

EBOOK

BREATHE

ADAPTIVE CHARGING FOR
THE NEXT GENERATION OF EVS

A new industrial revolution

How EVs are reshaping the automotive industry

The energy transition in automotive represents not merely a shift, but a profound technological revolution that is reshaping automotive design. Its rate of change is anything but linear - it's exponential.

The 2020s are emerging as a pivotal period, characterised by the large-scale adoption of electric vehicles (EVs), and the stakes have never been higher for automotive designers. Urgency is key. Falling behind in an exponential curve means playing catch-up might be impossible.

With this transition comes the emergence of new economic frameworks, business models and the rise of new industry leaders.

The automotive operational framework is also evolving from its traditional hierarchical pyramid structure, where OEMs used to depend on tier one suppliers, who in turn relied on tier two suppliers, and so on, down the supply chain. This tiered model resulted in OEMs depending on 'black box' solutions, where tier one suppliers provided fully integrated hardware and software components without disclosing the inner workings or allowing customisation.

The linear model is now giving space to a more fluid structure, optimised for agility and external partnerships. OEMs can now better balance outsourcing and in-house development, with a new approach that facilitates direct interactions with various tiers of suppliers and innovative start-ups for faster platform development.



New customer expectations

Redefining brand loyalty

Brand loyalty put to the test

In times of systemic change, consumers are more willing to abandon long-standing loyalties. This presents a test for established brands (Exhibit 2). More than 50 percent of respondents say they may try a new brand when they switch to electric. And if only BEVs are considered, the proportion rises to 70 percent.

Source: McKinsey, Electric-vehicle buyers demand new experiences, July 28, 2023

It started with Tesla, now electric vehicle manufacturers continue to reshape customer expectations and preferences.

As revealed by a recent McKinsey study, over half of the respondents are inclined to forgo their longstanding brand preferences in favour of new players in the electric domain. This tendency amplifies when considering battery electric vehicles (BEVs) exclusively, with the proportion of consumers open to switching brands soaring to 70%.

For OEMs, it's no longer just about the brand, but about who can deliver the most compelling EV experience, driving range, charging experience, technology integration, cost of ownership, and environmental impact are all drivers of an owner's experience.



Battery system performance

Driving the end-user experience

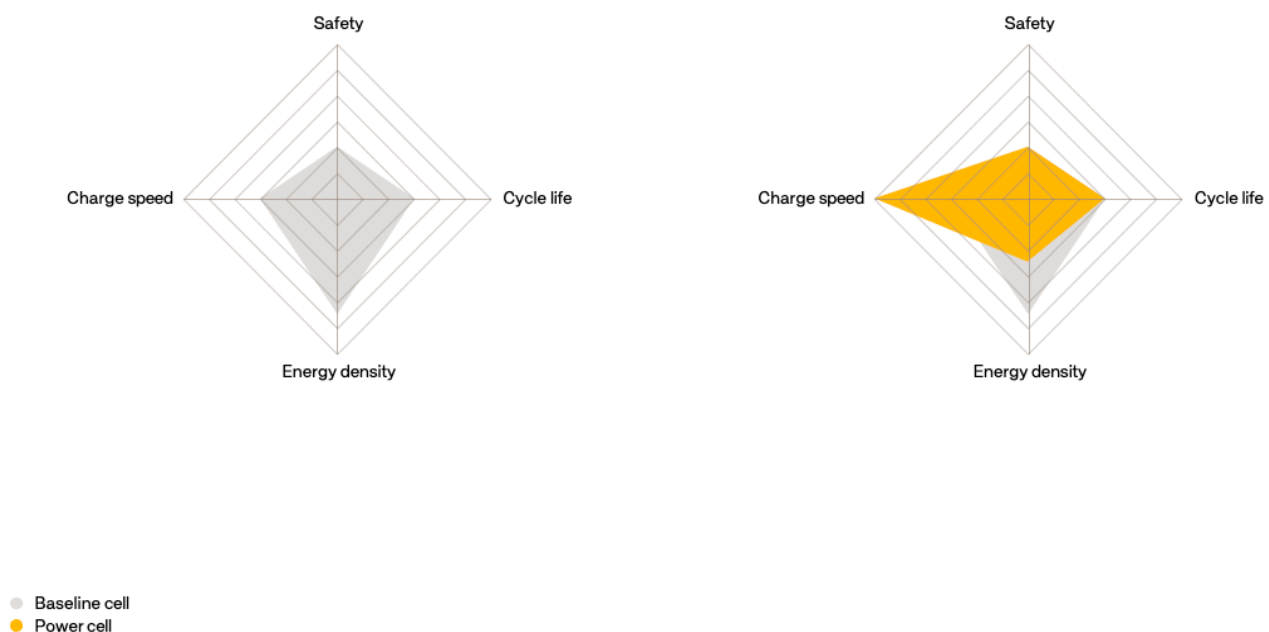
The battery system is at the core of electric vehicles and is central to the ownership experience.

