# EFFECTS OF BI-DIRECTIONAL CHARGING ON THE ENERGY AND RANGE OF A 2018 MODEL YEAR BATTERY ELECTRIC VEHICLE

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Transport Canada / Transports Canada
Environment and Climate Change Canada / Environnement et Changement climatique Canada
NRC·CNRC
Natural Resources Canada / Ressources naturelles Canada
Office of Energy Research and Development / Bureau de recherche et de développement énergétiques
Canada

THIS IS A MODIFIED VERSION OF THE PRESENTATION GIVEN AT THE 36TH INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM

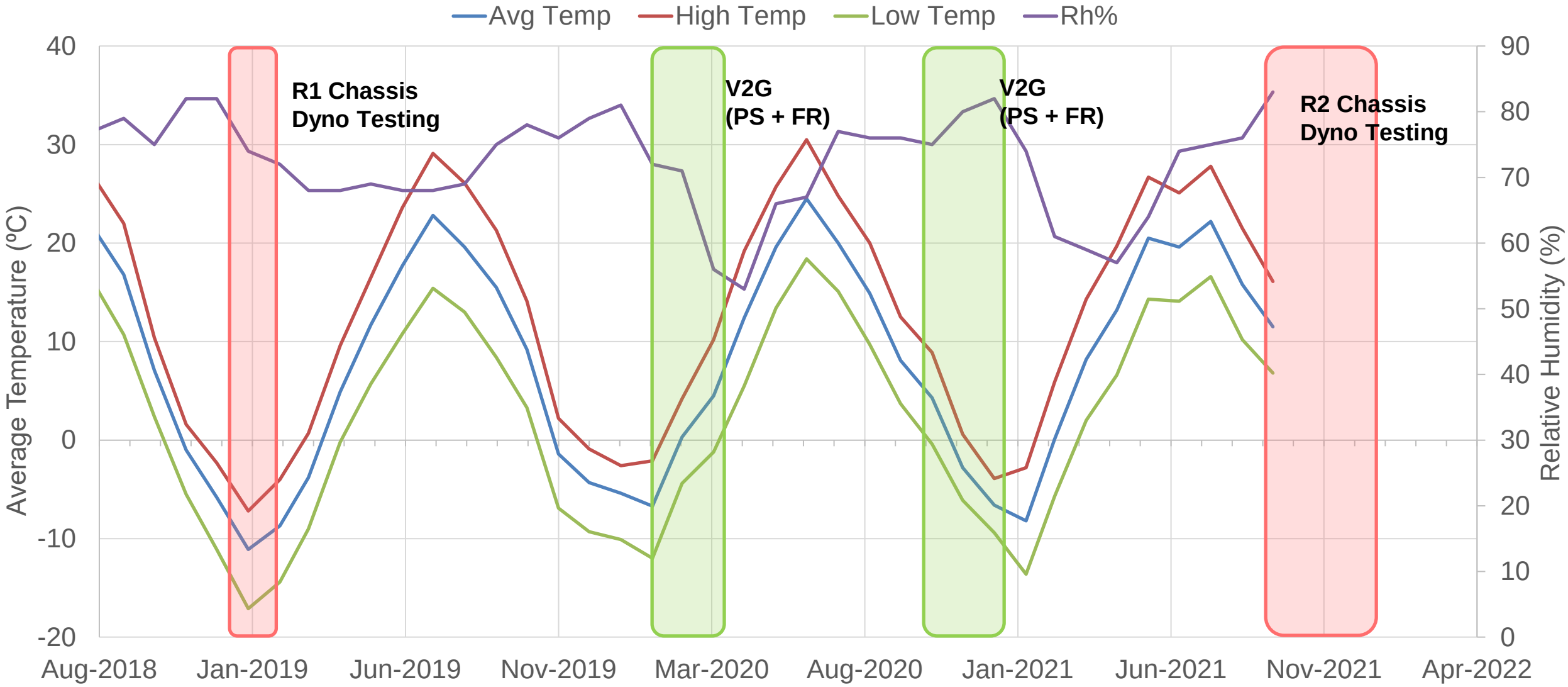
# PROJECT INCEPTION

- Bi-directional charging (BDC) is a burgeoning technology in BEV applications
- It can be a benefit to both BEV/building owners and grid operators
- Repeated charging and discharging from driving versus from bi-directional charging results in…differences?
- See Yeong Yoo (2021) on the Canadian National Research Council’s V2G portion of this study

# COLLABORATION AND DESIGN

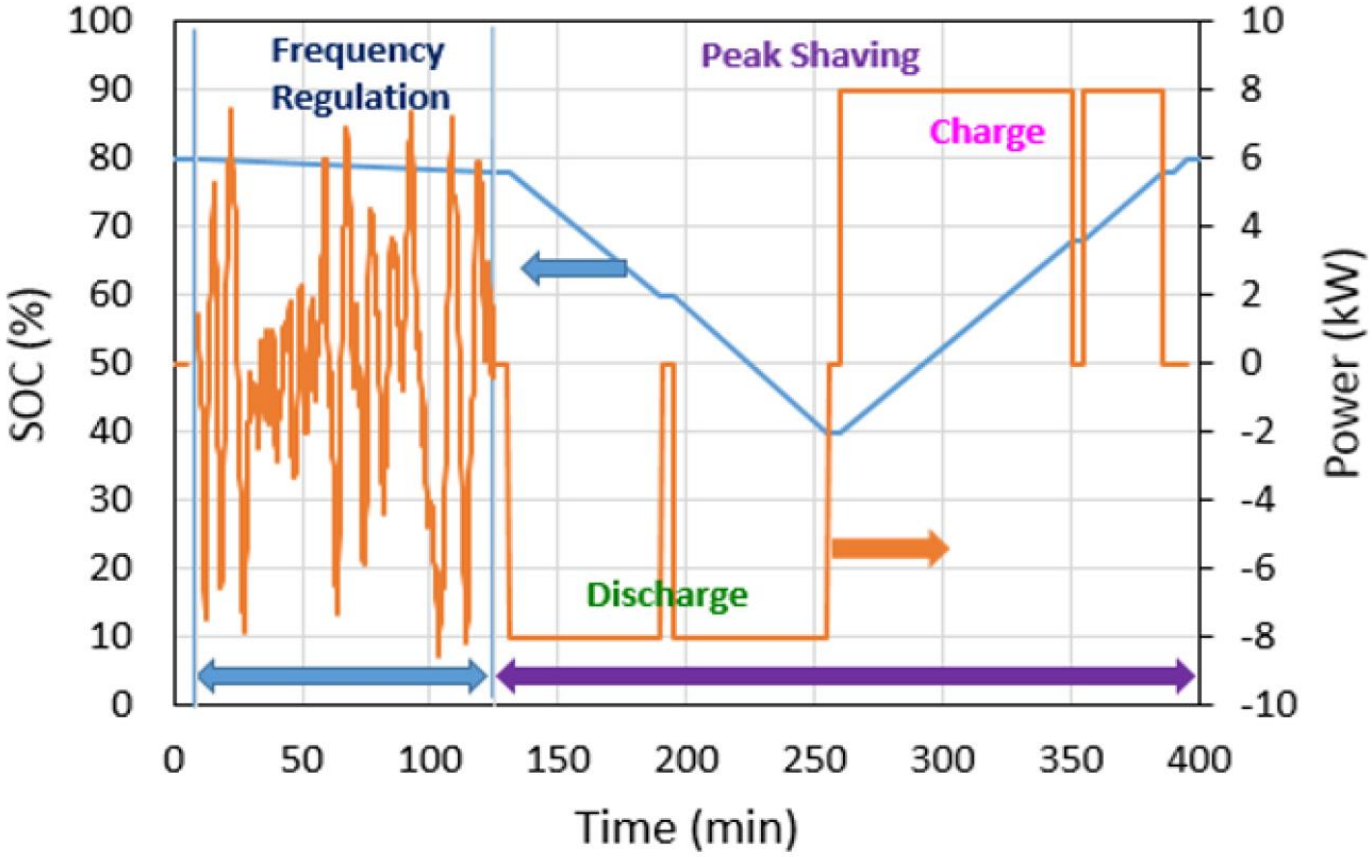
- **Transport Canada**:
  - Purchase two identical model 2018 BEVs: One Control BEV and one BDC BEV
  - Mileage accumulate and exercise BEVs and log OBD signals
- **National Research Council of Canada**:
  - BDC design and testing
- **Environment Canada**:
  - Chassis dynamometer testing at ‘break-in’ condition (Baseline)
  - Chassis dynamometer testing after BDC study (Round 2)

