Recent Developments in Energy Storage in California

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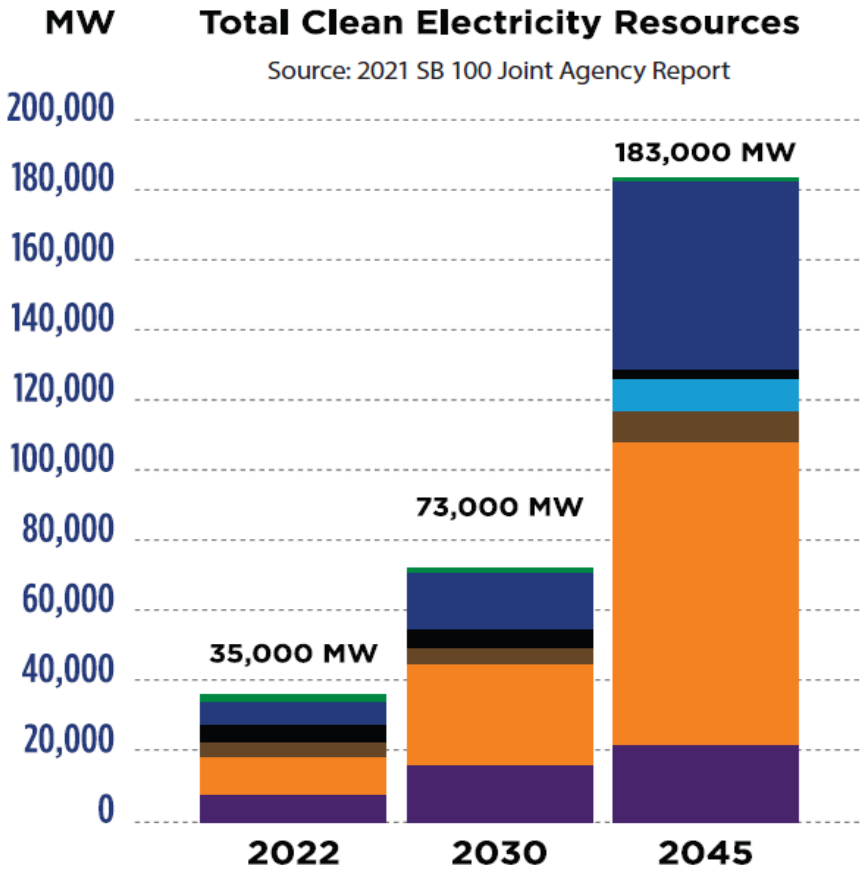
To provide 100% clean electricity by 2045,

California will build an unprecedented amount of new utility-scale clean energy resources

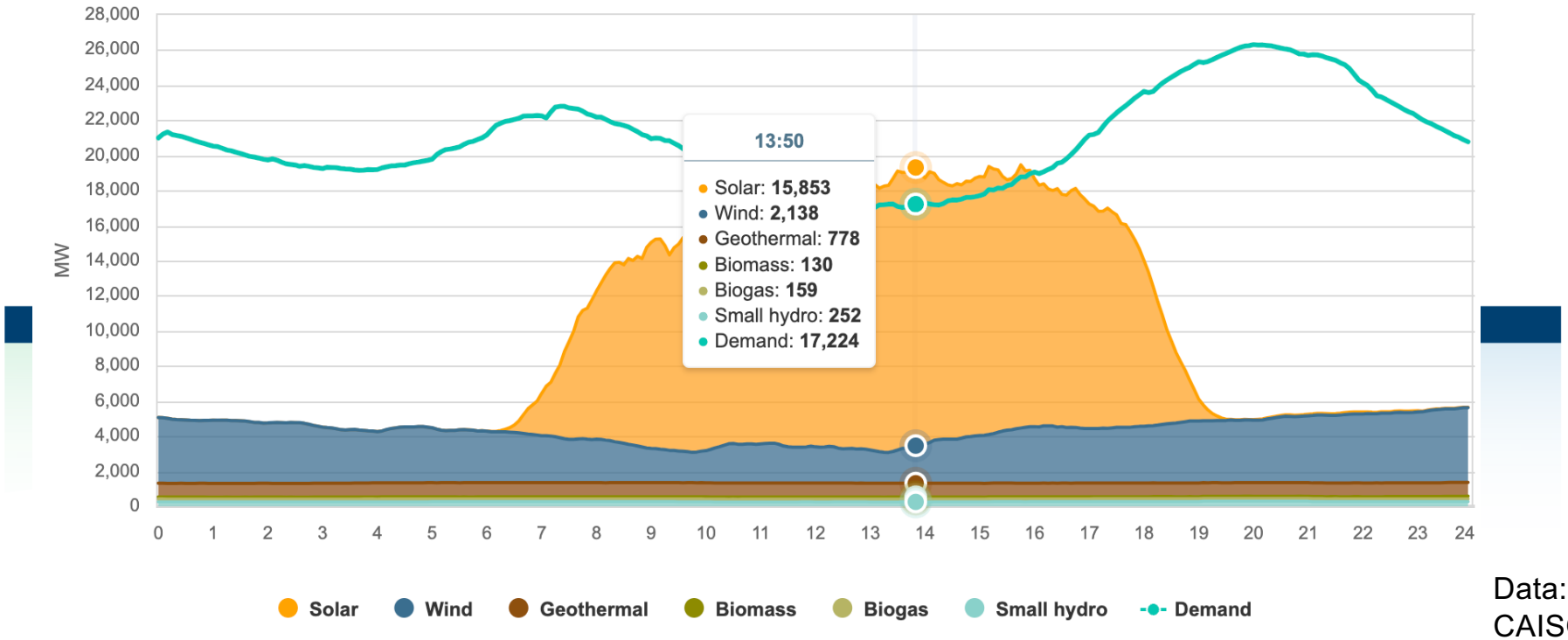
Totals represent new and existing resources. The 2021 SB 100 Joint Agency Report projects the need for 148,000 MW of new resources by 2045.

