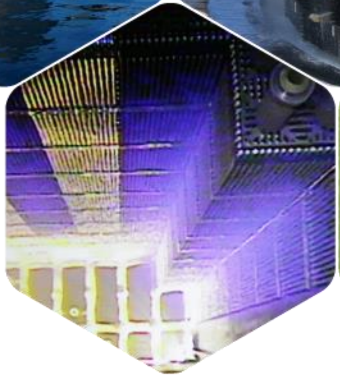




Nuclear Energy Solutions in a Changing World

RAPID Conference 2020

Jonathan Sontchi, MBA, MSA
Manager, Nuclear Strategy and Business Planning
Palo Verde Generating Station

September 28, 2020

About APS

Arizona's largest and longest-serving utility – since 1886

Service Territory

- 11 of 15 counties
- 34,646 square miles
- 1.2 million customer accounts

Arizona's largest taxpayer

- $3.4 B annual economic impact
- $1.0 B spent annually with local businesses statewide

About 6,000 employees

Peak load ~7,500 MW

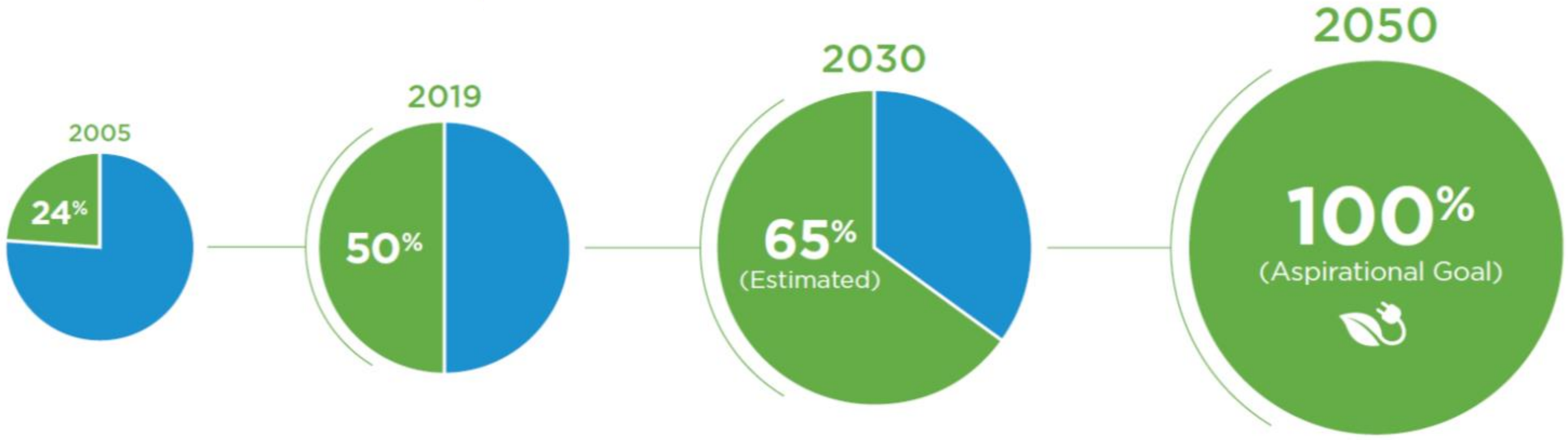
Our Clean Energy Future

Imagine a world with 100% clean energy.

We are.

aps

Our Clean Energy Commitment

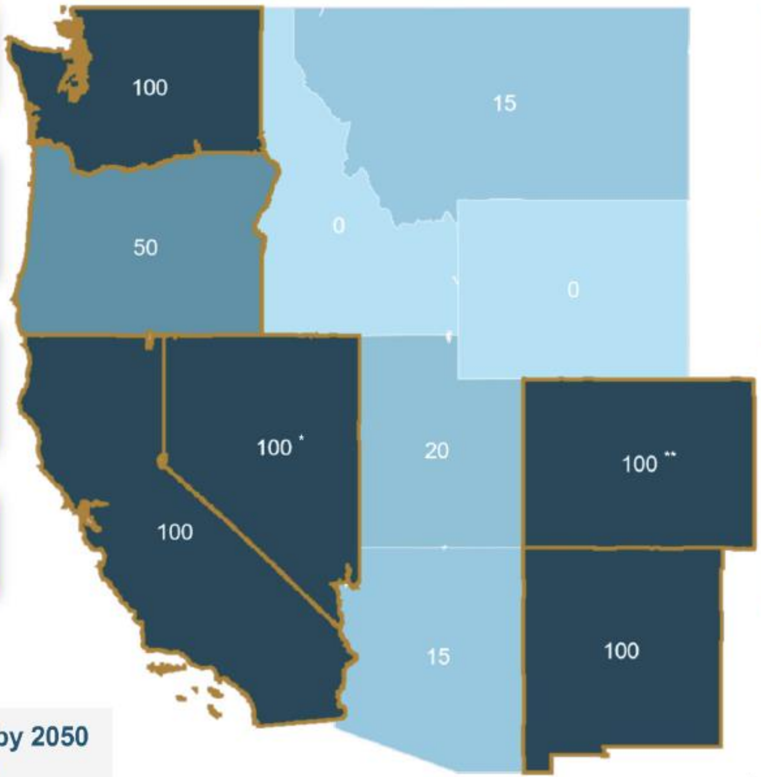


Washington
- **50% below 1990 by 2050**
- 80% by 2050

Oregon
- **75% below 1990 by 2050**
- 45% by 2035
- 80% by 2050

California
- **40% below 1990 by 2030**
- 80% by 2050
- Carbon neutral by 2045

Nevada
- **45% below 2005 by 2030**
- Near-zero emissions by 2050



CE Target
0 100

Clean energy target (%) by 2050
GHG economy emission
- **Bold = Law**
- Regular = Target