# STUDY TIMELINE AND WEATHER



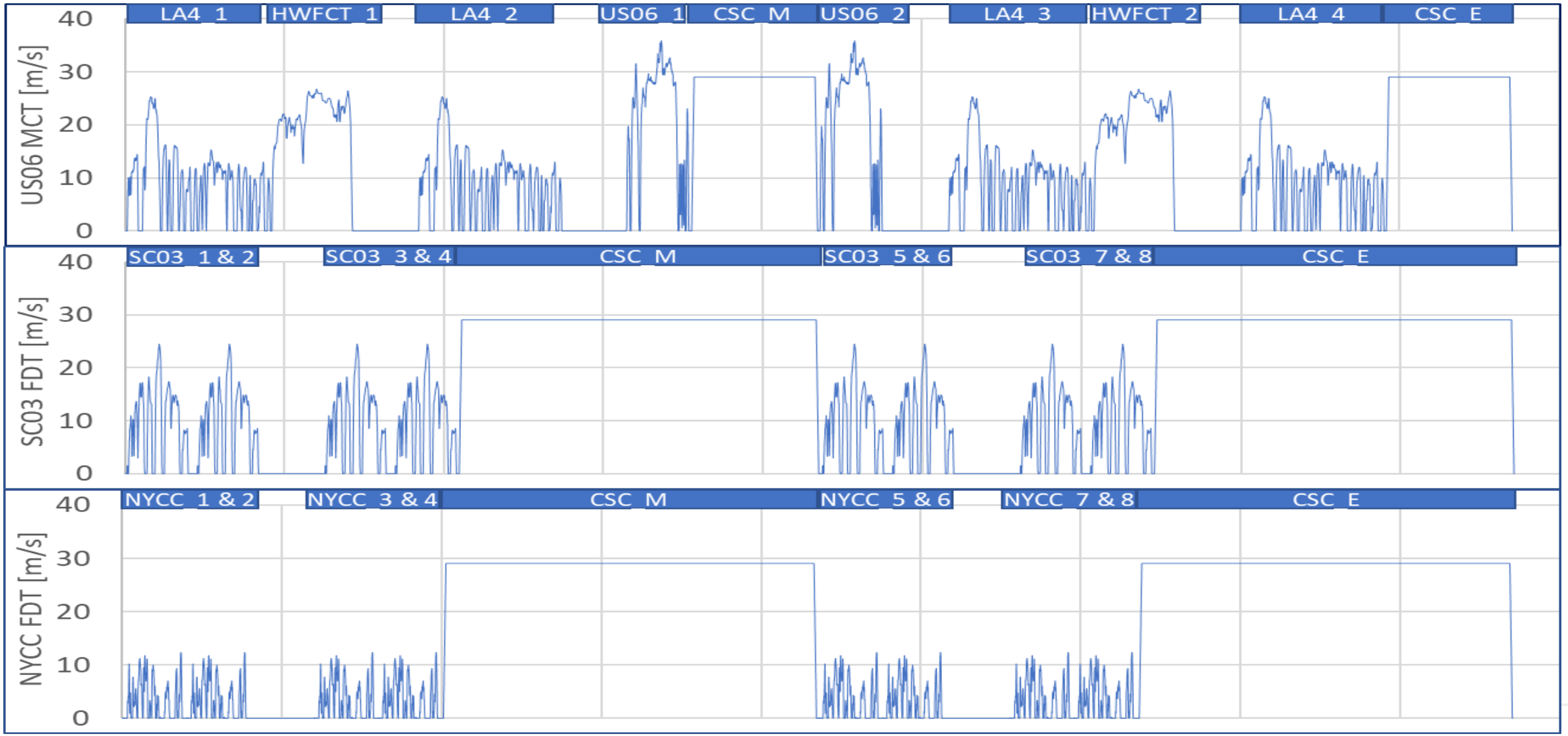
# BI-DIRECTIONAL CHARGING

- 10 kW DC fast bi-directional charger
- Conducted at the NRC's Canadian Centre for Housing Technology test facility (Ottawa, Canada)
- 220 FR and PS cycles
- 3.66 MWh discharged total
- 3.88 MWh charged total




Y. Yoo, Y. Al-Shawesh and A. Tchagang, "Coordinated Control Strategy and Validation of Vehicle-to-Grid for Frequency Control", *Energies*, **2021**, 14, 2530.