In addition, California also expects new capacity from energy efficiency, customer solar and demand response.

- Biomass
- Battery Storage
- Geothermal
- Offshore Wind
- Long Duration Energy Storage
- Utility-Scale Solar
- Wind

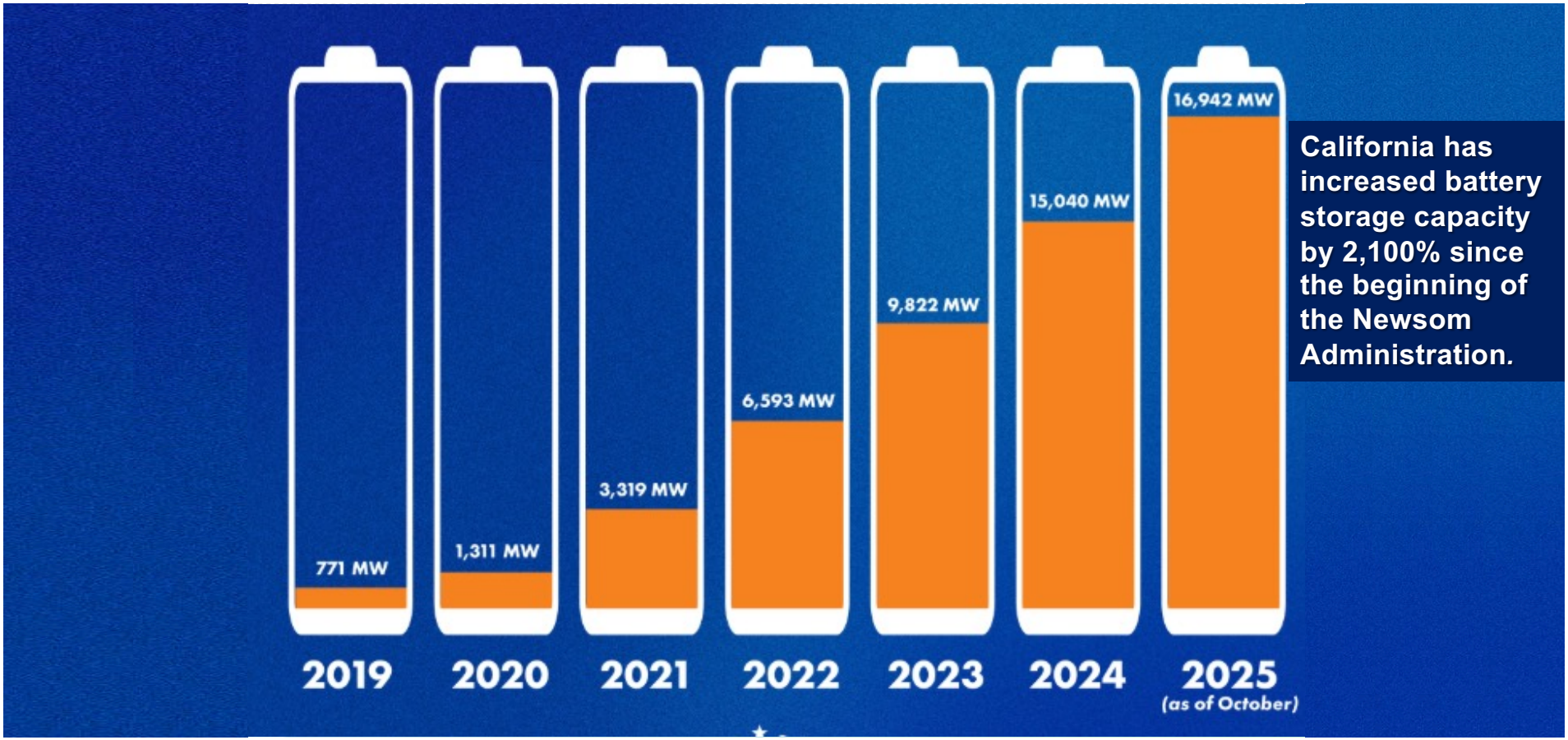


2025: 100% Clean Energy on 279 Days



Data: CAISO

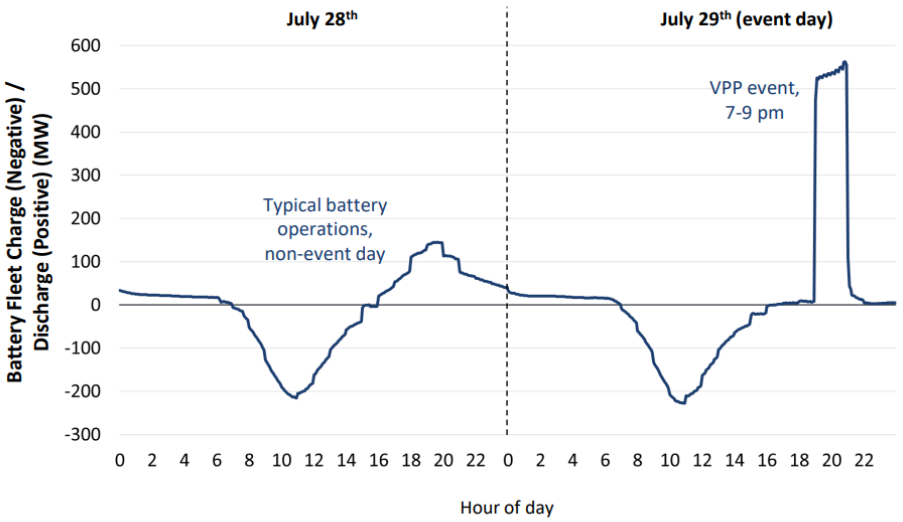
New Record: CA Hits Nearly 17 GW of Energy Storage



California has increased battery storage capacity by 2,100% since the beginning of the Newsom Administration.

