DECEMBER 5, 2023

ASSESSING THE RESOURCE ADEQUACY IMPACTS OF AN EVOLVING GRID

CONSIDERATIONS FOR NEW MEXICO AND OTHER STATE REGULATORS

TODD LEVIN
Electricity Markets Team lead
Argonne National Laboratory

RESOURCE ADEQUACY

What is resource adequacy?

- Resource adequacy reflects the ability of system to serve electricity demand at all times
  - i.e., there are adequate resources in the system
- It is one component of reliability, others include
  - Operational reliability
  - Resilience
- It does not necessarily reflect decisions made on operational time scales

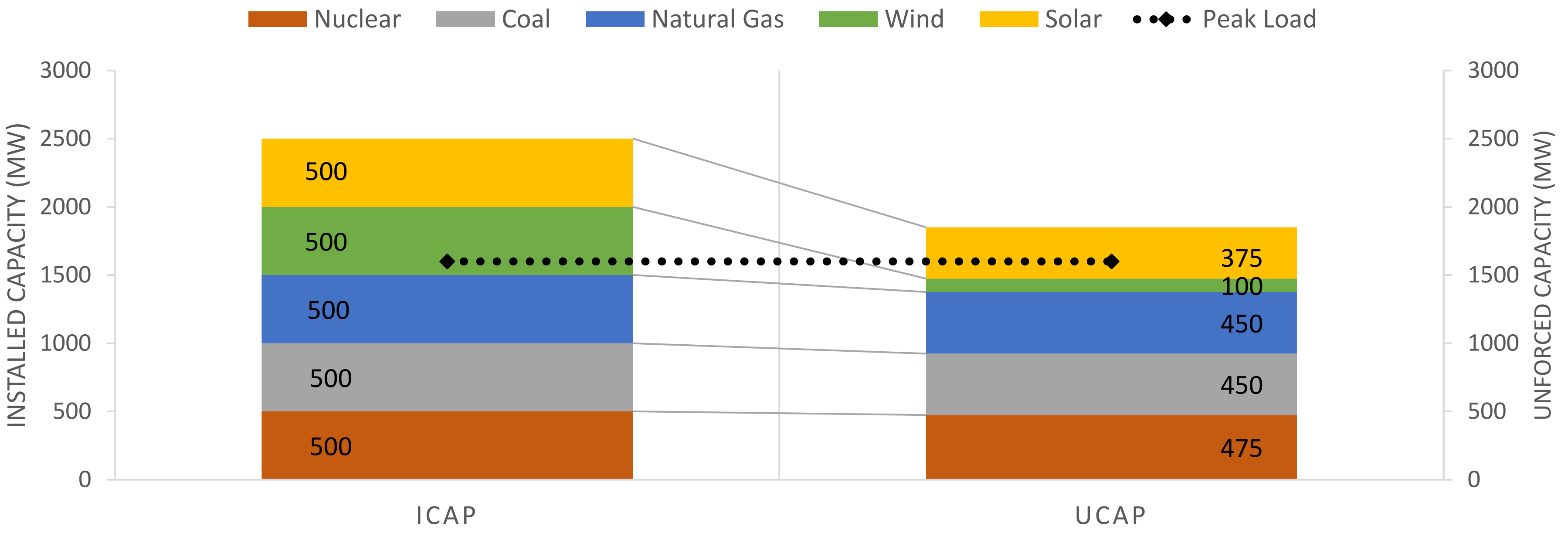
TRADITIONAL RESOURCE ADEQUACY METRICS

- **Installed capacity** (ICAP) – maximum output of a plant in MW
- **Unforced capacity** (UCAP) – capacity that can be relied upon to serve peak load
  - For fossil plants this is similar to installed capacity (~85%-98%)
  - For wind and solar it is less straightforward to determine
  - This conversion factor from ICAP to UCAP is typically called a **capacity credit**
  - **Capacity accreditation** methods differ between regions and markets
- **Planning reserve margin (PRM) -** amount by which UCAP exceeds forecast peak demand
  - Fixed target is typically set based on reliability assessment modeling
  - Has worked well as a measure of resource adequacy in thermal dominated systems
  - Less appropriate for systems with large amounts of wind and solar

