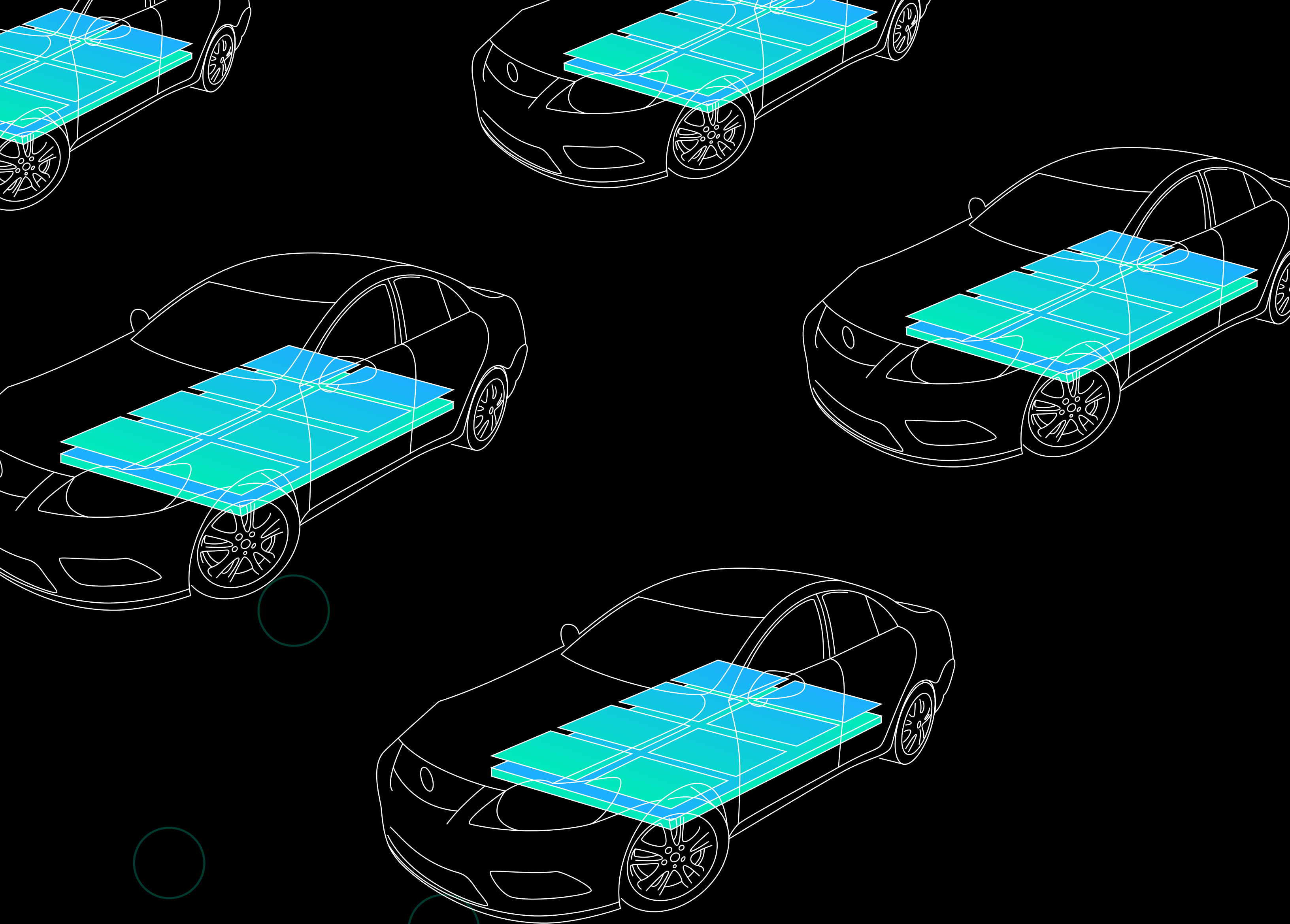

EBOOK

WELCOME TO THE EV AGE

VOLTAIQ

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Introduction

In 2006, the American filmmaker and environmental activist Chris Paine was nominated for an Academy Award for the documentary *Who Killed the Electric Car?* The film explored the culpability of a series of "suspects," ranging from oil syndicates to car companies, consumers, and the US government. While Paine may have erroneously tolled the bell for EVs, he proved prescient in one regard. He granted batteries a full acquittal, arguing that a new class of lithium-ion systems would emerge to extend EV range to more than 300 miles on a single charge.

Fast-forward 15 years, and the prediction has more than played out. Market leader Tesla has surpassed the 400-mile range, and CEO Elon Musk recently predicted that batteries will soon be six times more powerful, with a 16 percent increase in range, and cost less. "It's absolutely critical that we make cars that people can actually afford," Musk said at a Tesla event. "Affordability is key to how we scale."

