What is Utility Scale Battery Storage?

- Large capacity battery systems are designed to shift energy from one time period to another
  - Charge battery during off-peak times
  - Discharge battery during on-peak times
- Battery capacity is measured in kilowatts or megawatts
- Energy capacity is measured in kilowatt-hours or megawatt-hours
- A 1MW/4MWh battery can deliver one megawatt for four hours
  - For example, combining a battery with a solar power can help bridge the energy supply gap between sunset and the time when the load begins to decrease.

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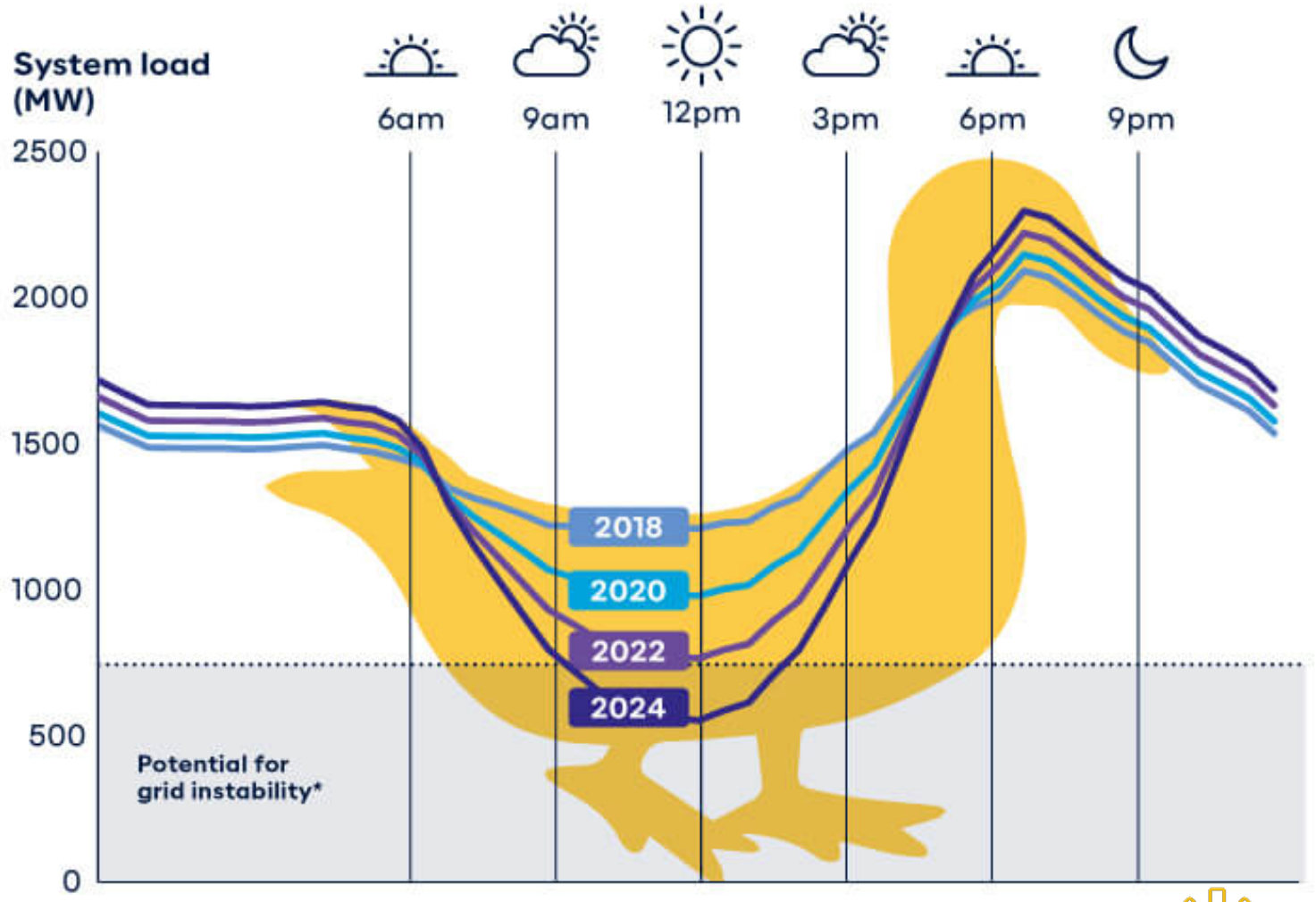
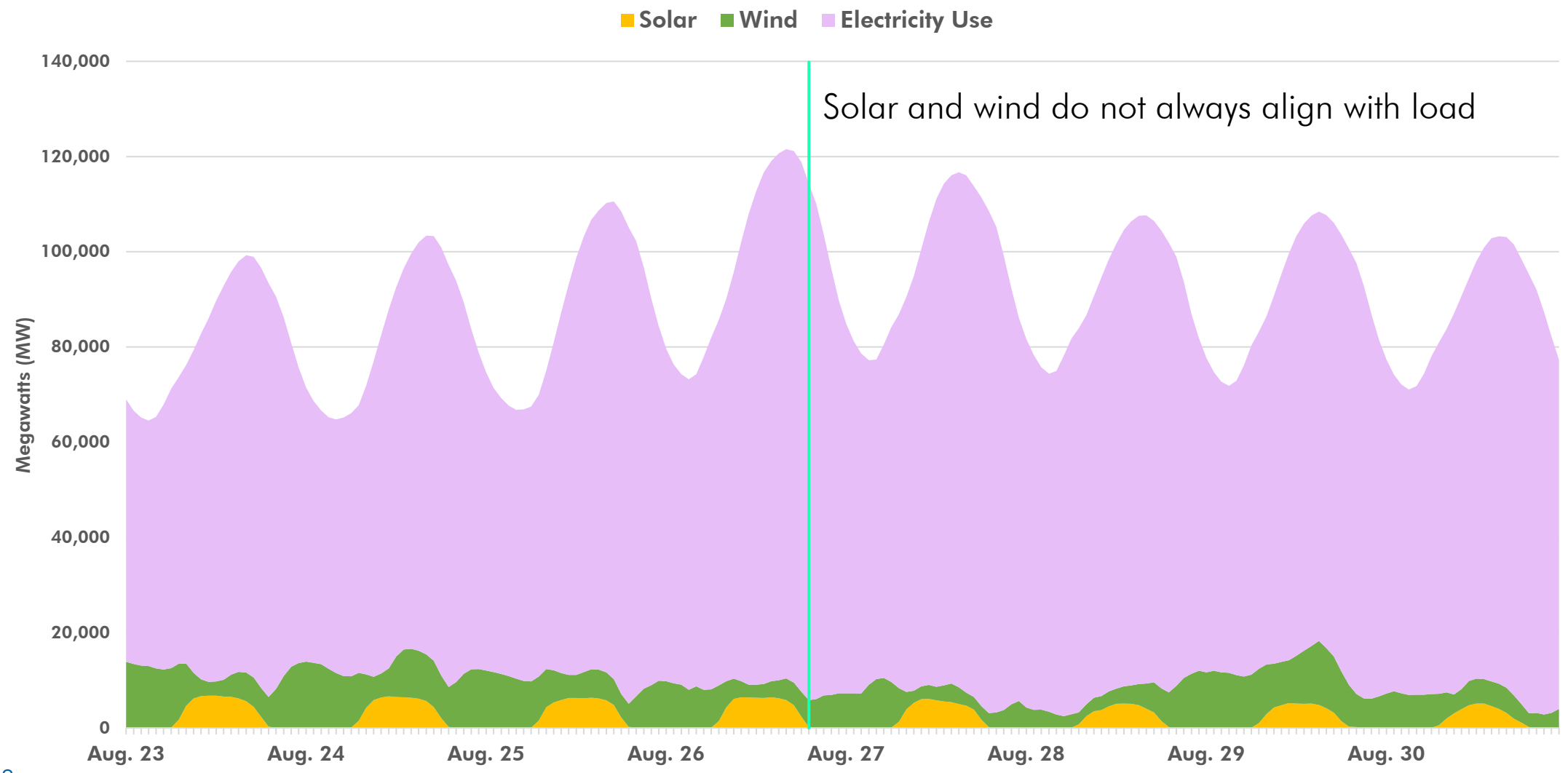
California's Solar Duck

