



BATTERIES WILL EAT THE WORLD

EV, ESS and Battery Global Overview

July 15, 2016

Primary Author: Sam Jaffe



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- PEV Market
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What is a Battery? *This?*



Source: Aquiziam, UFOcasebook.com

What is a Battery? *This?*



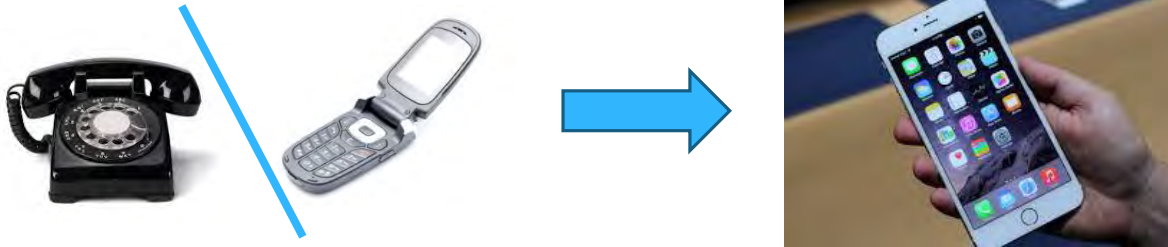
Source: CleanTechnica)

What is a Battery? *Or This?*



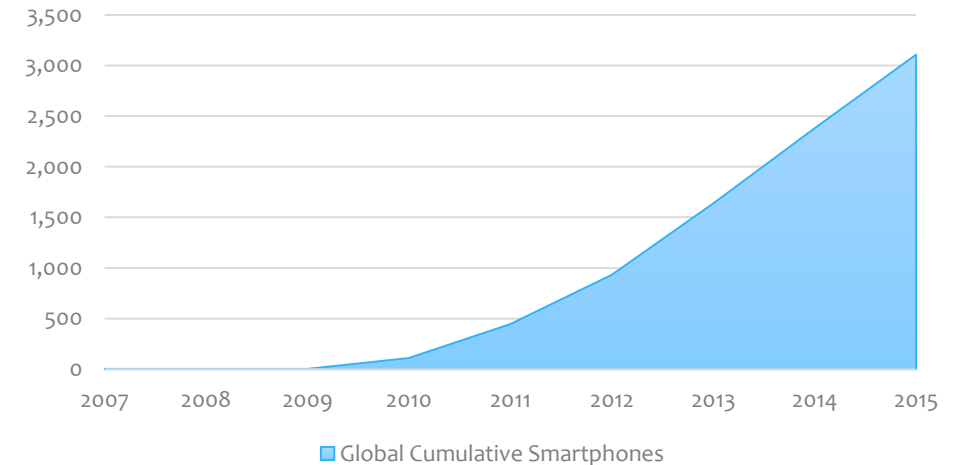
Source: CC BY-NC-SA 2.0 / original by origamiwolf: <https://flic.kr/p/oDCK1>

The “Battery as a Virus” Theory *Smartphones*



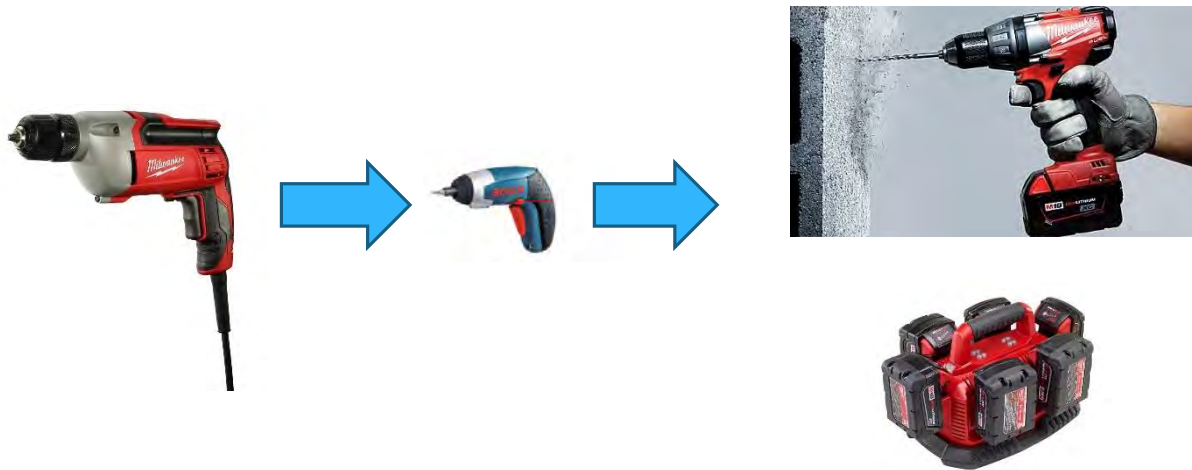
Source:
Gizmodo

Global Cumulative Smartphones in Service



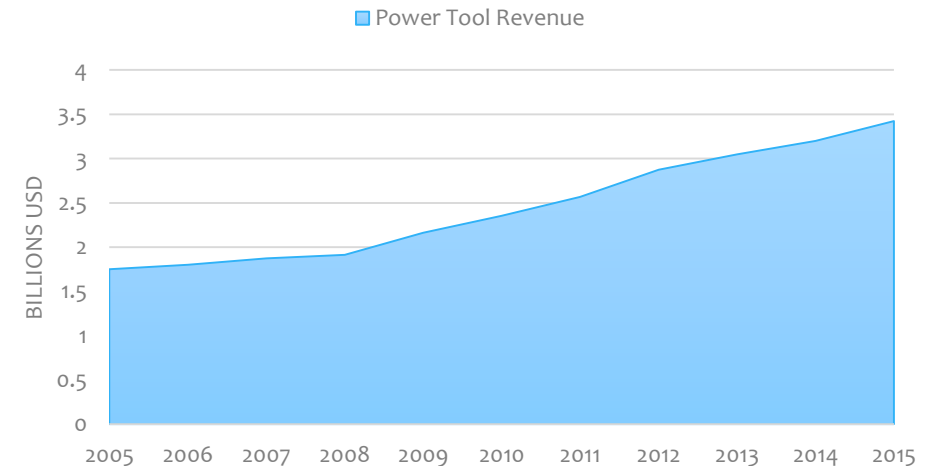
Batteries are not a dumb component in a device. They are a dynamic intelligent part of the machine. Putting a battery into something doesn't just enhance it, it changes it dramatically. And by changing it, a new device is created that is more battery than device.

The “Battery as a Virus” Theory *Power Tools*



Source: Home Depot,
Bosch Tool, Milwaukee
Tool

Global Power Tool Revenue



Batteries are not a dumb component in a device. They are a dynamic intelligent part of the machine. Putting a battery into something doesn't just enhance it, it changes it dramatically. And by changing it, a new device is created that is more battery than device.

Batteries in Cars



Chevy Malibu, Tesla Model X, FF 1
Source: Wikipedia, Car&Driver, Faraday Future

Batteries on the Grid

Historically, the grid hasn't used batteries because they are:



Too Expensive

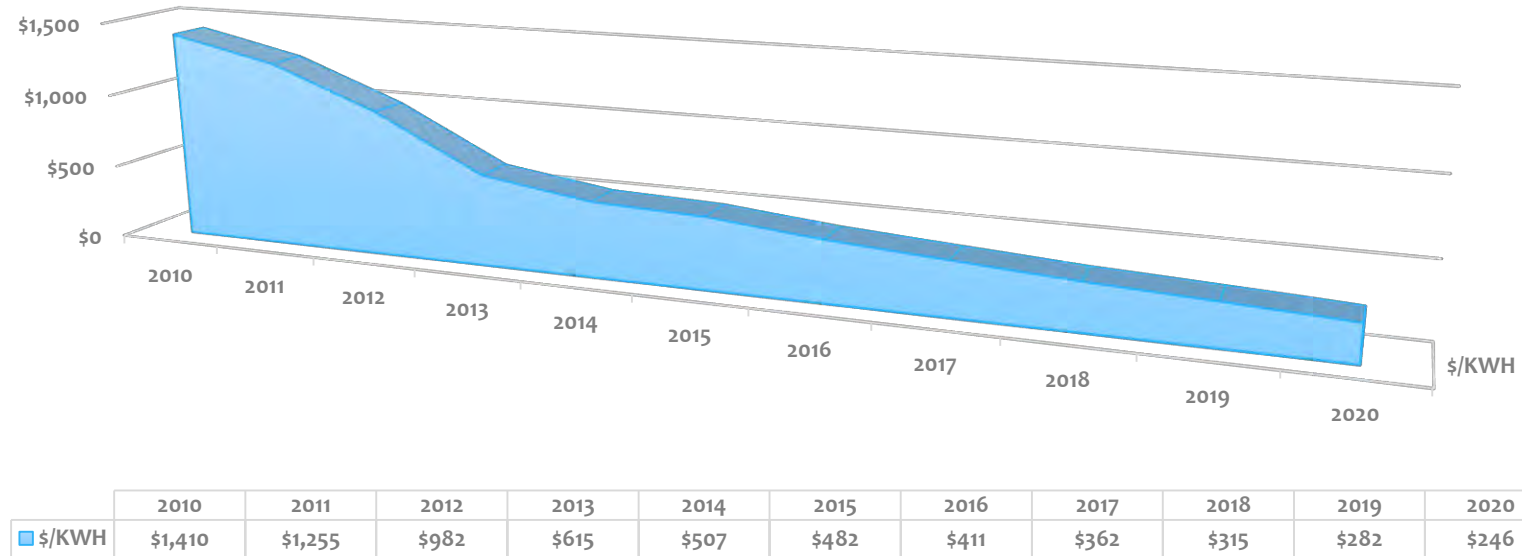
Too Dirty

Too Weak

Too Fragile

Li-ion Pricing

Global Average Pricing of PEV Li-ion Cells in \$/KWH



Source: Cairn ERA

- Lithium ion pricing has already dropped on an average cell-level basis from \$1410 per KWH in 2010 to around \$246 per KWH today (for automotive cells). Three factors underlie this trend:
 - Scale
 - Manufacturing expertise
 - Supply chain maturity

Pricing Reduction Reason: Scale



Source: Tesla



Source: Ford Motor

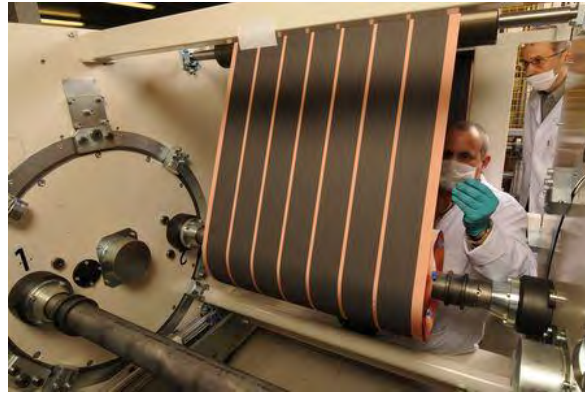
Manufacturing capacity of four of the top six manufacturers is expected to double or triple in the next five years. This will happen in both Asia and North America.

