

Energy Storage in Our Clean Energy Future

Yayoi Sekine

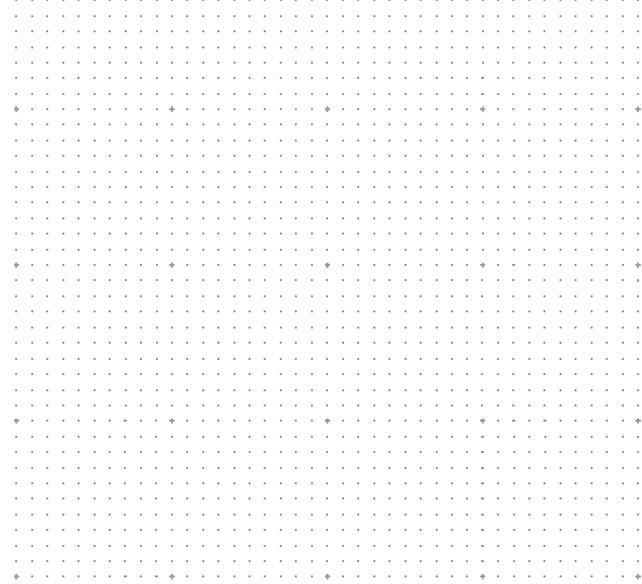
Dr. Yet-Ming Chiang

October 17, 2018



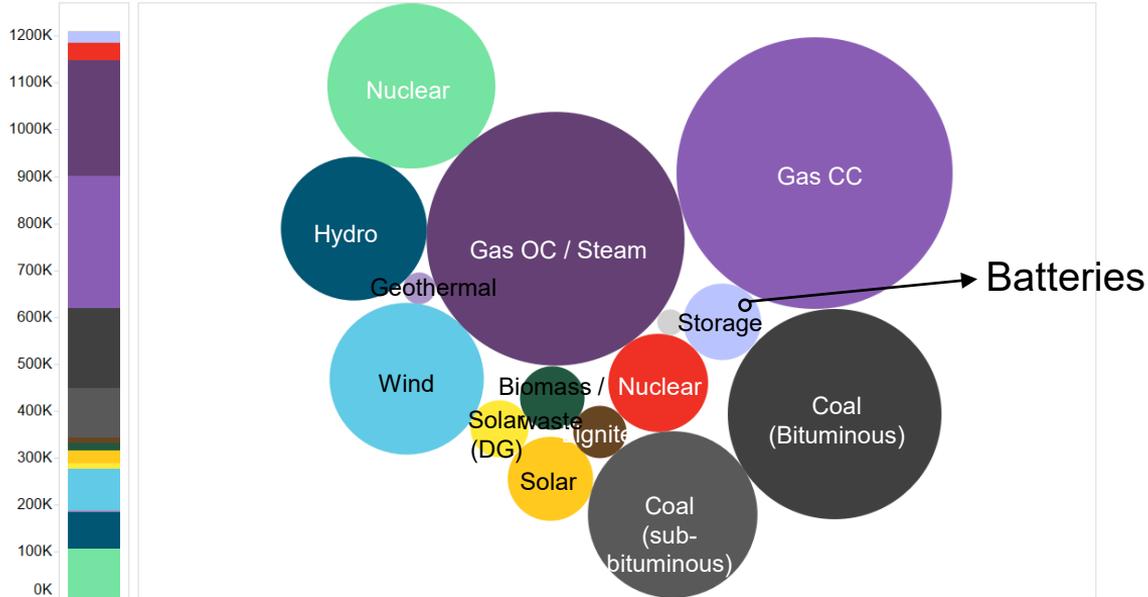
BloombergNEF

Trends



Energy storage is a tiny portion of our system today

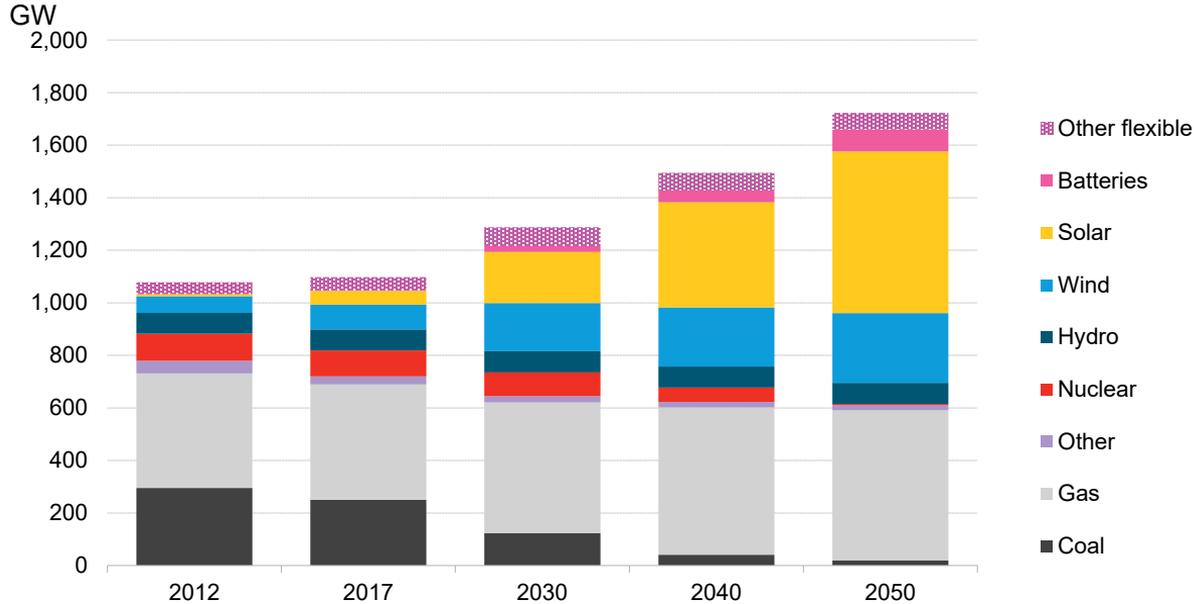
U.S. installed power capacity by technology



Source: Bloomberg NEF

Growth in capacity will be mainly in renewables

U.S. installed power capacity by technology



Source: Bloomberg NEF. Note: Forecast is part of analysis part of New Energy Outlook 2018.

Limiting global warming to 1.5°C



C2.2. In energy systems, modelled global pathways (considered in the literature) limiting global warming to 1.5°C with no or limited overshoot (for more details see Figure SPM.3b), generally meet energy service demand with lower energy use, including through enhanced energy efficiency, and show faster electrification of energy end use compared to 2°C (*high confidence*). In 1.5°C pathways with no or limited overshoot, low-emission energy sources are projected to have a higher share, compared with 2°C pathways, particularly before 2050 (*high confidence*). In 1.5°C pathways with no or limited overshoot, renewables are projected to supply 70–85% (interquartile range) of electricity in 2050 (*high confidence*). In electricity generation, shares of nuclear and fossil fuels with carbon dioxide capture and storage (CCS) are modelled to increase in most 1.5°C pathways with no or limited overshoot. In modelled 1.5°C pathways with limited or no overshoot, the use of CCS would allow the electricity generation share of gas to be approximately 8% (3–11% interquartile range) of global electricity in 2050, while the use of coal shows a steep reduction in all pathways and would be reduced to close to 0% (0–2%) of electricity (*high confidence*). While acknowledging the challenges, and differences between the options and national circumstances, political, economic, social and technical feasibility of solar energy, wind energy and electricity storage technologies have substantially improved over the past few years (*high confidence*). These improvements signal a potential system transition in electricity generation (Figure SPM.3b) {2.4.1, 2.4.2, Figure 2.1, Table 2.6, Table 2.7, Cross-Chapter Box 6 in Chapter 3, 4.2.1, 4.3.1, 4.3.3, 4.5.2}

“The 100 Percent Clean Energy Act”