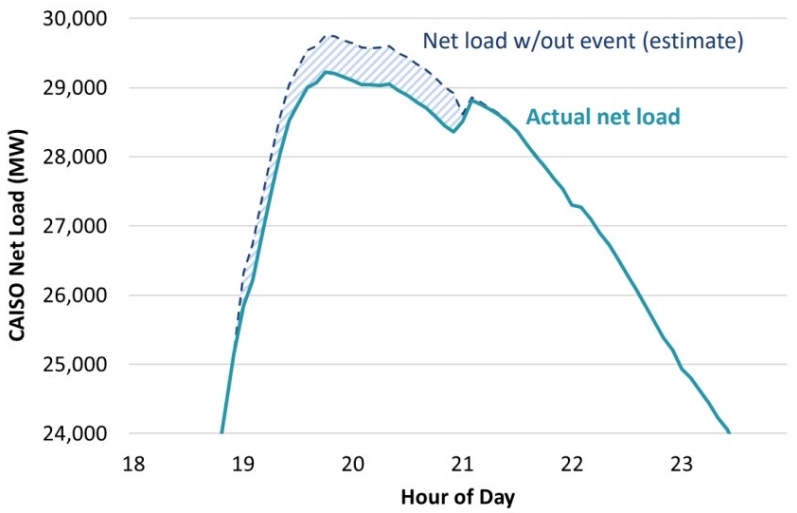
Largest VPP in the country: over 1 GW enrolled in DSGS

Battery Operations Before and During the Event



Notes: Based on Brattle analysis of 5-minute telemetry data provided by Sunrun and Tesla. Battery dispatch is raw power output, without any baseline adjustments.

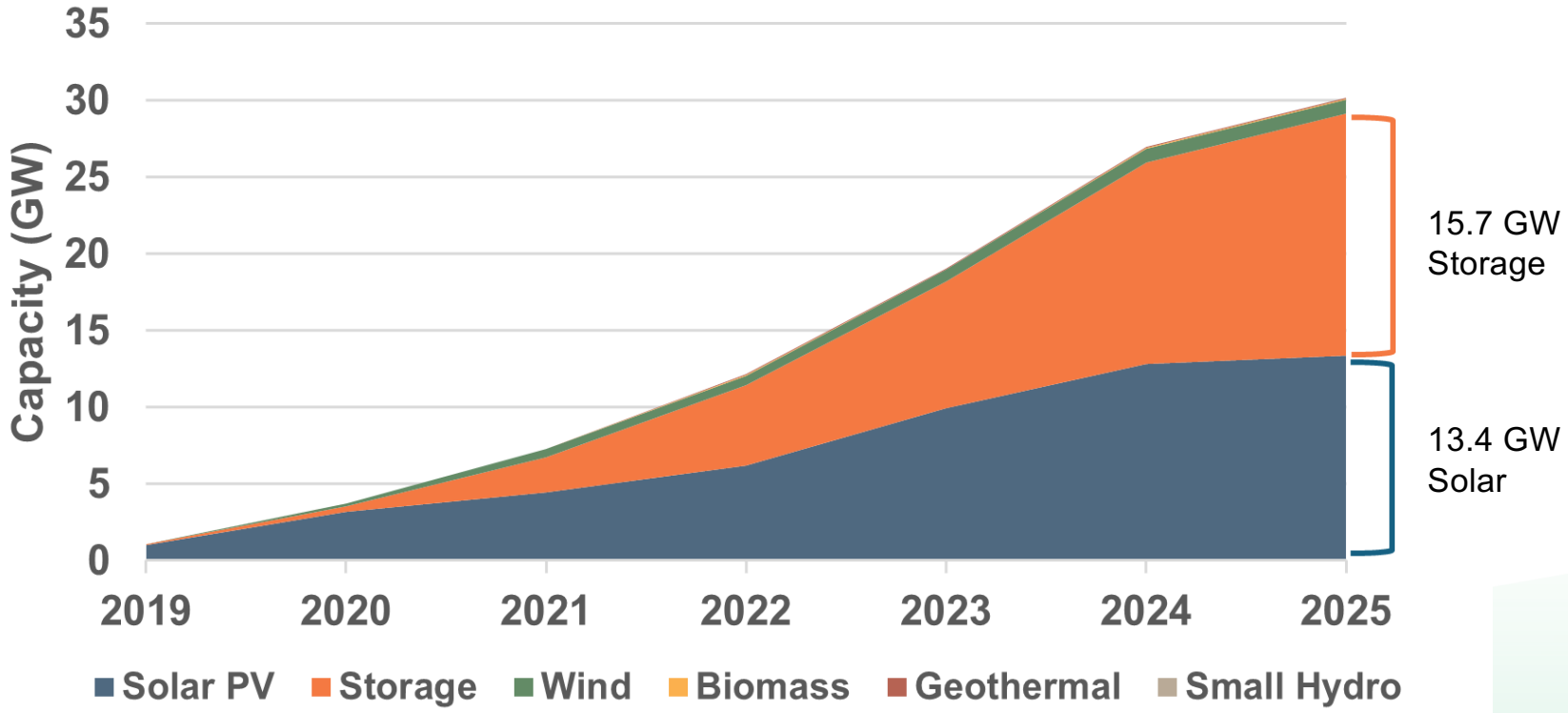
CAISO System Net Load on Event Day



Notes: Net load sourced from CAISO and reflects actual demand less solar and wind output. Baseline net load in the absence of the event was constructed using 5-minute telemetry data provided by Sunrun and Tesla. All battery output is shown as a reduction in net load.

