Findings from the EV-elocity project on the impact of V2G on battery degradation

Project 104250

Funded by:

Department for Business, Energy & Industrial Strategy

Office for Low Emission Vehicles

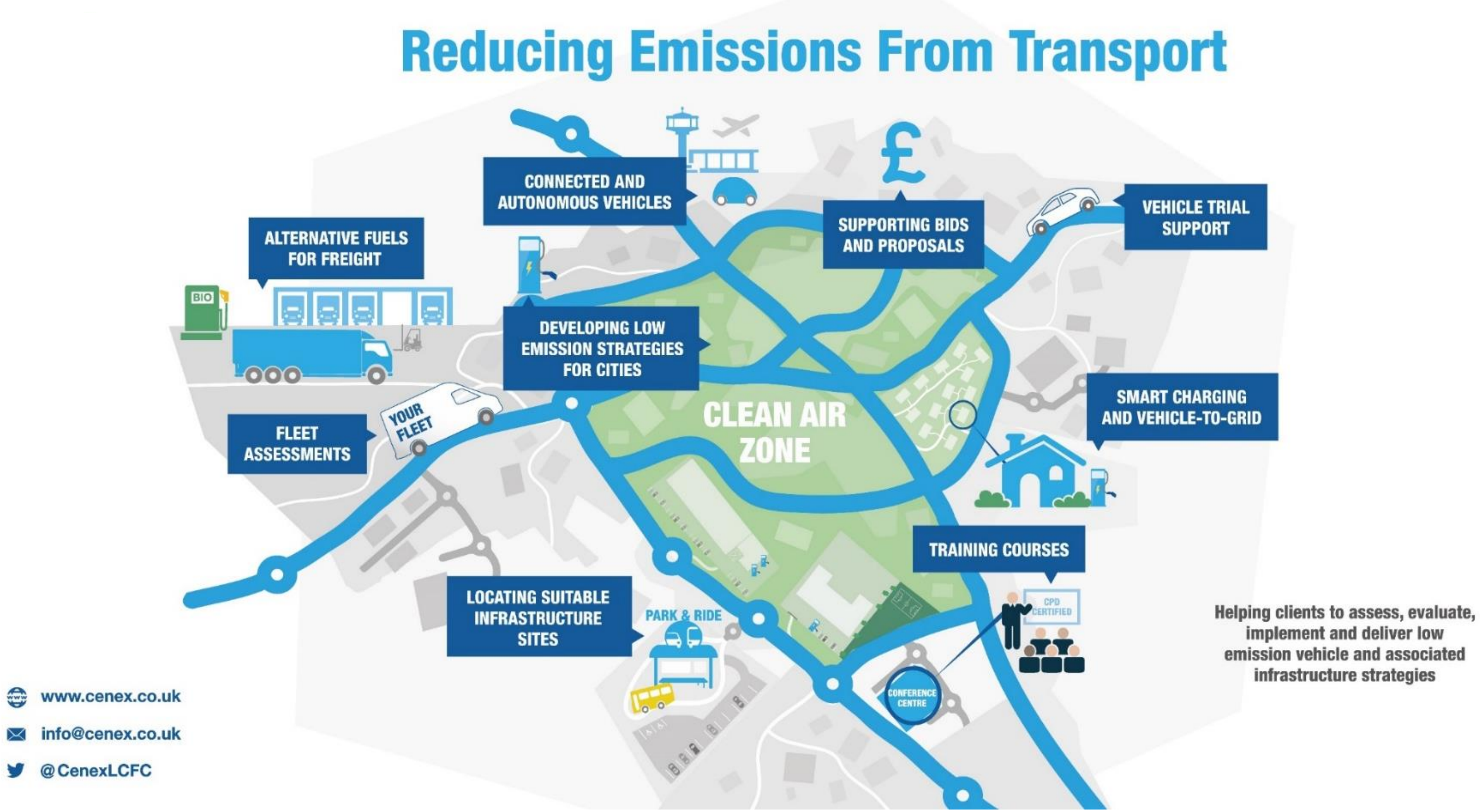
Innovate UK

About Cenex

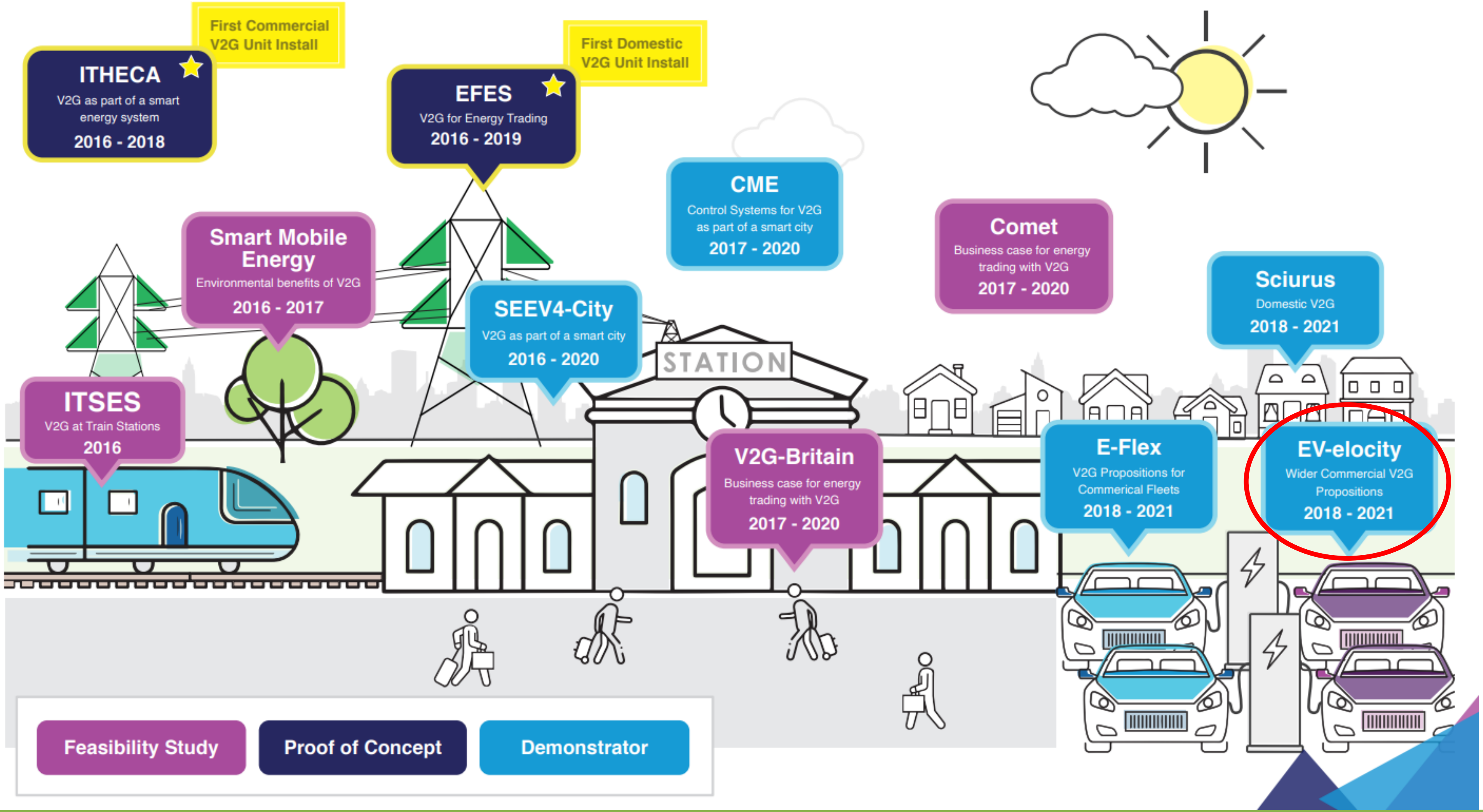
We are the UK's Center of Excellence for low carbon and fuel cell technologies.