Idaho and Wyoming have no clean energy nor economy GHG emission targets

Montana, Arizona, and Utah have no economy GHG emission targets

Colorado
- **90% below 2005 by 2050**

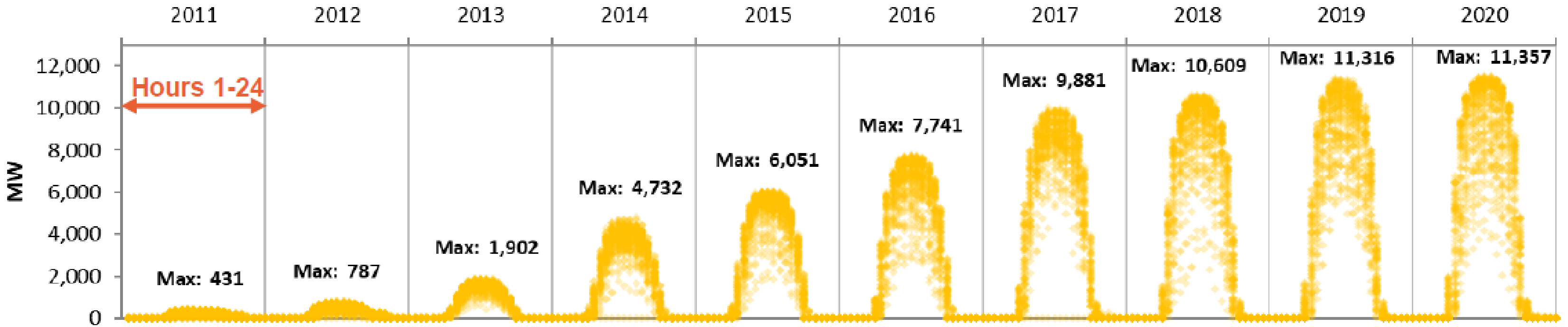
New Mexico
- 45% below 2005 by 2030

As of December 2019

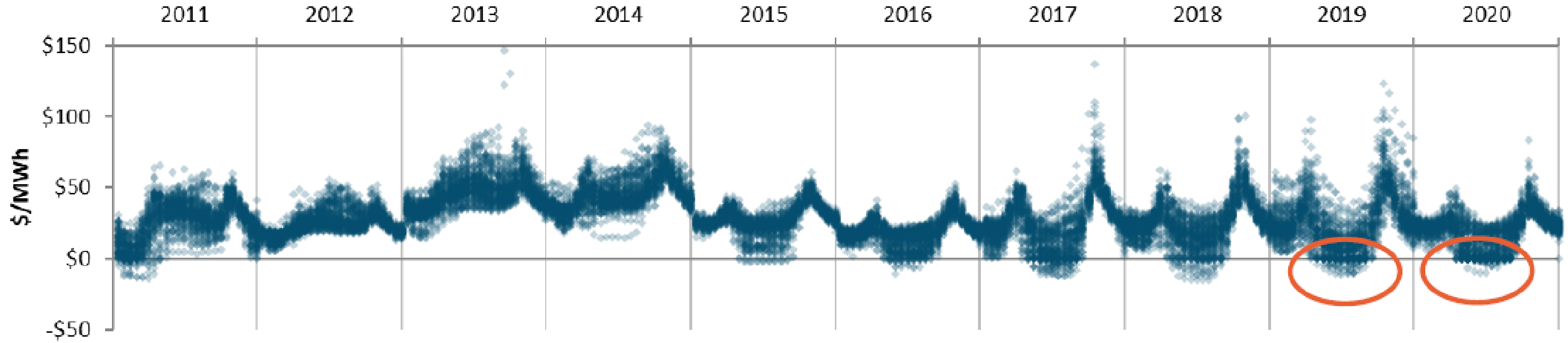
*Non-binding
**For utilities serving 0.5M+ customers