Source: Brattle

Newsom Administration Energy Progress: 30.2 GW of New, Clean Capacity* in CA Added Since 2019



*Includes clean energy and battery additions

Data: CEC

LDES Program Overview

Long Duration Energy Storage (LDES) Program

What is LDES?

Energy storage with 8+ hours of duration

Non-lithium-ion technology

Why LDES?

Reliability, decarbonization, affordability

Total funding
$273M

- Commercialization for utility-scale applications
- Established in 2022
- Non-competitive grants allowed

MCAS Miramar – RICU (LDS-23-002)

Project portfolio
10 projects
5 technologies

- Project eligibility:
  - Non-lithium-ion
  - 8+ hour duration
  - 1 MW+

Types of Long Duration Energy Storage

Electrochemical Storage

Sodium-Ion Batteries
Zinc-Based Batteries
Metal-Air Batteries
Flow Batteries

Thermal Storage

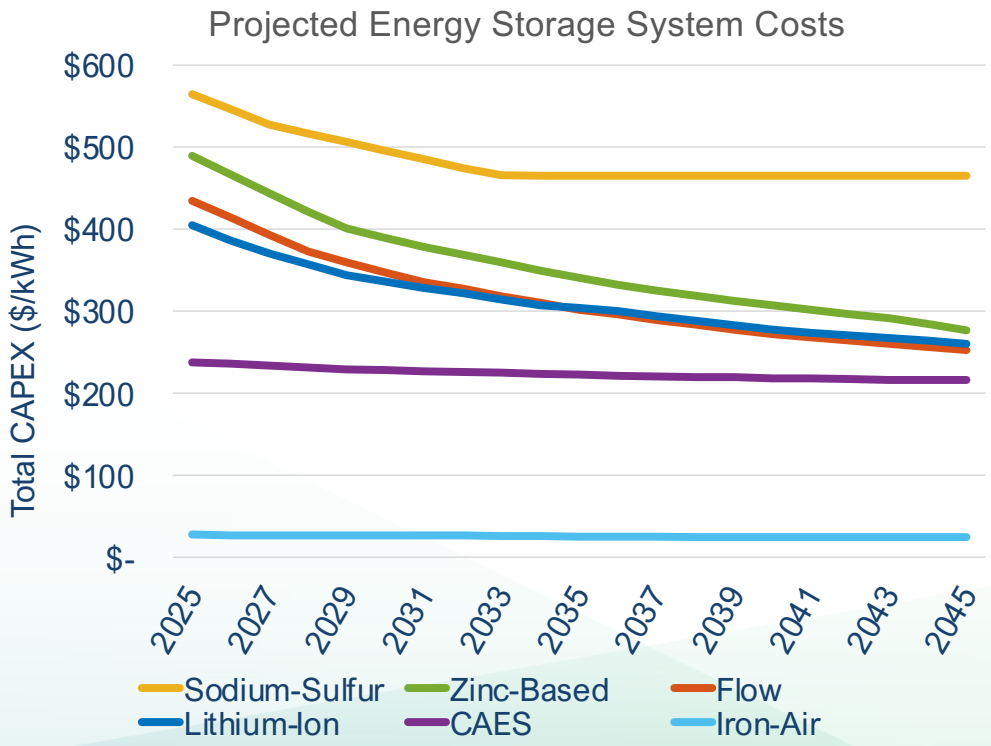
Molten Salt Thermal Storage
Heated Brick Energy Storage
Liquid Metal Battery
Liquid Air Energy Storage

Mechanical Storage

Pumped Hydro Storage
Gravity-Based Storage
Compressed Air Storage

Market Environment

- Falling Li-Ion costs are difficult to compete with
- Developers prefer lower CapEx (li-ion) over lower lifetime costs (LDES)
- Markets based around short-duration storage
- LDES costs are falling



Guidehouse Inc. (CEC-300-22-002)

Willow Rock - Hydrostor

- First large-scale advanced compressed air energy storage (A-CAES) project approved in California
- 500 MW / ~4,000 MWh long-duration storage, capable of delivering power for up to 8 hours
- Supports deep renewable integration by converting excess solar and wind into firm, dispatchable capacity
- Expands California's storage portfolio beyond lithium-ion, demonstrating technology diversity at scale
- Provides multiple grid services: reliability, resource adequacy support, and system flexibility
- Designed for multi-decade operation, aligning with California's long-term decarbonization goals

Project Challenges & Lessons Learned

Technology novelty

- Lack of LDES deployment experience and standardization
- Iterations of technologies cause unforeseen challenges
- Higher risk of companies becoming insolvent

Project considerations

- Site host – need to be a close partner
- Permitting challenges
- Overseas vs. Domestic – tariffs, tax credits

