Battery Storage: Technology, Performance, and Trends

Webinar Logistics

- All attendees are in “listen only” mode.
- We will answer questions during and after the presentation.
- Please send questions using the Q&A or chat box at any time.
- The webinar is being recorded and will be shared after the webinar.

SCP's Mission

Sonoma Clean Power is turning the tide on the climate crisis, through bold ideas and practical programs.

- Provide higher percentages of renewable energy and reduce greenhouse gas emissions.
- Help solve the climate crisis at a local level.
- React and respond to local needs.
- Deliver customer programs that make a difference.

CleanStart

- SCP's default electricity service
- Competitive rates – mix of renewables, carbon-free energy, and general system power.

50% Renewable

91% Carbon-Free

EverGreen

- Optional program available to residential and commercial customers
- Premium of $0.025/kWh (about $13 more per month than CleanStart for avg. home)

24/7 Renewable

100% Local

Solar & Geothermal

Sonoma Clean Power
Advanced Energy Center

- Explore how to power more of your life with renewable energy, instead of gas.
- Browse a large demonstration area with the best all-electric technologies and home systems.
- Learn about the many benefits of electrification: health, safety, climate action, etc.
- Attend classes and events.
- Take advantage of exclusive SCP customer discounts and incentives.

Customer Benefits

- The latest and greatest energy-saving technologies all under one roof.
- Get connected with certified local contractors to perform installations.
- Access unbeatable vendor discounts and pricing.
- SCP's zero-interest loan program allows you to avoid huge upfront costs and pay over time.

Speaker

Chris Calwell

Principal Researcher
Ecos Research – Durango, CO

Adjunct Faculty
Middlebury Institute for International Studies – Monterey, CA

Advanced Energy Center

An Introduction to Residential Energy Storage Systems

Chris Calwell

Presented on behalf of Sonoma Clean Power
Santa Rosa, CA
November 15, 2022

Background

- I am a principal at Ecos Research -- a small consulting firm based in San Luis Obispo, CA and Durango, CO.
- We seek to achieve breakthrough reductions in greenhouse gas emissions through technology and policy-driven improvements to energy storage, electric vehicles, PV, and consumer electronics.
- I joined the research team at CSIRO in Newcastle, Australia to conduct testing and research on residential energy storage research efforts in Feb-March 2019 through Fulbright Specialist funding from the US State Department.
- This presentation is a distillation of my findings from that research and our subsequent work for EPA ENERGY STAR, PG&E, Sonoma Clean Power, Portland General Electric, and Arizona Public Service on the residential energy storage topic.
- I also teach a graduate course in International Renewable Energy Policy in Monterey and work part-time as a clean tech investor.

Key Topics We'll Cover

- Batteries 101: Utility-scale and residential
- Market trends: What's happening to sales?
- Why residential battery sales are rising and how they're typically used
- Key challenges in understanding their performance claims, specifications and warranties
- The good, the bad and the ugly from early measurements of battery performance and efficiency
- Economics: Why it has been challenging to get them to pay for themselves now, but will be financially more attractive in the future
- Emerging alternatives to today's home battery systems: V2G electric vehicles, heat pump water heaters, and solid-state batteries

As residential PV installations have grown and designs have matured, costs have fallen steadily. Next frontiers: EVs and energy storage.

Photo source: Redwood Energy, A Zero Emissions All-Electric Single-Family Construction Guide, 2020.

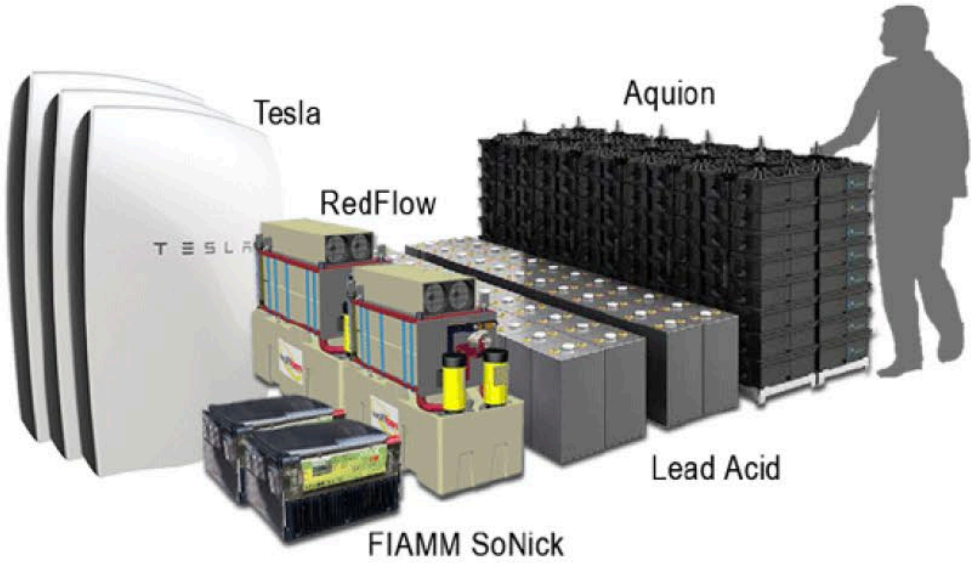
Early home battery designs were very limiting

- A dedicated room or shed to house everything
- Banks of heavy lead acid batteries that often required water to be added, or other maintenance, and could only utilize about half of their capacity to ensure a reasonable lifetime
- Many of these systems were strictly off-grid, and intended to power a small number of basic loads with a gasoline generator backup
- If they allowed a grid connection, significant extra hardware was needed

What’s driving the recent rise in home battery installations?

- Early systems mostly used costly, bulky, difficult-to-maintain lead acid batteries coupled with solar (and often backup generators) to allow people to live off-grid
- Newer designs connect to solar *and* the grid using mostly low maintenance lithium ion technology that was first developed for consumer electronics, electric vehicles, and utility-scale energy storage

Side-by-Side Comparison of ~20 kWh Battery Storage



ource: FIAMM

Each Tesla Powerwall 2 stores 13.5 kWh, so 1.5 of them would hold as much energy as the systems on the left

Exciting new residential energy storage demonstration projects

Soleil Lofts in Salt Lake City -- a new 600 unit apartment complex with 5.2 MW of rooftop and parking canopy PV, 150 on-site EV chargers, and a Sonnen battery system in every apartment. They are all linked together as a 12.6 MW microgrid and backup power system that also delivers grid services to Rocky Mountain Power.

Source: www.nytimes.com/2021/03/03/business/energy-storage-batteries-developers.html and www.utilitydive.com/news/virtual-power-plant-utah-sonnen-rocky-mountain-power-future-of-storage-distributed-energy/563734/

California's residential building code generally requires solar on new homes, but not yet batteries, which are being mandated in commercial buildings.

"**2022 Energy Code: Battery Storage & Electric Readiness**
California's Solar Mandate will receive a new update, effective in January 2023. Known as the 2022 Energy Code, it will require all single-family homes to be electric-ready. It will also include guidance for installing battery storage systems. The battery portion of the mandate currently only applies to select businesses, but it's a good indication of where future code updates are headed. Solar battery systems are a great way to increase energy independence by allowing onsite energy to be used when needed, reducing the grid's dependence on fossil fuel power plants."

Current residential building codes give extra credit to homes that include batteries, reducing the size of their required solar systems and other efficiency upgrades. CEC trying to reduce how much extra PV goes back onto the grid midday.

Sources: https://simplysolar.com/blog/california-solar-mandates/ and https://www.renewableenergyworld.com/storage/why-californias-new-home-solar-requirement-includes-batteries-and-not-zero-net-energy/#gref

Q: What are some reasons you might be holding off on putting solar on your roof and a stationary battery pack in your garage?

- Sonoma County has one of the cleanest electricity grids in the country, with a large fraction of geothermal power. So there's less incremental environmental benefit from replacing that power with home solar than there would be in many parts of the country.
- No upfront capital needed to be a 100% renewable customer, compared to a PV project at roughly $3 to $4 per watt, plus the cost of batteries, minus tax credits.
- The grid is a less expensive "battery" than having energy storage in your garage, but it can experience interruptions and disruptions.
- Stationary batteries and EVs are getting steadily cheaper and better performing, so waiting to install down the road could save money.

Renewables done at utility scale are very affordable

A field of solar panels and windmills in the desert. (credit: Getty)

A floating solar farm on the artificial lake above the Alqueva Dam in Portugal in June. *Photographer: Goncalo Fonseca/Bloomberg*

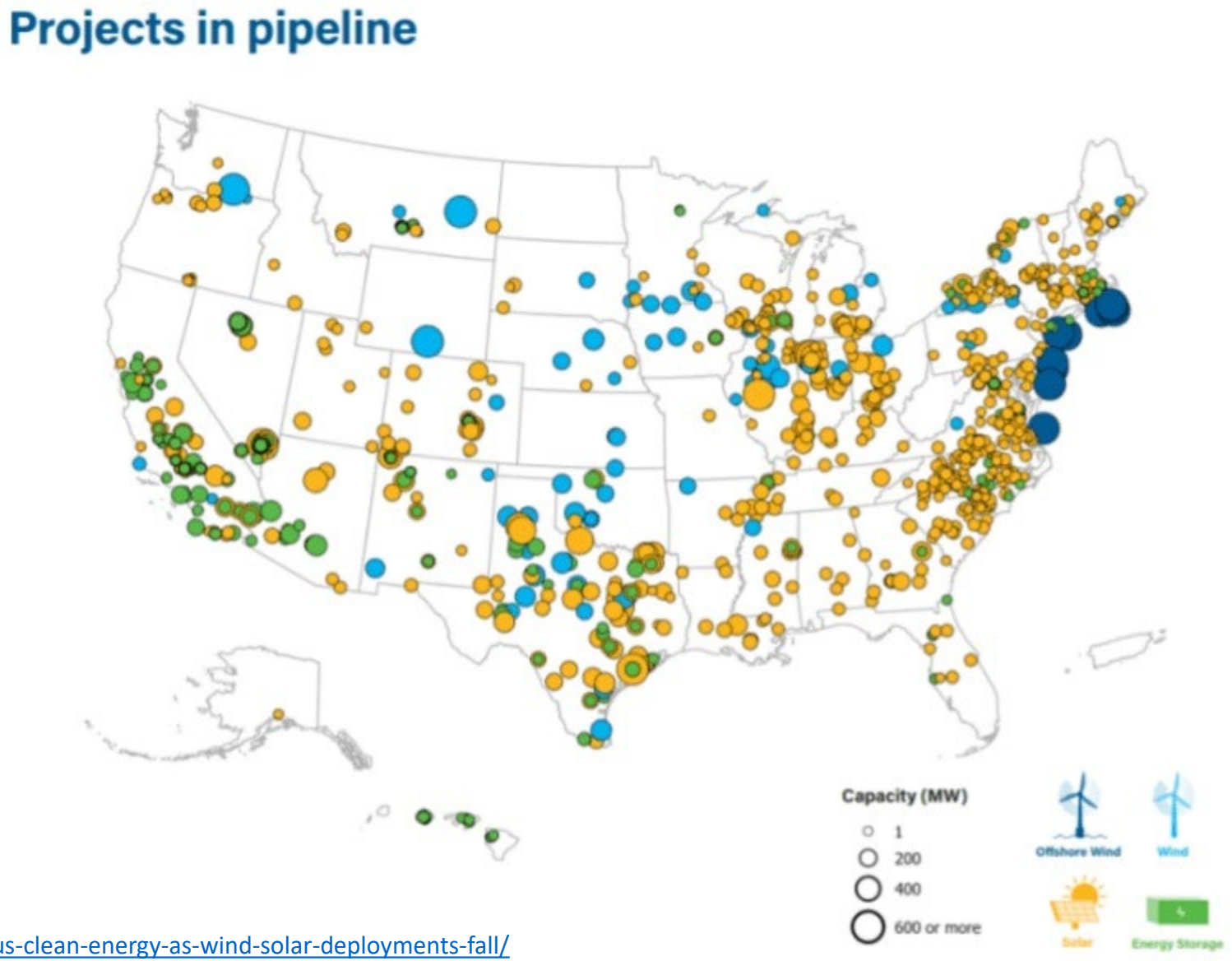
It’s a very exciting time in the history of renewables

Utility-scale renewable projects are ramping up at tremendous speed throughout the country right now.

60% of all the new capacity under development is solar.

Offshore wind finally being developed at significant scale.

3.1 GW (billion watts) of utility scale energy storage have been deployed so far this year and another 14 GW are in development.

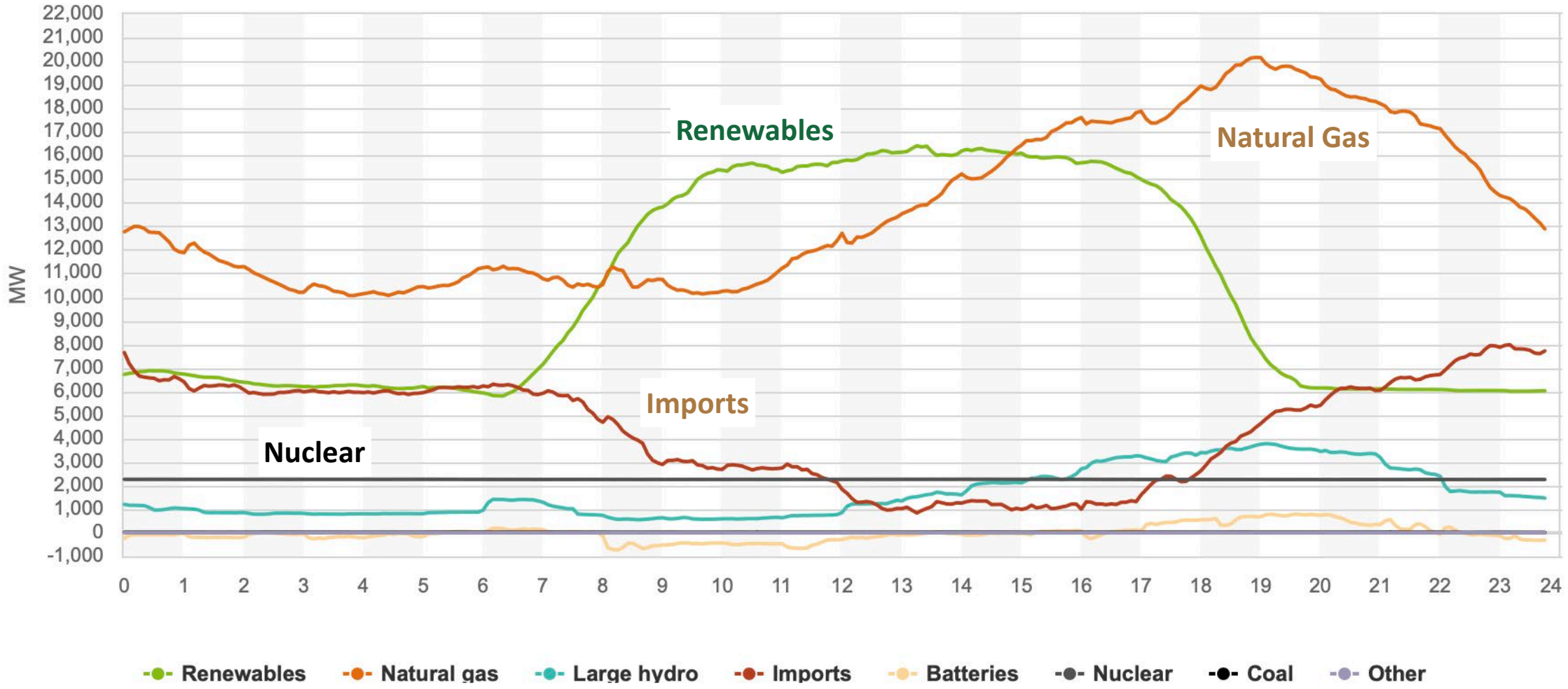


Source: www.energy-storage.news/energy-storage-a-bright-spot-for-us-clean-energy-as-wind-solar-deployments-fall/

Utility scale PV + storage has massive economies of scale

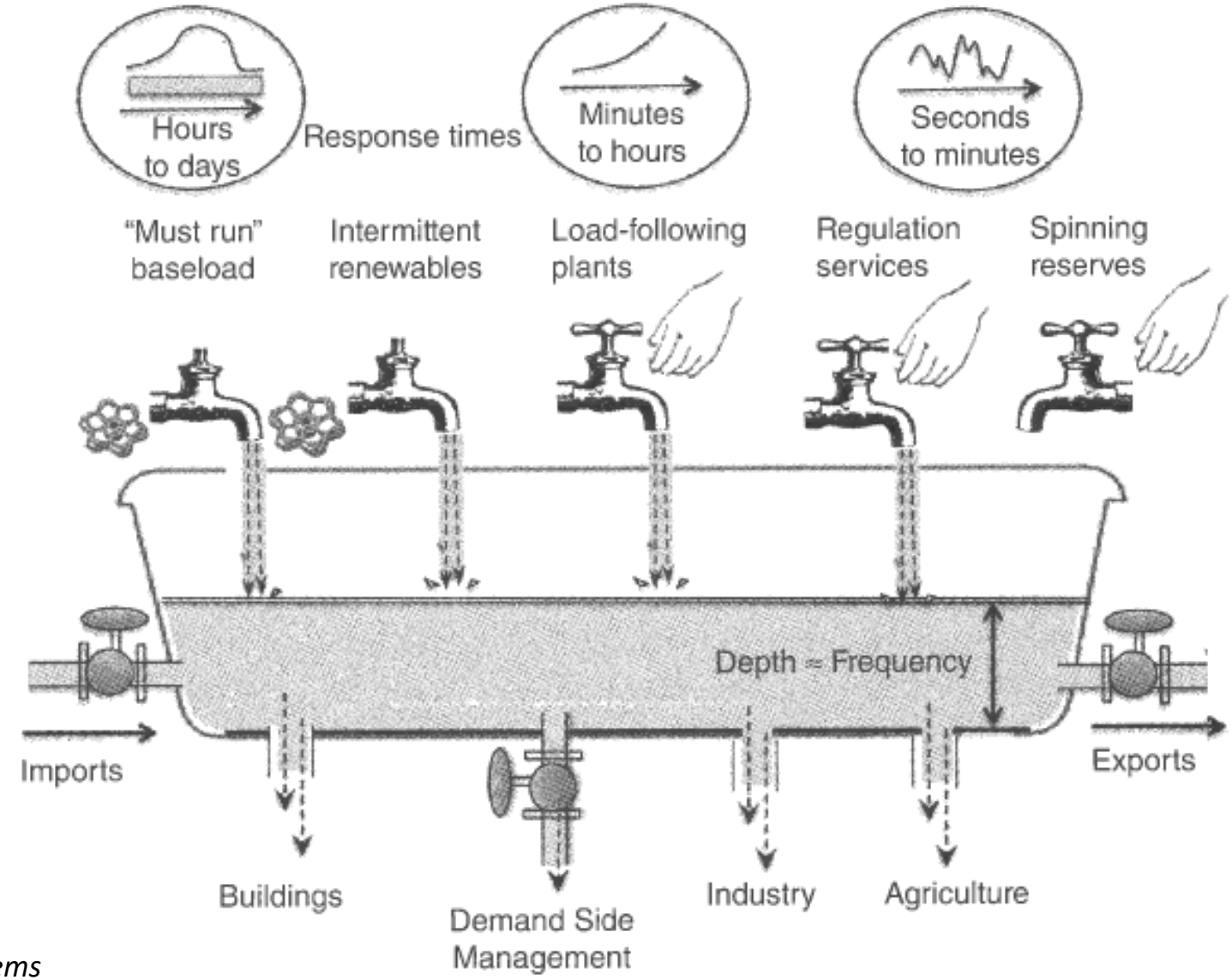
Storage shifts power output from solar and wind energy to times of day when natural gas power plants would otherwise need to run