Forbes

Sep 14, 2018, 09:02am

**California's Electricity Dreams
Still Need Natural Gas**



**Energy Storage to Play Key Role
in Reaching California Target of
100% Zero-Emission Electricity by
2045 and Beyond**

RTO Insider

**Can Calif. Go All Green Without a Western
RTO?**

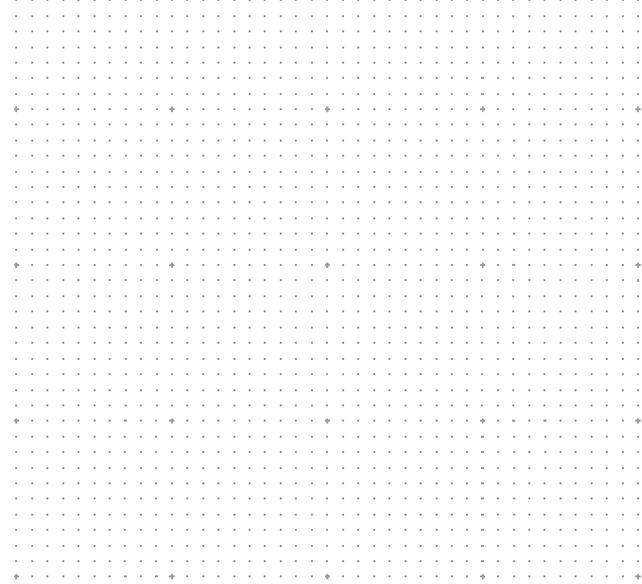
October 7, 2018

BloombergNEF

**California's 100% 'Clean Energy'
Law Omits Some Details**

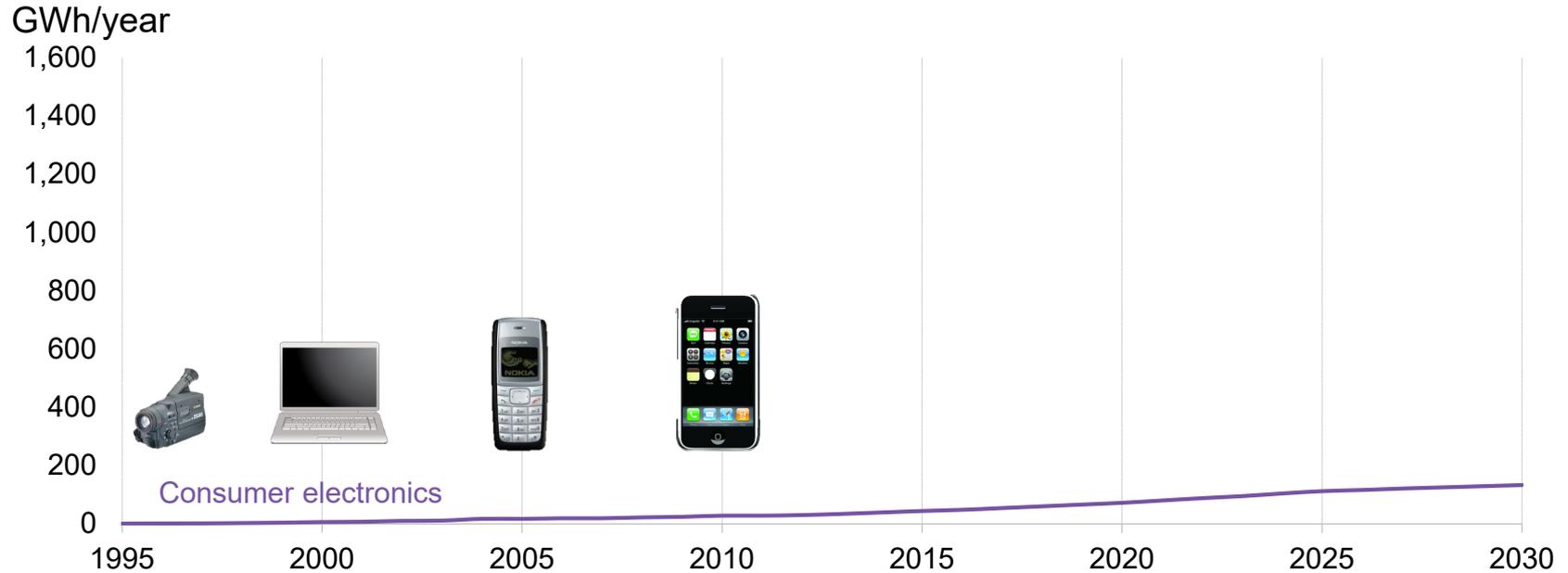
by [Stephen Munro](#) / 13 Sep 2018

Technology



Largest sources of lithium-ion battery demand over time

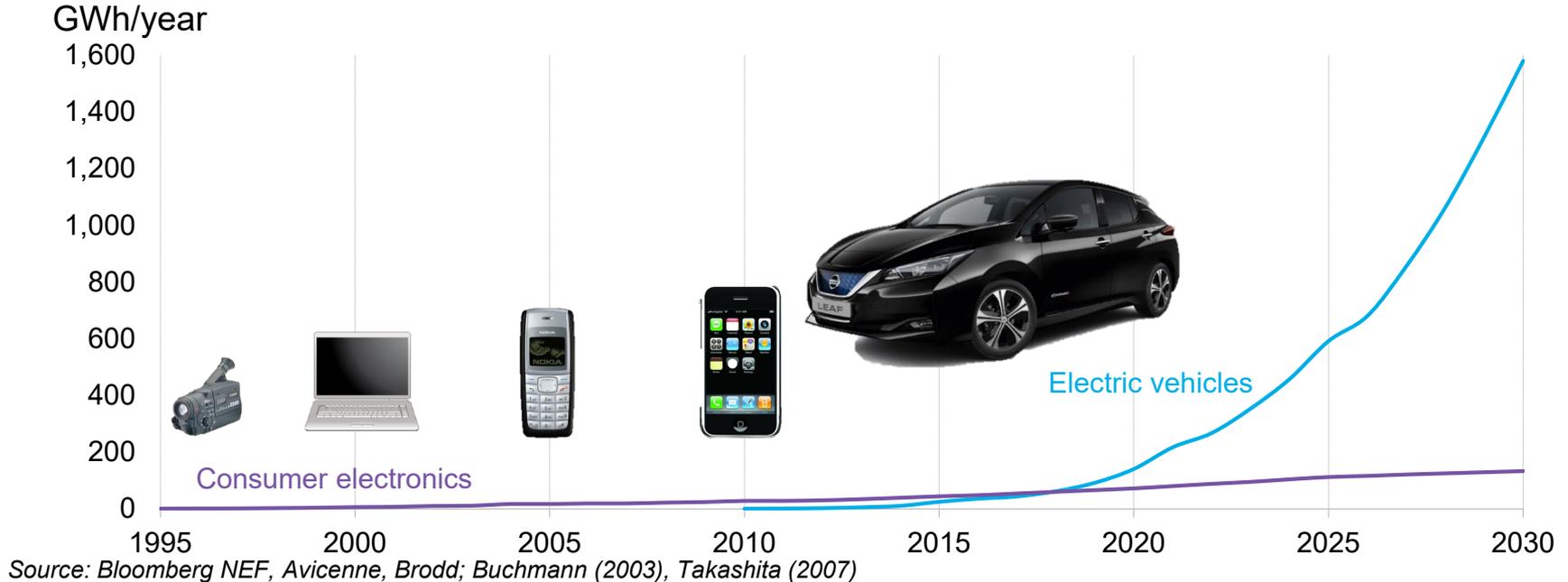
Lithium-ion battery demand by segment



Source: Bloomberg NEF, Avicenne, Brodd; Buchmann (2003), Takashita (2007)

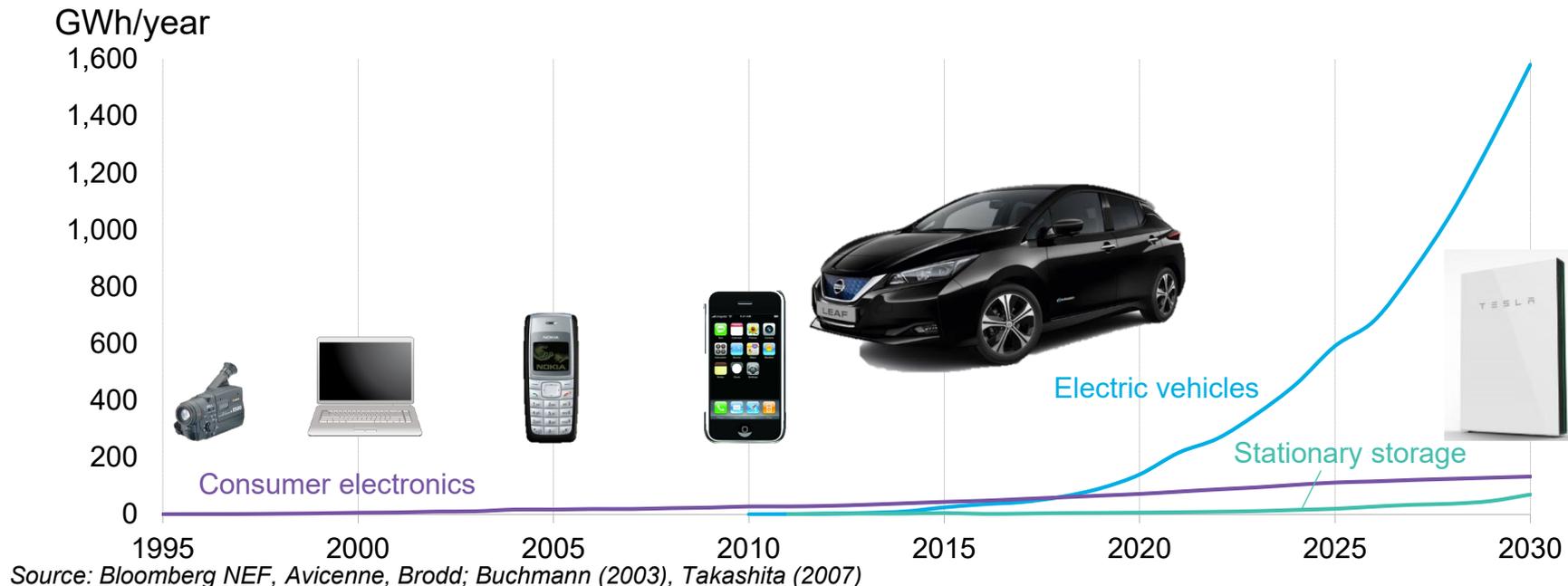
Largest sources of lithium-ion battery demand over time