It wasn't long ago that Musk was nearly alone on the road toward an all-EV future. Today it's a frantic race and everyone's in. There are many well-capitalized startups, including Rivian – which received a $700 million investment from Amazon, along with a commitment to buy 100,000 electric delivery vans – and many Chinese ventures, like Nio, which recently completed a $1.8 billion IPO. Volvo has its all-electric brand, Polestar, and Hyundai, Jaguar Land Rover, Nissan, and Porsche have several all-electric models in production.

Volkswagen has pledged to invest nearly $86 billion into its digital and electric vehicle technologies program over five years, which will include roughly 70 electric vehicles by 2025 and an electric version of 300 models across the brand portfolio by 2030. Ford has committed $22 billion to bring 40 electrified (including 16 fully electric) vehicles to market by 2023, including the Mach-E, which began shipping in late 2020. It's the first extension of the Mustang brand, meaning Ford is betting one of its strongest brands on its electrification strategy.

The F-150 Lightning isn't far behind. The electrified version of the best-selling pickup has Wall Street, Ford insiders, and the market-place buzzing. Reservations for the 2022 model surpassed 100,000 within months of the unveiling.

"The electric vehicle market overall is accelerating at an exponential rate," wrote Darren Palmer, Vice President Global Electric Vehicle Programs at Ford, in a blog post. "All of us here have unknowingly prepared for this our entire careers."

General Motors CEO Mary Barra has pledged $27 billion, with plans to launch 30 EVs by 2025. That's in addition to the $2.3 billion GM co-invested with lithium-ion supplier LG Chem to build a new battery cell assembly plant. The company claims its Ultium battery architecture will achieve a range of 450 miles. In early 2021, Barra announced plans to halt the sale of all gasoline- and diesel-powered passenger cars and SUVs by 2035.

"As one of the world's largest automakers, we hope to set an example of responsible leadership in a world that is faced with climate change," she said in a statement. (Ford followed with its own declaration to sell only EVs in Europe beginning in 2030. Volvo countered with: No more ICEs anywhere by 2030.) "The EV market overall is accelerating at an exponential rate. All of us here have unknowingly prepared for this our entire careers."

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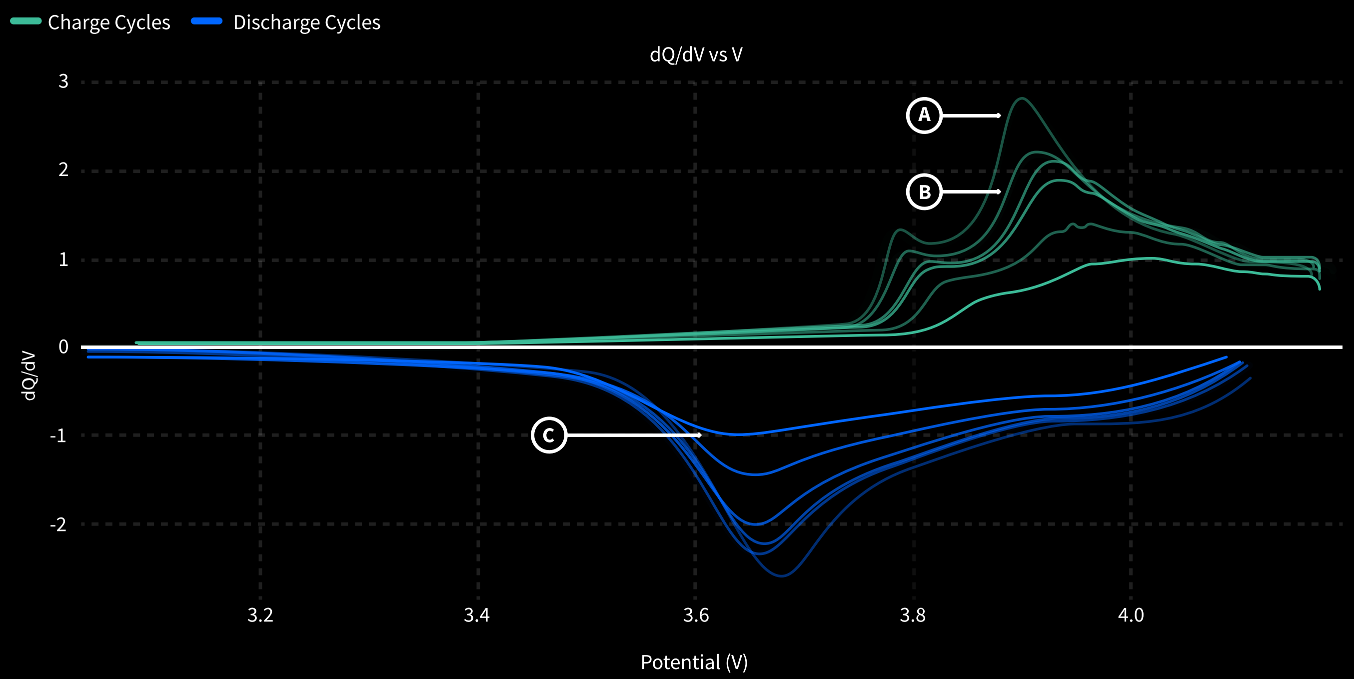
Lifting the Veil on Battery Performance

Three charts showing how Voltaiq instantly analyzes chemical composition, age, health, and behavior across a battery's life cycle.