# DRIVE CYCLE TEST SEQUENCES

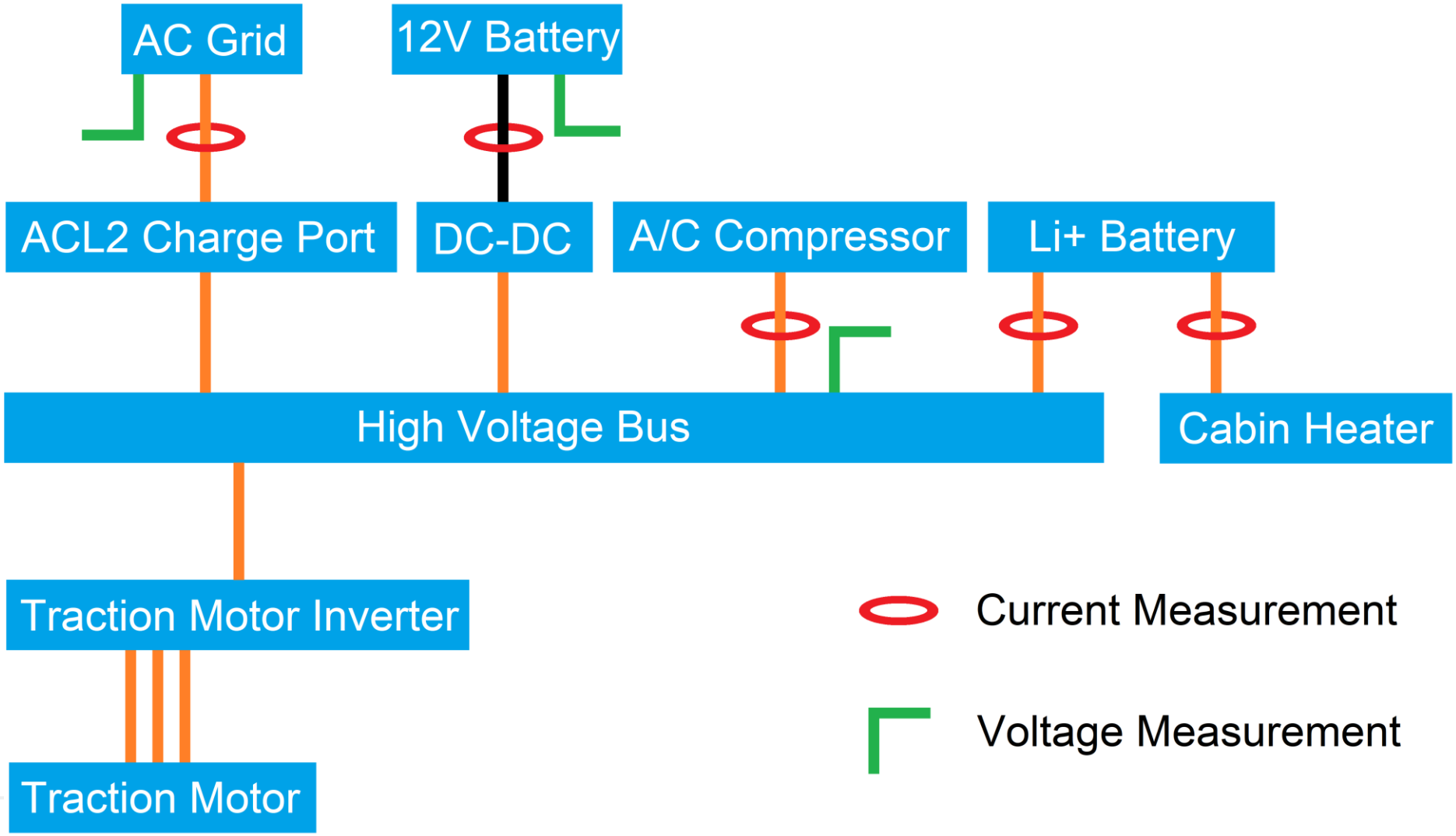


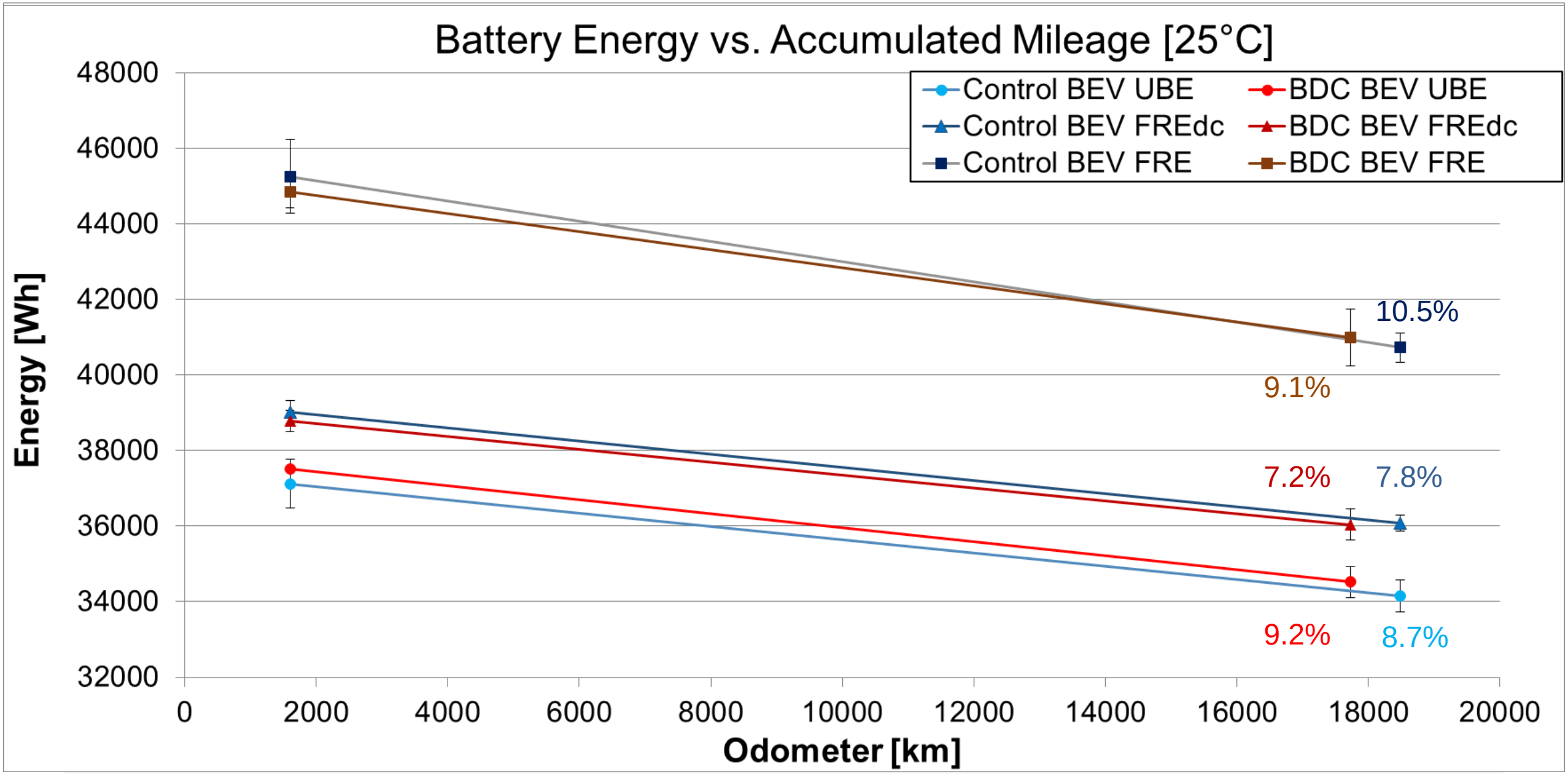
# TEST MATRIX

- SAE J1634 test sequences
- Test Temperatures: -7ºC, 25ºC and 35ºC
- Loading: Based on SAE J1263 procedures

