Economics of Flexibility

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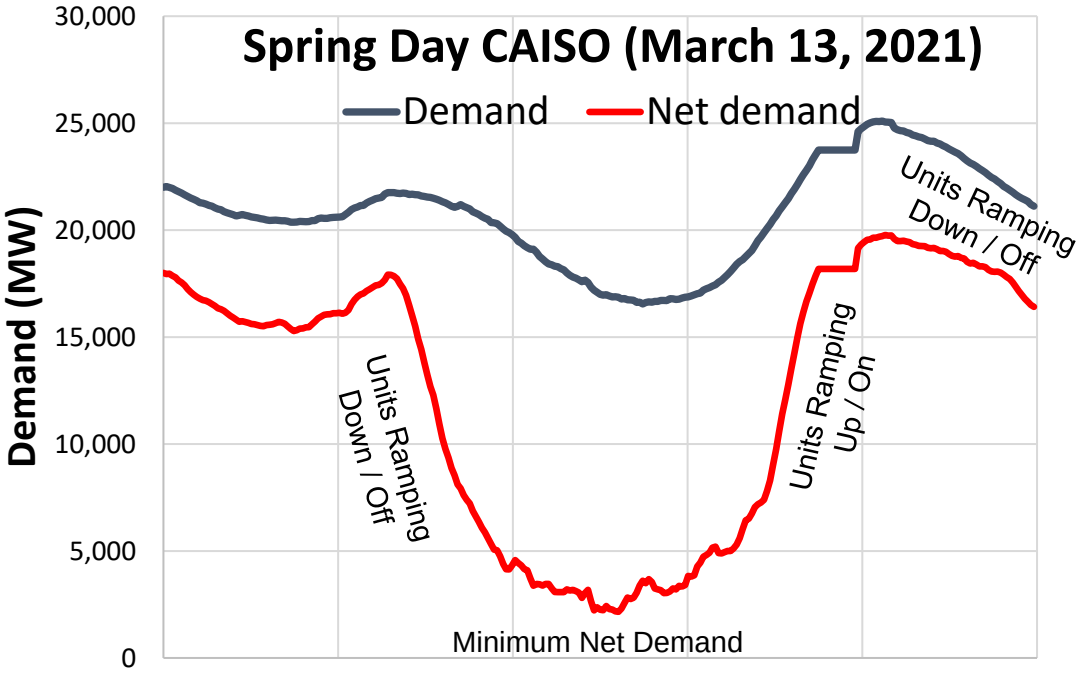
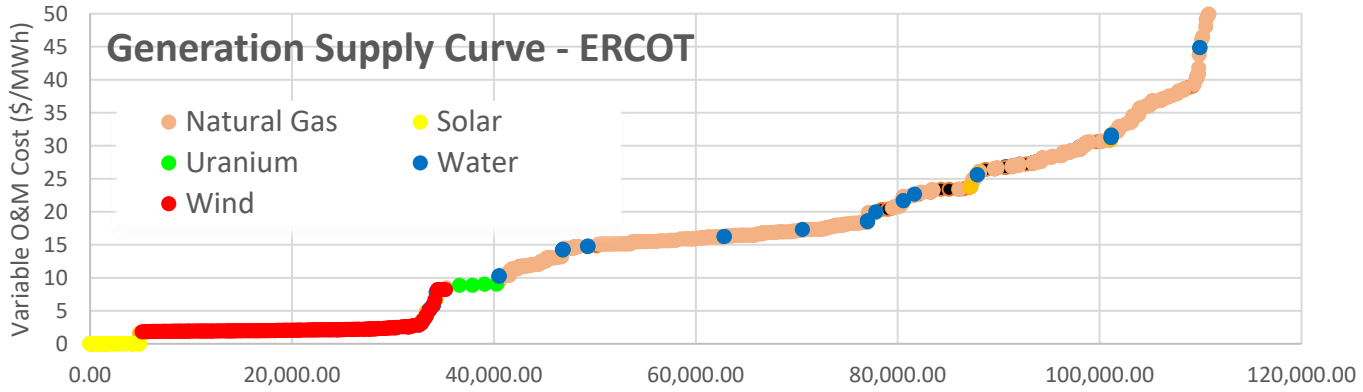
Understanding Flexibility
California and Texas