It influences everything from how far we can go on a single charge, to how quickly we can get back on the road. Drivers want more range without the wait. They also want to be able to use their EVs during any type of weather, without seeing their vehicle or charging performance drop off (low temperatures, for example, cause the electrolyte fluid in lithium-ion batteries to become thicker, slowing down the electrochemical process and therefore reducing charging speed).

The battery system also impacts an EV's total cost of ownership. According to an October 2023 [Statista](#) report, batteries represent on average 28% of the cost of large-size EVs, whilst uncertainties around how quickly battery packs will reach the end of life and the rapid pace of battery innovation are impacting residual values.

Yet, optimising EV battery design is extremely challenging. It involves striking a balance between range, charging speed, and durability whilst also addressing cost and safety considerations. Ultimately design engineers are having to make trade-offs that compromise the performance and longevity expectations of EV owners.

At Breathe, we believe that the industry shouldn't settle for a middle ground, but rather push boundaries. Customers don't want a vehicle that's just about compromises. They're looking for excellence — a battery system that delivers extensive range, quick charges, is durable, and performs well in all temperatures, while keeping vehicles affordable.



Product leaders and battery experts have to constantly make impossible trade-offs between charge speed, cycle life, and energy density, whilst never compromising safety.

Why current battery design is sub-optimal

And performance is being compromised

A lot is going on inside the batteries that power your electric car. Atoms move, driven by gradients in the concentrations of electrochemically active species such as lithium. Materials morph from one composition to another, expanding and contracting as they're intercalated. Copper and aluminium foil shuttle electrons out to semiconductors and motors to satisfy our demands for productivity.

Despite this complexity, almost every battery is controlled in a very simple way using only three measurable surface quantities: terminal voltage, temperature, and electrical current. Why? Because traditionally you have not been able to measure the internal states of a battery in real-world applications; sensors don't scale beyond the lab and high-fidelity simulation models have required too much processing power to be run within the constraints of real-time systems. Still today, the de facto in battery control is implemented in lookup tables hard-coded into the battery management system.

It's a one-size-fits-all, "fire and forget" attitude. An approach that assumes that these measurable quantities are sufficiently good proxies of what's happening inside, and that what's actually happening inside can be safely ignored.

At Breathe we believe relying only on what is easily measurable is the wrong approach because:

- It chokes the operating envelope of the battery system, limiting performance, and heavily underutilises the cell materials you've paid for.
- It requires engineers to constantly trade between the attributes that end-users care about (charge speed, cycle life, energy density and cost) in a zero-sum environment.
- It oversimplifies the ageing of the battery system.

It's an approach that leads to "defensive design" – the practice of deliberately over-engineering the battery system and/or limiting its performance to pre-emptively face off against its uncontrolled ageing. And it relies on significant safety margins to compensate for the lack of adaptability. In the end, this means end users pay more for less.



Software-defined vehicles deserve software-defined batteries

OEMs are doing everything they can to exploit chemistries and materials. Industry leaders are already using the newest chemistry nodes from their cell manufacturers, but there is still performance left on the table. There is only one viable option left to unlock additional battery performance, quickly and affordably, to satisfy the demands of today's customers.

So how do we make batteries dramatically better? By leveraging software to deliver the most advanced algorithms for adaptive control - and packaging it in a way that's incredibly simple to adopt.

Since internal states are not directly measurable with sensors at production levels of scale (sensors aren't yet where they need to be, even in the lab environment), they must be inferred using mathematical models of electrochemistry, running in real-time. Current, voltage and temperature measurements are still necessary, but those parameters are no longer the end goal.

Instead, the desired outcome is high-fidelity control of the internal battery states which are being estimated in real-time with a mathematical battery model implemented as software.

This is why we have brought to market our patented PHI-X2 physics-based battery model, a technology platform that enables **the most advanced health-adaptive battery management software.**

Our adaptive charging software ensures that two identical batteries, in two identical vehicles, will always have their own unique charging strategy, at every moment in time, based on the real-time state of that individual battery.

With Breathe, you have the true adaptive charging solution.



