



# **Electric vehicle batteries: How will they hold up?**

Technical and economic considerations  
for the vehicle resale market

**P**   
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Electrochemist  
Plug Life Consulting

## Introduction

Dr Euan McTurk



**Plug Life**  
Television



- MSci Renewable Energy, 2006 – 2011
  - PhD Electrochemistry, 2011-2014
  - DPhil Materials Science, 2014 – 2015
  - Project Engineer, 2016-2017
  - Electrochemist, 2017 – 2020
  - Consultant Battery Electrochemist, 2020 – present
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- Experience in next-generation battery chemistries and advanced lithium-ion cell characterisation
  - EV driver since 2009
  - Creator of the YouTube series Plug Life Television
  - GreenFleet EV Champion 2018 and Top 100 Most Influential

“What’s in an EV battery?”

# What's in an EV battery?

Cylindrical



Module

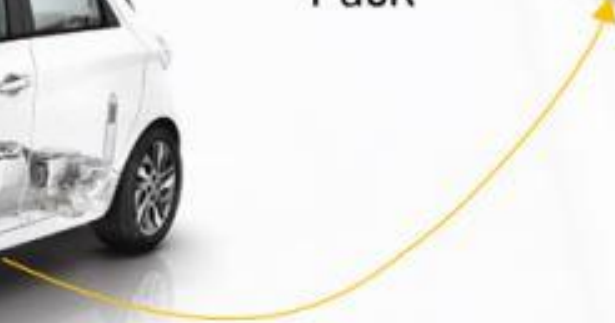


Pouch Cell

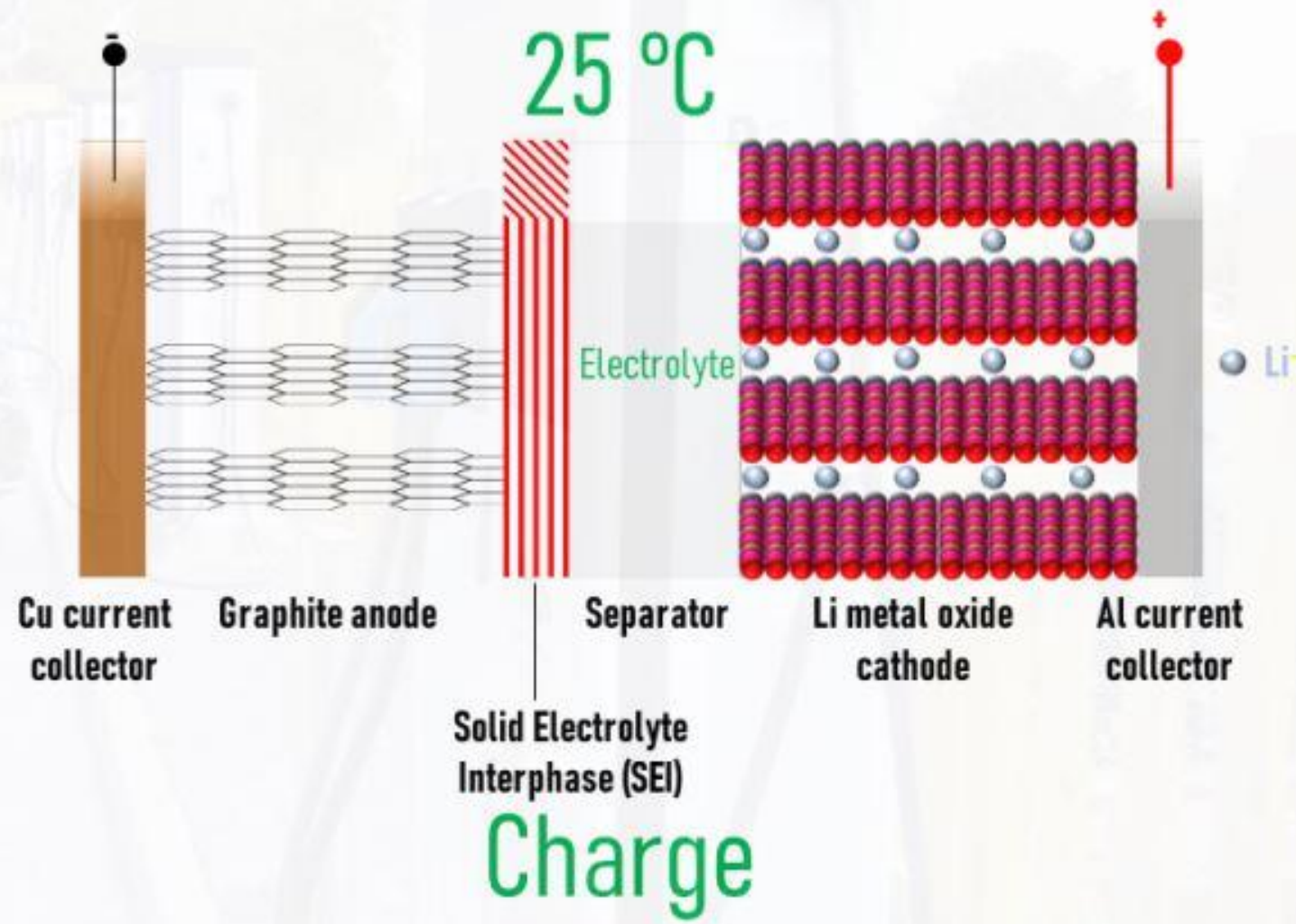
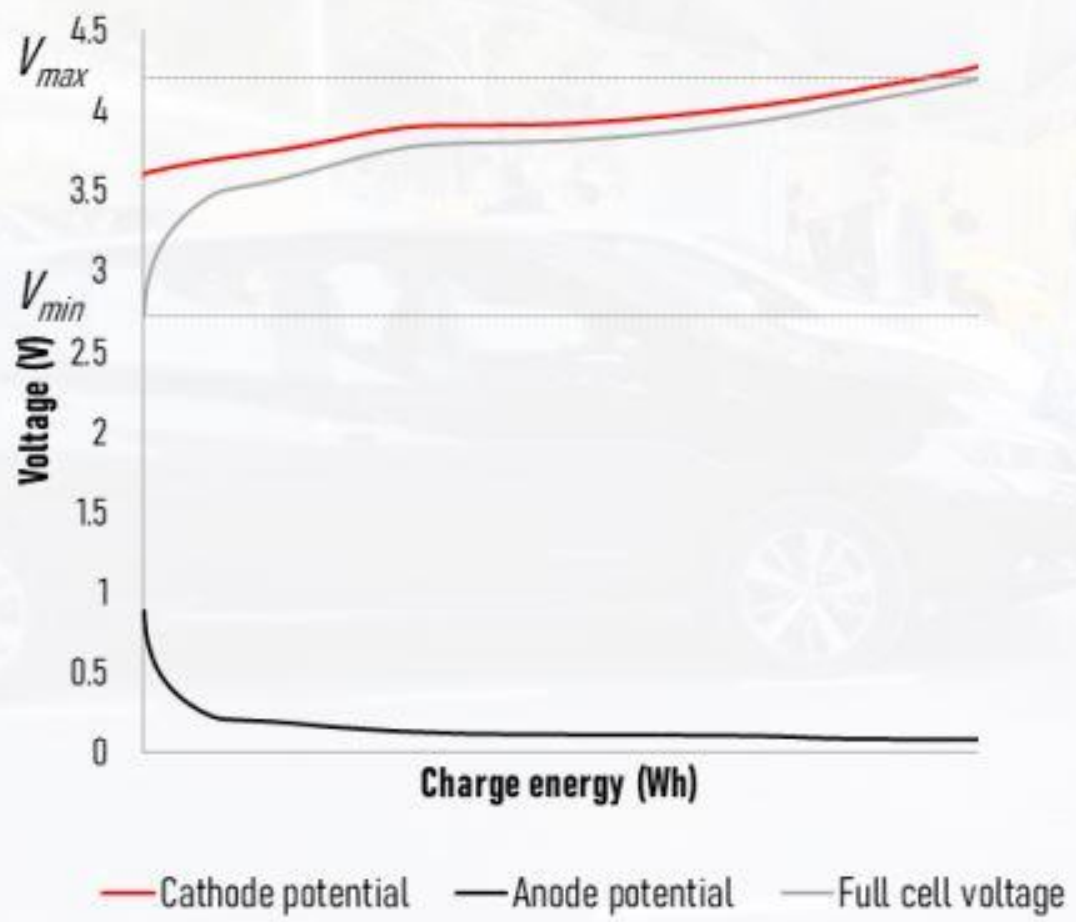