A non-profit, independent research and consultancy organisation.

Offices in Loughborough, Edinburgh and Amsterdam.



Cenex has a long history of involvement in UK V2G



Focus of today

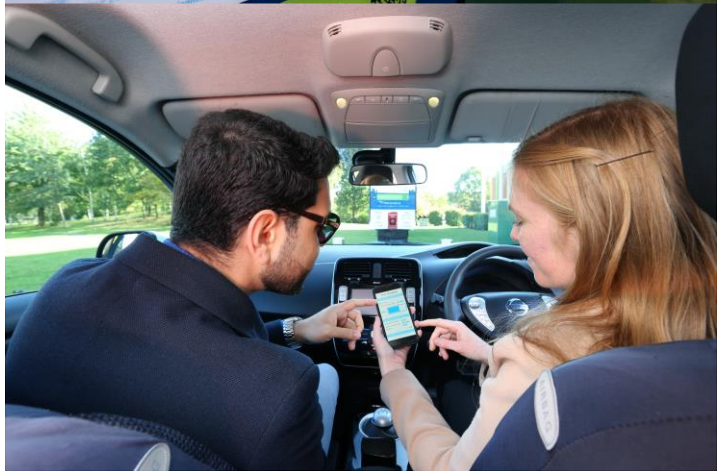
Project Summary: Exploring cost, carbon and conditioning benefits behind the meter

Overall summary:

EV-elocity aims to demonstrate vehicle-to-grid in a range of real-world situations to gain technical, customer and commercial insights into this emerging technology

5 main aims:

1. Deploy a technology-agnostic backend system and user interface to manage and operate V2G units
2. Demonstrate V2G across a range of UK locations, collecting data on charger, user and vehicle behaviour
3. Discover more about the user behaviour and operation of V2G
4. Deepen understanding around the impacts of V2G on battery degradation
5. Develop an evidence-based techno-economic model of the viability and value of V2G within the UK



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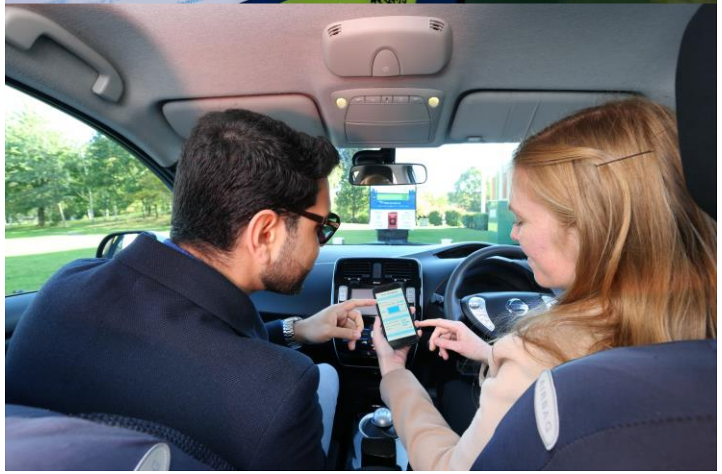


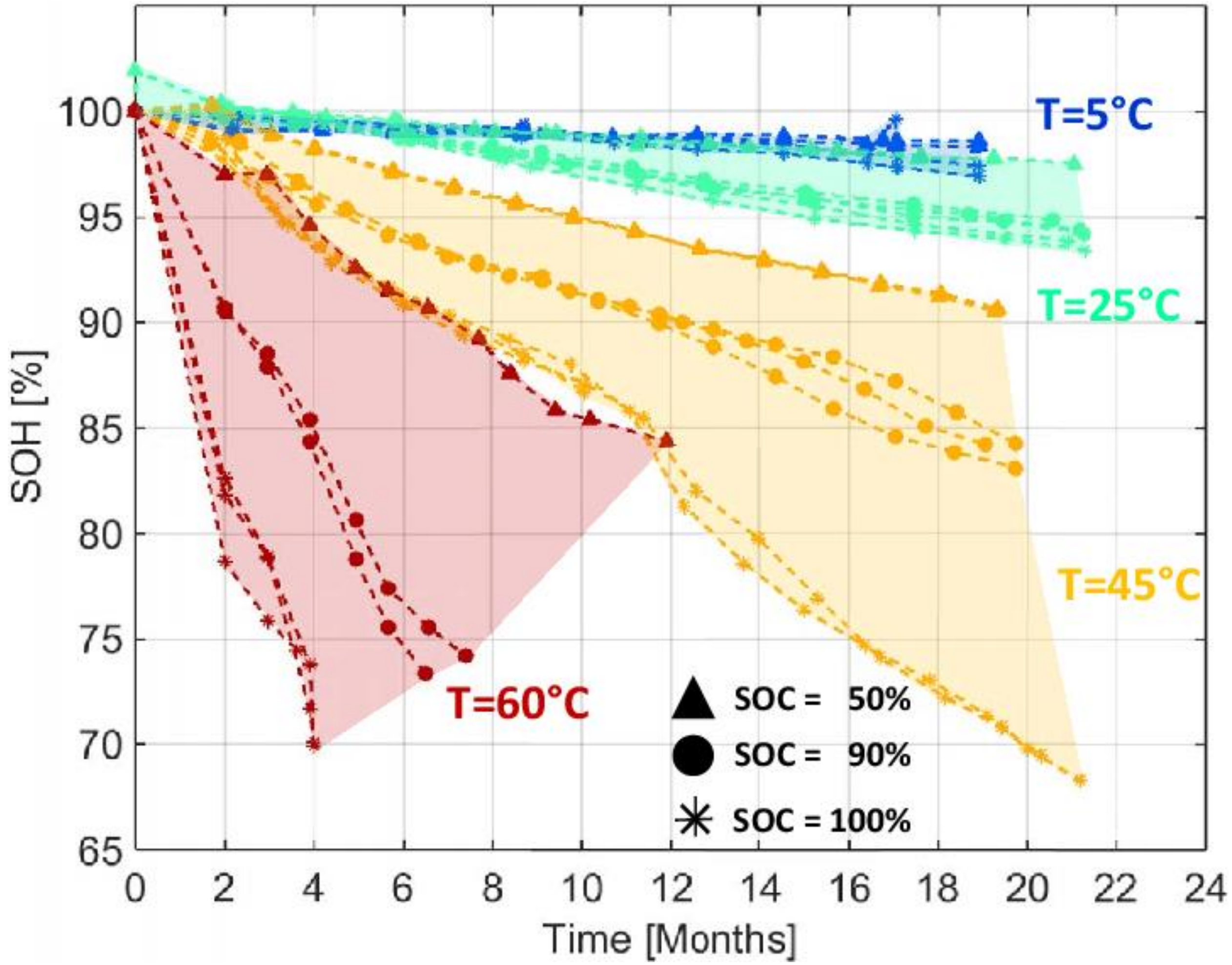
Performance of lithium-ion batteries declines with use and time