- Consumer-owned solar reduces the load during midday hours
- As solar output decreases and demand rises, utilities must quickly ramp up generation output or dispatch battery storage
- While the Midwest is far from California, we are beginning to experience the impact of increased renewable energy penetration

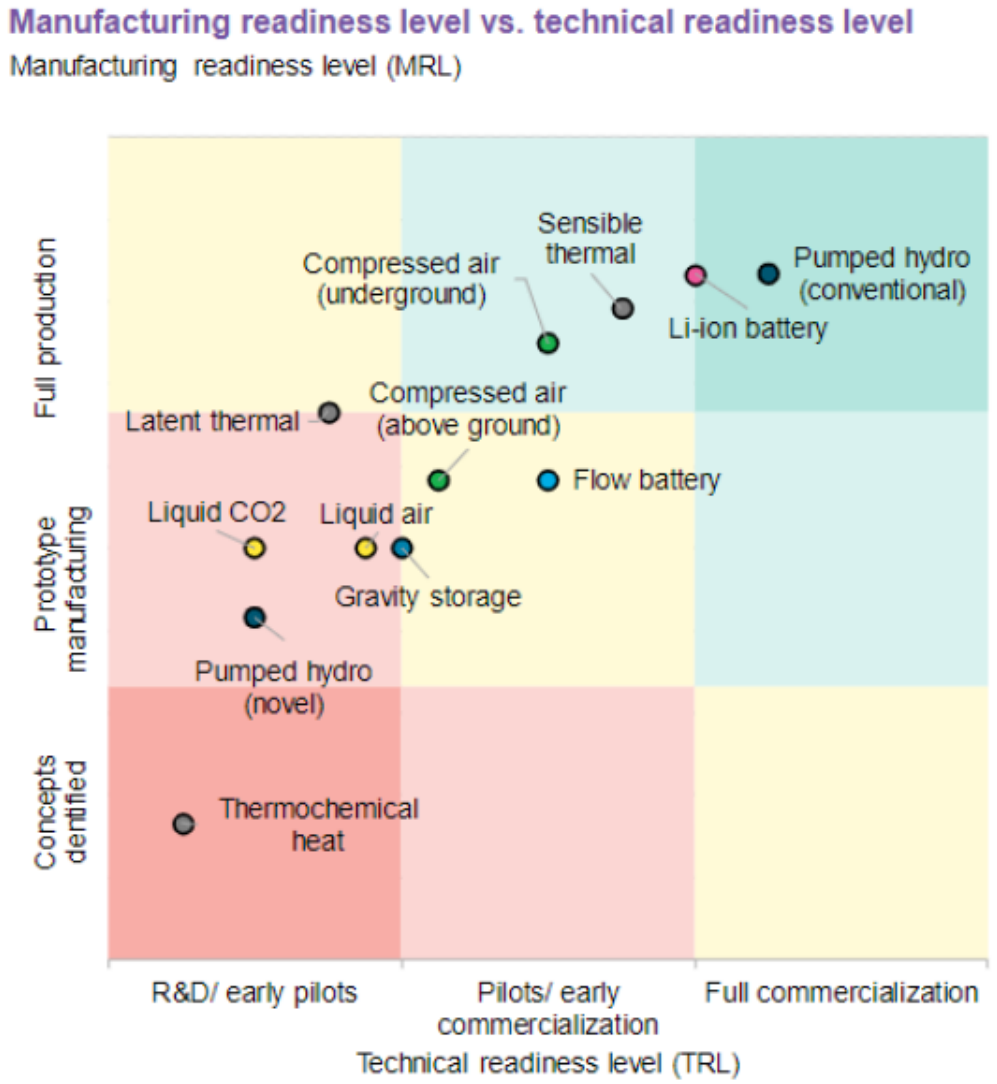


MISO Summer Load Example



Energy Storage Choices

- Pumped Hydro and Lithium-Ion technologies have reached maturity and are readily available
- Flow battery solutions are becoming more increasingly assessable, with Vanadium Redox and Iron Air serving as examples
- Electrolyzing Hydrogen and using a fuel cell to "discharge" is seeing a lot of interest
- Many other emerging technologies are in various stages of development



Source: Bloomberg New Energy Finance

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Why Now for Battery Storage?

- Increased penetration of renewables on the grid heightens the need for solutions that address the gaps caused by intermittent generation
- Battery storage solutions are becoming commercially available
- Grant funding and incentives for battery storage systems may be available
- Market price signals are enhancing the economics of energy storage

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Battery Storage System Differences

- Different technologies have different sweet spots
  - Lithium-Ion – Peak shaving
    - Relatively short duration output 4-6 hours
    - Compact footprint; 80% round trip efficiency; can cycle daily; life?
  - Vanadium Flow – Daily load smoothing
    - Medium output duration of up to 20 hours
    - Large footprint; 60% round trip efficiency; loves to cycle; long life
  - Iron Air – Seasonal capacity
    - Long duration output of up to 100 hours
    - Huge footprint; 30% round trip efficiency; infrequent cycles; long life

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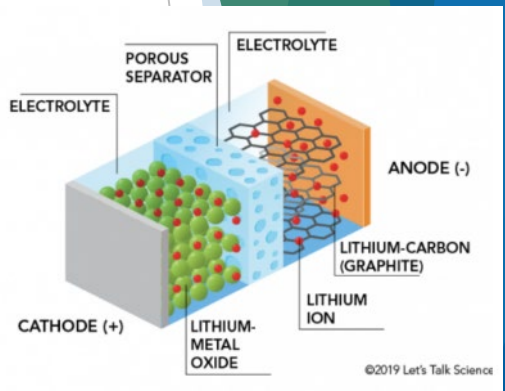
More about Lithium-Ion Batteries

- Lithium batteries are not all created equal