California Grid: August 13, 2021



Source: California ISO

The environmental case for energy storage: think of the grid as a bathtub…

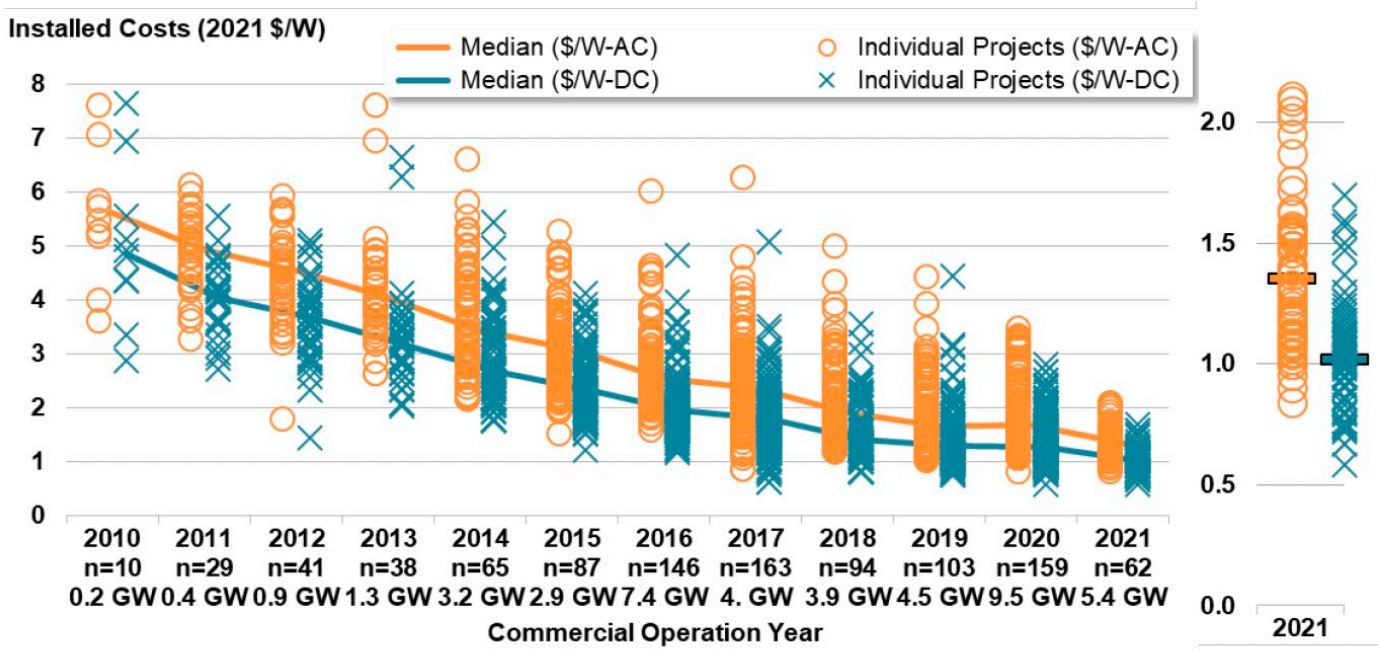


Gil Masters, *Renewable and Efficient Electric Power Systems*

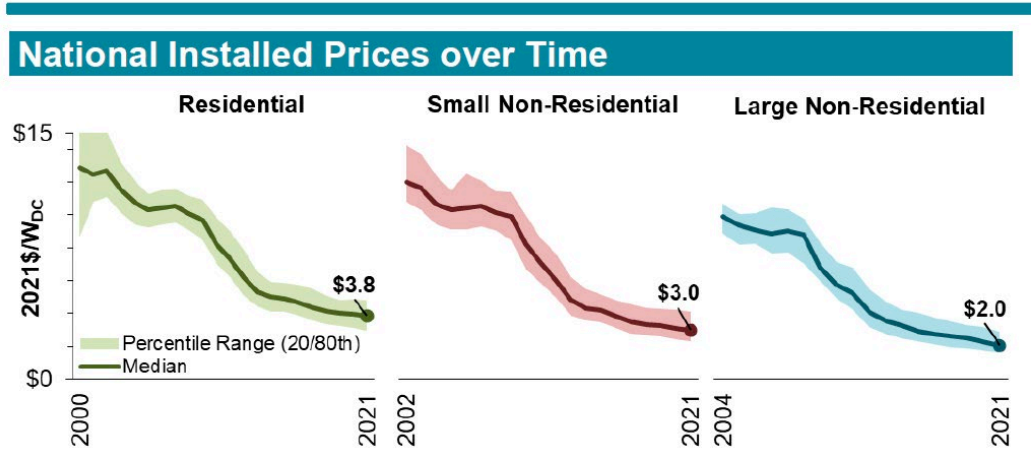
Residential PV systems cost far more than utility-scale systems ($3.80 vs. $1.02 per DC Watt), and average fewer hours of peak sun, so the cost per lifetime kWh produced is about 3x higher

Utility Scale Systems

Sample: 1,002 projects totaling 43,800 MW_{AC}



Residential & Commercial Systems



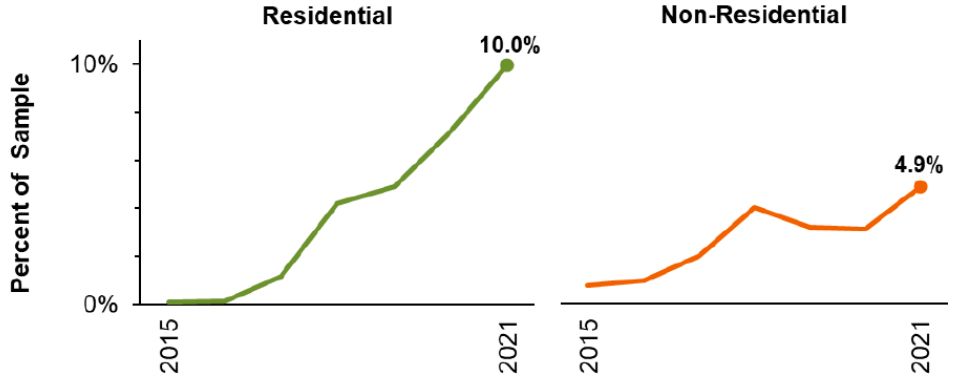
Source: https://emp.lbl.gov/tracking-the-sun

About 10% of new residential PV systems now have batteries included, but this will rise as net metering becomes less financially attractive

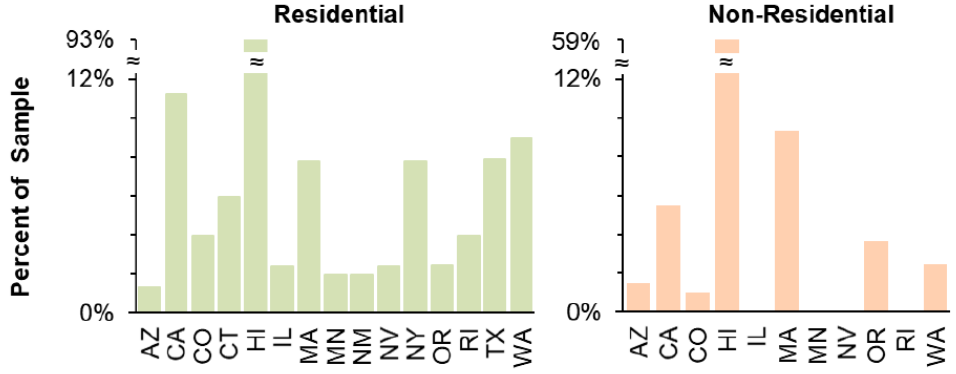
Storage Attachment Rates

Percent of PV systems installed each year with storage

Storage Attachment Rates over Time



Storage Attachment Rates by State (2021)



- Residential attachment rates have steadily risen over time, reaching 10% of the sample in 2021
- Non-residential attachment rates have fluctuated over time, but rose to an historical high of ~5% in 2021
- HI has, by far, the highest attachment rates of any state (93% residential, 59% non-res.), driven partly by net metering reforms that incentivize self-consumption
- CA, which hosts the vast majority of paired systems, has attachment rates of 11% (res.) and 5% (non-res.), driven by storage rebates and resilience concerns
- Other pockets of activity exist in the residential market (e.g., MA, NY, TX, WA)
- MA also stands out in the non-residential sector (9%), driven by SMART incentives

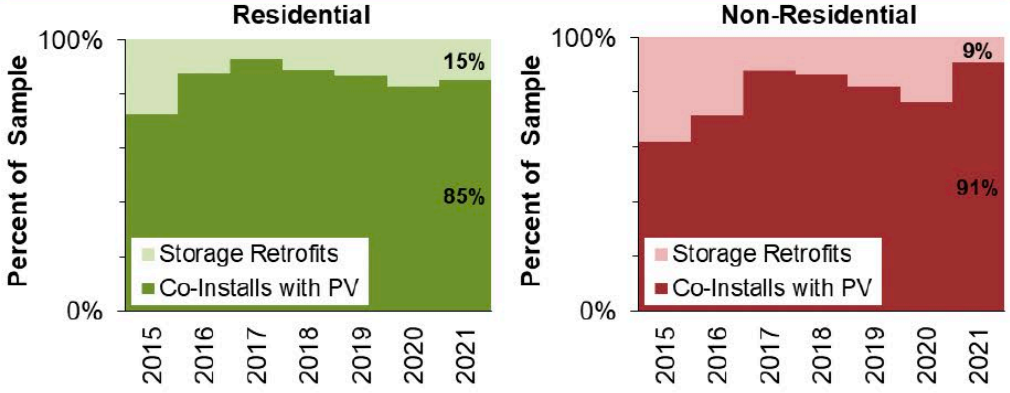
Notes: All storage-related figures aggregate non-residential systems into a single customer segment, as the sample sizes for large non-residential systems are generally quite small. The bottom figure shows only those states for which storage status is available for at least 20 systems and at least 50% of all statewide systems in the sample for the particular customer segment and year shown. Note the breaks in the y-axes for Residential and Small Non-Residential systems, to accommodate the data for HI.

Source: https://emp.lbl.gov/tracking-the-sun

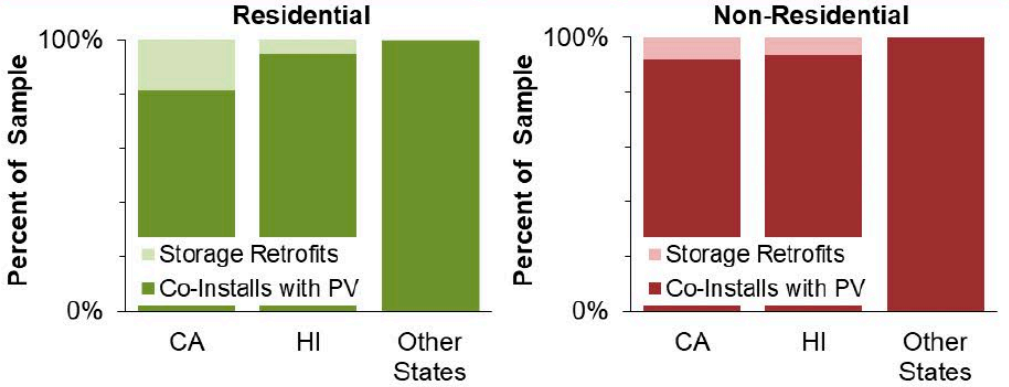
Most battery systems are installed with new PV systems, but retrofits are increasingly likely in California, which has many older PV systems

Storage Retrofits to Existing PV Systems

Retrofits vs. Co-Installs by Year



Retrofits vs. Co-Installs by State (2021 Installs)



- Some storage systems paired with PV are installed as retrofits onto existing PV systems, rather than co-installed at the same time
- In both the residential and non-residential sectors, roughly 10-20% of all paired storage systems installed each year are retrofits (in 2021, 15% of residential systems and 9% of non-residential systems)
- Within the residential market, retrofits are considerably more common in California than in other states, likely driven the combination of wildfire-related resilience concerns and new time-of-use (TOU) rates with high peak-to-off-peak price differentials

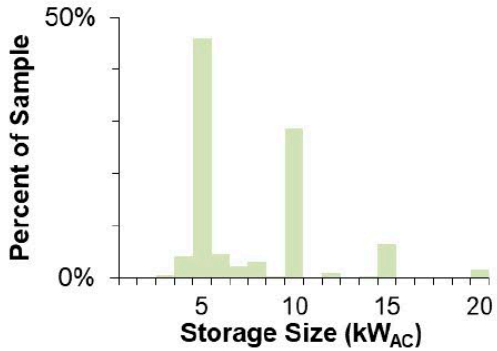
Source: https://emp.lbl.gov/tracking-the-sun

PV and battery systems getting bigger over time as more residential loads are being electrified and incentives help lower the price

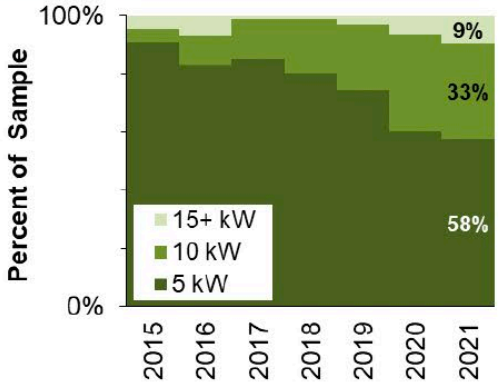
Residential Paired System Sizing

Storage Size Distribution

Systems Installed in 2021

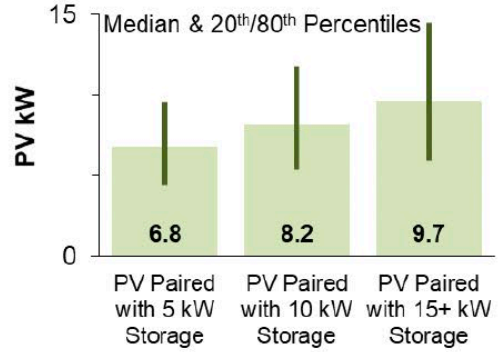


Storage Size Trend



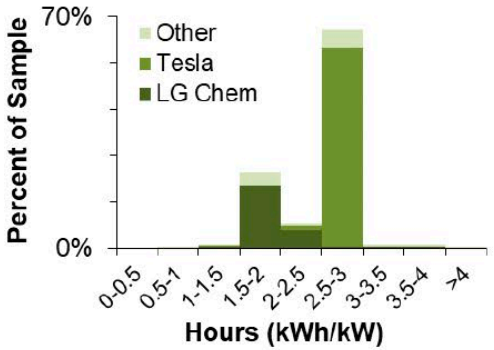
PV Sizing with Storage

Systems Installed in 2021



Storage Duration

Systems Installed in 2021



- Most residential storage systems paired with PV come in increments of 5 kW-storage
- The market has been trending toward systems with larger batteries, presumably driven in part by backup power demand → 42% of paired systems installed in 2021 had 10 kW or more of storage
- Paired systems with larger amounts of storage also tend to have more PV capacity
- Virtually all systems installed in 2021 had storage durations ranging from 1.5-3 hours (rated kWh/kW); reflects the two products that dominated market share (the LG Chem RESU10H @ 1.9 hrs and the Tesla PowerWall @ 2.7 hrs)

Source: https://emp.lbl.gov/tracking-the-sun

Battery storage is growing fast in the US, but only 14% of the new capacity installed in 2022 has been in homes

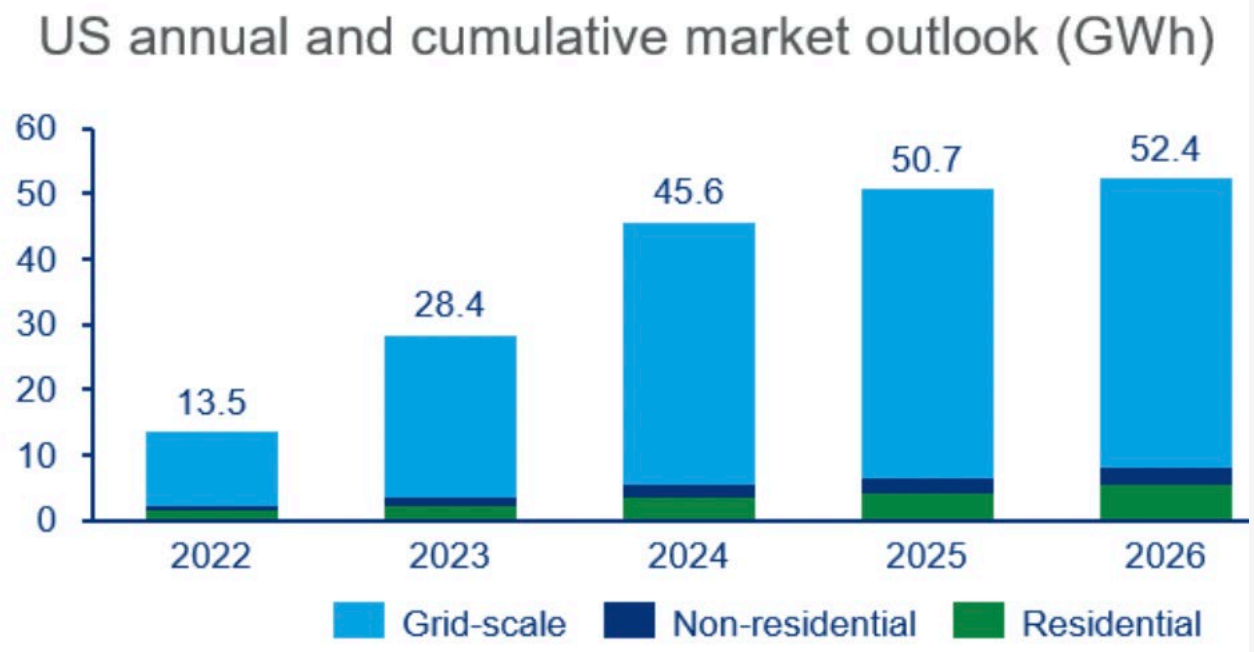


Image: Wood Mackenzie

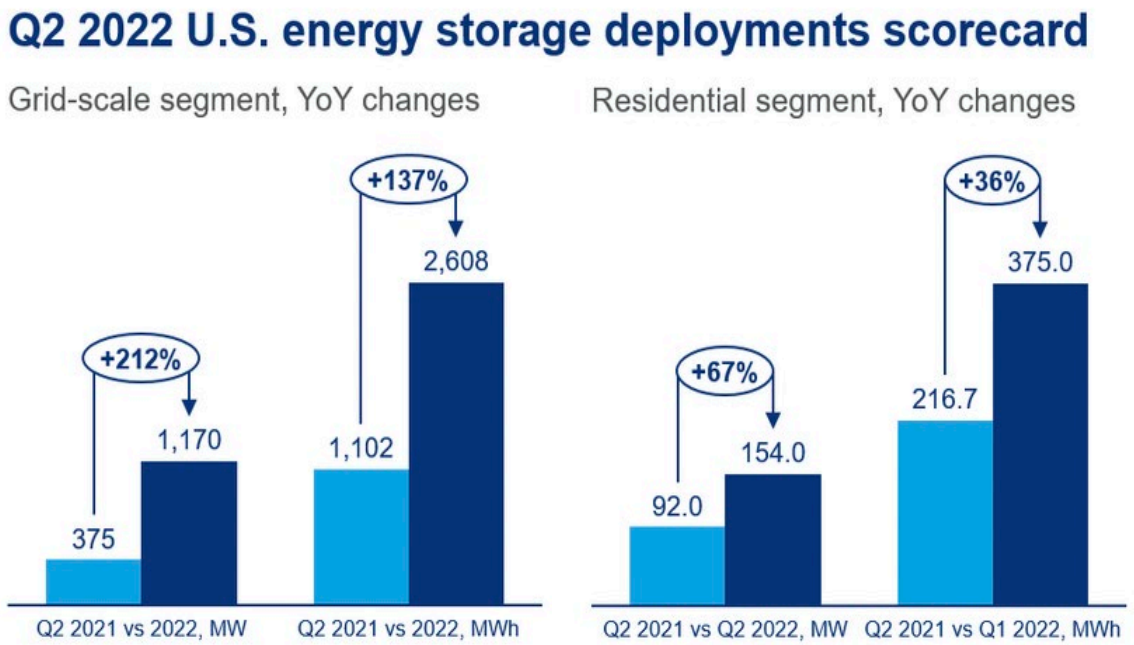


Image: Wood Mackenzie

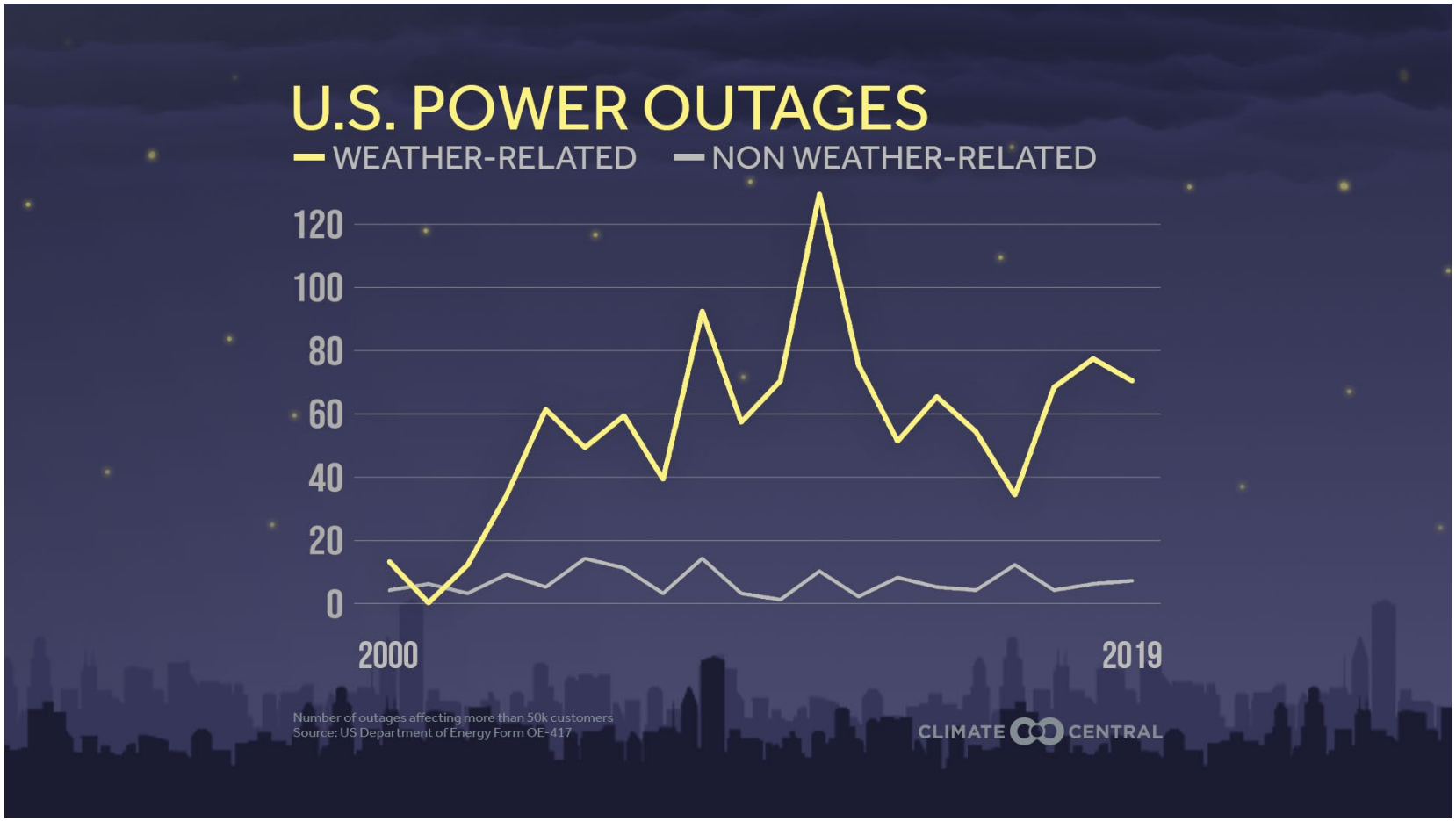
Absolute and percentage growth rates for grid-scale storage are much higher than for residential