Impacts of Renewables

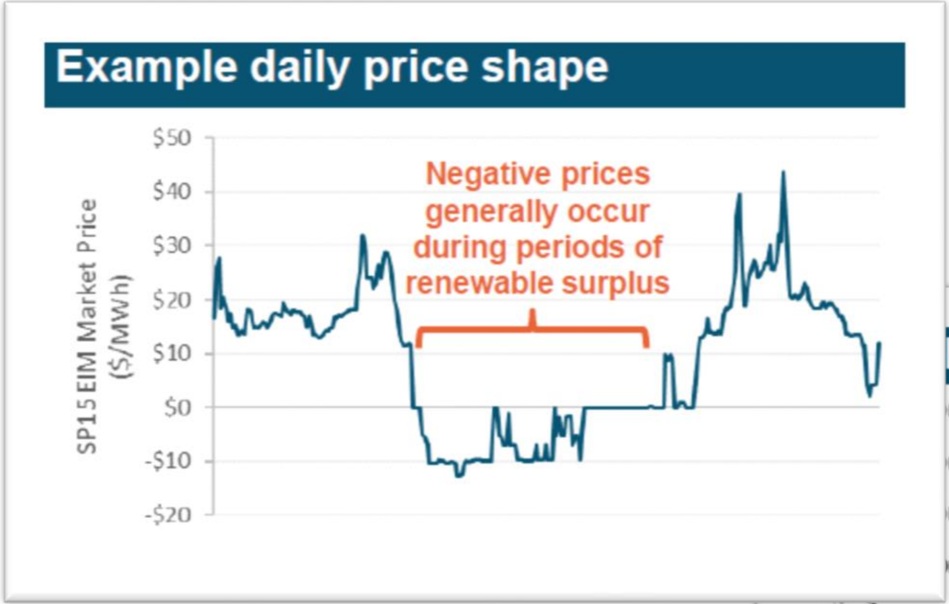
CAISO Hourly Solar Production, Spring Months (March – May)

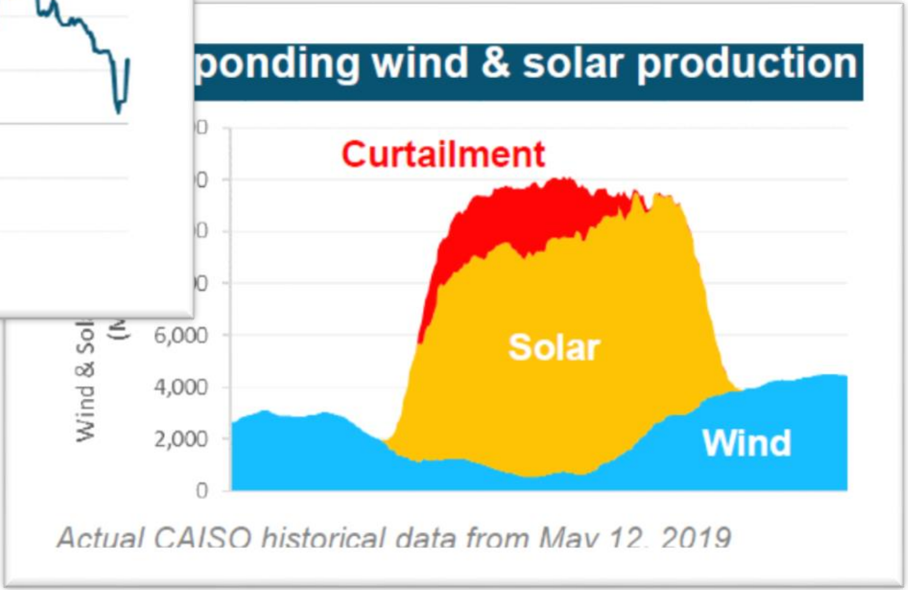


SP15 Day-Ahead Market Price, Spring Months (March – May)