1. Battery Fingerprinting

Voltaiq can reveal battery chemistry and age by analyzing standard charge-discharge data without cutting the battery open. In this graph, charge and discharge cycles feature peaks whose height and location correspond to a battery's constituent materials. As the battery ages, peaks flatten and diverge. Voltaiq automatically generates such graphs for every battery in its system, providing highly useful insights during R&D and supplier qualification, and for predictive maintenance.



The Life (And Loss) Of Energy

Ⓐ The outermost peaks represent the stored energy of a new battery.

Ⓑ Each subsequent trajectory represents the same battery after completing an additional 100 charge-discharge cycles.

Ⓒ The cycles flatten and shift due to increased electrical resistance, which causes the battery to generate more heat and accelerates degradation.

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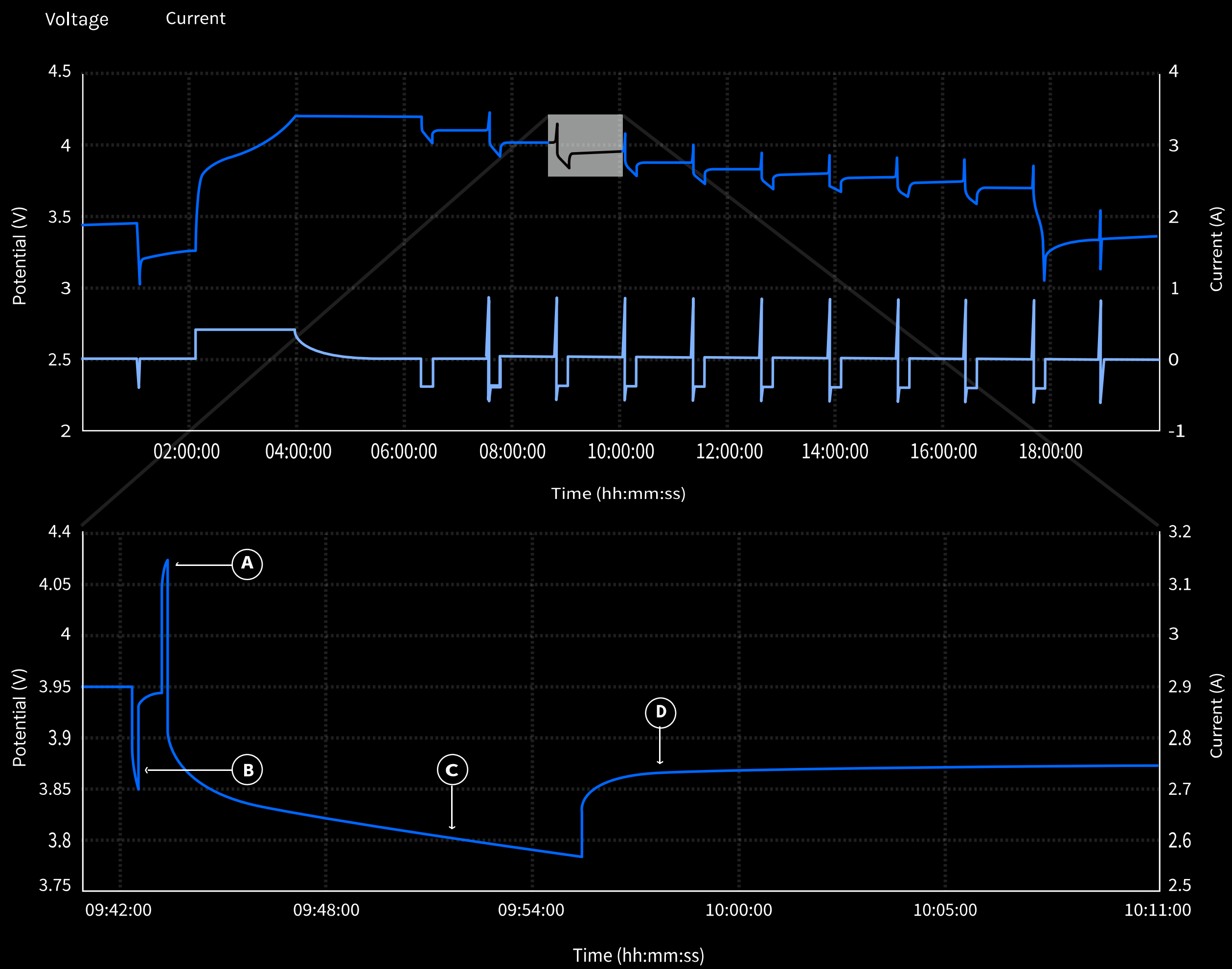
Lifting the Veil on Battery Performance (continued)