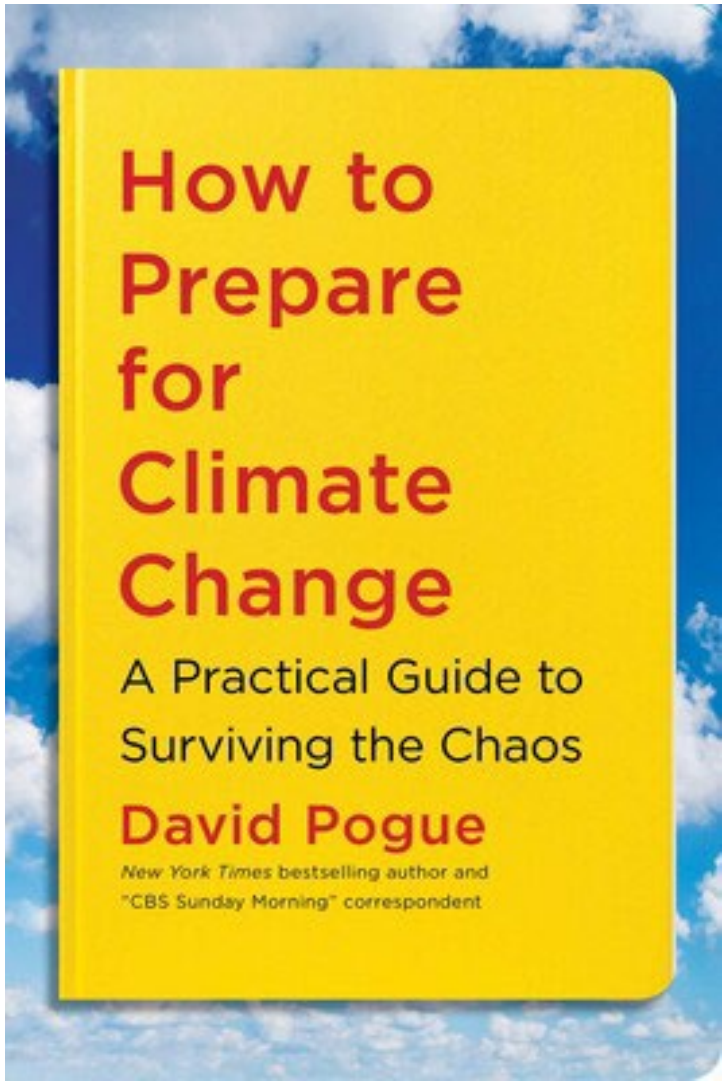
Source: https://pv-magazine-usa.com/2022/09/14/u-s-installed-a-record-2-6-gwh-of-grid-scale-energy-storage-in-q2

Key market drivers for residential storage systems

1. **Backup of whole house or critical loads** for early adopters that have the money to keep the lights on when the grid goes down. Otherwise, grid-connected solar-powered homes shut off automatically during outages to protect utility line workers.
2. **Solar self-consumption**: make extra electricity while the sun is shining and use it from batteries when the sun isn't shining to minimize environmental impact or avoid net metering limitations
3. **Arbitrage:** *consumers* buy power at cheap times of day under time of use (TOU) rates and sell it back to the utility or consume it at expensive times of day
4. **Virtual power plant (VPP)**: support *utility* grid by consuming or providing power when and where needed to balance loads

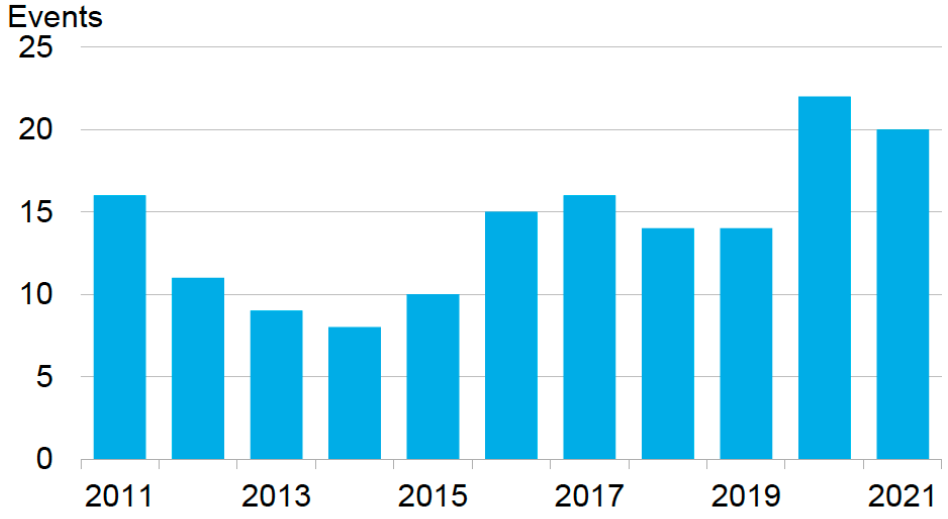
Power outages are becoming more common, mostly due to increasingly extreme weather and forest fires



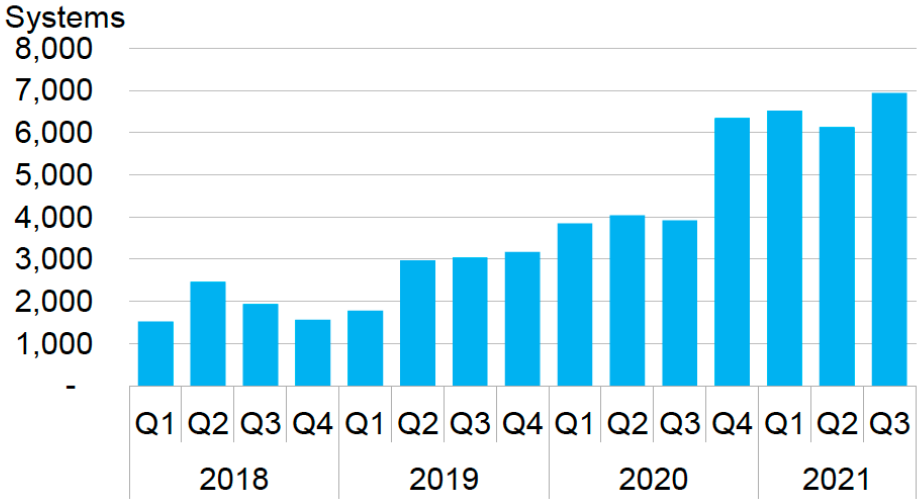


Natural disasters are a big driver of home battery purchases

U.S. billion-dollar weather and climate disasters



Quarterly residential energy storage systems installed in California



- The U.S. in 2021 experienced 20 climate disasters causing at least $1 billion in damage. The 2021 events, made up of tropical cyclones, severe storms, droughts and wildfires, are estimated to have cost $145 billion, the third most costly year on record after 2005 and 2017.
- California last year recorded the 2nd largest wildfire in its history. The Dixie fire, started by a tree falling onto a power lined owned by PG&E, burned through almost 1 million acres of land. In total, California experienced 4.3 million acres burned in 2021, compared to the 5-year average of 1.6 million acres.
- Motivated by policy incentives and concerns about grid reliability, California utility customers installed more than 19,607 residential energy storage systems Q1-Q3 2021 (the latest quarter for which there is complete data). This number is 66% greater than for the similar three quarters of 2020 and 152% higher than in 2019.
- Microgrids, primarily comprised of batteries, solar, and combined heat and power (CHP) systems, are growing primarily in Texas, California and New York. In 2020, 35 new microgrids came online, with 108MW of new capacity installed.

Source: National Oceanic and Atmospheric Administration, BloombergNEF. Note: Portrays annual counts of drought, flooding, freeze, severe storm, tropical cyclone, wildfire and winter storm events in the U.S. with losses of more than $1 billion each.

Climate change impacting this region profoundly

Sonoma County receives 85% of its electricity from renewable sources, and 100% of the electricity used to power the county's water system is renewable.

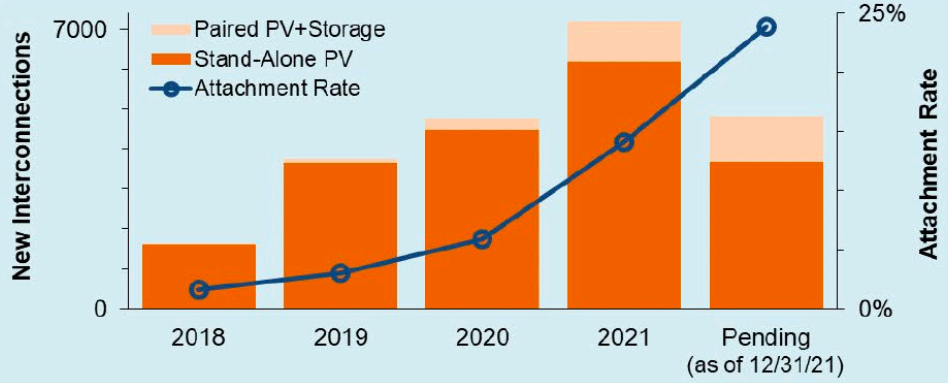
"Sonoma County is dealing with its fair share of climate impacts: The same Russian River that flooded 3,000 homes and businesses in Guerneville in 2019 nearly dried up this summer after years of drought; since 2017, eight big wildfires have devastated neighborhoods around Santa Rosa and destroyed wineries."

Source: KQED, 11/9/22
https://apple.news/AS4pvx8lXSHO7w10YXcK3Vw

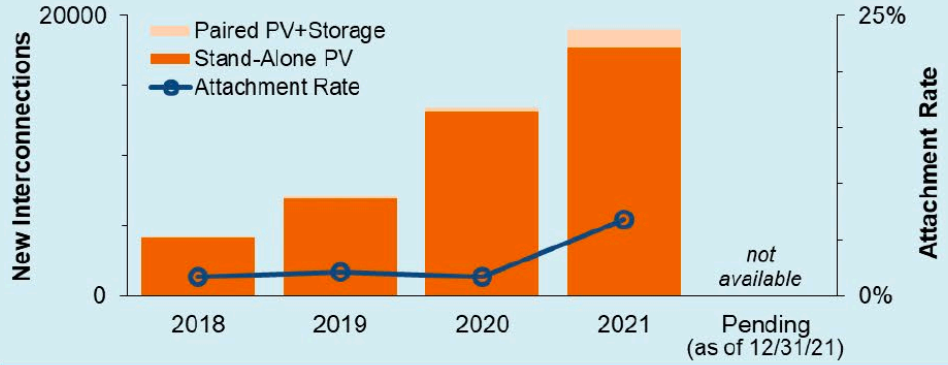
Extended, high-profile outages motivate battery buyers

PV+Storage Growth in Texas after 2021 Winter Storm

CenterPoint *(serving Houston metro area)*



Oncor *(serving Dallas/Fort Worth metro area)*



- An uptick in PV+storage adoption occurred after Winter Storm Uri, which hit Texas in February 2021
- From 2020-2021, new PV+storage interconnections increased by more than 3x in CenterPoint's service territory (from roughly 300 to 1,000) and by roughly 6x in Oncor's service territory (from 200 to 1,300)
- The uptick in attachment rates was most pronounced for CenterPoint, rising to 14% in 2021, and to 24% among applications pending at the end of the year
- Retail service providers in Texas also typically credit PV grid exports at less than the full retail rate, incentivizing PV customers to co-install storage in order to maximize self-consumption

BERKELEY LAB

Source: https://emp.lbl.gov/tracking-the-sun

Backup generator alternatives

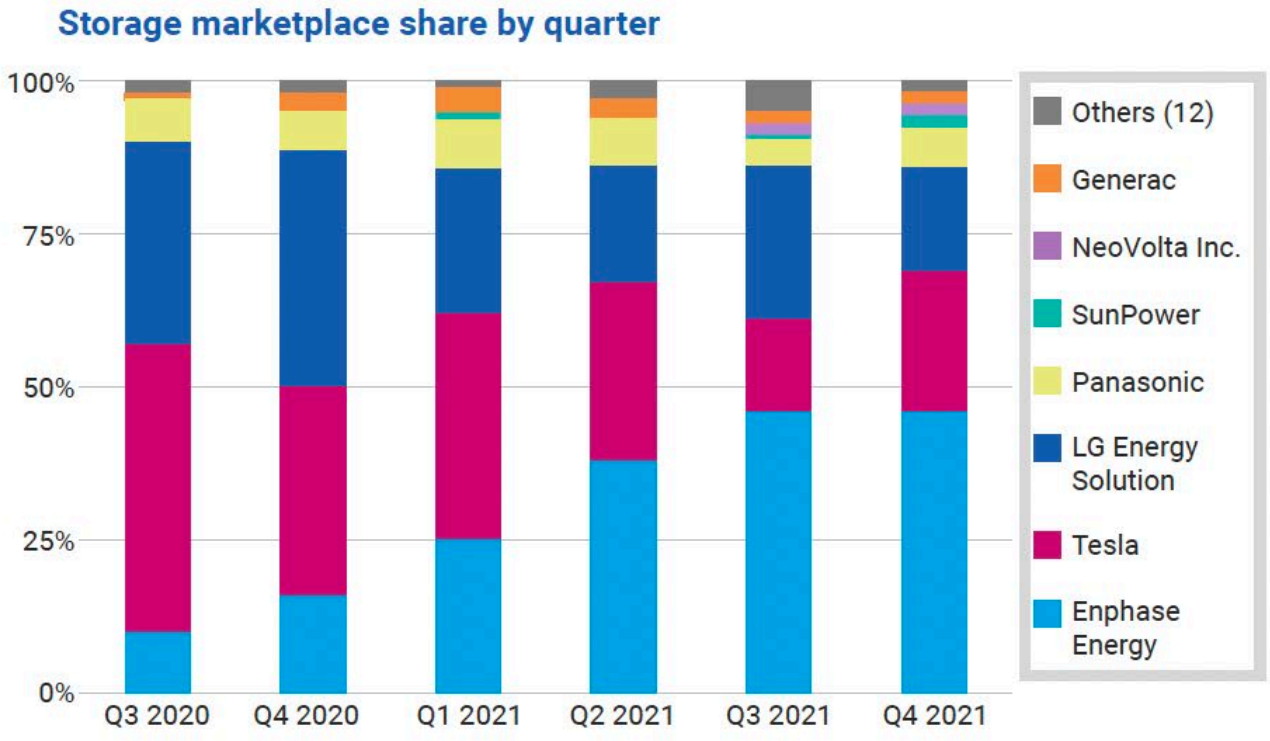
- Gasoline - very cheap to buy and portable, but with modest power output, can be noisy and expensive to operate. Fuel difficult to store for long periods or obtain during a widespread outage.
- Propane - takes advantage of a typically larger amount of onsite fuel storage, so can run longer, but can be expensive to fuel
- Diesel - primarily large scale systems intended to back up commercial and industrial facilities. Can have high standby power consumption, particularly in cold climates.
- Natural gas - seems to be batteries' most formidable competitor for extended and reliable backup purposes. 2021 quote: $5,700 for 22 kW output and no limit on the hours of operation as long as natural gas fuel supply is not interrupted. Gas distribution interruptions can occur too in fires or earthquakes, but are relatively uncommon.

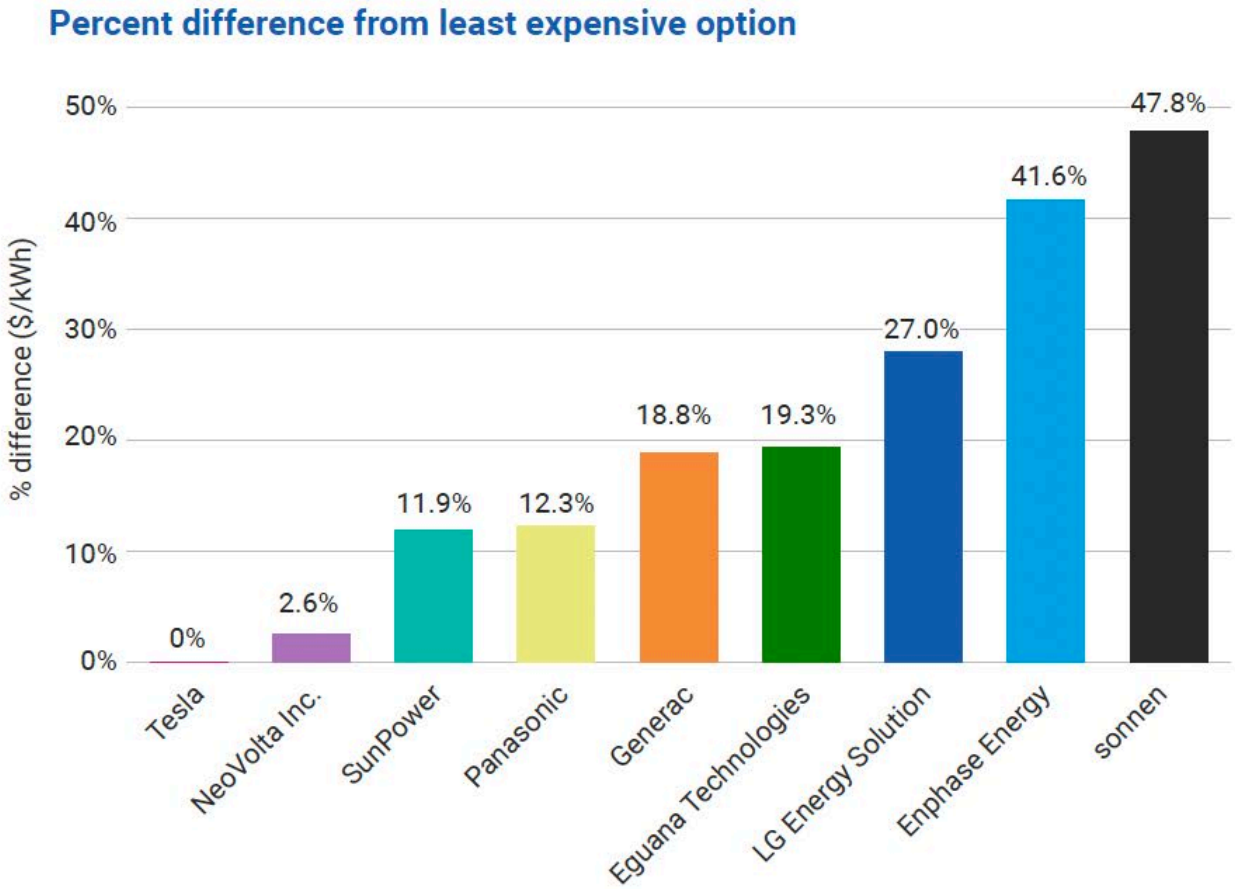
Residential market battery status

- At present, in the more mature Australian marketplace, nearly one-third of homes have solar on the roof (vs about 9% in California). There are nearly 250 competing residential models for sale in Australia representing at least 66 distinct brands of home energy storage systems.
- Good list of available models: www.smartenergy.org.au/batteryfinder
- Fewer models are presently available in the US market, but three key categories of competitors are seen here:
  - *Standalone battery makers*: Samsung, LG Chem, BYD, PylonTech, CATL, Eguana, etc.
  - *Inverter manufacturers* offering branded matching batteries: Enphase, SolarEdge, Generac, Outback, etc.
  - *Full system manufacturers* offering various combinations of solar panels, inverters, batteries, and control/monitoring systems: SunPower, Tesla, Sonnen, etc.

Sources: https://www.abc.net.au/news/rural/2022-02-08/record-amounts-of-rooftop-solar-installed-during-lockdown/100805838 and https://www.nytimes.com/2021/12/13/business/energy-environment/california-solar-roof-incentive.html

US market share varies by source; Tesla dominates SGIP rebates paid in California, but other brands are rising rapidly in popularity



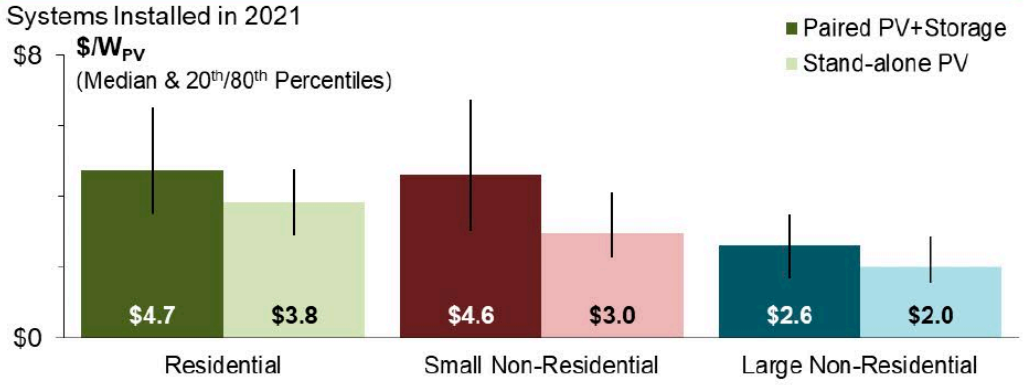


Note that costs per kWh for different companies' systems vary widely and don't always predict market share. Bigger standalone systems (like the Tesla Powerwall 2) are cheaper per kWh, while modular systems (like Enphase) can yield a lower total installed cost if the customer doesn't require a very large battery. Average quoted battery size is 10-13 kWh.
Source: EnergySage Solar Marketplace Intel Report

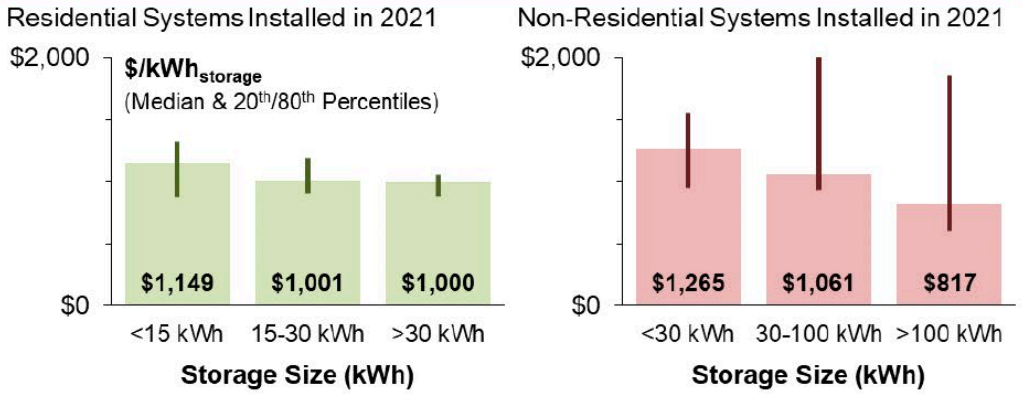
Storage raises the price of a typical home PV system by about 50% -- roughly $1,100 to $1,200 per kWh of battery size

Installed-Price Premium for Paired PV+Storage Systems

Installed Price Comparison: Standalone vs. Paired PV



Reported Storage Costs from California's SGIP



- Though otherwise excluded from the trends described in this section, installed prices for paired PV+storage systems are consistently higher than for stand-alone PV
- Direct comparisons can be misleading, given confounding factors; the multi-variate regression analysis (described later) estimates a $1.9/$W_{PV}$ storage premium for residential PV (for a 5 kW battery with 10-15 kWh of storage capacity)
- Given typical residential PV and storage sizes, this equates to an underlying incremental cost of roughly $1200/$kWh_{storage}$
- In comparison, median costs for similarly sized residential storage systems funded through California's Self Generation Incentive Program (SGIP) were $1,149/kWh in 2021
- The SGIP data also point toward modest economies of scale with storage system sizing, especially for large non-residential systems (though the error bands are quite wide)

Why not encourage storage in all homes?