TIME – "Calendar Aging"

- Batteries age degrade over time, even when not used

- Greater environmental <u>temperature</u> causes greater degradation

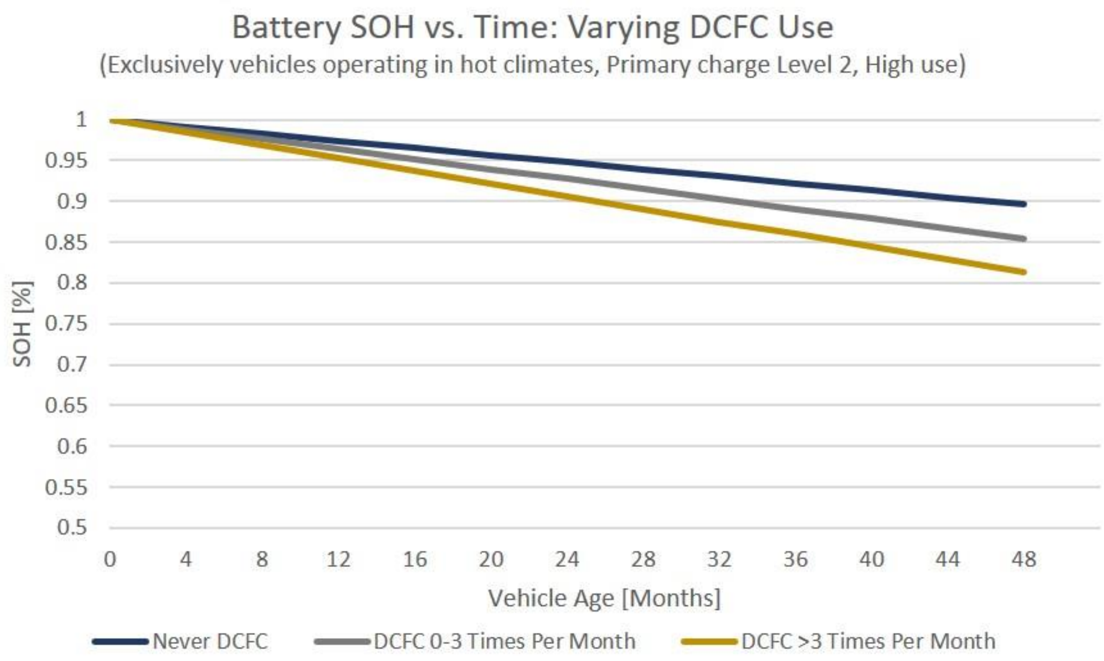
- Greater storage <u>state of charge</u> causes greater degradation



Performance of lithium-ion batteries declines with use and time

USE – "Cyclic Aging"

- Battery degrades over time due to use
- More extreme uses cause greater degradation (i.e. harsh acceleration or rapid charging)
- Greater mileage causes greater degradation
- Specific behaviour will depend on the battery chemistry and a combination of usage factors



Prior work

Dubarry et al 2017, Hawaii:

- Results show that additional cycling to discharge vehicle batteries to the power grid, even at constant power, is detrimental to cell performance.
- This additional use of the battery packs could shorten the lifetime for vehicle use to less than five years.

Uddin et al 2017, University of Warwick

- If a daily drive cycle consumes between 21% and 38% state of charge, then discharging 40%–8% of the batteries state of charge to the grid can reduce capacity fade by approximately 6% and power fade by 3% over a three month period.

Uddin and Dubarry 2018, Joint:

- The authors of these two major studies jointly reconcile their previous conclusions by providing clarity on how methodologies to manage battery degradation can reliably extend battery life.
  - Hawaii cycles are not realistic, cycling is unintelligent, results may be due to chemistry
  - Warwick model is not applicable in real-life, is not dynamic and is based on simulation
- In other words: it depends…

Research approach

Objectives:

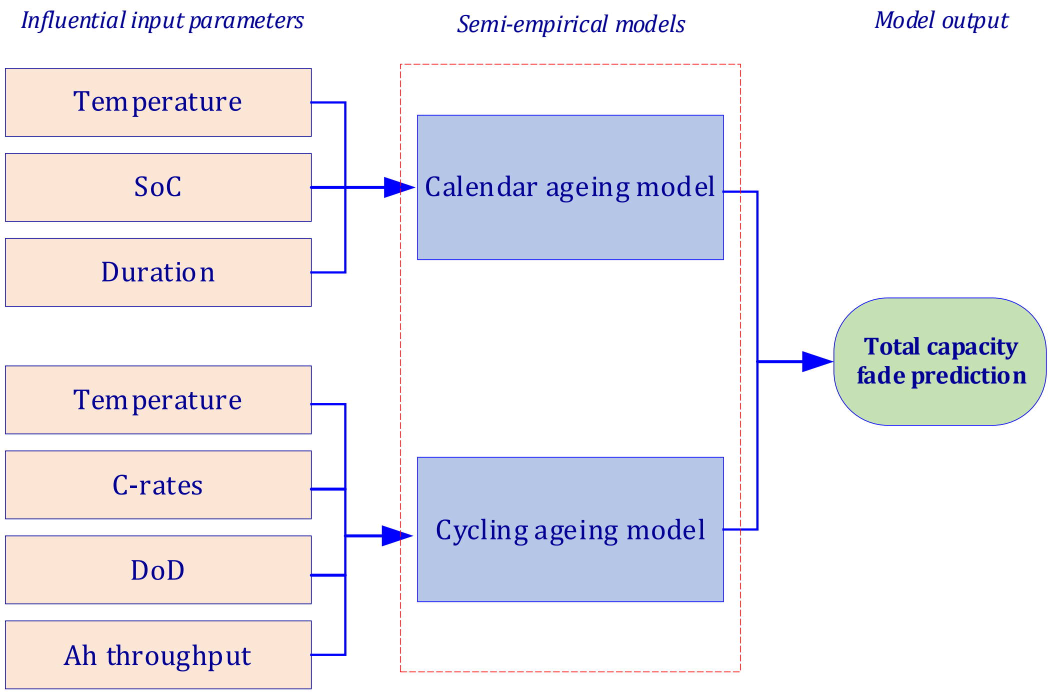
- Can EV batteries be pre-conditioned to minimize degradation through charging?
- Can the pre-conditioning strategies include options for V1G and V2G use cases?