Prismatic

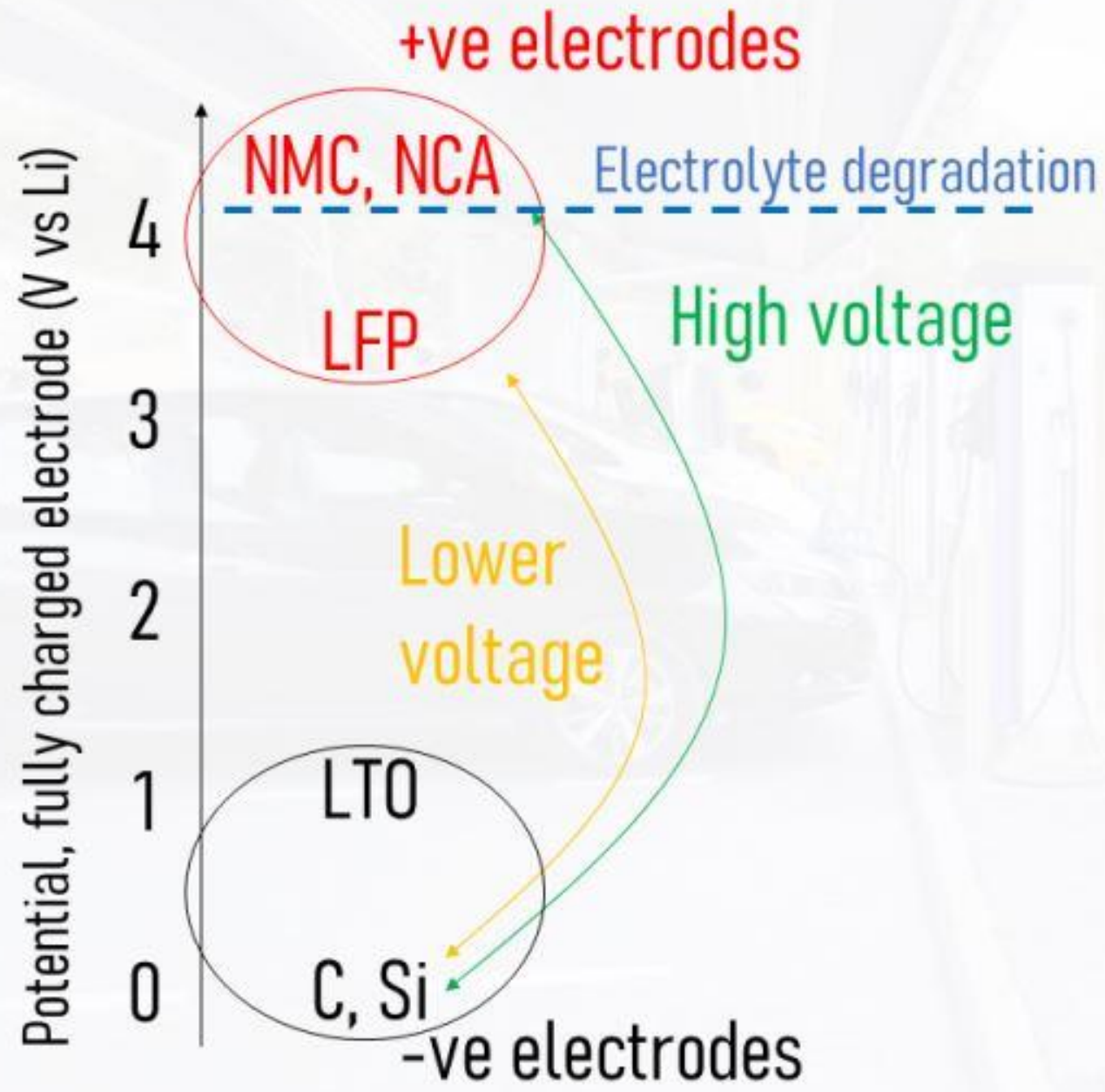
Pack



# The lithium-ion cell: what is it and how does it work?



Let's talk about electrode potentials...



### Electrode potentials

Accelerates degradation; shortens lifespan

- Voltage of a cell that you can measure with a voltmeter is the “potential difference” between the two electrodes (+ve minus -ve)
- A lithium-ion cell needs to pair a positive electrode and a negative electrode that make a good balance of good and bad properties e.g. power, energy, lifespan etc

Energy contained in battery (Wh) = current x time x voltage

“Are EV batteries reliable?”

Very...

## Bulletproof reliability: Wizzy the LEAF taxi



100000

# Bulletproof reliability: Wizzy the LEAF taxi



174,000 miles in four years



All 12 battery State of Health bars still showing after 100000 miles → battery in excellent health

Total repairs:



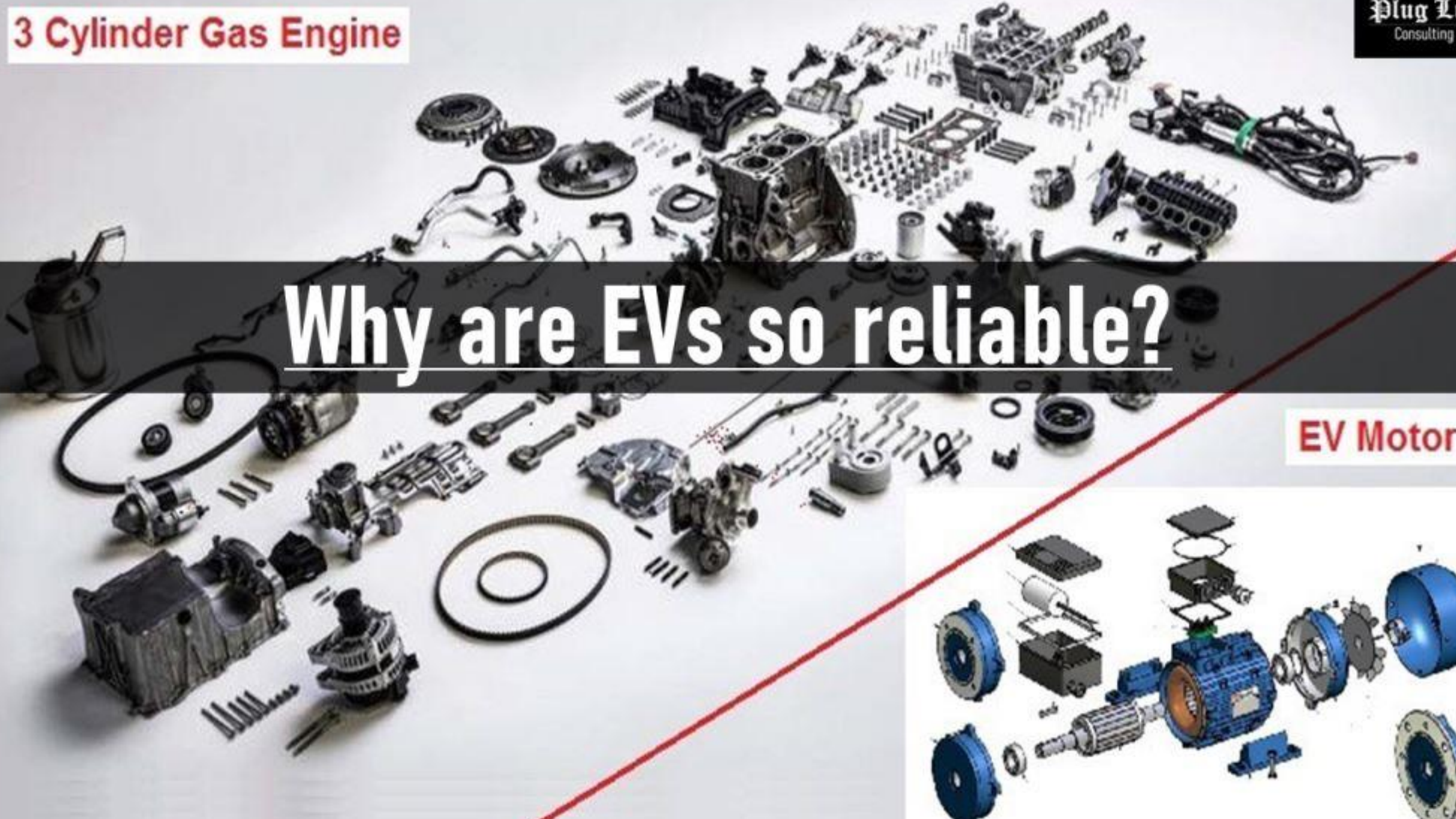
One ball bearing



**3 Cylinder Gas Engine**

# Why are EVs so reliable?

**EV Motor**



EVs are the **most reliable vehicles on the road**:

- Far less moving components → less to break
  - Electric motor has one moving component
  - An internal combustion engine has hundreds of moving components
  - An electric vehicle doesn't need a clutch, a gearbox, an exhaust gas regulator, timing belt...
- Far less heat and vibration
  - Electric motors are smooth and efficient → very little energy wasted as heat
  - Internal combustion engines are rattly and inefficient → lots of energy wasted as heat

EV Motor

# Why do EV batteries last longer than phone or laptop batteries?

- Better battery management
  - Superior **battery management system (BMS)** – better control electronics
  - Active thermal management (air/liquid cooling or heating) in many EVs
- Different operating environment
  - EVs: -10 to 30°C in UK environment → suits batteries well
  - Phones: 37 to 50°C → lives in your pocket, always warm, causes the cell to degrade quicker
  - Laptops: CPU gets up to 90°C → exposed to very hot temperatures AND temperature gradient (some cells nearer CPU than others)

This way to laptop



This row is closer to CPU  
→ gets hotter  
→ these cells degrade quicker

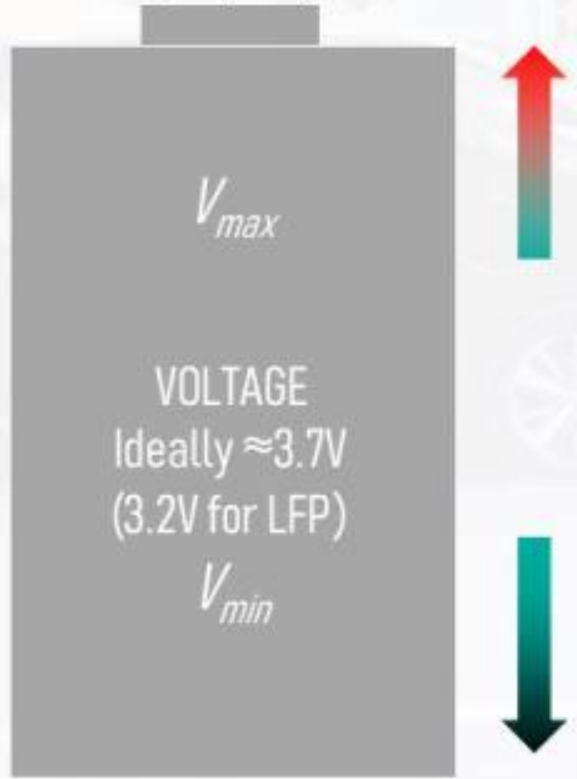


EV Motor

# The role of the Battery Management System

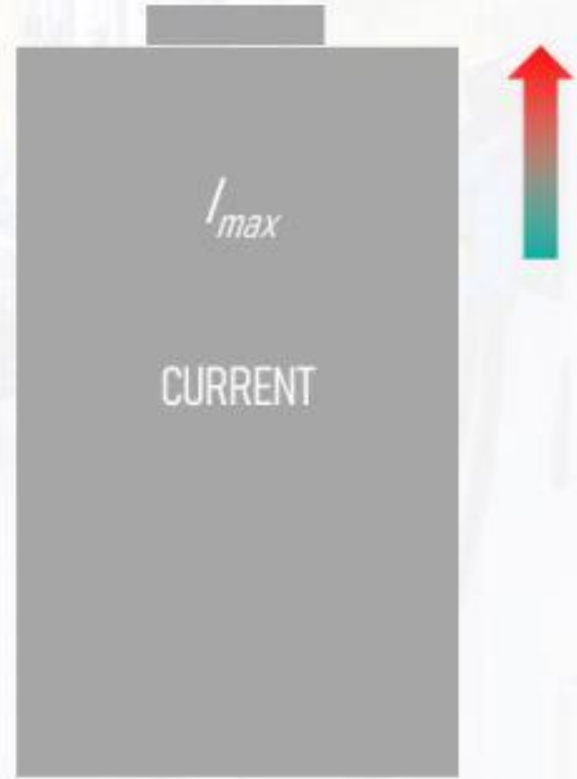
Lithium-ion cells risk being heavily degraded if they operate outwith certain parameters:

Cathode (+ve electrode) becomes unstable → greater chance of thermal runaway; electrolyte degrades against cathode → decreased capacity and performance



Cell is irreversibly discharged; unstable if recharged

Cell generates too much heat → thermal runaway



Electrodes become unstable → thermal runaway

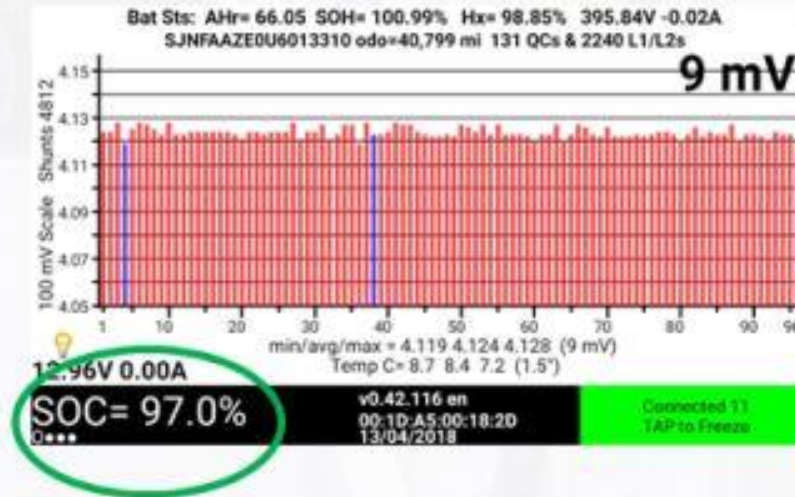


Lithium plates on anode during rapid charging → capacity loss, mechanical strain, risk of internal short circuit and thermal runaway

## The role of the Battery Management System

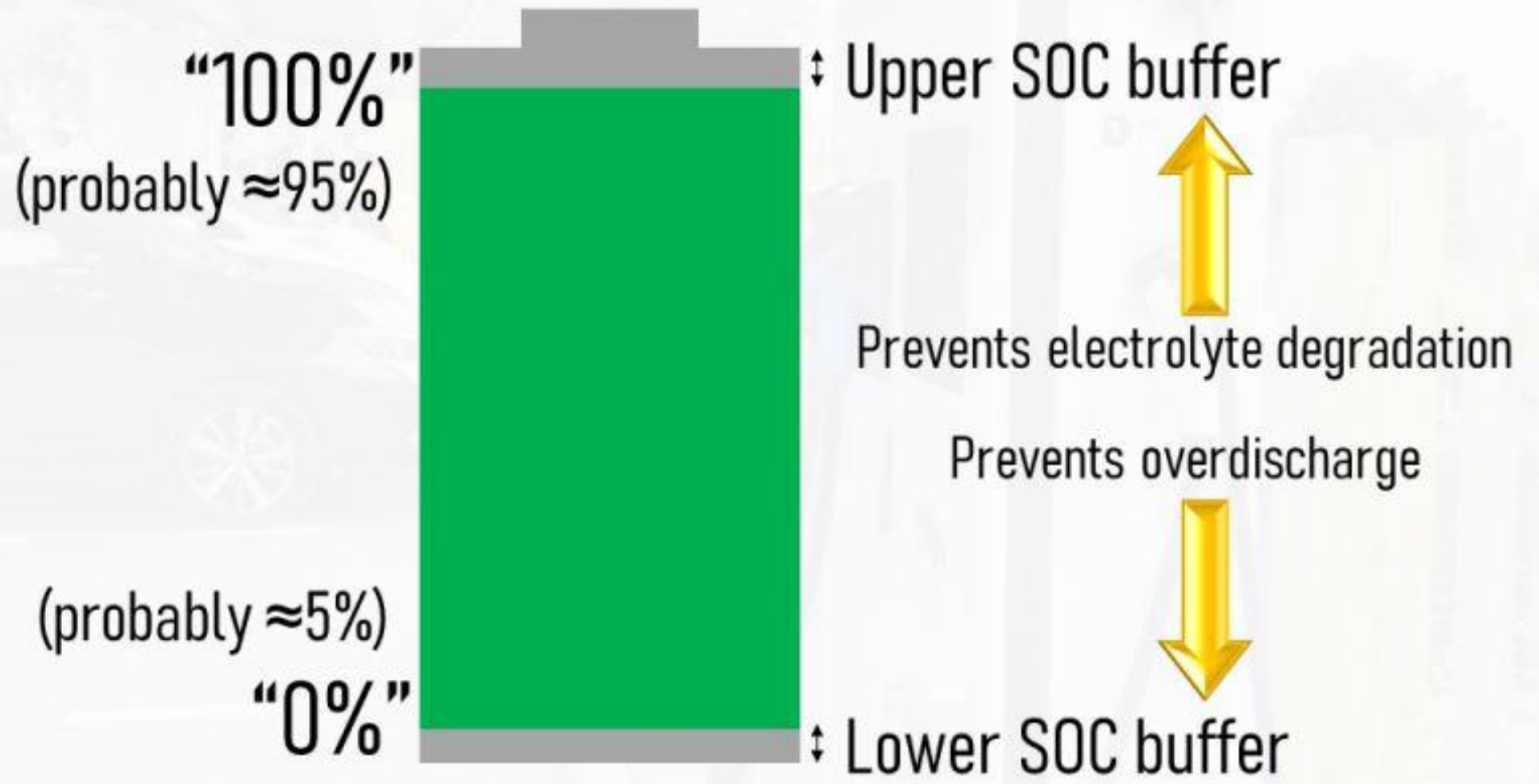
- The BMS:
  - Monitors voltage of every cell in pack
  - Monitors temperature of battery pack
  - Adjust peak power delivery
  - Turns on/off cooling system (“thermal management system”) accordingly
  - **State of Charge (SOC) buffers** at high and low SOC: extends lifespan of EV battery