Operational history and past deployments are key considerations to differentiate R&D vs deployment-ready technologies

[Backup Slides]

Senate Bill 100

Officially titled "The 100 Percent Clean Energy Act of 2018," Senate Bill 100 (SB 100, De León):

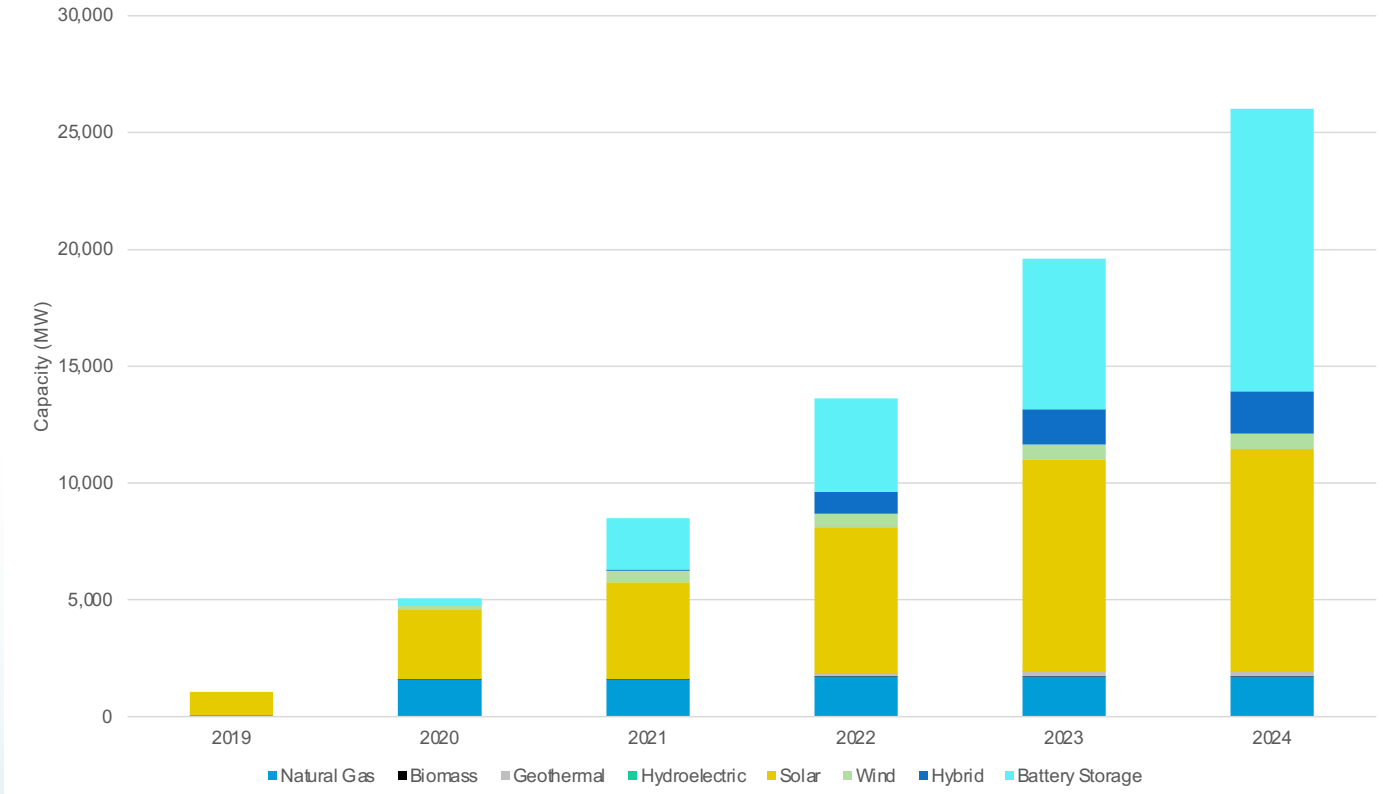
1. Sets a 2045 goal of powering all retail electricity sold in California and state agency electricity needs with renewable and zero-carbon resources.

