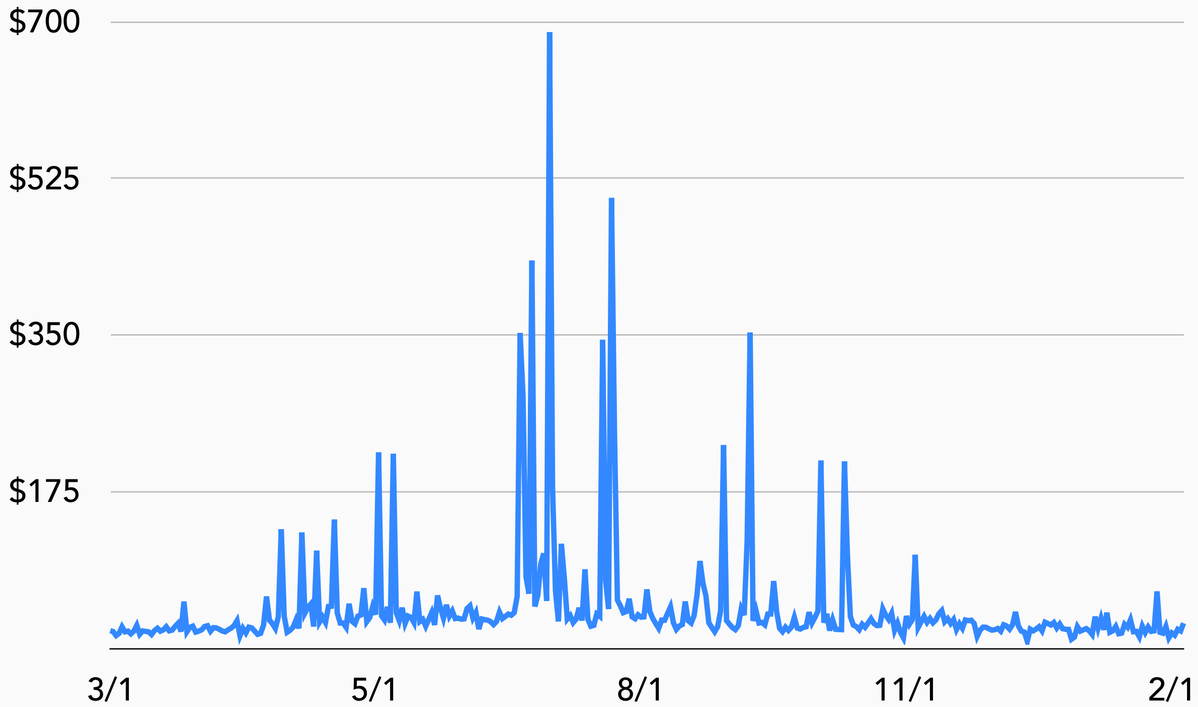
Mar 1, 2018 - Feb. 28, 2019



Early afternoon avg. price $ 30.60

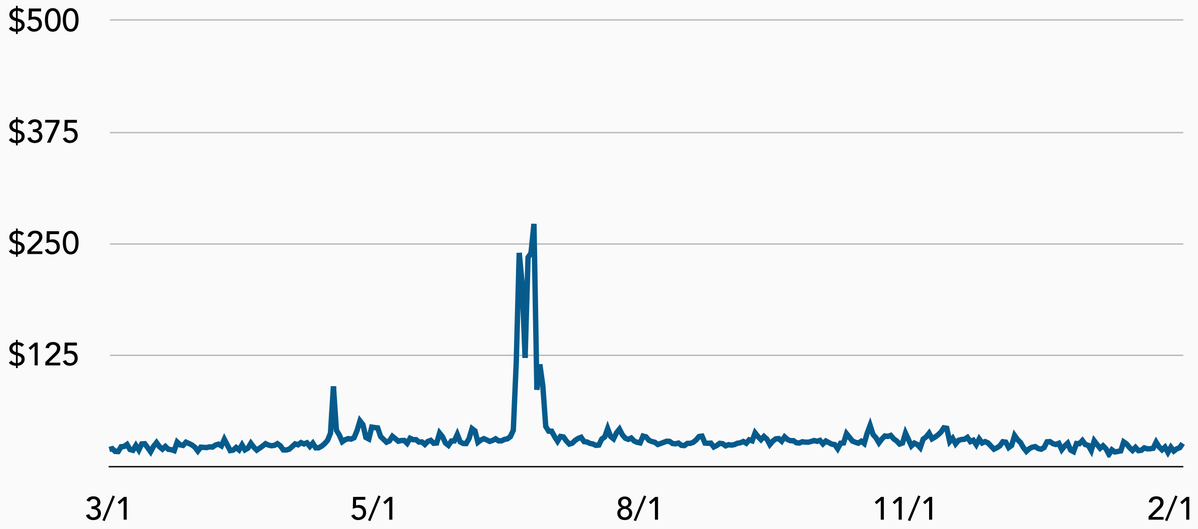


Evening avg. price $ 28.89

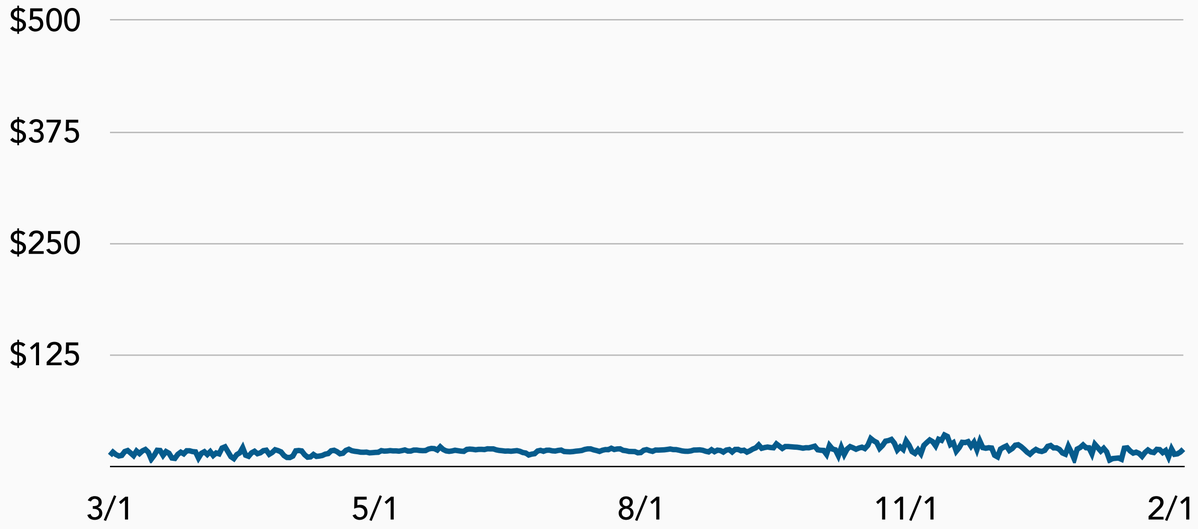


Afternoon peak avg. price $ 43.82

Day-ahead Market by time class (2018-19)

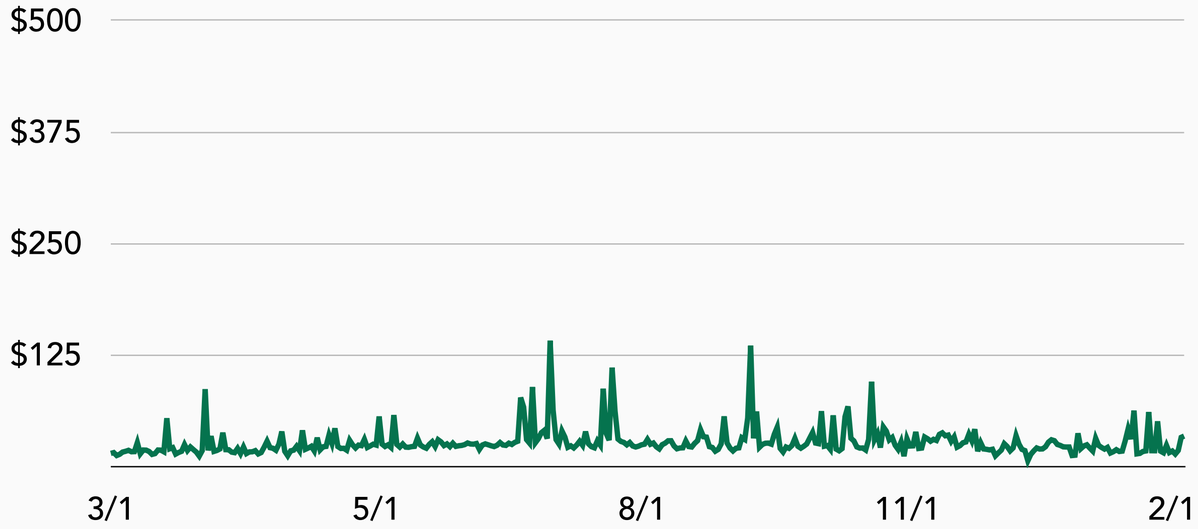


All Day avg. price per hour $ 32.14

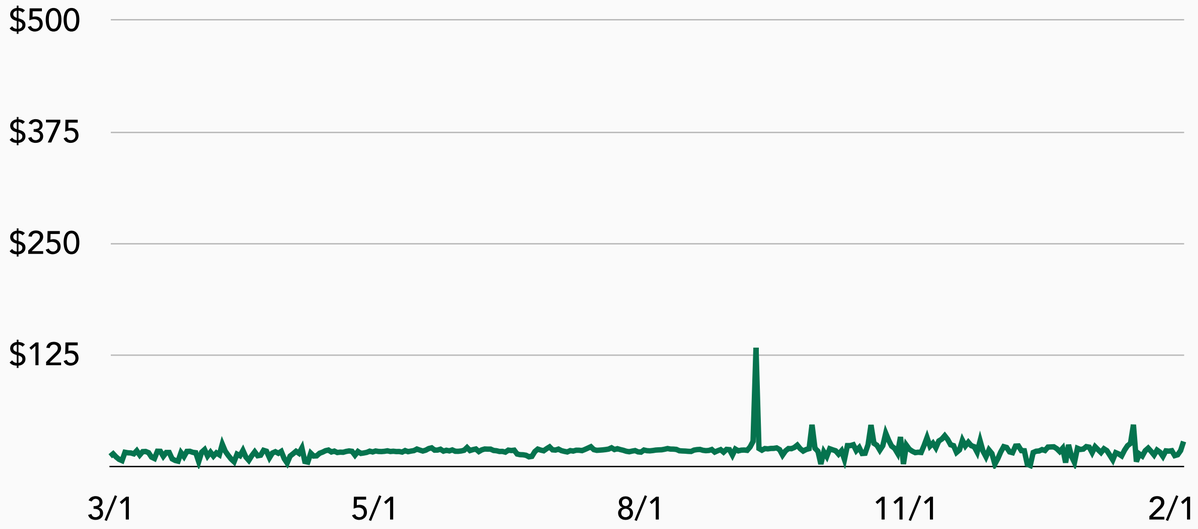


Night avg. price $ 18.90

Real-time Market by time class

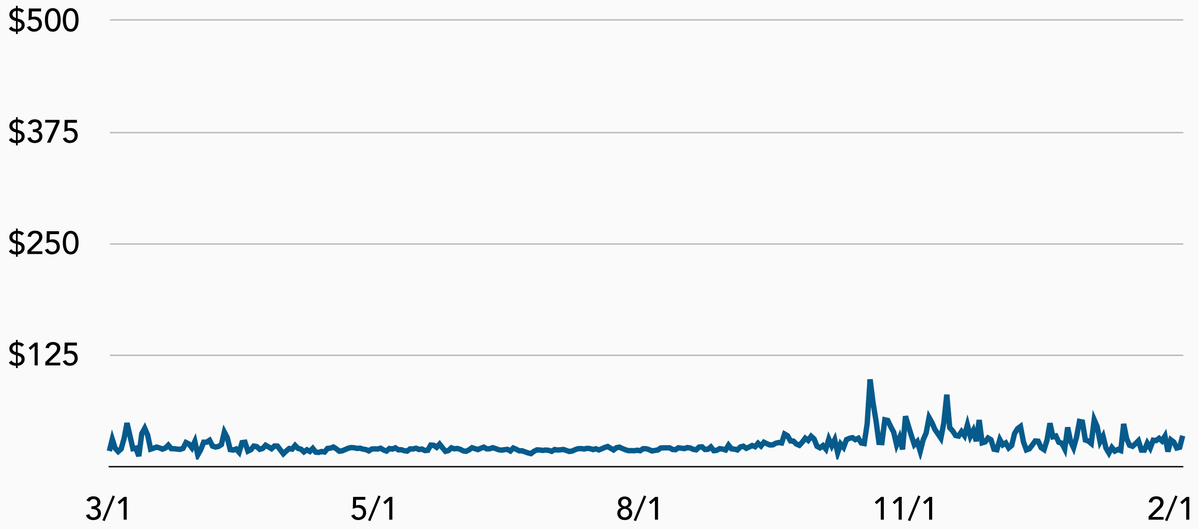


All Day avg. price $ 27.92

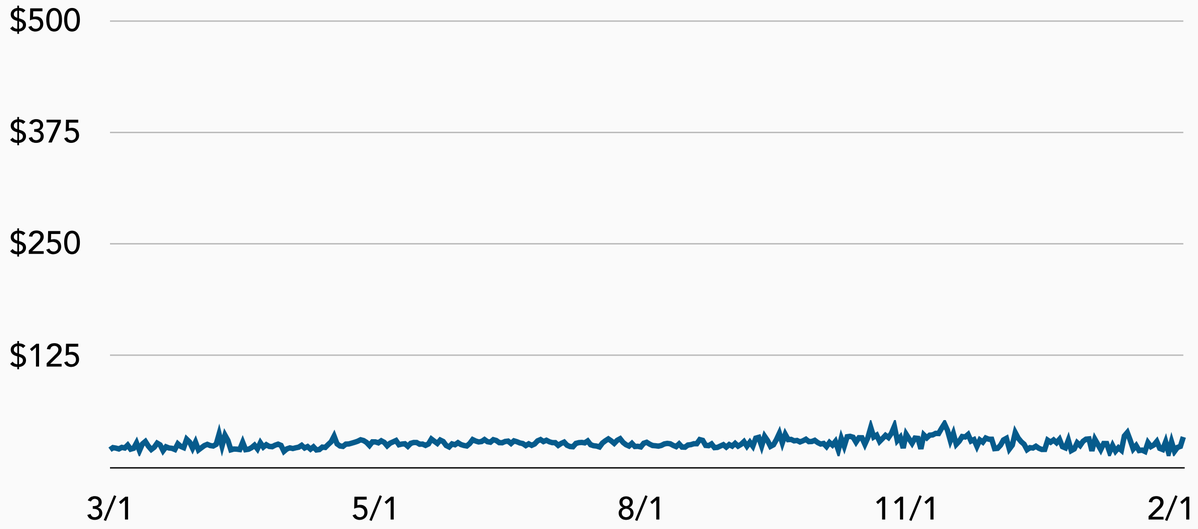


Night avg. price $ 18.56

Day-ahead Market by time class (2018-19)