Approach

- Degradation models developed to predict the lifetime capacity loss of the battery
- Semi-empirical approach selected due to fast and accurate capacity calculation
- Models trained and verified on historical aging datasets

Application

- Apply benefit to V2G strategies



Note: Nickel Manganese Cobalt Oxide ($LiNiMnCoO_2$) Cylindrical cells used for the test

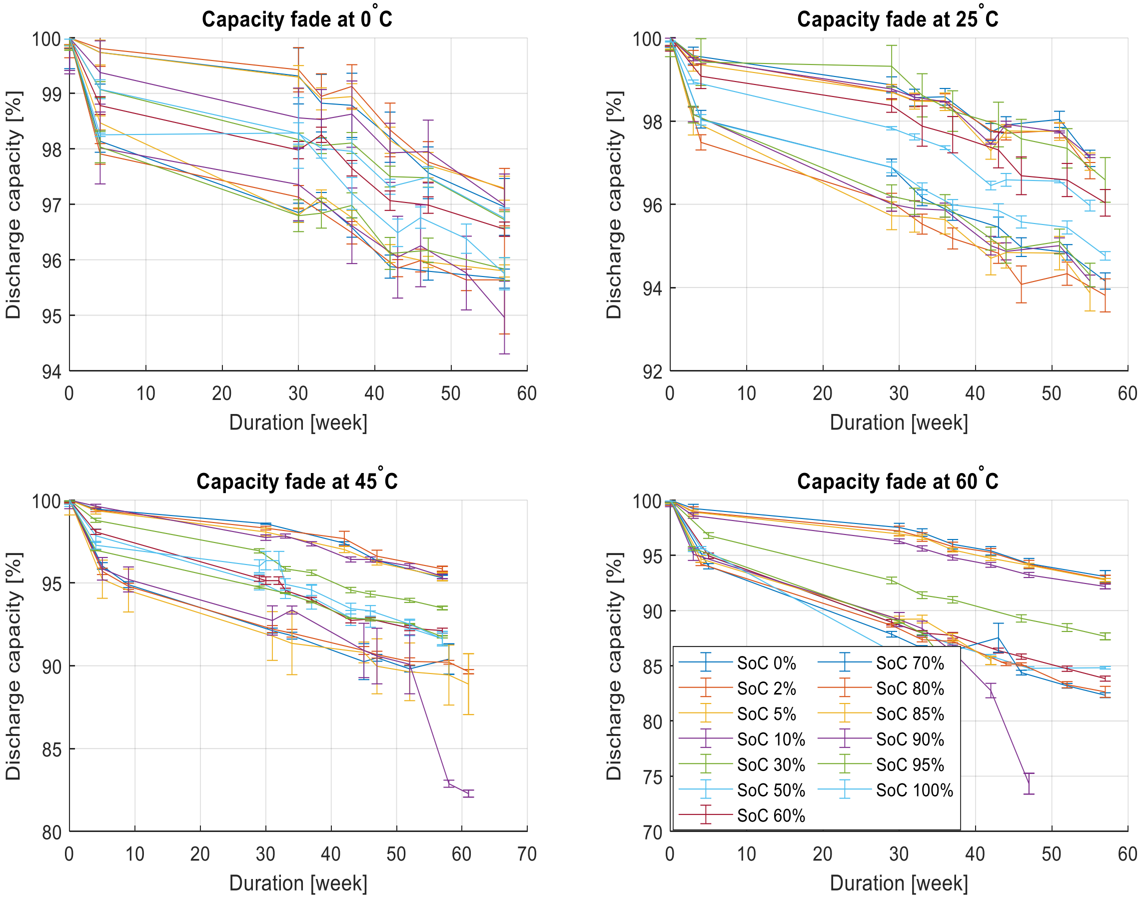
Training datasets used to create calendar aging model

Training dataset – calendar capacity loss

Calendar ageing test matrix

SoC (%)	Storing temperature (^{0}C)			
	0	25	45	60
0	3 cells	3 cells	3 cells	3 cells
2	3 cells	3 cells	3 cells	3 cells
5	3 cells	3 cells	3 cells	3 cells
10	3 cells	3 cells	3 cells	3 cells
30	3 cells	3 cells	3 cells	3 cells
50	3 cells	3 cells	3 cells	3 cells
60	3 cells	3 cells	3 cells	3 cells
70	3 cells	3 cells	3 cells	3 cells
80	3 cells	3 cells	3 cells	3 cells
85	3 cells	3 cells	3 cells	3 cells
90	3 cells	3 cells	3 cells	3 cells
95	3 cells	3 cells	3 cells	3 cells
100	3 cells	3 cells	3 cells	3 cells