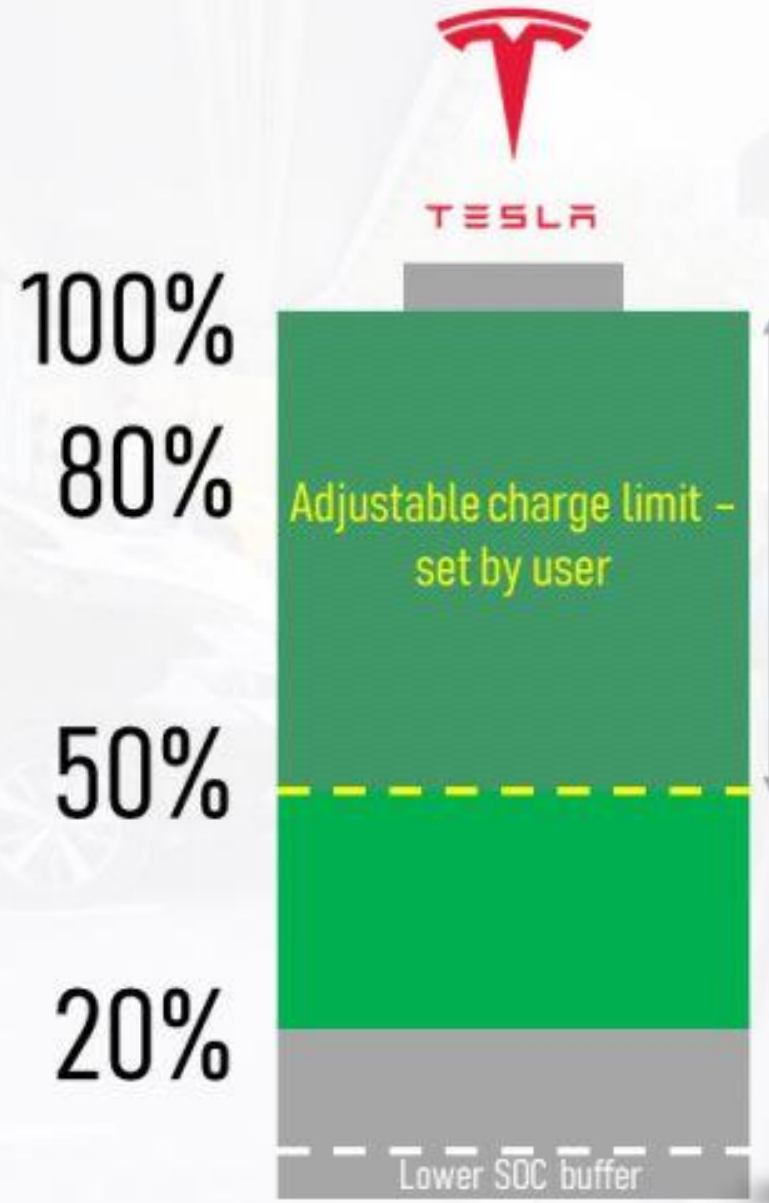
# SOC buffers: does your electric vehicle actually charge to 100%?



Why?

# SOC buffers and their purpose





- Charges cells to genuine 100%
- Will degrade battery if used regularly (warns driver if car has been charged to 100% too many times recently)
- Use only when necessary, or every 1-2 months to calibrate battery management system (BMS)



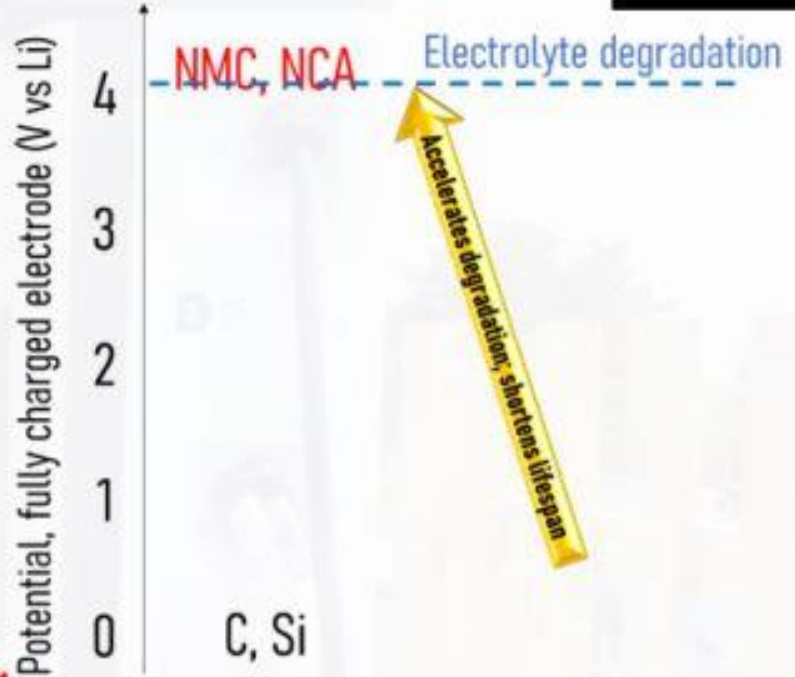
SOC buffers aren't completely fool-proof: here are some top tips to maximise your battery life...

Avoid shallow cycling at high SOC

100%  
80%



30 kWh LEAFs are particularly badly affected by this – high degradation of low mileage models



Continuously high SOC  
= more electrolyte degradation  
= accelerated cell degradation