The only viable players left in the battery manufacturing industry are the multinational conglomerates that have decades of manufacturing experience in the space.

Pricing Reduction Reason: Expertise



Source: Asahi Kasei



Source: Saft



Source: Shenzhen

- Making batteries is as much art as it is science, with millions of permutations in ingredient proportions and process tasks; After more than two decades, the Li-ion industry has finally reached the stage of a mature understanding of how to manufacture the batteries cheaply, efficiently and quickly
- Much like the solar photovoltaic industry before it, the Li-ion industry has recently moved from hand-built machinery to mass produced pieces of equipment that are sold into the multi-billion dollar industry; Capital costs for Li-ion manufacturing are much more consistent and understood by investors

Pricing Reduction Reason: Supply Chain Maturity



Source: Cairn ERA



Source: Cairn ERA



Source: Cairn ERA



Source: SZ Graphite

- Most battery material inputs have taken decades to turn from specialty, batch-processed chemicals into large-scale continuously processed chemicals; battery markets are also large enough to become the main demand sources for many materials, including cobalt, lithium and graphite
- Other high-cost materials are also dramatically declining in price, including the additives, solvents and binders that are inactive but highly important ingredients in the battery
- The battery industry, led by Tesla, is starting to successfully pressure further price declines in input materials

Supply Chain Forecast: Clear Horizon



• Lithium

- Only 12% of the cost of a Li-ion cell comes from Lithium
- Prices have increased by ~35% in last six months, while battery prices have contracted

• Graphite

- Industry is moving from synthetic graphite to natural graphite
- Currently too much supply, with multiple mining projects opening

• Cobalt

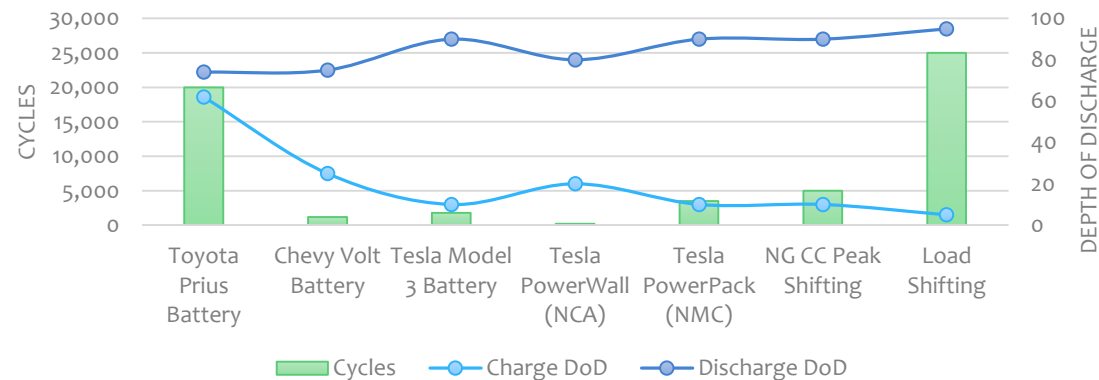
- Potential bottlenecks if growth happens too quickly
- Cobalt is dependent on copper production for new reserves

• Other Materials

- Copper
- Aluminum
- Specialty Chemicals

Still To Be Done: Durable Batteries

Depth-of-Discharge Profiles and Cycle Requirements of Sample Duty Cycles



Source: Cairn ERA



Source: Chianelli et al., 1976

- The anode and cathode of a battery change volume by .75x with every charge discharge cycle; On the nano-scale, spots of the separator can reach 300 degrees Celsius.
- For widespread adoption of grid storage to work, batteries have to now become much more durable.
- Unlike all other applications, battery usage in grid applications is a direct factor in revenue generation. The grid needs batteries to be cheap (below \$200/KWH), powerful (2C and above) and durable (20,000 cycles at 95% DoD). The first two goals have been achieved. We are now in the midst of the march to the third goal.

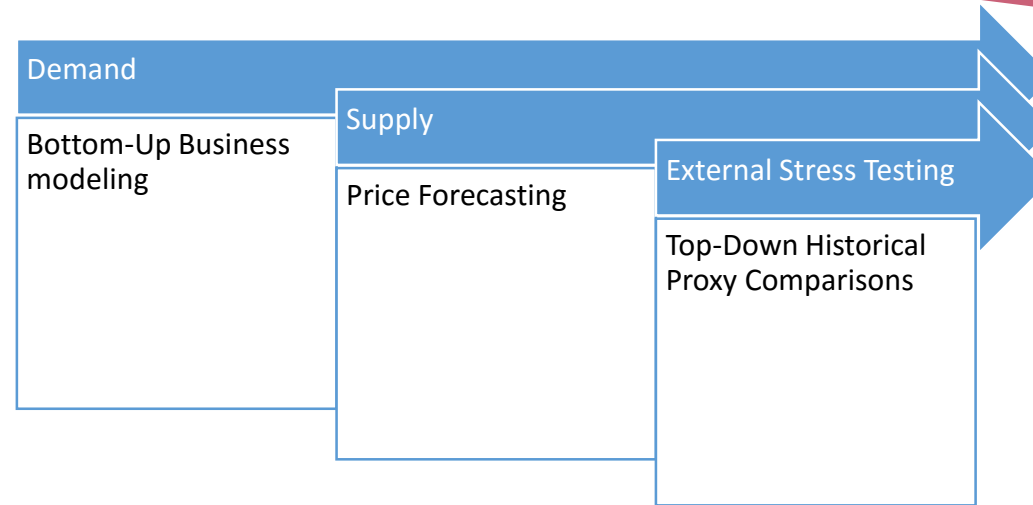


PEV MARKET

PEV Forecasts

About Cairn ERA's Forecasts

Methodology

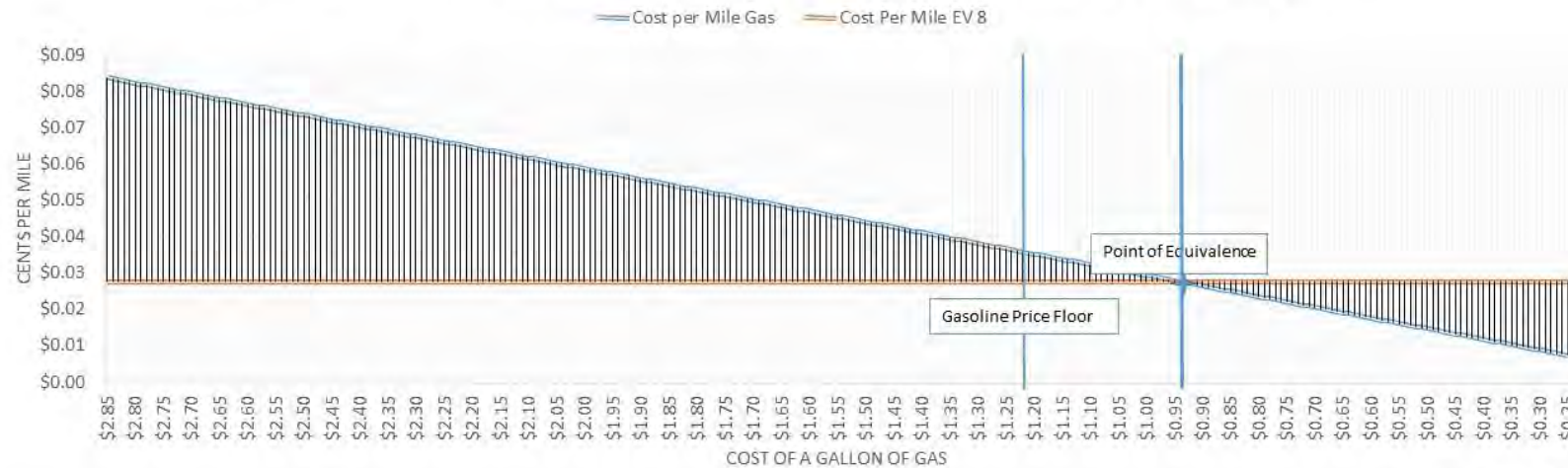


- Pricing threshold model: individual applications are modelled to determine an price threshold for that application to become feasible
- All automotive forecasts are done on an individual model basis, followed by a manufacturer basis, followed by country basis
- Pricing data is then forecasted based on knowledge of materials markets, manufacturing process and manufacturing capacity changes
- Forecasts are then built around expected pricing and expected market demand based on ROI-positive business models for each application
- Forecasts are then stress-tested against top-down historical proxy growth curves to determine how other historical examples have grown under similar supply/demand circumstances

PEV Forecast

Impact of Gas Prices

THE COST OF PUSHING A CAR WITH ELECTRICITY VS. GASOLINE



Source: Cairn ERA

Many people make the claim that EV sales should be influenced by gasoline prices. If so, then the current crash in oil prices should spell doom for our EV forecasts. But we haven't changed a thing. That's because the cost of pushing an EV with electricity will always be cheaper than pushing it with gasoline. Here's why:

It costs the driver of a Nissan Leaf 2.6 cents per mile to charge the car (based on U.S. average electricity prices). At the current price of a gallon of gas (\$1.85), it costs a Nissan Versa (an equivalent size car with excellent mileage), 5.4 cents worth of gasoline to push the car one mile. Gasoline would have to reach a price point of \$0.93 per gallon before it reaches an equivalent per mile cost with electricity. And gasoline can never reach that price because taxes cost \$0.49 per gallon (EIA), refining costs \$0.40 per gallon (Exxon Mobil) and distribution costs \$0.33 per gallon (California Department of Revenue). Thus vendors would stop selling a gallon of gas if the cost dropped below \$1.22 per gallon, because they would lose money in trying to sell it.