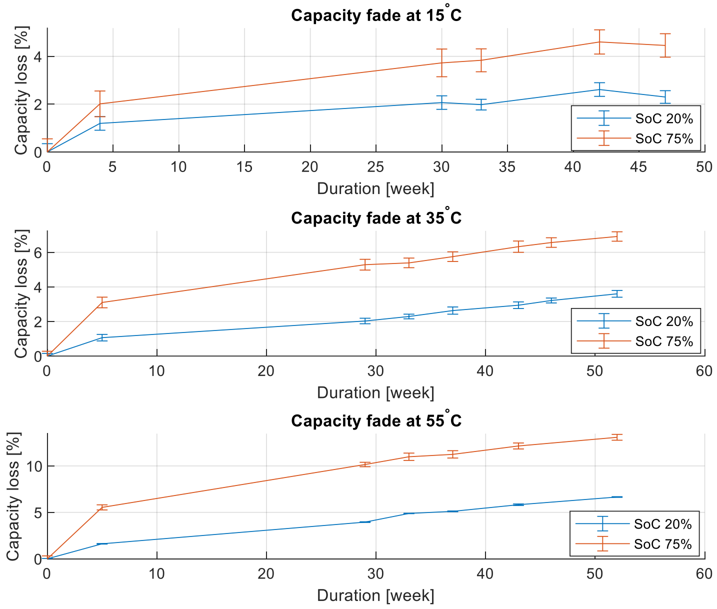
Reference test case



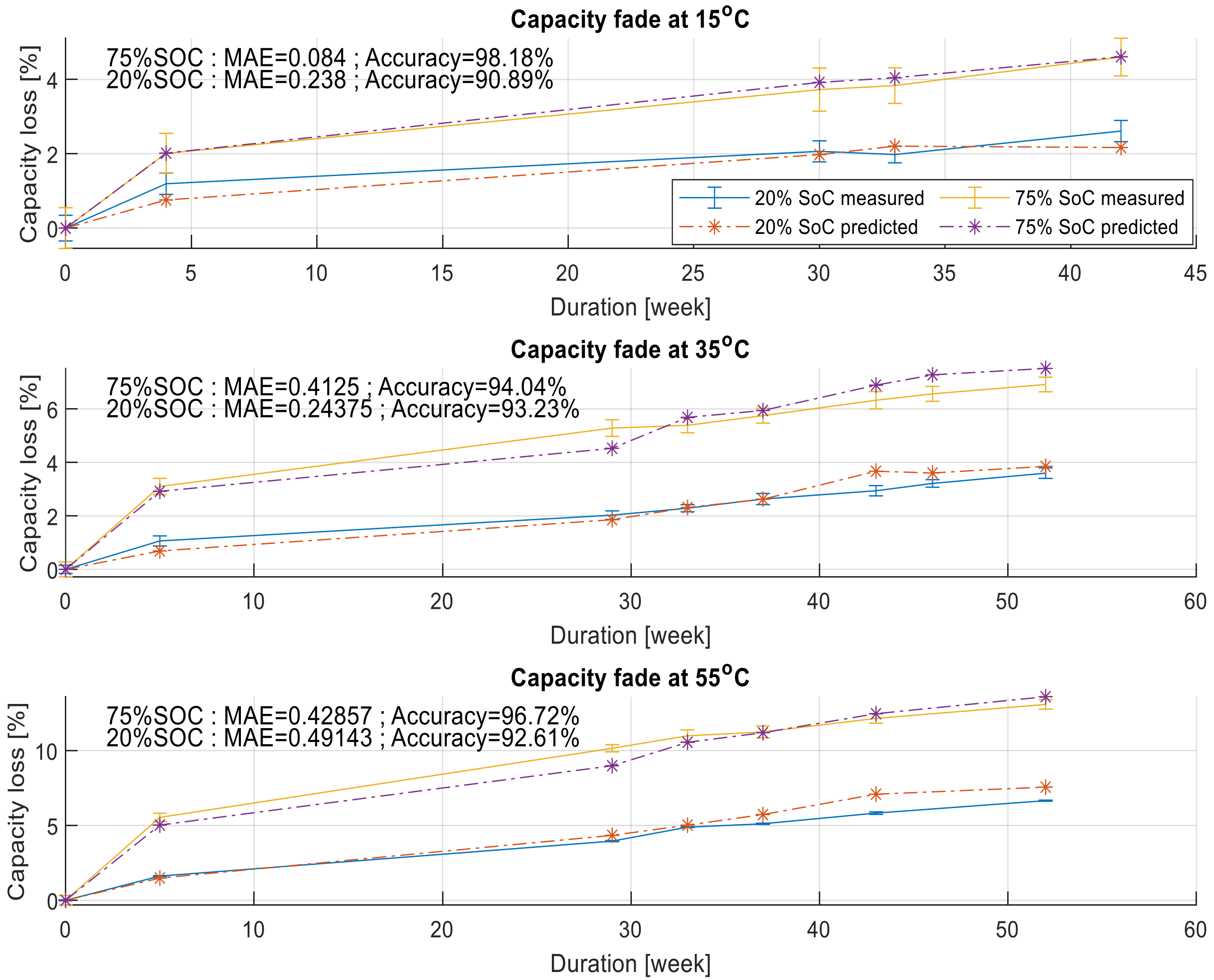
Testing dataset – calendar capacity loss

Calendar ageing test matrix

SoC (%)	Storing temperature (^{0}C)		
	15	35	55
20	3 cells	3 cells	3 cells
75	3 cells	3 cells	3 cells



Then the calendar aging model was tested



- Linear interpolation is used to predict the calendar ageing at any specific ageing condition (storing SoC, temperature, duration).
- Linear extrapolation is used to predict the capacity loss beyond the tested data. However, limitation of linear extrapolation is the inaccuracy due to more non-linear end of life region associated with cell ageing.
- The testing accuracy is varied within 90.89 ~ 98.18%

Then the cyclic ageing model was trained and tested

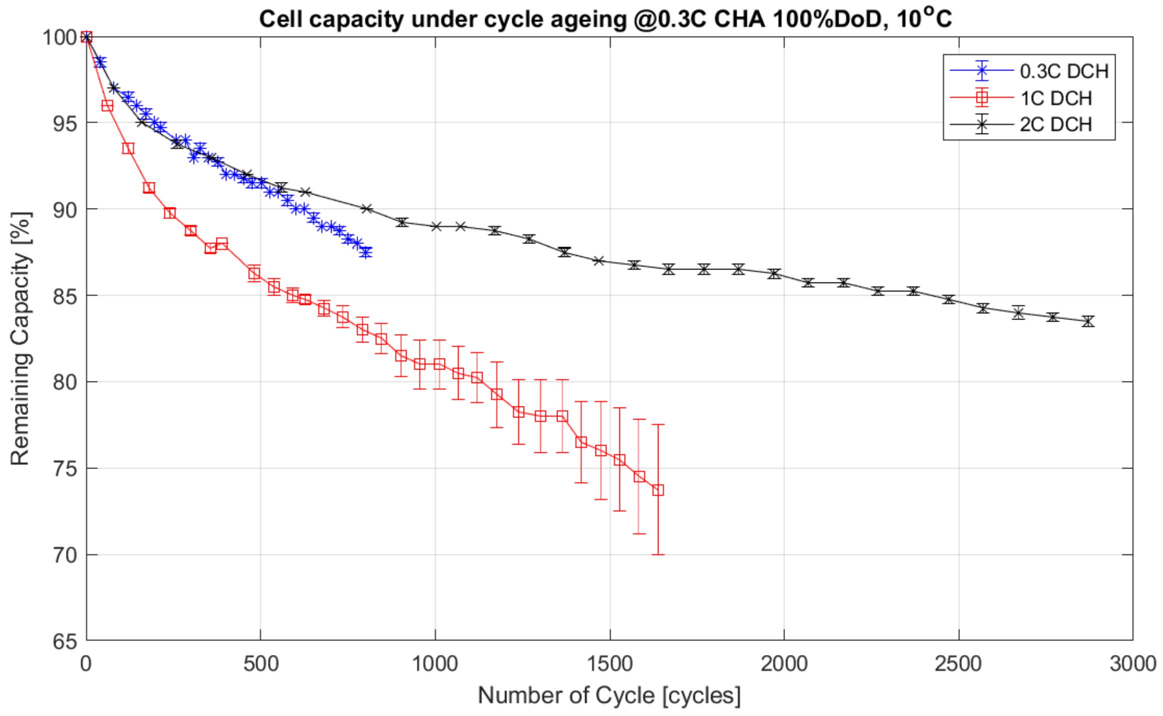
T (^{0}C)	C-rates		
	0.3C Charge 0.3C Discharge	0.3C Charge 1C Discharge	0.3C Charge 2C Discharge
0	3 cells	3 cells	3 cells
10	3 cells	3 cells	3 cells

Cycling ageing dataset
(for training and testing)

Because of the lack of historical ageing data for verifying of the cycling ageing model.

-> For model training and testing purposes, a ratio of historical ageing data (in %) is examined to evaluate the modeling accuracy.

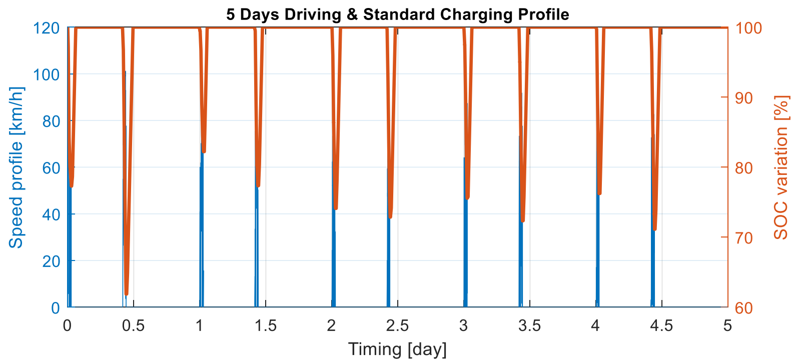
-> Polynomial curve fitting method used for testing purposes.