# Leaving an electric vehicle parked for a prolonged period of time



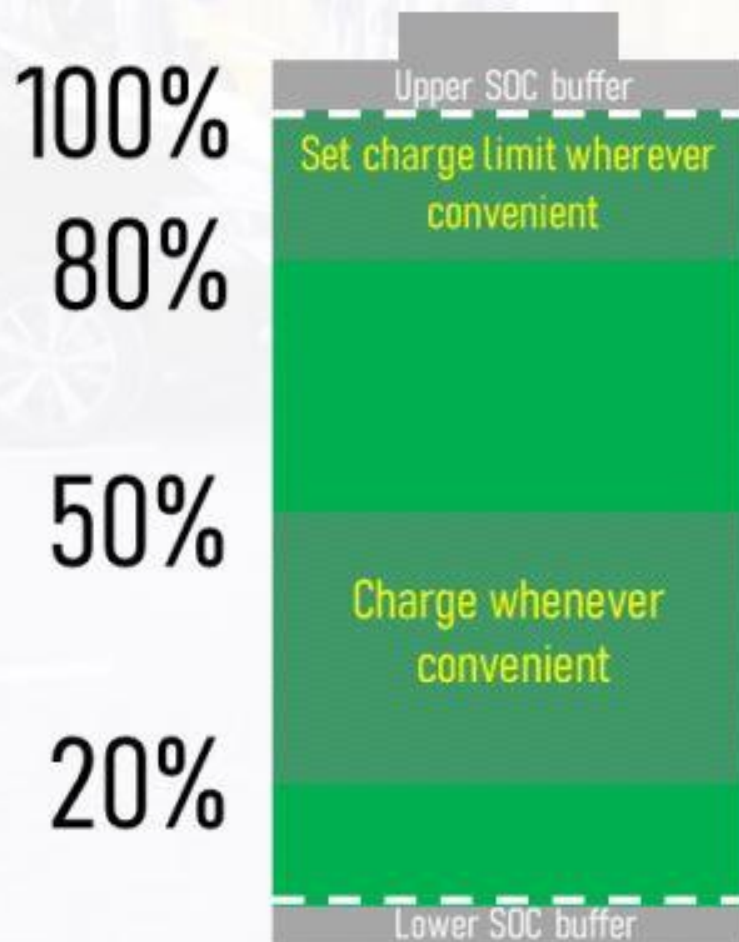
80%

Leave stored in this SOC range

50%



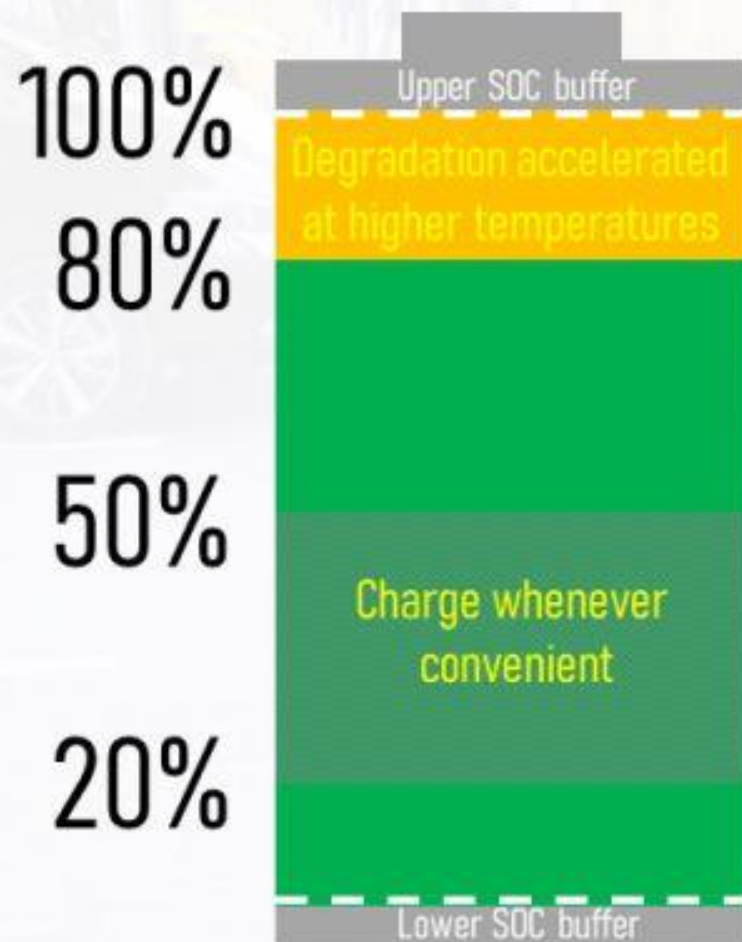
Ambient temperature  Mild-moderate (<math><30^{\circ}\text{C}</math>)



Difference in degradation is minimal when vehicle is used regularly

Remember to fully charge and balance occasionally

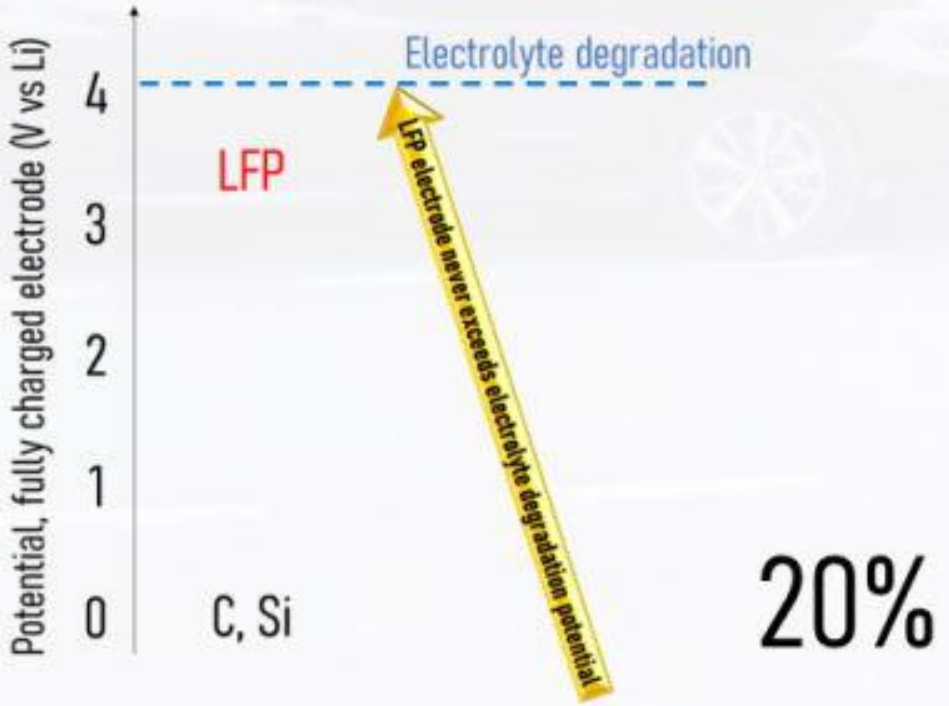
Ambient temperature  Hot ( $>35^{\circ}\text{C}$ )



Degradation may be accelerated above 80% SOC

Remember to fully charge and balance occasionally

# Exception to the rule: LFP

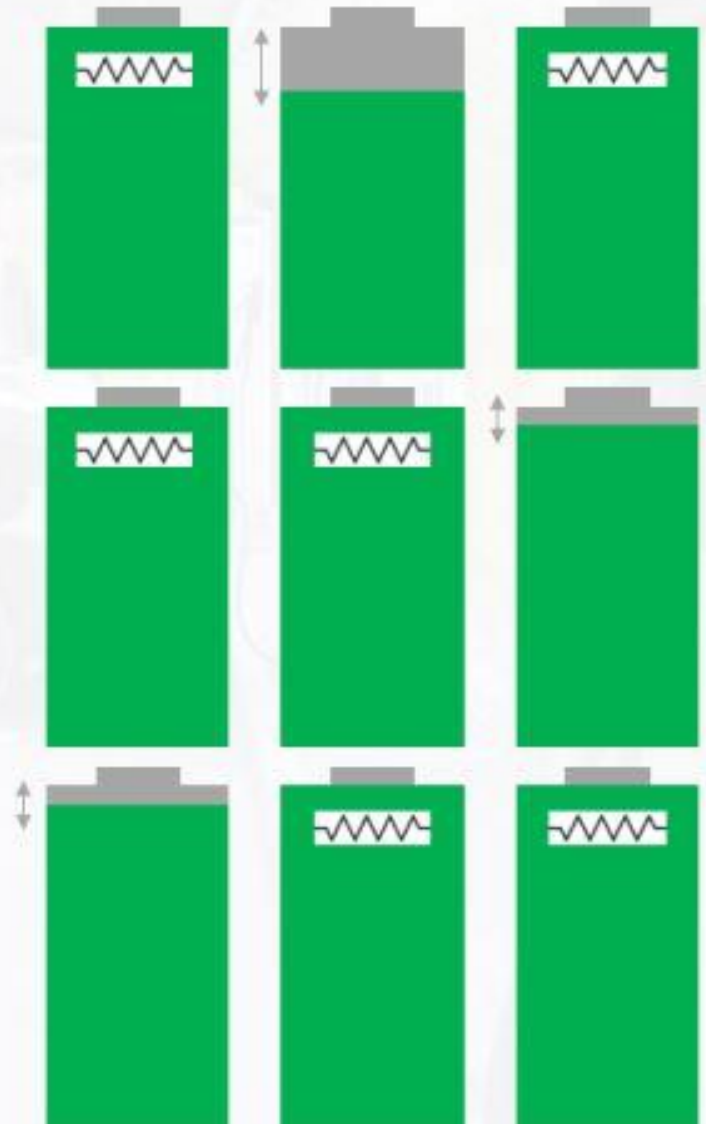


- Used in Standard Range Tesla Model 3/Y, Standard Range MG4, many electric buses, upcoming Fords, VWs, Mercedes, Rivians etc.
- LFP potential is lower than NMC/NCA; never exceeds electrolyte degradation potential
- Fine to routinely charge to 100% SOC