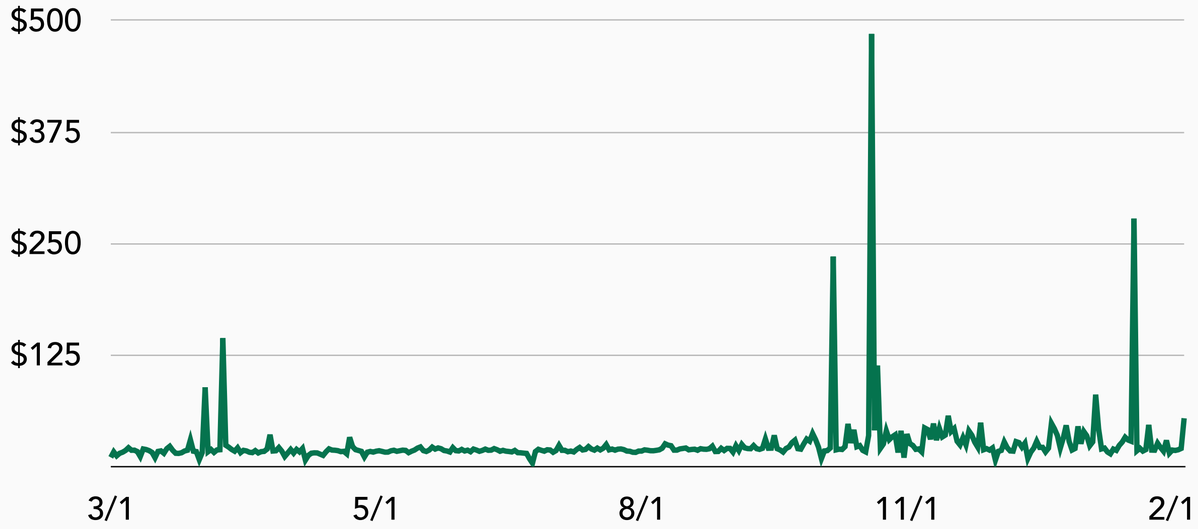


Morning peak avg. price $ 25.83

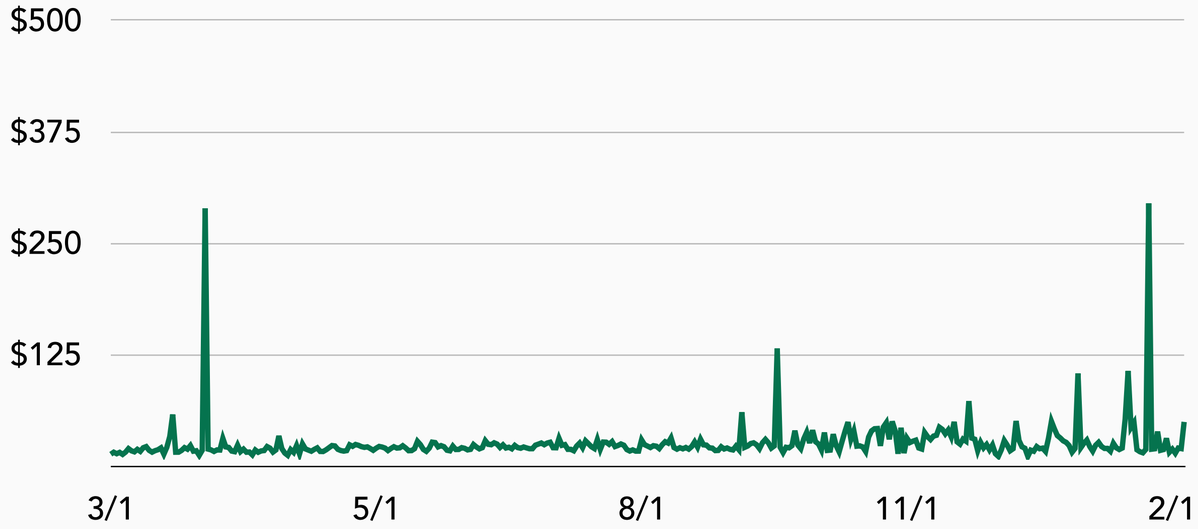


Mid-morning avg. price $ 26.94

Real-time Market by time class

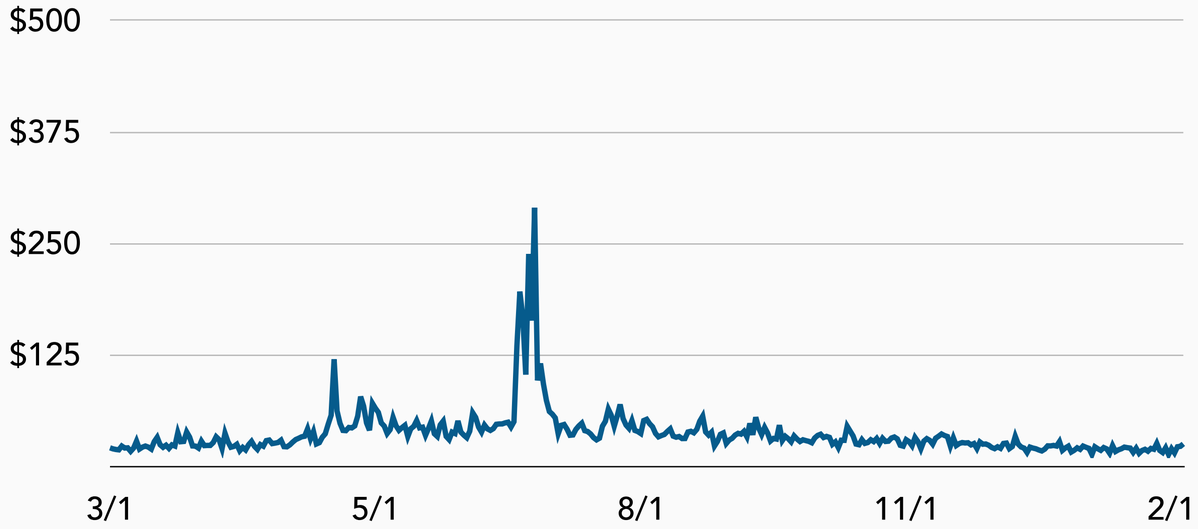


Morning peak avg. price $ 25.65

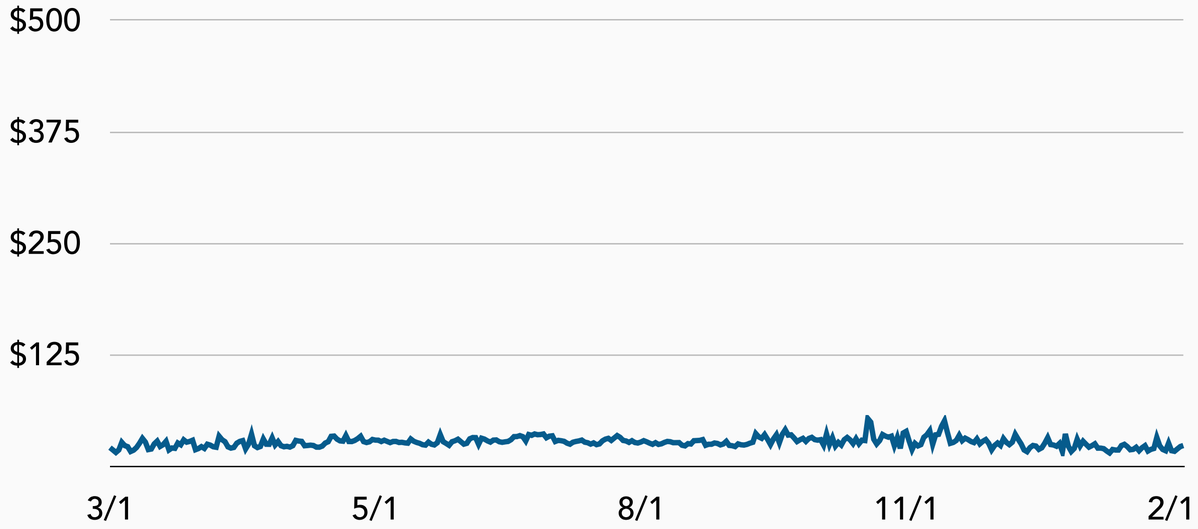


Mid-morning avg. price $ 26.87

Day-ahead Market by time class (2018-19)