- It's a costly way to keep the lights on if you only experience occasional, brief outages, as most of the country does.
- Round trip energy conversion losses can be 15 to 20%, or more, and the paired inverters have high standby losses, **so adding batteries increases a home's total electricity use**.
- If most of the home's electricity consumption passes in and out of the battery before use, overall home energy use rises by as much as having another refrigerator in the home.
- The best system designs may have half of the energy losses of the least efficient inverter/battery systems
- Performance, longevity, safety, and warranty coverage differ dramatically among available products, which greatly affects whether they will be cost-effective to purchase. And not all manufacturers report their products' performance in the same way, so it's difficult to compare product spec sheets fairly to each other.

Manufacturers and installers routinely show exterior installation in their marketing materials, but exterior temperatures can vary widely

Marketing photos may not resemble your actual installation

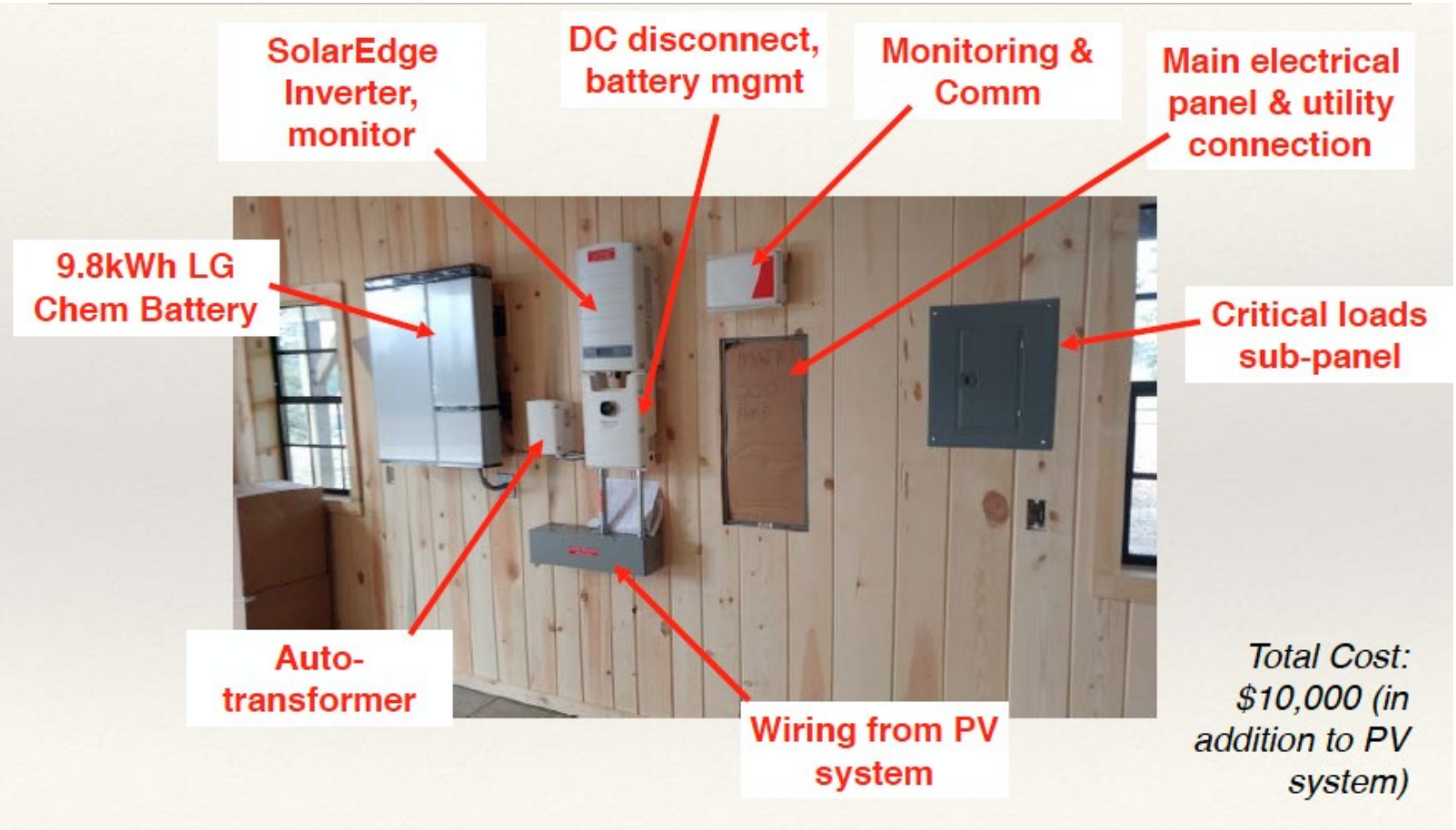
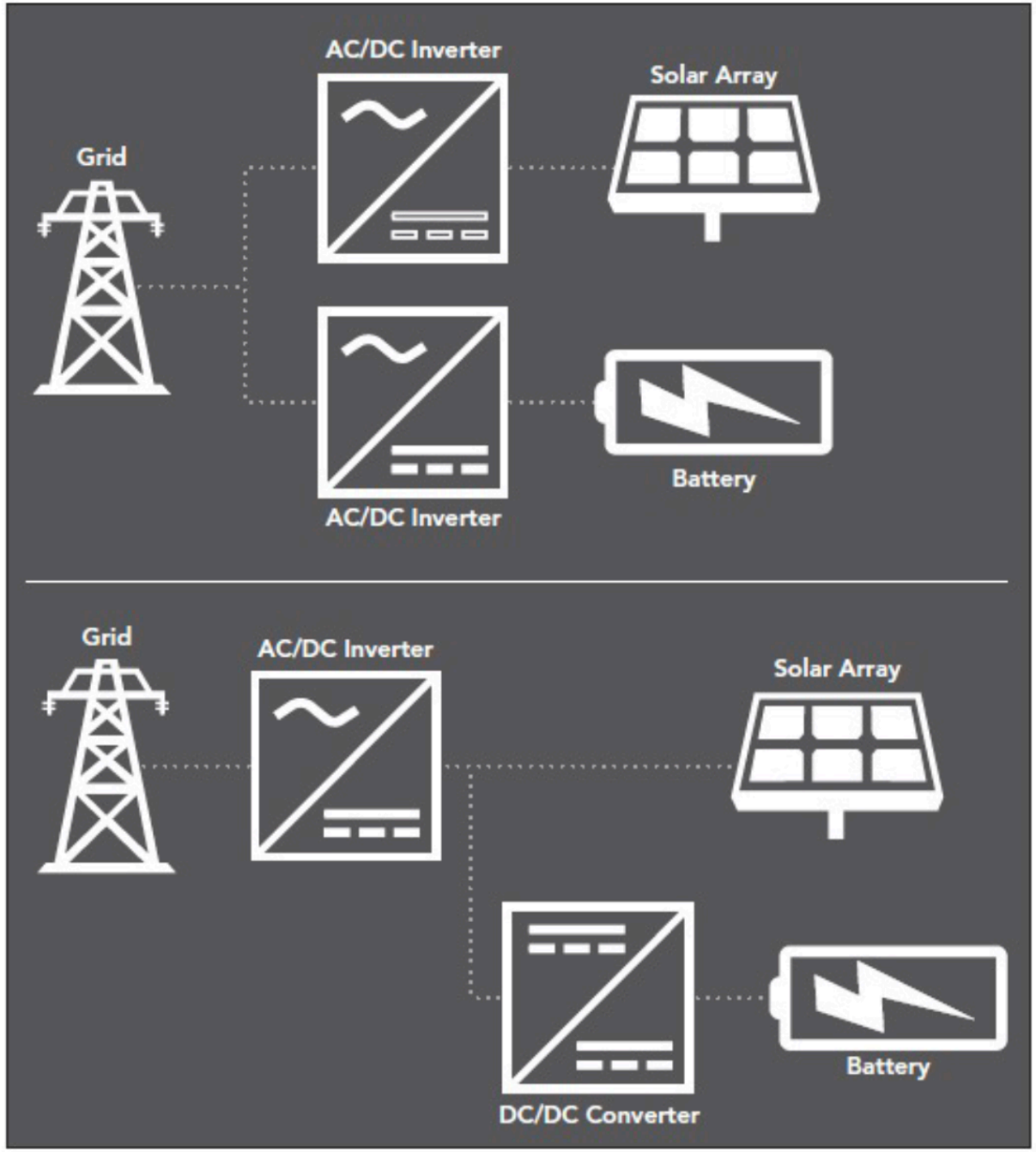


Image sources: Sonnen and Shaw Solar

Which architecture will win out: AC-coupled or DC-coupled?

- AC-coupled advantages:
  - Can retrofit to existing solar home
  - Flexible battery placement location
  - Can be higher combined solar + battery power output to grid or home
- DC-coupled advantages
  - More energy efficient
  - Lower cost in new construction (don't have to buy two inverters)
  - Simpler installation
  - Less inverter clipping at peak solar output (extra charges battery)



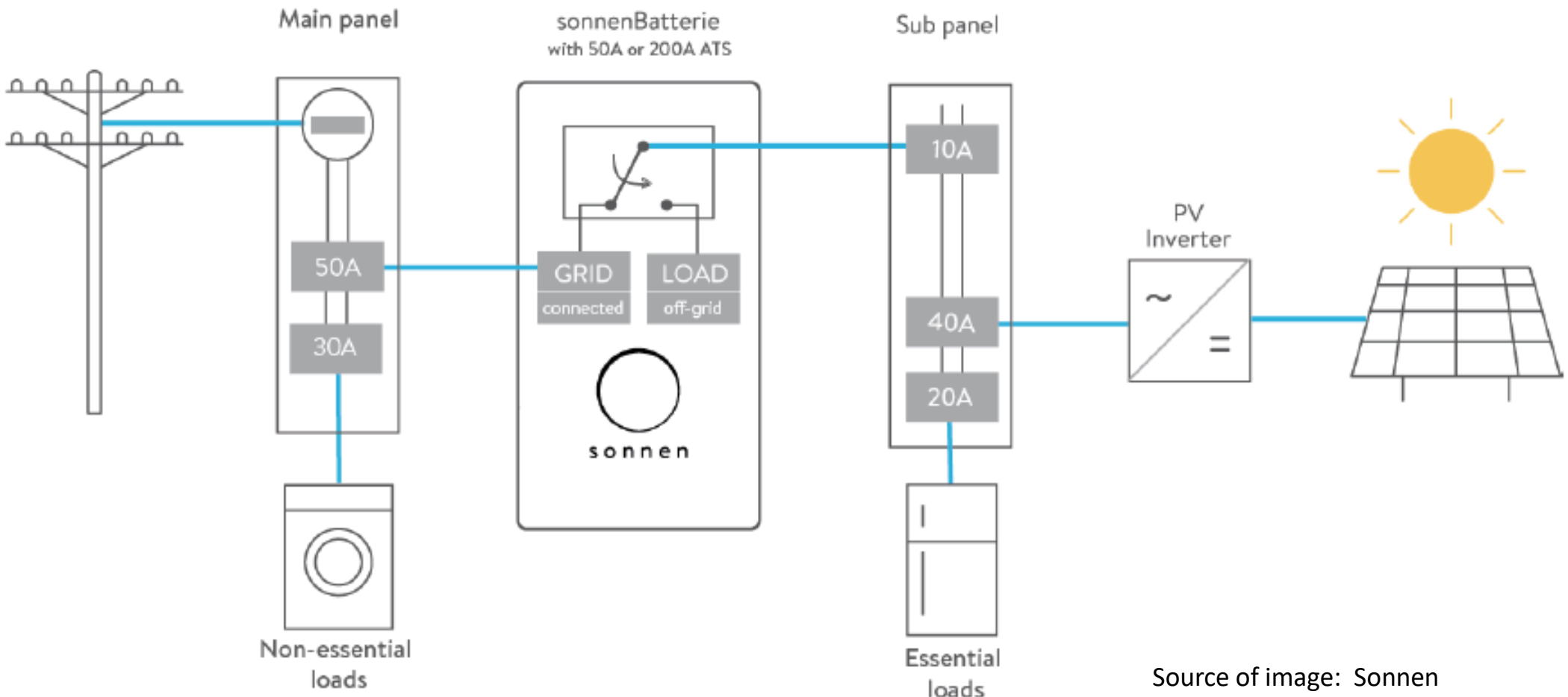
www.pv-tech.org | August 2019

Key caveats during the installation process

Main panel is often on the AC-disconnect side of the battery. So all loads you wish to backup have to be relocated to a critical loads sub-panel.

Challenging to find a battery with enough peak current capability to drive loads like AC, space heating, water heating, pool pumps, or EV charging

Critical loads sub-panel usually must be physically proximate to main panel, inverter and battery in retrofits, so need significant wall space for all of the hardware. Safety concerns lead to garage or exterior installs, where temperatures can be unfavorable.



Source of image: Sonnen

What’s involved in backing up your whole house with batteries?

- Multiple battery banks that can store a total of 25 to 40 kWh worth of energy.
- Peak power output may need to be 12 to 20 kW to handle HVAC systems, water heaters, cooking, clothes dryer, etc. Even then, homeowners need to be careful about what they try to run simultaneously.
- Multiple new load panels, often with all breakers moved out of old panel.
- Additional electrical boxes mounted to wall for gateway, power monitoring, disconnects, etc.

There have also been some recent advancements simplifying home battery installations

Meter socket transfer switches reduce need to move circuits to a critical loads subpanel

Streamlined gateways and AC transfer switches simplify installations

How do we know which batteries are best?

- Manufacturer claims vary widely, and they don’t always measure the same things or compare performance under identical conditions.
- Most claims are made under more favorable temperature or charge and discharge conditions or lifetime conditions than will occur in the field.
- There is a need for standardized comparative data to see how all the products perform on a level playing field.

Results from Australia's long term lab testing of batteries

- 26 different lead acid, lithium ion, and other chemistry battery systems were tested over multiple years (in three phases) to determine how much capacity they lose with age, heavy usage, and temperature cycling
- Testing was conducted by IT Power in Canberra under $1+ million of grants from Australian government
- Live data streamed to web (http://batterytestcentre.com.au/) from individual round trip measurements.
- Reports were published twice a year summarizing key findings
- Most of the batteries it tested either experienced problems in installation/setup/commissioning, or operation, or both
- Impacts on capacity, efficiency, and performance over time were significant

IT Power testing approach: 3 complete charge and discharge cycles of 3 hours each, while varying temps between 50 and 97 degrees F

Table 2: Daily temperature settings for summer and winter regimes

Time	Charging regime	Summer temperatures	Winter temperatures
02:00 - 05:00	Charge	Low	Low
05:00 - 06:00	Rest		
06:00 - 09:00	Discharge		
09:00 - 10:00	Rest	Transition to high	Transition to high
10:00 - 13:00	Charge	High	High
13:00 - 14:00	Rest		
14:00 - 17:00	Discharge		
17:00 - 18:00	Rest		Transition to low
18:00 - 21:00	Charge		Low
21:00 - 22:00	Rest		
22:00 - 01:00	Discharge		
01:00 - 02:00	Rest	Transition to low	

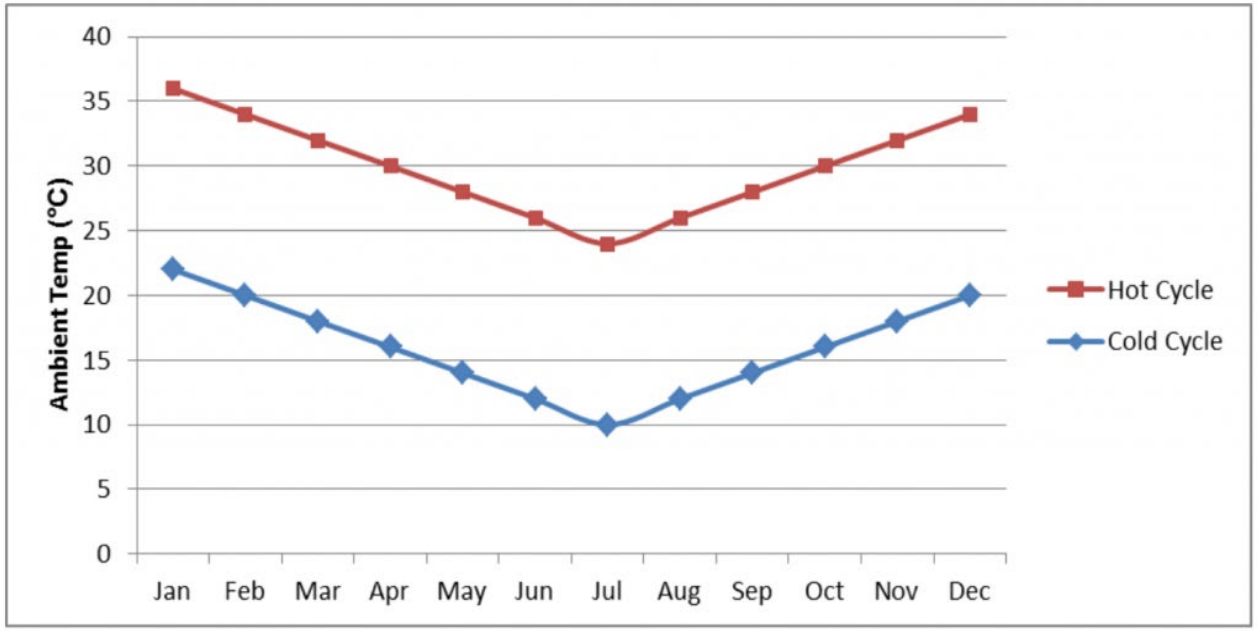
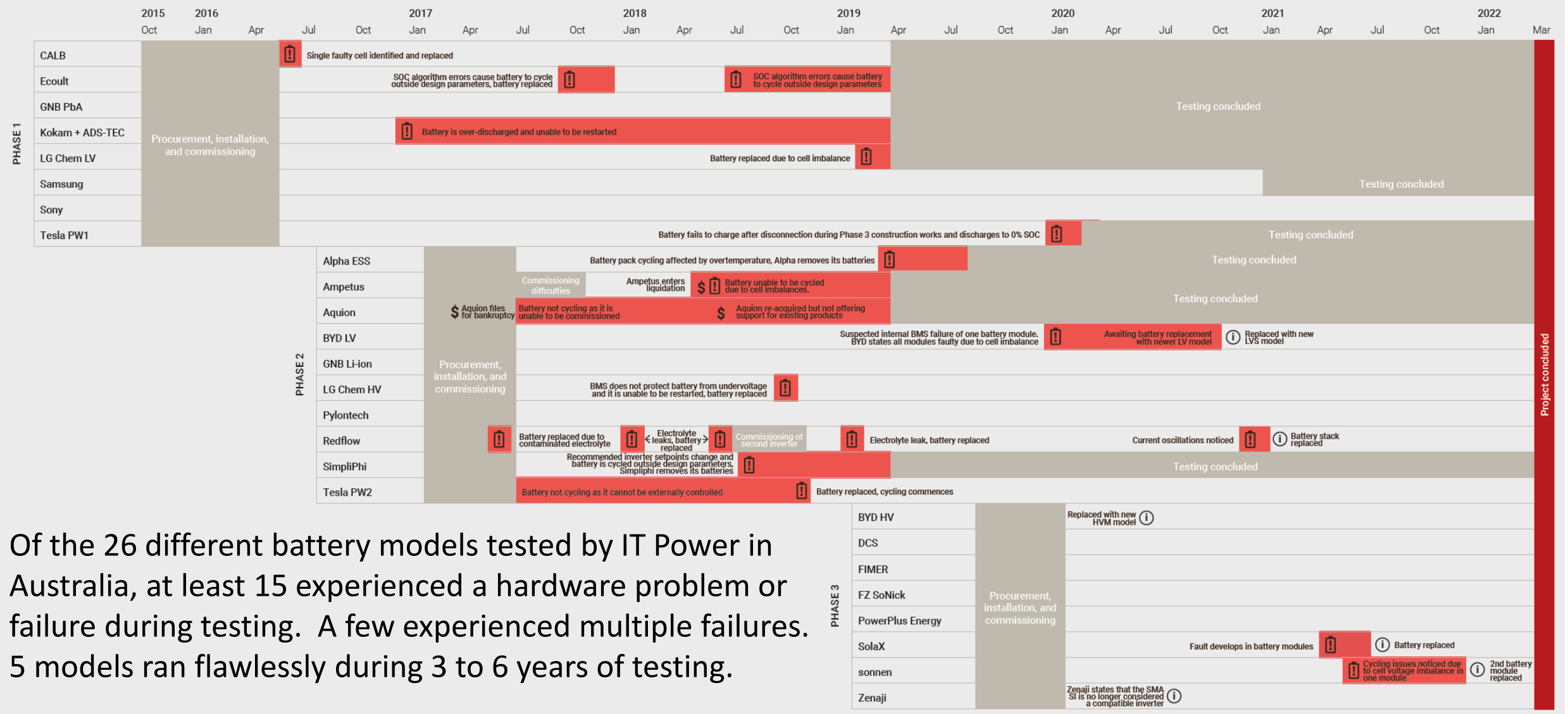


Figure 1: Daily hot and cold cycle temperatures throughout the year

Source: https://batterytestcentre.com.au/

Mostly what the Australian testing revealed was how rare it was for a battery system to have no technical failures after multiple years of operation

Figure 1 gives an overview of the issues experienced by battery packs installed in the trial. Note that only issues causing a complete interruption to cycling or an equipment replacement are displayed.