*https://www.ercot.com/gridinfo/resource

PRM EXAMPLE

Hypothetical system



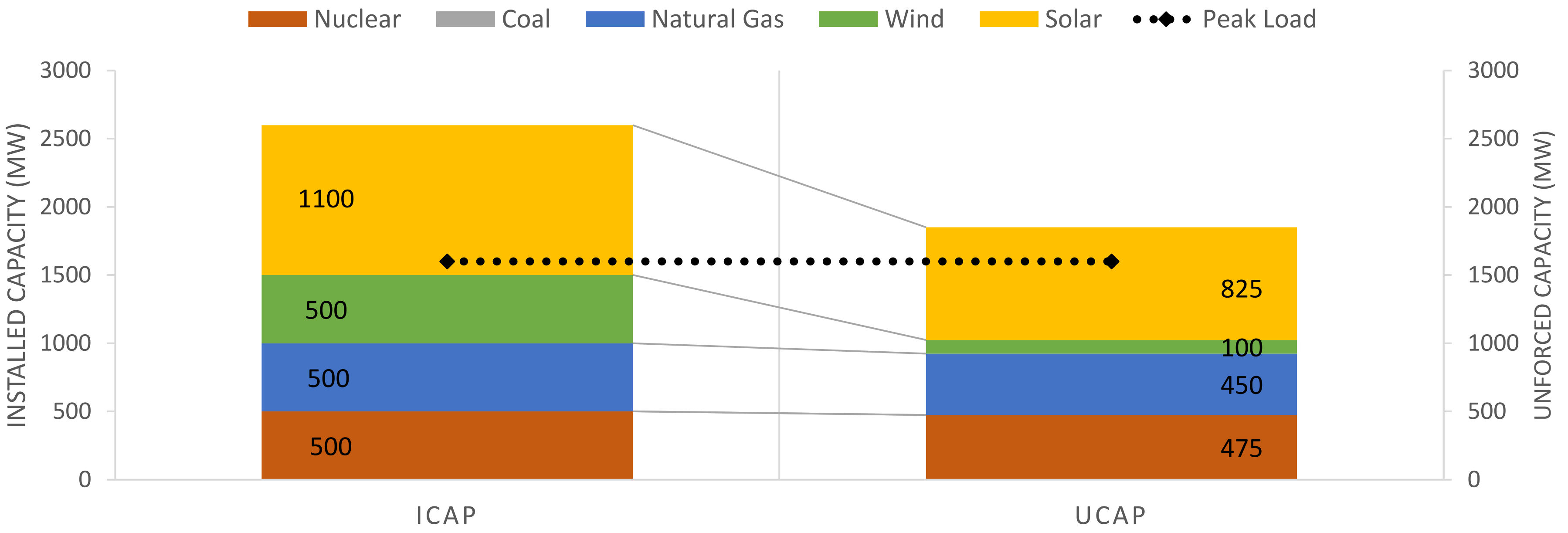
Peak Load = 1600 MW

Unit Type	ICAP	Capacity Credit	UCAP
Solar	500	75%	375
Wind	500	20%	100
Nuclear	500	95%	475
Coal	500	90%	450
Natural Gas	500	90%	450
Total	2500		1850

$$PRM = \frac{1850\ MW}{1600\ MW} - 1 = 15.625\%$$

PRM EXAMPLE

500 MW of coal is retired, how much solar as a replacement?



Solar Replacement = 500 * $\frac{90\%}{75\%}$

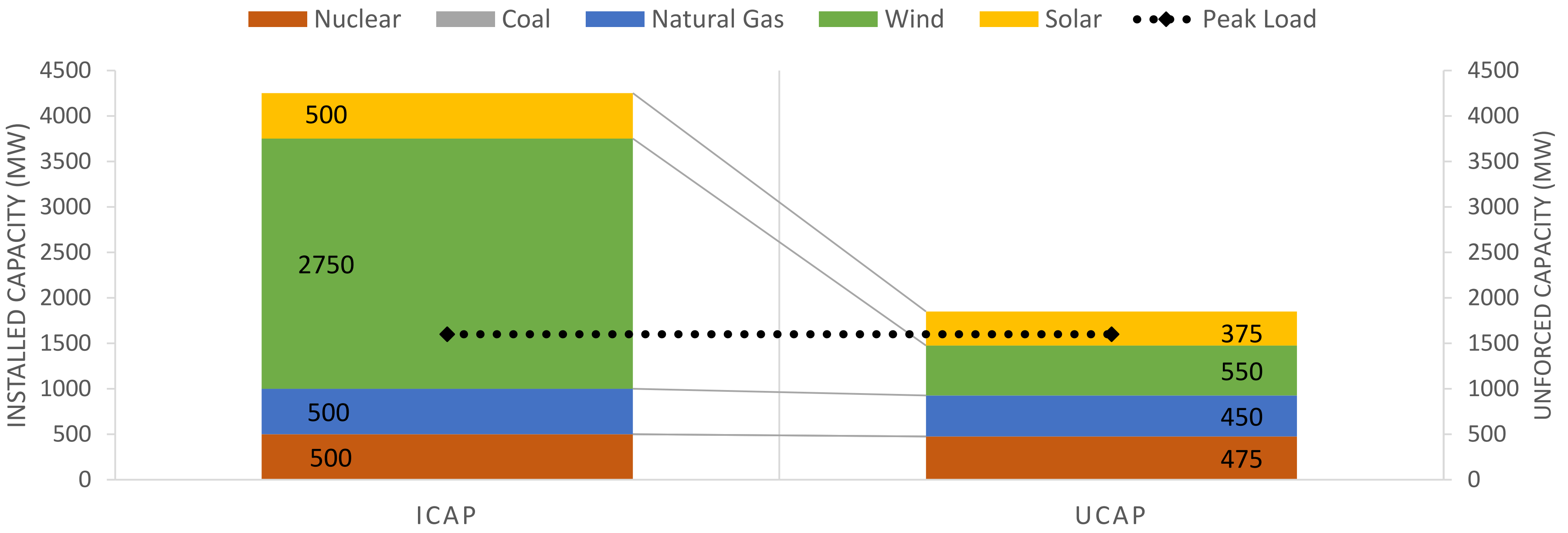
= 600 MW

Unit Type	ICAP	Capacity Credit	UCAP
Solar	1100	75%	825
Wind	500	20%	100
Nuclear	500	95%	475
Coal	0	90%	0
Natural Gas	500	90%	450
Total	2600		1850

PRM = $\frac{1850\ MW}{1600\ MW}$ - 1 = 15.625%

PRM EXAMPLE

500 MW of coal is retired, how much wind as a replacement?



Wind Replacement = 500 * $\frac{90\%}{20\%}$

= 2250 MW

Unit Type	ICAP	Capacity Credit	UCAP
Solar	500	75%	375
Wind	2750	20%	550
Nuclear	500	95%	475
Coal	0	90%	0
Natural Gas	500	90%	450
Total	4250		1850