  - Batteries used for cars are optimized for highest energy density and lowest weight
  - Electric vehicle batteries (NCA & NMC) are flammable though fires are VERY rare
  - Lithium Iron Phosphate batteries, commonly used for utility storage, are less energy-dense by volume and are heavier, but they are less flammable and do not contain nickel or cobalt.
- Sodium batteries are starting to enter the market and offer some attractive properties: they are not flammable, low cost, and have a reasonable life.
- Other chemistry variations are in the laboratory demonstration phase



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Electrical Configuration Matters

- Battery storage that is paired with solar can be DC coupled
  - Batteries are charged exclusively by solar
  - Energy delivered to the grid flows through the same inverter(s) as solar energy
  - This approach is less expensive but less flexible than AC coupled batteries

- AC coupled batteries can be stand alone or co-located with solar
  - Battery can be charged at any time – even when there is no solar
  - Discharge from the battery flows through a dedicated inverter, enabling discharge even when the solar system is also supplying power to the grid.
  - More expensive to install but maximizes the flexibility of the battery

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Reliability, Resilience, and Uninterruptible

- Battery storage can enhance reliability by offering system support during peak periods, thereby reducing the risk of system overload and outages.
- Resilience is the ability to recover after/during an outage
  - Most batteries are paired with grid following inverters, which only operate when grid power is present, and would therefore offer limited assistance during an outage.
  - When paired with switching equipment for system isolation, and equipped with a grid forming inverter, battery systems can operate in islanded mode.
- Utility-scale battery storage systems differ from Uninterruptible Power Systems (UPS) because they do not yet provide no-blink power.