Driven by Renewables
Near Zero Marginal Costs and Variability of Supply

Spring Day CAISO	Demand	Net Load	Implication
Minimum Demand	16,700 MW	**2,200 MW**	Lower minimum loads, more on/off operation
Peak Ramping Rate	~2900 MW / hr	**~8300 MW / hr**	Faster loading/unloading, wear and tear
Peak Demand	25,000 MW	**20,000 MW**	Installed dispatchable capacity required
Daily Total Energy	498,000 MWh	**294,000 MWh**	Fewer units of production across capacity
Mileage (5 min)	21,200 MW	**48,200 MW**	More flexible capacity required





Financial Implications
Economics of Flexibility

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Near Zero Marginal Costs and Variability of Supply

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1. Annual Capacity Factors Drop
   Renewables cover more and more annual energy needs
2. Dispatchable Capacity need does not drop as fast as CF
   Windless Nights
3. Flexible operation
   Driven by renewable variability, and very low energy prices when renewable energy is available (Sunny / Windy, Spring days)

Cost Element	Drivers	Implication
Capital Cost $/kW	1,2	Low-capacity factors mean long payback times if relying on energy payments (debt repayment)
Annual Fixed Costs ($/kW)	1,2	Low-capacity factors mean difficult to cover annual fixed costs (going forward costs)
Variable O&M Costs ($/MWh)	1,2,3	Good trade-off for these to be higher if they allow for more flexible operation and/or allow for Capital and Annual Fixed Costs to be minimized

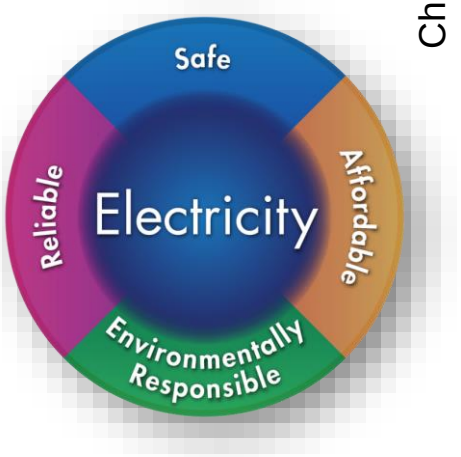
Spectrum of Flexible Operation

Operating Mode

Defining Characteristics

Increasing Relative (Marginal) Cost of Generation

Baseload	Load Following	Cycling (Weekend)	Cycling (Two-Shift)	Extended Shutdowns (week / month / season)
Maximum Load Operational Reliability Cost	Maximum Load Minimum Load Ramp Rate Operating Reliability Cost	Start Reliability Minimum Load Ramp Rate Operating Reliability Cost	Start Reliability Startup Speed Minimum Load Ramp Rate Operating Reliability Cost	Minimum Load Preservation of Equipment Availability of Equipment (Startup Speed) Cost



Economic Viability

Lower Minimum Load

Fuel Changes (Lower-Cost Fuels)

Energy Market — **Balancing Markets** — **Capacity Market**

Externalities significantly impacting costs / operation includes fuel prices, changing regulations