2. Hybrid Pulse Power Characterization

Battery performance is mapped using the HPPC protocol. This technique discharges the battery in increments and applies pulses to determine how much power can be practically pulled out or put in at each charge level. Repeating this analysis at various temperatures and charge rates reveals the battery's behavior over its entire operating range. Voltaiq processes this data in seconds, generating valuable analysis in EV battery pack and battery management system (BMS) development.



Analyzing Performance at Various States of Charge

A — Charge pulse is analyzed to see how quickly energy can be put back into the battery at this State of Charge (SOC). This is helpful in determining, for example, how well an EV can recharge through regenerative braking.

B — Discharge pulse is analyzed to see how quickly energy can be pulled out of the battery at this SOC. This is useful in determining how fast an EV can be accelerated at a given SOC without overheating and damaging the battery.

C — Here the battery is discharged another 10 percent to begin the next round of pulses at the next phase of SOC.

D — Here the battery is at rest, allowing the voltage to relax back to an equilibrium for the next SOC.

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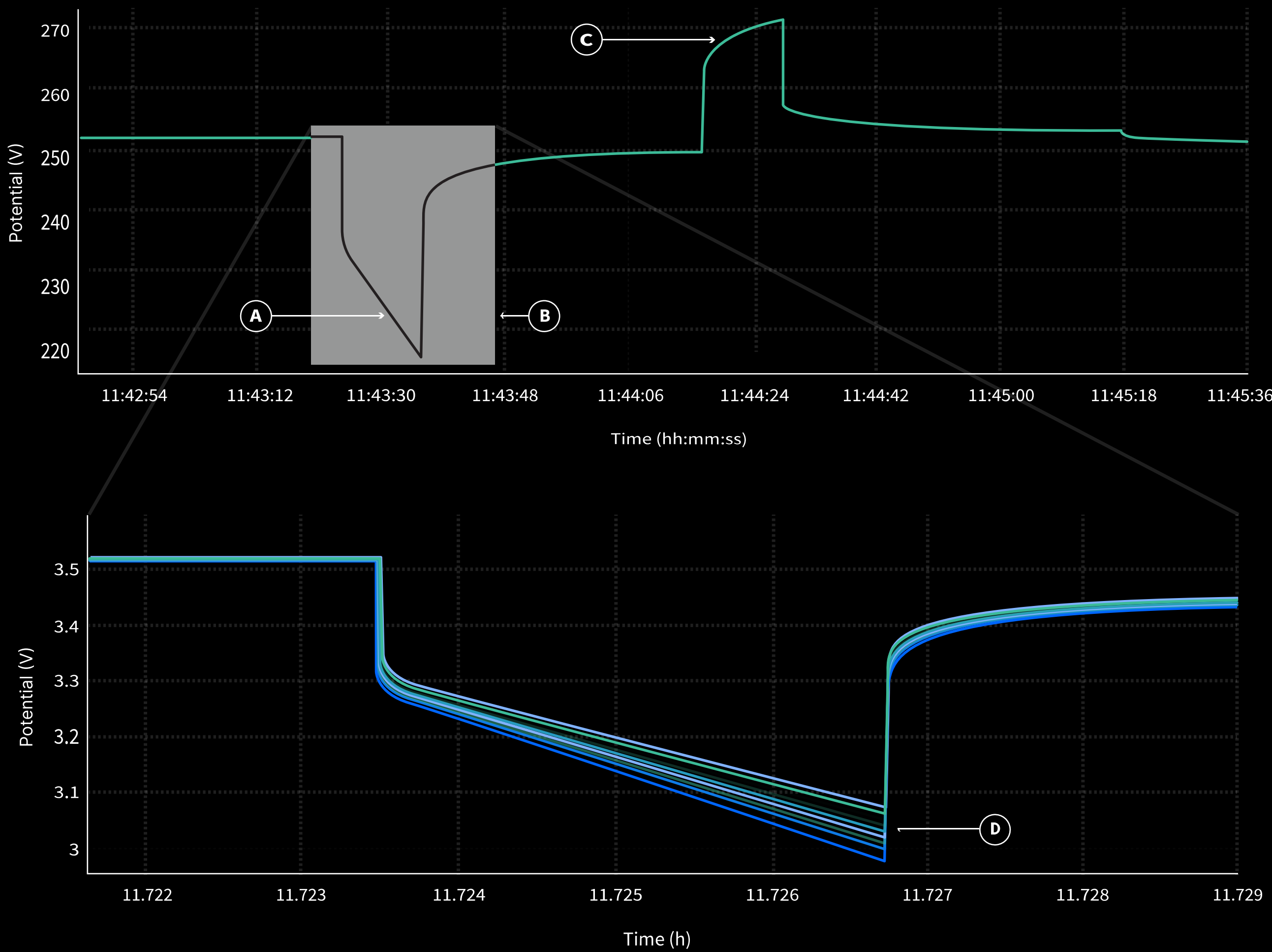
Lifting the Veil on Battery Performance (continued)