Solar generation in CAISO linked to negative prices

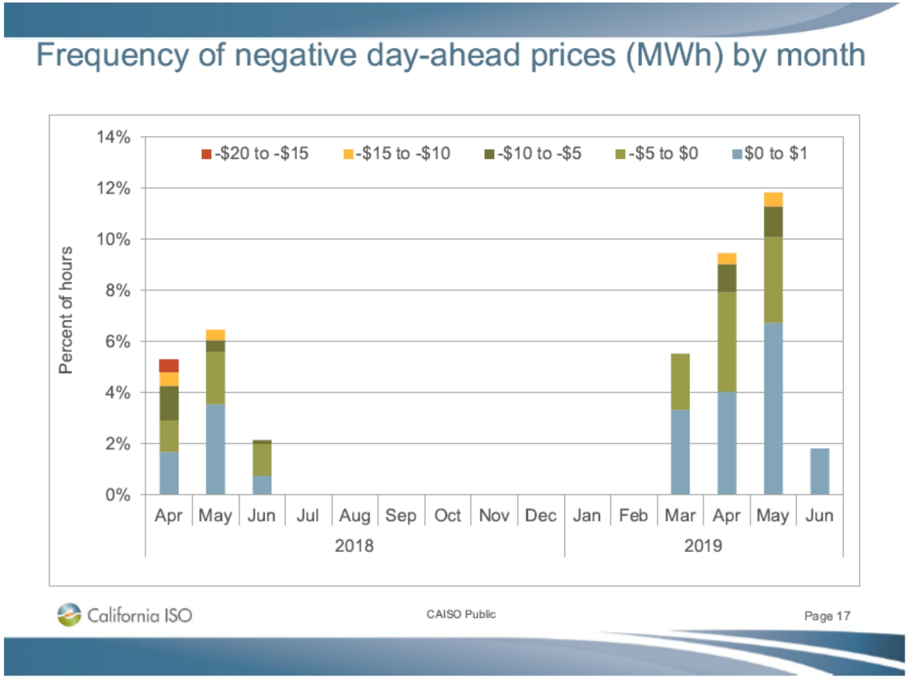


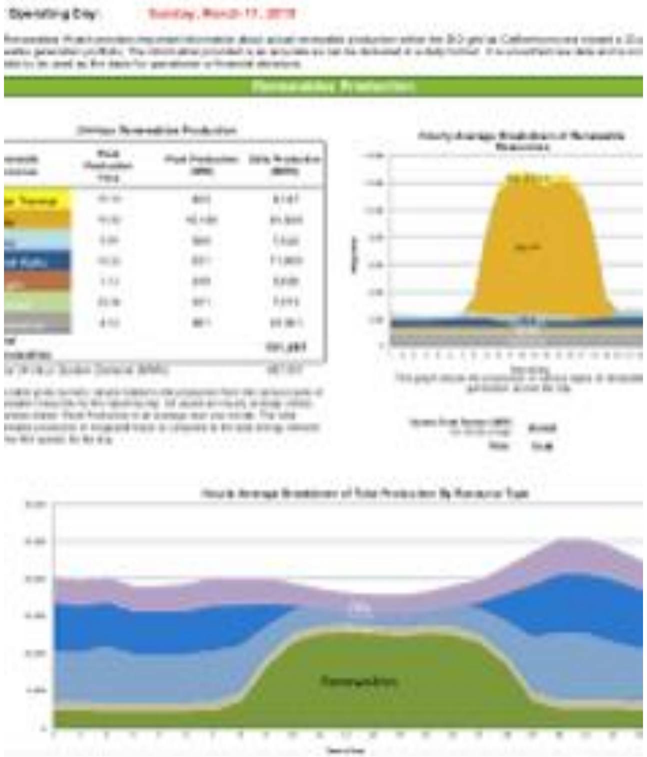


Drivers of curtailment

- **Local and transmission constraints**: Occurs where there is local congestion as the renewable build outpaces new transmission infrastructure. The source of curtailment can be mitigated through storage placement in congested pockets.
- **System wide over generation**: Occurs when there is either high renewable generation or inflexible thermal commitment that surpasses the needed load. This source of curtailment may be mitigated by storage, exports, and reduced commitment from thermal resources.

Negative day-ahead prices





E3 2025 Price Forecast – PV Node (2018$/MWh)

Month\Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Avg.
1	28	28	28	29	31	36	40	28	21	21	19	18	18	18	19	20	31	34	31	29	29	28	29	28	26.73
2	27	27	27	27	29	36	41	27	19	17	15	14	14	15	14	18	26	37	38	37	35	32	29	28	26.27
3	32	31	31	31	32	38	41	24	8	0	0	-1	-3	-2	-2	1	19	[illegible]	[illegible]	47	45	39	34	32	23.55
4	27	26	27	27	29	30	30	18	1	1	-1	-3	-2	-3	-3	-1	17	36	41	36	35	33	30	28	19.18
5	25	25	25	25	26	25	25	10	5	3	4	5	5	5	6	9	14	27	30	[illegible]	31	27	26	25	18.33
6	26	25	25	25	26	25	26	21	20	20	20	20	20	21	20	21	24	32	34	[illegible]	32	30	[illegible]	26	25.25
7	28	28	27	28	28	27	28	23	21	20	19	19	20	20	20	21	25	32	38	40	42	33	31	29	26.91
8	29	29	28	29	30	31	29	22	22	21	20	20	21	20	20	22	25	35	48	46	43	36	33	31	28.73
9	28	28	28	27	29	30	28	23	23	23	22	22	22	21	21	24	27	43	50	46	39	36	30	29	29.10
10	25	28	28	29	30	33	29	21	18	17	16	16	18	19	20	23	30	39	42	42	36	36	31	30	27.39
11	28	27	27	27	29	34	32	23	16	18	17	14	15	16	17	24	32	26	30	30	33	30	30	28	25.13
12	28	27	27	27	29	34	41	32	25	22	21	18	18	20	22	25	33	34	34	32	32	29	29	28	27.84