Lithium-ion battery demand by segment



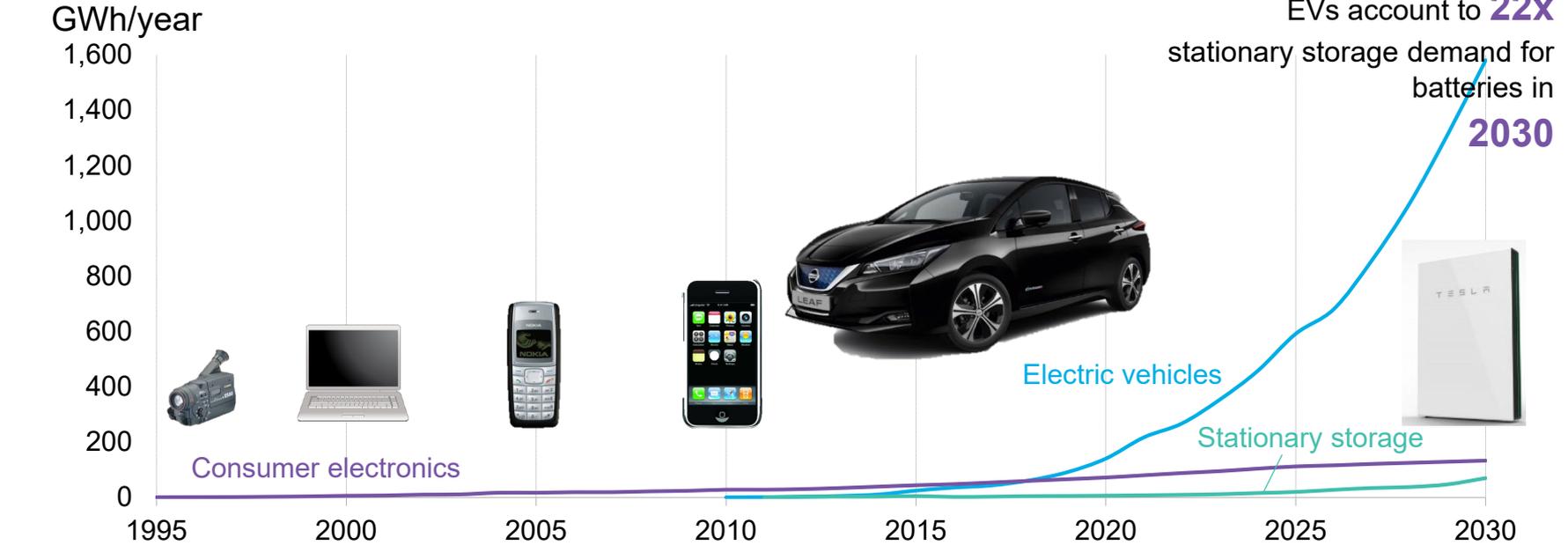
Largest sources of lithium-ion battery demand over time

Lithium-ion battery demand by segment



Largest sources of lithium-ion battery demand over time

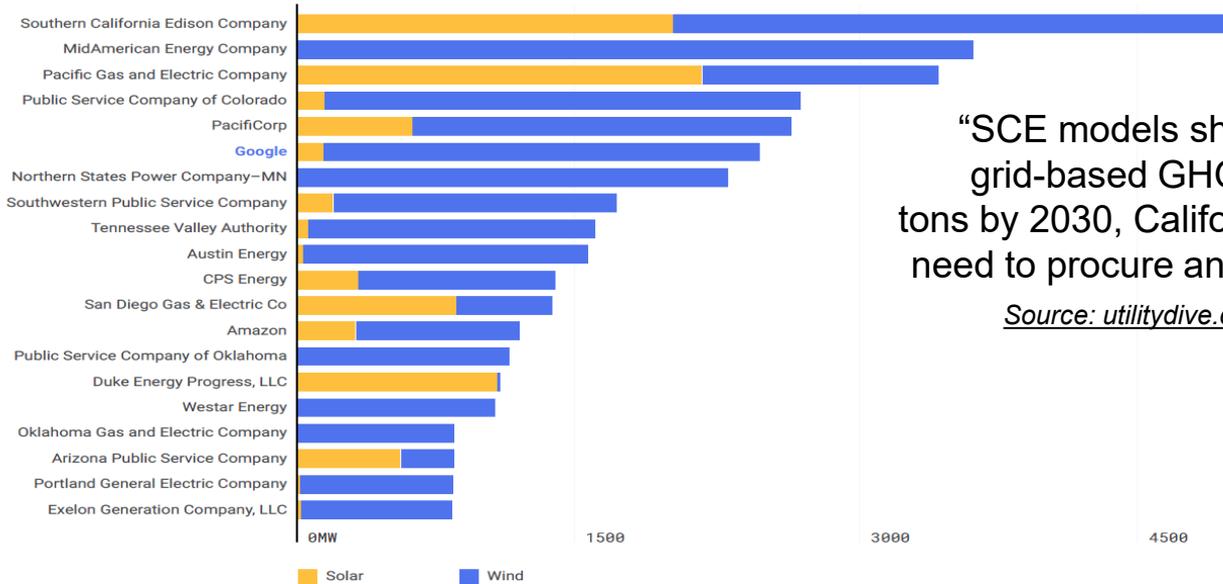
Lithium-ion battery demand by segment



Source: Bloomberg NEF, Avicenne, Brodd; Buchmann (2003), Takashita (2007)

How much grid lithium-ion required by 2030?

LARGEST U.S. RENEWABLE ENERGY OFFTAKERS—BOTH UTILITIES AND CORPORATES—NOVEMBER 2016



“SCE models showed that in order to reduce its grid-based GHG emissions to 28 million metric tons by 2030, California load-serving entities would need to procure an additional 9,604 MW of energy storage.”

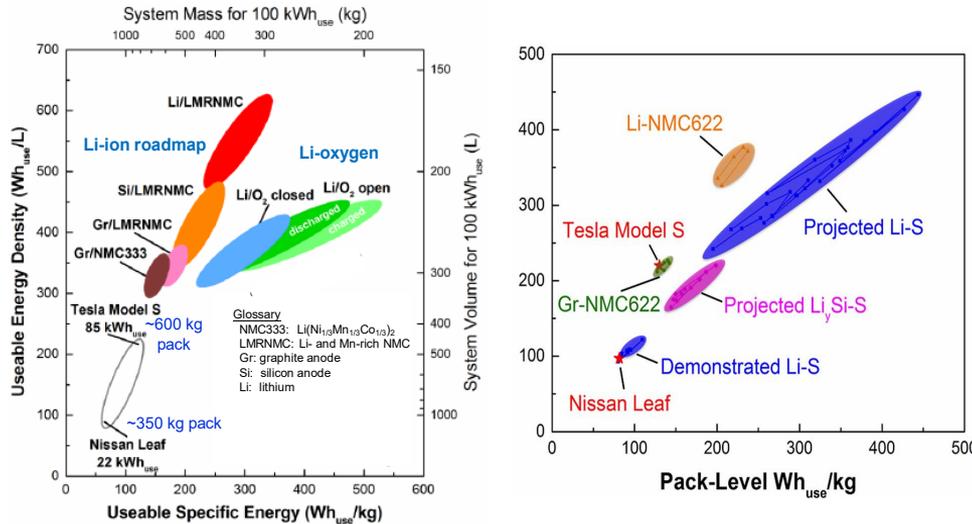
Source: utilitydive.com

$$\begin{aligned}
 &9,604 \text{ MW} \times 5\text{h} = \\
 &48 \text{ GWh (1 Gigafactory)} \\
 &\times \$200/\text{kWh} = \\
 &\mathbf{\$9.6B}
 \end{aligned}$$