PEV Forecast

Growth Drivers and Inhibitors

Drivers

- Carbon reduction was responsible for initial market, but won't be enough for expansion
- Pollution reduction in China
- CAFÉ pressures are rising globally
- Carpool lane stickers have been more important than subsidies
- Volkswagen scandal proves that fully electrified drivetrain is the only full solution to efficiency and environmental problem

Inhibitors

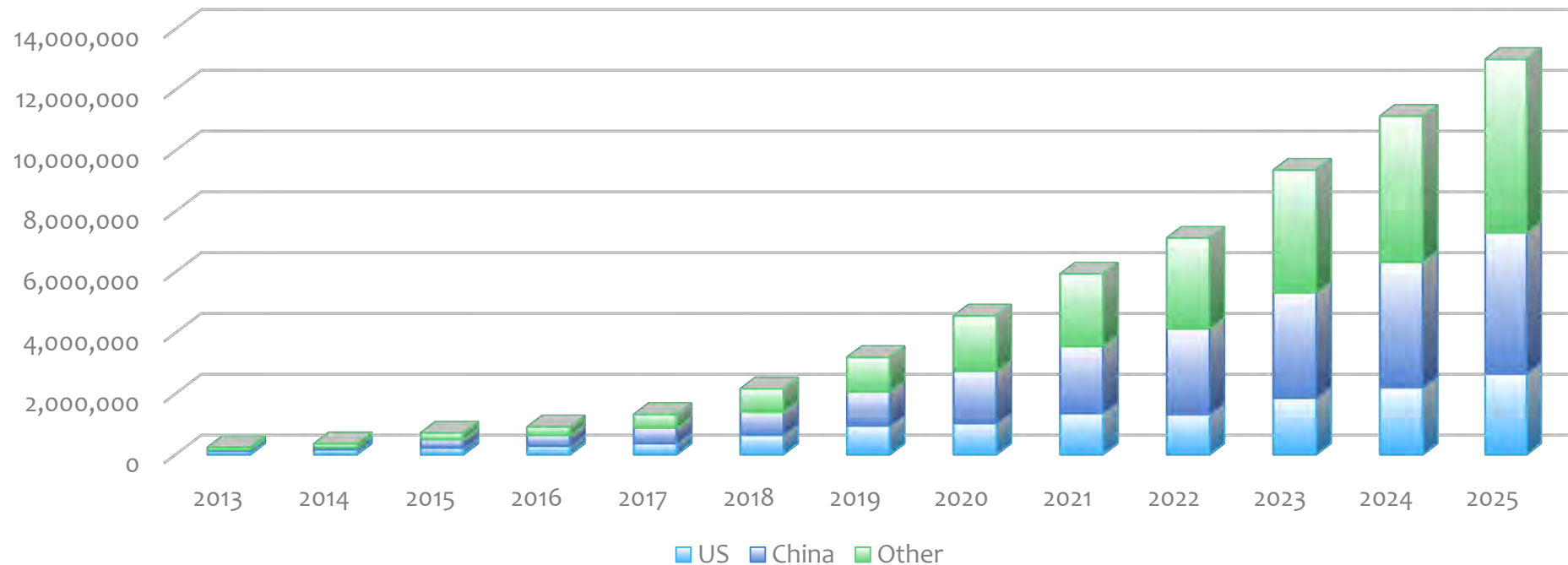
- Upfront Cost
- Upfront Cost
- Upfront Cost



PEV Forecast

Global Unit Sales

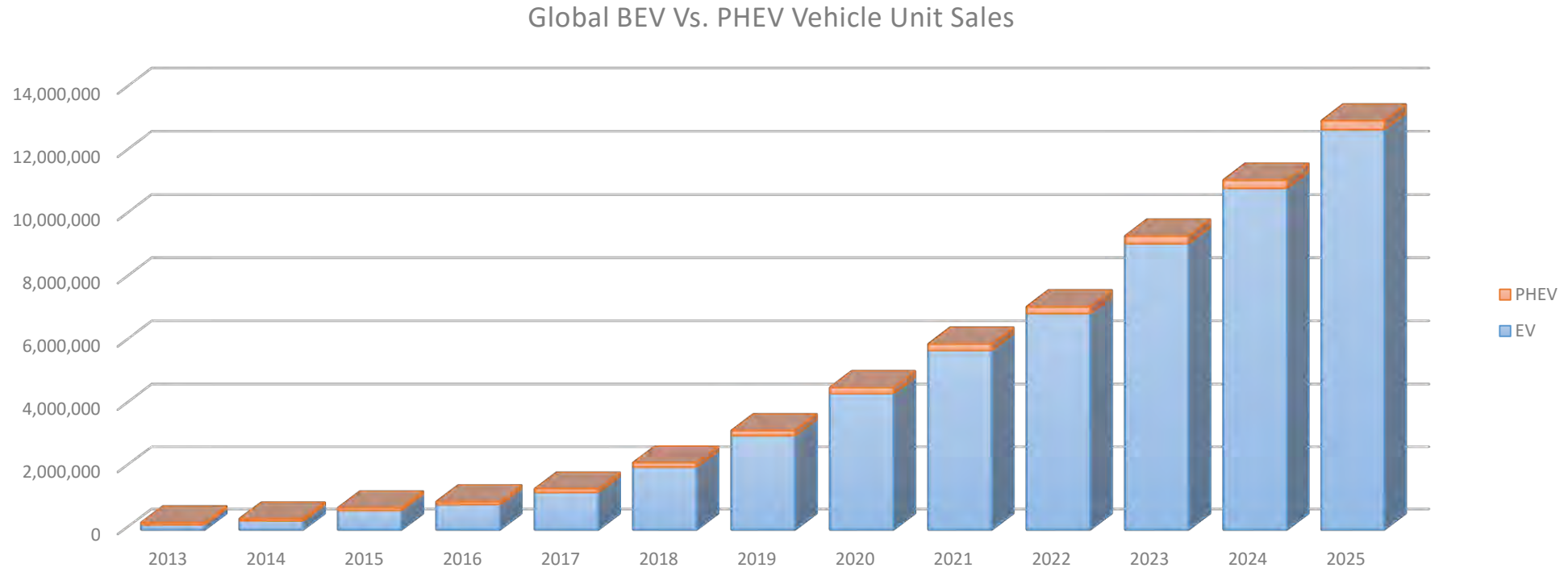
Global PEV Sales in U.S, China and Rest of World, 2013-2025



- EV Sales will rise from 705,000 in 2015 to 13 million by 2025.
- By the end of the next ten years, North America, Western Europe and North Asia EV markets will be similar in size, with rest of world accounting for about 20%

PEV Forecast

Global Unit Sales BEV vs. PHEV

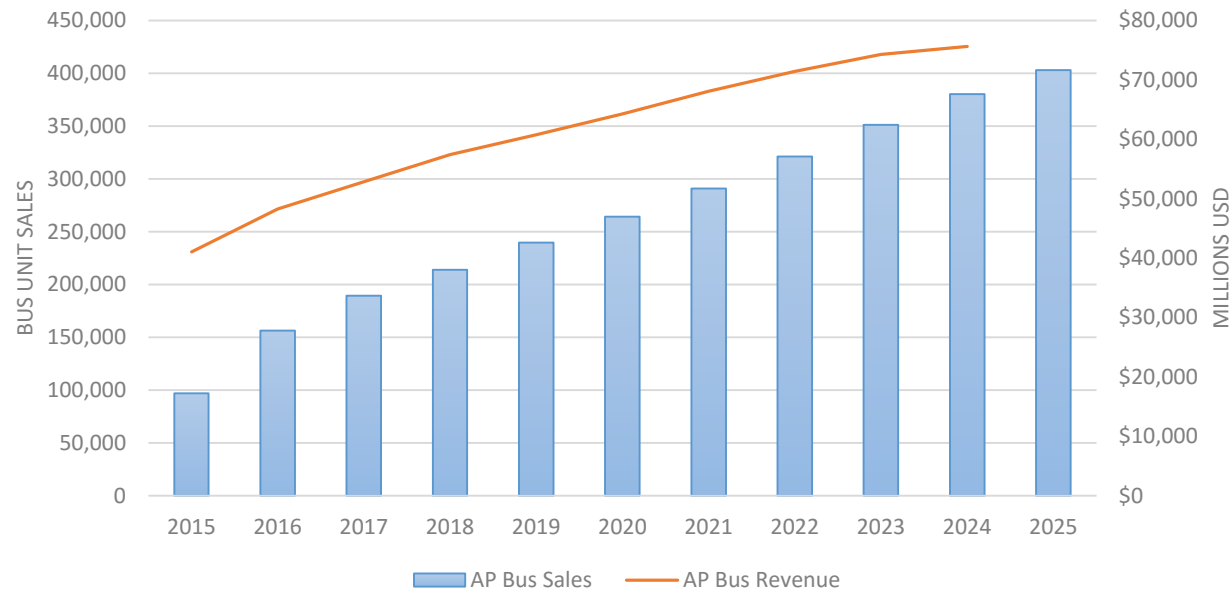


- BEV is and will be the dominant drivetrain for next ten years
- Charging infrastructure hasn't caught up to BEV needs, but it will in next ten years.
- No car manufacturer has produced a reasonably priced PHEV in any model class.