2025: prices in spring turn negative

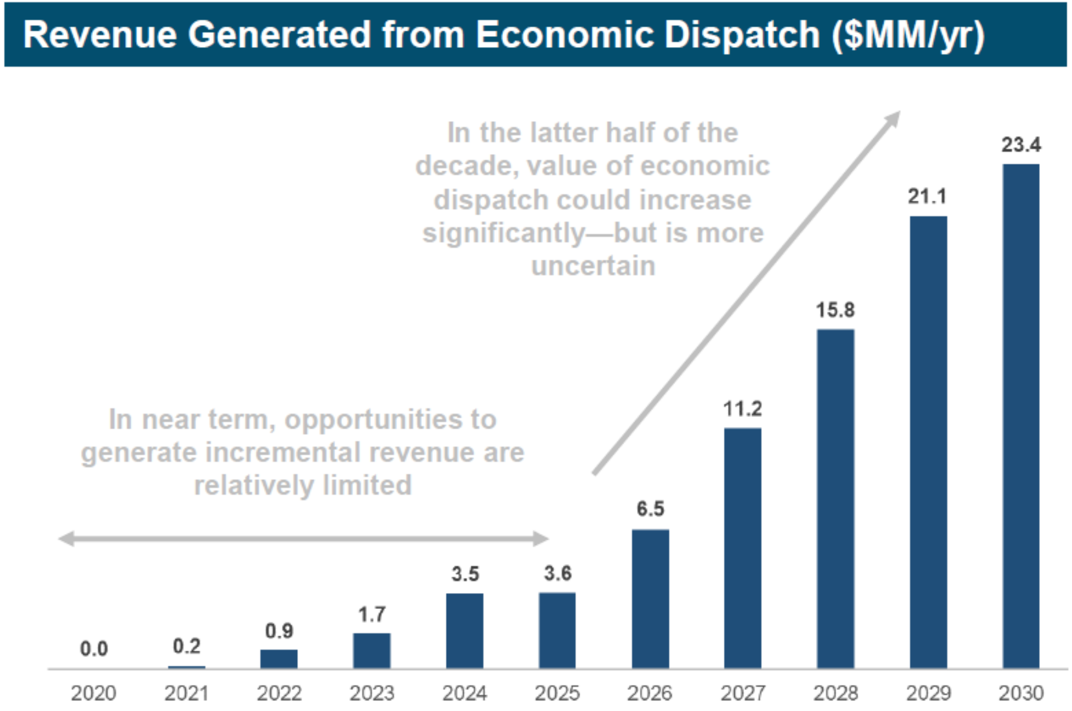
Curtailment drives frequent negative pricing during spring months

E3 2030 Price Forecast – PV Node (2018$/MWh)

Month\Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Avg.
1	48	48	47	45	45	46	43	39	13	2	-3	-2	-3	-4	-2	10	47	55	48	49	50	49	51	52	32.20
2	44	42	43	42	42	42	46	34	15	12	9	8	6	0	10	8	31	58	56	53	50	48	47	45	32.95
3	59	57	56	57	57	58	61	17	-21	-21	-15	-19	-20	-26	-16	-23	-14	[illegible]	[illegible]	60	63	[illegible]	[illegible]	[illegible]	28.70
4	58	55	55	52	53	53	47	-10	-24	-21	-26	-24	-23	-26	-26	-21	-17	57	64	63	63	61	59	57	24.12
5	55	53	53	52	52	43	39	-18	-24	-24	-24	-25	-23	-20	-21	-19	-3	[illegible]	[illegible]	60	60	[illegible]	[illegible]	54	22.53
6	34	32	32	33	34	28	27	8	-3	-1	-1	-2	0	2	5	9	20	44	46	47	46	41	[illegible]	55	23.12
7	35	34	34	34	36	32	31	20	6	8	7	7	9	9	10	14	21	34	40	39	41	39	37	37	25.47
8	37	36	36	36	39	40	32	23	10	11	8	8	12	12	13	17	24	35	42	41	41	40	40	38	28.03
9	40	41	38	36	40	44	34	19	9	7	2	3	8	10	11	19	30	47	46	42	44	45	43	41	29.18
10	50	49	46	43	46	48	46	17	3	-3	-7	-8	-6	-3	1	20	53	80	81	68	62	61	56	55	35.75
11	47	44	41	41	41	44	52	29	2	-3	-7	-8	-9	-6	-3	19	57	54	55	52	52	53	48	48	30.98
12	36	36	34	33	34	36	40	40	35	26	22	17	17	20	23	30	49	43	42	39	38	37	37	37	33.28

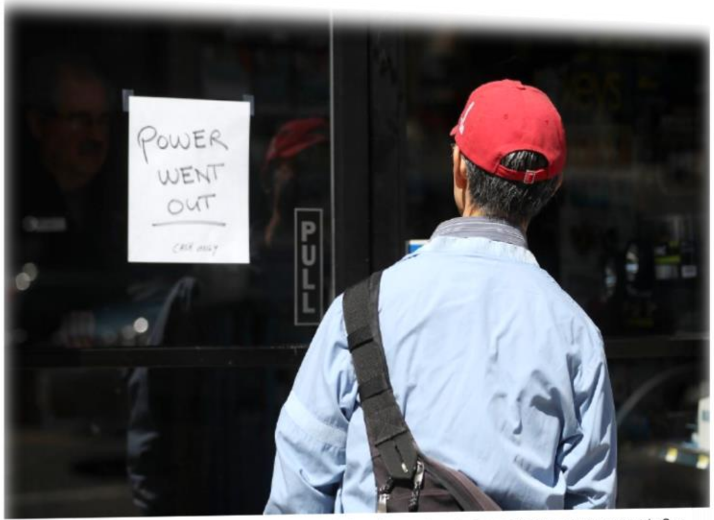
2030: daytime negative pricing is the norm