Source: Google

EVs demand high energy density and low cost

Energy density by battery type



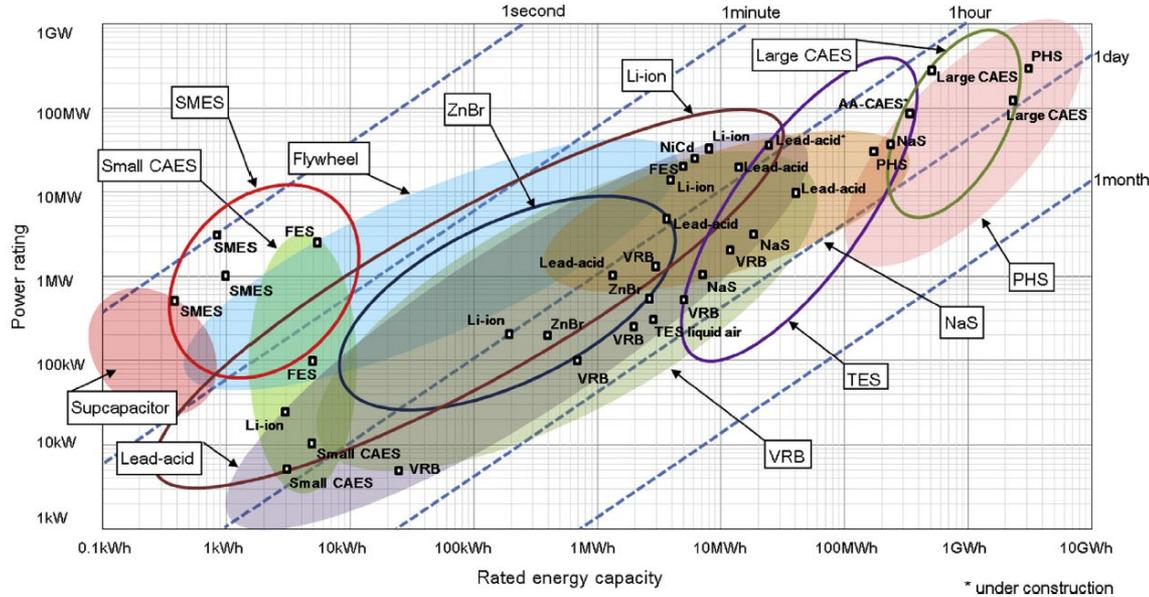
High energy density roadmap depends on lithium metal

Drivers are energy density and cost

Source: K.G. Gallagher et al, *Energy Environ. Sci*, 7, 1555 (2014), D. Eroglu et al., *J. Electrochem. Soc.*, 162, A982 (2015)

Grid storage options are much broader than lithium-ion

Battery technology energy and power ratings

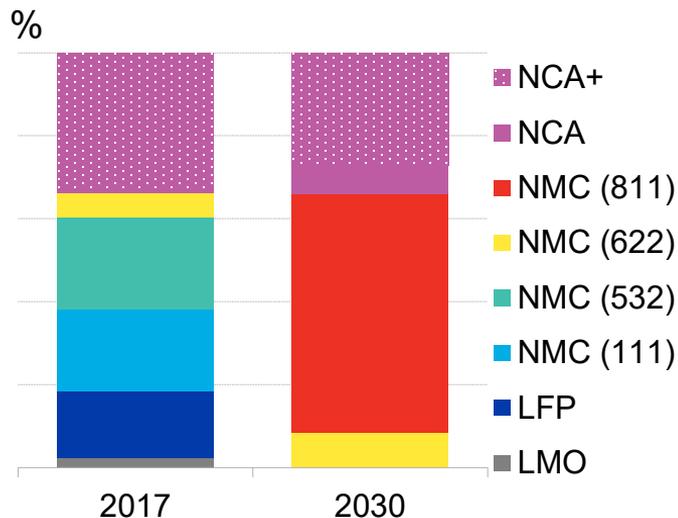


But can any compete with declining lithium-ion battery costs?

Source: *Applied Energy* 137 (2015) 511–536.

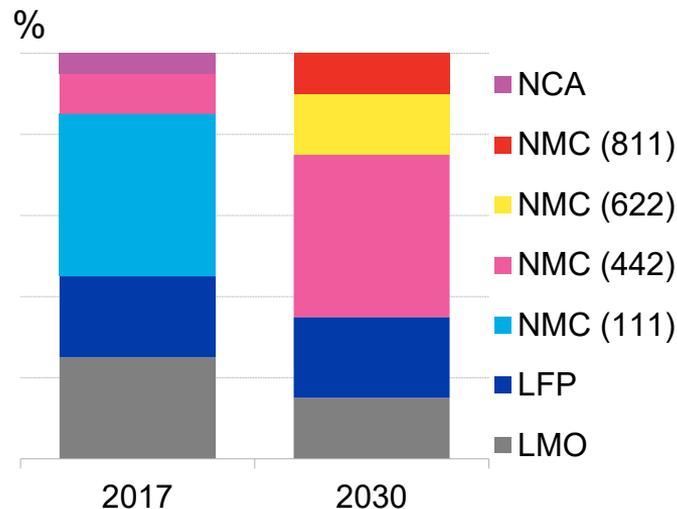
Lithium-ion battery cathode chemistry mix outlook

Passenger electric vehicles



Source: Bloomberg NEF

Utility-scale energy storage

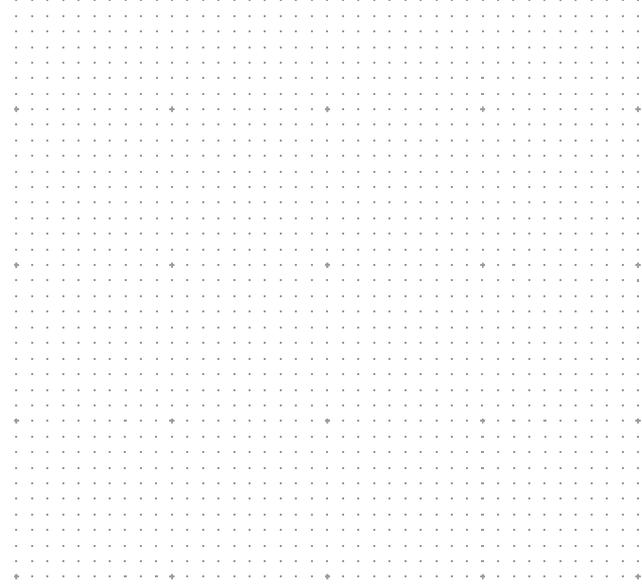


Source: Bloomberg NEF

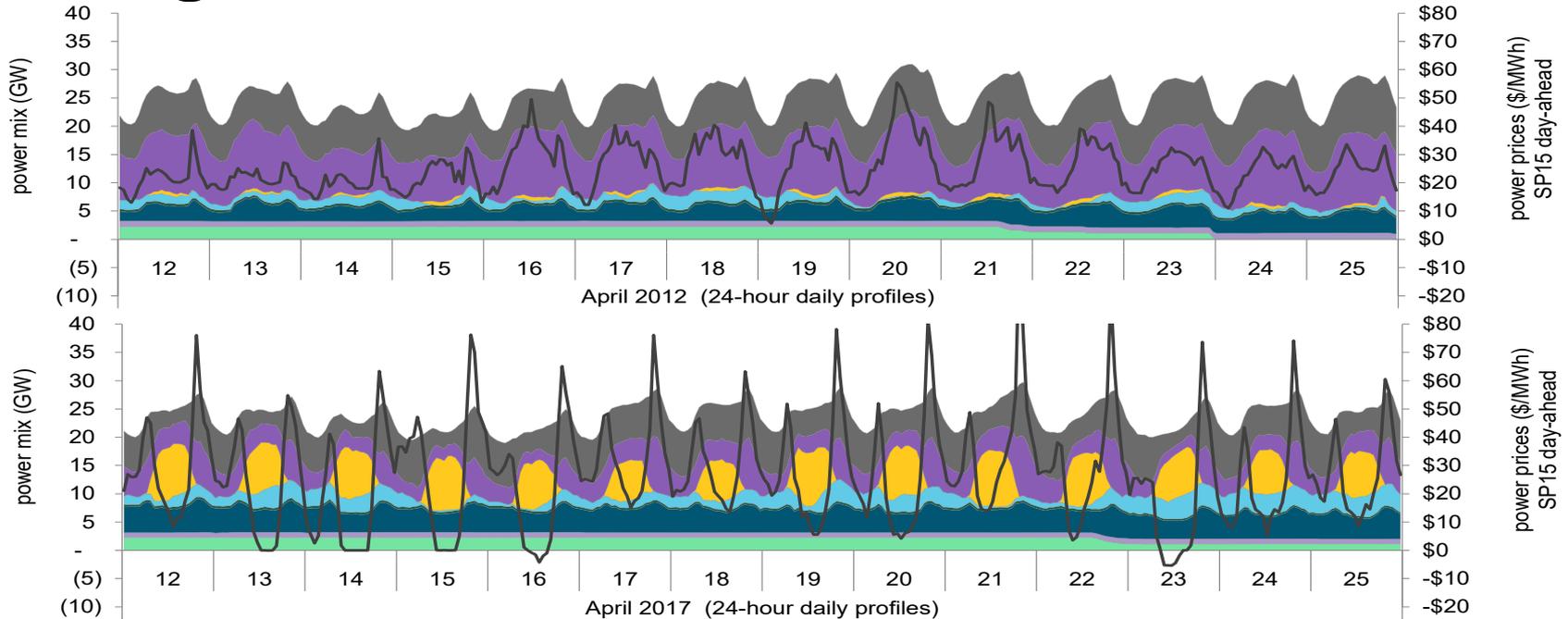
811 = 8x more Nickel than Manganese & Cobalt