**PLUS** no cobalt, no nickel, cheaper, safer, longer lifespan

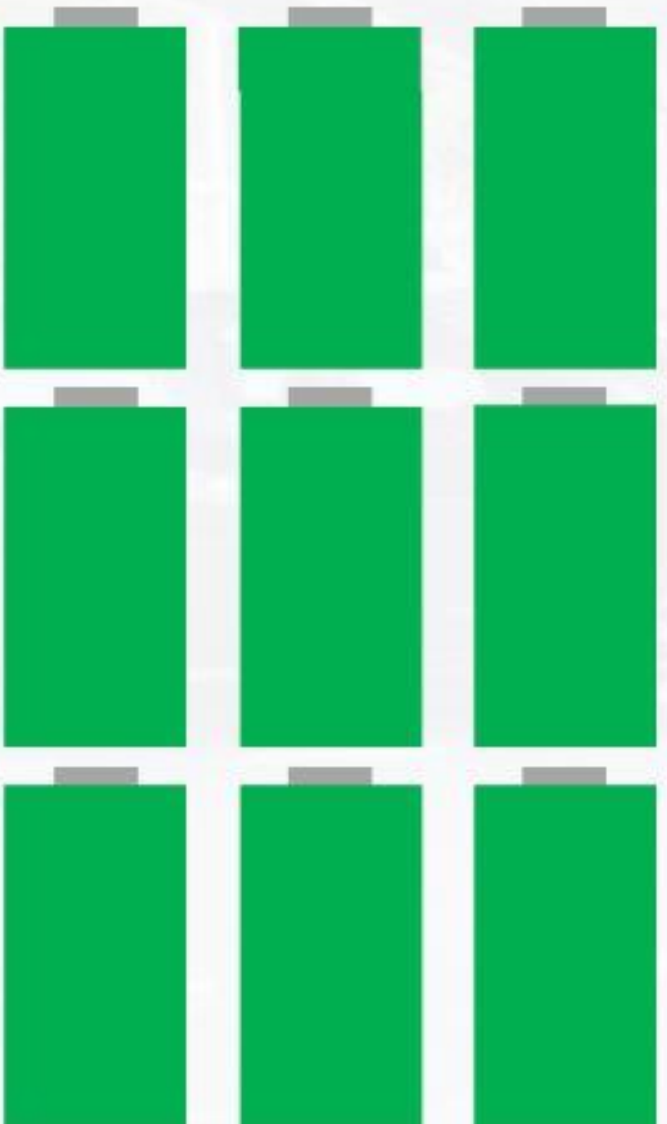
# The importance of cell balancing

Bleed resistors remove excess charging current from fully charged cells



Balancing allows cells at lower voltages to catch up with cells at higher voltages without the latter being overcharged

Full charge and balance recommendation



**Battery size**

<25 kWh

25 – 50 kWh

>50 kWh

**Charge to 100%**

Every 1-2 weeks

Every 2-4 weeks






Every 1-2 months

\*for cars in regular use (e.g. daily commuter)

\*Aim to drive car within a few hours of charge completing

Some EVs look after their battery  
better than others...

## A lesson in thermal management: the Nissan LEAF

Model	Battery Life	Reasons
 <p>Mk1 24 kWh Japanese-built (2010-2013)</p>	≈100,000 miles	Cell chemistry had <b>poor heat tolerance</b> ; battery had <b>no thermal management system</b>
 <p>Mk1 24 kWh UK-built (2013-2018)</p>	≈170,000 miles	New cell chemistry with <b>improved heat tolerance</b> ; battery still had no thermal management system
 <p>Mk1 30 kWh (2016-2018)</p>	≈120,000 miles	Bigger battery capacity in same space + no thermal management = <b>increased heat dissipation</b> = increased degradation during heavy use. <b>Upper SOC buffer too small</b>
 <p>Mk2 40 kWh (2018 onwards)</p>	≈120,000 miles	Bigger battery capacity in same space + no thermal management = <b>increased heat dissipation</b> = increased degradation during heavy use. <b>"Rapidgate"</b> – charging speed limited when battery gets hot
 <p>Mk2 62 kWh "e+" (2019 onwards)</p>	Likely 200,000+ miles	No thermal management, but range is so big that <b>heat should have enough time to dissipate</b> between rapid charges. Also, bigger battery supply a given load <b>works less hard and gets less hot</b>

Compare and contrast with...

## A lesson in thermal management: other older EVs

Model	Battery Life	Reasons
	Mk1 22 kWh Renault Zoe (2013 - 2016)	Still going strong  Very basic thermal management system (redirected air-con flow over battery pack) is enough to keep pack at healthy temperature
	Mk1 60 Ah BMW i3 (2013-2016)	Still going strong  Liquid thermal management system and generous SOC buffer
	Mk1 Tesla Model S (2014 - 2016)	Still going strong  Advanced liquid thermal management system that Tesla uses to optimise both performance and lifespan. Lots of examples with hundreds of thousands of miles on the clock. (N.b. some older packs were replaced or refurbished due to build defects)

Most Nissan LEAFs with failed packs would still be going strong if they had a thermal management system

## Modern batteries are even better

### Cell level improvements

- Improvements in heat tolerance
- Electrolyte additives
- Electrodes with robust structures e.g. “single crystal” electrodes
- Improving energy density of chemistries that have longer lifespan e.g. LFP

### + System level improvements

- Improvements in thermal management systems and heat dissipation
- SOC buffers
- Improvement in battery management

### = LONGER LIFESPAN

Forbes

SUSTAINABILITY

## Tesla Researcher Demonstrates 100-Year, 4-Million-Mile Battery

James Morris Contributor @

*I write about the rapidly growing world of electric vehicles*

May 28, 2022, 05:00am EDT

One of the biggest concerns about EVs is that the batteries will need replacing after a few years, at great expense. After all, your smartphone battery is likely to have seen better days within as little as three years. But a Tesla researcher is getting ready to kick this idea into touch once and for all, after demonstrating batteries that could potentially outlive most human beings.

Tesla enthusiasts are likely to have heard of Jeff Dahn already. He’s a professor at Dalhousie University and has been a research partner with Tesla since 2016. His focus has been to increase the energy density and lifetime of lithium-ion batteries, as well as reducing their cost. Dahn appears to have hit the motherload along with colleagues on his research team. In a paper published in the *Journal of the Electrochemical Society*, the group claims to have created a battery design that could last 100 years under the right conditions.

Most batteries in EVs used today will last hundreds of thousands of miles

Biggest reason for “lack” of EV battery recycling today is that most EV batteries are still going strong!

“Are Vehicle to Grid (V2G) and Vehicle to Home (V2H) bad for the battery?”

No, V2G/H can be good for the battery!

# Vehicle to Grid/Home (V2G/H): not detrimental to EV battery life

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Clean energy stored in electric vehicles to power buildings

## Clean energy stored in electric vehicles to power buildings

- Energy stored in electric vehicles can be used to power large buildings, thanks to ground-breaking research from WMG, University of Warwick
- Researchers discover that by intelligently managing vehicle-to-grid technology, energy from idle vehicle batteries can be pumped back into the grid – and this would improve vehicle battery life by around 10%
- 'Smart grid' developed, which calculates how much energy can be taken from electric vehicles without affecting batteries, and actually improving longevity and performance
- Previously thought that vehicle-to-grid tech only acts to degrade battery life – this research shows that it could keep vehicle batteries healthier for longer

Stored energy from electric vehicles (EVs) can be used to power large buildings – creating new possibilities for the future of smart, renewable energy - thanks to ground-breaking battery research from WMG at the University of Warwick.

Dr Kotub Uddin, with colleagues from WMG's Energy and Electrical Systems group and Jaguar Land Rover, has demonstrated that vehicle-to-grid (V2G) technology can be intelligently utilised to take enough energy from idle EV batteries to be pumped into the grid and power buildings – without damaging the batteries.

This new research into the potentials of V2G shows that it could actually improve vehicle battery life by around ten percent over a year.

For two years, Dr Uddin's team analysed some of the world's most advanced lithium ion batteries used in commercially available EVs - and created one of the most accurate battery degradation models



How?