Ebus China

Trends and Developments

Asia Pacific E-Bus Sales and Revenue Forecast, 2015-2025



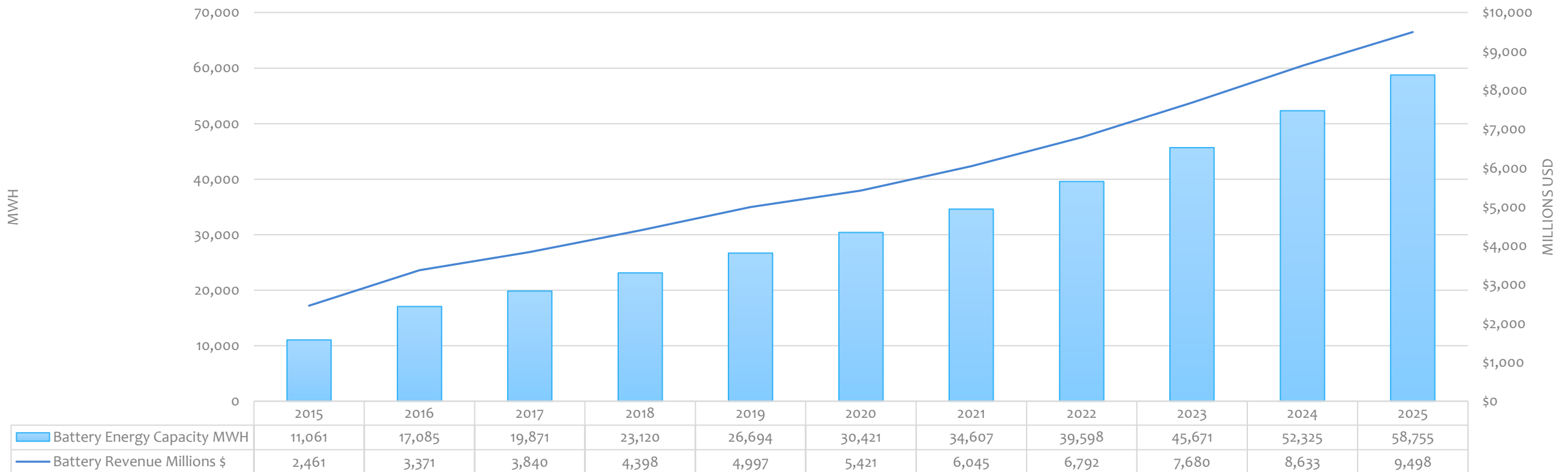
Wanxiang E-Bus drivetrain and chassis with LFP batteries.
Source: *China-EV.org*

- Ebus market in China has had global repercussions throughout the global battery industry.
- Chinese Ebus sales mushroomed in 2015 and growth will continue for at least next four years.
- Rest of world will never catch up to the Chinese Ebus market because of lack of political will to match subsidy regime

EBus Battery Forecast

Global Energy Capacity and Battery Revenue

Global E-Bus Battery Energy Capacity and Revenue Forecast, 2015-2025

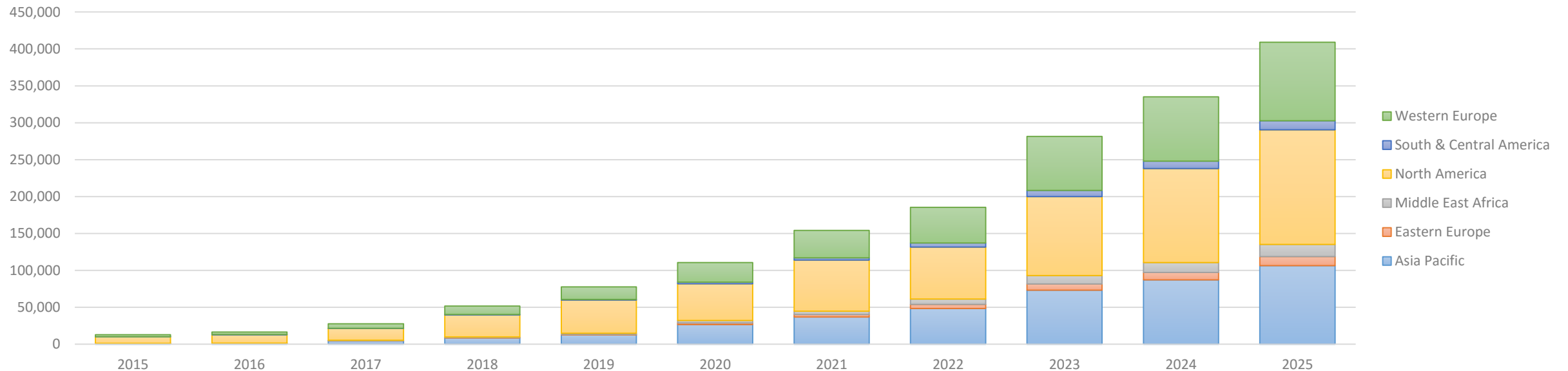


- Battery capacity for the Ebus market in China was less than 1 GWh in 2014. It grew to nearly 10 GWh in 2015. It will continue to grow by 60% in 2016 and by 20% in 2017 before growth will lessen.
- The sudden unexpected demand for new Ebus batteries in 2015 was the reason for price spike in Lithium

PEV Battery Forecast

Global PEV Energy Capacity

Global PEV Energy Capacity by Region, 2015-2025



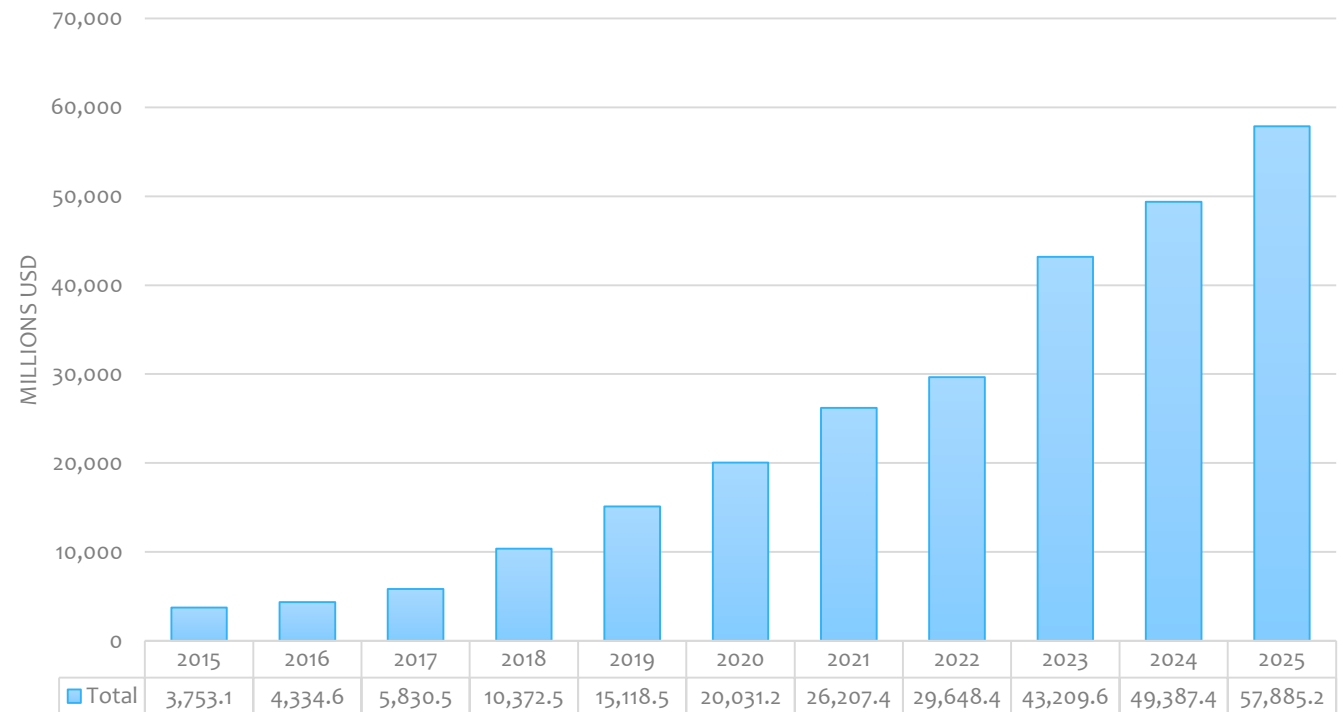
- The global automotive industry consumed ~12.8 GWH of batteries in 2015. By 2025, it will consume over 400 GWH's.
- North America is by far the highest consumer today (thanks to Tesla). By 2025, it still will be, but Asia and Europe will be close.