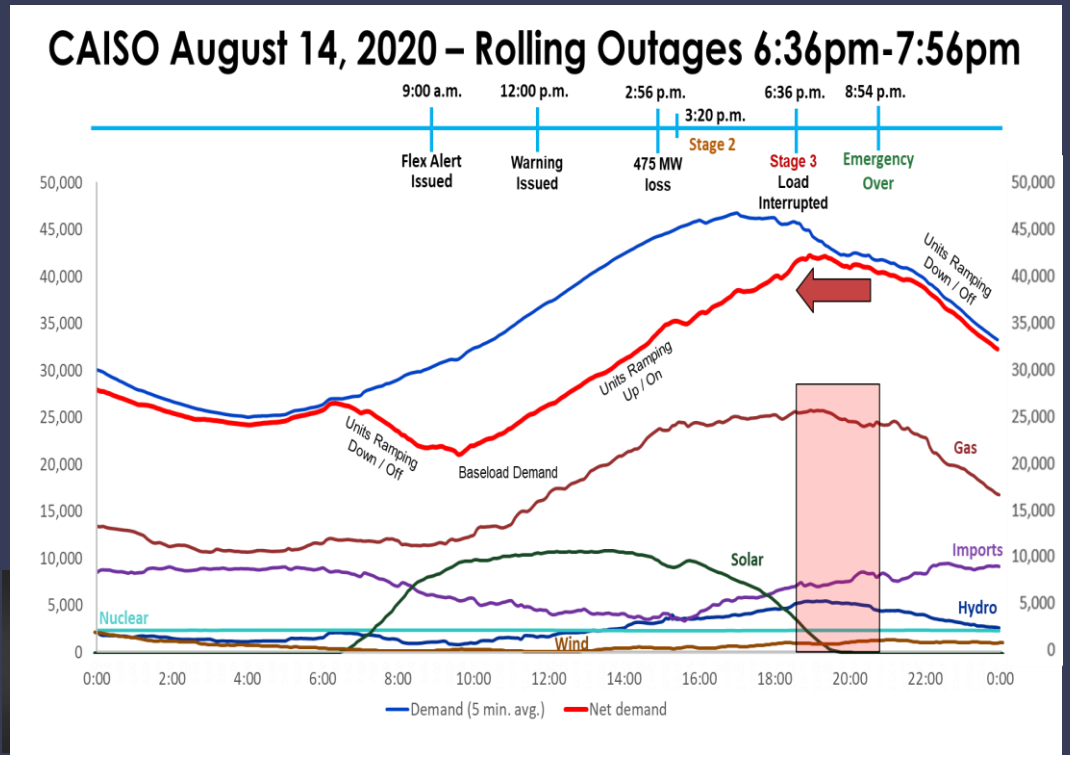
Retrofits for flexibility are possible but economics can be challenging (especially for ramp rate)

Key Days for Dispatchable Generation (Flexible Thermal)