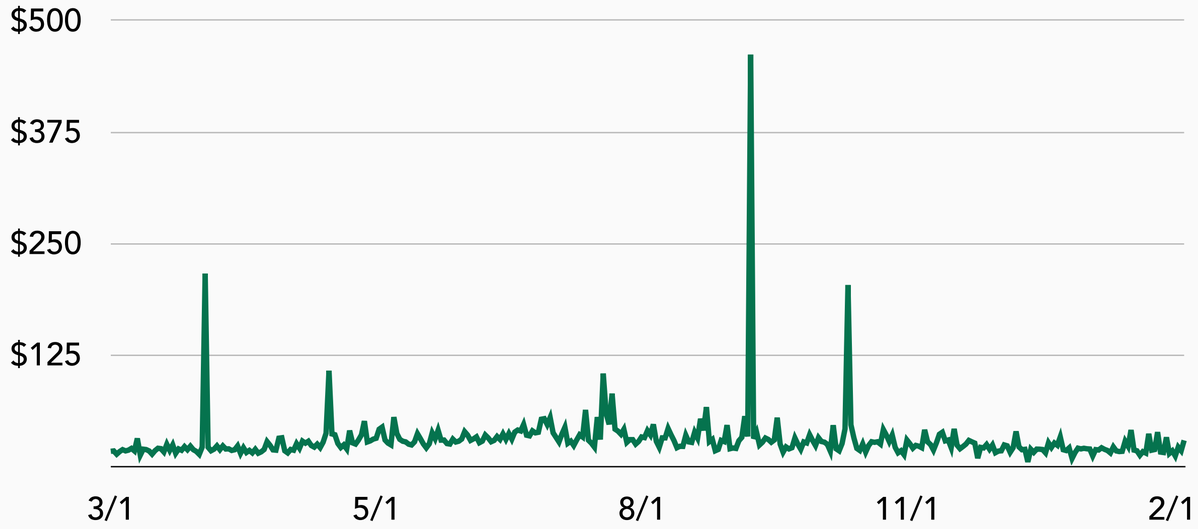


Early afternoon avg. price $ 37.30

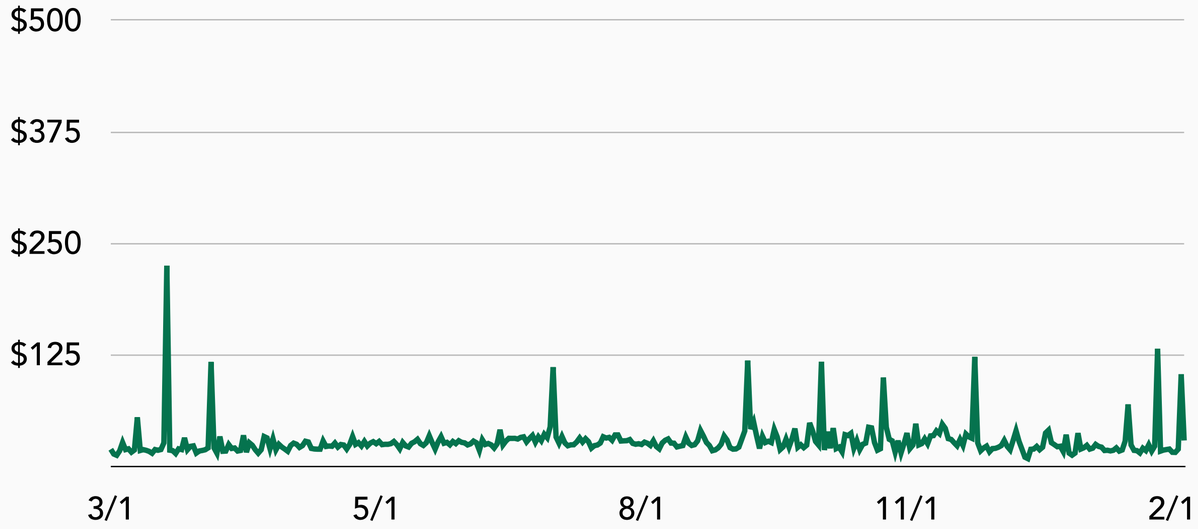


Evening avg. price $ 27.88

Real-time Market by time class

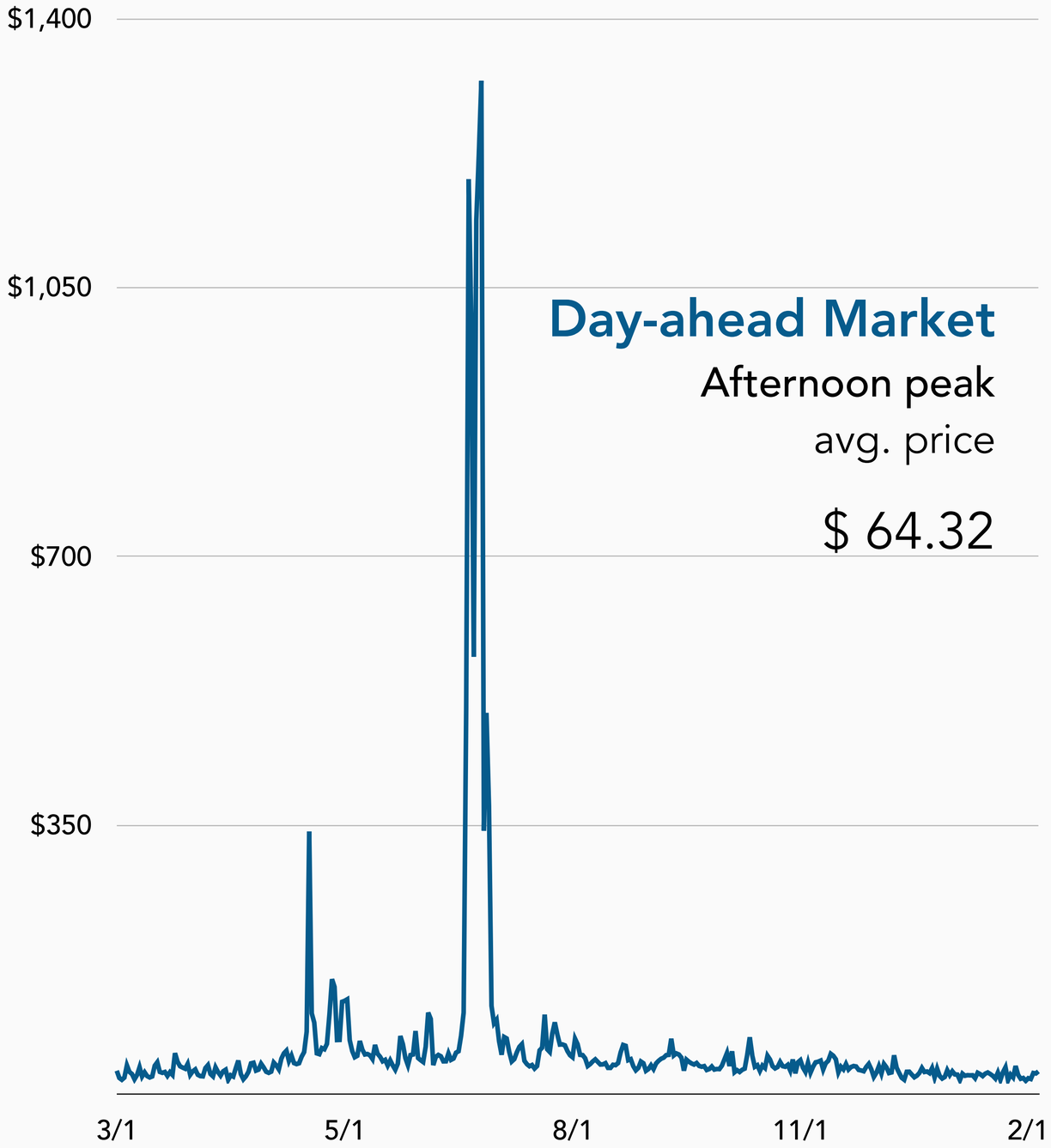


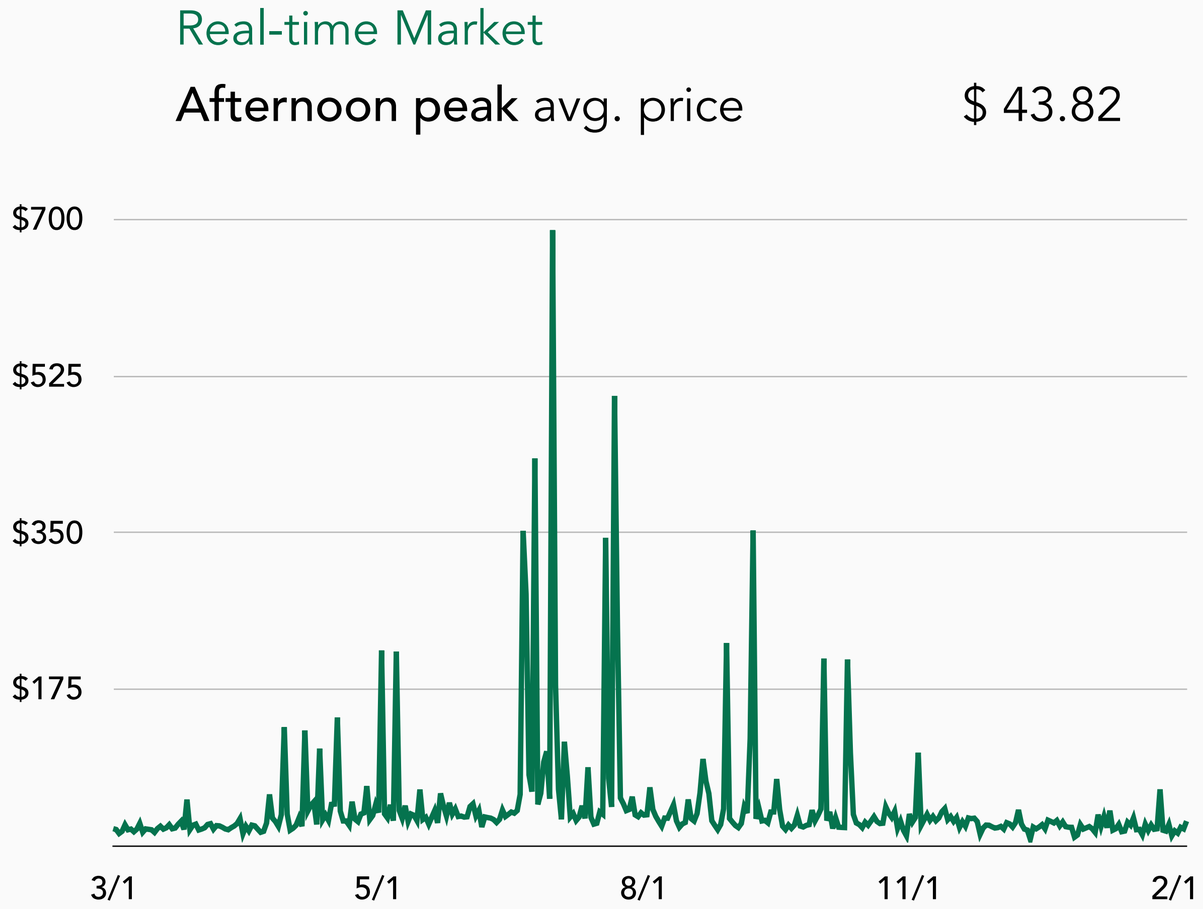
Early afternoon avg. price $ 30.60



Evening avg. price $ 28.89

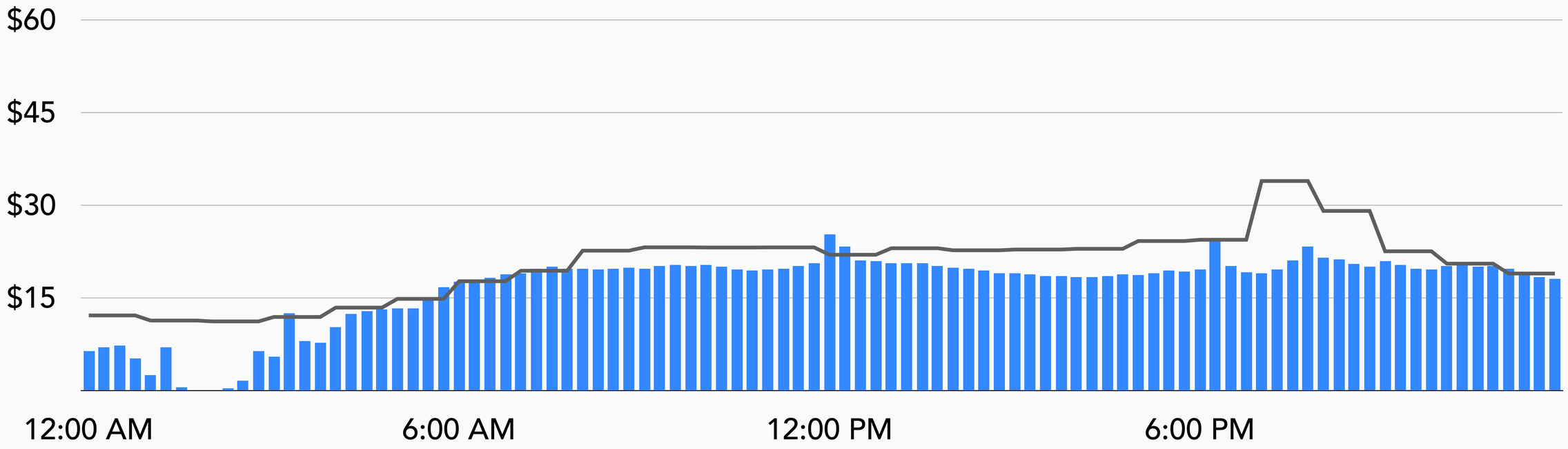
Real-time Market by time class





So why not just buy on the real-time market always?

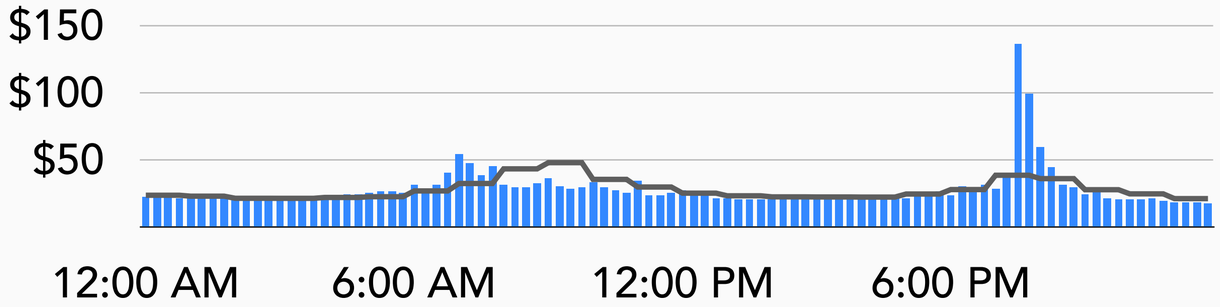
2018	Day-ahead	Real-time	Premium ($)
Year	**32.95**	**28.33**	**4.62**
May	34.01	26.06	7.95
June	29.97	26.20	3.77
July	78.86	37.52	41.34



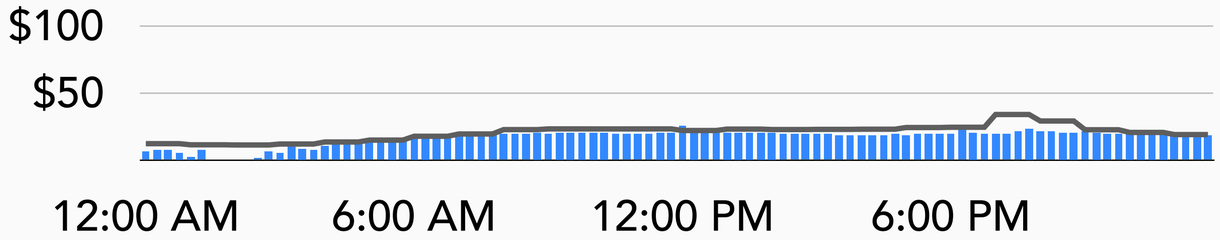
Price per MWh - **Real-time Market** compared to **Day-ahead Market**

Saturday, March 23, 2019

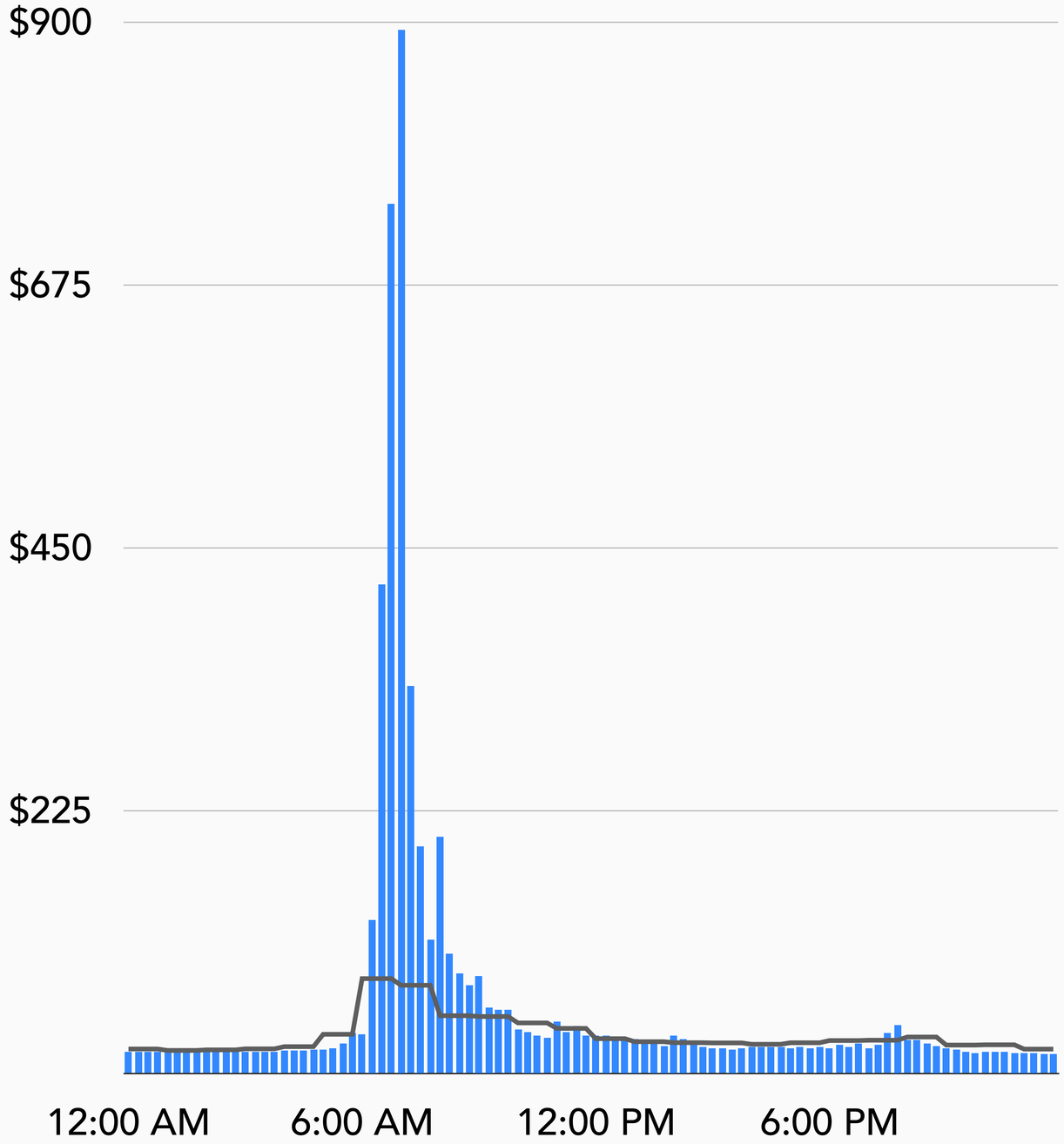
Price per MWh - **Real-time Market** compared to **Day-ahead Market**