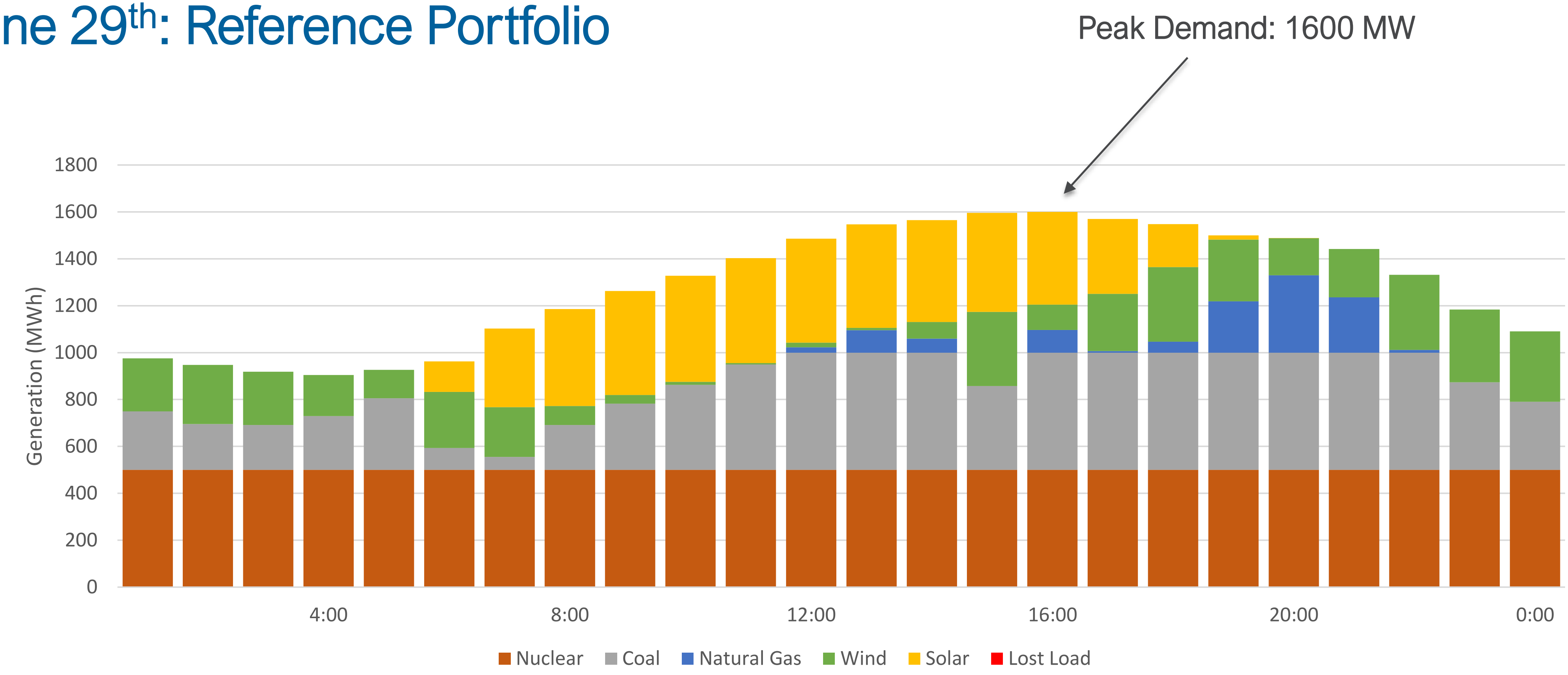
PRM = $\frac{1850 \text{ MW}}{1600 \text{ MW}}$ - 1 = 15.625%

SHORTCOMINGS OF PRM

- Only accounts for the single peak load hour
  - Peak **net** load hour will shift as the system portfolio evolves
- Capacity credits of wind and solar resources depend on system portfolio
  - Credit value decreases with increasing penetration
- Demonstration with a **stylized merit order dispatch**
  - Dispatch costs: Solar < Wind < Nuclear < Coal < Natural Gas
- Adding progressively more solar
- Wind, solar and load data from NREL's ReEDS model for New Mexico (p31)