Of the 26 different battery models tested by IT Power in Australia, at least 15 experienced a hardware problem or failure during testing. A few experienced multiple failures. 5 models ran flawlessly during 3 to 6 years of testing.

Figure 1: Overview of battery operation

How a fully sealed battery pack can degrade over time

Battery went from a usable capacity of about 7.7 kWh to about 6 kWh over 1,183 charge and discharge cycles before failing entirely.

In the process, it would often de-rate for periods of time from 2500 watts to 800 watts due to overheating.

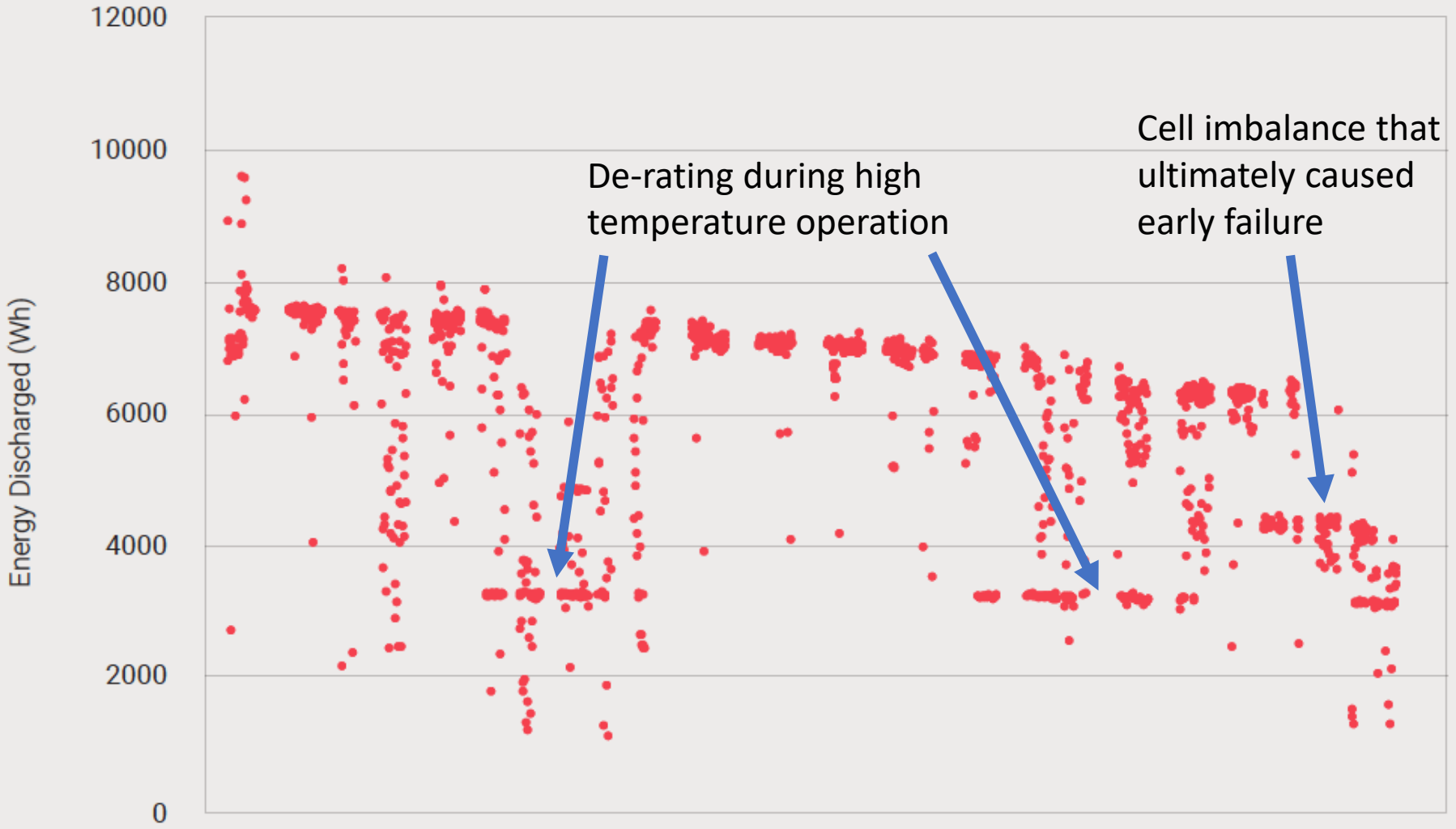


Figure 5. Energy discharged per cycle by the LG Chem RESU 1 battery pack

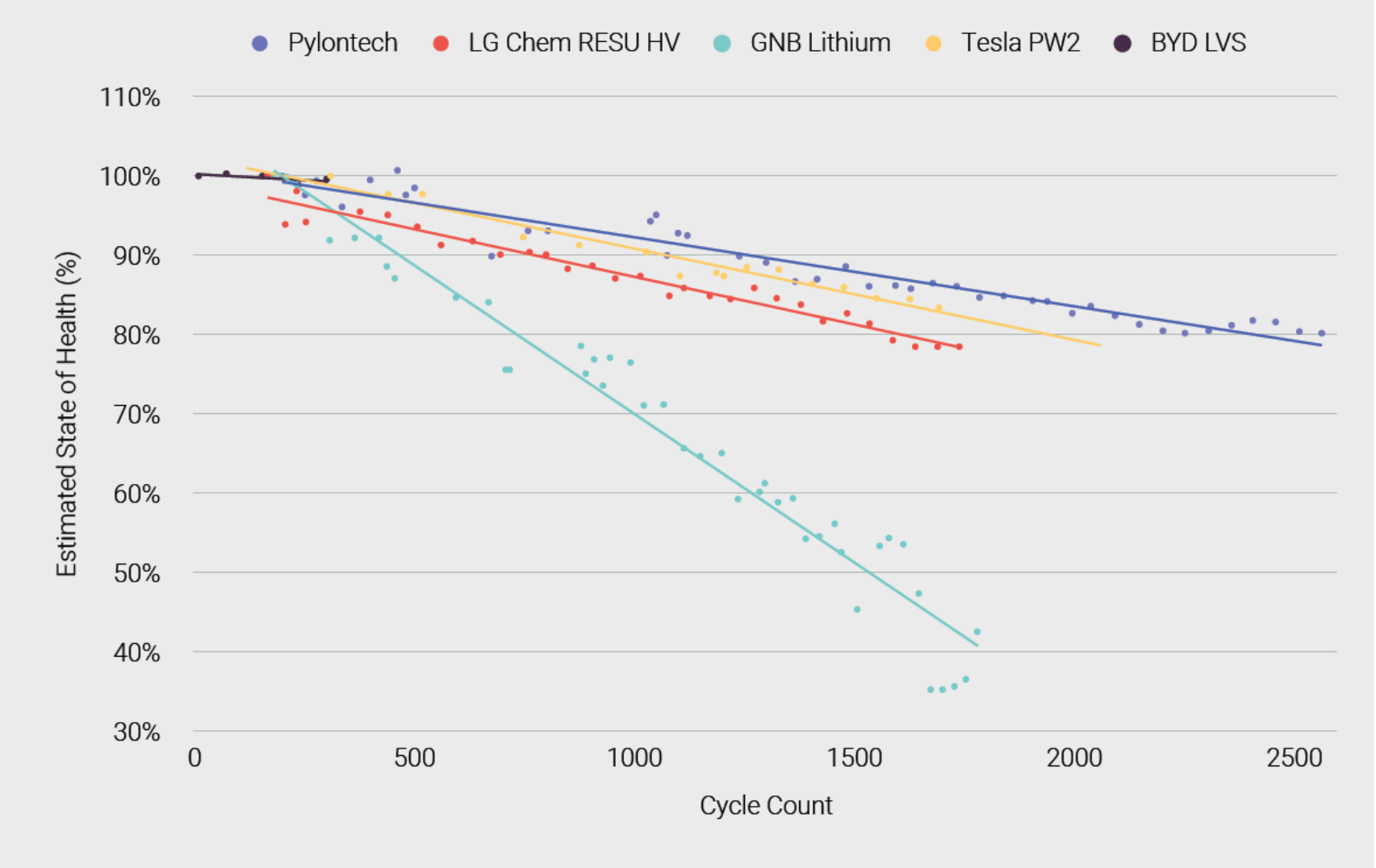
Source: https://batterytestcentre.com.au/

Capacity fade matters greatly to battery economics

Phase 2 testing showed significantly different degradation in battery capacity over time.

In general, the lithium iron phosphate batteries are holding up the best after hundreds of charge and discharge cycles.

A battery that is still usable after 3,000 charge and discharge cycles will offer significantly better value than one that loses 30% of its capacity after only 1000 cycles.



Source: https://batterytestcentre.com.au/

Phase 3 testing (2020-2022) shows considerable progress

- Some of the newest battery designs are showing very flat degradation curves over the first 1000 cycles.
- In some cases, firmware updates allowed battery systems to deliver *higher* storage capacities over time.
- Still, some models continue to have unacceptably rapid degradation in performance.

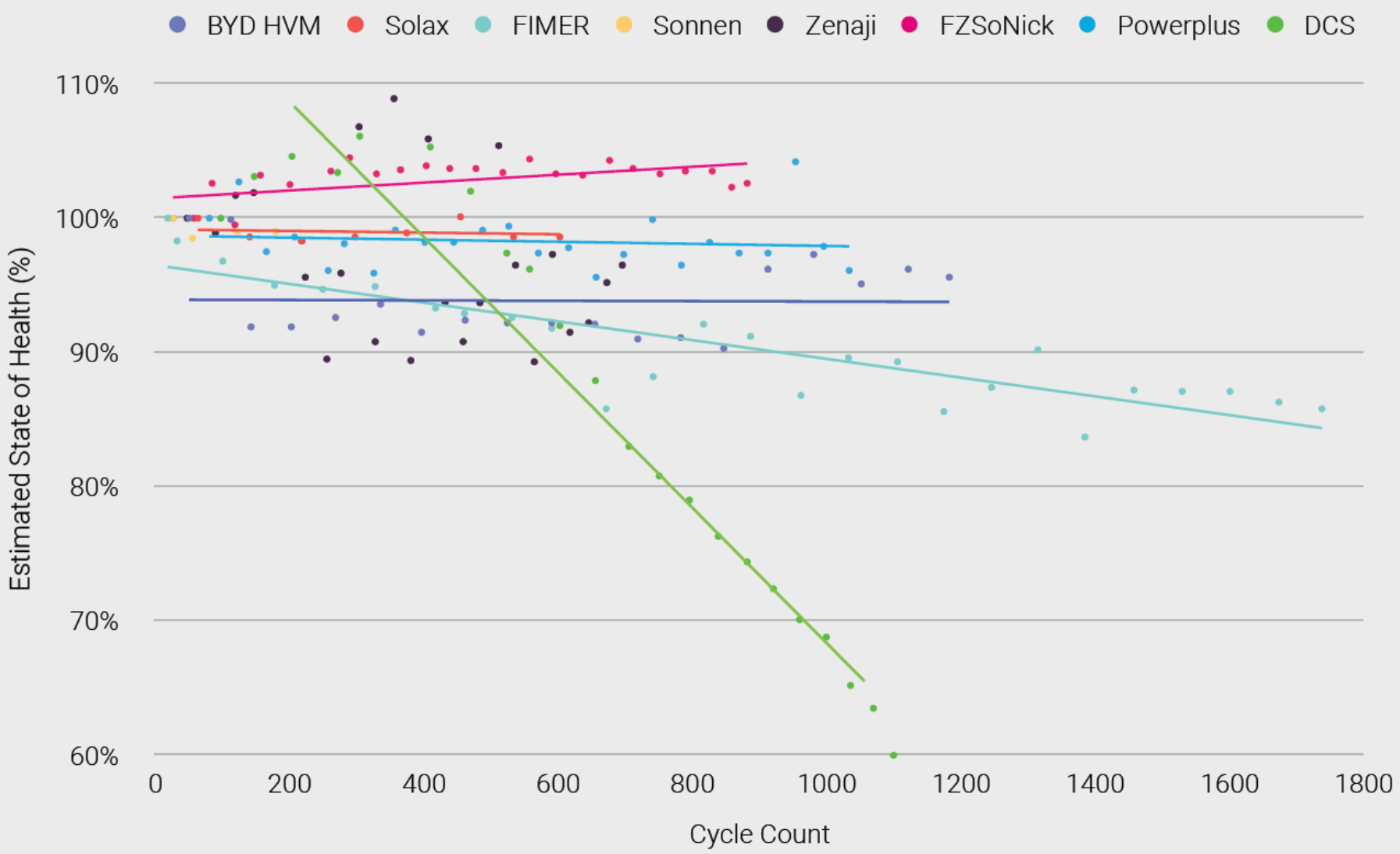


Figure 19: Capacity fade of Phase 3 battery packs based on monthly capacity tests

Source: https://batterytestcentre.com.au/

How much does round trip efficiency matter?

- The difference between a 94% and 82% round trip efficiency battery system can really add up over thousands of cycles.
- Especially true when considering AC-AC conversion and including standby losses in the inverter.
- The least efficient battery systems can consume thousands of kWh more energy over their lifetimes than the most efficient systems.

Source: https://batterytestcentre.com.au/

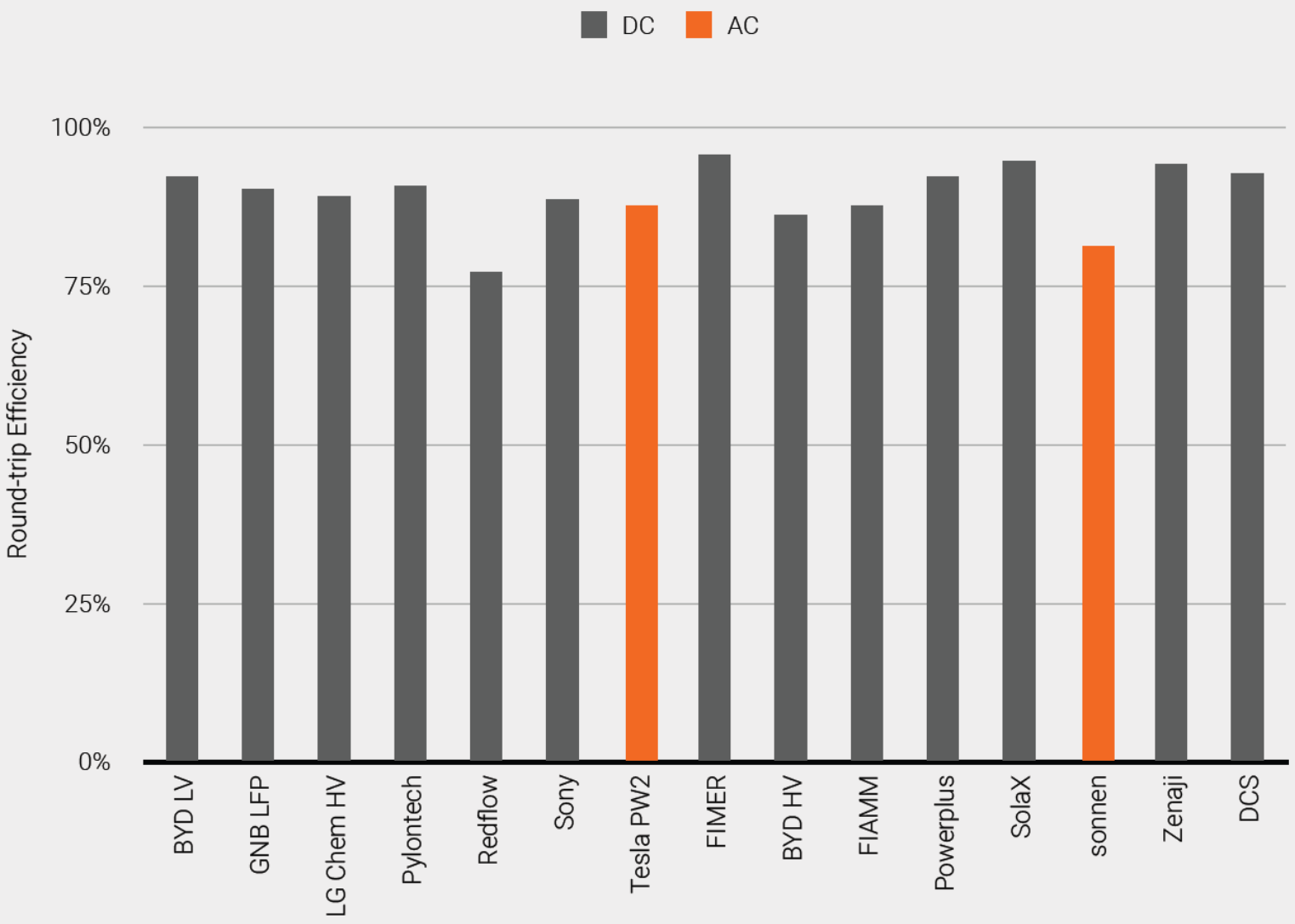


Figure 20: Lifetime round-trip efficiency for each battery pack

Where do most of the energy losses occur?

- I conducted testing of competing systems in partnership with CSIRO in Australia in 2019 and found four key sources of losses in residential energy storage systems:
  - Power conversion losses within **the inverters** were the largest source of losses in the overall HESS -- often about 6% when charging and 8% when discharging. That's an average of 200 watts being lost of the 3000 watts that might be sent to or from the battery by the inverter.
    - **Inverters** can also waste significant energy when idling, waiting to charge or discharge connected batteries.
  - Wiring between the batteries and their inverter accounted for a surprisingly high share of losses, often 1 to 2% in each direction.
  - The losses inside the **battery** itself when charging and discharging (coulombic losses) or when sitting idle (self-discharge losses and battery management system overhead) were typically only 1% or less. So lithium ion batteries themselves are very efficient.

How much energy could be saved by promoting more energy efficient residential batteries?

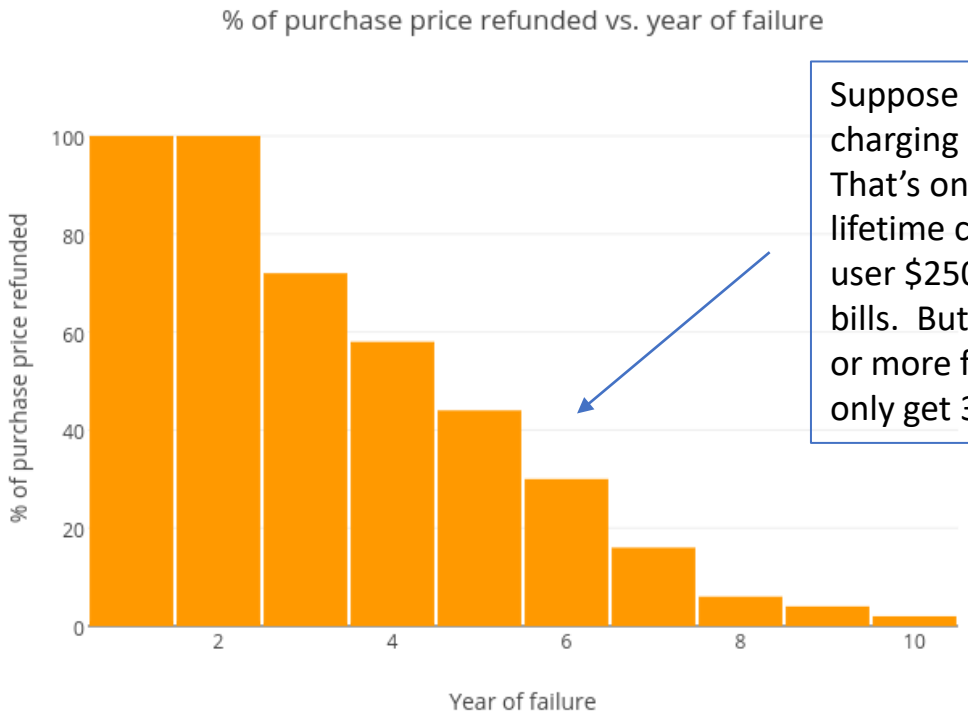
Criteria	Inefficient Battery and Inverter	Efficient Battery and Inverter	Savings
Average size	10 kWh	10 kWh	
Depth of discharge	90%	90%	
Roundtrip AC-AC efficiency	83%	88%	
Charge and discharge losses with one round trip cycle per day	673 kWh/yr	448 kWh/yr	225 kWh/yr
Inverter standby power	30 W	7 W	134 kWh/yr
Annual Total energy consumption	848 kWh/yr	489 kWh/yr	359 kWh/yr
Annual operating cost at $0.38/kWh	$106	$61	$45

Additional considerations

- Safety and Permitting
  - Products covered by an ANSI/UL safety standard but not their installation, which is left to electrical and building codes that vary regionally and locally. Most states encourage them to be installed outside or in garages, where higher temperatures can make them perform worse than they would in conditioned space.
- Energy vs. Power
  - Batteries can be optimized to deliver relatively lower power over long time periods (energy-prioritized) or high power over short time periods (power-prioritized), so both their energy and power ratings matter.
- Warranties
  - Batteries differ greatly not just in the duration of their warranties, but in whether they are framed on a calendar year basis, a number of charge and discharge cycles basis, or a total MWh throughput over time basis. Differences make it hard for consumers to fairly compare competing systems.