Why adaptive charging is changing the game

Including for the world's most iconic brands

Breathe's patented PHI-X2 physics-based battery model is a platform technology that enables the most advanced health-adaptive battery management software. This means:

- Fast calibration, which enables accelerated development times.
- Lightweight implementation compatible with real-world systems.
- Developed and qualified to automotive quality standards.
- Production-ready with performance proven to scale to system level.

Breathe's adaptive battery management software increases charge speed and cycle life, never compromising on safety.

It is the foundation to our suite of scalable solutions with zero compromise on energy density or safety.

- **Breathe Charge** increases charging speed and adds more range per minute charging, while adapting to the evolving battery health.
- **Breathe Life** enhances cycle life and average state of health to deliver better range retention and increased longevity without slowing charging speeds.

With our technology and our research pipeline at Breathe, we are now pioneering the next wave of battery performance and control, to immediately improve the user experience.

That's why some of the most iconic electric vehicle brands trust us.

Read more about our newly announced partnership with **Volvo Cars** and why it chooses Breathe to enhance the charging experience for its new generation fully electric vehicles.



Volvo Cars partners with, and invests in, Breathe for next generation fast charging.



Credit: Volvo Cars

Gothenburg, Sweden, March 12, 2024.

Volvo Cars has partnered up with Breathe Battery Technologies (“Breathe”), becoming the first car company to get access to the latest version of its patented, algorithm-enabled charging software for use on our new generation fully electric cars.

By integrating Breathe’s software in Volvo Cars in-house developed battery management platform to optimise and improve the performance of our charging technology, we can provide Volvo customers with even faster charging times and an enhanced overall driving and charging experience.

We will implement the new technology in our new generation fully electric cars, where we expect it will reduce the time it takes to charge your fully electric Volvo from 10 to 80 per cent charging state by as much as 30 per cent*, while maintaining the same energy density and range. Even better: the charging time improvements will last across the full battery life cycle without impacting its health status.

The collaboration with Breathe is the result of a sourcing agreement for its flagship product, Breathe Charge, and represents the latest investment by the Volvo Cars Tech Fund, our corporate venture capital arm. It reflects our ambition to lead the development of premium electric cars and become a fully electric car maker by 2030.

“The investment and commercial partnership with Breathe helps us address a familiar pain point for electric car customers and makes our charging performance even more competitive,” says Ann-Sofie Ekberg, CEO of the Volvo Cars Tech Fund. “Faster charging times, in the range where customers typically fast charge, represent a major step in the right direction as we continue to boost electric mobility and make it available to more people.”