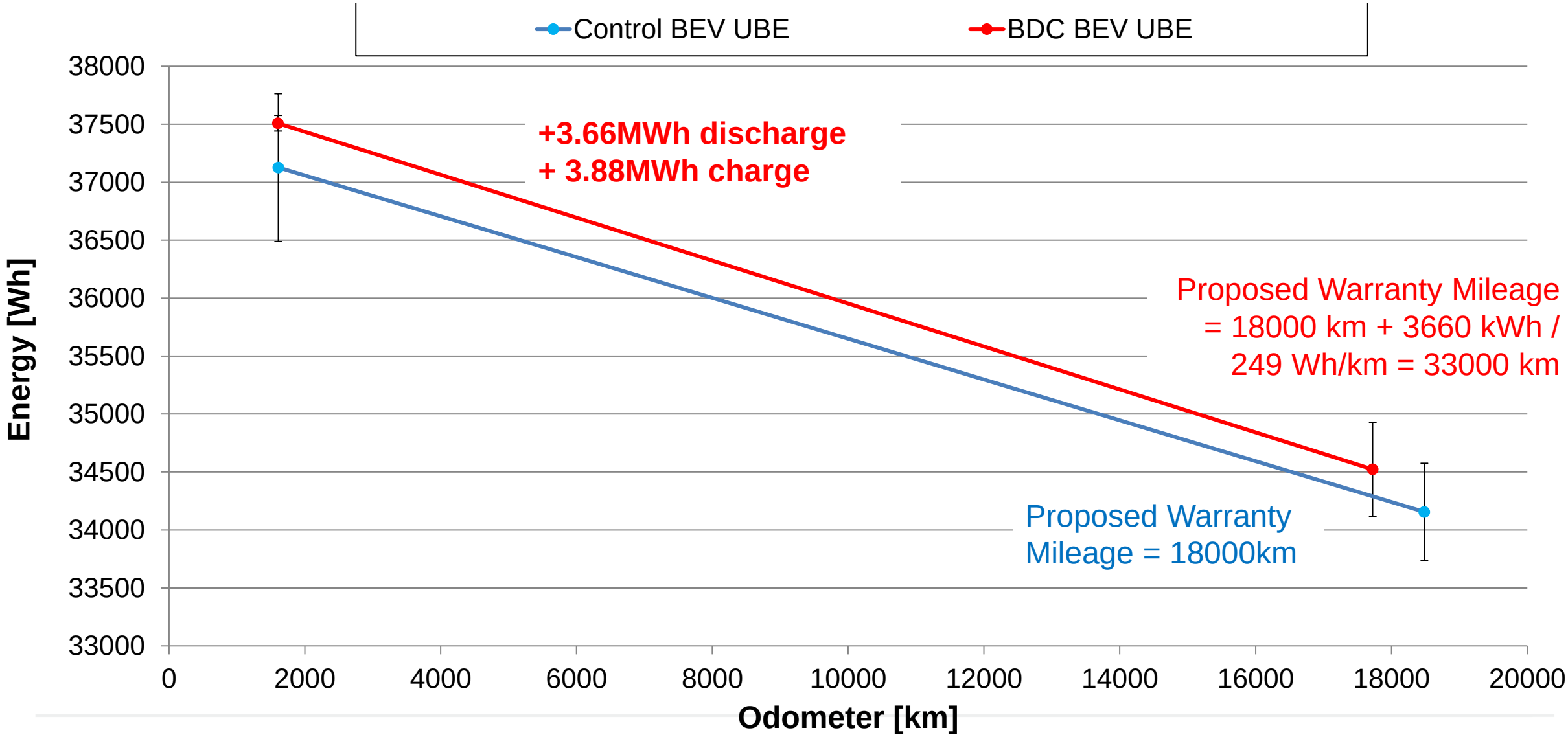
| Round | Odometer [km] | Test Specimen | -7°C | | 25°C | | 35°C | |
|---|---|---|---|---|---|---|---|---|
| | | | US06 MCT | NYCC FDT | US06 MCT | NYCC FDT | NYCC FDT | SC03 FDT |
| 1 | 1,607 | Control BEV | | | 3 | | | |
| | 1,603 | BDC BEV | | | 2 | | | |
| 2 | 18,845 | Control BEV | 2 | 2 | 2 | | 2 | 2 |
| | 17,725 | BDC BEV | 2 | 1 | 2 | 2 | | 2 |

# INSTRUMENTATION

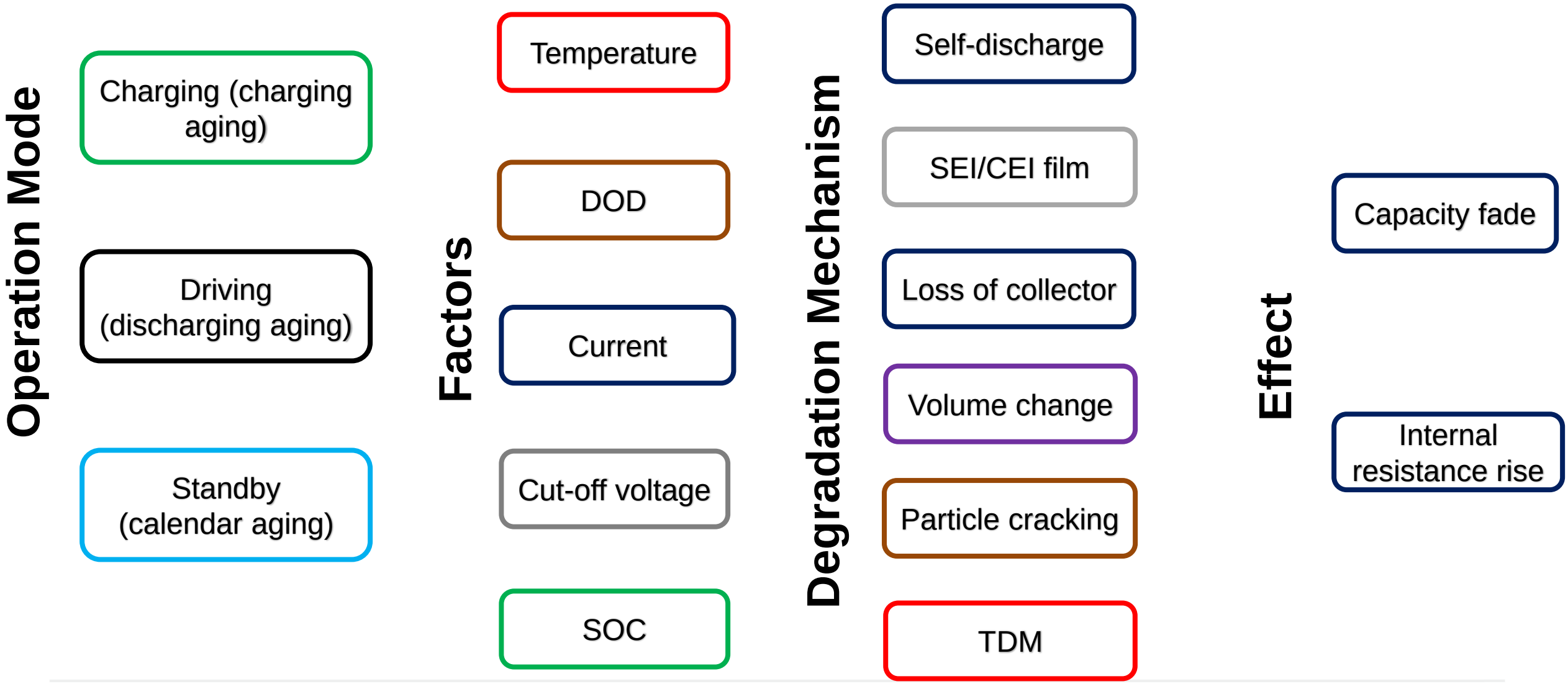



Battery Energy vs. Accumulated Mileage [25°C]
Control BEV UBE
BDC BEV UBE
Control BEV FREdc
BDC BEV FREdc
Control BEV FRE
BDC BEV FRE
Energy [Wh]
48000
46000
44000
42000
40000
38000
36000
34000
32000
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Odometer [km]
10.5%
9.1%
7.8%
7.2%
8.7%
9.2%