Example of the fine print of lithium ion battery warranties

- LG Chem warranty states 10 years, but the system is only warranted to deliver 60% of its capacity at that point.
- Likewise, they will only warranty 16,100 kWh of total lifetime storage in their 6.5 kWh nominal pack.
- Share of purchase price covered by warranty drops sharply over time:
  - 0-2 years: 100%
  - 2-3 years: 72%
  - 3-4 years: 58%
  - 4-5 years: 44%
  - 5-6 years: 30%
  - 6-7 years: 16%
  - 7-8 years: 6%
  - 8-9 years: 4%
  - 9-10 years: 2%



Suppose product fails after 5 years of charging and discharging 6 kWh/day. That's only 68% of its warranted lifetime capacity and might save the user $2500 to $3000 on their utility bills. But they would have paid $8000 or more for the system and would only get 30% back on the warranty.

Source: https://www.solarquotes.com.au/blog/new-lg-chem-resu-batteries-smaller-powerful-cheaper-powerwall/

About $1,000 to $1,900 to put your toe in the water with a small residential energy storage system for backing up fridge, wi-fi router, computer and phones

EcoFlow Delta 1300
(https://ecoflow.com)

Goal Zero Yeti 1500X
(www.goalzero.com/product-features/portable-power-stations/)

Bluetti AC 200
(www.indiegogo.com/projects/bluetti-ac200-most-versatile-solar-power-station#/)

Most of these can be charged straight from an AC wall outlet, or from a car's 12 volt socket, or, most importantly, straight from an extra PV panel. Allows you to charge and run key items in your house off of the battery unit each sunny day, even if your main PV system is offline during the outage.

Economics of home systems improving steadily in Australia

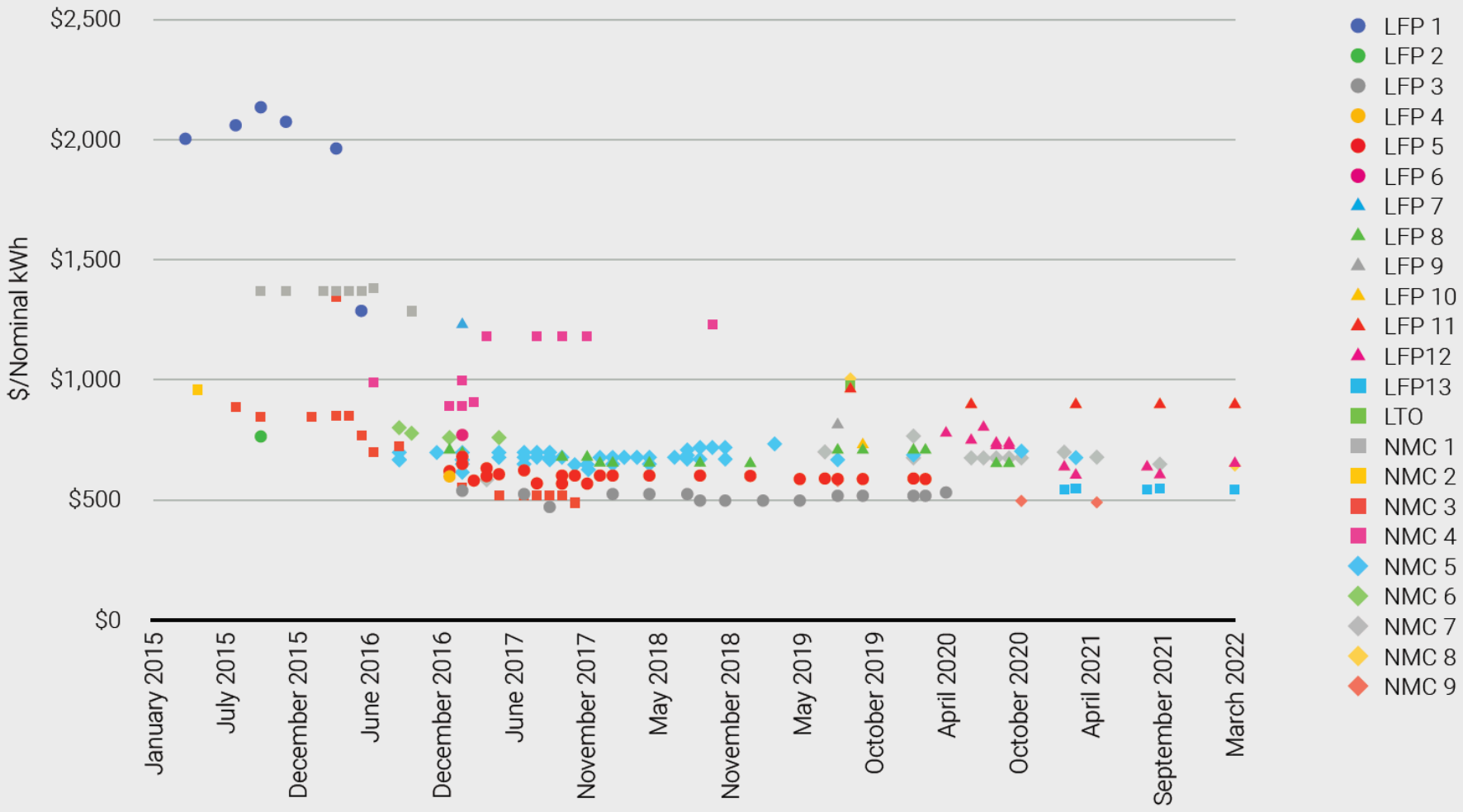


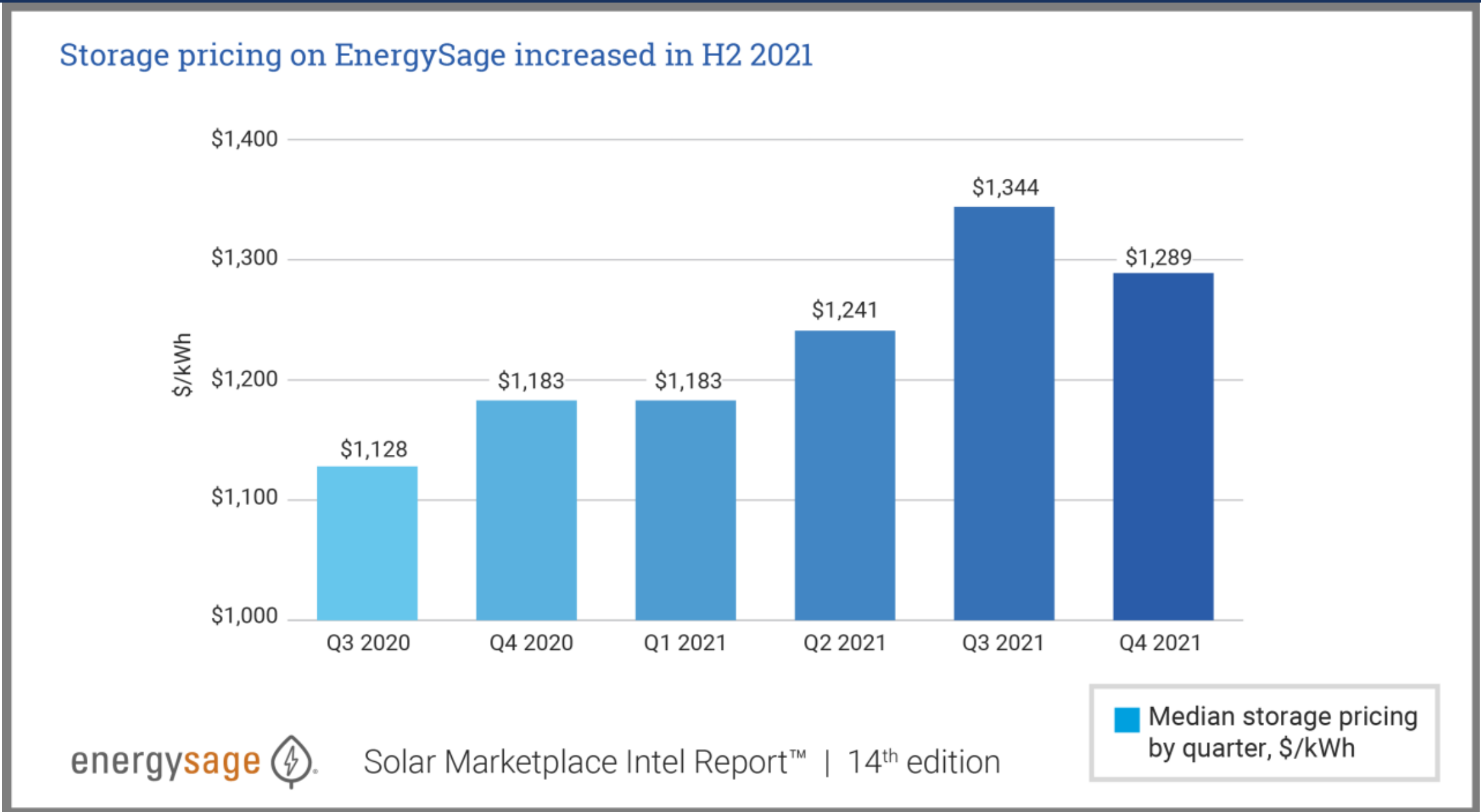
Figure 21: Wholesale prices for lithium-ion battery products installed in the Battery Test Centre

Wholesale prices of the most expensive systems tested in Australia have declined from $2,100/kWh in 2015 to $900/kWh in 2022 in Australian dollars, or from about $1,400 to $630/kWh in US dollars.

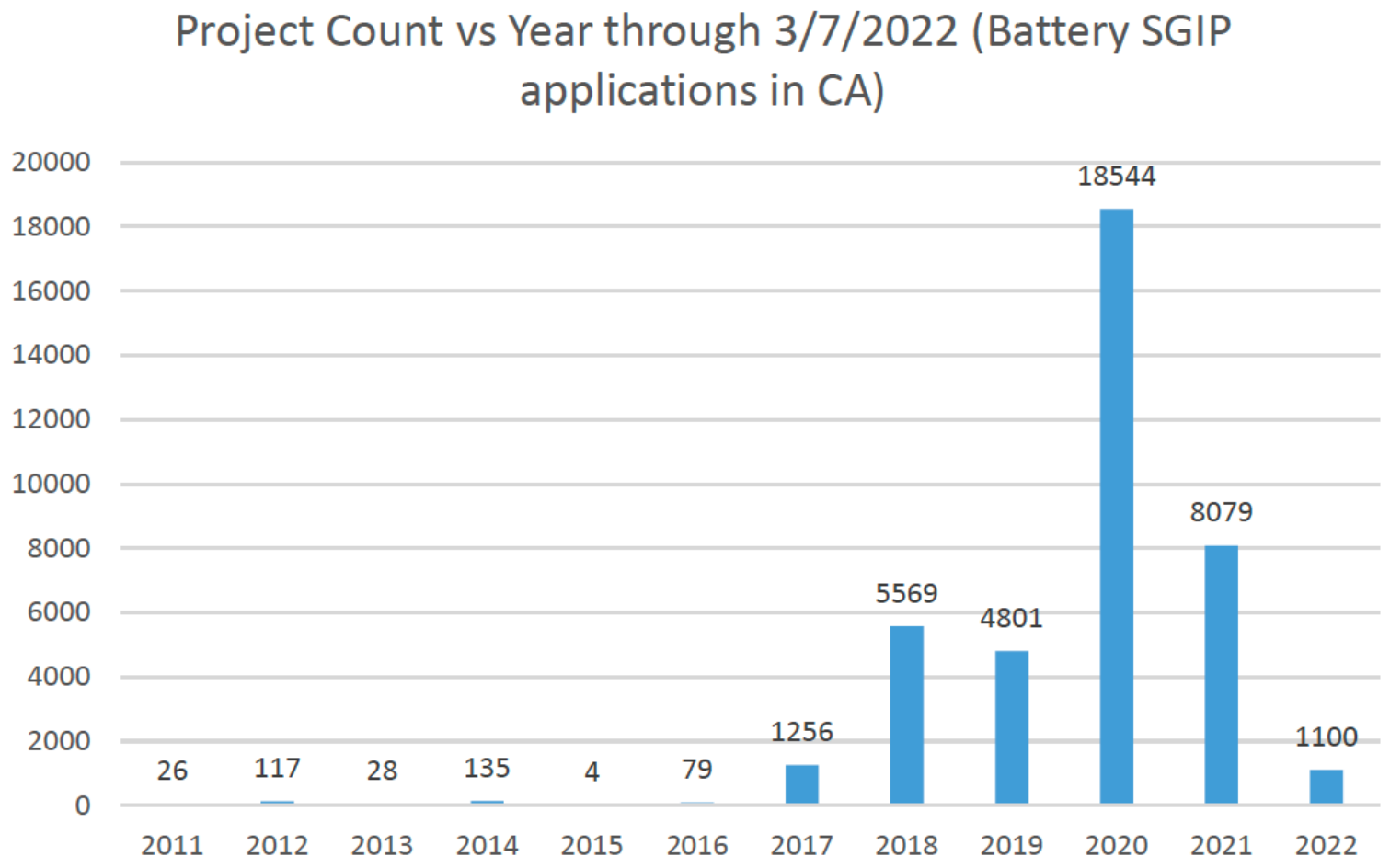
Meanwhile, the most affordable systems have declined in price from about $850/kWh in 2015 to about $500/kWh in 2022 in Australian dollars, or from about $590 to $350/kWh in US dollars. These are consistently lower than US battery prices.

Source: https://batterytestcentre.com.au/

US pricing trends are less encouraging…



Self Generation Incentive Program (SGIP) incentives have been declining in California after a sharp peak in 2020



Source: CALSSA SGIP Dash: https://calssa.org/sgip-dashboard, also available under Reports: https://www.selfgenca.com/home/resources/

The search for a comprehensive cost-effectiveness metric

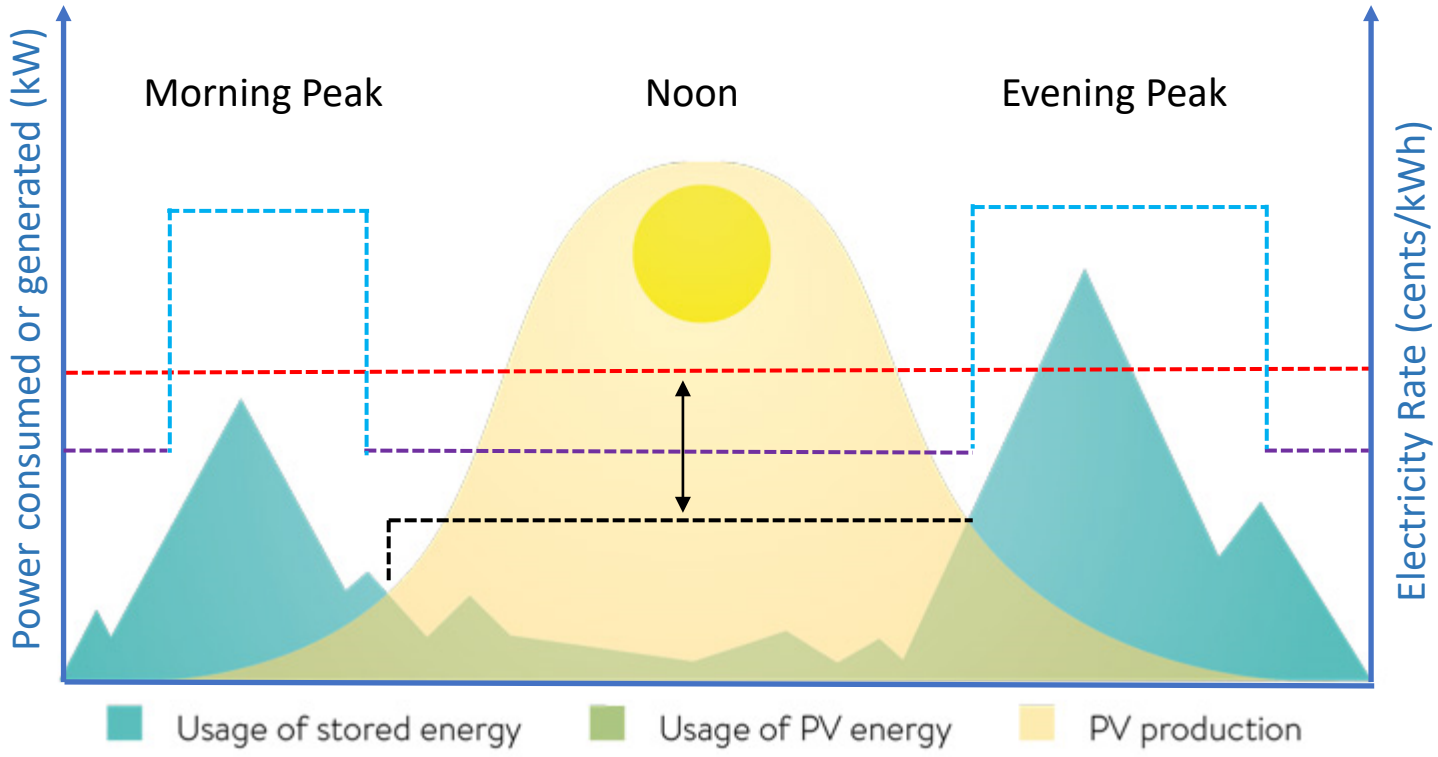
- SolarQuotes.com proposes upfront cost per lifetime warranted kWh.
- Example 1:
  - Suppose battery A costs $10,000
  - It has a nominal capacity of 10 kWh
  - It's warranted for 5,000 cycles
  - $10,000 / (10 kWh/cycle * 5000 cycles) = **$0.20/lifetime warranted kWh**
- Example 2
  - Supposed battery B also costs $10,000
  - It has a nominal capacity of 10 kWh
  - It's warranted for 7 years, assuming 1 cycle/day for solar self consumption
  - $10,000 / (10 kWh/cycle * 1 cycle/day * 365 days/year * 7 years) = **$0.39/lifetime warranted kWh**
- If the batteries only allow 90% depth of discharge, *actual* capacity is 10% lower than nominal, so upfront cost/lifetime kWh is 11% higher.
- If the batteries are warranted to be delivering at least 60% of their actual new capacity at end of life, their actual *lifetime average* capacity is about 80% of nominal, so upfront cost/lifetime kWh is 25% higher.

Sample calculations with two popular battery models

Manufacturer	Nominal Battery Size (kWh)	Lifetime Warranted Capacity (kWh)	Implied Cycles	Installed Upfront Cost	Cost/Warranted Lifetime kWh	Cost/Cycle
Tesla	13.5	37,800	2,800	$16,200	$0.429	$5.79
LG Chem	9.8	27,400	2,796	$11,760	$0.429	$4.21
Sources of data:	https://pv-magazine-usa.com/2022/09/30/how-long-do-residential-energy-storage-batteries-last-2					
	https://emp.lbl.gov/tracking-the-sun					

- Employs LBNL assumption of $1,200 installed cost per nominal kWh of battery capacity.
- Does not include the impact of the federal tax credit, utility incentives, or SGIP on reducing installed system price.
- But also does not include real-world losses in operation from higher than tested operating temperatures, reserve margins in the battery left unused during daily discharge, standby losses in the inverter and wiring, or declining battery capacity and round trip efficiencies over time. All of these would tend to decrease the amount of useful energy storage delivered in practice.

Batteries don't generally save money under flat rates, but can with time of use (TOU) rates or some kinds of net metering rates



On peak rate paid by consumer

Flat electricity rate paid by consumer

Off peak rate paid by consumer

Wholesale rate paid to consumer

Morning: minimal energy production, high energy needs.

Midday: highest energy production, low energy needs.

Evening: low energy production, high energy needs.

SCP Billing (non-solar)

Your Account Summary

Amount Due on Previous Statement	$417.01
Payment(s) Received Since Last Statement	-418.01
Previous Unpaid Balance	$0.00
Current PG&E Electric Delivery Charges	$120.39
Sonoma Clean Power Electric Generation Charges	75.69
Current Gas Charges	208.92

Automatic Payment Service (APS)
to be applied 02/24/2020 **$406.00**

Details of PG&E Electric Delivery Charges

01/04/2020 - 02/03/2020 (31 billing days)

Service For:
Service Agreement ID:
Rate Schedule: E1 X Residential Service

01/04/2020 – 02/03/2020	Your Tier Usage	1	▼ 2	
Tier 1 Allowance	325.50	kWh	(31 days x 10.5 kWh/day)	
Tier 1 Usage	325.500000	kWh	@ $0.23581	$76.76
Tier 2 Usage	325.500000	kWh	@ $0.29675	96.59
Generation Credit				-76.67
Power Charge Indifference Adjustment				17.56
Franchise Fee Surcharge				0.44
Santa Rosa Utility Users' Tax (5.000%)				5.71

Total PG&E Electric Delivery Charges **$120.39**

2014 Vintaged Power Charge Indifference Adjustment

- CleanStart rates match PG&E's rates as of March 1, 2020.
  - SCP's Generation Rate
    - Generation-Total + PCIA + FF
  - PG&E Generation Rate
    - Generation Credit

Details of Sonoma Clean Power Electric Generation Charges

01/04/2020 - 02/03/2020 (31 billing days)

Service For:
Service Agreement ID: ESP Customer Number:

01/04/2020 – 02/03/2020

Rate Schedule: E-1

EverGreen	651.000000	kWh	@ $0.02500	$16.28
Generation - Total	651.000000	kWh	@ $0.08544	55.62
			Net Charges 71.90	
Utility Users Tax				3.59
Energy Commission Surcharge				0.20

Total Sonoma Clean Power Electric Generation Charges **$75.69**

SCP Billing (solar and solar plus)
NetGreen 2.0

Roles of Responsibility:

PG&E	Sonoma Clean Power
Approves Installation & Interconnection	
Maintains Meters & Wires	
Bills delivery charges annually + monthly minimum bill charges	Bills generation charges monthly
Annual True-Up for delivery charges/credits	Annual Cash Out for generation exported to the grid

NetGreen +

- NetGreen + is SCP's net energy metering (NEM) program.
- NetGreen is available to any SCP customer with solar.
- NetGreen credits customers the retail rate plus a bonus penny for any over-generation during a TOU period.
- Each spring, SCP does a cash-out for customers that exported more energy (kWh) than consumed on an annual basis at double PG&E's net compensation rate or about 6 cents.