Sun., March 17, 2019

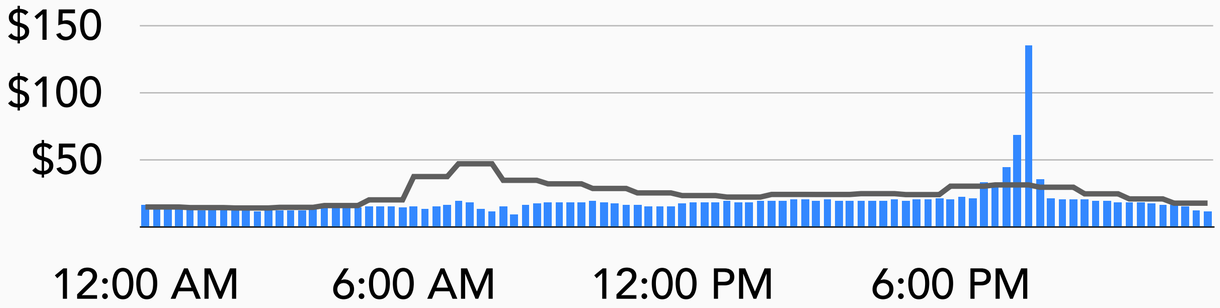


Sat., March 23, 2019

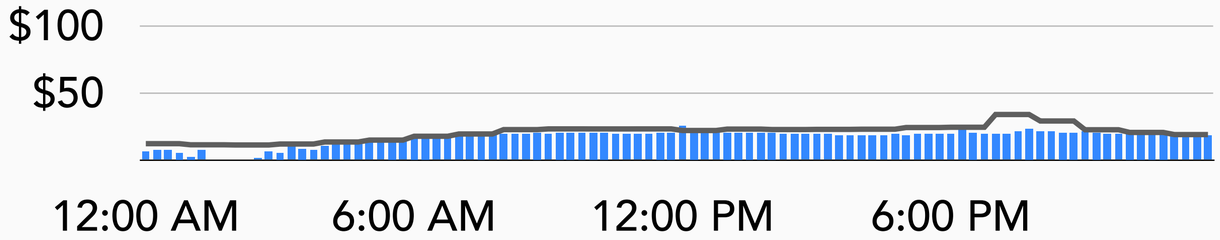


Mon., March 18, 2019

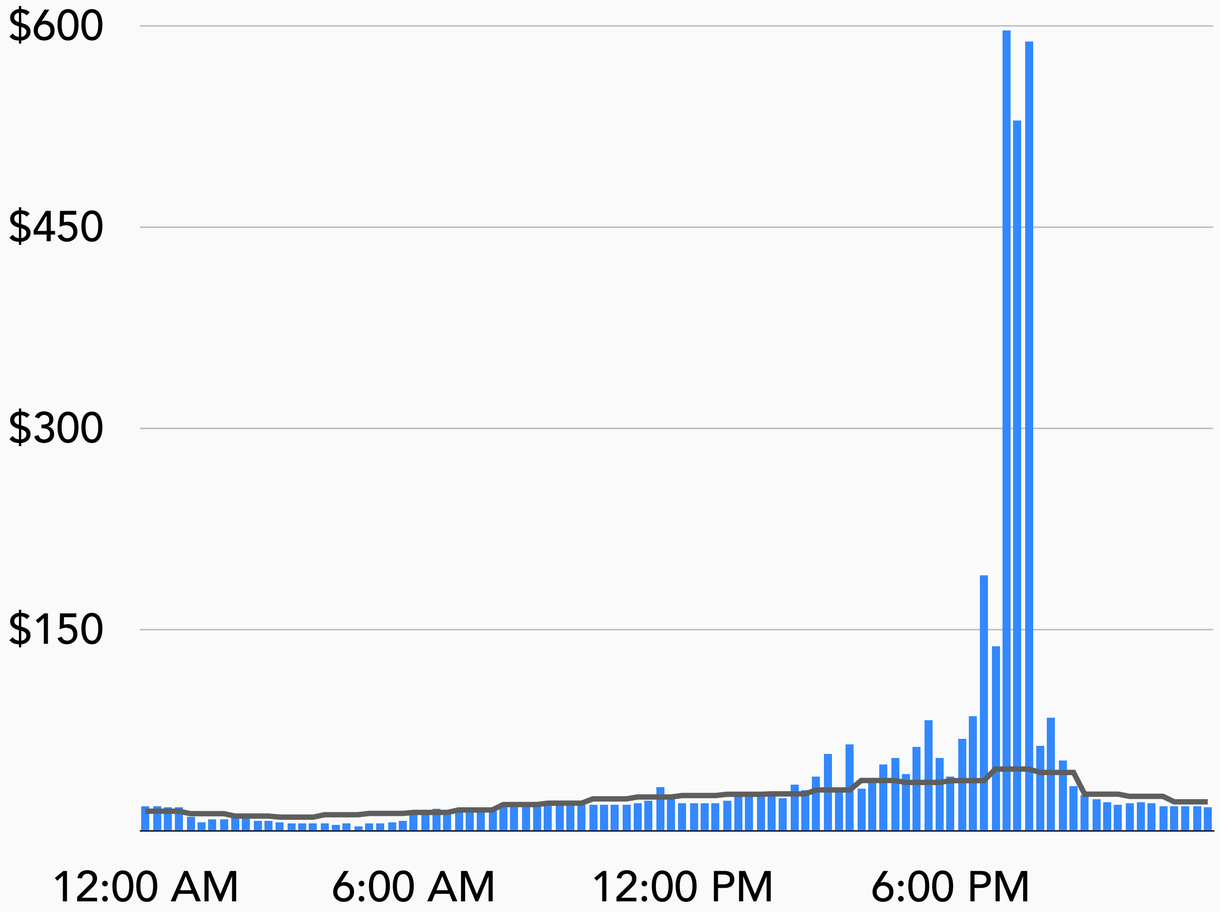
Price per MWh - **Real-time Market**
compared to **Day-ahead Market**



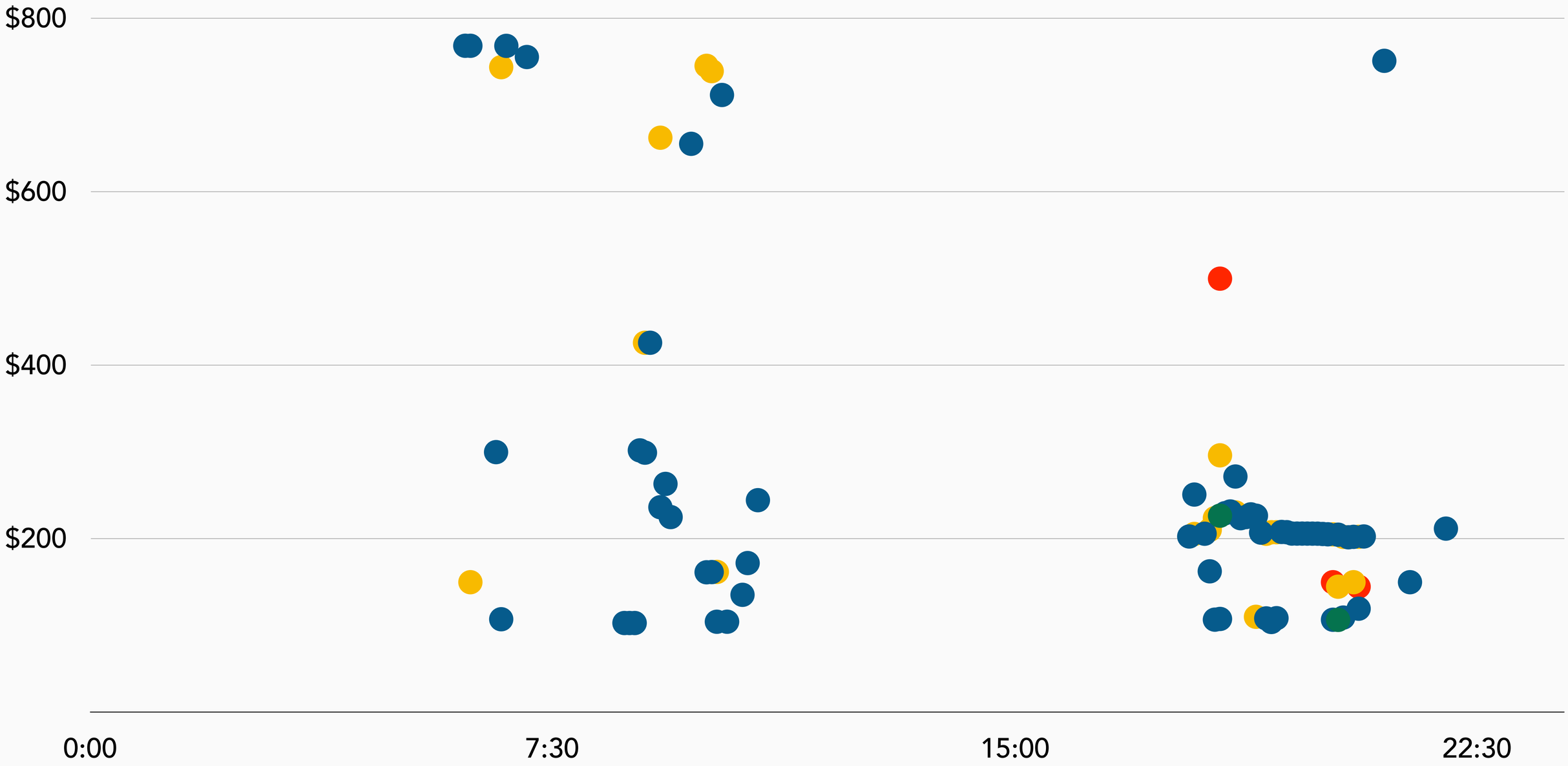
Tue., March 19, 2019



Sat., March 23, 2019



Sun., March 24, 2019



Real-time market prices over $100, Feb. 2019

Economics of renewables

Buyer questions include

How much electricity do I need to buy tomorrow and into the future?

Is it more advantageous to buy in –

- day-ahead market?
- real-time market?

If I lock in supply through a power-purchase agreement, how much should I pay?

Seller questions include

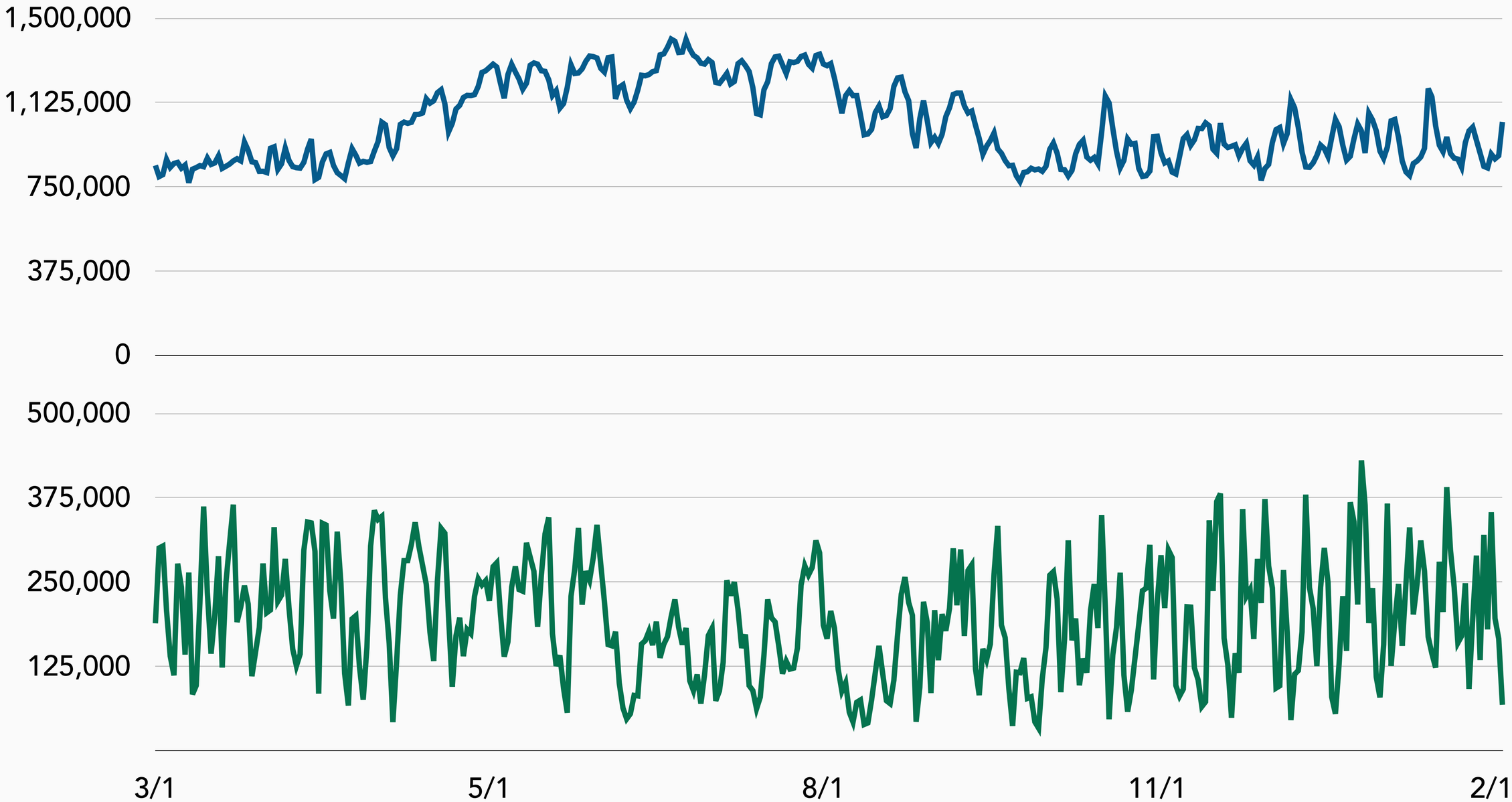
Producers

- Is building more generation capacity a good investment?
- Should I shut down any of my existing capacity?

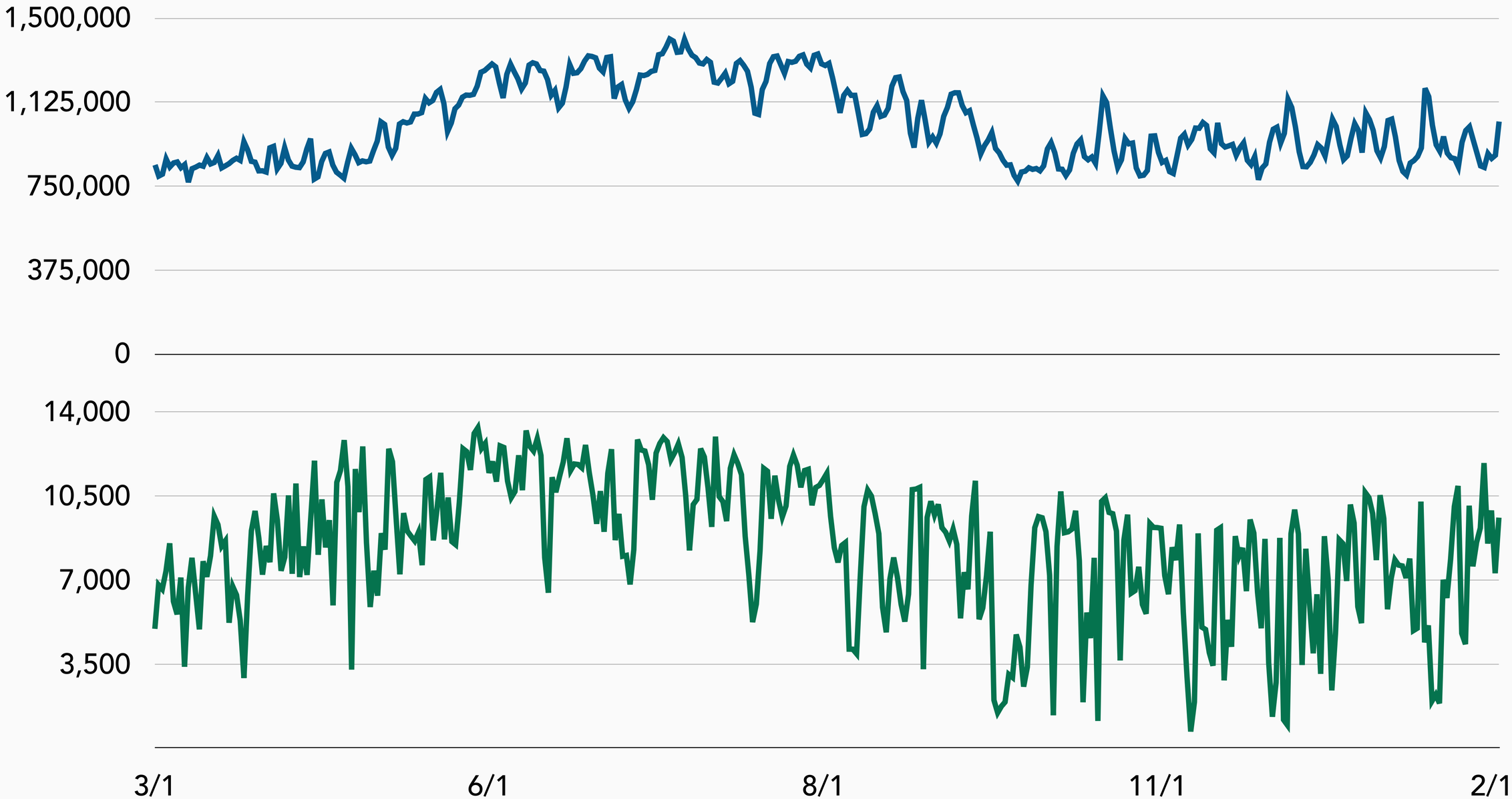
Re-sellers

- Is it profitable to buy some electricity on the day-ahead market and re-sell it tomorrow on the real-time market?