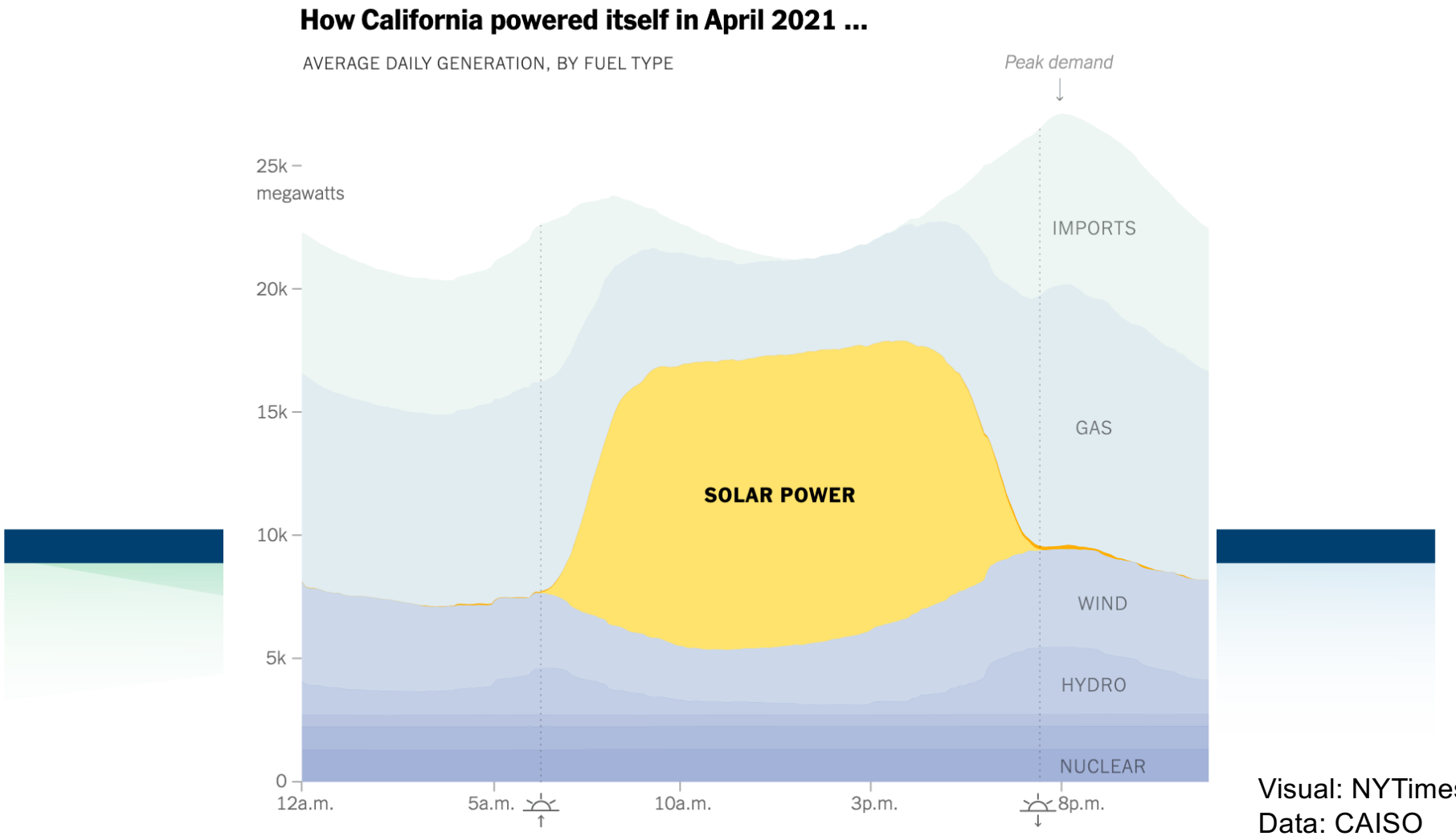
2. Updates the state's Renewables Portfolio Standard to ensure that by 2030 at least 60 percent of California's electricity is renewable.

3. Requires the CEC, CPUC, and CARB to use programs under existing laws to achieve 100 percent clean electricity and issue a joint policy report on SB 100 by 2021 and every four years thereafter.

Cumulative New Resources 2019-24

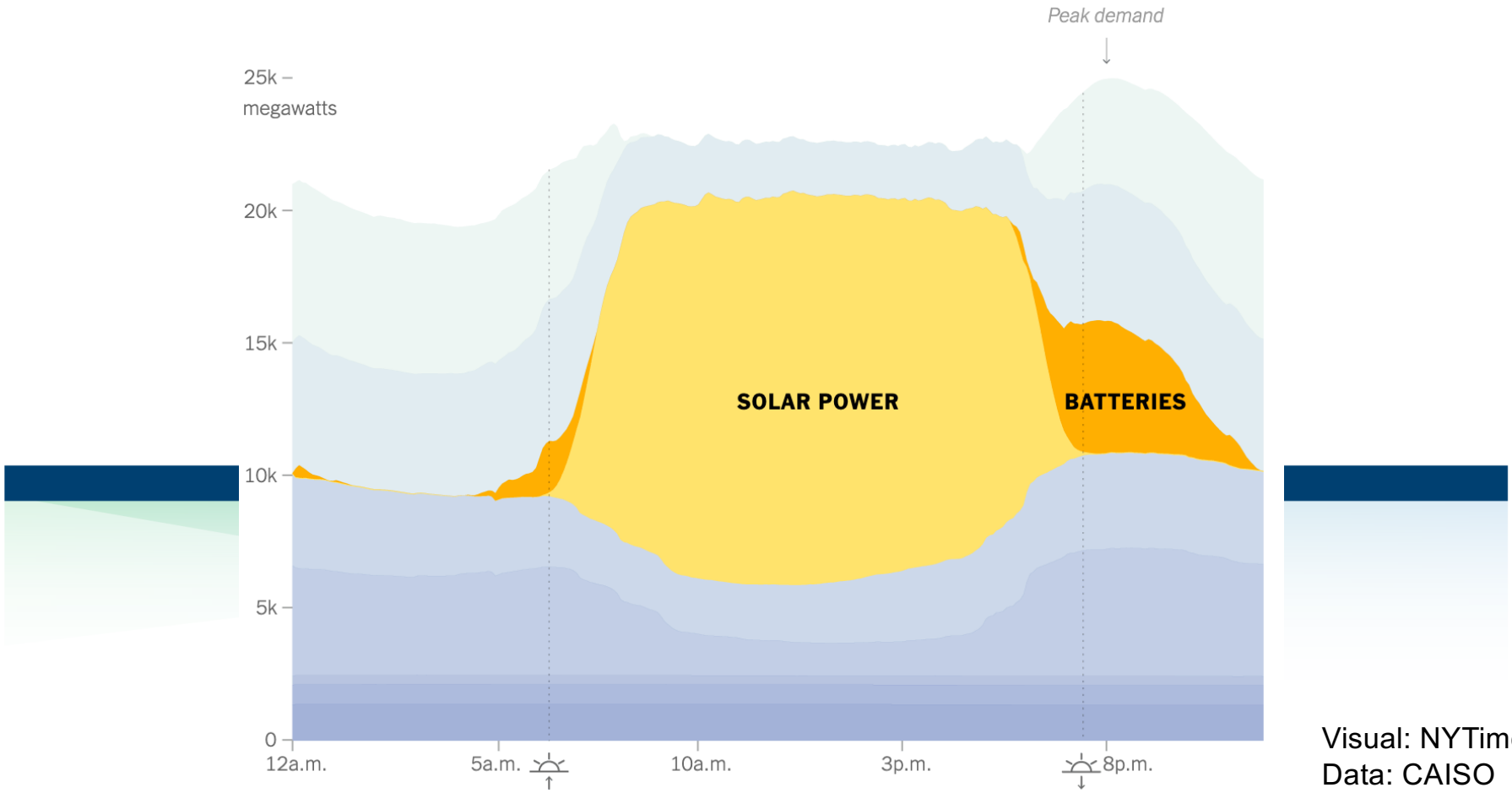
- **26,016 new resources** since 2019
- Annual new resource installations is now **~6 GW/year**, in-line with 3x and 8x recs in 2021 SB 100 report
- Most of the new energy resources were solar PV and battery storage.