Increasingly defined by Variable Renewable Energy

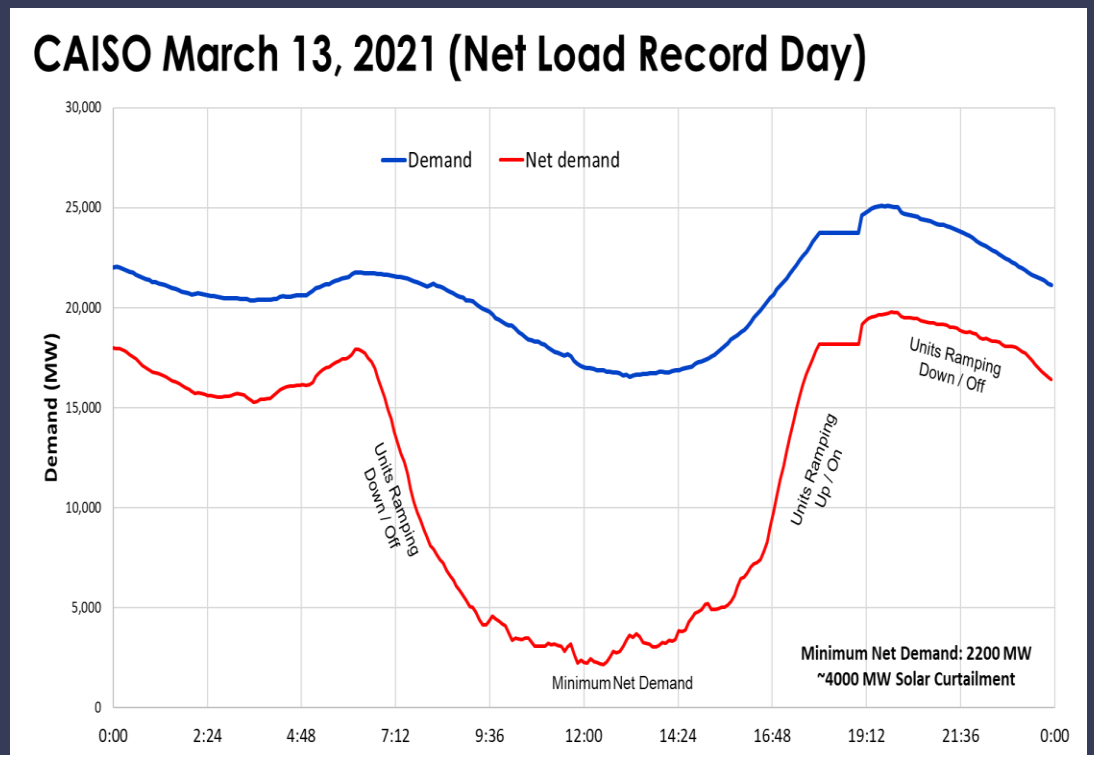
Net Load Peak Days

- All units required to meet the peak
- Hottest or coldest days
  - Hot days limit output and efficiency
  - Cold days reliability concerns



Net Load Minimum Days

- Units needed to turn down or shut down but prepared to respond
  - Can be offline for days before being required



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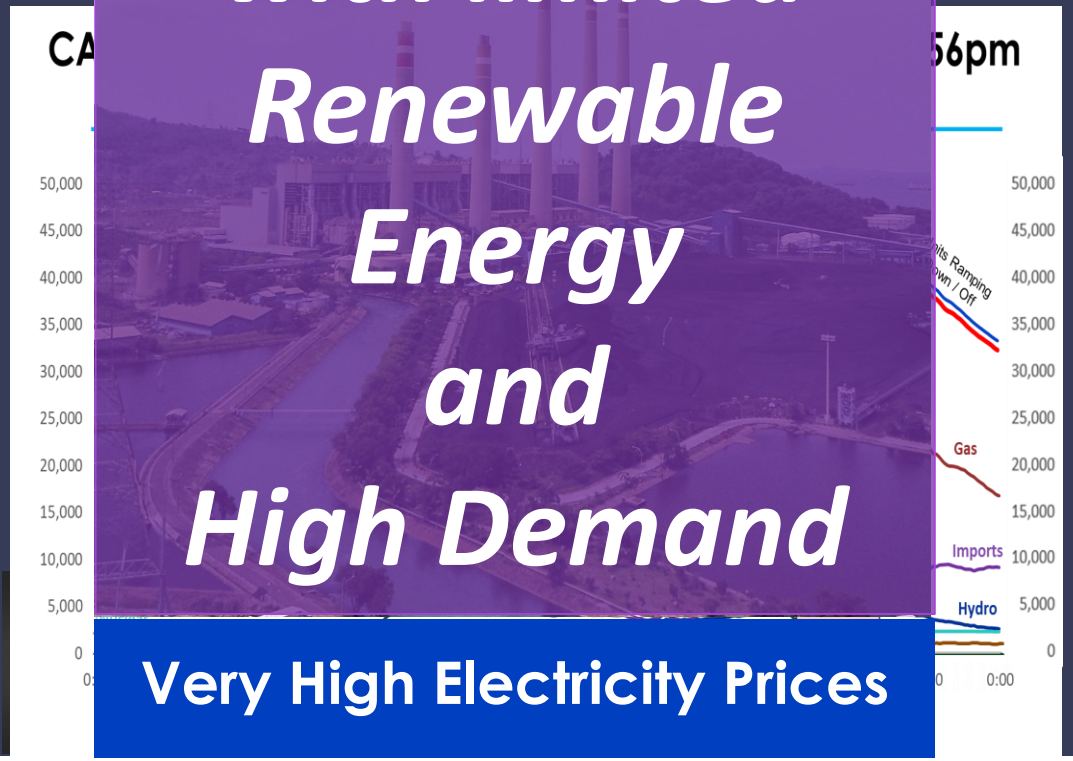