More information available at:
sonomacleanpower.org/programs/netgreen

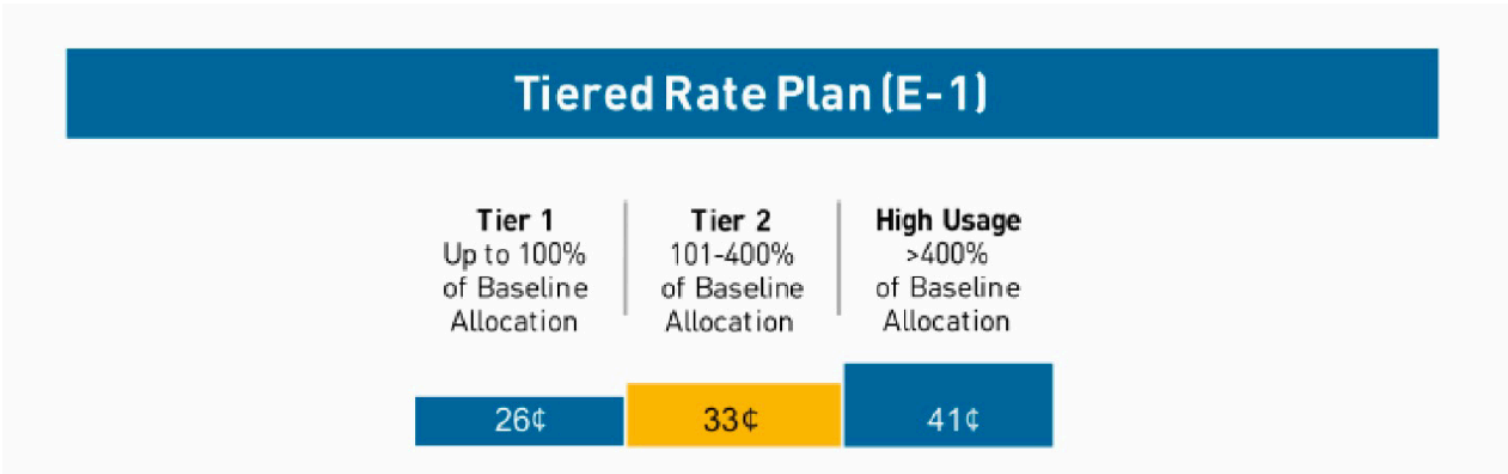
Residential Rate Options

Rate	Description
E-1 (Tiered Rate)	Flat rate, same price for all hours
E-TOU-C (Peak Pricing 4-9pm everyday)	Time of Use (TOU) rate with 19 hours of off-peak pricing and 5 hours of peak pricing
E-TOU-D (Peak Pricing 5-8pm weekdays)	TOU rate with 21 hours of off-peak pricing and 3 hours of peak pricing on weekdays, weekends are all off-peak.
EV2A (Home Charging Rate)	Peak period 4-9pm, part-peak 3-4pm and 9pm-12am, all other hours are off-peak

E-TOU-A, E-TOU-B, E-6, and EVA rate options are closed to new customers

How should you think about batteries in the context of PG&E's rate plans?

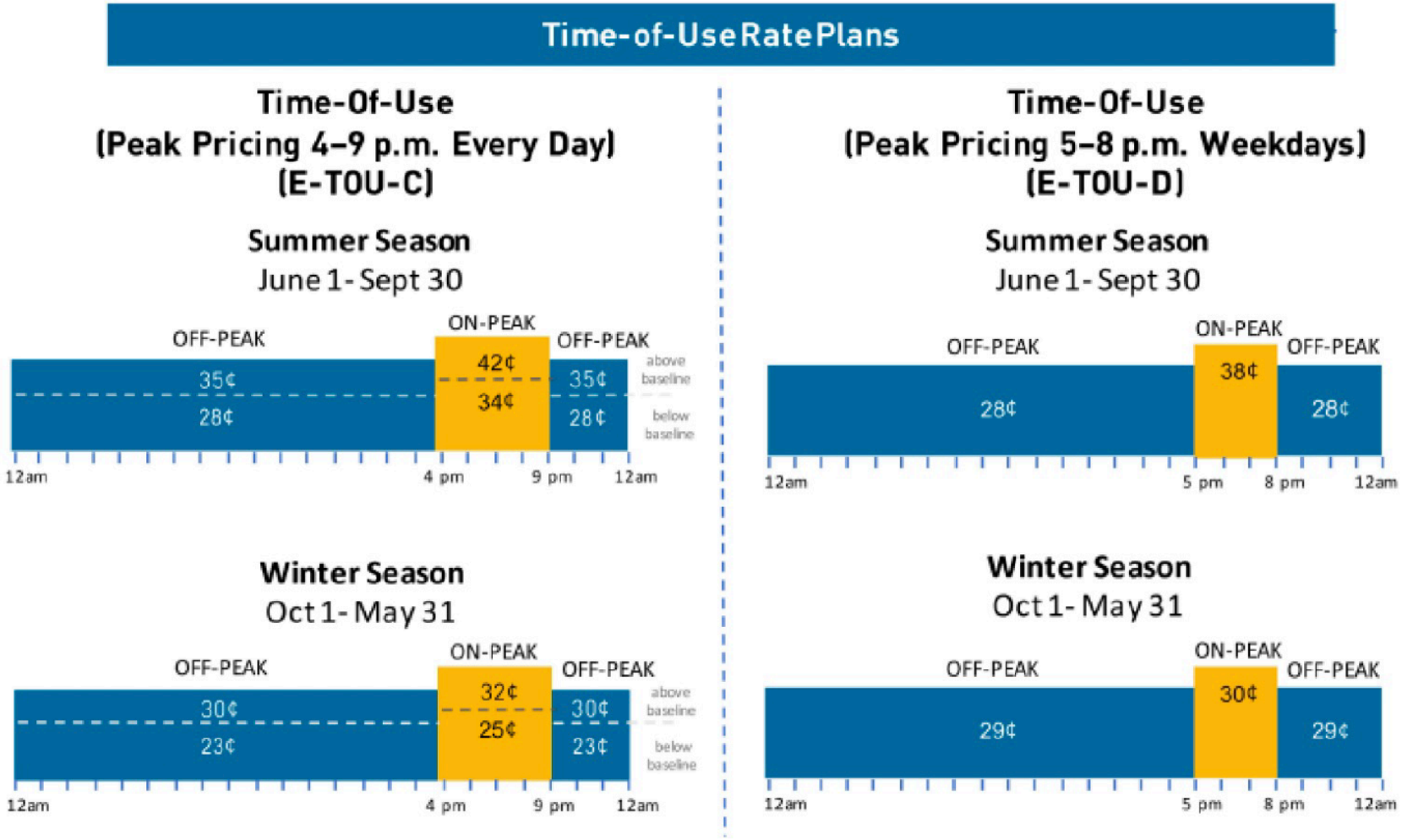
- PG&E has progressively tiered rates by default, where you pay more for each unit of electricity as you use more. This is intended to help encourage conservation, because any electricity you save on the margin can save you a significant amount of money:



Time of Use (TOU) rates from PG&E apply automatically if you have solar

It can make sense to arbitrage electricity between cheap and inexpensive times of day if the price difference is at least 20 to 30 cents/kWh.

With PG&E's TOU rates, the price differences between peak and off peak times are much smaller than that (1 to 10 cents/kWh), so batteries may not be financially attractive with those rate plans.

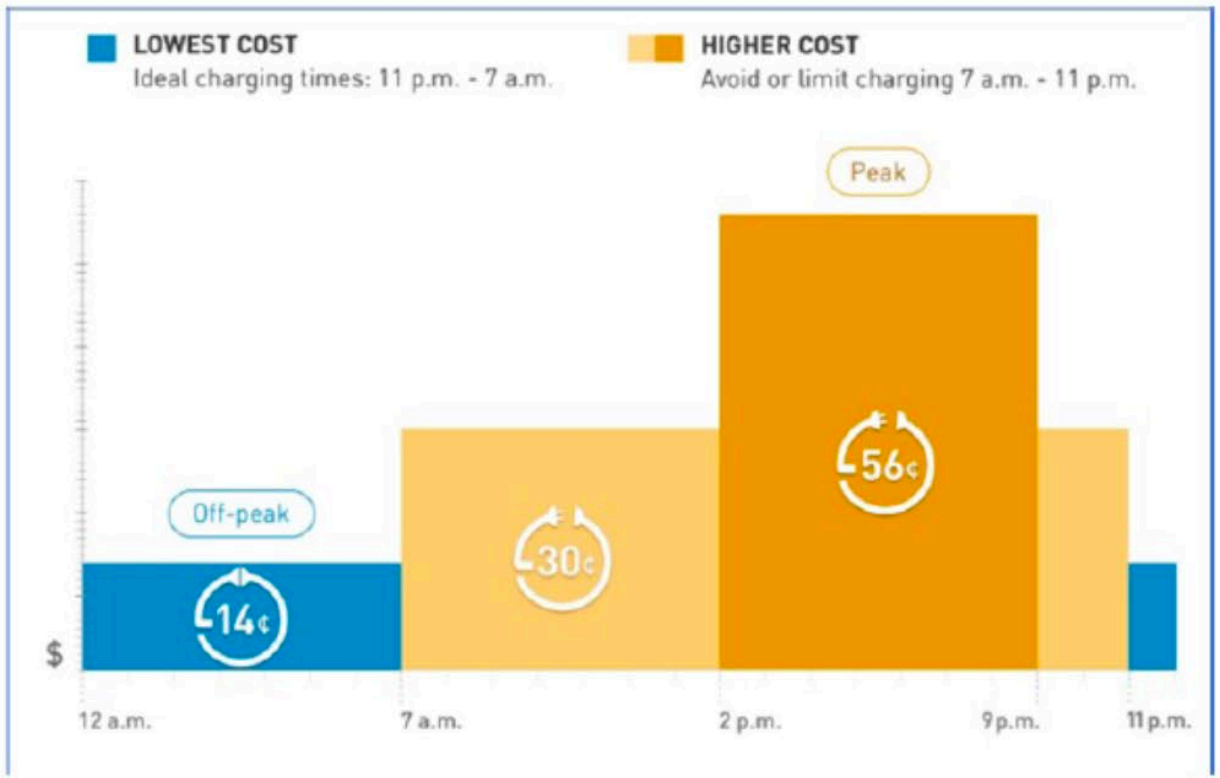


Source: https://www.pge.com/pge_global/common/pdfs/rate-plans/how-rates-work/Residential-Rates-Plan-Pricing.pdf

PG&E's EV rates are the most promising for shifting power between different times of day: 32 to 42 cents/kWh price difference differences between peak and off-peak rates

EV 2A rate (cheaper peak but more expensive off-peak)

EV B rate (bigger price differences between peak and off-peak, but only separately metered EV consumption is eligible)



source: www.pge.com/en_US/residential/rate-plans/rate-plan-options/electric-vehicle-base-plan/electric-vehicle-base-plan.page

More information

Online: sonomacleanpower.org/billing
sonomacleanpower.org/programs/netgreen

Email: info@sonomacleanpower.org (billing)
programs@sonomacleanpower.org

Local Contact Center: 1 (855) 202-2139, M-F 8am-5pm

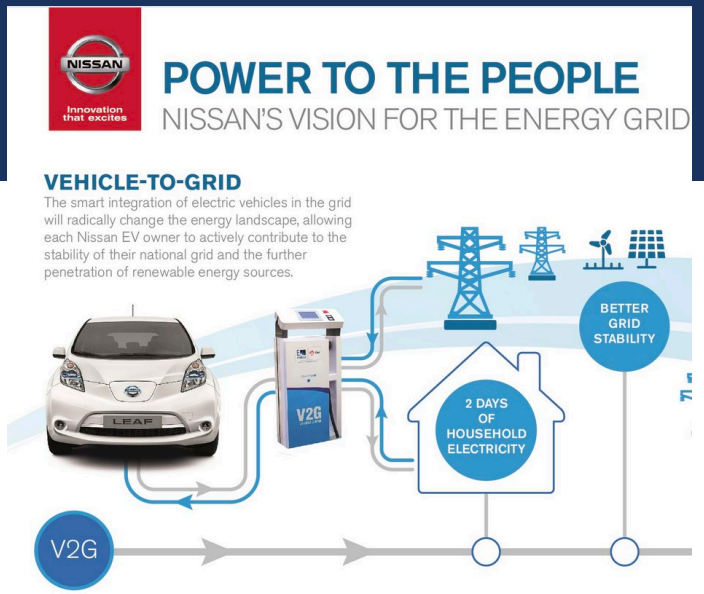
What about using your electric car for home energy storage instead?

- An electric vehicle represents about 1/3 of a house in terms of annual electricity consumption.
- But on a *power* basis, most electric vehicles are able to discharge far more kW instantaneously than is needed to power all of the electrical equipment in your home simultaneously.
- Each EV contains 3-10x the battery capacity of a typical home battery, already bought or leased by you for transportation, and sitting unused 70-90% of the time.
- It's nice that EVs can absorb extra renewables at times of day when they would otherwise be wasted, but their ability to discharge large amounts of power and energy to the grid on short notice when needed by the customer or utility is even more valuable.
- Early studies in Japan and Denmark showed only a 2% or less reduction in battery life from using an EV for V2G purposes over 5 to 8 years, according to Nuvve. Economic value from using the battery bidirectionally is much higher.
- Could make money with peak / off-peak price differences as low as 15 to 20 cents/kWh

See https://zecar.com/post/watt-is-bidirectional-charging-v2g-v2h-v2l for financial analysis

Bidirectional power flow capability increasingly available in EVs and chargers

- Hardware capability to send power in both directions has existed in EVs for awhile; software now being increasingly enabled.
- V2G chargers now available from Nuvve, Ossiaco, Wallbox Quasar, Highbury, Delta, Ford, and other manufacturers.
- Can be an ideal arrangement if you work from home. If your EV is away from the house during the day when the sun is shining, this option makes less sense for you.
- But it may make increasing sense for employers to provide it under solar canopies in the parking lot, trading free charging to its employees' EVs for the ability to use their batteries bidirectionally to minimize demand charges during the day.



V2G-capable personal vehicles

- Earliest models: Nissan Leaf EV and Mitsubishi Outlander PHEV (CHAdeMO charge port)
- 2021 models: Porsche Taycan, Lucid Air, Volkswagen ID4
- 2022 models: Hyundai Ioniq, Kia EV6, Ford F-150 Lightning, Toyota bZ4X
- 2023 models: Chevy Silverado pickup and other models pending from VW and Hyundai, plus the Volvo EX90
- Porsche testing bidirectional charging on its Taycan and expected expected to announce software update enabling V2G in 2022 or 2023.
- Rivian may not be far behind with a software update on its R1T and R1S vehicles.

Tesla's insistence that the feature doesn't make sense increasingly looks like the perspective of a company that wants to sell more stationary battery systems.

Sources:
https://newmotion.com/en/knowledge-center/news-and-updates/the-future-of-ev-charging-with-v-2-x-technology
www.greencarreports.com/news/1131835_mass-market-vw-evs-will-have-bidirectional-charging-starting-in-2022
https://evannex.com/blogs/news/five-porsche-taycans-provide-grid-services-in-bidirectional-charging-test
www.carscoops.com/2021/05/how-the-new-ford-f-150-lightning-can-help-you-keep-the-lights-of-your-house-always-on/#lg=1&slide=28
https://electrek.co/2021/10/29/toyota-unveils-first-all-electric-car-bz4x-an-electric-suv-packed-cool-features/
www.rivianownersforum.com/threads/can-a-rivian-power-a-house-during-an-energy.959/
www.electrive.com/2022/04/12/hyundai-to-include-v2g-capabilities-for-their-evs/

F-150 LIGHTNING FORD INTELLIGENT BACKUP POWER VS. PRO POWER ONBOARD

BUILT Ford TOUGH

FORD INTELLIGENT BACKUP POWER

WHAT IS IT?
Powers your home: 9.6 kW via the available 80-amp Ford Charge Station Pro, similar to a central home generator system.*

WHAT'S NEEDED?
Works when connected to home through the 80-amp Ford Charge Station Pro and home integration system.

WHAT WILL IT RUN?
Powers an average-size home with up to 9.6 kW of power through a home integration system.

UNIQUE BENEFITS
Automatically powers a home during an outage and switches back to the truck's charge schedule once power is restored.

CONNECTION POINT
Both standard- and extended-range F-150 Lightning via the charge port when connected with the 80-amp Ford Charge Station Pro.

PRO POWER ONBOARD

WHAT IS IT?
Power out of home: Up to 9.6 kW onboard power for a variety of electrical devices like power tools and camping gear direct from 11 outlets on the truck.**

WHAT'S NEEDED?
Works from standard 120/240-volt AC outlets located throughout the truck.

WHAT WILL IT RUN?
Power tools like saws, compressors, drills and consumer electronics items such as TVs, stereos, refrigerators and lighting.

UNIQUE BENEFITS
Up to 9.6 kW of portable power that's ready when you are. It is easy to use and can power a combination of devices and tools.

CONNECTION POINT
The standard 2.4 kW Pro Power Onboard features eight 120V outlets. The available 9.6 kW Pro Power Onboard features 10 120V outlets and one 240V outlet.

*When home is properly equipped and home transfer switch disconnects the home from the grid. **See owner's manual for important operating instructions.

Ford’s design:

- Charges the EV at a rate of up to 19.2 kW AC
- Can discharge from the Ford EV into a separate Home Integration System at up to 9.6 kW DC
- The Home Integration System includes an inverter to create AC to power critical home loads.
- Also an inverter in the truck for V2L of 120 and 240 V loads.

Ford Charge Station Pro

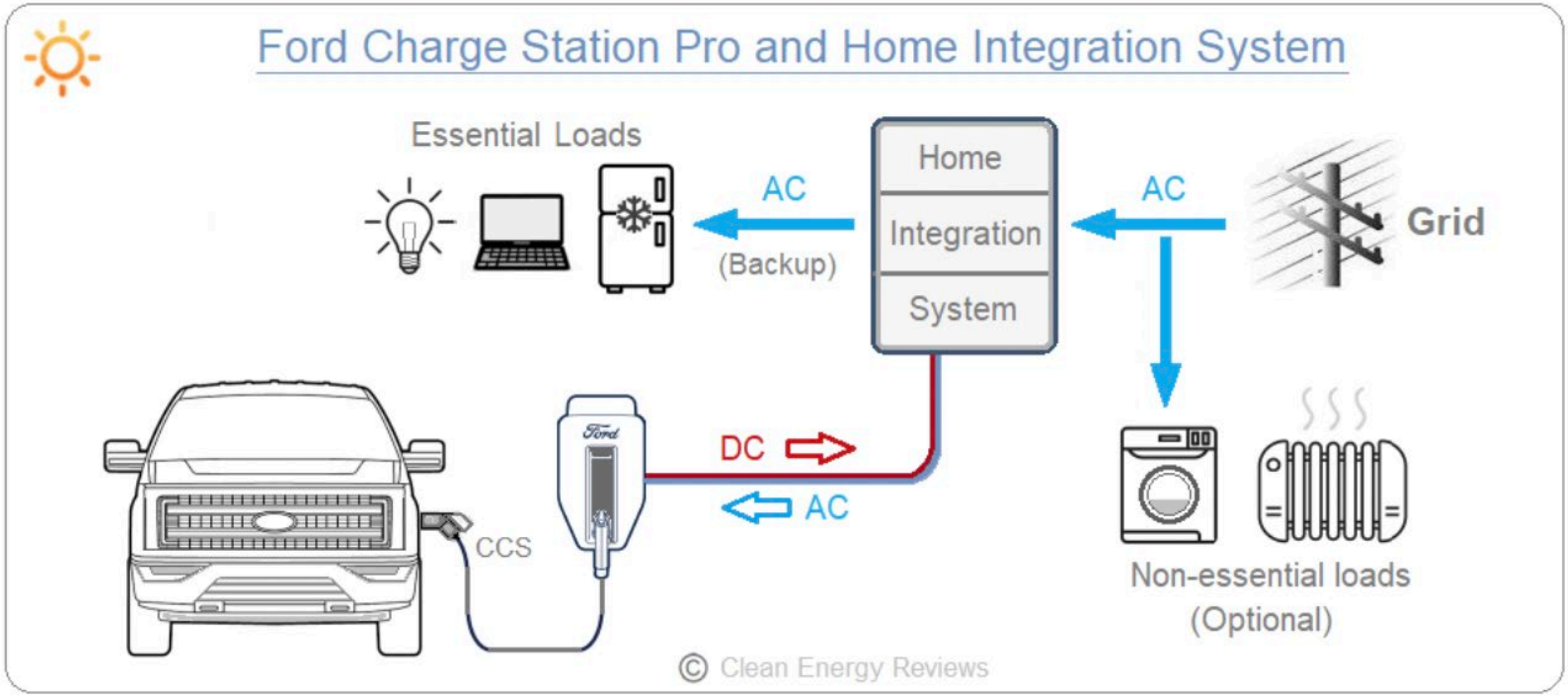
The Charge Station Pro is a Ford exclusive bidirectional EV charger rated at a maximum of 80-Amps, or 19.2kW (240V). It is due to be released along with the new Ford F-150 Lightning Electric Pickup in mid-2022. The charger was developed in collaboration with Siemens eMobility and will allow the F-150 EV to power a home providing up to 9.6kW when installed together with the Home Integration System and enable what Ford has dubbed intelligent backup power.

It is still unclear exactly how the Ford Charge Station Pro functions in regards to the DC power conversion, but it appears the charger can operate as either a regular EV charger using the US standard J1172 connector (J plug) or as a bidirectional charger using the CCS-DC connector when combined with Ford’s **home integration system** which consists of a DC to AC inverter and a transfer switch to enable islanding (grid isolation) in the event of a blackout. Download the Charge Station Pro datasheet.

Learn more about the Ford Charge station Pro in our technical insight.