PEV Battery Forecast

Global PEV Revenue

- The battery industry will grow sales into the PEV market from \$3.7 billion in 2015 to \$57.9 billion by 2025.
- This represents a 12-fold increase. Energy Capacity increase over that time period will be more than 36x. So cost per unit will decrease by a factor of 3 over that time.
- Despite the GigaFactory, the vast majority of cells will be produced in Asia by 2025.

Global PEV Battery Revenue in Millions USD, 2015-2025



Competitive Landscape: New Car Startups

	NextEV	Atieva	Dyson	Rimbac	Faraday Future	TechRules	Karma	Elio	Google	Apple
Supercar	?	?	?	✓	✓	✓	✓	No	No	?
Luxury		✓	?	✓	✓	?	✓	No	?	?
Medium Class	?	?	?	?	✓	?	?	No	?	✓
Economy	?	?	?	?	?	?	?	No	?	?
Specialized	?	?	?	?	?	?	?	✓	✓	?
Expected Date of First Production Car	2020	2019	2022	2017	2020	2020	2019	2016	2020	2020

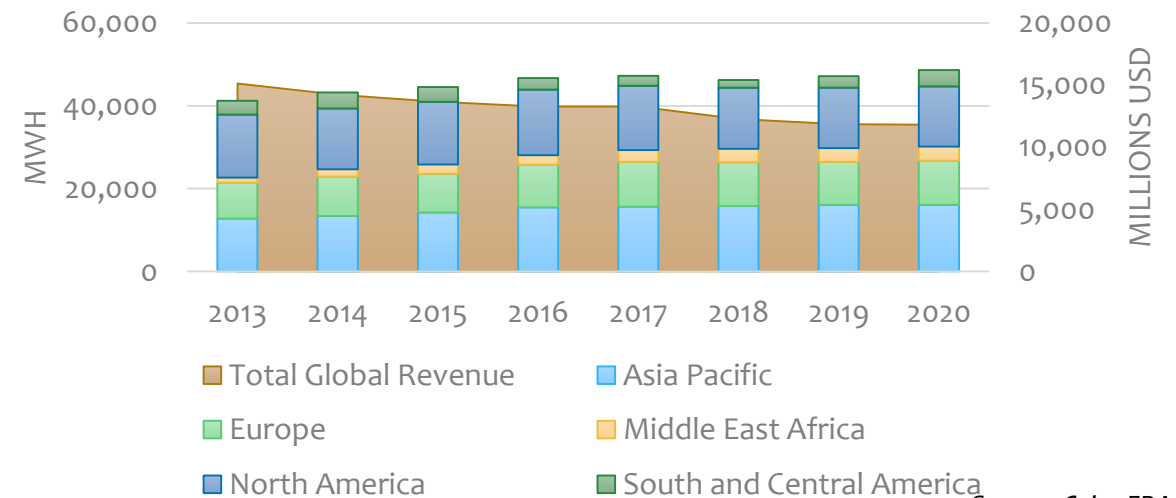
- At least 10 new car startups are actively developing EV models for the global market (this does not count the dozens of relatively new car companies in China developing only for the Chinese market). Cairn ERA expects that only a handful of these companies will actually produce a production vehicle.
- While all of these companies represent potential competition for Tesla, that competition won't be felt until 2020 at the earliest.

Forecasts: Consumer Electronics Forecast



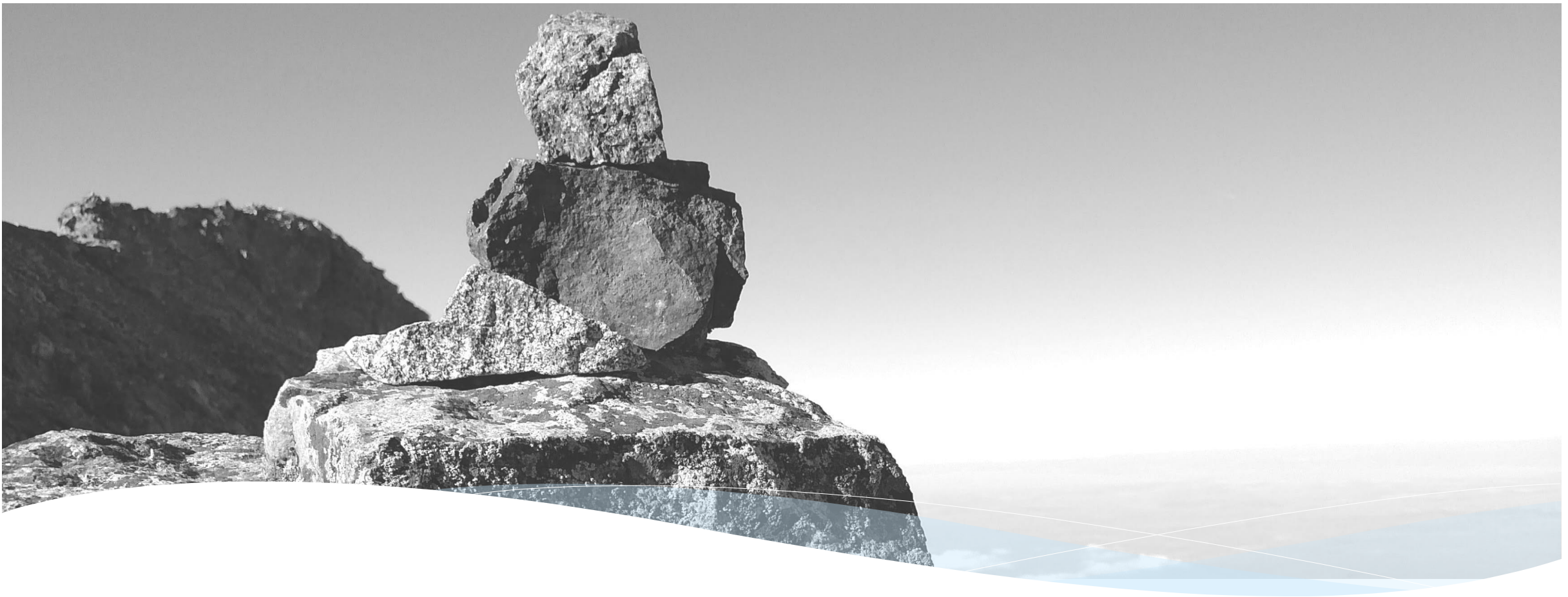
Source: Wired

Consumer Electronics Battery Energy Capacity by Region and Global Revenue Forecast: 2013-2020



Source: Cairn ERA

- The appetite for consumer electronics batteries will grow at a tepid pace between 2013 and 2020, from 41.1 GWH in 2013 to 48.6 GWH in 2020. Some regions, primarily North America, will actually see declining growth in energy capacity.
- Revenue will decline at a 2.9% CAGR between 2015 and 2020 thanks to declining prices, especially for higher end polymer electrolyte chemistries used in tablets and smartphones



ESS Market Trends

Forecasts and Trends



Explanation of Applications

Reserve Power

- Providing emergency reserve power when grid goes down.
- Duration of Cycle: **5-30 minutes**

Ancillary Services

- Merchant energy provision of ancillary electricity services (spinning reserve, frequency regulation, etc.)
- Duration of Cycle: **15-45 minutes**

Grid Management

- Electric utilities distribution grid services to ensure reliability and resilience (harmonics, voltage management, etc.)
- Duration of Cycle: **15-60 minutes**

Peak Shifting

- Moving generation from low-demand hours to periods of peak demand.
- Duration of Cycle: **30 minutes to 2 hours**

Load Shifting

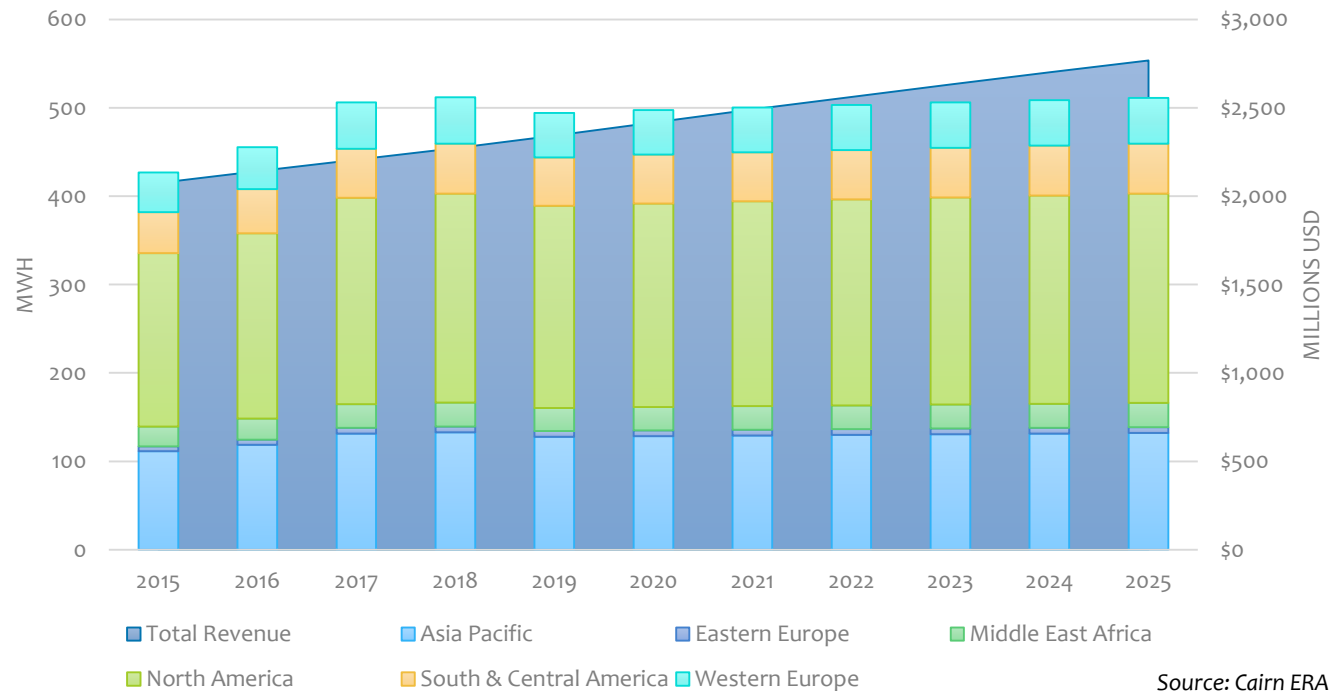
- Moving large blocks of generation from night to day
- Duration of Cycle: **2 to 12 hours**