Software-defined batteries

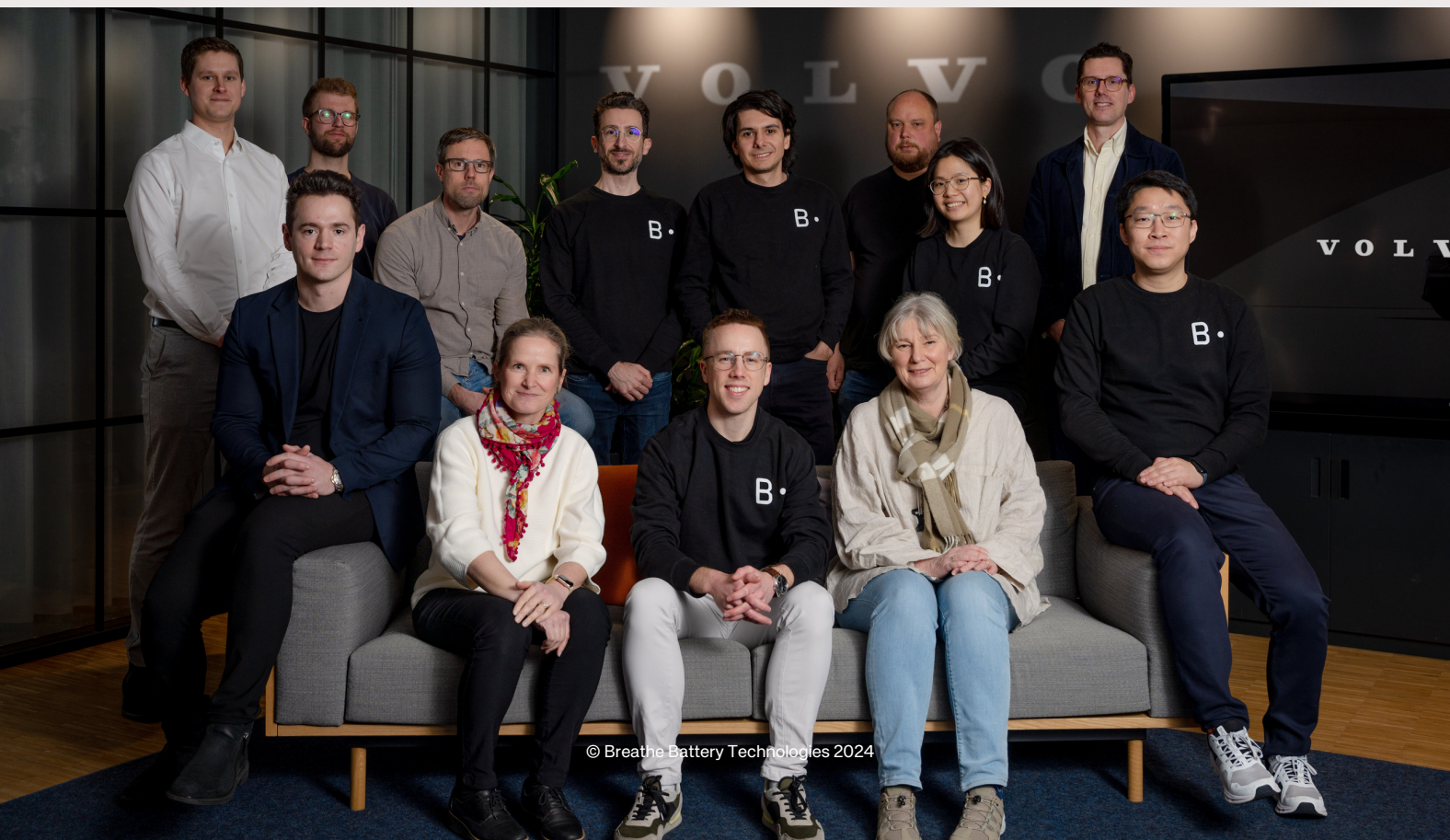
Unlike traditional stepped charging which relies on pre-determined rules, Breathe's software uses adaptive charging to dynamically control the battery in real-time, resulting in significantly shorter charging times. Using algorithms, the software manages the charging process in line with the battery's health to deliver the best driver experience while avoiding the risk of lithium plating, which can harm the battery's performance and lifespan.

Our investment in Breathe helps position us for an all-electric future, but it also fits with our ambitions of reaching net zero greenhouse gas emissions and becoming a circular business by 2040. While reducing charging times for our cars, the technology achieves this without the need to change battery pack design or mine additional materials, without additional environmental impacts. Also, since it is fully compatible with the hardware used in our new generation fully electric cars, scaling will be easy as we expect our electric sales to increase significantly in coming years.

"We're very pleased with this investment and sourcing agreement with Volvo Cars and support their exciting journey towards full electrification," says Dr Ian Campbell, CEO of Breathe Battery Technologies. "Deploying our technology at scale on Volvo's next generation EV platform opens doors to innovative car designs and performance improvements. We share a profound passion for electric mobility, and convenient, fast charging is one of the cornerstone enablers for the future we strive towards."

The Volvo Cars Tech Fund was established in 2018 to invest in companies and technology areas that transform the automotive industry, such as electrification, AI, autonomous driving, sustainability, and digital commerce. The Tech Fund makes strategic investments to help start-ups thrive and jointly accelerate the transformation of the global mobility industry.

**Different battery packs will result in varying charging times. Testing indicated charge time improvements ranging from 15-30%.*



Conclusion

Together, we can accelerate the rate of progress

At Breathe, we are pioneering the next wave of battery performance and control. Our state-of-the-art battery lab, the largest in London, is a hub of excellence, producing over 5,000 hours of validation data every day.

Designed to mirror the real-world use cases of our customers' battery systems, our lab meets the strictest product qualification standards and aligns with ASPICE standards. This allows us to partner with you to effortlessly integrate into your production programs. Our collaborative approach ensures that we deliver a custom, software-defined battery system that enhances product performance at every point in your product roadmap.

By integrating with your battery and product development teams, we're able to inject our battery innovations directly into the design process, shaping the future of the electric vehicle charging experience.

Our well-established proof-of-concept process has been designed to help you objectively understand how much performance Breathe software can unlock in your battery system. We meticulously replicate your in-house qualification process to ensure a like-for-like comparison and demonstrate cell-level performance gains.

If you're looking to elevate your current battery system's performance and revolutionise your end-user experience, please reach out, we'd love to learn more about your EV roadmap and demonstrate how Breathe software can help you do more with the power you already have.

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