All non-summer months experience negative pricing on a routine basis



Notes:
- *'Revenue saved' = (P_{max} – P_t) * Energy Price$_t$*
- *Results for two units, each with P_{max} = 1,310 MW*
- *Results based on day-ahead market*
- *2018 real dollars*

"Revenue Generated" is translated to "revenue saved" by combating the impact of negative prices



A pedestrian looks at a sign posted on the door of a hardware store during a citywide power outage in San Francisco, Calif. | Justin Sullivan/Getty Images

CALIFORNIA

California has first rolling blackouts in 19 years — and everyone faces blame

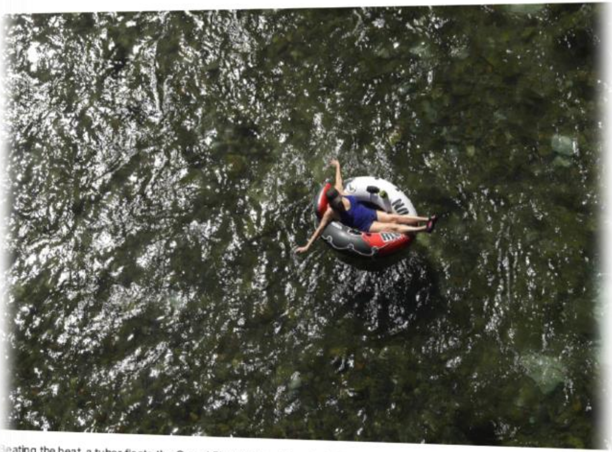
While California braced for another round of rolling blackouts Monday night, the state's grid operator held off for a second straight night.

By DEBRA KAHN and COLBY BERMEL | 08/18/2020 12:19 AM EDT | Updated 08/18/2020 01:24 PM EDT

Texas Power Prices Briefly Surpass $9,000 Amid Scorching Heat

y Chris Martin and Naureen S Malik
ugust 12, 2019, 1:36 PM MST
pdated on August 13, 2019, 1:25 PM MST

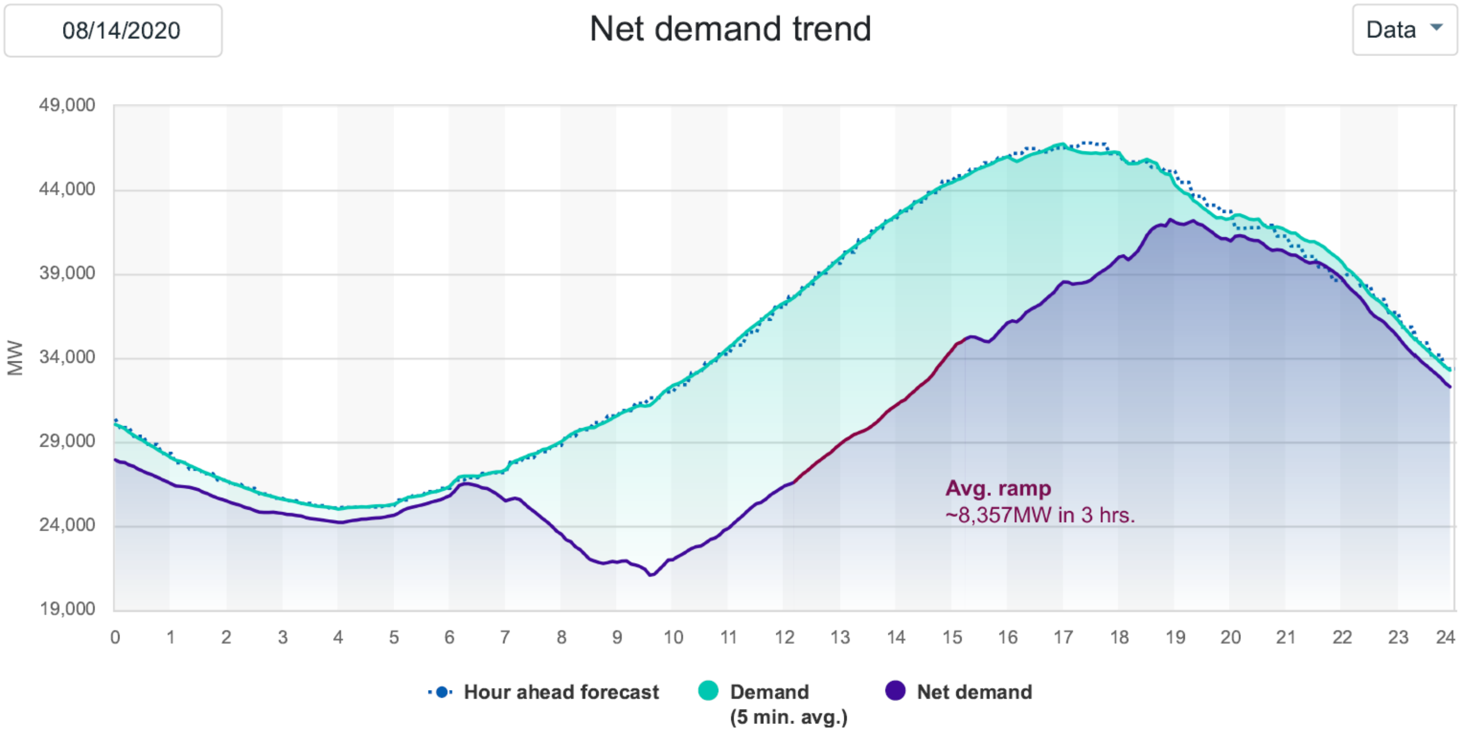
- Texas grid operator expects to break Monday's record demand
- Heat to peak on Tuesday, after temperatures top 100 degrees