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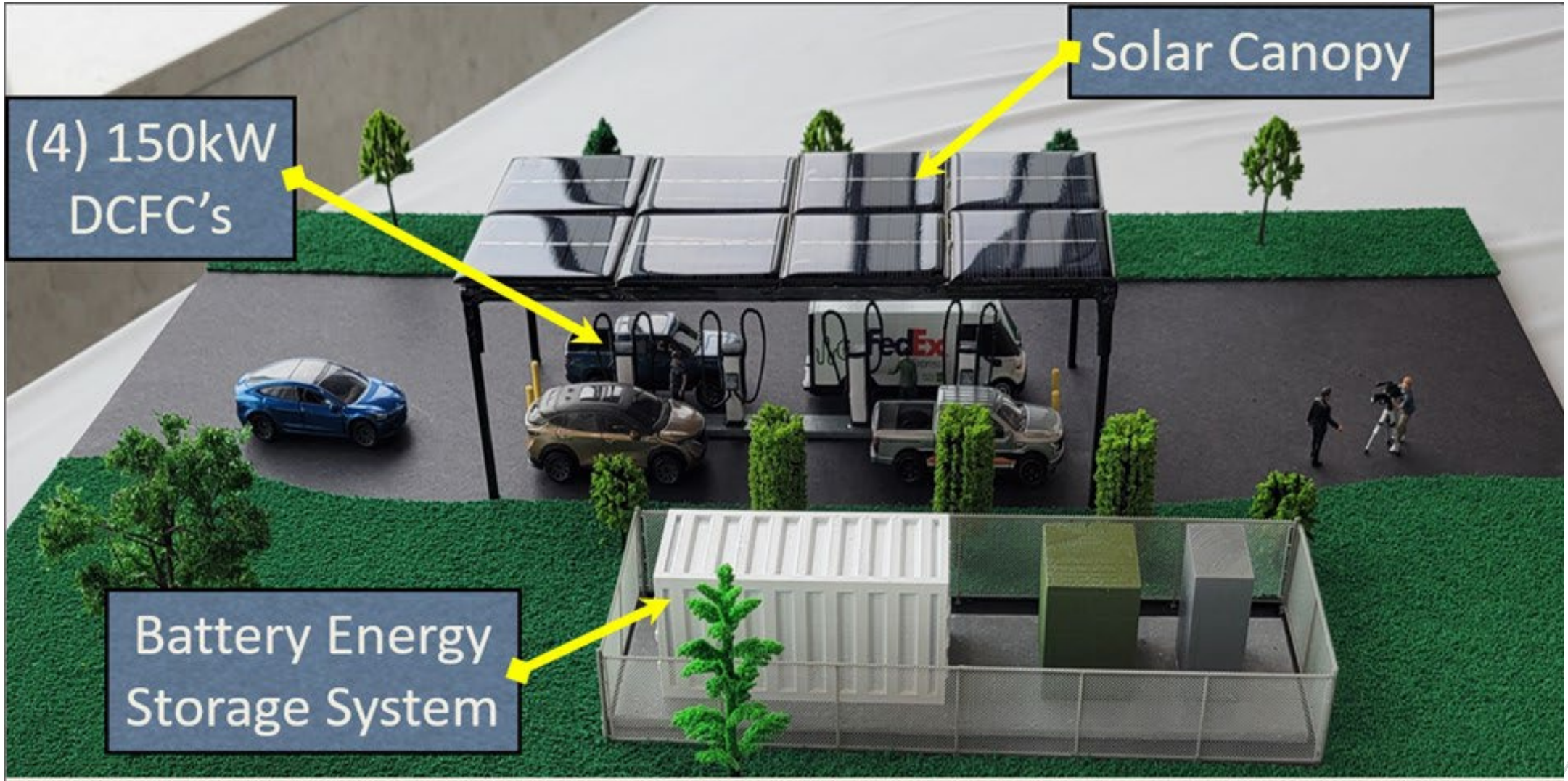