Days / Hours with limited Renewable Energy and High Demand

Very High Electricity Prices

Net Load Minimum Days

- Units
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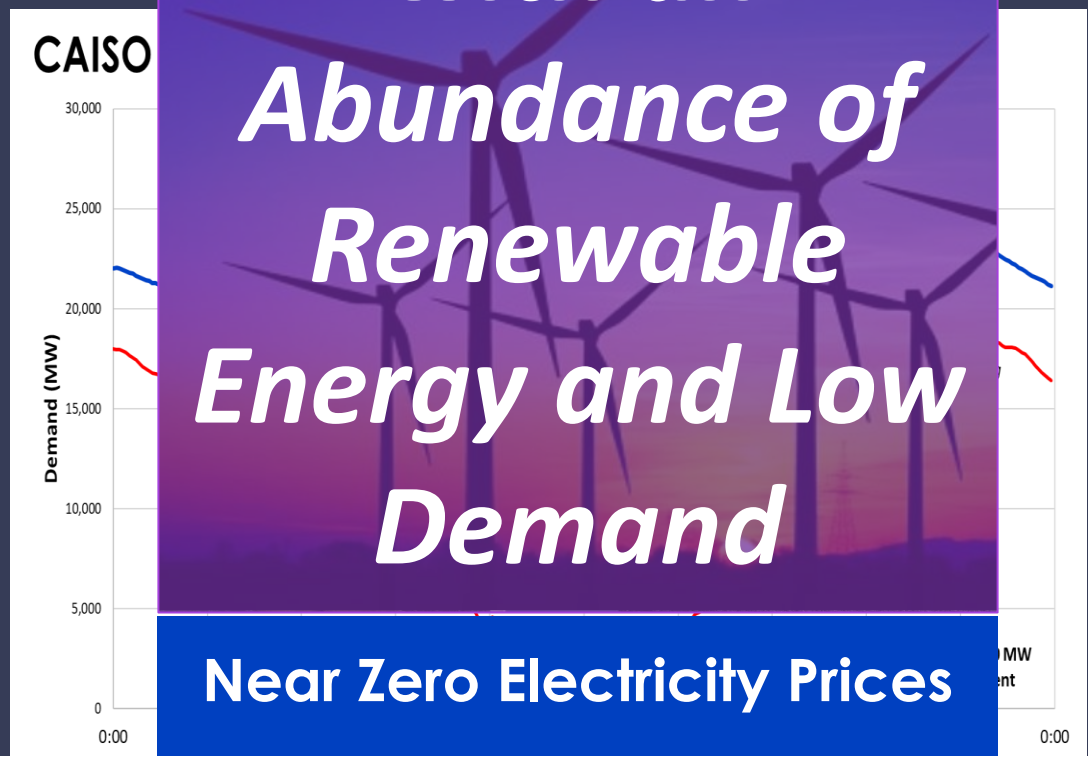

Days / Hours with an Abundance of Renewable Energy and Low Demand

Near Zero Electricity Prices

Asset Integrity & Flexible Operation – “Bow Wave Effect”

- Most asset integrity issues arising from increased operational flexibility are ‘bow wave’
  - Do not result in immediate operational limits, damage is being accumulated but it is not simple to quantify
  - By the time damage is apparent it may have become very costly to correct

Complexity feeds the wave

Complexity tends to increase with flexibility

Example Relative Operating Statistics

	Load Changes	Starts	Capacity Factor
Baseload	4	1	92%
Load Following	2024	1	70%
Weekend Cycling	1646	49	51%
Daily Cycling	2178	242	41%
Extended Shutdown	1206	134	23%