Energy

Contents lists available at ScienceDirect

ELSEVIER

Journal homepage: www.elsevier.com/locate/energy

Energy 133 (2017) 719–722

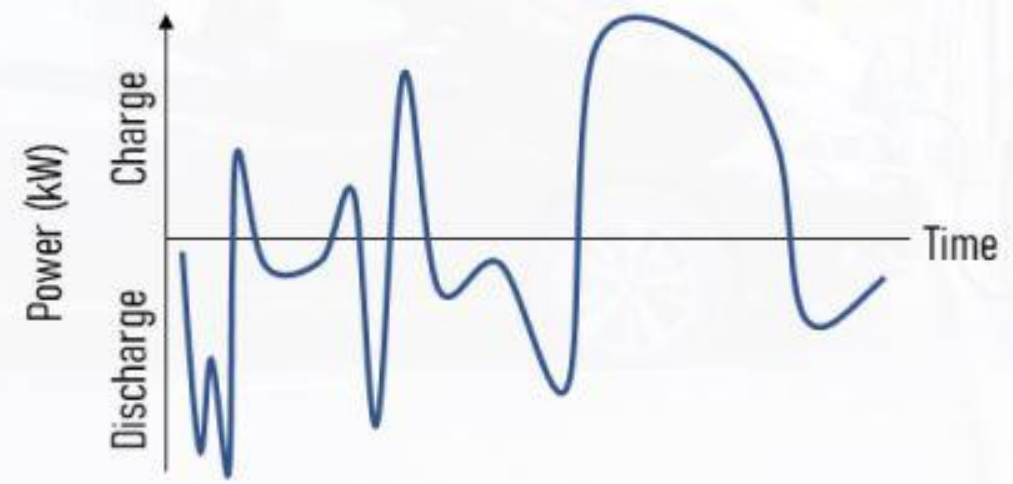
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## On the possibility of extending the lifetime of lithium-ion batteries through optimal V2G facilitated by an integrated vehicle and smart-grid system

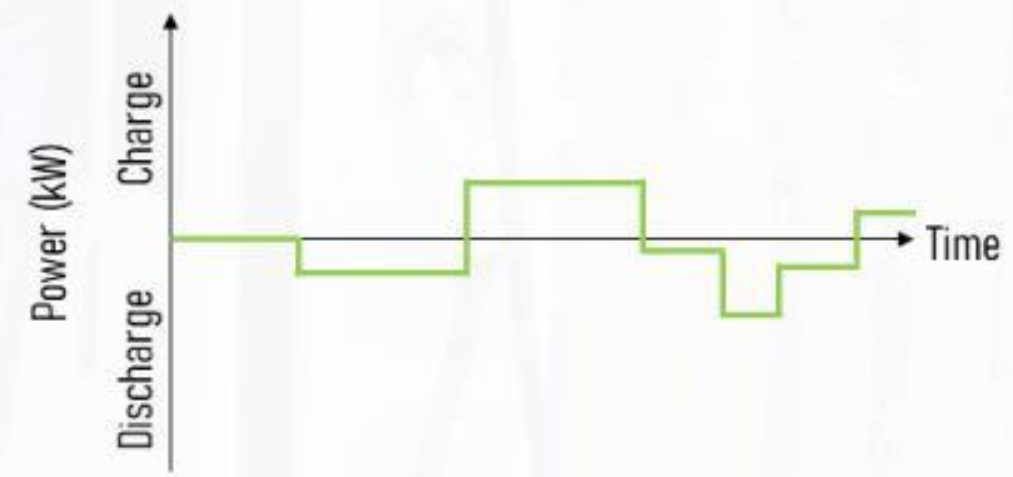
Kotub Uddin<sup>a,\*</sup>, Tim Jackson<sup>a</sup>, Widanalage D. Widanage<sup>a</sup>, Gael Chouchelamane<sup>b</sup>, Paul A. Jennings<sup>a</sup>, James Marco<sup>a</sup>

<sup>a</sup> WMG, International Digital Laboratory, The University of Warwick, Coventry CV4 7AL, UK  
<sup>b</sup> Jaguar Land Rover, Banbury Road, Warwick, CV35 9EF, UK

# Vehicle to Grid/Home (V2G/H): not detrimental to EV battery life



- Very dynamic: constantly changing power demand
- High power acceleration, regenerative braking and rapid charging
- Sits at high SOC for long periods of time e.g. overnight
- A hard life for batteries, but modern EV batteries are still likely to last as long as the car

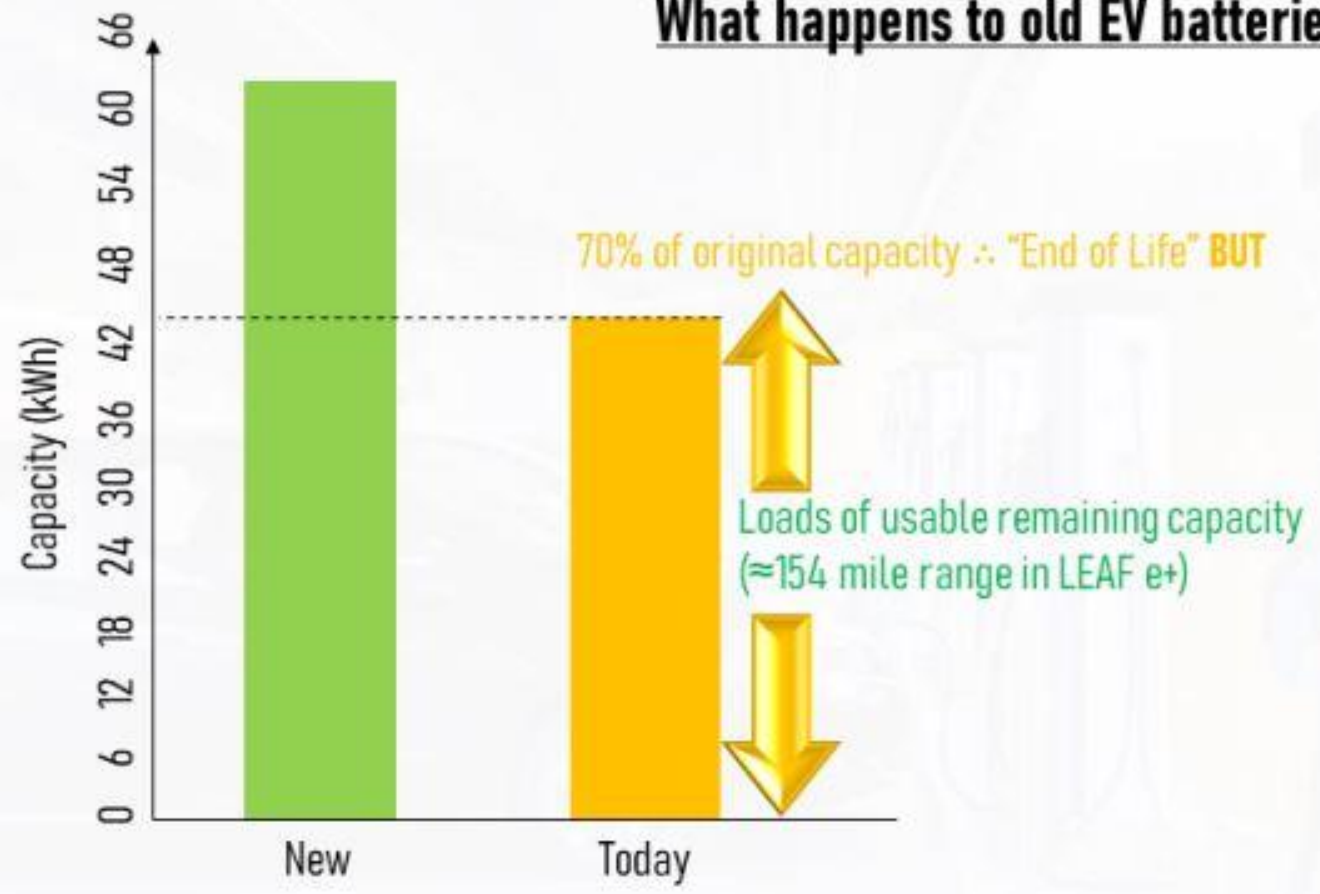


- More constant, less fluctuating power demand
- Lower power charge and discharge
- Less time spent at 100% SOC - better for battery health (NMC/NCA batteries, i.e. most EVs today)

“What happens to EV batteries when they die?”

They get reused, then recycled

# What happens to old EV batteries: reuse

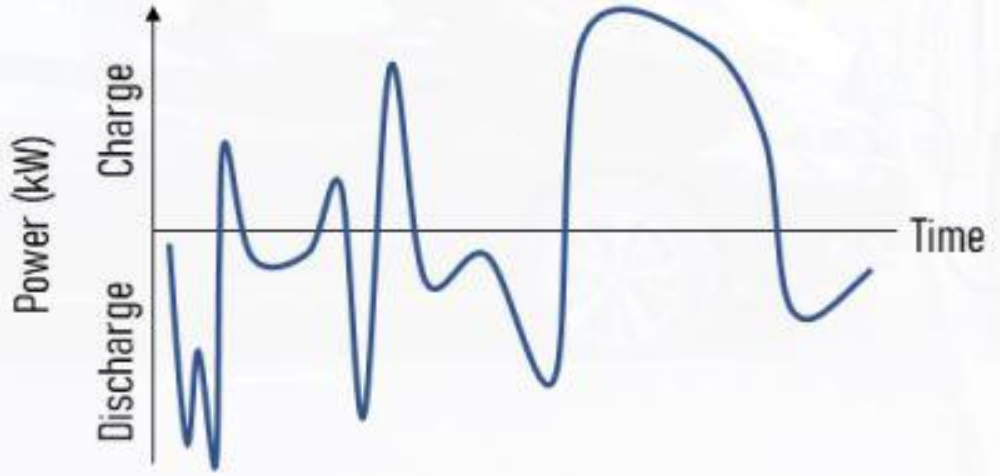


End of Life for electric vehicle battery pack  
= 70% State of Health (SOH)  
= 70% of original capacity