3. EV Pack and Grid Storage System Diagnostic

Large-scale EV pack and grid storage systems are tested with charge and discharge pulses during design validation, on the manufacturing line, and in the field. System-level behavior may appear normal while concealing divergent voltages and temperatures at the cell or module level. Voltaiq can automatically identify these anamolies, uncovering faulty design, poor assembly, or imminent catastrophic failure.



Finding a Weak Link in the Battery System

A Diagnostic discharge pulse.

B System-level analysis indicates that everything seems fine.

C Diagnostic charge pulse.

D Individual cell voltages show significant divergence at the bottom of the discharge pulse, indicating major potential problems.

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In late 2020, the German luxury automaker Daimler, corporate parent of Mercedes-Benz, announced an $85 billion investment aimed at advancing electrification. Daimler CEO Ola Källenius said in a statement that the company tripled sales of all-electric and plug-in hybrid vehicles in 2020 over the year prior. In 2019, such vehicles represented roughly 2 percent of sales for the company. In 2020, it was 7.4 percent. For 2021, Mercedes is targeting 13 percent.

One Voltaiq customer, the head of research and development for a European luxury automaker, says the market signals are aligned toward an all-EV future & his employer, which asked not to be named for competitive reasons, is all-in. “We’re not in the early-adopter space, but our customers know when we get into a market, we get it right. We’re transforming the business not only in terms of the end product, but also in the way we adapt internally. We have to get the battery right.”

This Voltaiq customer scours the marketplace for novel approaches to batteries, which puts the onus on his team to do much of the vetting and testing. “A lot of what we do is cutting the wheat from the chaff. Every week, there are, like, 10 new game-changing ideas, so it becomes very important to screen and benchmark these companies on all kinds of metrics very quickly,” the customer says. Which is where Voltaiq comes in. “They’re not just a data company trying to pivot to this space. The platform was built with an understanding of batteries right from the start.”

One of the EV researcher’s major goals revolves around sustainability. The team is placing a premium on removing cobalt and other difficult-to-source materials from its battery architectures to both reduce costs and address ethical concerns associated with mining. And while today’s lithium-ion batteries are highly recyclable, the goal is to make them fully compostable.

In the shorter term, the EV researcher wants to put an end to the dynamic where consumers must alter their behavior for the sake of EV batteries. No owner of a luxury automobile should have to limit a road trip or sit for an hour at a charging station. The vision is for them to only think about the fact that they’re driving an EV when they’re marveling at its acceleration.

“You shouldn’t have to alter what you want to do for the sake of your transportation,” the researcher says.

> **Voltaiq isn’t just a data company trying to pivot to this space. The platform was built with an understanding of batteries right from the start.**

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The High Cost of Failure

In an October 2019 ceremony held by the Royal Swedish Academy of Sciences, the Nobel Prize in Chemistry was awarded to John B. Goodenough, M. Stanley Whittingham, and Akira Yoshino for their roles in creating lithium-ion batteries and for "making possible a fossil fuel-free society." Around the same Amazon co-founded The Climate Pledge, a vow to achieve net-zero carbon emissions by 2040.

Several signatories have joined, including Best Buy, IBM, Mercedes-Benz, and Verizon. Microsoft has pledged to go carbon free and reverse all emissions since the company's founding. And Google has stated it will operate on carbon-free energy 24/7 by 2030 as part of an initiative, according to CEO Sundar Pichai, "to spur more than $5 billion in clean energy investments, take more than 1 million cars off the road each year, and create more than 8,000 clean energy jobs."

> **Every week, there are 10 new game-changing ideas, so it becomes very important to screen and benchmark these companies on all kinds of metrics very quickly.**

Renewable energies are clearly driving the trend. Wind and solar technologies have made great progress in recent years, increasing efficiency while driving down costs. But that's only half of the equation. Turning these corporate pronouncements into reality will require a massive uptake in energy storage – that is, battery systems – and the money is pouring into this arena as well.