Visual: NYTimes,
Data: CAISO

and in April 2024.



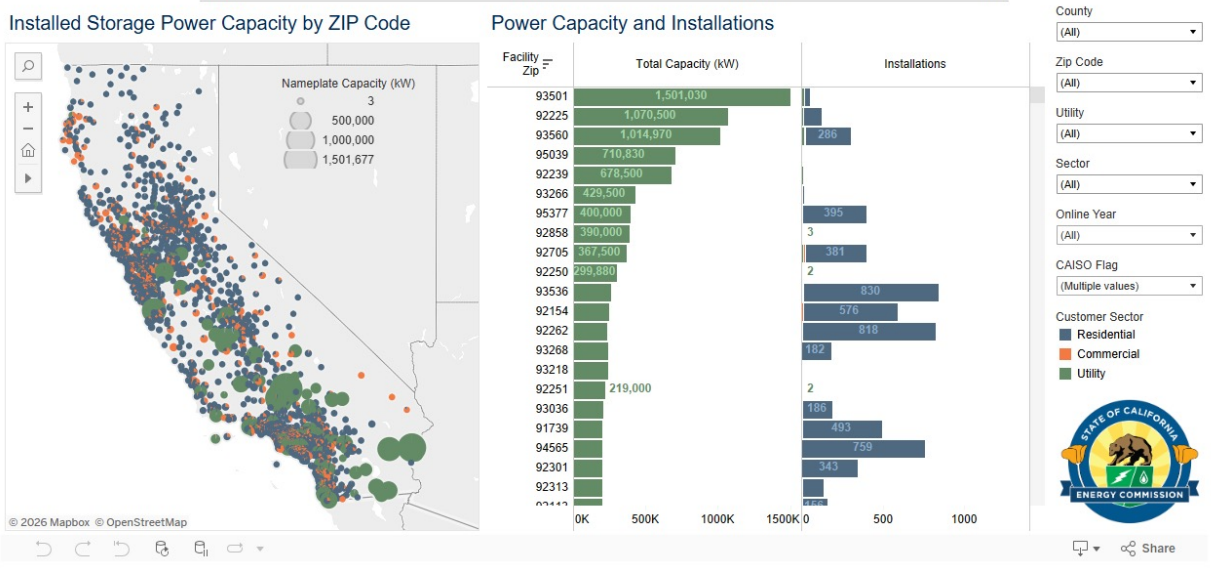
Visual: NYTimes,
Data: CAISO

CEC Storage Dashboard

California Energy Storage System Survey

Statewide Energy Storage Power Capacity: **16,942 MW**

Customer Sector	Total Capacity (MW)	Installations	Average Capacity (kW)
Residential	2,213	280,423	8
Commercial	849	3,797	224
Utility	13,880	248	55,966
Total	16,942	284,468	60



[California Energy Storage System Survey]

World's Largest Battery Storage Project

Comparison to Lithium Ion

	Lithium-ion	LDES (Typical)
Duration (hrs)	2 – 4 hrs	8 – 24 hrs, Multiday (max: 100 hrs)
RTE (AC) (%)	**83% – 86%**	40% – 80%
Energy Density (MWh/Acre)	**>125**	15 – 100
Lifespan (years)	<10 years	**25+ years**
LCOS ($/MWh)	$150	**$50 – $200**
Safety	Thermal runaway risk	**No fire risk**
Temperature Reqs.	Needs active cooling	**No temperature control needed**

Large-scale LDES Deployments

Key Electrochemical Storage Companies

Eos Energy Storage

Zinc Hybrid-Cathode Battery

Established 2008
3 - 12 hrs duration
75% - 80% RTE
137+ MWh installed capacity

- Large systems in operation: **72 MWh** in SC, **50 MWh** in TX
- First project of latest generation battery commissioned July 2025
- Additional **250+ MWh** being installed currently
- **11+ GWh** of planned deployments
- Planned manufacturing expansion to **>8 GWh/yr**

Form Energy

Iron Air Battery

Established 2017
100 hrs duration
40% - 50% RTE
300 kWh installed capacity

- Large footprint
- First commercial **150 MWh** system installing late 2025
- CEC's **150 MWh** system installing early 2026
- **14+ GWh** of planned deployments