MERIT ORDER DISPATCH

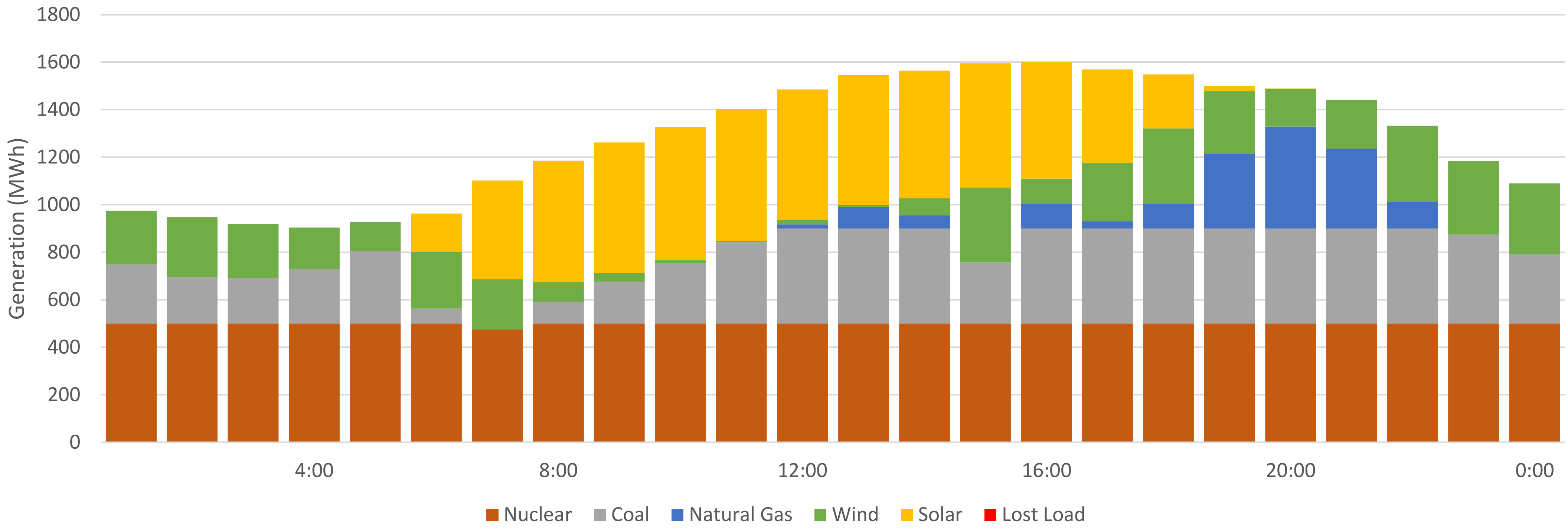
June 29th: Reference Portfolio



MERIT ORDER DISPATCH

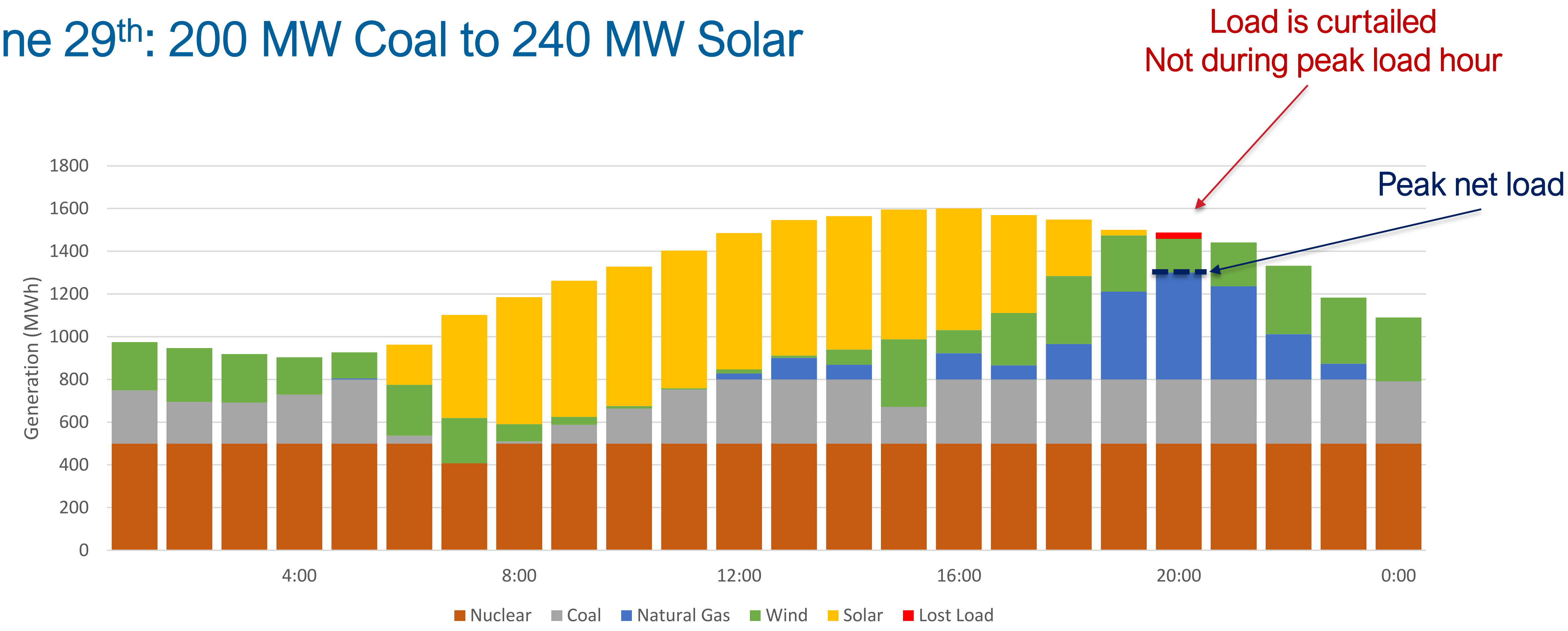
June 29th: 100 MW Coal to Solar

No reliability issues



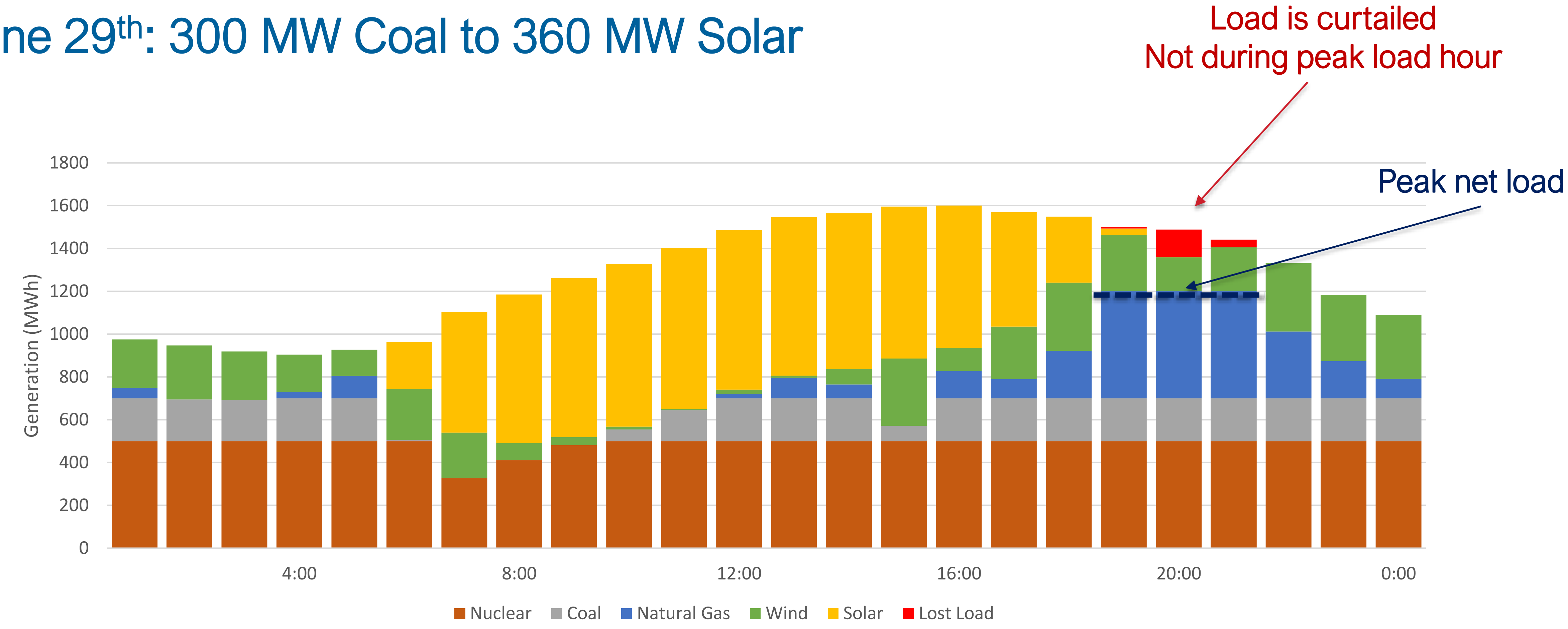
MERIT ORDER DISPATCH

June 29th: 200 MW Coal to 240 MW Solar



MERIT ORDER DISPATCH

June 29th: 300 MW Coal to 360 MW Solar

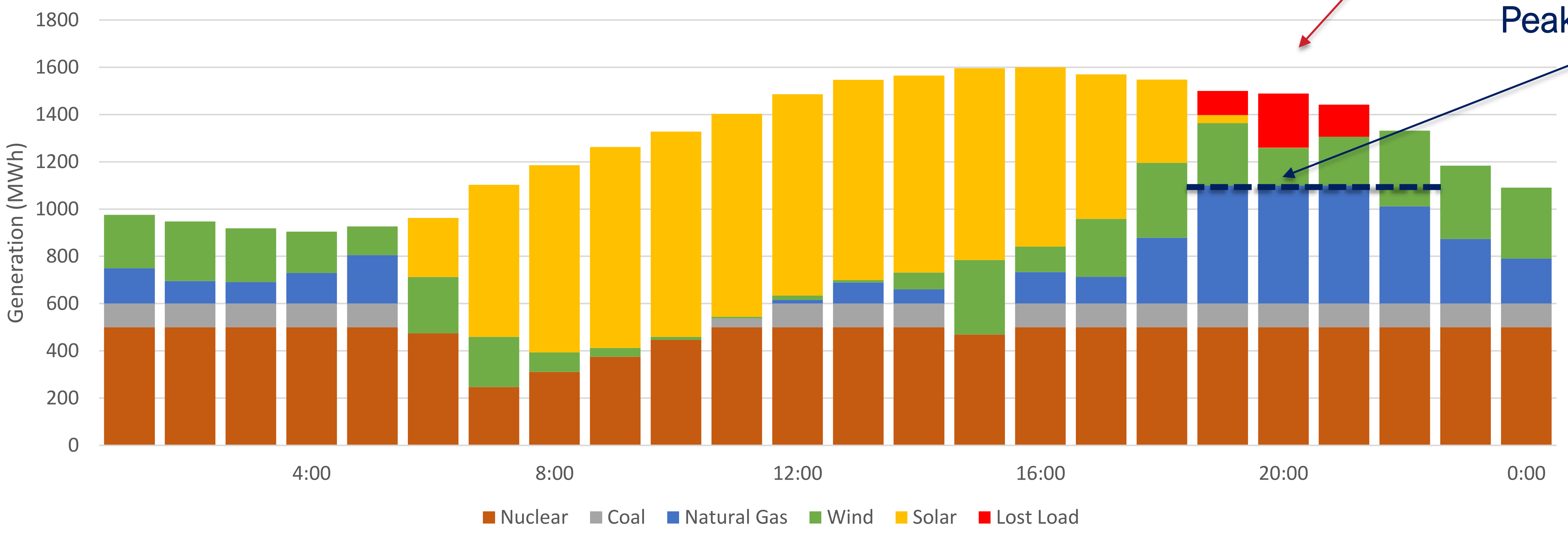


MERIT ORDER DISPATCH

June 29th: 400 MW Coal to 480 MW Solar

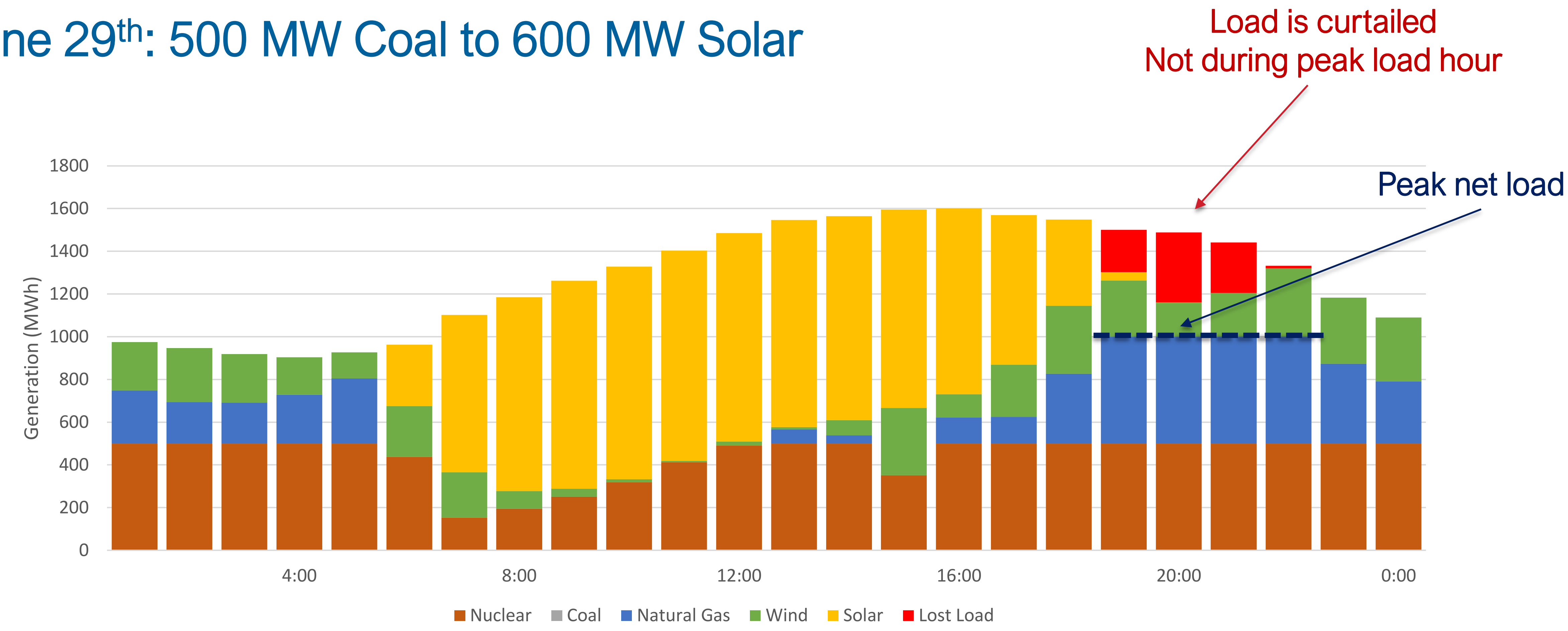
Load is curtailed
Not during peak load hour

Peak net load



MERIT ORDER DISPATCH

June 29th: 500 MW Coal to 600 MW Solar



SHORTCOMINGS OF PRM

- All of these example have the same PRM
  - They do not have the same level of reliability
- The required coal-to-solar replacement ratio changes as more solar is added
- In fact, no amount of solar can be added to avoid outages at 20:00