According to Wood Mackenzie Power & Renewables, grid-scale storage is projected to increase thirteen-fold between 2018 and 2024. In large markets like China, Germany, the US, and South Korea, deployments are doubling and tripling every year.

The massive battery systems being deployed at large-scale solar projects – in Colorado, Hawaii, Texas, and elsewhere – have the potential to disrupt the energy industry in much the way that mainframes revolutionized financial services.

As more investments stream into materials and manufacturing, form factors and costs will shrink, lifecycles will extend, energy density will improve, batteries will power everything from IoT devices to entire city blocks. "Electricity is why we have cities," Voltaiq CEO Tal Sholklapper says. "It gave us elevators and skyscrapers and high-density housing."

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How a Battery Fails

What makes a silent object with no moving parts so apt to swell, degrade and combust?

Swelling

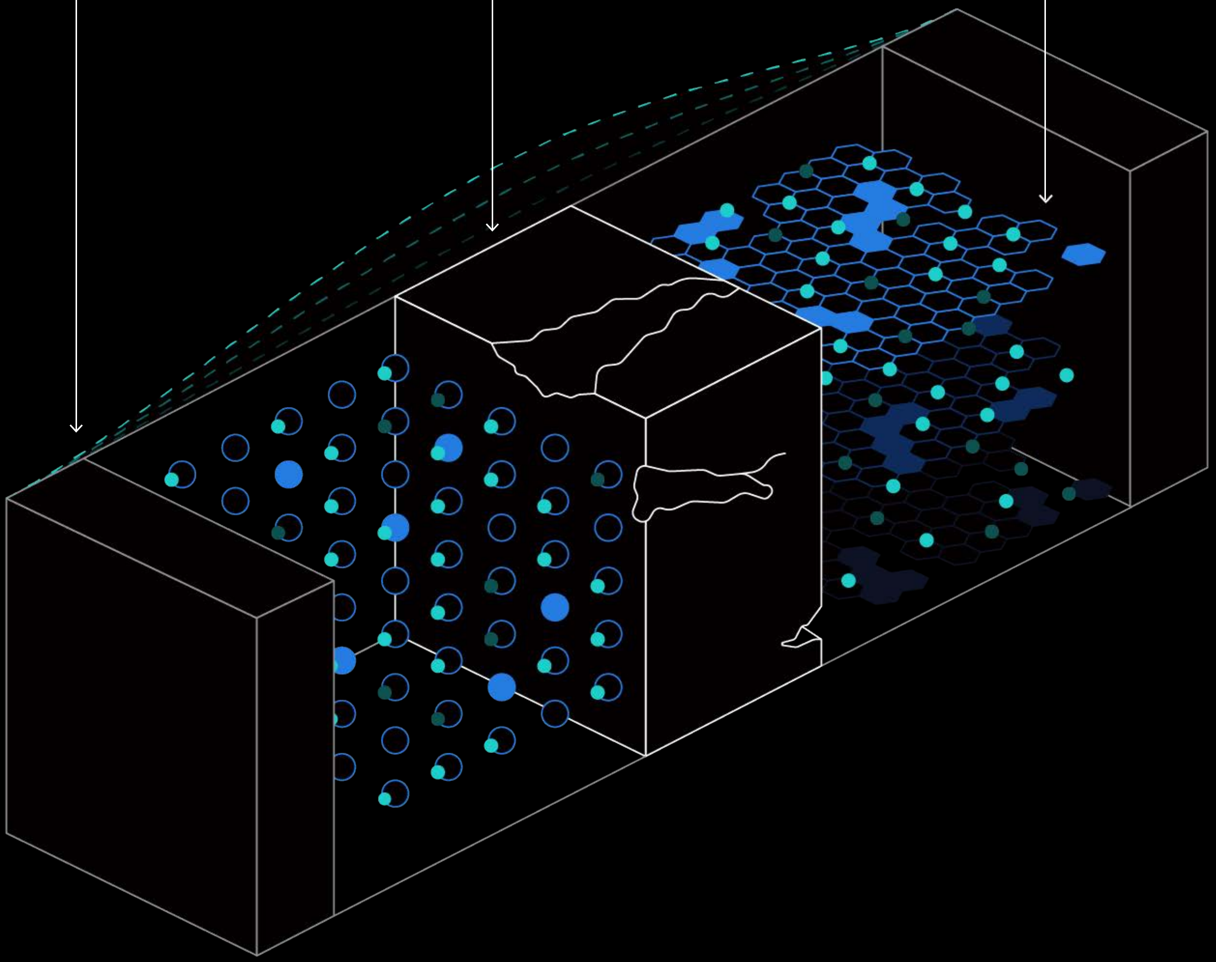
Poor cell quality and/or design, overcharging, faulty charging equipment, and internal mechanical damage can all cause lithium-ion cells to swell. Deep discharging can also trigger decomposition and, as a result, gas formation that leads to bloat. A device should not be operated with a swollen battery. It must be discharged and replaced.