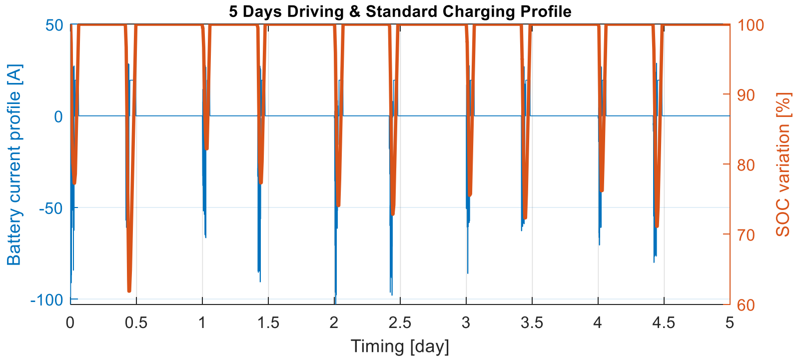


Preconditioning

Gentle driving profile

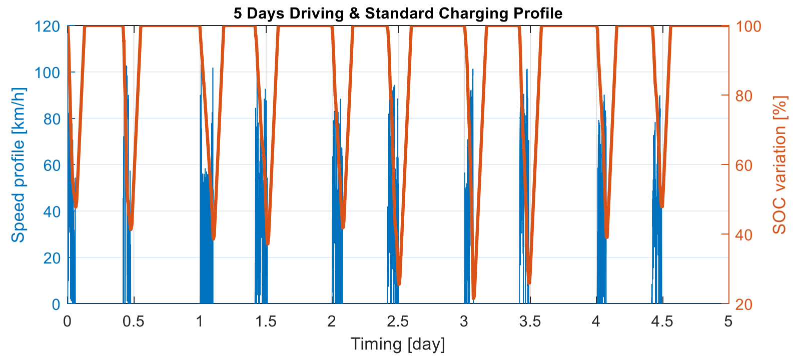
- Mileages of each trip/day is about 20-40 miles
- Starting SoCs are between 60-80%

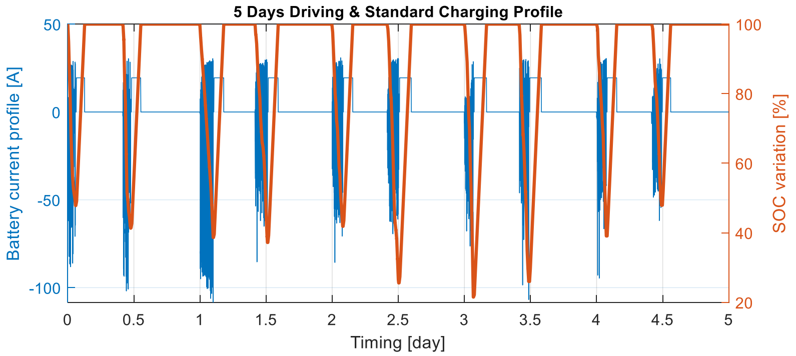




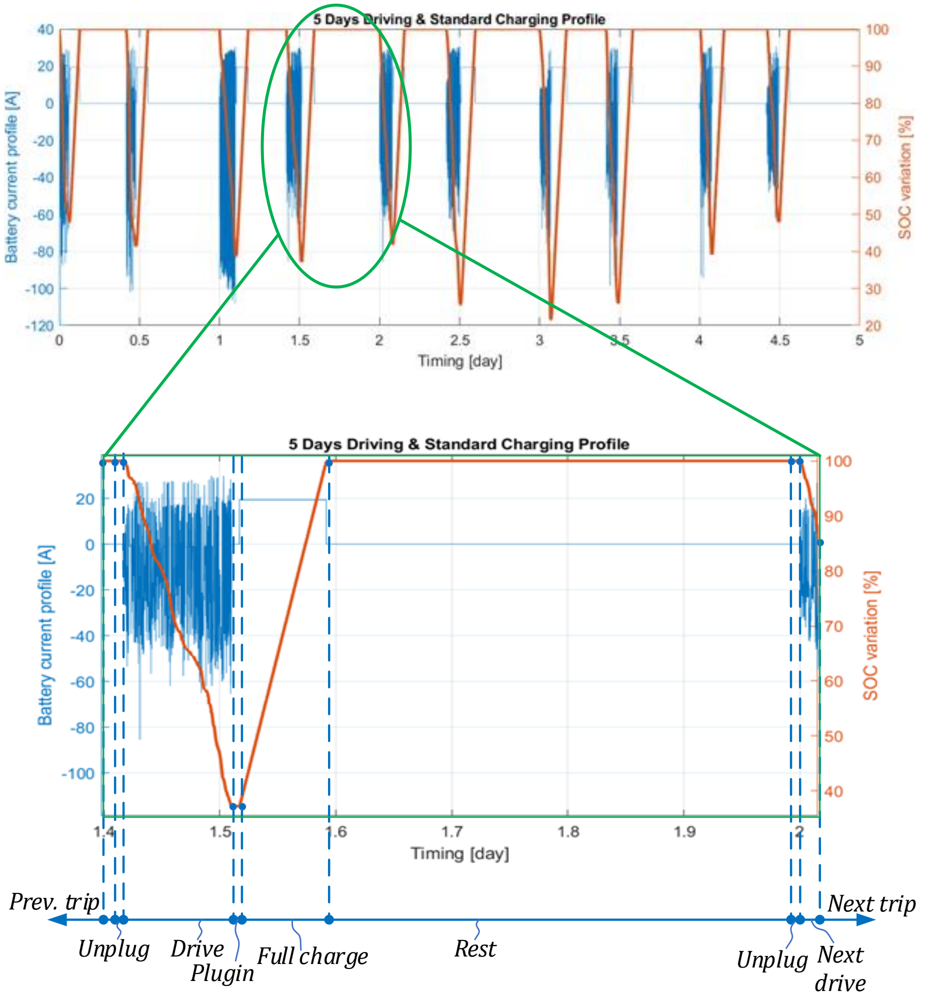
Intensive driving profile

- Mileages of each trip/day is about 50-90 miles
- Starting SoCs are within 20-50%