eating the heat, a tuber floats the Comal River in New Braunfels, Texas. *Photographer: Eric Gay/AP Photo*

lectricity prices in Texas soared to $9,000 a megawatt hour as the state's grid operator called or energy conservation amid extreme heat scorching the region.

August 14, 2020 CAISO



CAISO Prices

- Wednesday, September 9, 2020, hours 0800-0900
- Marginal energy cost (Day-ahead) $24.81 / MWh
- No Negative Prices

CAISO Prices

- Tuesday, August 18, 2020, hours 18-19
- Marginal Energy Cost (Day-ahead) $1,062.64 / MWh
- No negative prices

Potential Solutions

Supply-side solutions

Potential Solutions

Curtail generation during periods of system wide over generation that is causing negative pricing.

- Challenges operations
- Plant does not reach full capability factor of clean energy source
- Response time for power maneuvers

Potential Solutions

Shift the supply curve through utilizing storage during periods of system wide over generation and resupplying during ramp periods in the evening when renewable generation natural curtails due to environment

- Large storage medium needed
- Keeps plant at full capability factor
- Takes advantage of high ramp prices

Potential Solutions

Repurpose excess energy during system wide over generation periods to a different commodity / market

- Introduces new emerging markets to the companies portfolio
- Can have multiple purposes with commodity
- Challenges in the regulatory arena

The Hydrogen Economy

Hydrogen Usage

Hydrogen has been used as an energy carrier for more than a century

- Transportation
  - Motor vehicles
  - Dirigibles and hot air balloons to human spaceflight
- Economic and Industrial Development
  - Petroleum refining – 33%
  - Ammonia production and fertilizers – 27%
  - Methanol production – 11%
  - Steel production – 3%

Hydrogen Production

Worldwide “on purpose” production of hydrogen is ~70 MMT per year

- 96% of “on purpose” hydrogen production is from steam methane reformation
- U.S. produces and uses ~10 MMT per year (12%–16% of the worldwide production)

Hydrogen Production

Steam Methane Reformation

- High-temperature steam (700°C–1,000°C) to methane at 3–25 bar
- Produces hydrogen, carbon monoxide, and carbon dioxide

Electrolysis

Low Temperature Electrolysis – Anode & Cathode with Electrolyte

- Alkaline Electrolysis - Electrolyte is sodium or potassium hydroxide
- Proton Electrolyte Membrane Electrolysis - Electrolyte is a solid specialty plastic material

High Temperature Electrolysis

- Solid ceramic material at very high temperatures (700°–800° C)

The future of hydrogen production

- SMR with carbon capture and storage (CCS), or “BLUE” hydrogen: This method involves coupling SMR with CCS which allows for the reduction of atmospheric carbon emissions.
- Electrolysis using renewable electricity, or “GREEN” hydrogen: This method involves splitting water into hydrogen and oxygen via electrolysis with renewable electricity from generations sources on0site (e.g. dedicated wind or solar plant) or sourced from the grid to make use of otherwise-curtailed renewable electricity.
- Electrolysis using nuclear energy, or “PINK” hydrogen: This method involves splitting water into hydrogen and oxygen using electricity, and in some cases heat, from nuclear energy.

Current Policy Activities

European Union

- Long-term decarbonization strategy including hydrogen pathways
- Revised directive on use of renewables to allow hydrogen produced from renewables to count toward 2030 targets
- Established “Hydrogen Energy Network” for member states
- Twenty-eight countries and 100 businesses, NGOs and institutions signed Linz Declaration “Hydrogen Initiative” promoting sustainable hydrogen

European Union (country specific)

- Austria – focus on renewables to hydrogen for power generation
- Germany – significant investments in fuel cells, hydrogen refueling stations, fuel cell vehicles and micro cogeneration; supported first commercial hydrogen powered train
- United Kingdom – investments in storage at scale, investigating hydrogen for building heat decarbonization, testing blending up to 20% hydrogen blend in national natural gas network