Explosions

The cathode and anode aren't meant to come into contact, so if the separator degrades, the cell can go boom. "Thermal events" can also occur due to overheating (don't leave your phone in the car on a hot day), overcharging, poor design, or shoddy construction. Cheap headphones and hoverboards are highly susceptible – but $100,000 EVs are certainly not immune.

Degradation

As lithium ions travel between cathode and anode, they cause physical damage to the electrode structures, breaking them apart over time. The faster you charge and discharge, the quicker the battery loses capacity. EVs face another dilemma: They're exposed to extreme weather, fast charging, and highly variable user behavior – all of which can make battery health and lifespan difficult to predict.



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How Battery Development Fails

It takes a ton of money, time, organization, and talent to master testing and development. There are no shortcuts.

Talent Shortage

There's a frenetic competition to hire battery engineers. Worse, highly compensated talent is often wasted. Battery engineers can spend as much as 30 percent of their time gathering data, writing Excel macros, and analyzing spreadsheets. Such work slows innovation and saps morale.

Pack & Cell Testing

Cell quality and performance vary widely, even within the same manufacturing lot – and pack life is limited by the worst cell. Battery packs require novel, complex cooling systems. And the diagnostic process is arduous. Cell testing takes years to simulate real-world use and conditions; there are no shortcuts.

Organization & Culture

Every EV model represents a billion-dollar bet on the battery. Relying on battery manufacturers or external labs is risky. An OEM properly organized around battery mastery is more likely to reduce late-stage failures, ensure product safety and performance, and drive innovations in the marketplace.

What happens when you remove the requirement to be connected to the grid? It's sort of like imagining a few decades ago how mobile phones would affect the world. That's the order of change we're going to see." Of course, there's an obvious barrier to realizing such ambitions, and anyone with a passing interest in batteries knows what it is. Fire. Exploding laptops and phones. Combustible cars and headphones and hover-boards and home energy storage units.

These adverse events have been happening for decades because no one has been able to sufficiently untangle the enormous complexity of battery systems. Not Amazon or Apple, Best Buy, Dell, Samsung, Microsoft, Nvidia, Panasonic, LG, or dozens of Fortune 500 companies. They've all implemented costly product recalls due to battery quality issues. Such actions are hugely expensive. Sony recalled 9.6 million laptop batteries at a cost of $429 million.

GM called back over 140,000 EVs due to a battery cell manufacturing flaw, costing an estimated $1.8 billion. Ford recalled its Kuga plug-in for $400 million. And Hyundai is spending an estimated $900 million to recall the Kona EV – roughly $11,000 per vehicle.

Even worse, such recalls can do long-term brand damage. Think about when Samsung's Galaxy Note phones were banned from airplanes. "The company is still living with that," says Sholklapper. "In the EV space, recalls are actually stunting growth. When early-adopter consumers are being told not to park a car in the garage because it might explode that creates a lot of fear, uncertainty, and doubt for anyone considering going electric."