111 = equal parts Nickel Manganese Cobalt

Economics



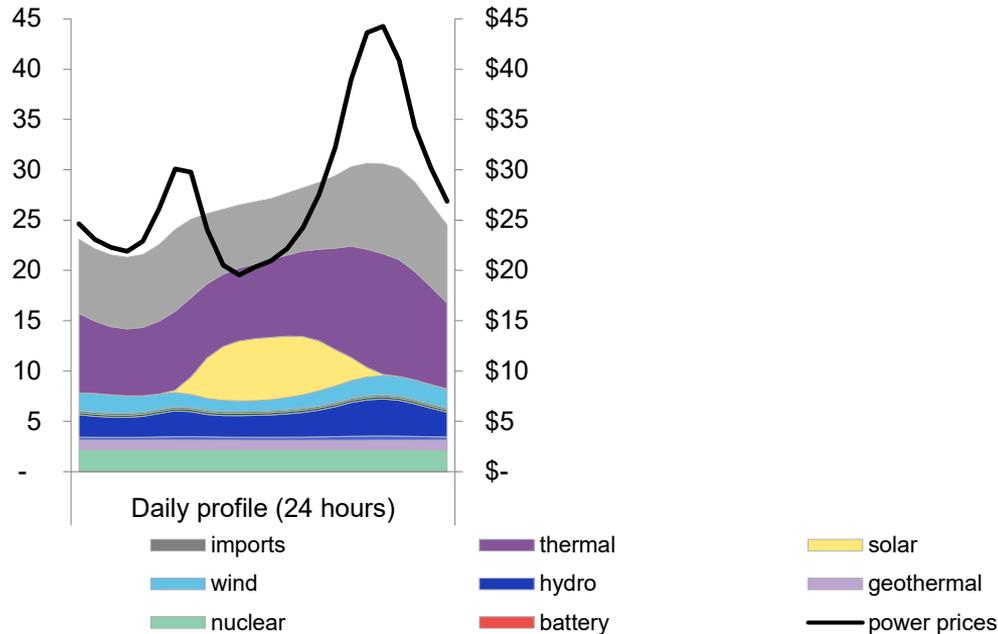
California challenge: Fading value of solar



Source: California Independent System Operator (CAISO)

How batteries can bolster solar economics

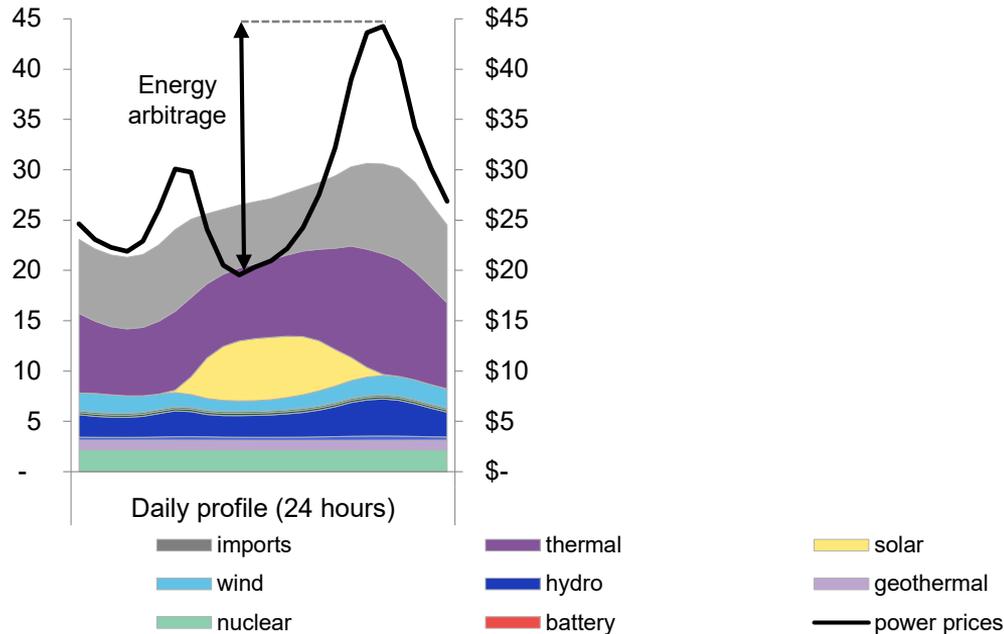
No batteries



Source: Bloomberg NEF. Note: Shows CAISO SP15 Day-Ahead power prices

How batteries can bolster solar economics

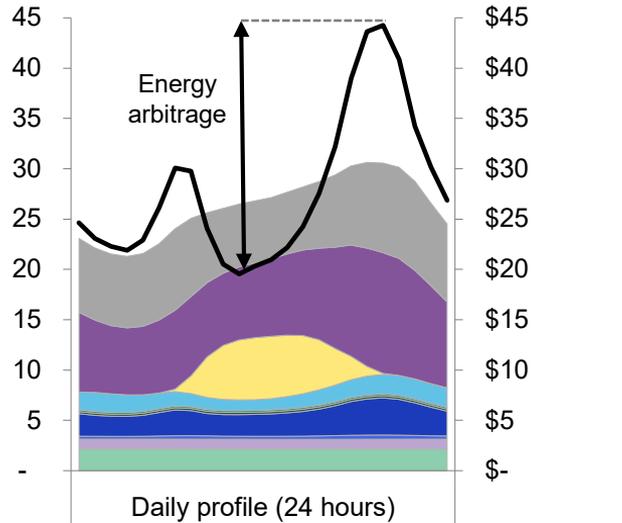
No batteries



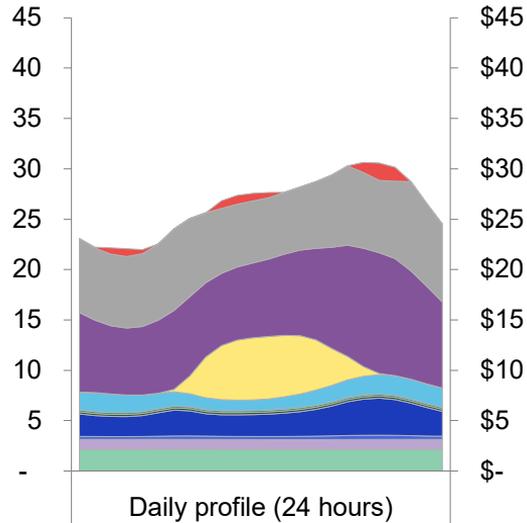
Source: Bloomberg NEF. Note: Shows CAISO SP15 Day-Ahead power prices

How batteries can bolster solar economics

No batteries



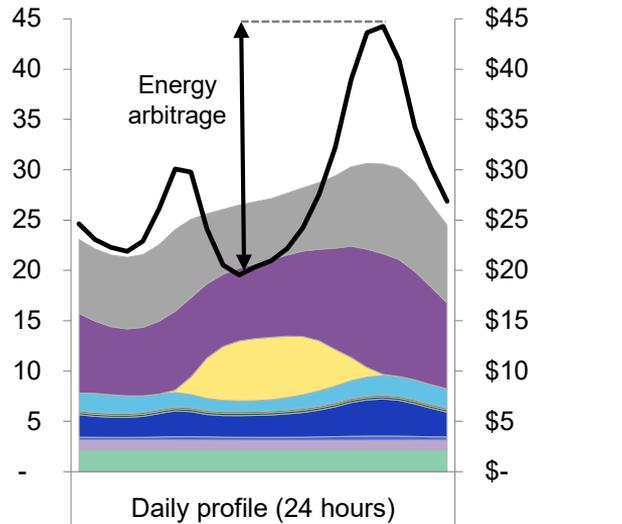
6GWh of batteries



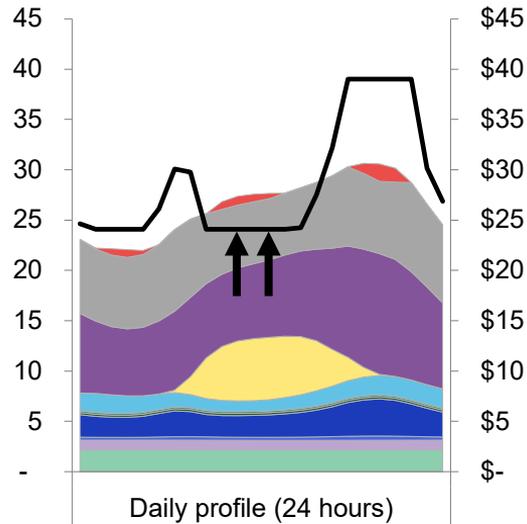
Source: Bloomberg NEF. Note: Shows CAISO SP15 Day-Ahead power prices