Current Policy Activities

Japan

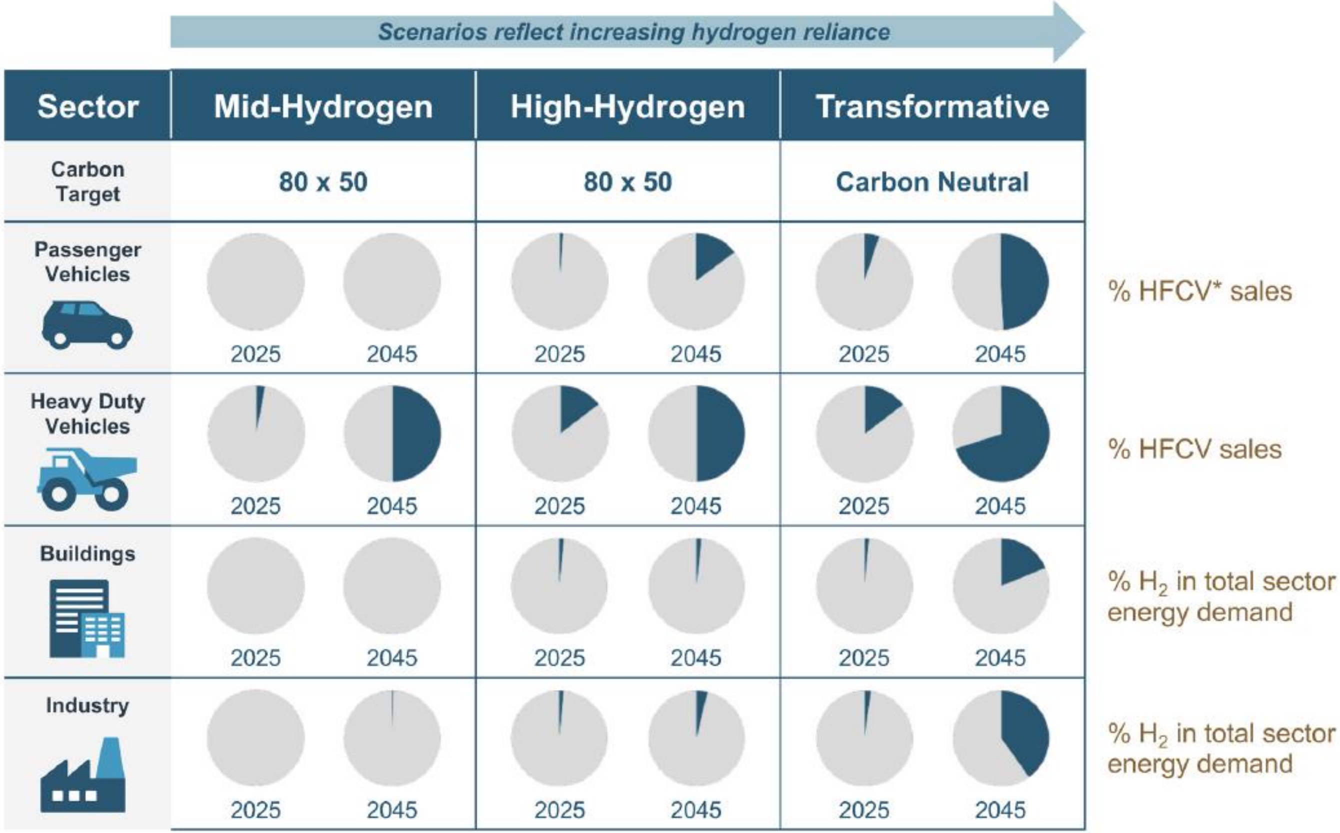
- Hosted first Hydrogen Energy Ministerial (associated with Clean Energy Ministerial)
- Updated Basic Hydrogen Strategy to revise hydrogen production goals, fuel cell cost and deployment, and burning of hydrogen in combustion turbines

China

- Ten Cities program for electric vehicles to be replicated for hydrogen powered vehicles
- Announced first Chinese Hydrogen City
- Committed to 1,000 hydrogen refueling stations and 1,000,000 fuel cell electric vehicles by 2030

United States

- Extended and enhanced 45Q regarding storage of CO_2, and conversion of CO_2 to other products using hydrogen
- American Energy Innovation Act (S. 2657)
- California – Amended Low Carbon Fuel Standards to require more stringent carbon reduction by 2030, and established California Fuel Cell Partnership that targets 1,000 hydrogen refueling stations and 1,000,000 fuel cell electric vehicles by 2030



* HFCV refers to hydrogen fuel cell vehicle.

Potential uses of hydrogen

- Energy storage (load shifting)
- Combustion when blended with natural gas or as pure hydrogen burner for electric power generation
- Industrial processes and transportation fuel

Opportunities

Opportunity 1

- Energy Storage (Load Shifting)
    - Core opportunity for near term carbon-free grid capacity through the use of small scale modular hydrogen turbines (5-10MW) and advanced fuel cell systems
    - Potential for synthetic hydrocarbon fuel production from carbon free hydrogen to replace fossil fuels for the diesel generator peaking units

Opportunities

Opportunity 2

- Existing Generation Decarbonization
  - Core opportunity for repowering existing combustion turbines and large scale on-site hydrogen storage
- New Hydrogen-fueled Generation and Regional Very Large Hydrogen Storage
  - Evaluation of storage in caverns

Opportunities

Opportunity 3

- Hydrogen Fuel for Hydrogen for Industrial Processes and Transportation
    - Optional opportunity for revenue generation to support the growth of hydrogen in the transportation sector
    - Optional opportunity for revenue generation for hydrogen as a feedstock for other energy commodities in regional markets

Closing

Questions?