Stationary Storage: Reserve Power Forecast



Source: Electrical Engineering

Global Reserve Power Batteries Forecast in Energy Capacity and Revenue, 2015-2025



Source: Cairn ERA

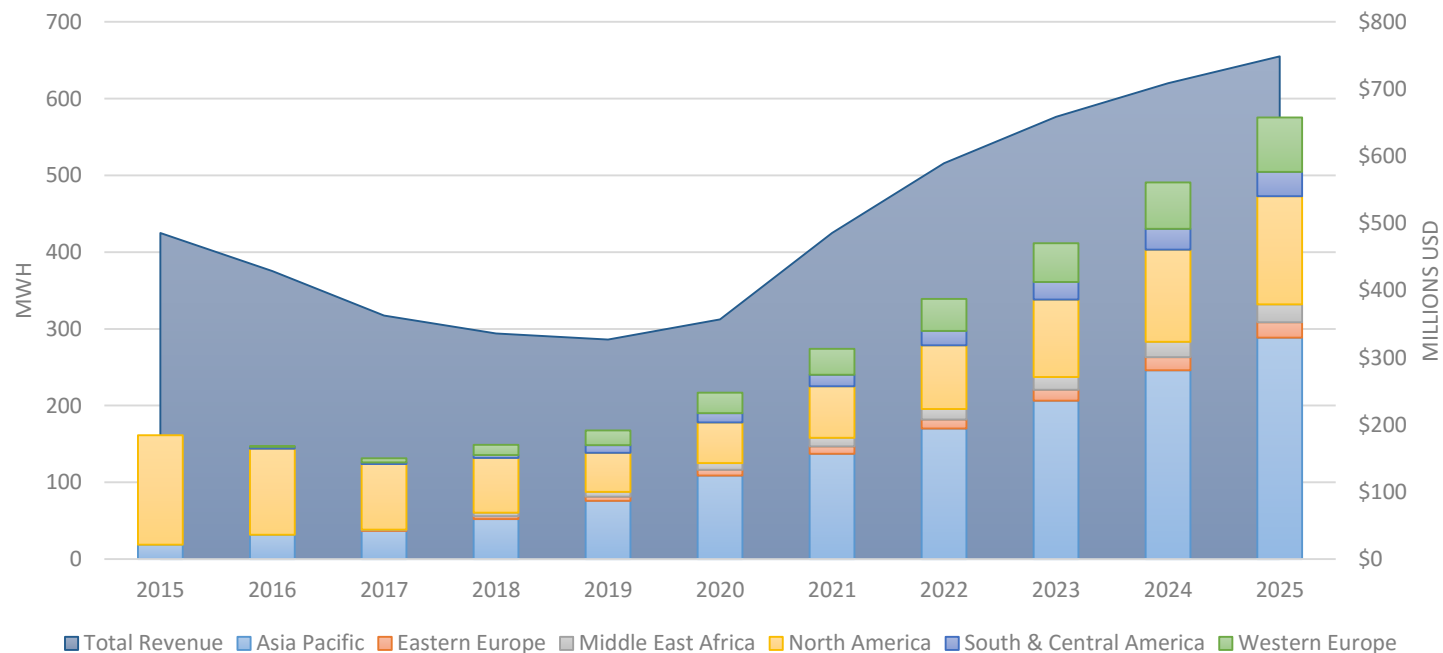
- Reserve power is a stable, mature market, growing revenue at 1.8% for the next ten years and growing in energy capacity by 2.9% annually.
- The reserve power segment is moving from lead acid towards Li-ion, but not wholesale. By 2020, half of new UPS systems will have Li-ion batteries.

Stationary Storage: Ancillary Services Forecast



Source: ECoult

Global Ancillary Services Batteries Forecast in Energy Capacity and Revenue, 2015-2025



Source: Cairn ERA

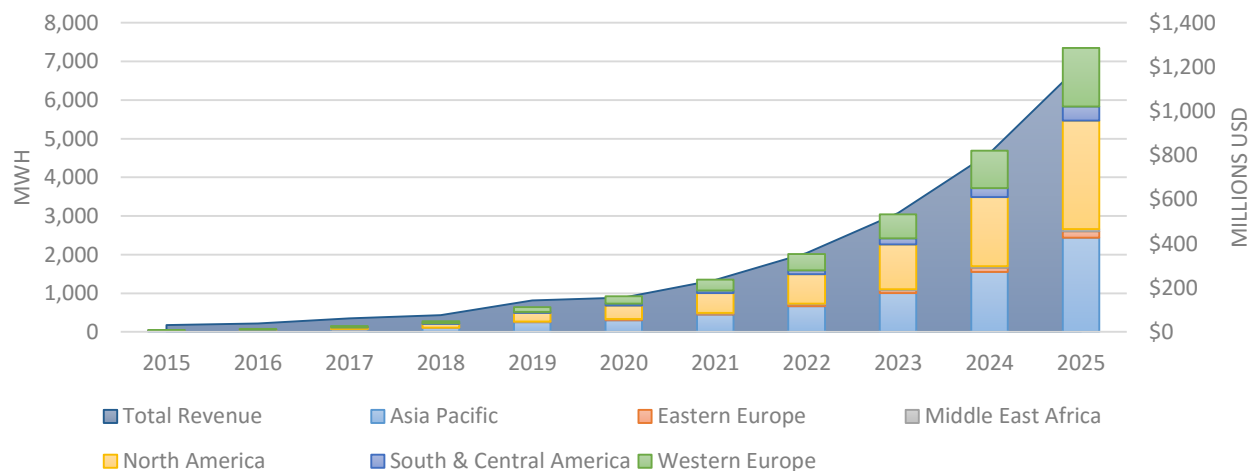
- The use of batteries for ancillary services on the grid will see low growth between 2015 and 2025 globally, but significant contractions in growth in some regions (North America) and expansions in others (Asia Pacific). Globally this will even out to an annual CAGR of 13.6% in terms of energy capacity of systems sold, and 4.4% in terms of revenue for batteries sold. Globally, system shipments will grow from 161 MegaWatt-Hours in 2015 to 575 MegaWatt-Hours in 2020 and revenue for battery cells sold will reach \$748 million in 2025.

Stationary Storage: Load Shifting Forecast



Okinawa Seawater Pumped Hydro Plant
Source: Worldwatch

Global Load Shifting Batteries Forecast in Energy Capacity and Revenue, 2015-2025



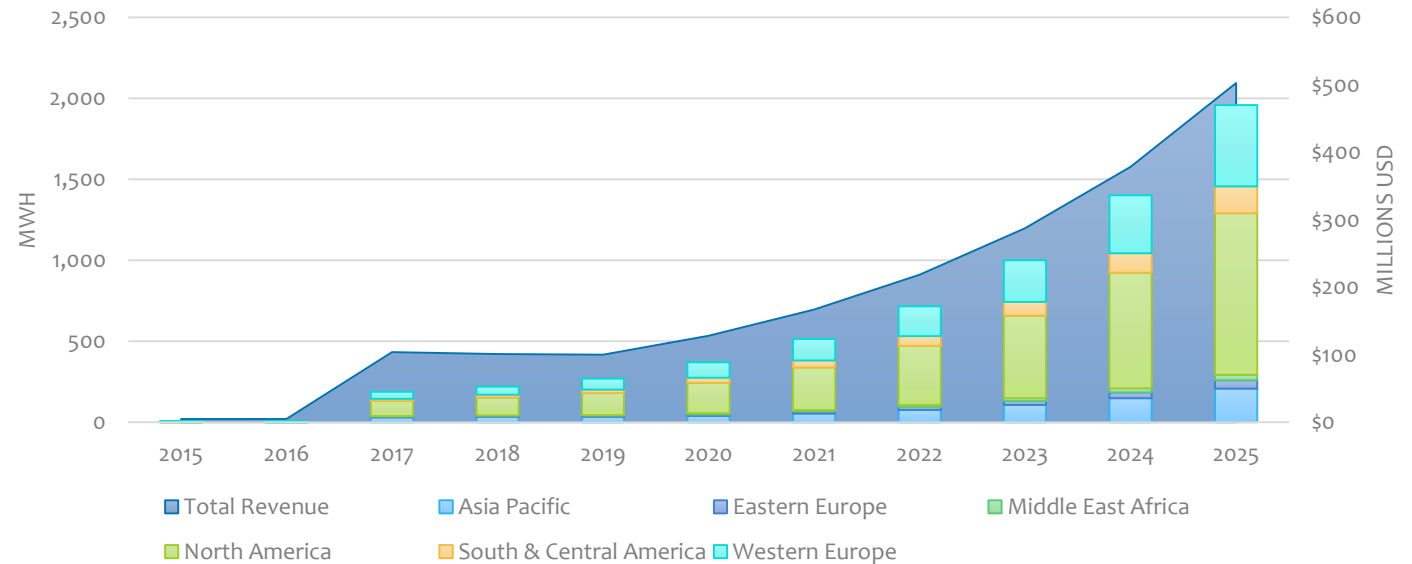
Source: Cairn ERA

- Traditional load shifting has been done with pumped hydro/nuclear systems; To meet those costs with batteries, prices have to significantly decline further
- Load shifting with batteries is the most immature market today, with growth expected late in the coming decade.
- Energy capacity will grow from 46 MegaWatt-Hours in 2015 to 7,300 MegaWatt-Hours in 2025. Revenue will grow from \$31 million to \$1.2 billion in 2025.
- Load shifting will be the one application which will see significant competition for Li-Ion, in the form of flow batteries