Reuse old EV modules and batteries in energy storage



# Energy storage: an easy life for old EV batteries



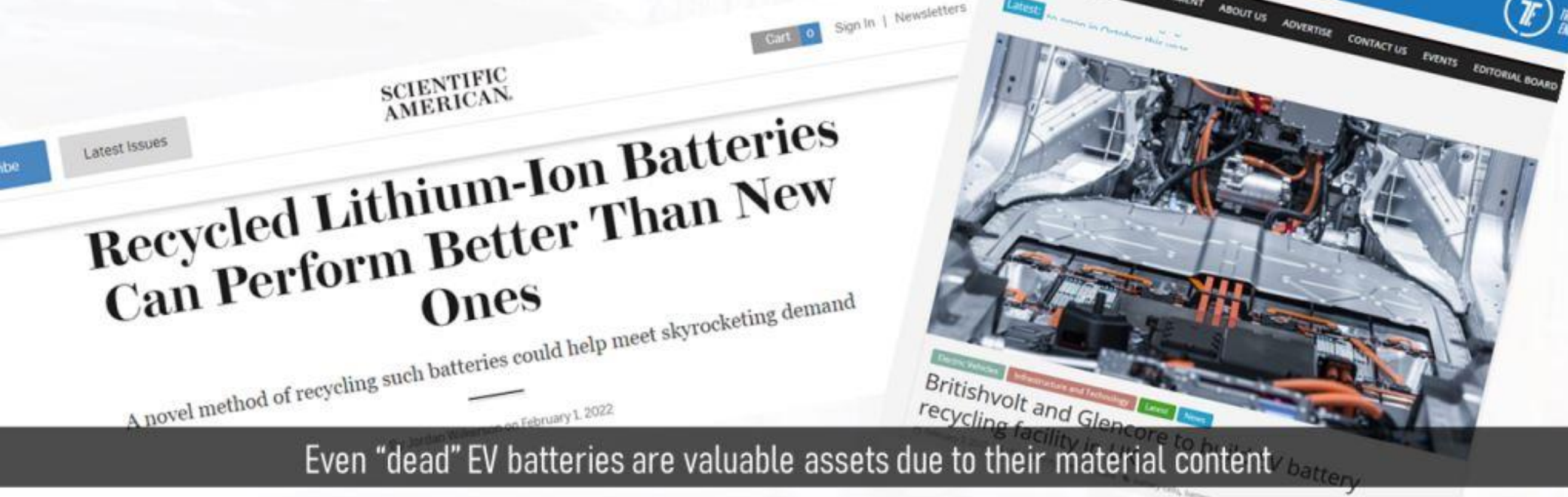
- Very dynamic: constantly changing power demand
- High power acceleration, regenerative braking and rapid charging
- A hard life for batteries, but modern EV batteries are still likely to last as long as the car



- More constant, less fluctuating power demand
- Lower power charge and discharge
- A very easy life for an old battery, which reduces its rate of degradation and gives it many more years of useful life

# EV battery recycling

- Increasingly efficient: latest techniques recover up to 100% of battery materials
- Batteries made from recycled materials shown to perform better than batteries made from new materials
- EV battery recycling not done in large volumes yet because there aren't large volumes of batteries to recycle yet – they're all still going strong in EVs!
- Over 100 companies working globally to scale up recycling facilities ahead of first wave of End of Life EV batteries



Even "dead" EV batteries are valuable assets due to their material content

“How can I tell the State of Health of the battery in an EV that I am selling?”

It can sometimes be tricky...

# SOH diagnosis in a used electric vehicle

The certain way:



- Remove battery from vehicle
- Connect battery to battery cycler
- Fully charge battery
- Fully discharge battery and measure capacity

✓ Accurate

✗ Time-consuming  
Requires specialist equipment



## SOH diagnosis in a used electric vehicle

The practical way:



- Take SOH reading from dashboard – BMS tracks SOH using inbuilt algorithm

### **BUT**

- Only Mk1 LEAFs show SOH on dashboard
- LEAF SOH algorithm needs to be taken with pinch of salt

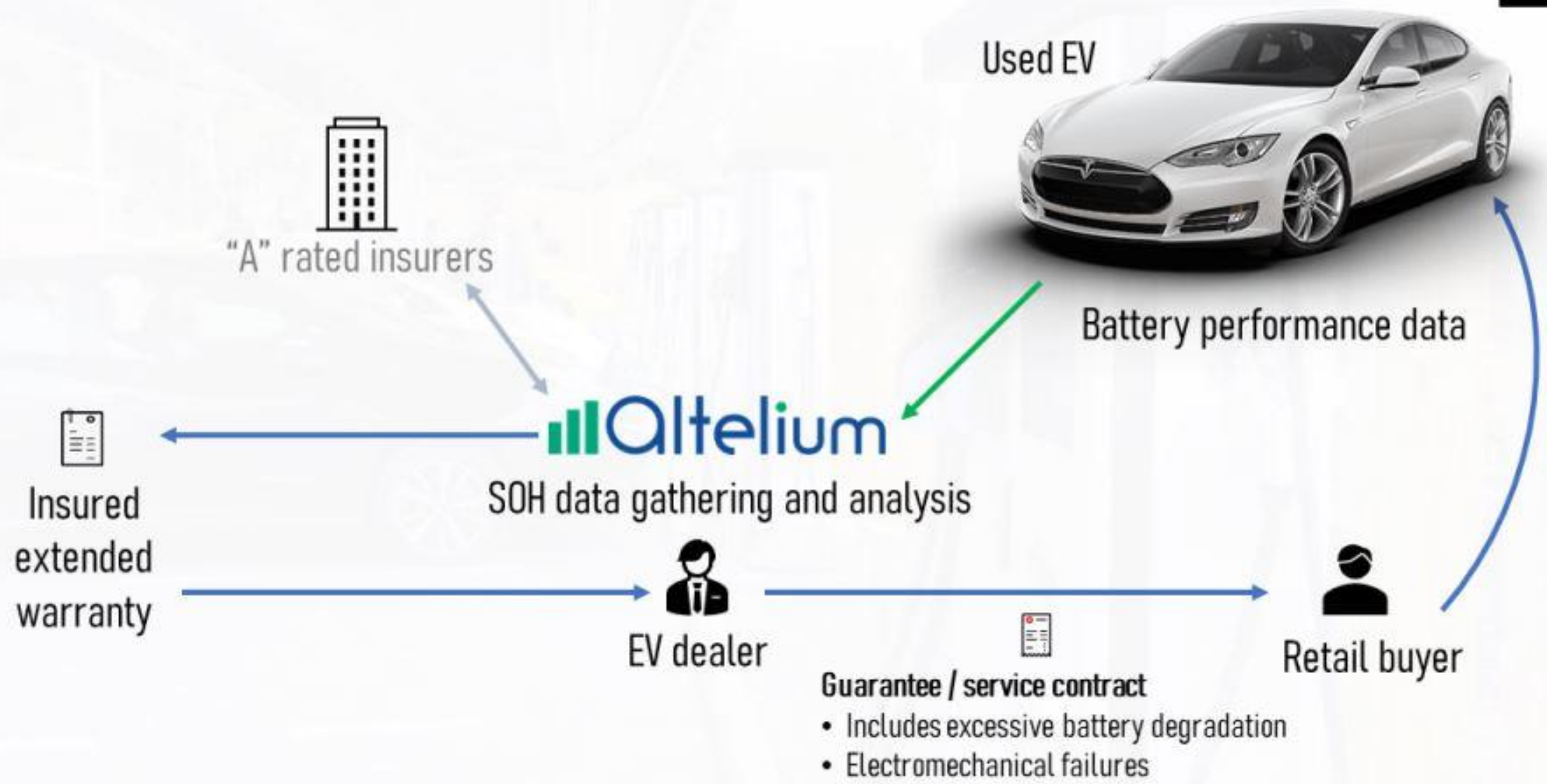
### **OTHER EVs?**

- SOH sometimes obtainable from CAN bus, but not always reliable/accurate
- Some companies offer SOH tests, but knowledge of battery variations in the “same” make and model of EV is important – otherwise results are skewed



If this problem can be resolved, then valuable products and services can be offered to EV owners...

# Altelium's solution: EV Battery Extended Warranty



Altelium has shown great attention to detail regarding the specifics of different model variants of the same EV

# Plug Life

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Television

Now on YouTube

<https://www.youtube.com/c/pluglifetelevision>



**Thank you**

**[consulting@pluglifetelevision.co.uk](mailto:consulting@pluglifetelevision.co.uk)**