How batteries can bolster solar economics

No batteries



6GWh of batteries

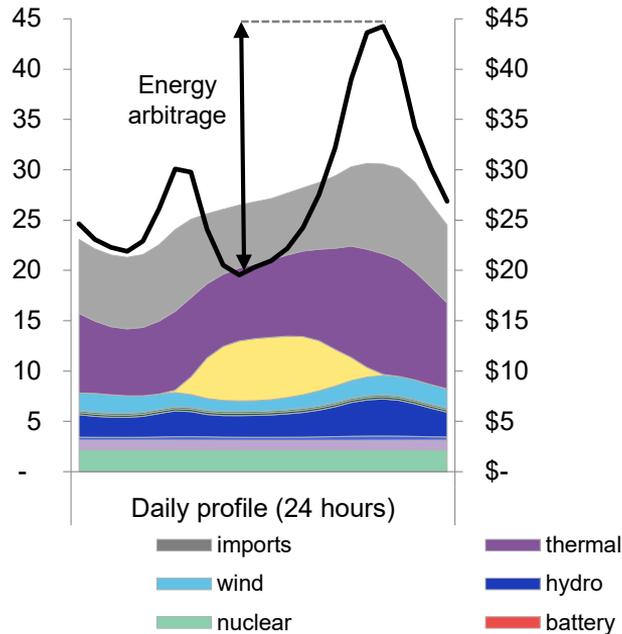


- imports
- thermal
- solar
- wind
- hydro
- geothermal
- nuclear
- battery
- power prices

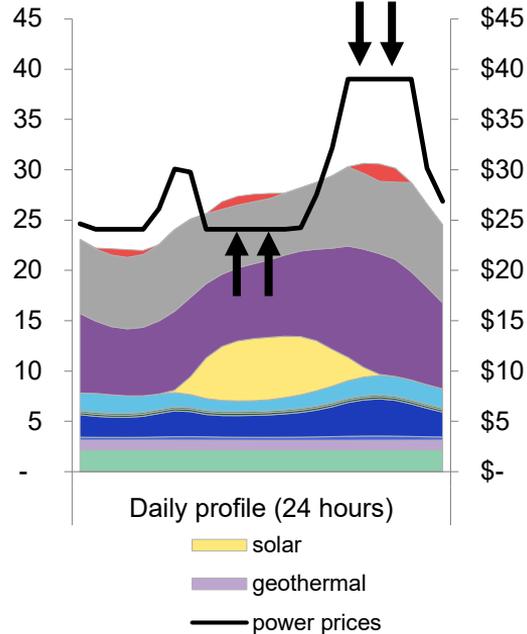
Source: Bloomberg NEF. Note: Shows CAISO SP15 Day-Ahead power prices

How batteries can bolster solar economics

No batteries



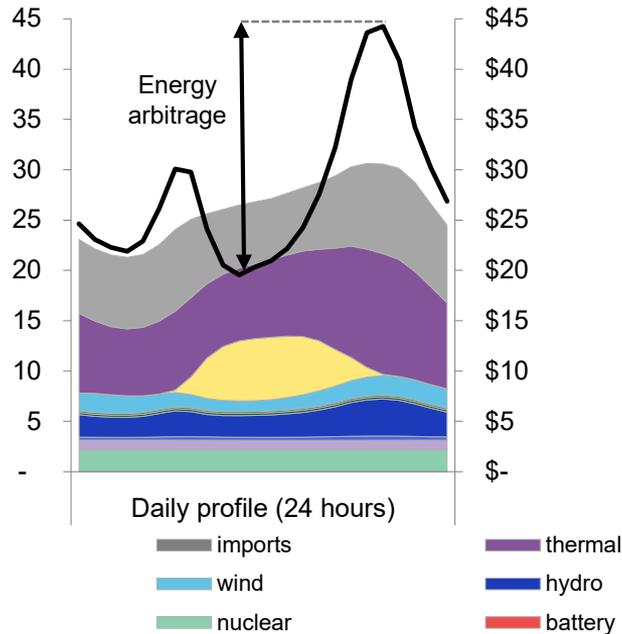
6GWh of batteries



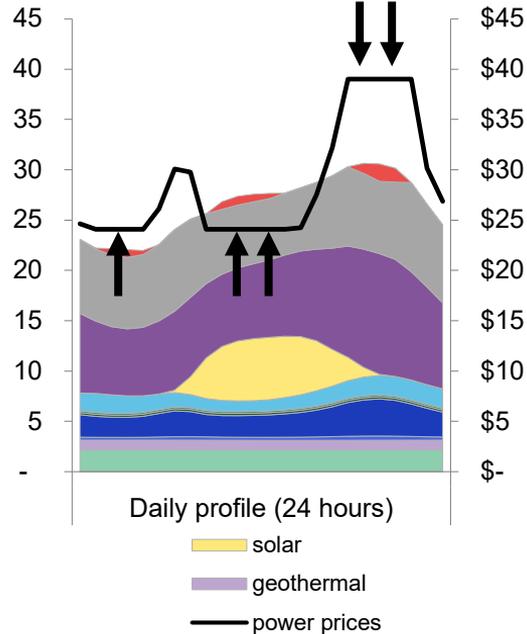
Source: Bloomberg NEF. Note: Shows CAISO SP15 Day-Ahead power prices

How batteries can bolster solar economics

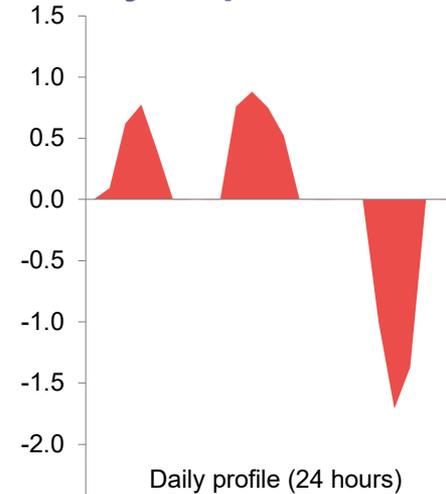
No batteries



6GWh of batteries

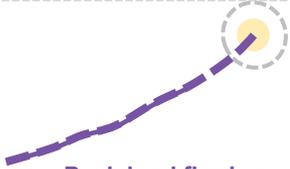
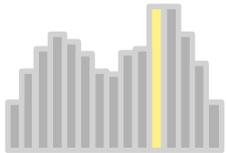
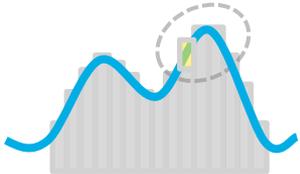
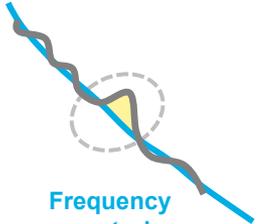


Battery dispatch

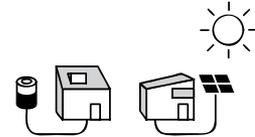
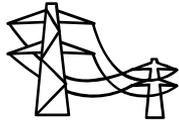
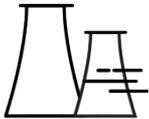


Source: Bloomberg NEF. Note: Shows CAISO SP15 Day-Ahead power prices

Batteries in wholesale markets deliver value in different timescales

Market	Resource Adequacy Capacity markets	Energy (Day-Ahead)	Energy (Real-Time)	Ancillary Services
Delivery window	Years	Hours	Minutes	Seconds
	 <p>Peak load firming</p> <p>Passive market</p>	 <p>Daily dispatch</p>	 <p>Intra-hourly adjustments</p> <p>Active markets</p>	 <p>Frequency control</p>