Stationary Storage: Grid Management Forecast



Global Grid Management Batteries Forecast in Energy Capacity and Revenue, 2015-2025



Source: Cairn ERA

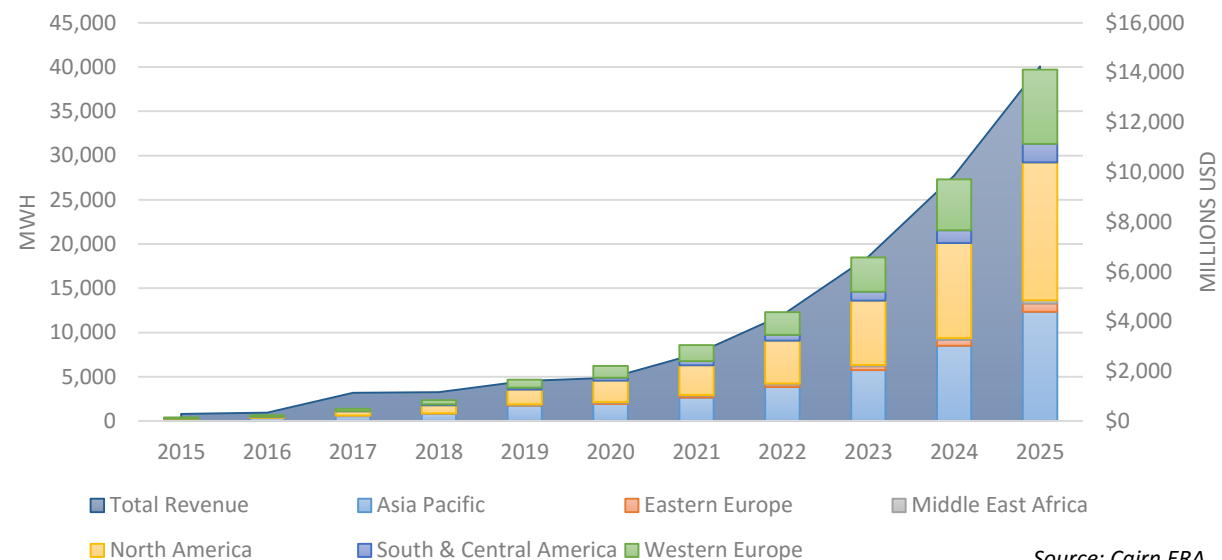
- The use of batteries for grid management today is largely the realm of pilot projects. However Cairn ERA expects electric utilities to start purchasing large amounts of batteries in the 2017 time frame for grid management (voltage control, harmonics management, etc.) By 2025, this market will account for 1,900 MegaWatt-Hours worth of new batteries sold, or \$503 million.

Stationary Storage: Peak Shifting Forecast



Source: Enernoc

Global Peak Shifting Batteries Forecast in Energy Capacity and Revenue, 2015-2025



- Batteries sold to provide peak shifting services will grow from 403 MegaWatt-Hours in 2013 to 39,700 MegaWatt-Hours in 2025, representing a CAGR of 58.2% between 2015 and 2020. Peak shifting will become the main application of batteries on the grid. Revenue for battery sales will increase from \$289 million in 2015 to \$3.9 billion in 2025, representing a ten year CAGR between 2015 and 2025 of 47.7%.

The Toehold Application: Demand Charge Mitigation

- Commercial ratepayers in North America usually pay demand charges that are calculated on their peak demand periods. Combining a solar photovoltaic system with a battery pack can mitigate the amount of demand charges that an individual commercial ratepayer will be charged.
- The market for demand charge mitigation energy storage systems installations is expected by Cairn ERA to grow from \$31.8 million in 2013 to \$7.9 billion in 2025. The vast majority of those systems will be installed in North America. The majority of systems are, and will continue to be, installed at small commercial sites, ranging from 50 to 500 Kilowatts of installed PV.

Example Demand Charge Mitigation System: CA School ROI Analysis

	Comparable Rooftop System
Photovoltaic System Size	500 Kilowatts
Energy Storage System Size	178 KW, 178 Kilowatt-Hours
Total Cost of System	\$1,334,870
Total Cost of System After local California subsidy	\$569,870
Residual Value of System at End of Loan	\$240,777
Profits Earned	\$1,691,365
Annual ROI	19.8%

Source: Cairn ERA

The Killer App: Hybrid NG/Battery Peak Shifting

Comparison of 1.2 Combined Cycle Natural Gas Plant With Same Built with 1,600 Megawatt-hours of Batteries

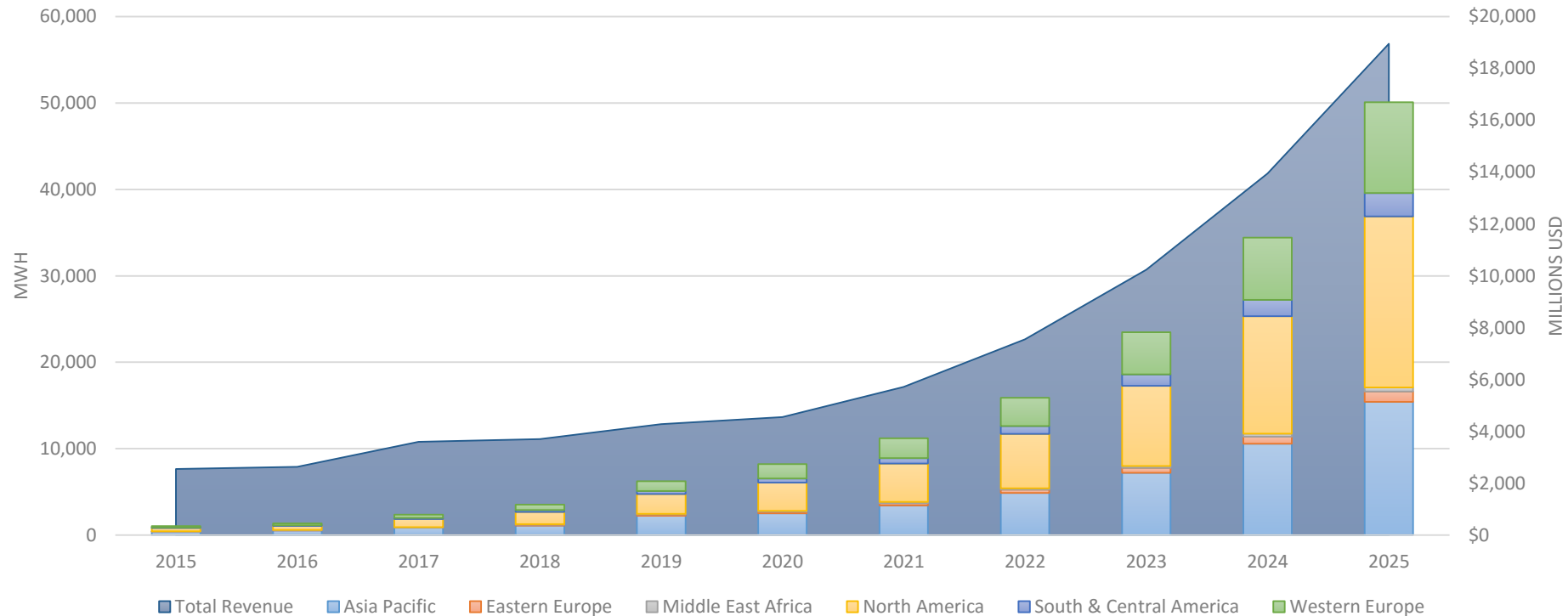
	Units	NG Combined Cycle	NG Combined Cycle + Batteries
Power Capacity of Plant	Megawatts	1,200	1,200
Cost of Plant Equipment	Millions USD	\$2,160	2,620
Cost of 20 Years of Fuel	Millions USD	\$5,124	\$3,942
Revenue Produced	Millions USD	11,432	12,220
Annual ROI	Percentage	7.3%	12.7%

Source: Cairn ERA

- All generation technologies suffer from lack of ability to efficiently match load demand
- The most expensive use of batteries is to directly match to solar or wind.
- By using batteries to make natural gas turbines more flexible and efficient, the grid will be able to absorb far more renewables than it is otherwise capable of doing.
- Systemic use of batteries as a balancing tool in direct linkage with natural gas generators will be the largest application of batteries on the grid in the coming ten years.