  - There is zero resource potential in that hour
- PRM does not capture time shifting of peak net-load as more resources are added
- Clearly new reliability metrics and more detailed assessments are needed
  - This requires a portfolio-wide approach to resource adequacy
  - Energy storage resources in particular will play an important role

EMERGING RESOURCE ADEQUACY METRICS

- Loss of load expectation (LOLE)
  - The expected number of days that will experience a shortfall of electricity supply relative to demand over the study period.
- Loss of load probability (LOLP)
  - The probability of demand exceeding available generating capacity during a given time period.
- Expected unserved energy (EUE)
  - The expected total energy shortfall over the study period, expressed in energy units (e.g., GWh per year).

EFFECTIVE LOAD CARRYING CAPACITY (ELCC)

Beyond PRM

- ELCC is a resource level metric to quantify its resource adequacy contribution
  - Alternative to UCAP

Load approach: Amount of additional load that can be added to the system along with the resource while maintaining the same level of reliability (e.g., the same LOLE).

Generation approach: Ratio between the capacity of target resource and capacity of a "perfect" resource required to maintain the same level of reliability (e.g., the same LOLE).

- ELCC is more complex to determine than UCAP
  - Will vary based on location and other system conditions
  - Generally, requires applications of power system models
  - Therefore, the resultant depends on modeling assumptions
  - Can account for correlated outage risks that UCAP overlooks

STYLIZED ELCC ANALYSIS

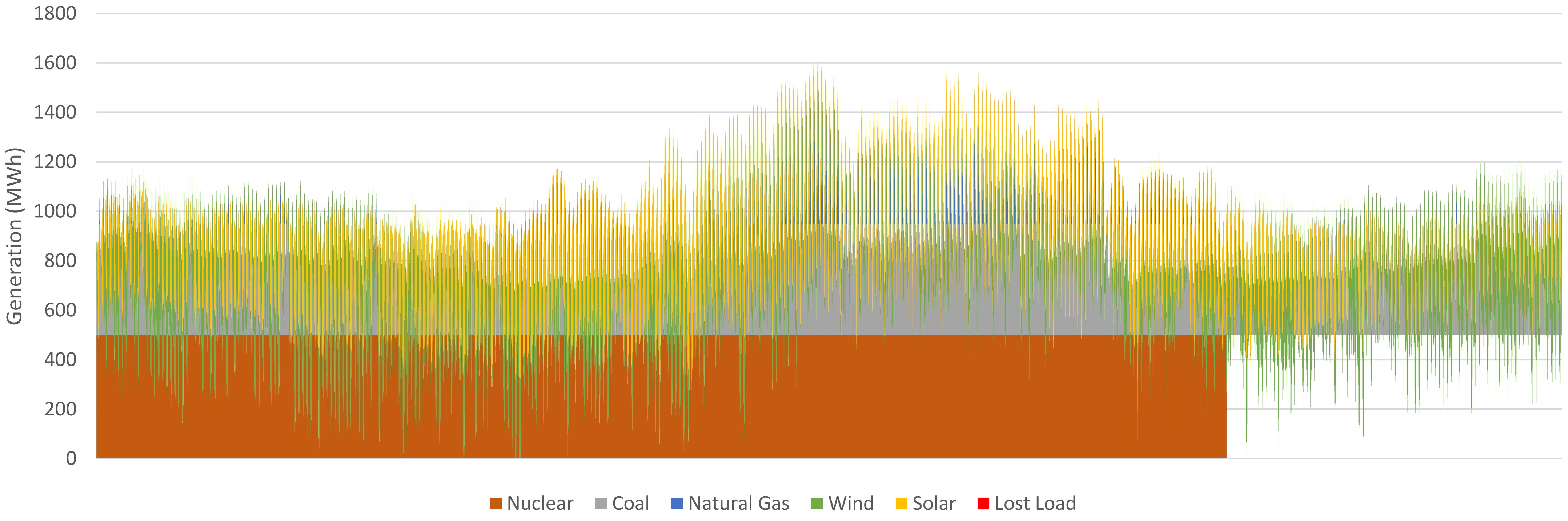
Marginal capacity value of wind and solar decrease with increasing penetration