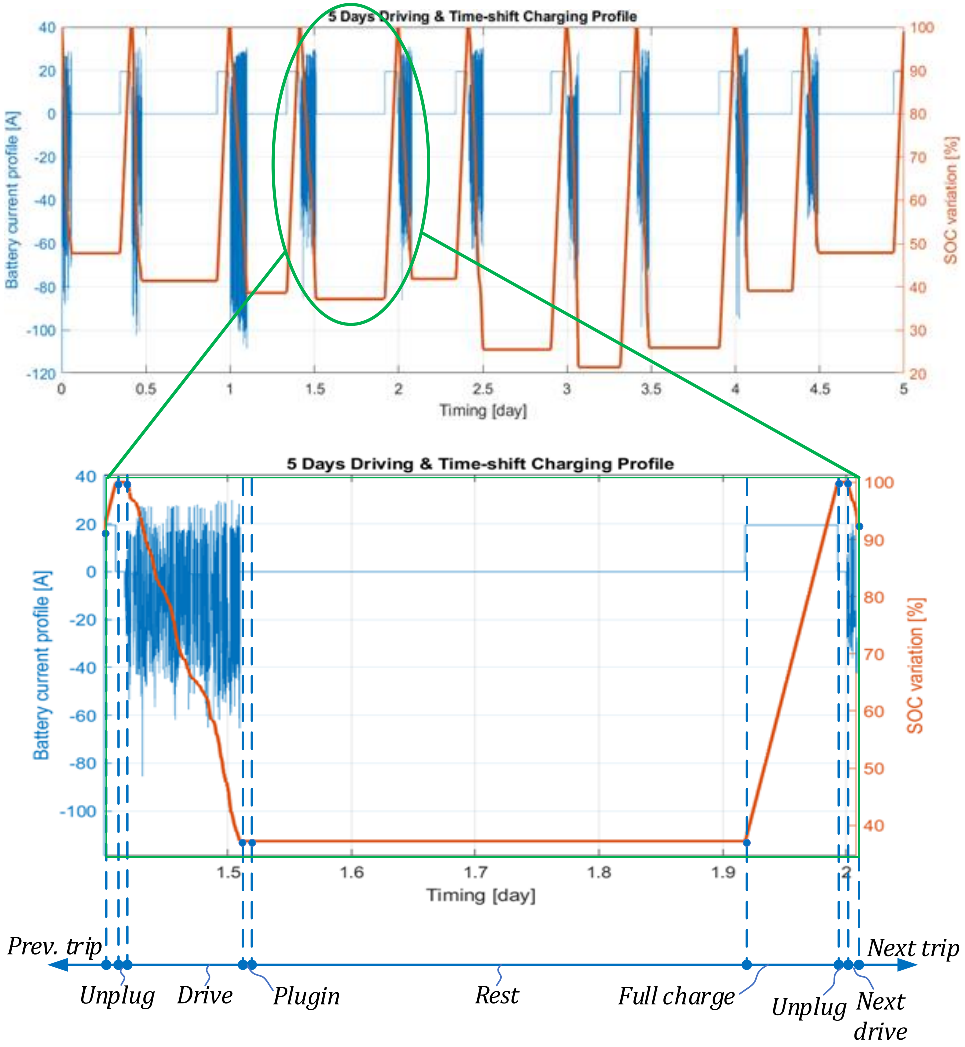
Strategy 1 – STA CHA



Standard “dumb” charging

- Conventional “dumb” charging.
- EV battery is fully charged as soon as it is connected to the charger, then left at 100% SoC until departure

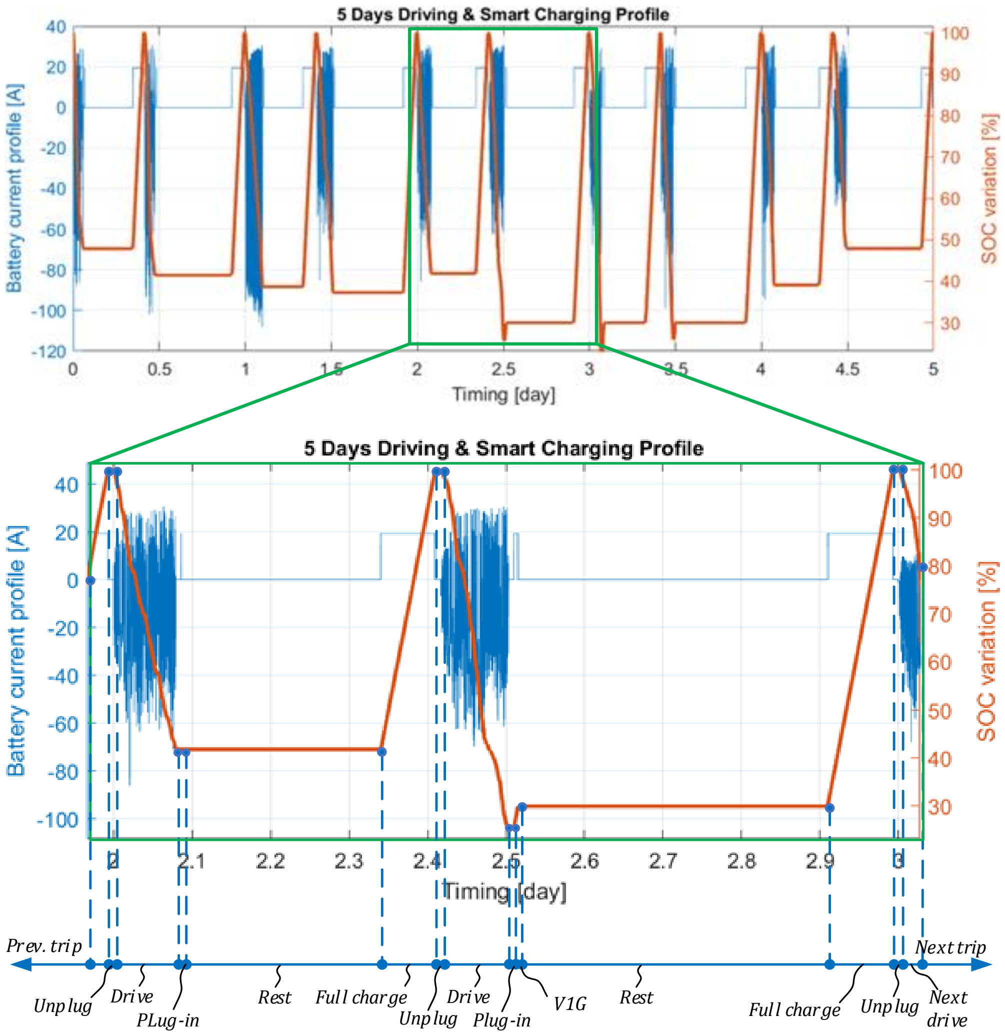
Strategy 2 – TS CHA



Time-shifted Charging

- Smart-charge method with delayed charging.
- EV battery is left at SoC and is charged at appropriate time to be 100% at departure.