The "Prentice Solar EV Hub"

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Battery Charge and Discharge Ratings

- Maximum battery charge and discharge rates are expressed as a ratio of the energy storage capacity (C-rates)
- Examples:
  - A car battery with 100kWh of storage that can be charged in 30 minutes has a rating of 2C
  - A 4MWh battery storage system that needs 4 hours to charge has a rating of 0.25C
  - Ultra long duration storage could have a rating as low as .01C (100 hours)
- These ratings reflect a combination of the actual battery capability and the charge/discharge equipment in the system. For instance, while the battery may be capable of delivering 4MW, if the inverter can only handle 1MW, the inverter becomes the limiting factor.

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When to Recharge

- Batteries do not need to be recharged immediately once the charge has been depleted
- Shifting the charge period to off-peak times or the next sunny period can improve economics (energy arbitrage)
- Monitoring system load when scheduling charging will reduce the chance of creating a new peak

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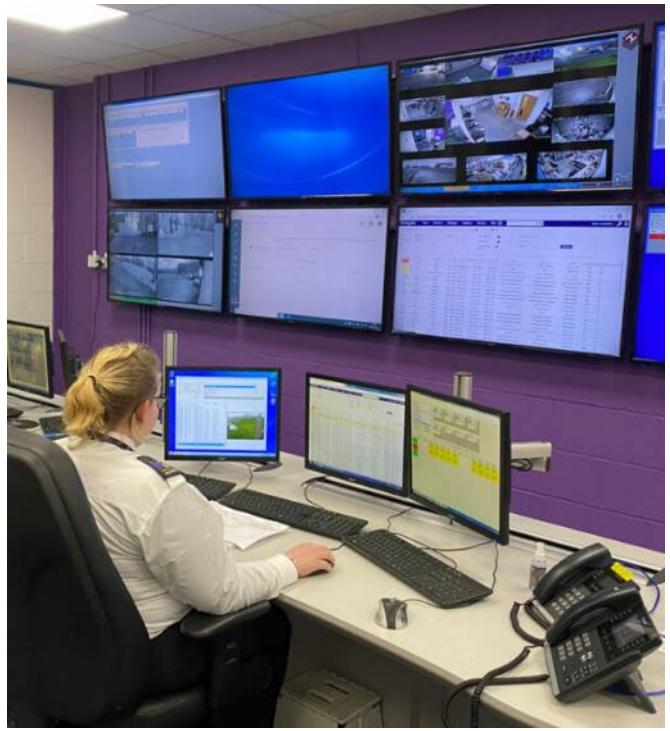
Controlling Batteries



- Battery storage systems are only as good as the system that controls them
- For systems less than 10MW of capacity, battery dispatch may be integrated into a traditional load management system
- Larger systems may be better suited to integration with other system dispatch functions

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Aggregating Batteries - Virtual Power Plant

- Companies like Tesla collaborate with residential consumers to pool their battery storage capacity and sell it into the energy market
  - Consumers get a refund for participation and Tesla takes a cut of the profits
  - This approach bypasses the local utility and may cause local capacity issues
- Electric Vehicles are battery packs on wheels, and they have substantial capacity
  - Vehicle to Grid programs are common in other countries and the technology may make its way to our markets
  - Consumer participation is uncertain, but the potential is huge

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Example MISO Winter Day

Fuel Mix

21-Jan-2025 - Interval 15:40 EST

Total Megawatts

100,647

- Coal (33,868 MW)
- Natural Gas (27,838 MW)
- Nuclear (11,897 MW)
- Wind (17,968 MW)
- Solar (7,393 MW)
- Imports (1,492 MW)
- Other (458 MW)