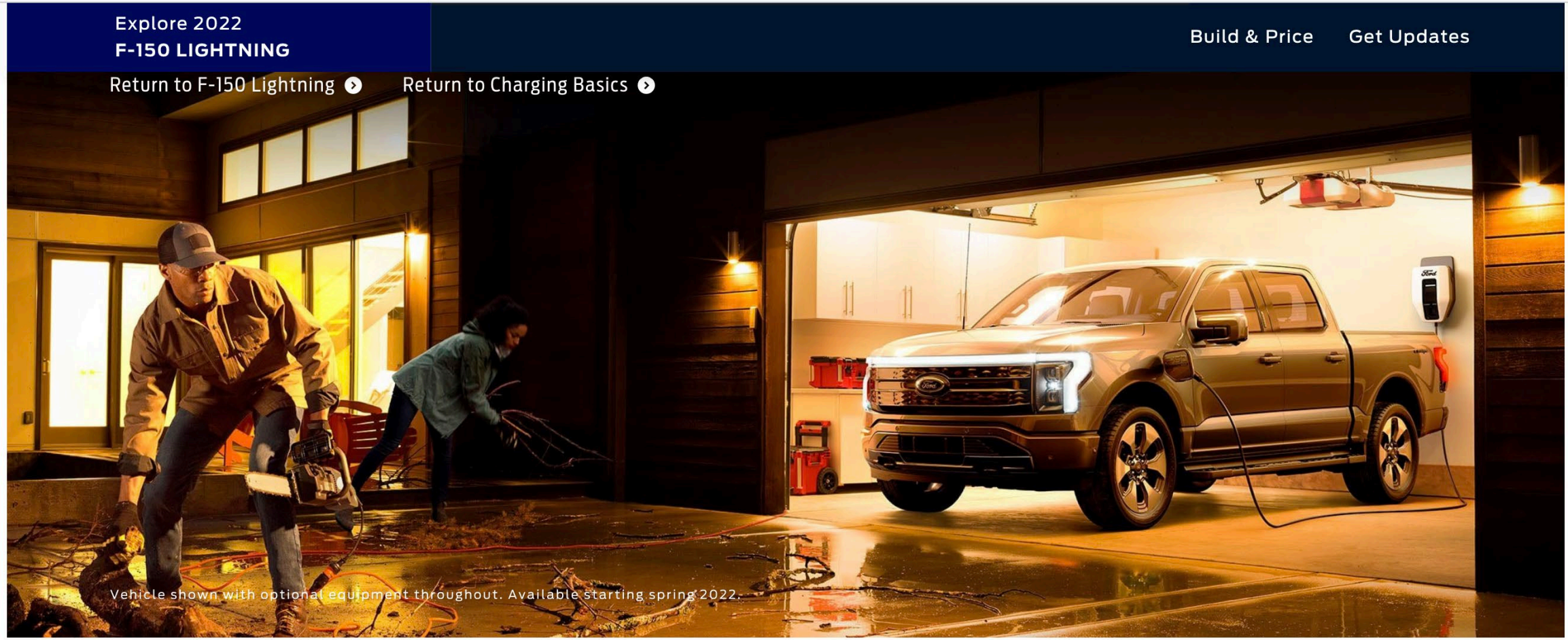
The official price of the Ford Charge Station Pro is US$1310 plus installation. Pricing is not yet available for the Ford Home integration System.

Ford's Charge Station Pro system designed to cost less than $6,000 installed, while storing more energy and delivering higher power than a stationary battery



Ford Home Integration System and EV charger power flow diagram with backup essential loads

Ford’s marketing of V2G has been effective: 200,000+ pre-orders



READY TO WORK, EVEN WHEN IT’S PARKED

If the lights go out at home, rest easy. Your F-150 Lightning™ automatically begins powering your home when connected to the 80-amp Ford Charge Station Pro and Home Integration System. *

*When home is properly equipped and home transfer switch disconnects the home from the grid.

Source: www.ford.com/trucks/f150/f150-lightning/2022/features/intelligent-backup-power/

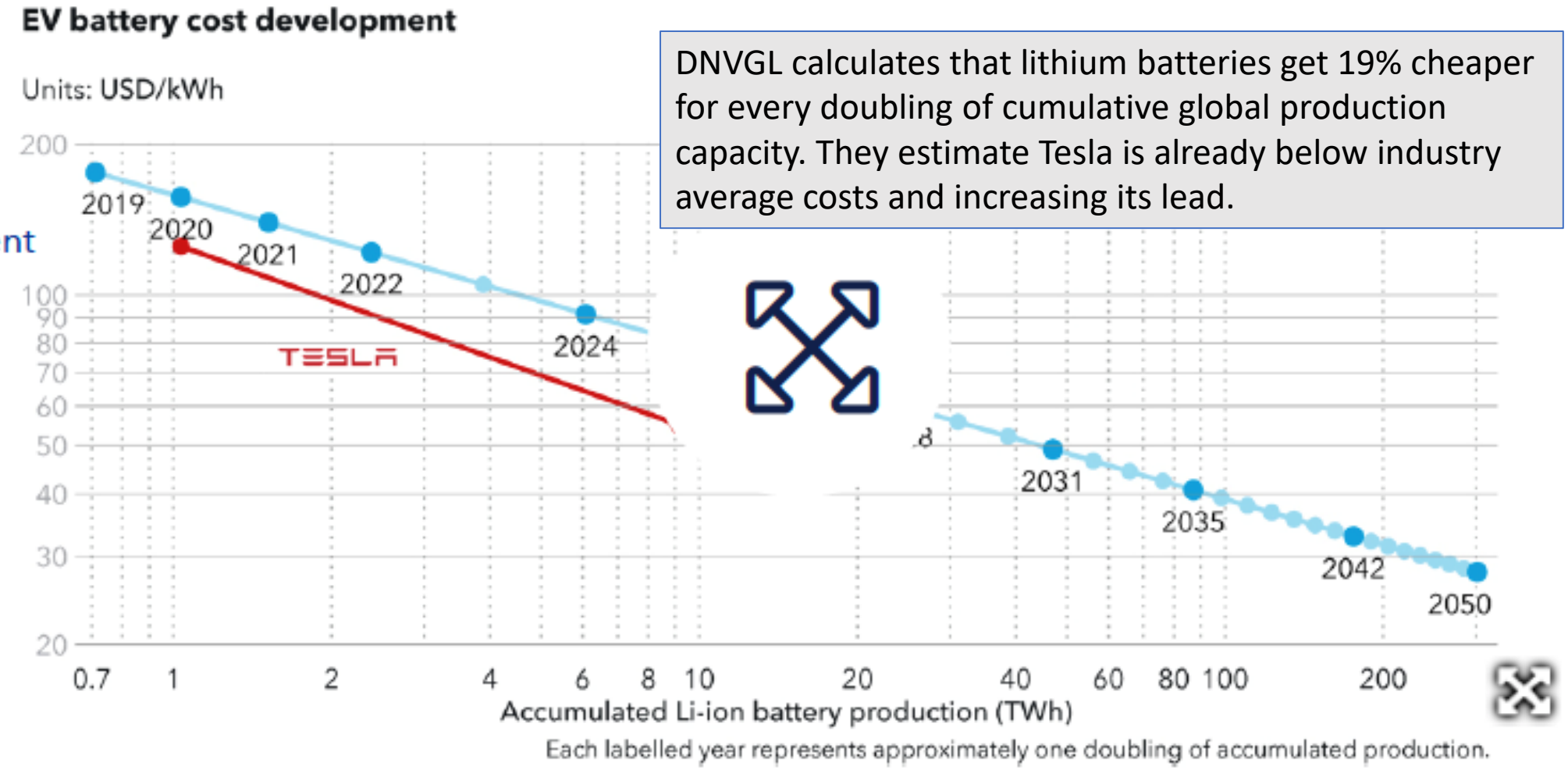
Using a heat pump water heater (HPWH) as an energy storage device

- Typical sizes are 40, 50, 65 or 80 gallons. Bigger is better if you can afford it and have the space.
- Water heaters add about 60 degrees F to the incoming water temperature (T_{in} = 60 degrees F, T_{out} = 120 degrees F)
- 8.34 pounds/gallon * 65 gallons * 60 degrees F = 32,526 BTUs or about 10 kWh of equivalent electric resistance water heater storage
- The most efficient HPWH's are about 400 to 500% efficient.
- Recommendation: put an HPWH in a part of the house you'd like to cool and dehumidify as much of the year as possible. Program it to operate only during the hottest, sunniest part of the day in heat pump only mode. Store solar electricity that would otherwise be going to the grid for use in the evenings or mornings when you consume most of your hot water. Uses almost no grid power!

PERFORMANCE PLATINUM™
ProTerra Hybrid Electric Water Heater

We are descending a steep learning curve toward cheaper batteries

▸ Figure 1: EV battery cost development

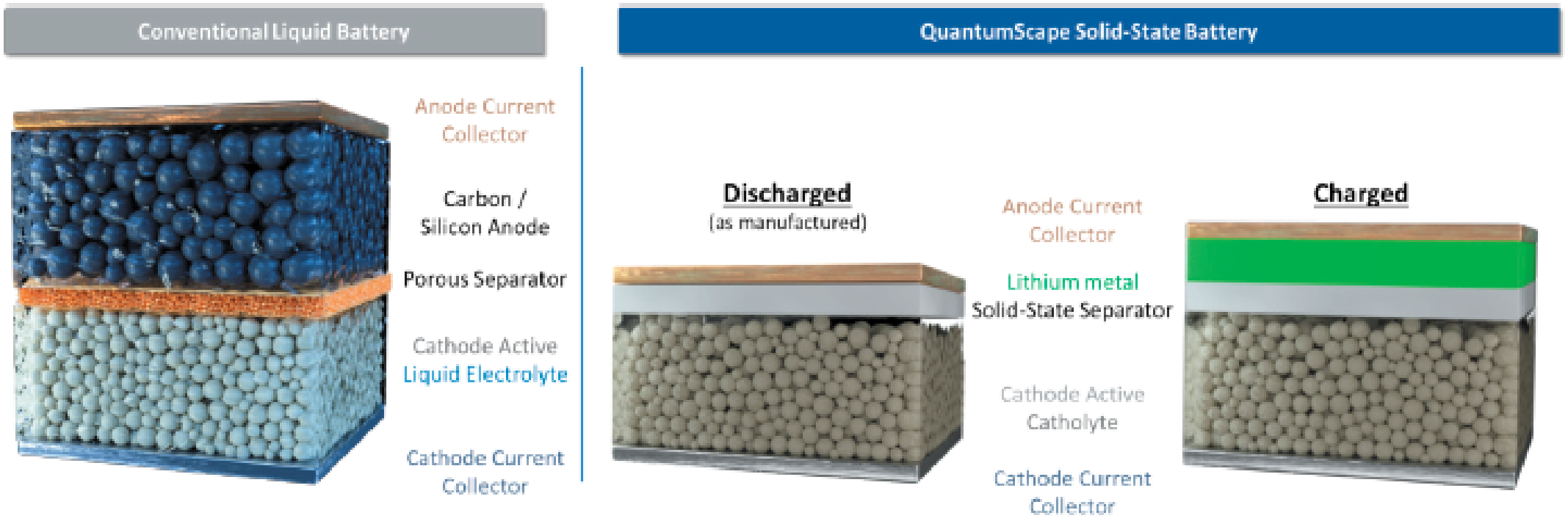


DNVGL calculates that lithium batteries get 19% cheaper for every doubling of cumulative global production capacity. They estimate Tesla is already below industry average costs and increasing its lead.

https://www.dnvgl.com/feature/tesla-battery-day-energy-transition

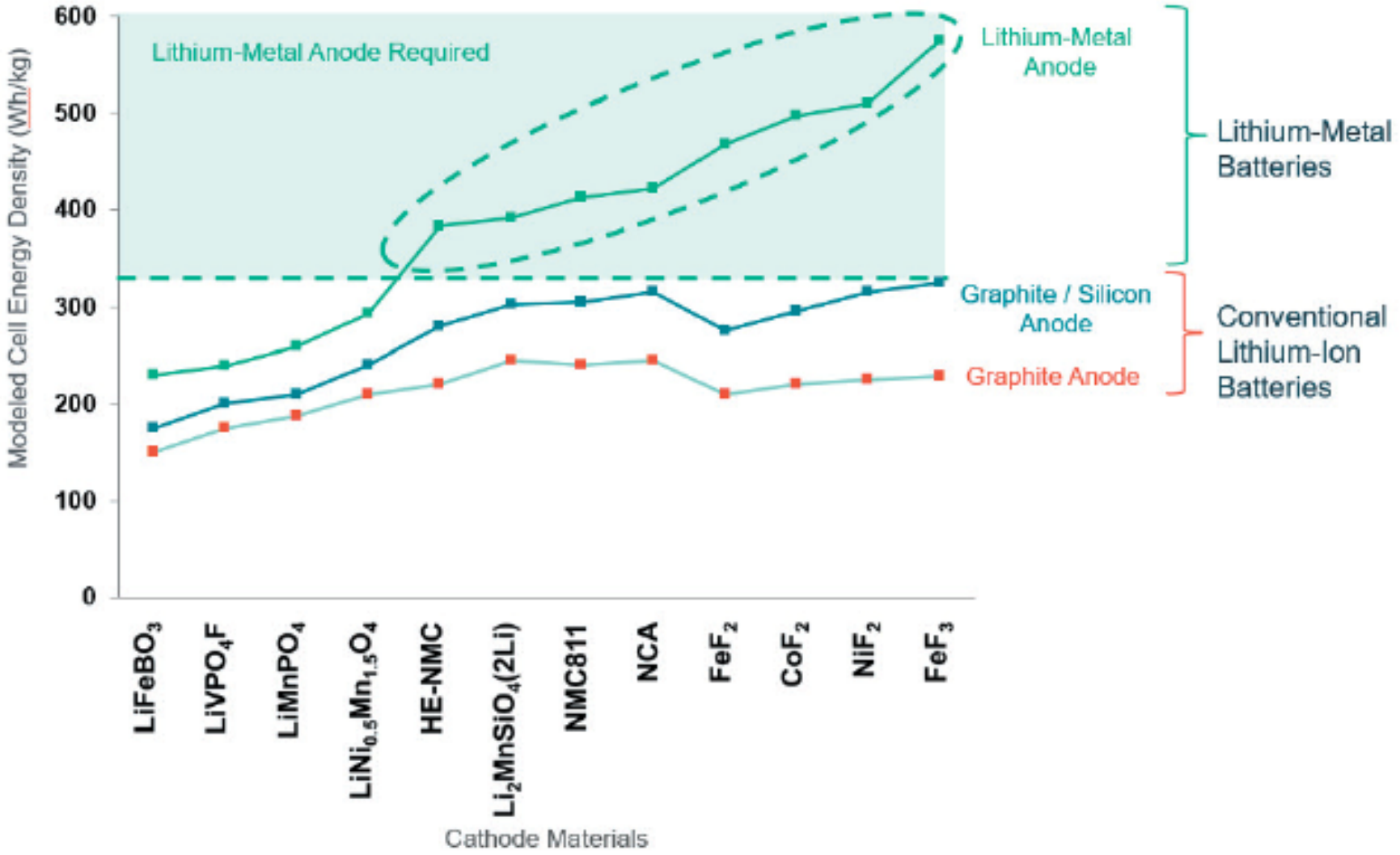
Though most of the focus in lithium battery innovation has been on the cathode, eliminating the anode offers the biggest breakthrough

Traditional lithium-ion cells use a hosted anode in which the host material, such as carbon or silicon, provides a structure to hold the lithium. For example, in the case of carbon, it takes six carbon atoms to hold one lithium atom. **If, however, an anode of pure metallic lithium were to be used, as shown in the schematic below, all the carbon in the anode could be eliminated and the energy could be stored in a much smaller volume, thereby dramatically increasing the energy density of the cell.**

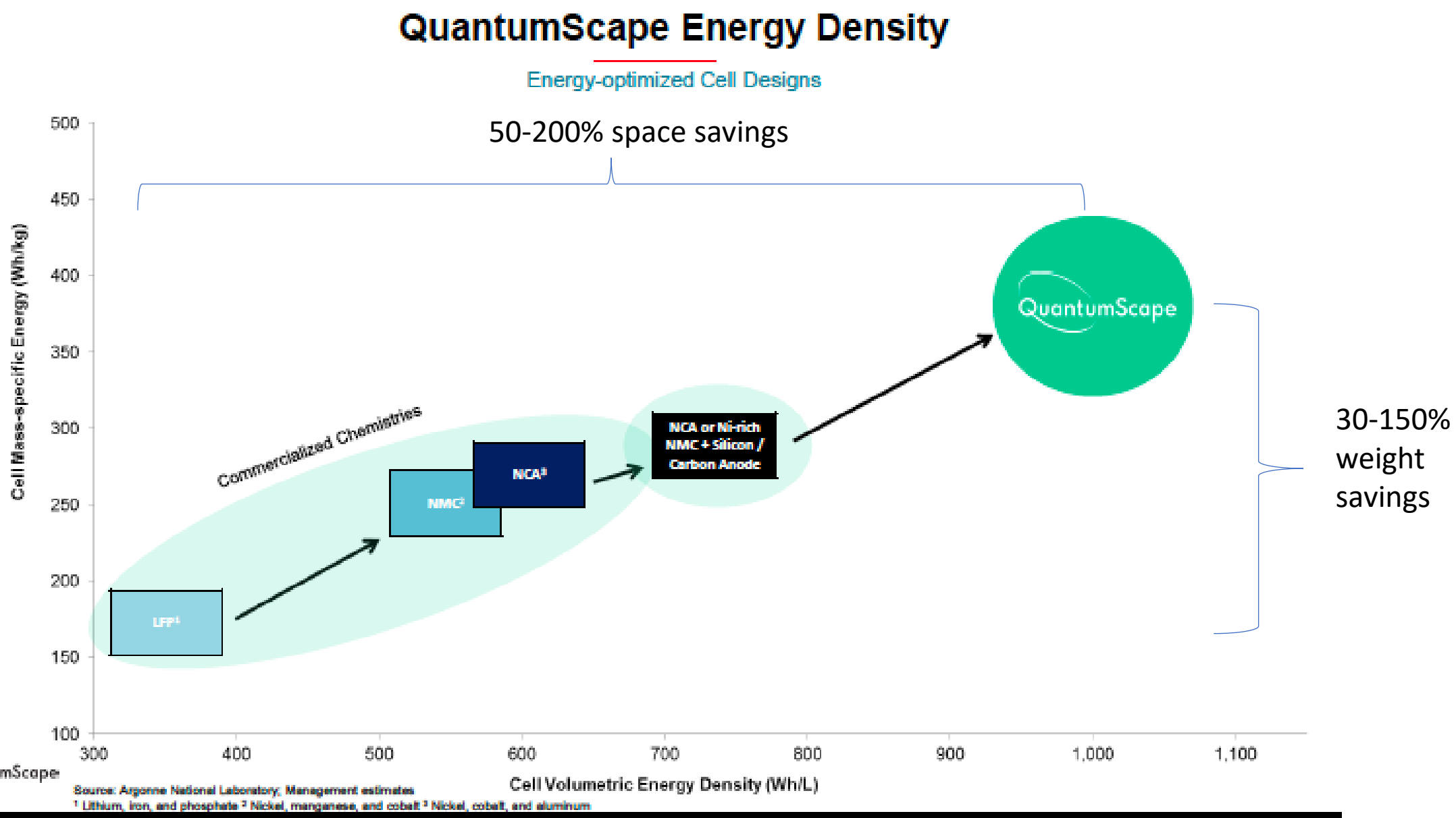


https://ir.quantumscape.com/home/default.aspx

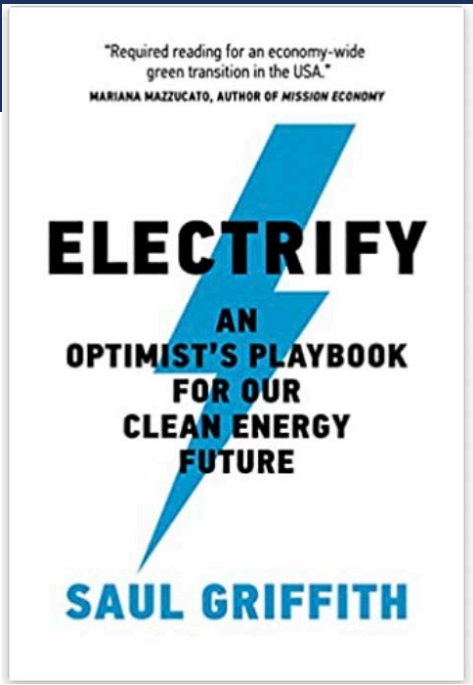
Lithium batteries have many different cathode materials, but the anode is always either pure graphite or graphite + silicon



Appealing that solid state batteries would occupy far less space in the home and weigh less than conventional lithium batteries of similar capacity



A parting thought about batteries from Saul Griffith



Can we make and install enough batteries and renewable energy fast enough worldwide to stabilize the global climate?

The world produces close to 90 billion(!) bullets per year….

What is a bullet, though, but a metal wrapper around some energy dense materials?

We'll need trillions of batteries to power the future if we are using something like the canonical 18650 lithium ion battery. But if we can make a trillion bullets in a decade, we can surely ramp up battery production.

Sources: https://mitpress.mit.edu/9780262545044/electrify/ and www.wired.com/2013/07/incredible-cross-sections-of-real-ammunition/

Conclusions

- Residential energy storage systems are tremendously promising, but don't automatically save money, pay for themselves, or reduce greenhouse gas emissions, especially compared to good green power plans.
- There are big differences between the best and worst-designed battery systems, and more systematic testing and labeling are needed to help consumers buy the best products.
- It's worth promoting the most efficient systems with good incentives that ensure charging and discharging occurs when most beneficial to society and the user.
- Products need to last a long time and continue performing well to eventually pay for themselves, but the economics and durability are steadily improving every year you wait.
- Breakthroughs coming in the next 1 to 3 years with V2G and solid-state batteries should yield sharply better performance and economics than today's home battery systems. Coming soon to a garage near you!

Thank you!

Chris Calwell

ecos™ research

ccalwell@ecosresearch.com

(970) 759-9737

Thanks also to August Goers for furnishing key visuals. He works at Luminalt -- a leading solar and battery system installer in CA: august@luminalt.com

Thank you

Advanced
Energy Center