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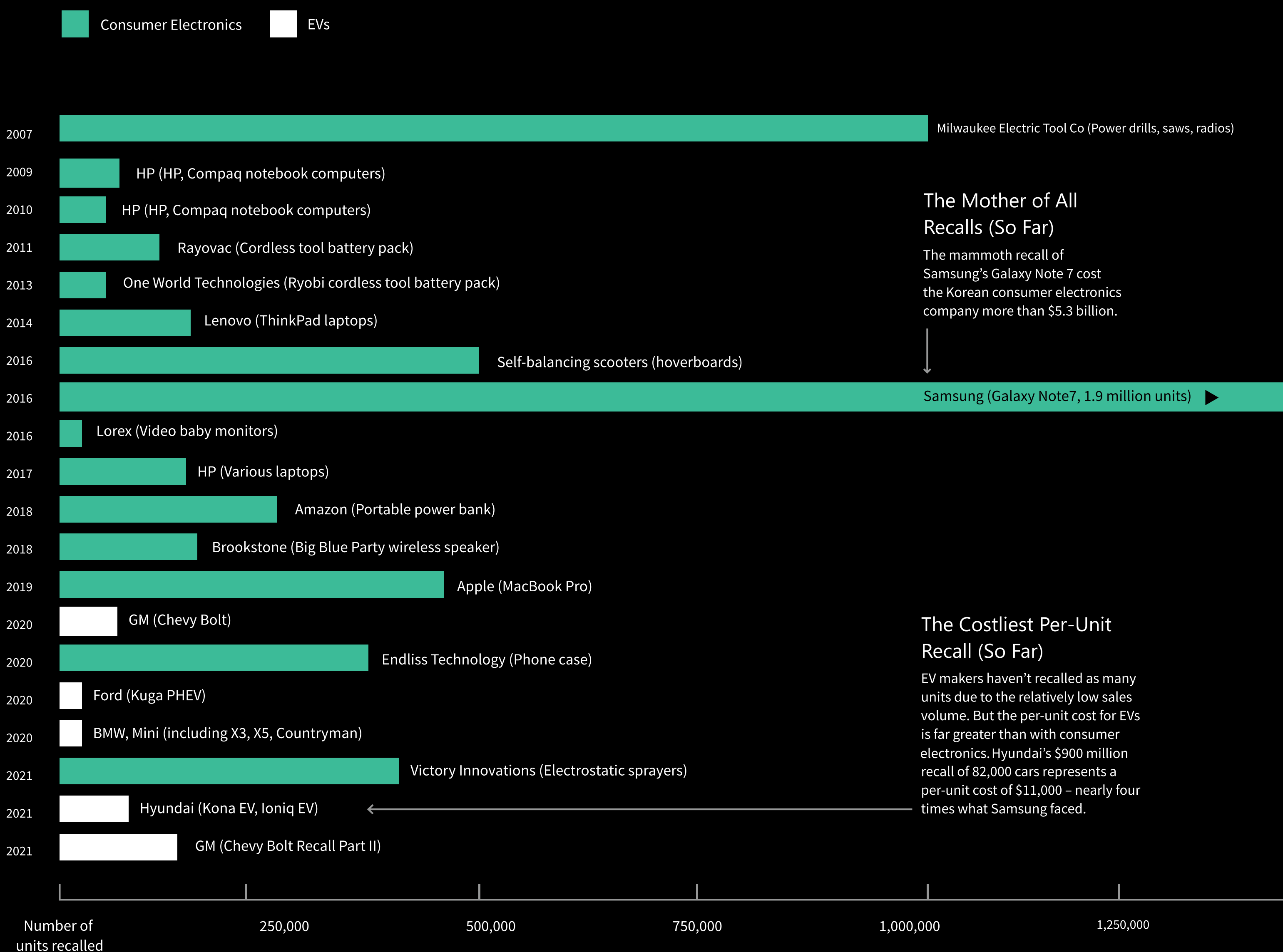
The Long, Sordid History of Battery Recalls

It's not just EV batteries that are overheating, exploding, and catching fire. The same thing has been happening in laptops, cars, headphones, and power tools for decades.



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> **Every EV represents a billion-dollar bet on the battery. If you can identify a faulty batch of batteries, that can make all the difference, whether that means hitting a product launch or avoiding a costly recall.**

Why does this keep happening? Here's the easy, unsatisfying answer: a lot of reasons. Highly charged (positive and negative) materials sit mere microns apart in a battery's housing. When everything is properly aligned, the combination seems almost magical – providing silent, efficient, instantaneous power. But the smallest misalignment or minor abuse can cause the energy in the materials to combine – and go boom!

"Good engineering and process control can help, but when you look at the rapid expansion of production, materials innovation, and supply chain developments, there are bound to be problems," says Sholklapper. "There are just so many unknown unknowns, and none of the old tools, systems, or skills apply. There's a pressing need for a better data analysis infrastructure."

Voltaiq greatly reduces this risk. The platform sheds light on variations or misalignments – without having to open the battery – months or even years before they're detectable through traditional methods. It's almost akin to a CT scan or an MRI, laying bare the battery's underlying chemistry during normal operation to identify cell degradation, conduct root-cause analysis, and perform competitor benchmarking.

"It takes time-series charge and discharge data, combines it with analytics about the inner electrochemistry, and matches behavior against known profiles that can lead to failure," Voltaiq CTO Eli Leland says. "The most important thing to understand is the effect. If you can identify a faulty batch of batteries, that can make all the difference, whether that means hitting a product launch or avoiding a costly recall after you've gone to market."

Contact Voltaiq Today and Prepare Your Business for the EV Age!

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About Voltaiq

Voltaiq has built the industry's first Enterprise Battery Intelligence (EBI) software platform, helping its customers optimize battery performance, reliability and financing, while avoiding costly recalls and catastrophic battery fires. Voltaiq's EBI platform is the only purpose-built, fully automated software solution that marshals vast quantities of battery data from across the full product lifecycle, providing a window into real-time battery function and a detailed view into future performance and behavior. Founded in 2012 by veteran battery and software entrepreneurs, Voltaiq's global customer base includes industry leaders in transportation, consumer electronics, energy storage, and the full battery supply chain. For more information, please visit www.voltaiq.com.