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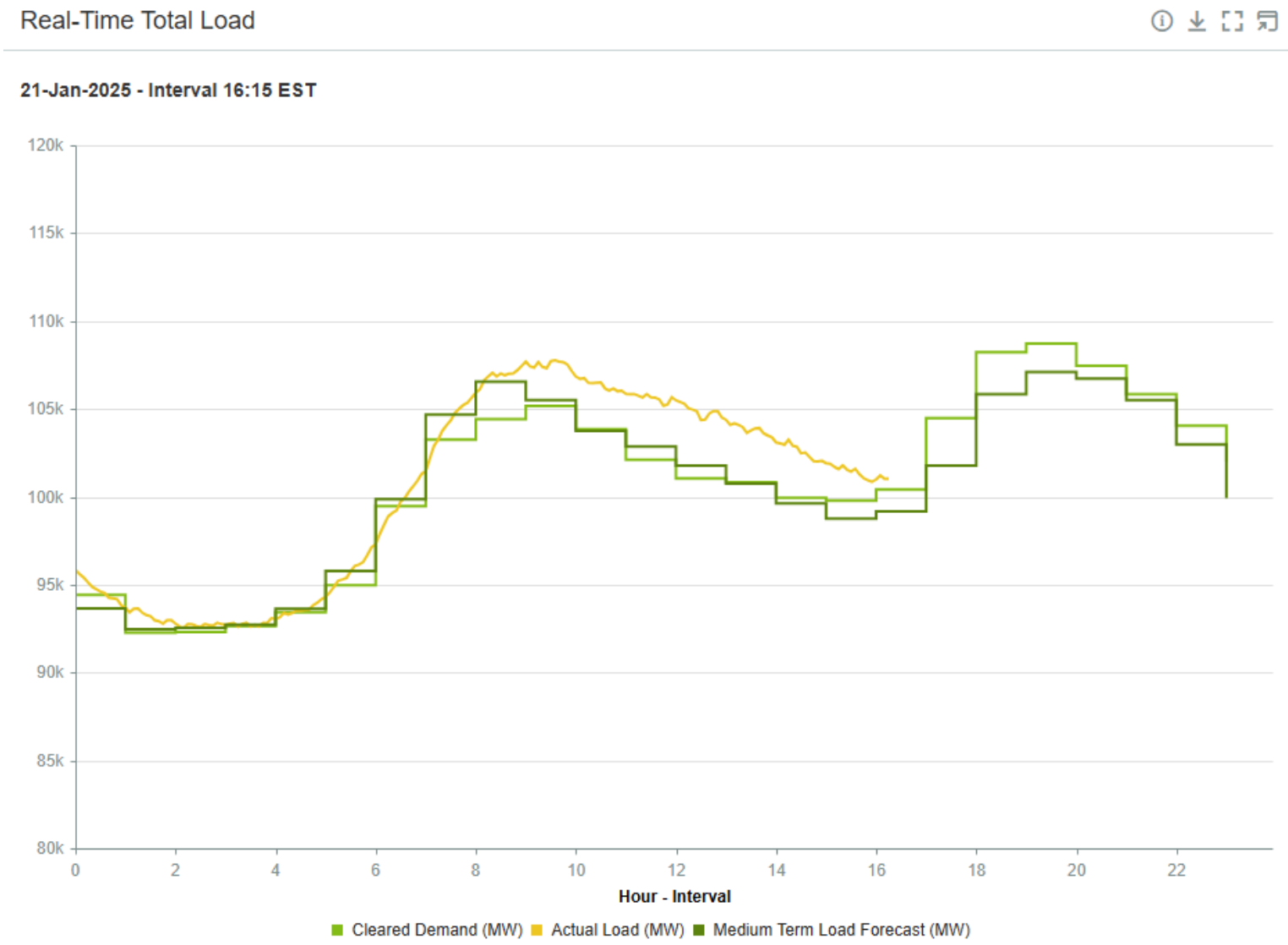
MISO Real Time Load