2018-19 Daily Total **System Load** and **Wind Generation** (MWh)

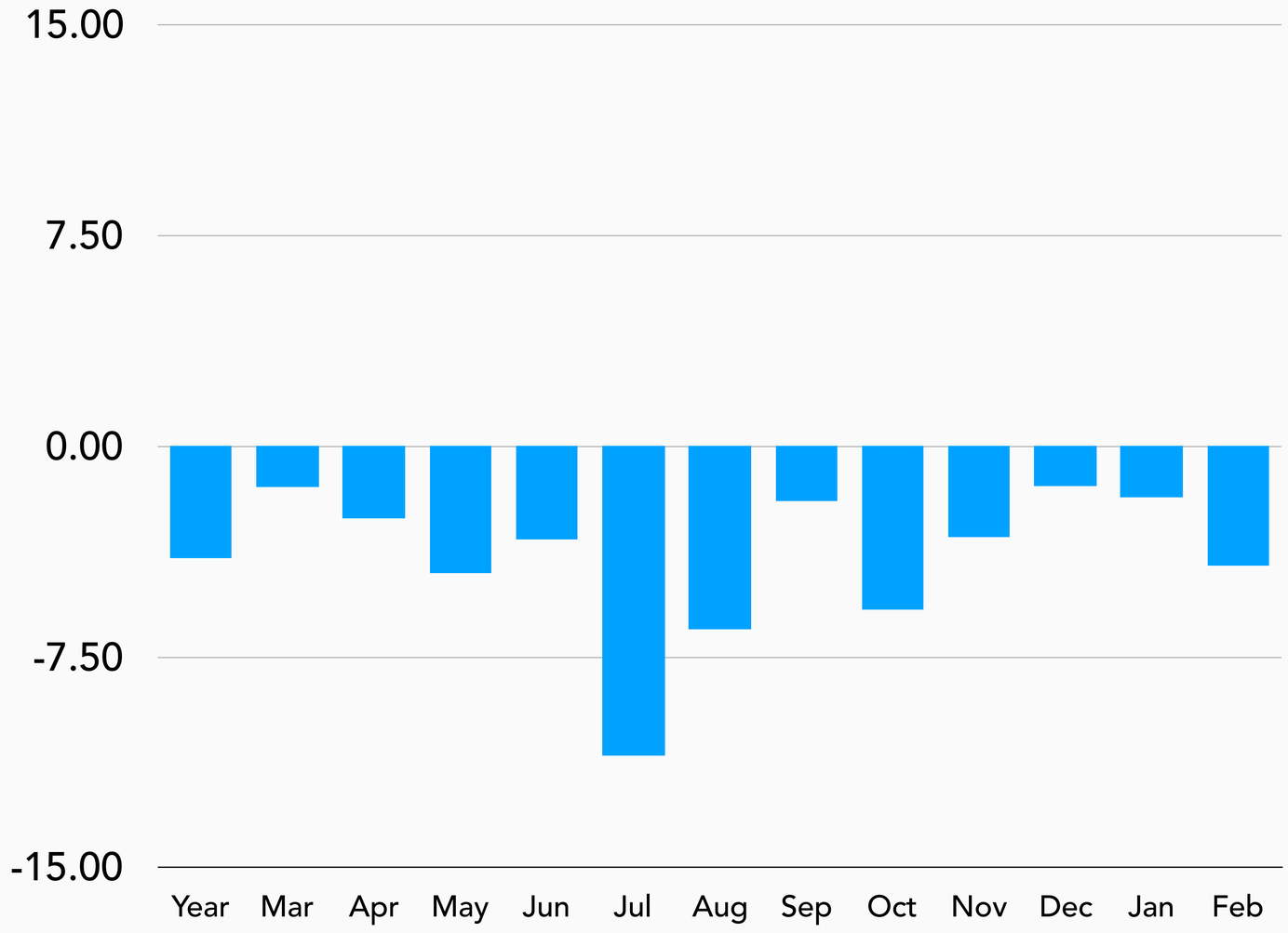


2018-19 Daily Total **System Load** and **Solar Generation** (MWh)



2018-19	Wind	All Sources	Premium ($)
12 month	**25.50**	**29.47**	**-3.97**
March	18.30	19.74	-1.44
April	21.66	24.20	-2.54
May	23.55	28.05	-4.50
June	24.37	27.66	-3.29
July	30.84	41.86	-11.02
August	30.11	36.64	-6.53
September	25.77	27.70	-1.93
October	29.92	35.74	-5.82
November	30.88	34.11	-3.23
December	26.17	27.59	-1.42
January	21.59	23.40	-1.81
February	22.27	26.51	-4.24

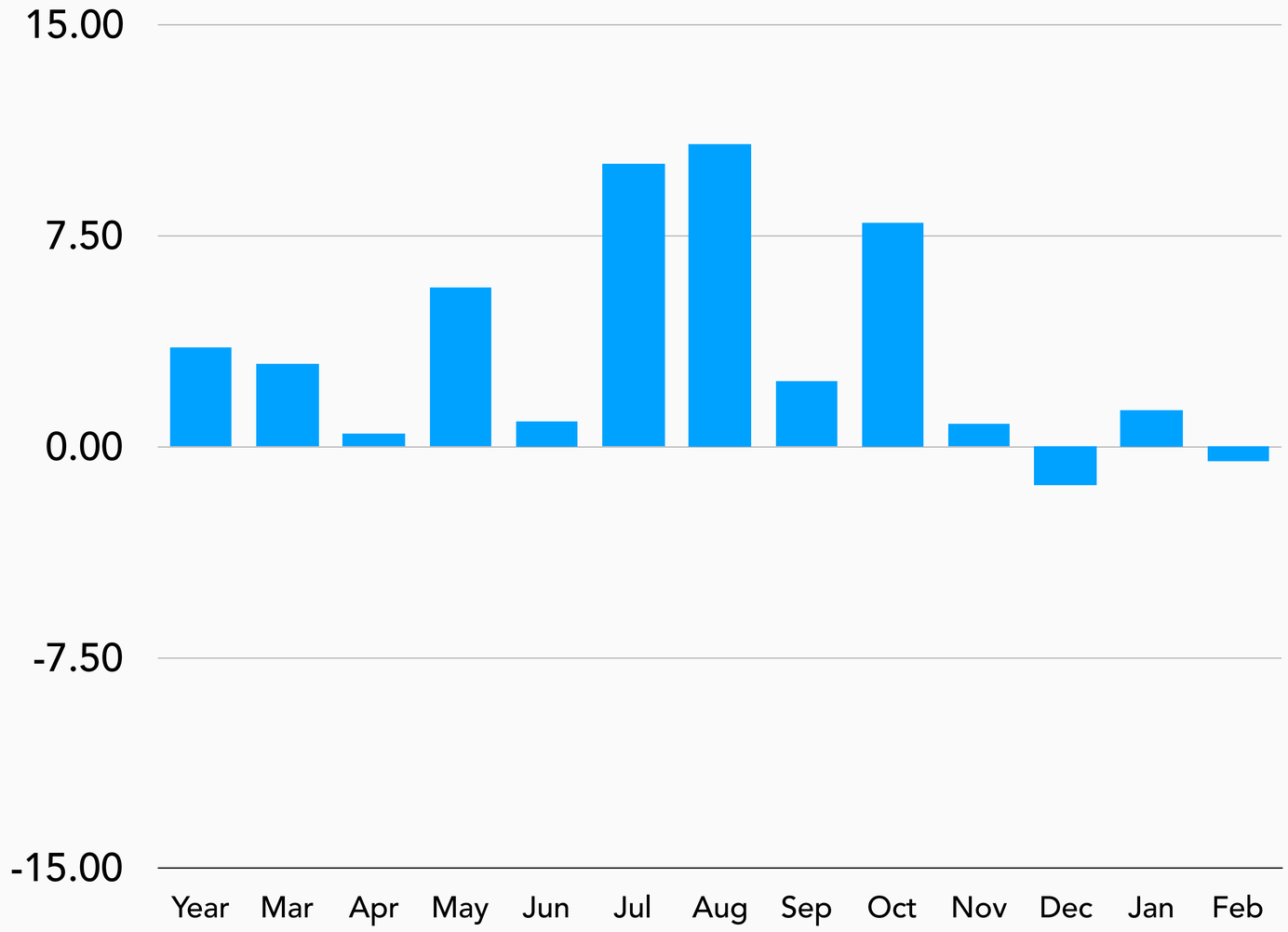
Average price premium for selling MWh wind power compared to selling MWh from all sources



Average wind and all-source prices are weighted averages

2018-19	Coastal Wind	All Sources	Premium ($)
12 month	**33.00**	**29.47**	**3.53**
March	22.70	19.74	2.96
April	24.66	24.20	0.46
May	33.70	28.05	5.65
June	28.57	27.66	0.91
July	51.93	41.86	10.07
Aug	47.43	36.64	10.79
Sept	30.04	27.70	2.34
Oct	43.70	35.74	7.96
Nov	34.91	34.11	0.80
Dec	26.22	27.59	-1.37
Jan	24.71	23.40	1.31
Feb	26.01	26.51	-0.50

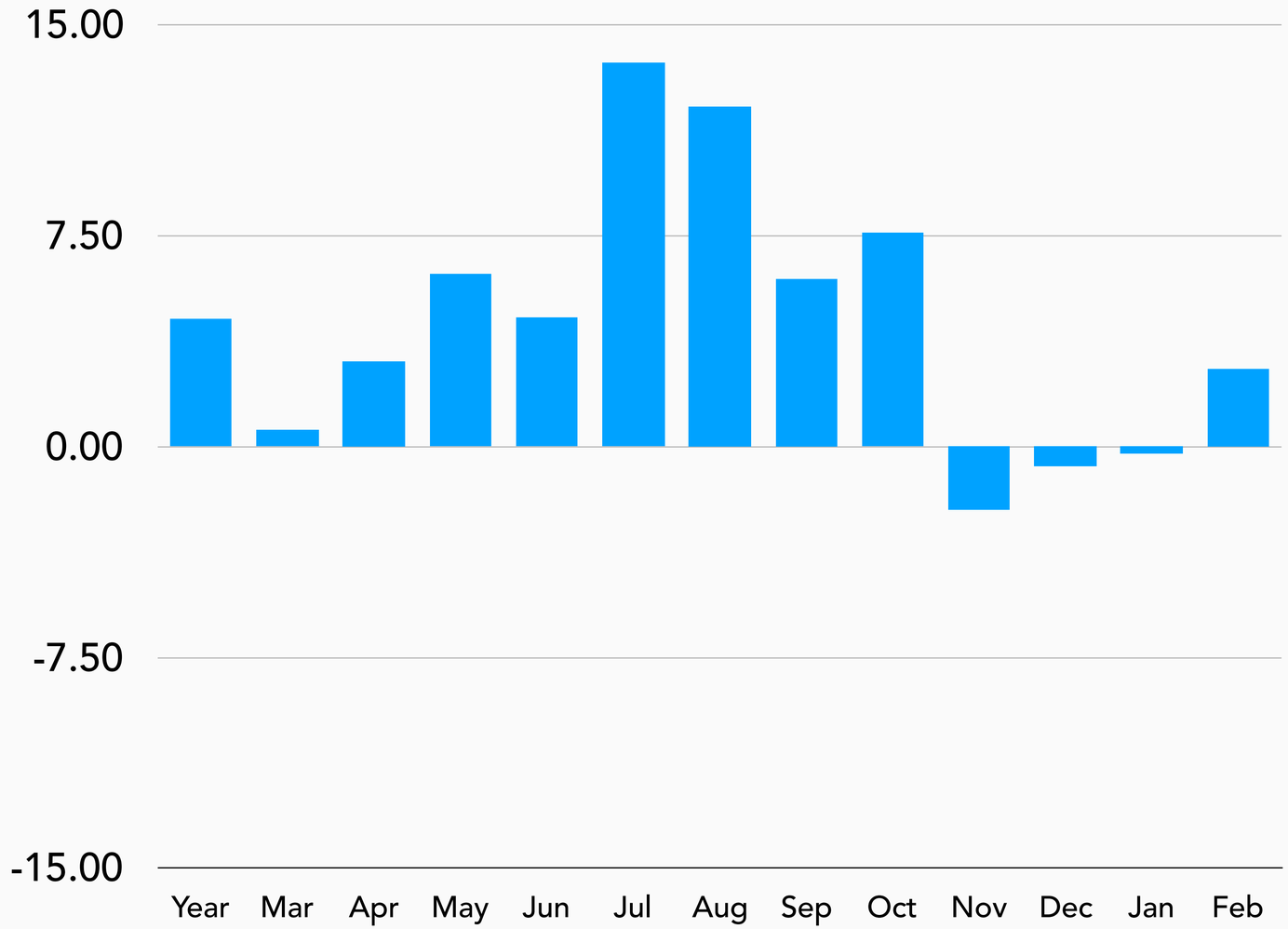
Average price premium for selling MWh of **coastal wind** compared to selling MWh from all sources



Average wind and all-source prices are weighted averages

2018-19	Solar PV	All Sources	Premium ($)
12 month	34.02	29.47	4.55
March	20.33	19.74	0.59
April	27.25	24.20	3.05
May	34.20	28.05	6.15
June	32.24	27.66	4.58
July	55.51	41.86	13.65
August	48.77	36.64	12.13
September	33.68	27.70	5.98
October	43.35	35.74	7.61
November	31.87	34.11	-2.24
December	26.89	27.59	-0.70
January	23.15	23.40	-0.25
February	29.28	26.51	2.77

Average price premium for selling MWh of **solar PV** compared to selling MWh from all sources



Average wind and all-source prices are weighted averages

Implications

Buyers

Wind and solar generation experience significant daily fluctuations. Particularly for buyers considering power purchase agreements:

- Prepare for days when wind production greatly exceeds averages. Create flexibility in other power purchase arrangements.
- Prepare for days/hours when wind output drops sharply. This could necessitate purchases in the real-time market.

Producers / Sellers

Implications

The pricing and profitability of renewable generation is highly region specific.

For instance, because their generation skews to afternoons, when wholesale prices typically are higher, solar PV and coastal wind can command higher prices and more profits than inland wind.