- Demonstration of this effect with a stylized case study using generation approach
- Disclaimers
  - This is intended to demonstrate the method only
  - ELCC calculation requires proper simulation models
    - We are using a merit order dispatch model
  - ELCC calculation requires uncertainty representation with many simulations
    - We are using a deterministic representation
  - ELCC is calibrated based on replacing a “perfect” resource
    - In our merit order model coal is such a resource, but this is not true in reality
  - These numerical results are not intended represent actual system outcomes

STYLIZED ELCC ANALYSIS

Full hourly merit order dispatch for one year

	ICAP (MW)
Solar	500
Wind	500
Nuclear	500
Coal	500
Natural Gas	500



Note that merit order dispatch leads to unrealistic nuclear and coal cycling
Does not capture system flexibility and operating reserve needs

STYLIZED ELCC ANALYSIS

Generation approach: transition from 500 MW to 400 MW of coal

Add solar capacity until original LOLP is restored

	ICAP
Solar	0
Wind	500
Nuclear	500
Coal	500
Natural Gas	525
Total	2025

Hours with lost load: 3
Total lost load: 29 MWh

	ICAP
Solar	0
Wind	500
Nuclear	500
Coal	400
Natural Gas	525
Total	1925

Hours with lost load: 73
Total lost load: 3108 MWh

	ICAP
Solar	124
Wind	500
Nuclear	500
Coal	400
Natural Gas	525
Total	2049

Hours with lost load: 3
Total lost load: 24 MWh

Note that total lost load may differ

$$\text{ELCC} = \frac{\text{100 MW Coal*}}{\text{124 MW Solar}} = 81\%$$

*given assumption that coal is a "perfect" resource

STYLIZED ELCC ANALYSIS

Generation approach: transition from 400 MW to 350 MW of coal

	ICAP
Solar	124
Wind	500
Nuclear	500
Coal	400
Natural Gas	525
Total	2025

Hours with lost load: 3
Total lost load: 24 MWh

	ICAP
Solar	124
Wind	500
Nuclear	500
Coal	350
Natural Gas	525
Total	1999

Hours with lost load: 26
Total lost load: 674 MWh

	ICAP
Solar	213
Wind	500
Nuclear	500
Coal	350
Natural Gas	525
Total	2088

Hours with lost load: 3
Total lost load: 47 MWh

$$\text{ELCC} = \frac{\text{50 MW Coal}}{\text{89 MW Solar}} = 56\%$$

STYLIZED ELCC ANALYSIS

Generation approach: transition from 350 MW to 325 MW of coal

	ICAP
Solar	213
Wind	500
Nuclear	500
Coal	350
Natural Gas	525
Total	2088

Hours with lost load: 3
Total lost load: 47 MWh

	ICAP
Solar	213
Wind	500
Nuclear	500
Coal	325
Natural Gas	525
Total	2063

Hours with lost load: 13
Total lost load: 230 MWh

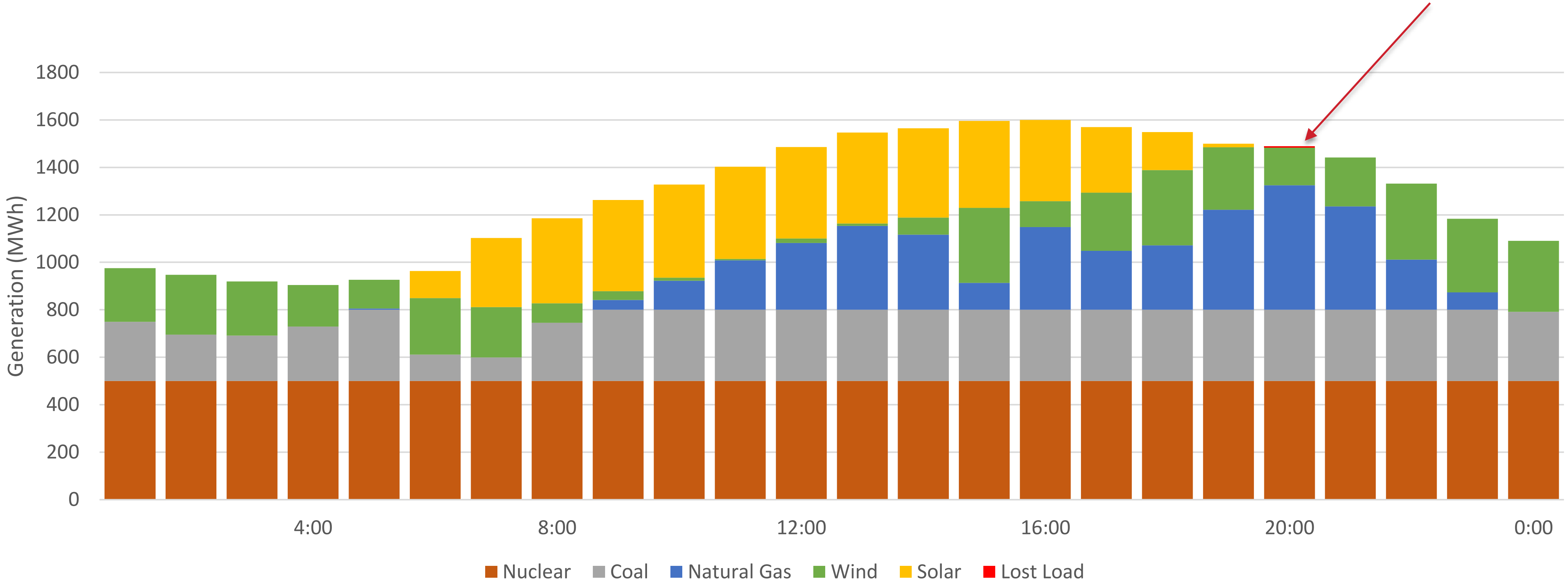
	ICAP
Solar	434
Wind	500
Nuclear	500
Coal	325
Natural Gas	525
Total	2284