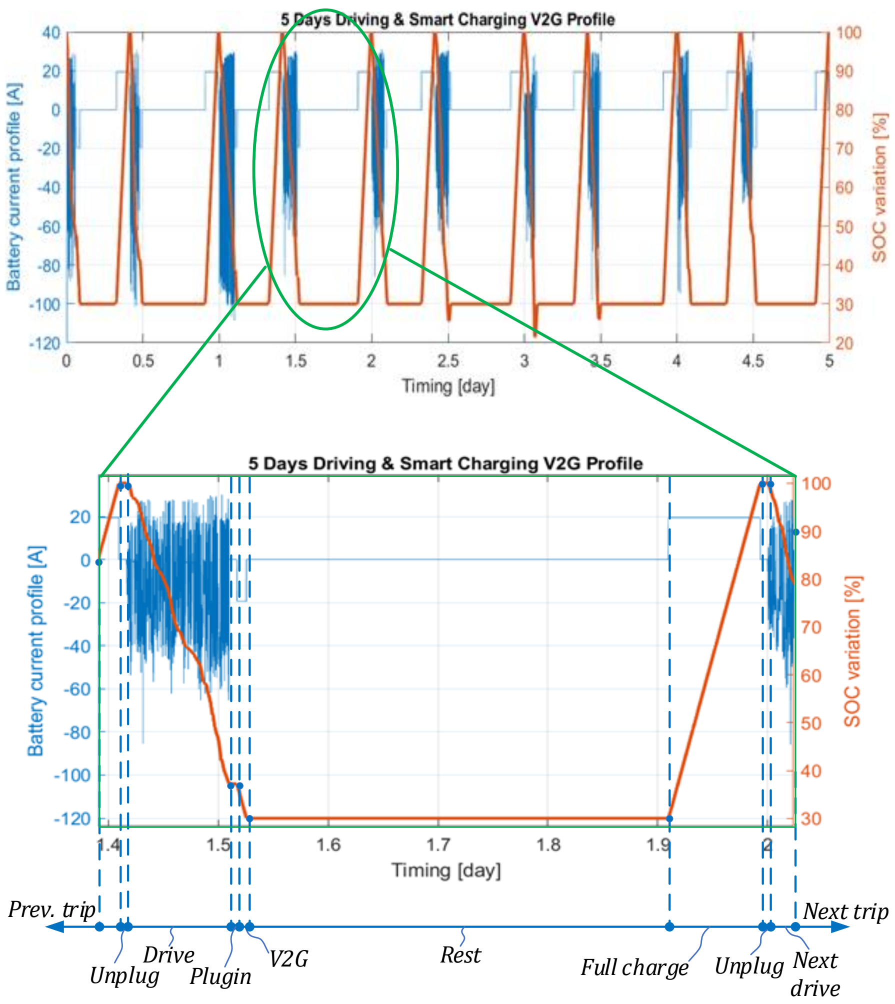
Strategy 3 – SC V1G



Smart charge V1G

- Smart charging without feeding back into the grid.
- EV battery is left resting at SoC (or an SoC with smaller calendar aging rate), then charged at an appropriate time to be 100% at departure

Strategy 4 – SC V2G



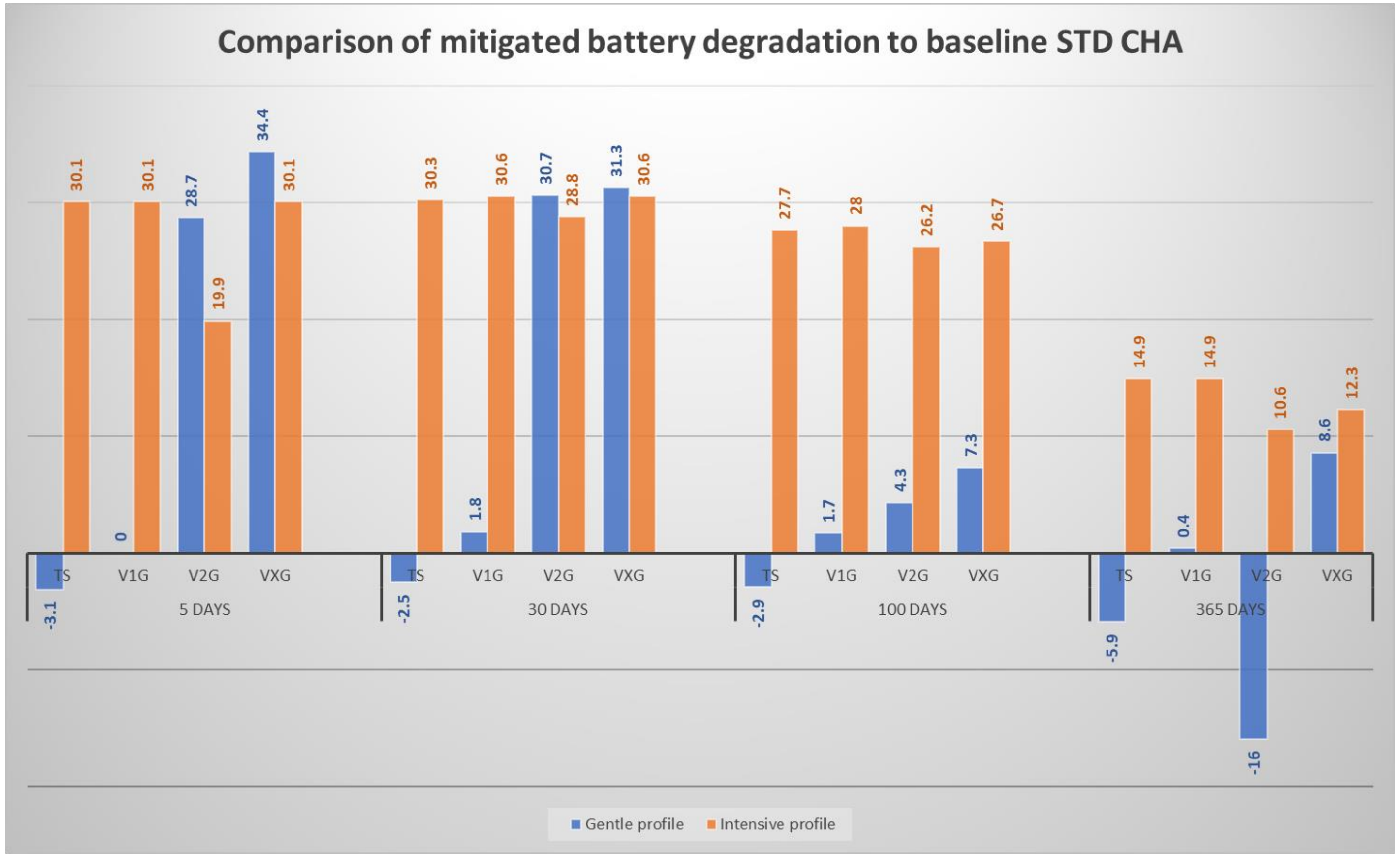
Smart charge V2G

- Smart bi-directional charging.
- EV battery is discharged to the SoC with lowest calendar aging rate, then charged at an appropriate time to be 100% at departure.

Preconditioning Strategies

Strategy	Explanation
Standard Charging Strategy **STA CHA**	Conventional “dumb” charging. EV battery is fully charged as soon as it is connected to the charger, then left at 100% SoC until departure
Time-shifted Charging **TS CHA**	Smart-charge method with delayed charging. EV battery is left at SoC and is charged at appropriate time to be 100% at departure.
Smart charge V1G **SC V1G**	Smart charging without feeding back into the grid. EV battery is left resting at SoC (or an SoC with smaller calendar aging rate), then charged at an appropriate time to be 100% at departure
Smart charge V2G **SC V2G**	Smart bi-directional charging. EV battery is discharged to the SoC with lowest calendar aging rate, then charged at an appropriate time to be 100% at departure.
Combined SC V1G + V2G **SC VxG**	A combination of SC V1G and SC V2G that considers the trade-off having extra cyclic aging to achieve optimal SoC vs reduction of calendar ageing at optimal SoC

Results



Gentle profile (higher starting SoC)

- All pre-conditioning strategies improve battery life
- But V2G will degrade faster due to increased charge throughput
- VXG improves battery life because it balances aging modes

Intensive profile (lower starting SoC)

- All pre-conditioning strategies improve battery life
- Time-shifted charging provides the most gain for least complexity
- As battery ages, increased charging throughput to condition the battery starts to degrade the improvement

Results have been published

- Thanks to the WMG University of Warwick team, the results have been peer-reviewed and published

- **A Study of Reduced Battery Degradation Through State-of-Charge Pre-Conditioning for Vehicle-to-Grid Operations**
- Bui, Sheikh, Dinh, Gupta, Widanalage, Marco
- IEEE Access, Volume 9
- https://ieeexplore.ieee.org/document/9617644

Final Report

- Project Overview here: https://www.cenex.co.uk/case-studies/ev-elocity-case-study/

- Final Report available here: https://www.cenex.co.uk/app/uploads/2022/06/EV-elocity-Final-Report_published.pdf

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