# GTR APPROACH TO V2G ACTIVITY

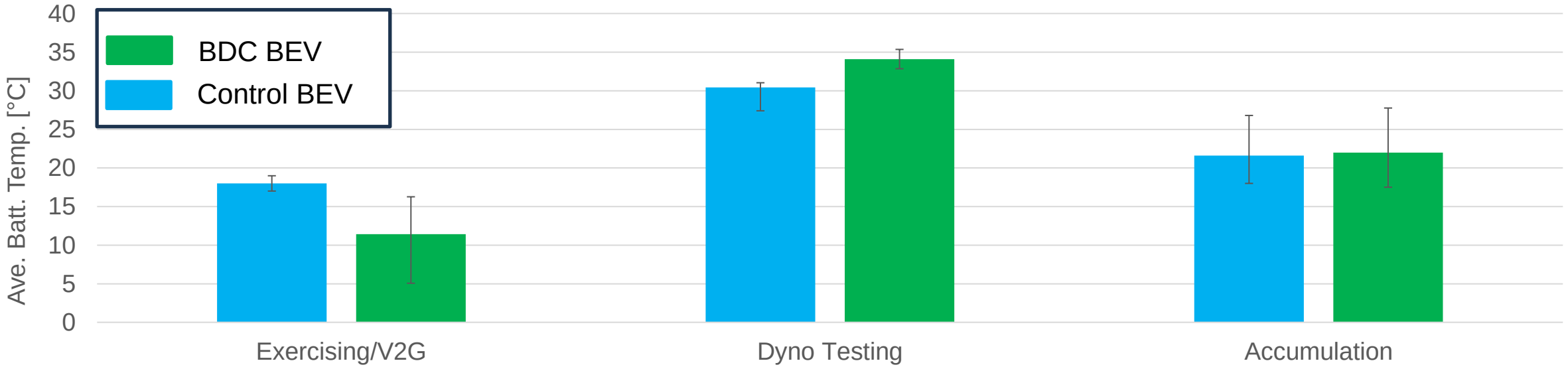


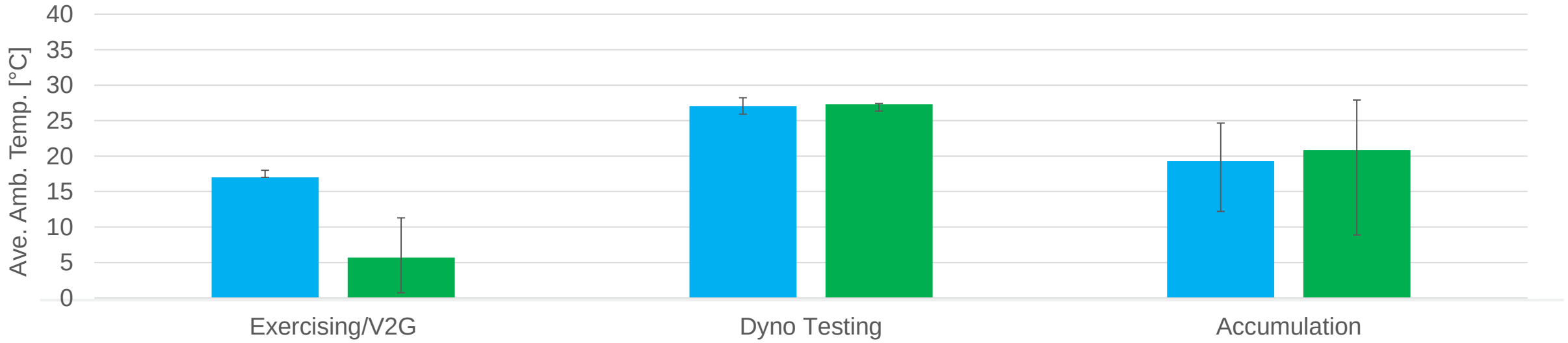
# WHY DO THEY DEGRADE SO SIMILARLY?




Adopted from: J. Guo, Y. Li, K. Pedersen, and D.-I. Stroe, “Lithium-Ion Battery Operation, Degradation, and Aging Mechanism in Electric Vehicles: An Overview,” Energies, vol. 14, no. 17, p. 5220, Aug. 2021, doi: 10.3390/en14175220.