Hours with lost load: 3
Total lost load: 31 MWh

$$\text{ELCC} = \frac{\text{25 MW Coal}}{\text{221 MW Solar}} = 11\%$$

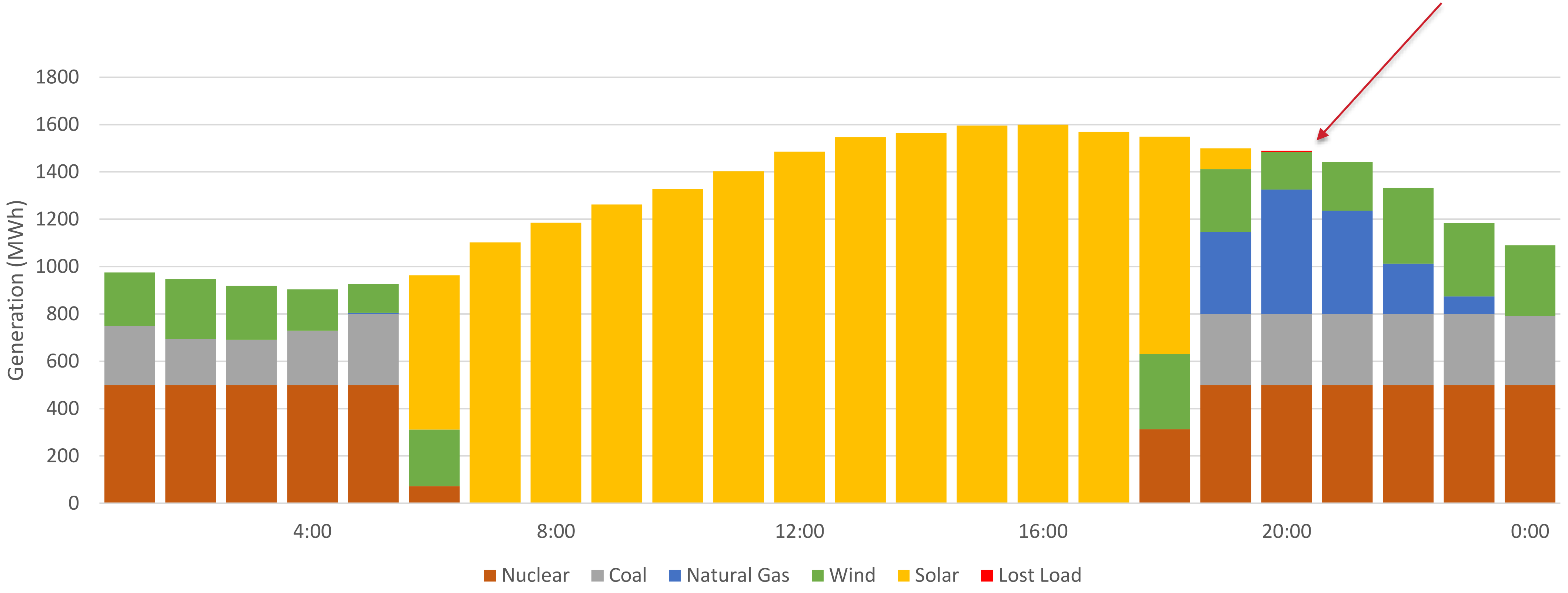
STYLIZED ELCC ANALYSIS

Generation approach: transition from 325 MW to 300 MW of coal +0 MW solar



STYLIZED ELCC ANALYSIS

Generation approach: transition from 325 MW to 300 MW of coal +2,000 MW solar



No amount of new solar can serve this lost load

ELCC = 0%!

Numerical result for demonstration purposes only!

IMPLICATIONS

- The marginal resource adequacy contribution of wind and solar diminish as more capacity is added to the system
  - Because the availability of these resources is correlated
- Therefore, models are needed to assess resource adequacy implications
  - Not sufficient to assume constant contributions of different technologies
- Storage can help to mitigate this diminishing effect

CONSIDERATIONS FOR REGULATORS

- Resource adequacy metrics can provide a snapshot of system reliability levels
  - Traditionally very easy to calculate (PRM)
  - Becoming more complex out of necessity (LOLP, EUE, ELCC)
  - No single metric is a substitute for a full reliability assessment
- Regulators can use these metrics to assess reliability impacts of fossil retirements
  - Important to understand these metrics and the models that generate them
- Regulators will often rely on other entities to calculate these metrics
  - Particularly as metrics become more complex and require modeling
  - Important to understand the assumptions used to quantify these metrics

RESOURCES

- PJM: ELCC Overview
  - https://www.pjm.com/-/media/committees-groups/task-forces/ccstf/2020/20200407/20200407-item-04-effective-load-carrying-capability.ashx
- ESIG: Redefining Resource Adequacy
  - https://www.esig.energy/resource-adequacy-for-modern-power-systems/
- NREL: Using Wind and Solar to Reliably Meet Electricity Demand
  - https://www.nrel.gov/docs/fy15osti/63038.pdf
- NREL: Comparing Resource Adequacy Metrics
  - https://www.nrel.gov/docs/fy14osti/62847.pdf
- Astrape: ERCOT ELCC Study
  - https://www.astrape.com/wp-content/uploads/2023/01/2022-ERCOT-ELCC-Study-Final-Report-12-9-2022.pdf