Significance
of residential electricity use

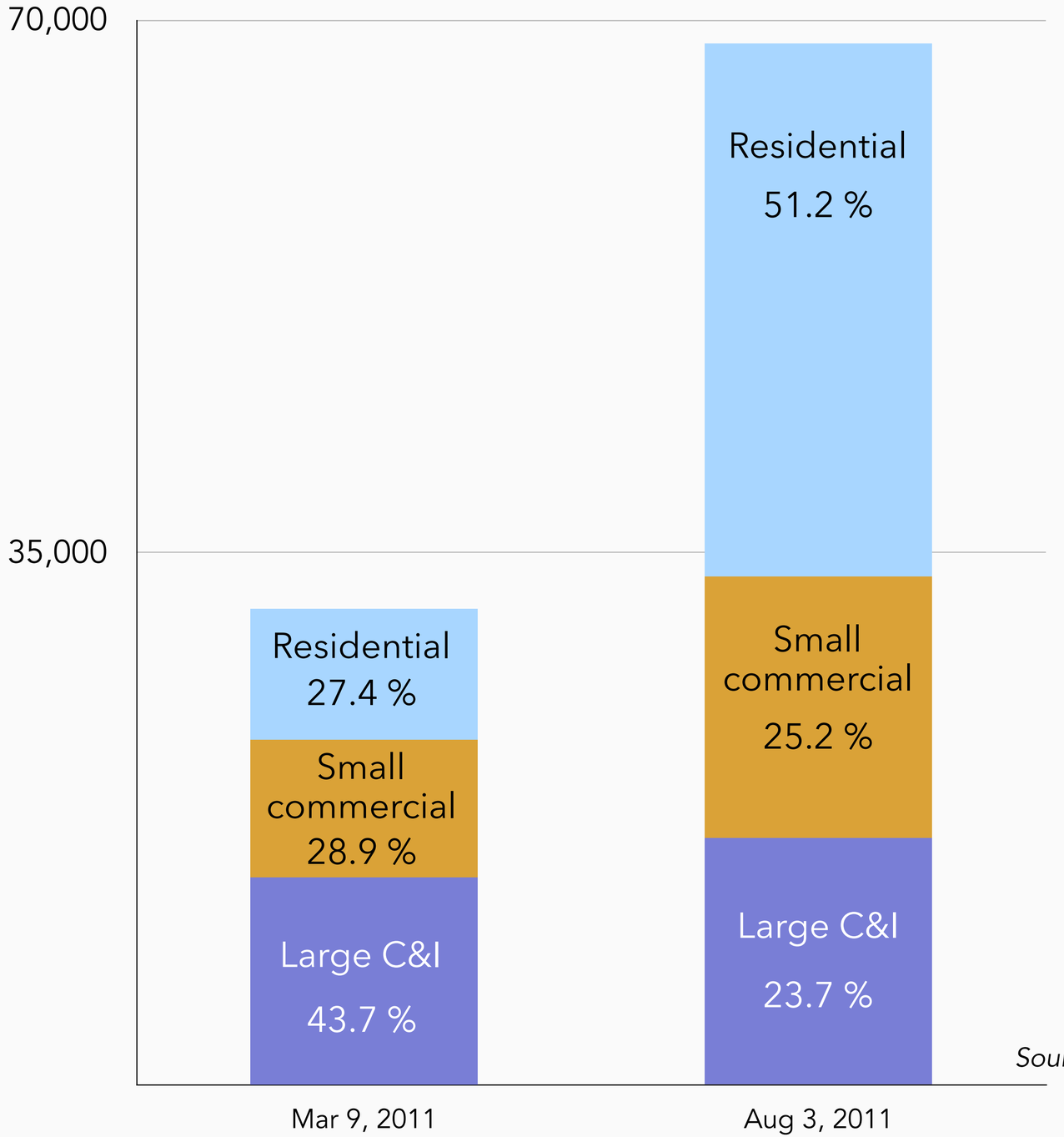
Change in peak load

by customer class

5:15 pm

March 9, 2011
31,262 MW

August 3, 2011
68,416 MW



Source: ERCOT

Afternoon peak (Texas Interconnect)

Spring	31,262 MW
Summer	68,416 MW
Increase	37,154 MW
percent increase	119 %

Percentage of total increase in peak demand

Large commercial & industrial	7 %
Small commercial	22 %
Residential	71 %

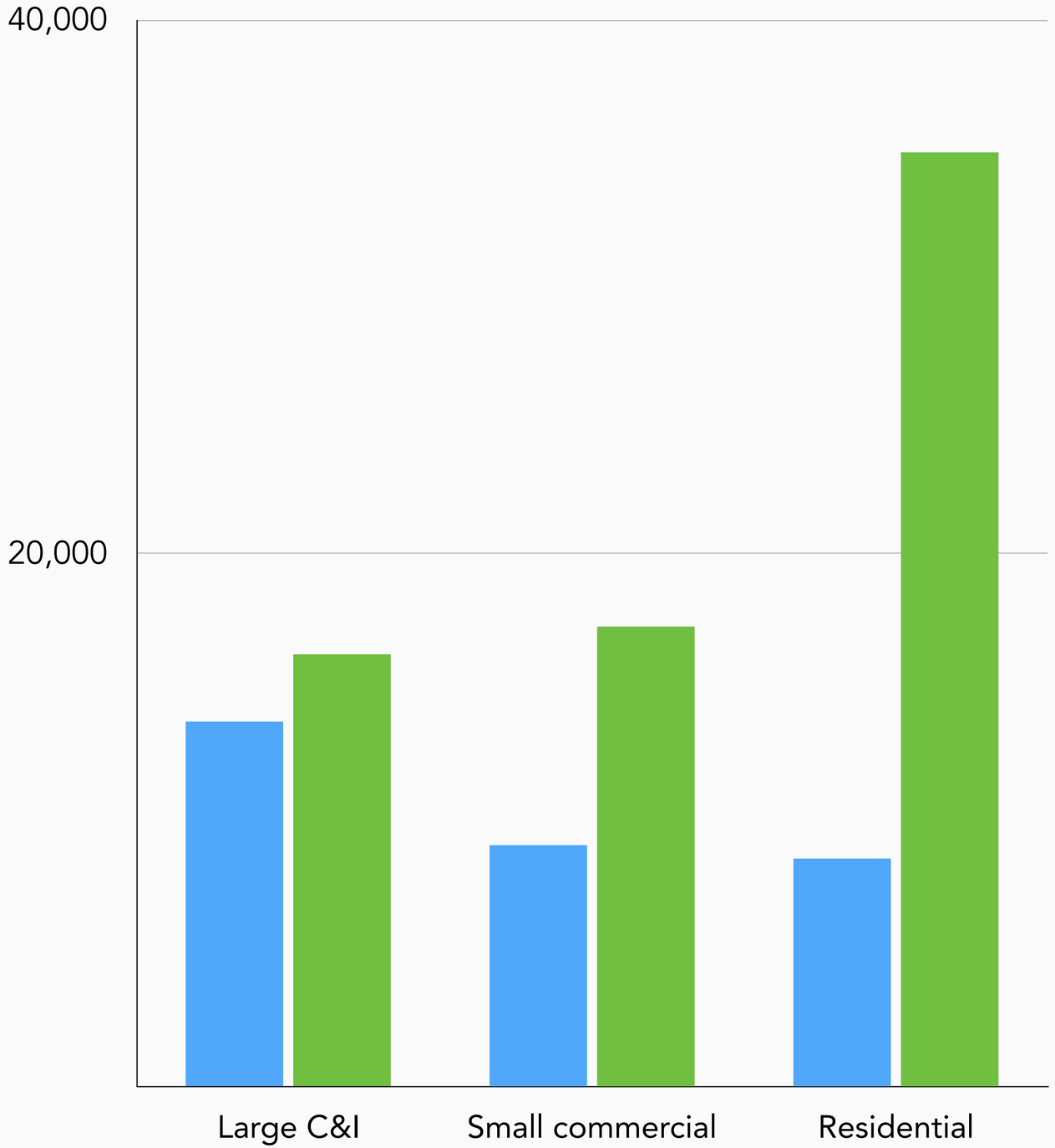
Change in peak load

by customer class

5:15 pm

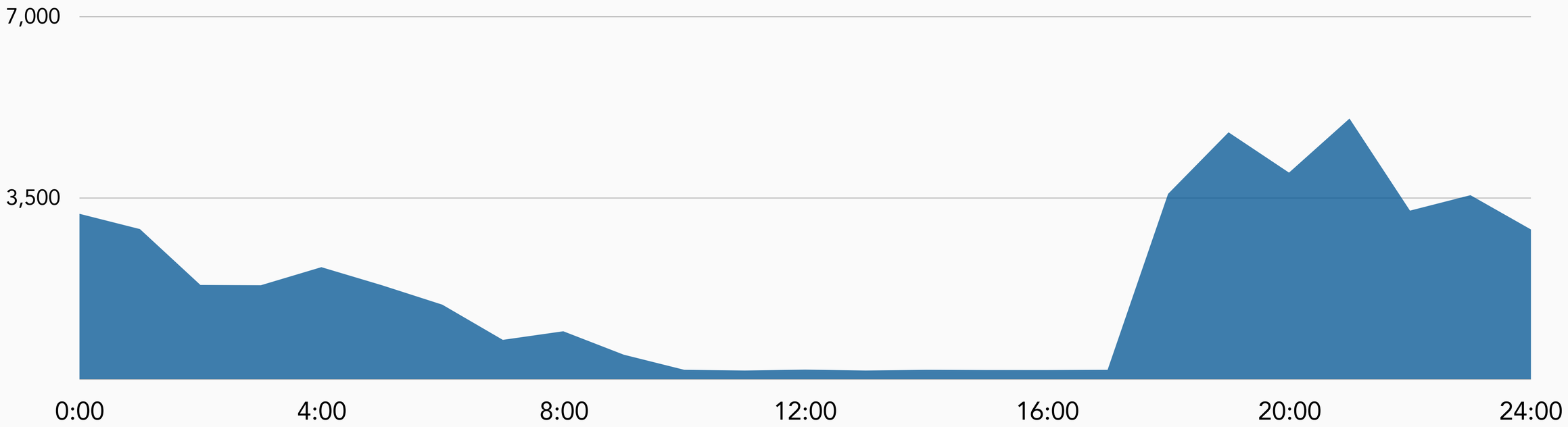
March 9, 2011
31,262 MW

August 3, 2011
68,416 MW

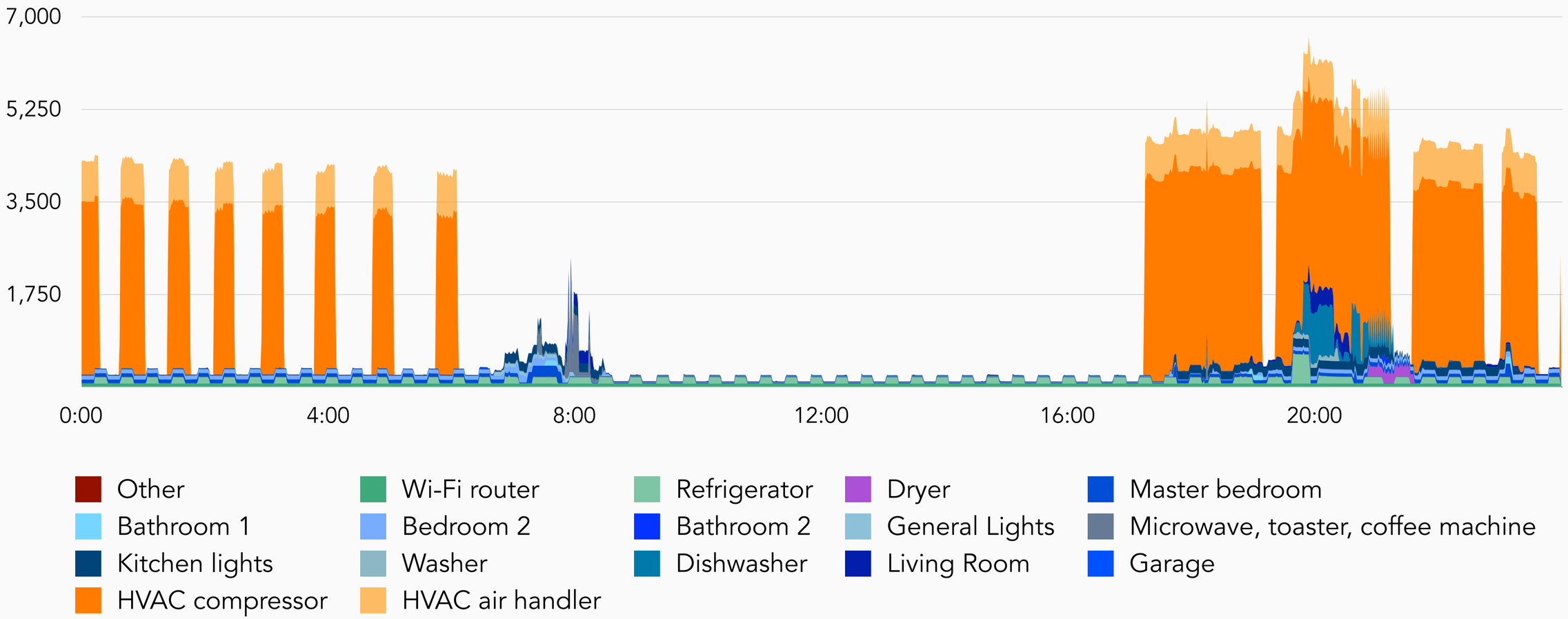


Source: ERCOT

Summer day Daily electric use (watts): smart meter



Summer day Daily electric use (watts): individual circuits



Measurements are from consumer current transformer device, not electric smart meter

Device	Top range instantaneous loads
Electric space heating	5 - 10 kW

Device	Top range instantaneous loads
Electric space heating	5 - 10 kW
Electric clothes dryer	> 6 kW

Device	Top range instantaneous loads
Electric space heating	5 - 10 kW
Electric clothes dryer	> 6 kW
Electric water heater	2 - 6 kW

Device	Top range instantaneous loads
Electric space heating	5 - 10 kW
Electric clothes dryer	> 6 kW
Electric water heater	2 - 6 kW
Pool pump	2 - 4 kW

Device	Top range instantaneous loads
Electric space heating	6 - 10 kW
Electric clothes dryer	> 6 kW
Electric water heater	2 - 6 kW
Pool pump	2 - 4 kW
Air conditioner	1.5 - 4 kW

Device	Top range instantaneous loads
Electric space heating	6 - 10 kW
Electric clothes dryer	> 6 kW
Electric water heater	2 - 6 kW
Pool pump	2 - 4 kW
Air conditioner	1.5 - 4 kW
Electric oven	3 - 4.5 kW

Device	Top range instantaneous loads
Electric space heating	6 - 10 kW
Electric clothes dryer	> 6 kW
Electric water heater	2 - 6 kW
Pool pump	2 - 4 kW
Air conditioner	1.5 - 4 kW
Electric oven	3 - 4.5 kW
Electric car (*Level 2 charge*)	3.3 - 6.6 kW
Electric car (*Level 1 charge*)	1.45 kW

Device	Top range instantaneous loads
Electric space heating	6 - 10 kW
Electric clothes dryer	> 6 kW
Electric water heater	2 - 6 kW
Pool pump	2 - 4 kW
Air conditioner	1.5 - 4 kW
Electric oven	3 - 4.5 kW
Electric car (*Level 2 charge*)	3.3 - 6.6 kW
Electric car (*Level 1 charge*)	1.45 kW