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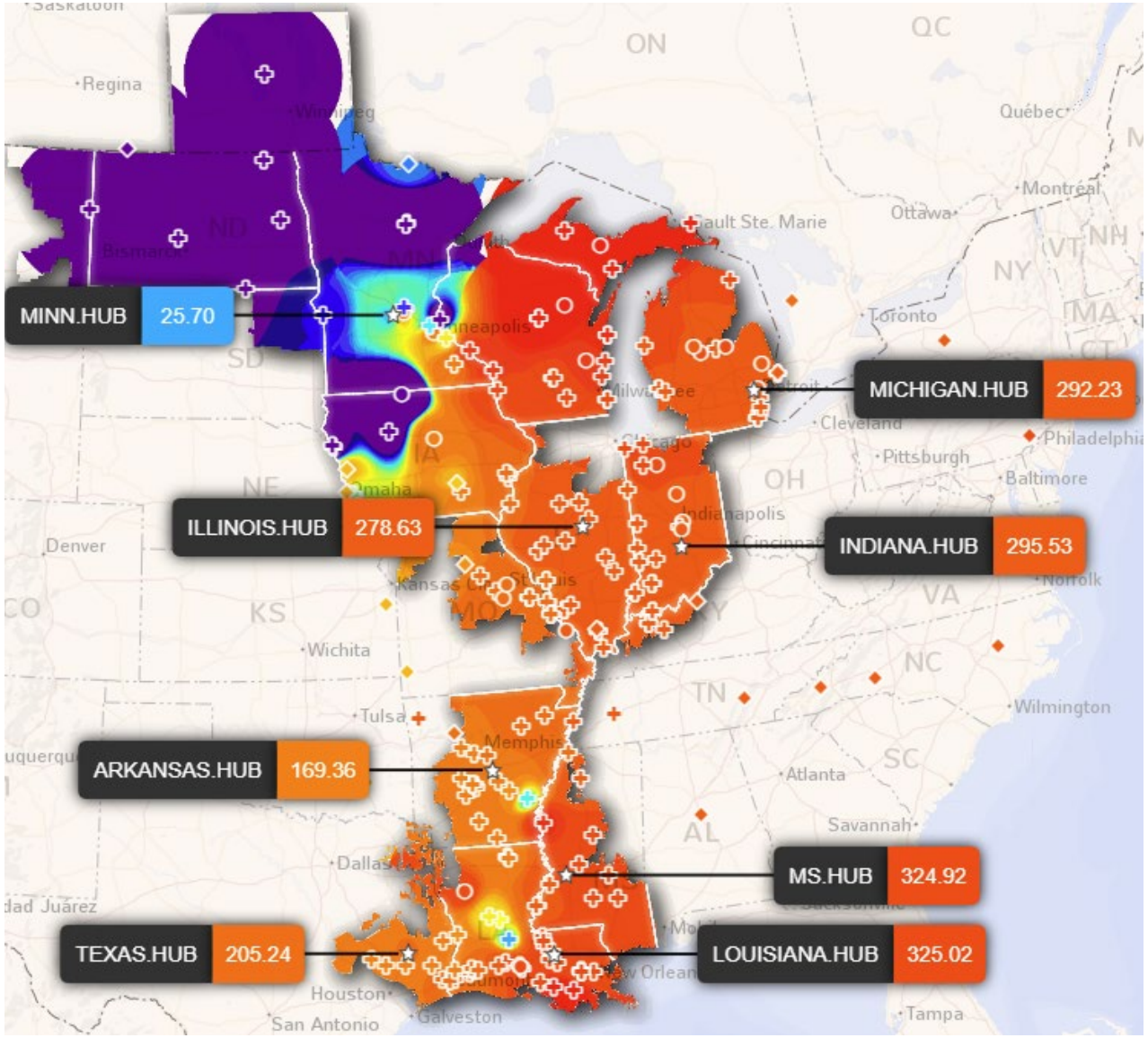
MISO LMP Prices During a Cold Snap



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Comments and Questions