Stationary Storage: All Applications

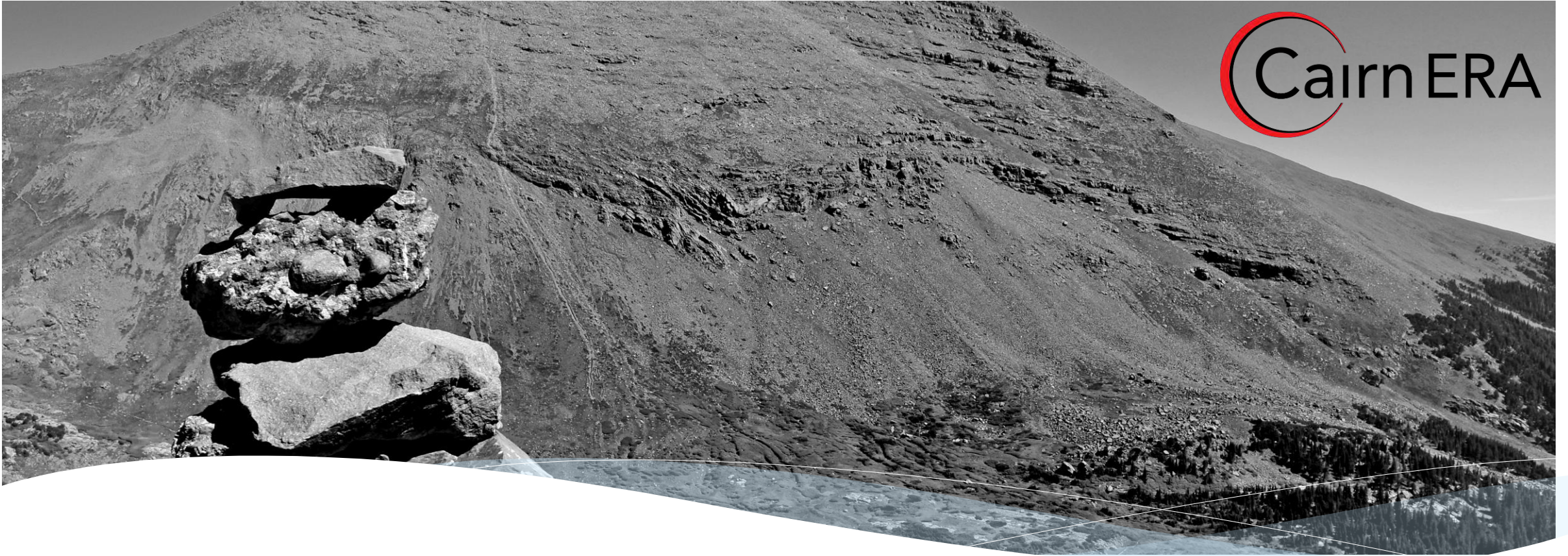
All Stationary Storage Applications Forecast in Energy Capacity and Revenue, 2015-2025



Source: Cairn ERA

- Stationary storage battery sales will grow from 671 MegaWatt-Hours in 2015 to 8,200 MegaWatt-Hours in 2025. The 2015 to 2020 forecasted CAGR is 51.1%. Cell revenue will grow from \$2.3 billion in 2015 to \$4.8 billion in 2025. The Forecasted CAGR for revenue growth between 2015 and 2020 is 12.4%.



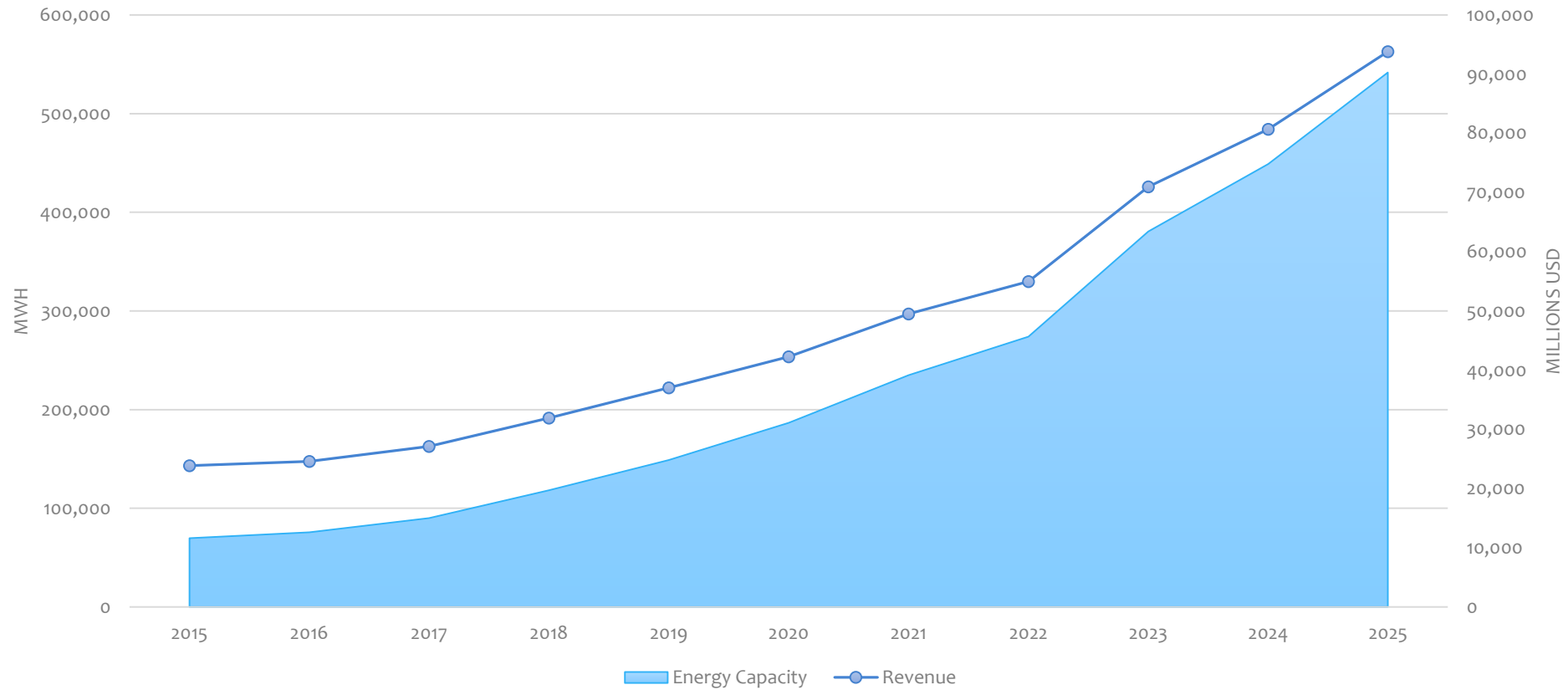


Global Battery Forecast

All Applications

Global Battery Forecast

All Applications



About Cairn ERA

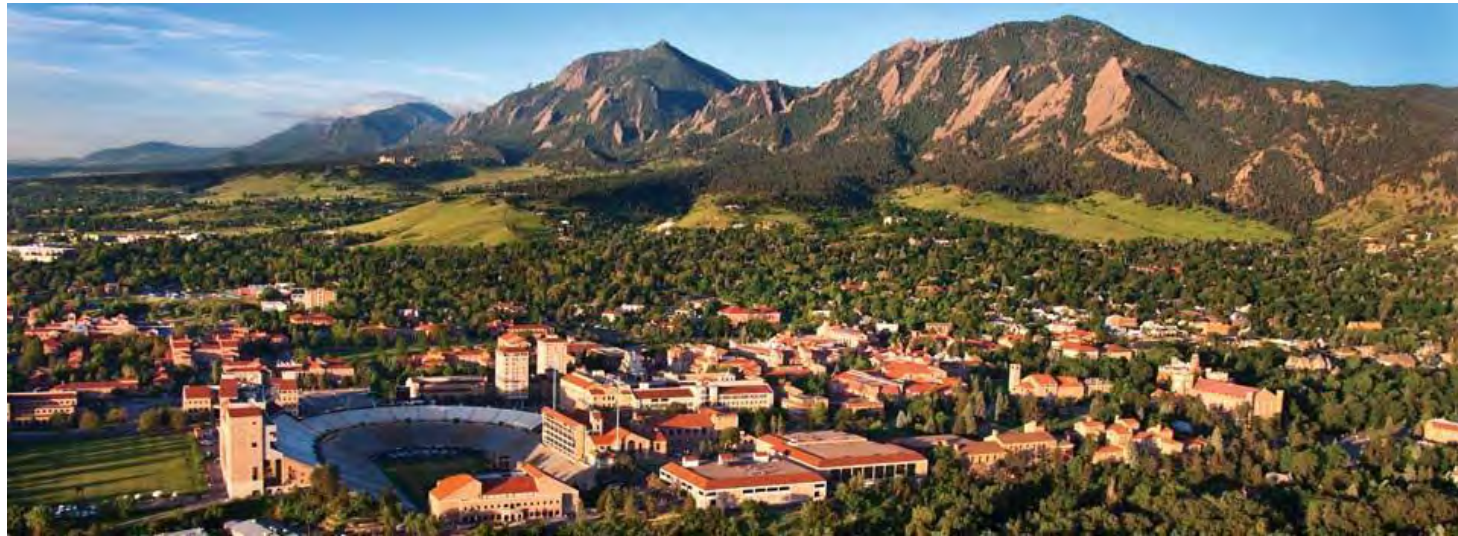
Sam Jaffe

Cairn Energy Research Advisors is a strategic market research and consulting firm with a specialization in energy storage and other emerging energy technologies. Cairn ERA approaches all projects from a first principles philosophy: all models are bottom-up and no data is entered that is not extremely robust. Cairn ERA's strength is in its people and its processes. All Cairn ERA partners have multiple years of experience working in the energy sector and have a strong and diverse network of contacts throughout the industry. And the Cairn ERA approach to research and modelling has been honed over decades of experience in providing first-rate deliverables to some of the world's most successful and demanding companies.

Sam Jaffe is the co-founder and Managing Director of Cairn ERA. He has more than 10 years of experience as an analyst, consultant, executive and entrepreneur in the energy storage space.



Battery Markets



Cairn Energy Research Advisors is a research and consulting firm with a focus on energy storage. We provide strategic insight and data that allows our clients to thrive in the dynamic global energy marketplace.

We are based in Boulder, CO and work with clients in Asia, Europe, the Middle East and North America.

+1 720 598 3048

info@cairnera.com