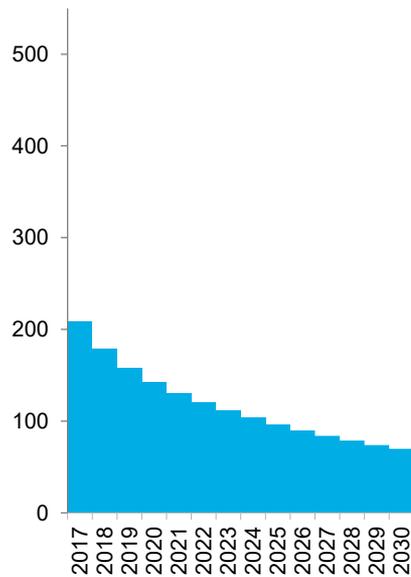
Additional use-cases will add complexity and value



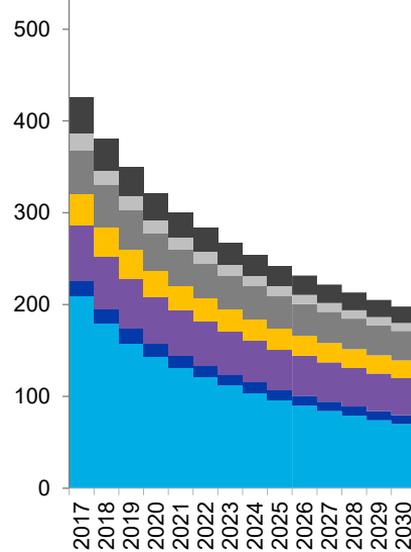
Energy storage system costs are complex

Battery cost forecast (\$/kWh)

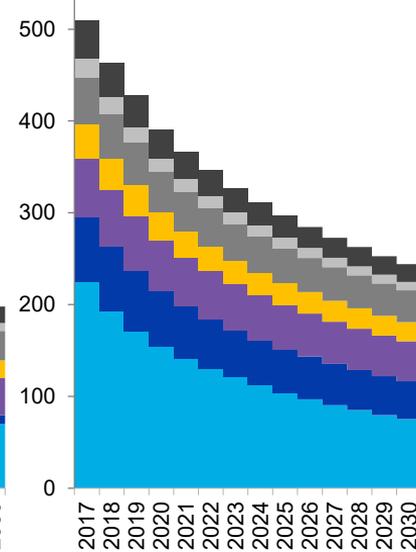
Pack only



Built for resource adequacy (4-hour duration)



Built for arbitrage (1-hour duration)



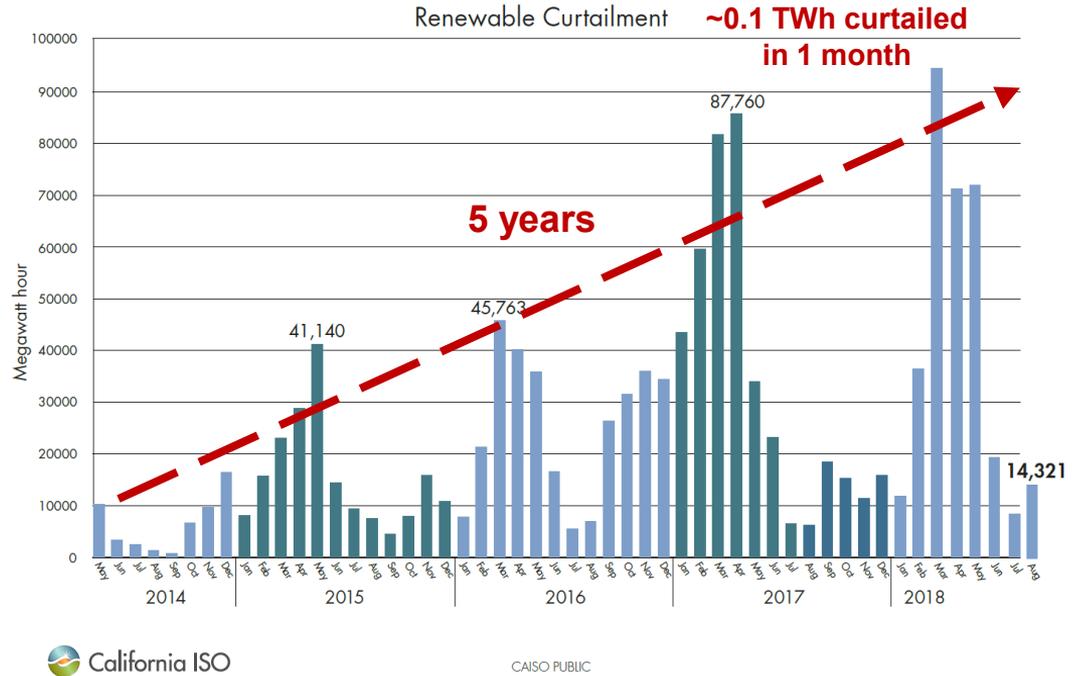
- Developer margin
- Developer overheads
- EPC*
- Energy Management System
- Balance of System
- PCS
- Battery pack

Source: Bloomberg NEF

Curtailment

Varies over months, not just hours and days

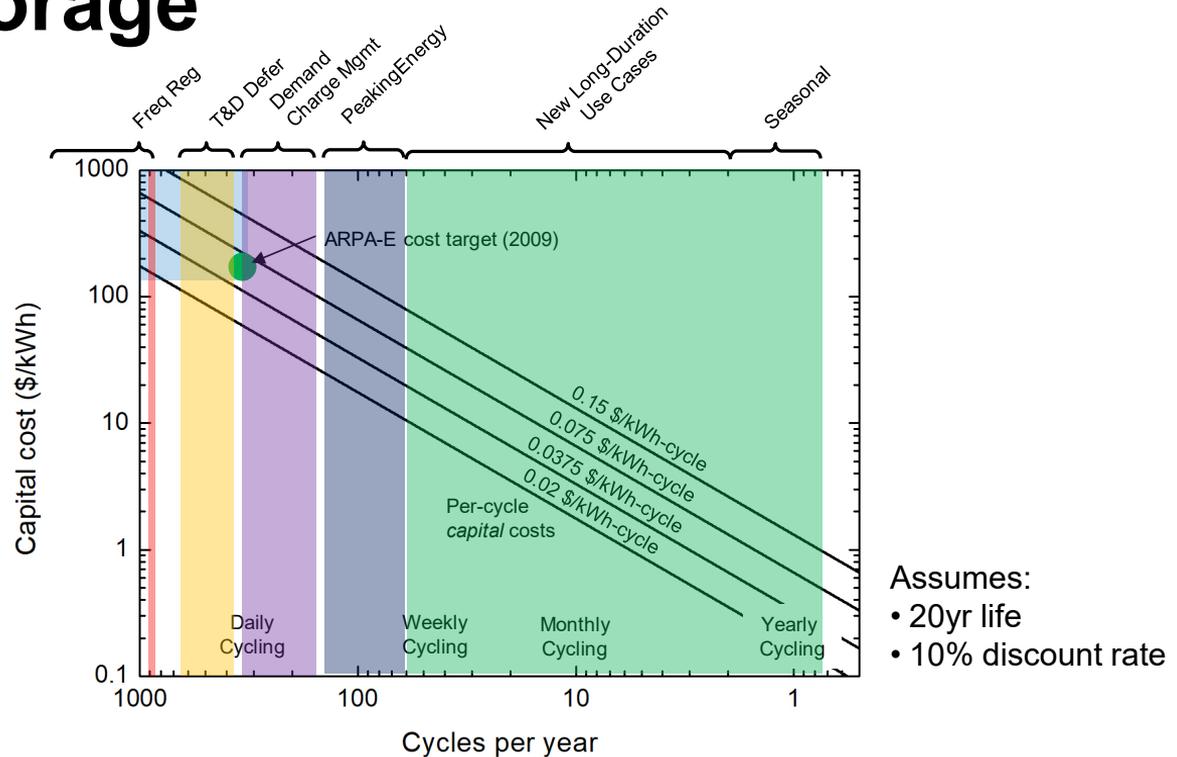
Growing rapidly with increased renewable penetration