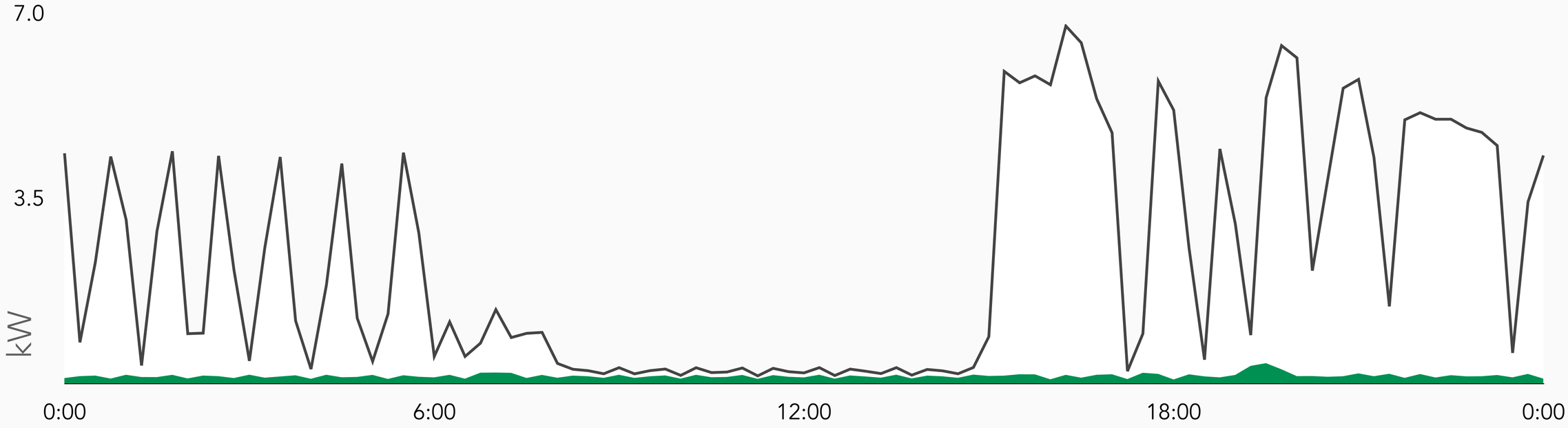
Four Categories of Electricity Use

Always On

Thermal

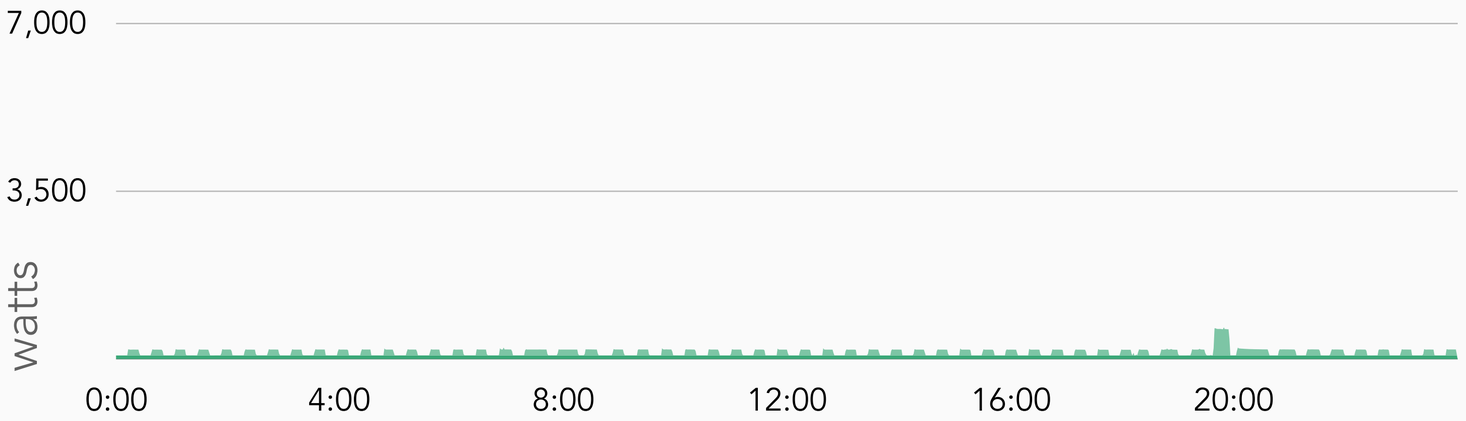
Electric-gas substitute

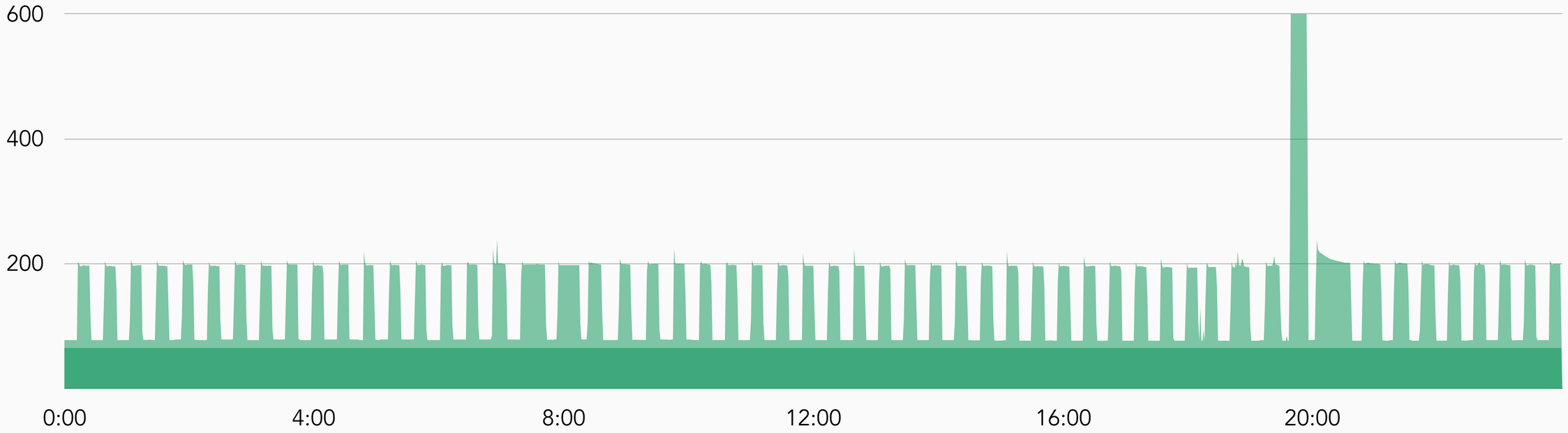
Intentional



Four Categories of Electricity Use

Always On





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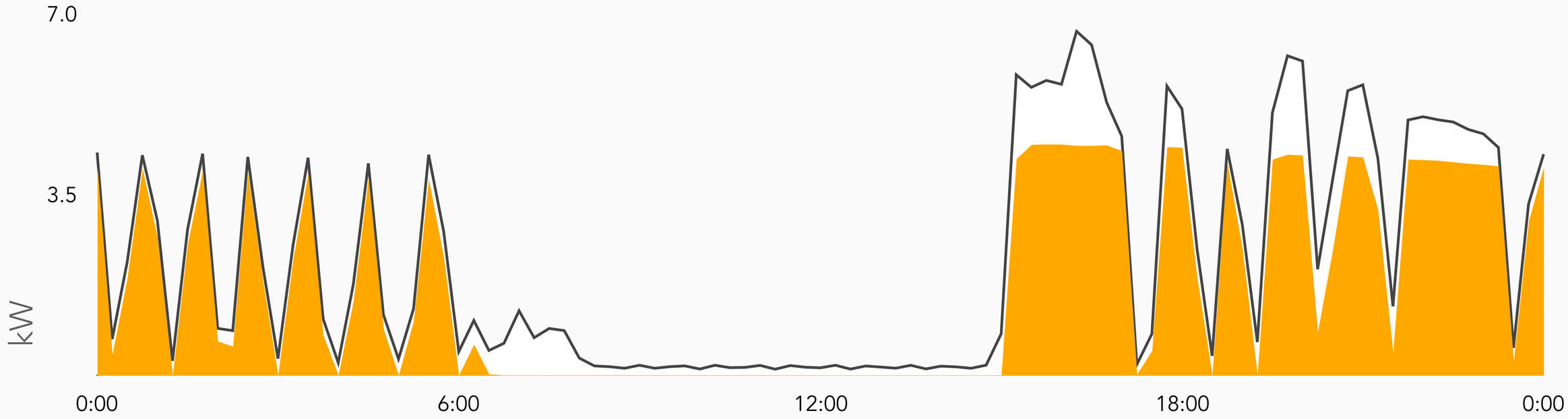
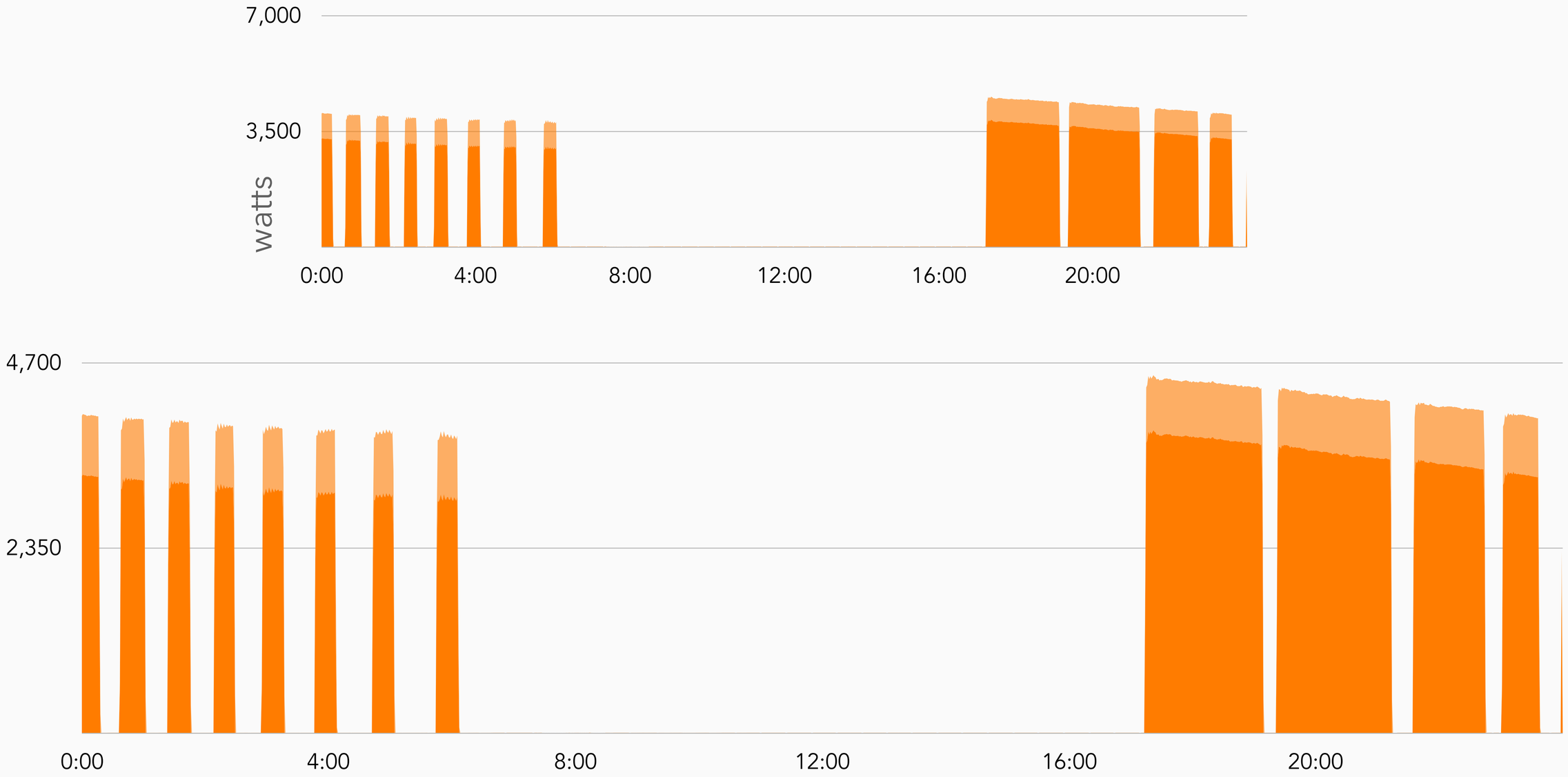


Four Categories of Electricity Use Thermal



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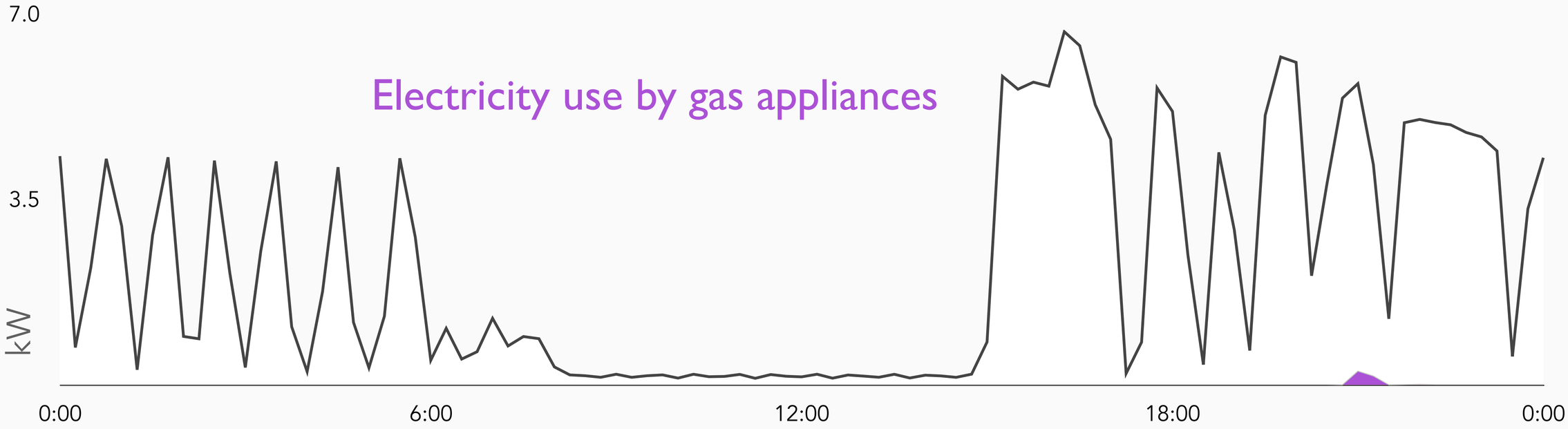

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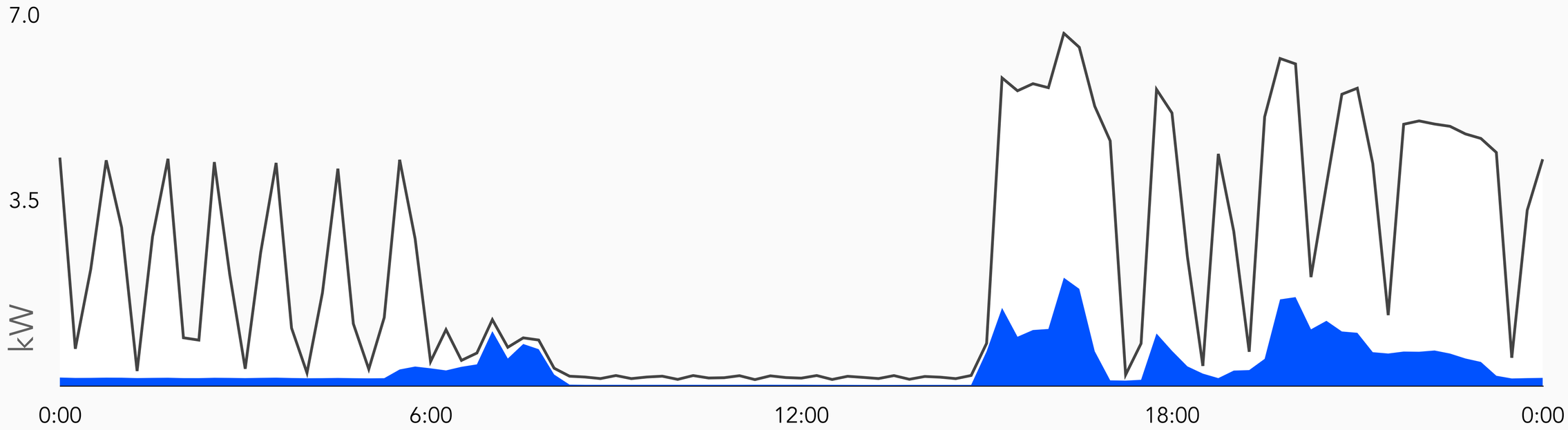