Key Flow Battery Companies

CellCube

Vanadium Flow Battery

Established 2000
2 - 24 hrs duration
60% - 70% RTE
65 MWh installed capacity

- Longest-running flow battery: **14+ years** of operation
- **10 MWh** deployment at MCB Bridgeport in 2025
- Upcoming **1 GWh** system deployment

Invinity

Vanadium Flow Battery

Established 2020
3 - 18 hrs duration
60% - 70% RTE
80+ MWh installed capacity

- Founded by merger of flow battery companies
- New generation released (2024)
- Recent manufacturing expansion to **>1 GWh/yr**
- **190+ MWh** of planned deployments

Sumitomo Electric

Vanadium Flow Battery

Program est. 1984
4 – 8+ hrs duration
70% RTE
190+ MWh installed capacity

- Part of large electronics company
- **8 MWh** system with SDG&E, operating **10+ years**
- Two **50+ MWh** systems deployed
- New generation released (2025)

Key Mechanical Storage Companies

Hydrostor

Compressed Air Battery

Established 2010
8- 24 hrs duration
65% RTE
10 MWh installed capacity

- **10 MWh** demonstration in Ontario, commissioned 2019
- **1.6 GWh** project finishing permitting in AUS
- **4 GWh** project undergoing permitting with CEC

Energy Dome

Compressed CO_2 Battery

Established 2020
8 - 24 hrs duration
73% RTE
4 MWh installed capacity

- **4 MWh** demonstration in Italy, commissioned 2022
- First full-scale **200 MWh** system being commissioned
- **760+ MWh** of planned deployments, each **~200 MWh**
- Google partnership to serve data centers

Overview: Tech Provider Comparison

		Electrochemical					Mechanical	
		Non-Flow		Flow				
	Lithium-ion (Baseline)	Eos*	Form*	CellCube	Invinity*	Sumitomo	Hydrostor	Energy Dome
Technology	Lithium-ion	Zinc Hybrid	Iron Air	Vanadium Redox Flow			Compressed Air	Compressed CO_2
Duration (hrs)	2 – 4 hrs	3 – 12 hrs	100 hrs	2 – 24 hrs	3 – 18 hrs	4 – 8+ hrs	8 – 24 hrs	8 – 24 hrs
RTE (AC) (%)	83% – 86%	75% – 80%	40% – 50%	60% – 70%	60% – 70%	70%	65%	73%
Lifespan (years)	<10 years	20 years	15-20 years	30 years	25+ years	30+ years	50 years	30 years
LCOS ($/MWh)	$150	$100 – $200	$50 – $100	$90 – $120	$90 – $120	$100 – $200	(not available)	$50 – $150

* Technologies in the LDES Program portfolio

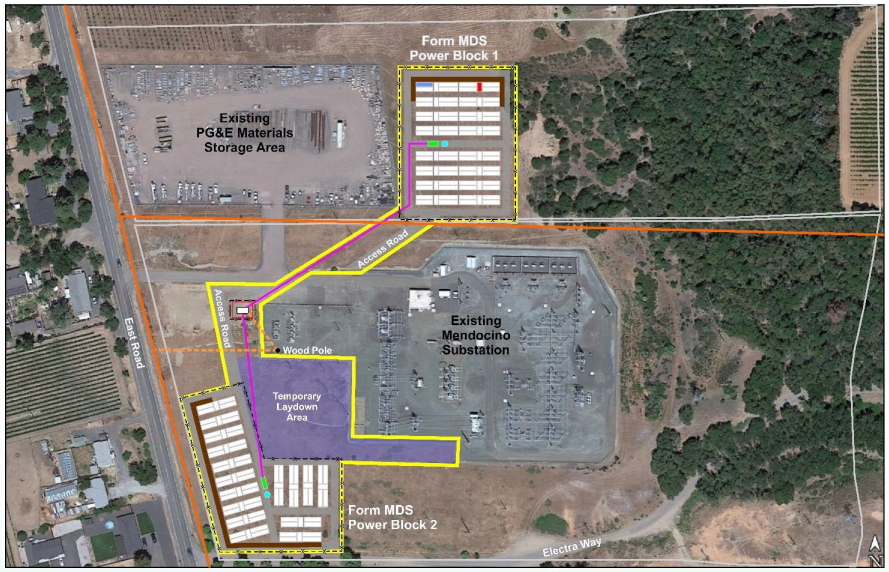
LDES—Diverse Demonstrations of Non-Lithium-Ion LDES Technologies

- California has 6 Different Non-Lithium-Ion LDES technologies in different phases of initial field demonstrations
  - Zinc hybrid
  - Vanadium redox flow battery
  - Zinc bromine flow battery
  - Iron Flow battery
  - Iron air
  - Zinc Air
  - Future LDES program competitive award could add 1-3 additional technologies or vendors

LDES—Largest LDES system in California Awarded in December 2023—Form Energy

Form Energy's Multi-day Storage System

- 100-hour duration, 5 MW, 500 MWh
- PG&E's substation at Redwood Valley, Mendocino County
- Use case and market application analysis
- Design, construction and operation of the multi-day storage system



Policy Environment

- Energy storage projects often funded with IRA's investment tax credits
  - Recent budget bill keeps storage tax credits; phases out for wind/solar
  - ITCs granted for: Prevailing wages, domestic content, support DAC/LIC
- Some technologies manufactured or rely on hard-to-source materials abroad
  - Tariff & ITC impact
  - Long-term strategy moving toward U.S. facilities