Lower capital cost targets for long duration storage

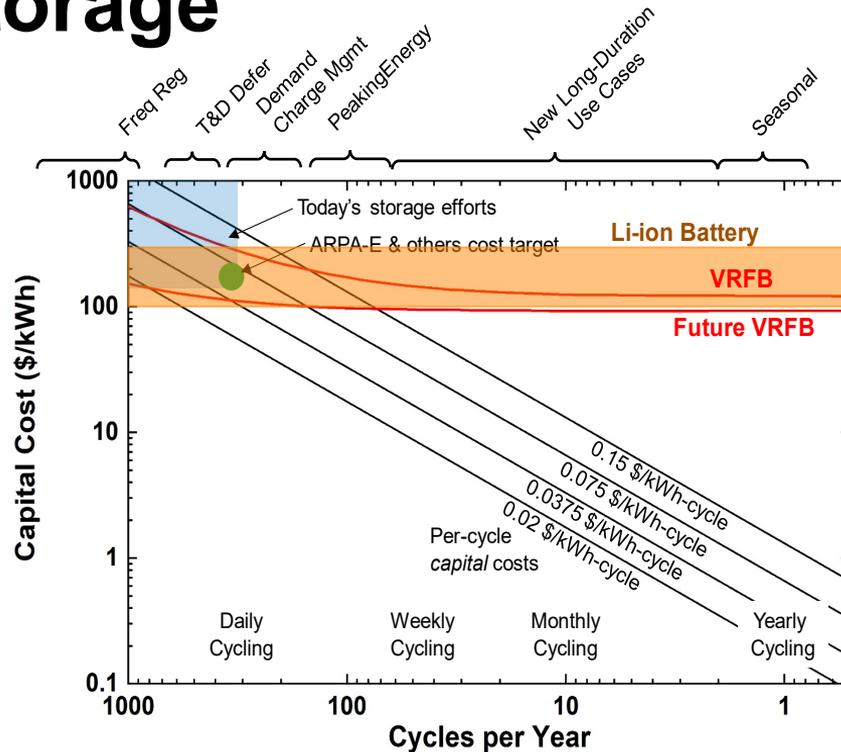
Grid storage spans 3 orders of magnitude in time scale

Fewer cycles over life requires lower storage capex to be economical on a levelized cost basis



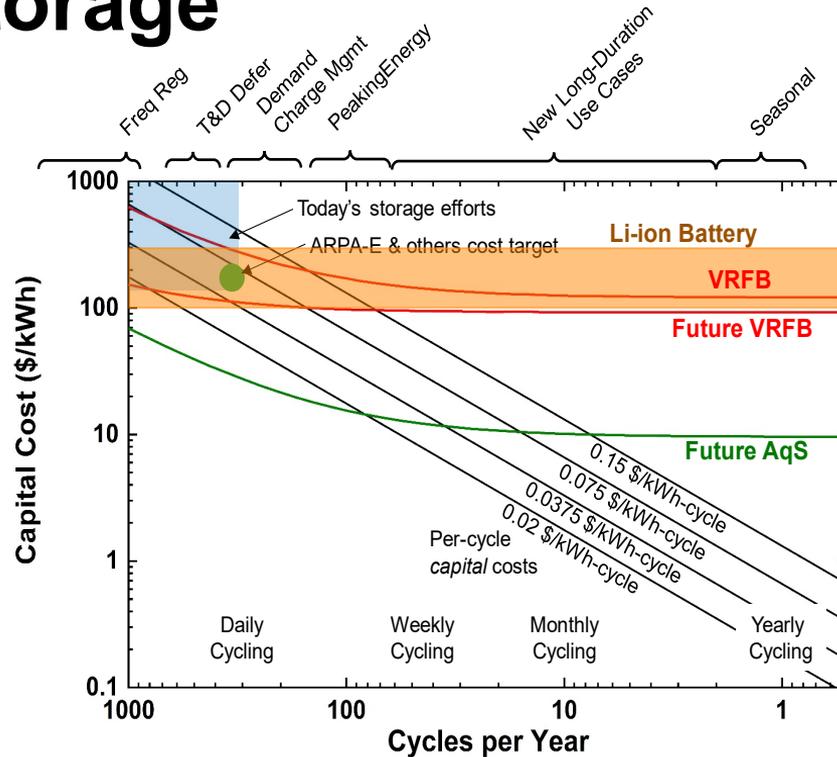
Lower capital cost targets for long duration storage

Current storage technologies too expensive for long duration storage



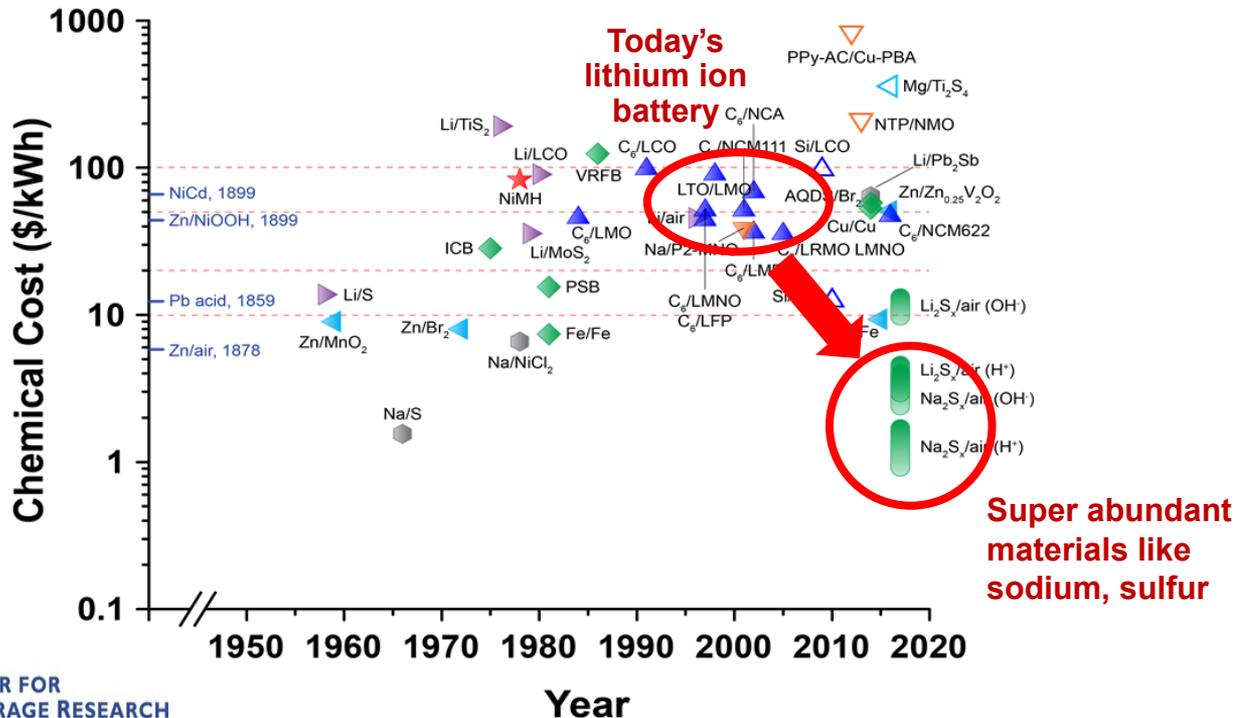
Lower capital cost targets for long duration storage

New battery chemistries with <\$20/kWh capital cost required for multi-day storage and beyond



What if you could have grid storage at 1/10th the cost of lithium-ion with no materials constraints?

FORM ENERGY



Global Storage Potential: Pumped Hydro vs. Aqueous Sulfur

FORM ENERGY



Pumped Hydro Facility: Ludington, Michigan

Volume: 39M m³ of Water

Area: 3.4 km²

Storage: **1.9 GW/15 GWh**

Global Pumped Hydro:

~170 GW/2 TWh Installed



Berri Gas Plant Sulfur Pyramid: Al Jubayl, Saudi Arabia

Volume: 1.6M m³ Sulfur (70% of KSA annual production)

Area: 0.171 km²

Storage: **24 GW/1.2 TWh Storage Potential**

Global Sulfur Resource:

Annual Production: 69 megatons* - **0.5 GW/25 TWh storage potential**

*<https://minerals.usgs.gov/minerals/pubs/commodity/sulfur/mcs-2017-sulfu.pdf>

Storage at Giga Scale

FORM ENERGY

Today's battery technology
for transportation



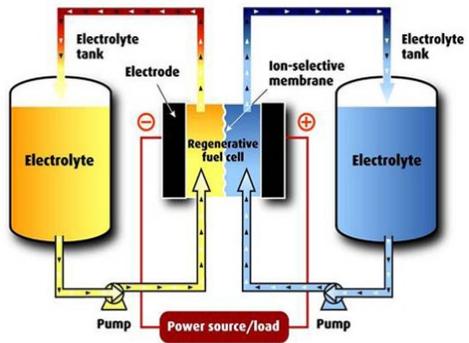
Tesla

\$ 200/kWh



Raccoon Mtn (TN)

Power Plants Around the World



Tomorrow's battery
technology for grid storage



San Diego G&E

Looks more like a chemical
plant → < \$20/kWh

Key takeaways

- Grids are becoming increasingly renewable and storage is essential to the clean energy future.
- It will add complexity and value.
- We will need lower-cost, longer-duration storage.
- Multiple technologies will be needed beyond lithium-ion batteries.

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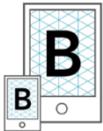
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