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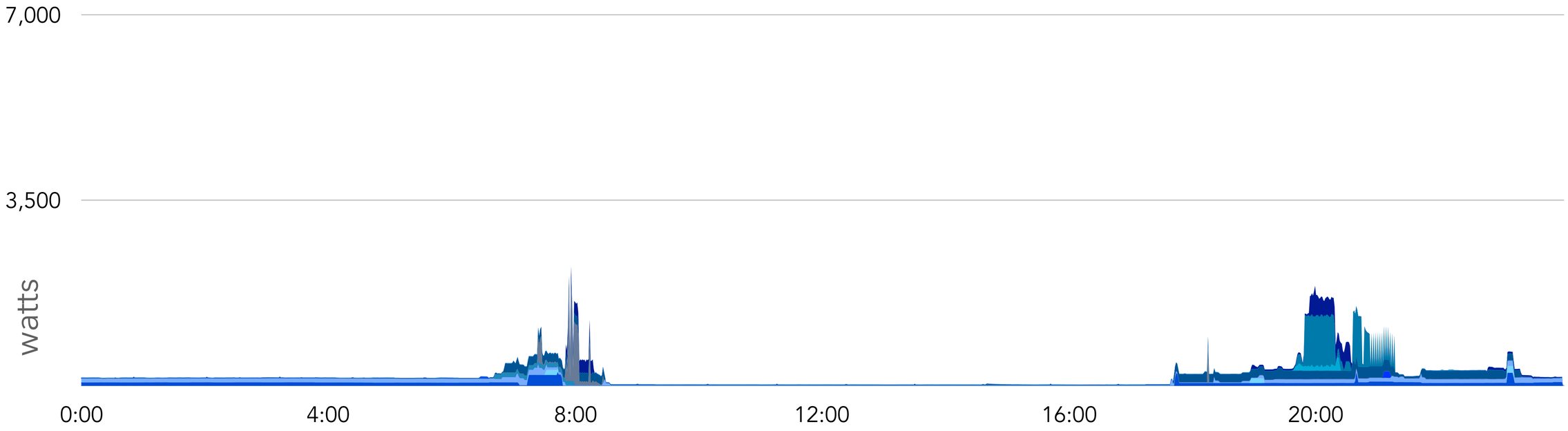
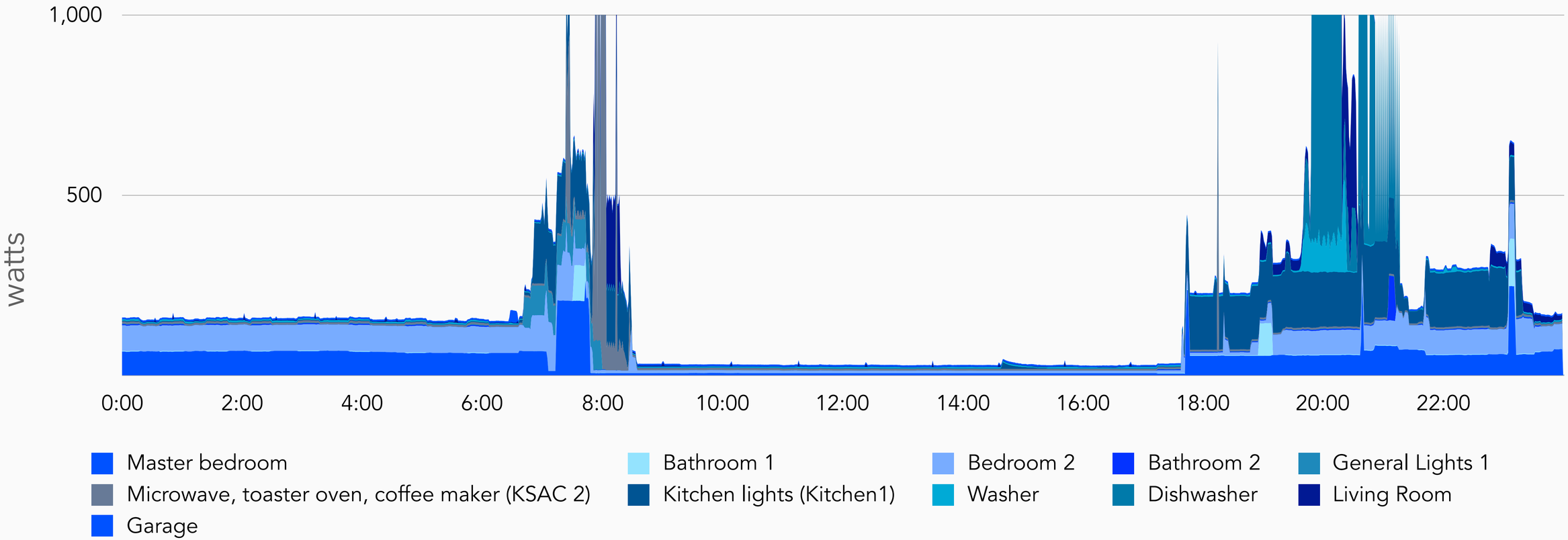
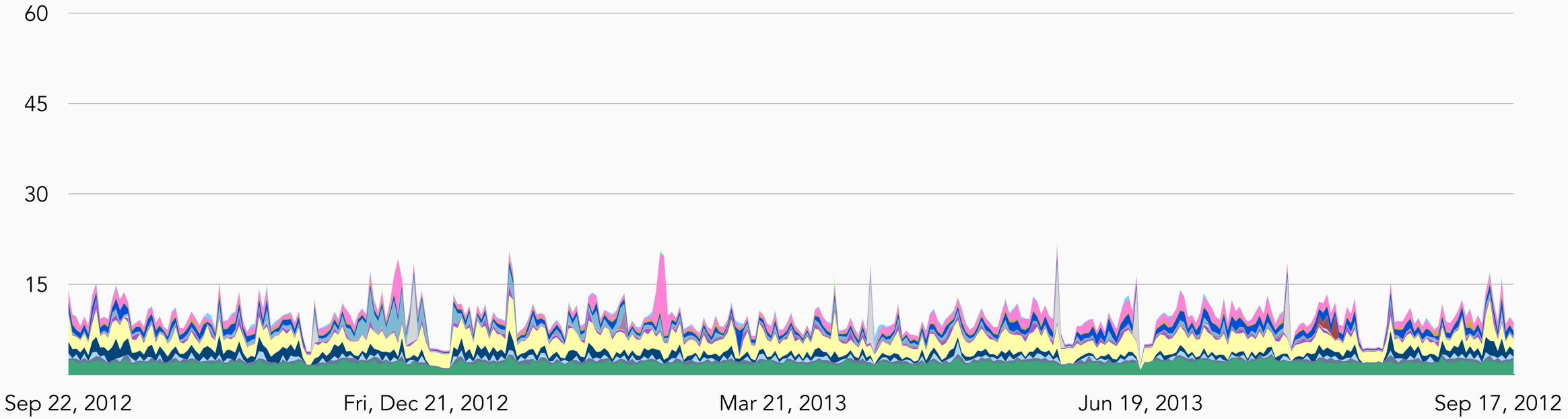


Four Categories of Electricity Use Intentional

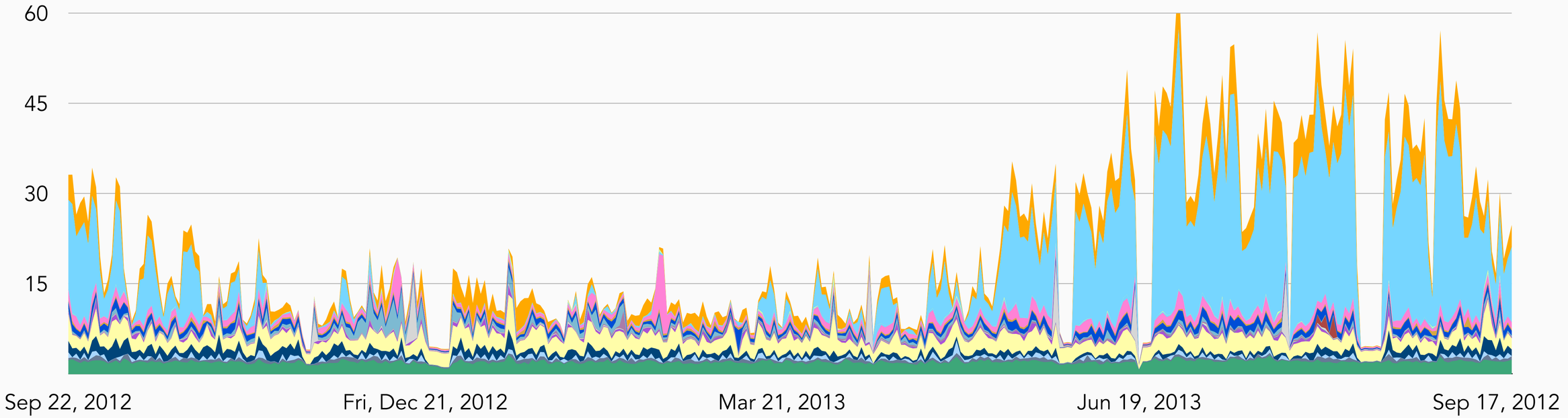


One year Single home – daily electricity use – non-seasonal



- Refrigerator [KSAC 1]
- Living Room-TV [kW]
- Plugs 1
- Bedroom 1 [kW]
- Microwave and toaster oven [KSAC2]
- Washer/Dryer
- Plugs 2 [kW]
- Bedroom 2 [kW]
- Dishwasher
- Dining Room
- General Lights 1 [kW]
- Bathroom 1 [kW]
- Kitchen Lights [Kitchen 1]
- Garage
- Bedroom-Master [kW]
- Bathroom 2 [kW]

One year Single home – daily electricity use + HVAC



Homework and Summary

Homework Questions

Instructions

Due Thursday, April 18

Question 1: (*see spreadsheet document homework_problem_1.xlsx*)

You are the power purchasing manager for Acme retail utility. Today is July 12. Yesterday (July 11), your total customer load was 77,311.47 megawatt hours (MWh).

You have to plan for how much wholesale electricity your utility will have to purchase tomorrow (July 13) and the next day (July 14).

- Acme has power purchase contracts from a gas-fired plant for up to 1,200 MWh per hour. Acme is not required to purchase all 1,200 each hour but does need to provide 24 hours notice if it won't.
- You have a power purchase agreement for the output from a West Texas wind facility. You have to pay for all of the generation, regardless whether you use it. Yesterday, that generation provided 24,573.09 MWh.

Homework Questions

Instructions

Question 1: (*continued*)

The spreadsheet contains:

- Actual load per hour for your region yesterday (July 11)
- Forecasted load for your region tomorrow (July 13) and the next day (July 14)
- Actual wind generation (MWh) per hour on July 11 for West Load Zone, where your contracted wind generation is located
- Forecasted wind generation for the West Load Zone tomorrow (July 13) and the next day (July 14)

On a spreadsheet or table, detail:

1. The amount of electricity (MWh) Acme has under contract from the gas plant for each hour on July 13 and July 14
2. The amount of wind generation that you forecast Acme can plan on for these days
3. The amount of electricity Acme should reserve from the gas plant.
4. The amount of electricity, if any, that you forecast Acme will need to purchase each hour from the wholesale market.

Homework Questions

Instructions

Due Thursday, April 18

Question 2: (*see spreadsheet document homework_problem_2.xlsx*)

Congratulations, you have projected how much electricity that Acme will have to buy from the wholesale markets on July 13 and July 14.

Now, you have to plan for how of these purchases should come from the day-ahead market versus the real-time market.

The spreadsheet for this problem identifies the average settlement point price for Acme's load zone for which you are responsible for purchases. The first column of prices is the average over the past 4 weeks for the day-ahead market. The second column is the average for the real-time market.

Homework Questions

Question 2: (*continued*)

In the blank columns, develop a purchase plan for July 13 and July 14. Take the wholesale MWh hour values you calculated in problem 1. Apportion them between day-ahead and real-time market values.

Remember that simply choosing the lower average price for all purchases for that hour may lead to considerable risk to Acme.

Instructions

One you have apportioned purchases, write a short paragraph explaining why you chose the apportionment. Identify the risks that exist in the approach you have elected to take.

Homework Due Thursday, April 18

Summary

1. In systems such as ERCOT, most utilities are not vertically integrated.
2. In such systems, buyers of wholesale electricity include retail utilities and re-sellers/arbitragers.
3. Sellers of wholesale electricity include generation owners (power plants, wind, solar) and re-sellers/arbitragers.
4. Key questions that buyers must address include (a) whether it is more advantageous to buy in the day-ahead market or the real-time market and (b) if buying electricity through a power-purchase agreement, what price should the buyer pay.
5. Sellers confront the questions that include whether market prices mean that building more generation capacity is a good investment and whether existing capacity should be shuttered.

Summary

cont'd

6. Re-sellers/arbitragers seek to make money by buying at a lower price on the day-ahead market and selling at a higher price on the real-time market.

7. In wholesale markets such as ERCOT's, whole electricity is sold on both a day-ahead (futures) market and a real-time market.

8. As a general matter, the day-ahead market price for electricity is frequently slightly higher than the price on the day-ahead market. This is commonly described as a "price premium".

9. Day-ahead electricity frequently commands a slightly high price because buyers want to avoid the risk of facing significant shortfalls or sudden severe price spikes on the real-time market.

10. The price premium for day-ahead versus real-time electricity can vary significantly by season and by time-of day.

Summary

cont'd

11. Segmenting price over the course of a day by time class often provides a clearer picture of potential price volatility. Time classes are night (11 pm - 6 am), morning peak (6 am - 9 am), mid-morning (9 am - noon), early afternoon (noon - 3 pm), afternoon peak (3 pm - 7 pm) and evening (7 pm - 11 pm).

12. In ERCOT, afternoon peak prices in the summer frequently are significantly higher than average prices for other hours. Morning peak prices in the winter can get very high, though not on the sustained basis that occurs in afternoon peak in the summer.

13. While real-time prices typically are lower for a time period than the day-ahead price, real-time market prices frequently experience significant spikes during which prices can increase to nearly $1,000 per MWh.

Summary

cont'd

14. Both wind and solar power can experience significant fluctuations in output over the course of a day or days.

15. In ERCOT, the average value per MWh for wind power typically is slightly lower than power from all sources. That is because wind power generation skews toward times of day (such as overnight) when wholesale prices are lower. That is highly region specific, however. For instances, wind power on the Texas coast has nearly a 12 percent annual higher value than all sources because coastal wind tends to generate more in the afternoon.

16. Solar generation has over a 15 percent annual higher value than all power sources because solar generates more in the afternoon, when overall wholesale prices are higher.

17. For ERCOT, the highest contributor of seasonal differences in total load is residential.

18. Residential heating and cooling accounts for the vast bulk of seasonal variability.

Summary

cont'd