# 1. TEMPERATURES



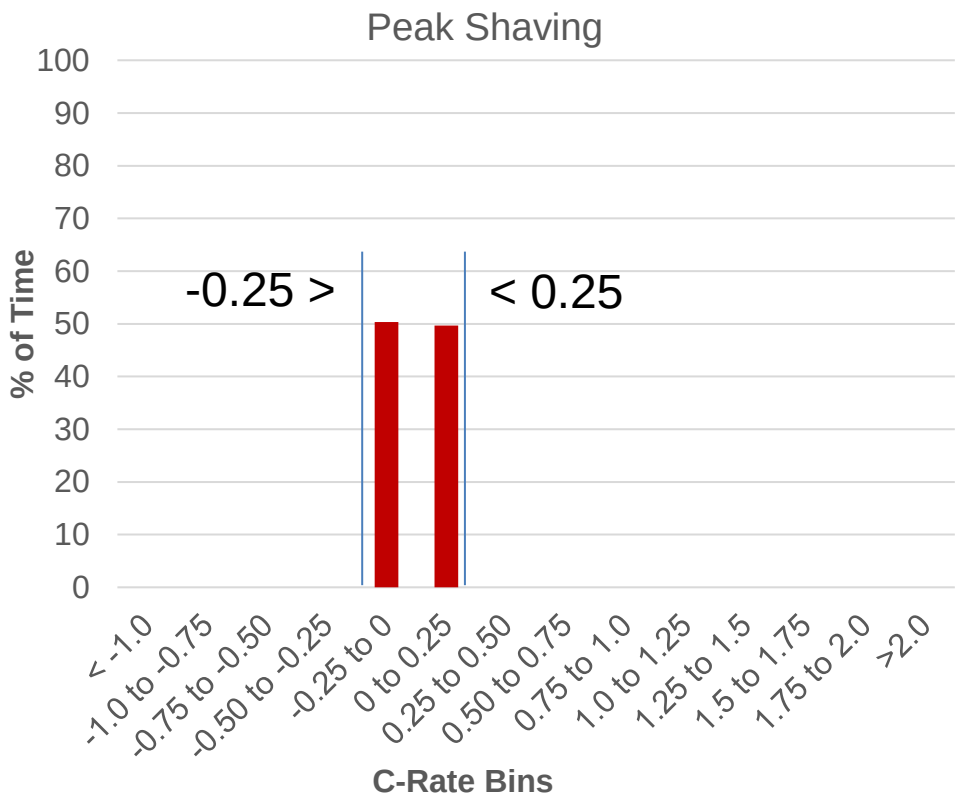



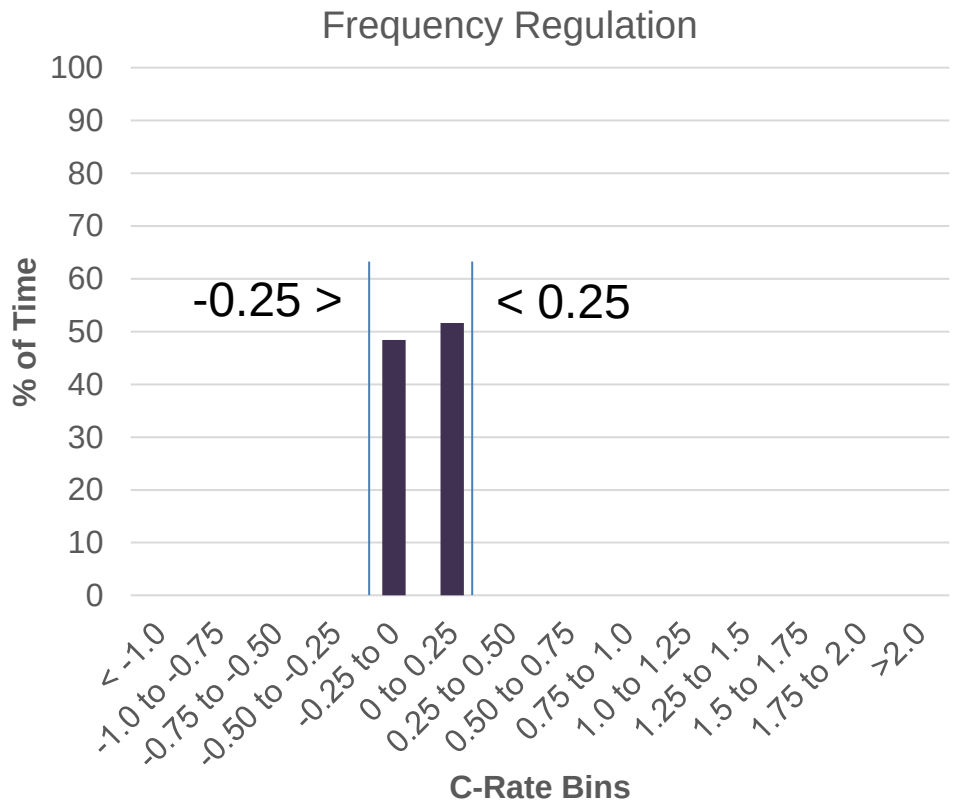
# 2. DOD

Skip this for now. Will address together with Number 5: SOC

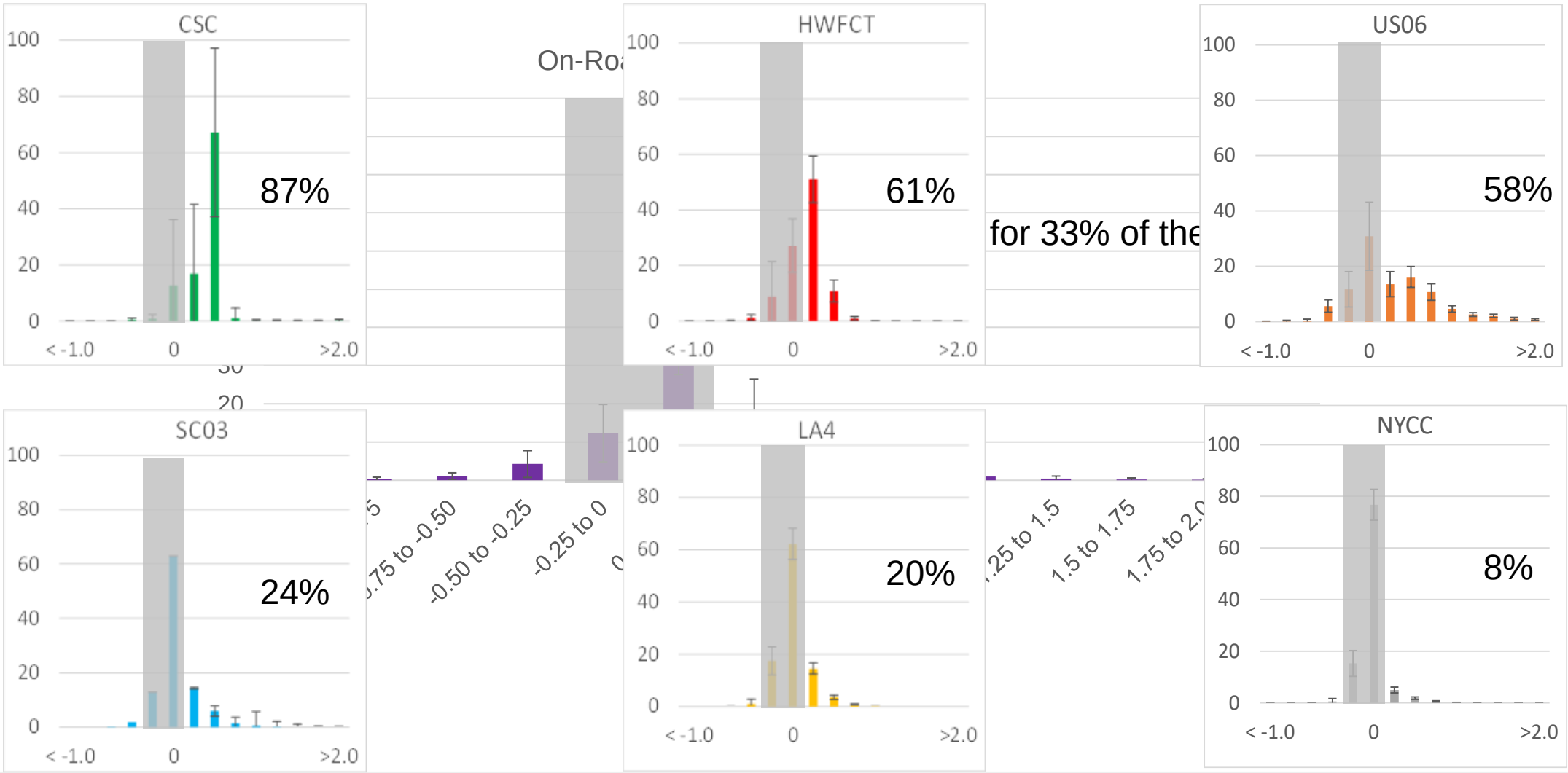
# 3. CURRENT

## Baseline for Comparison: Bi-directional Charging Activity



# 3. CURRENT CONT'D

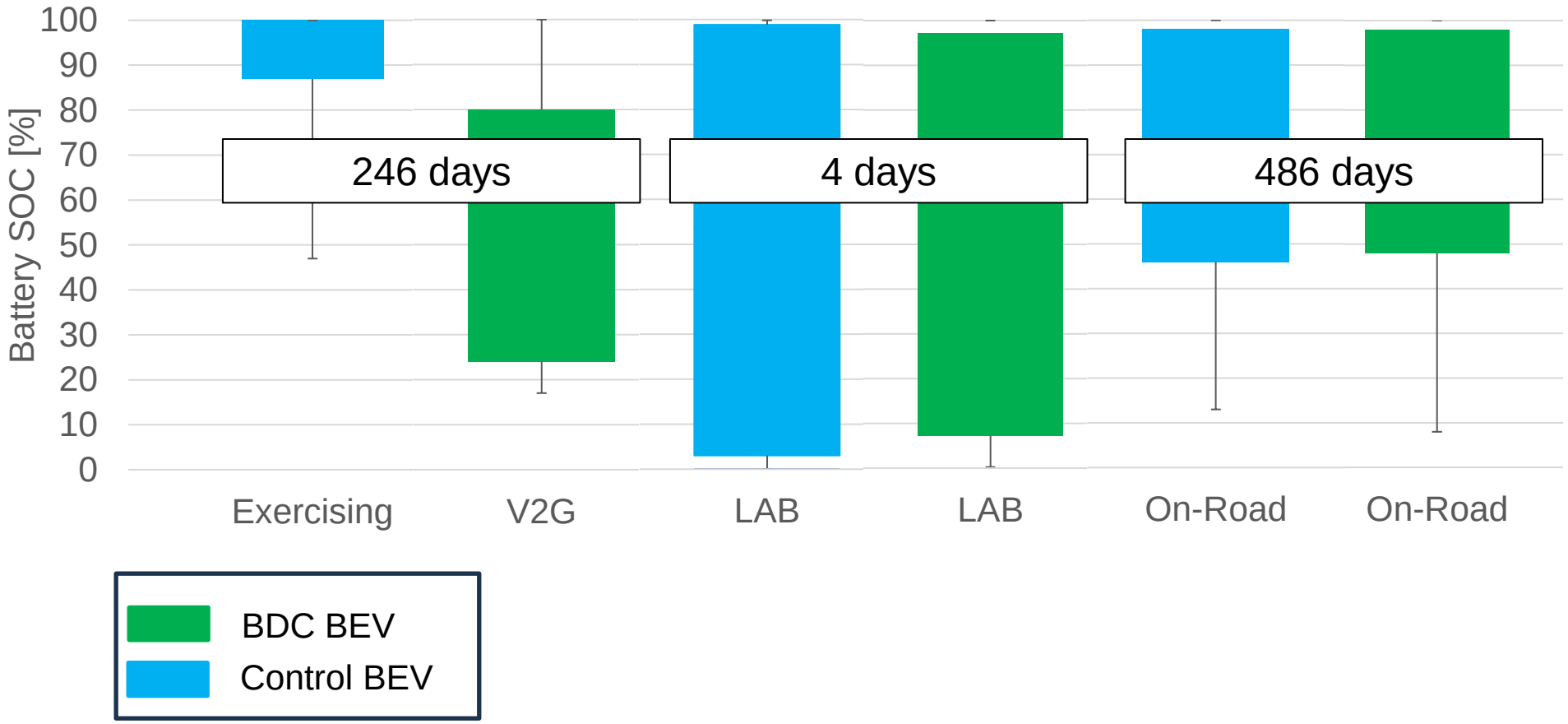


# 4. CUT-OFF VOLTAGE

IDENTICAL CUT-OFF VOLTAGES

From dyno full-depletion testing, pack voltage bottoms out at approximately 250V

# 2. DOD AND 5. SOC



# DIFFERENCES IN FACTORS OF DEGRADATION

1) Temperatures: different during V2G testing, but both are in a good range
2) DoD: very narrow for control BEV compared to BDC BEV
3) Current: C-rates are generally all low. BDC C-rates are all below 0.25. Mileage accumulation/Exercising C-rates > 0.25 for 33% of the time
4) Cut-off Voltage: Identical
5) SOC: Control BEV close to 100% SOC while BDC BEV was tested with SOCs between 26% to 80%.
6) Energy exchange: BDC BEV discharged 3.66MWh and charged 3.88MWh MORE than the control BEV

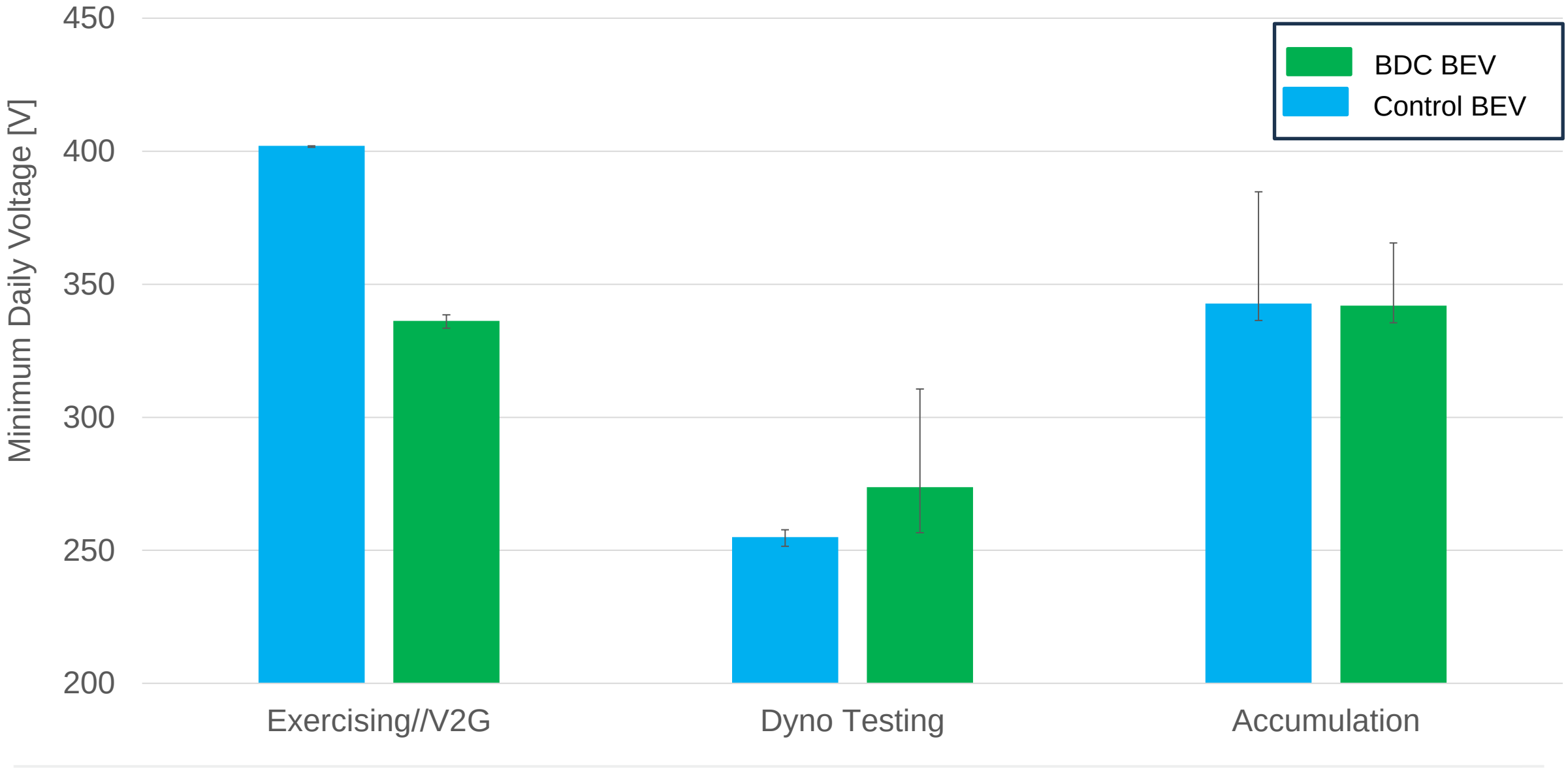
# CONCLUSIONS / RECOMMENDATIONS

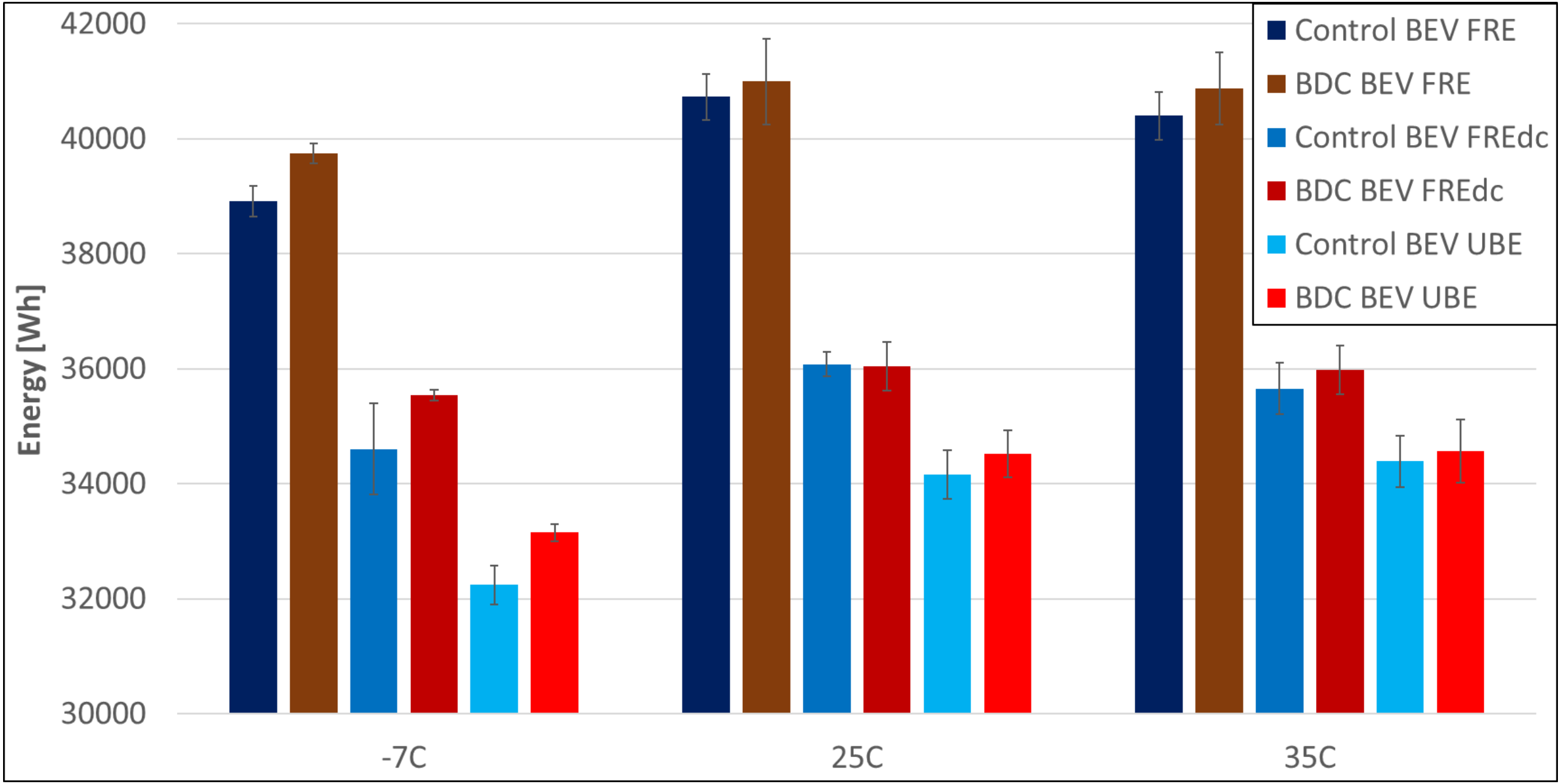
- BDC can be designed to operate the battery in regions of its SOC and at C-rates that promote capacity retention.
- In this study, BDC effects may be lost in ‘noise’ of the different SOC operation zones for each vehicle and/or the effects of mileage accumulation and calendar aging
- Regulators and OEMs can use studies like this to determine how to fairly attribute BDC activity to durability metrics

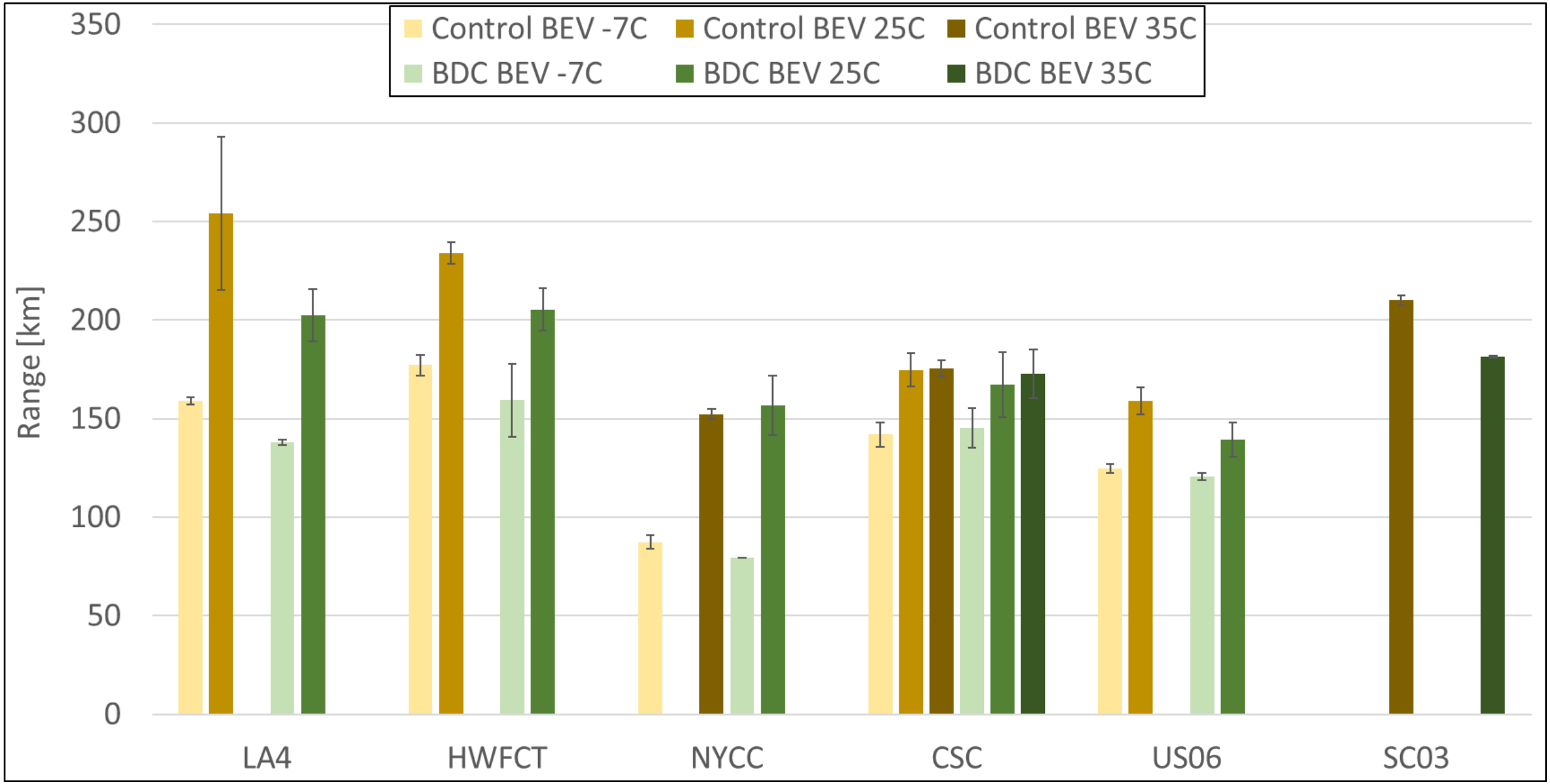
# ACKNOWLEDGEMENTS


- Thank you to all the staff at the ERMS who contributed to instrumentation, test preparations and logistics, data logging and performing the actual tests!
- Thank you to Dominique-Pierre Dion for fleet management in this project
- This study was funded by the PERD under the auspices of the OERD of NRCan
- This study was also funded by Transport Canada and ECCC

# ADDITIONAL DATA CHART SLIDES


450
400
350
300
250
200
Minimum Daily Voltage [V]
BDC BEV
Control BEV
Exercising//V2G
Dyno Testing
Accumulation


42000
40000
38000
36000
34000
32000
30000
Energy [Wh]
-7C
25C
35C
Control BEV FRE
BDC BEV FRE
Control BEV FREdc
BDC BEV FREdc
Control BEV UBE
BDC BEV UBE


Control BEV -7C
Control BEV 25C
Control BEV 35C
BDC BEV -7C
BDC BEV 25C
BDC BEV 35C
Range [km]
350
300
250
200
150
100
50
0
LA4
HWFCT
NYCC
CSC
US06
SC03