



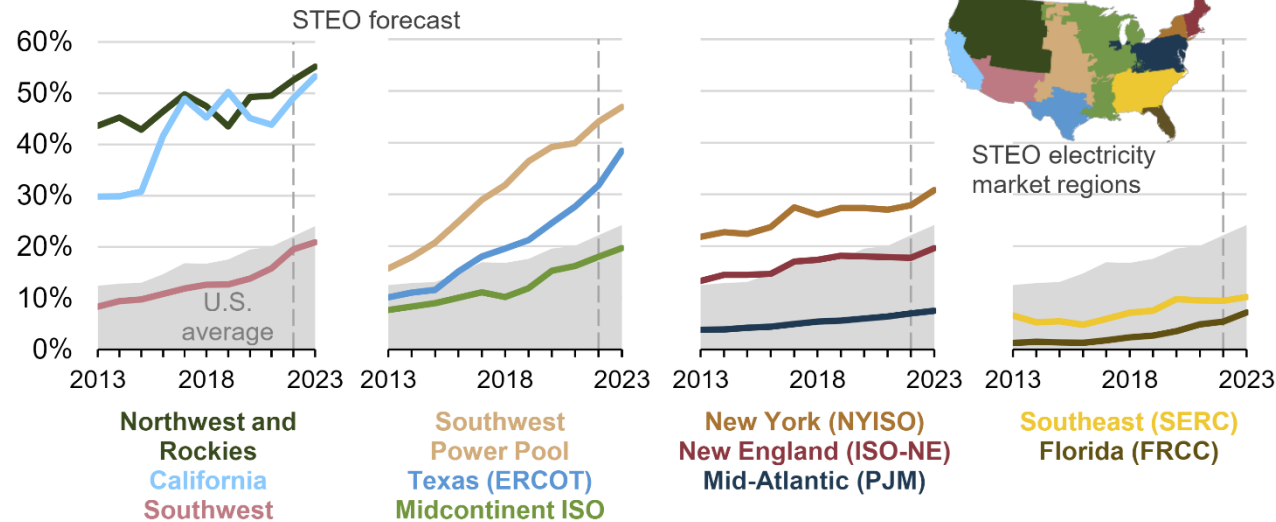
Energy Management for V2X

Dr Jiaqi Liang, Dr Matthew Gonzalez - AMP

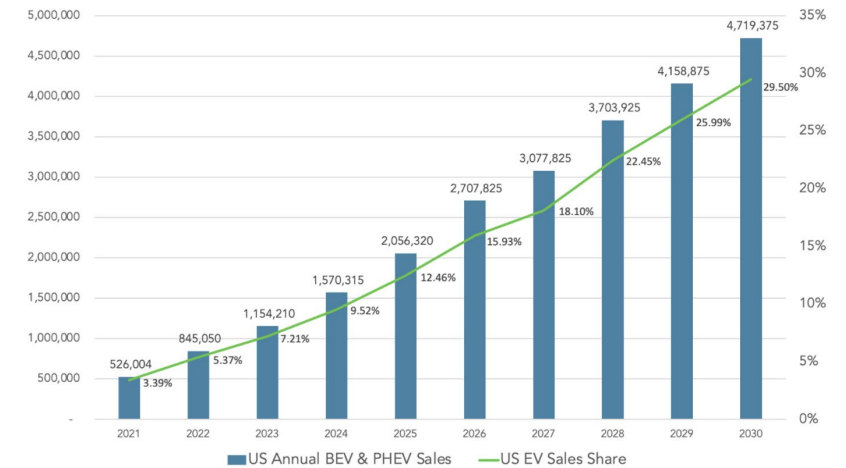
The World Wants Zero Carbon

How can we truly get there?

- US renewable penetration has increased from 13% to 22% in the last 10 years
- US EV sales are expected to increase from 3% to 30% in the next 10 years



Annual renewable electricity generation in selected regions (2013-2023)
Percentage of regional total electricity generation

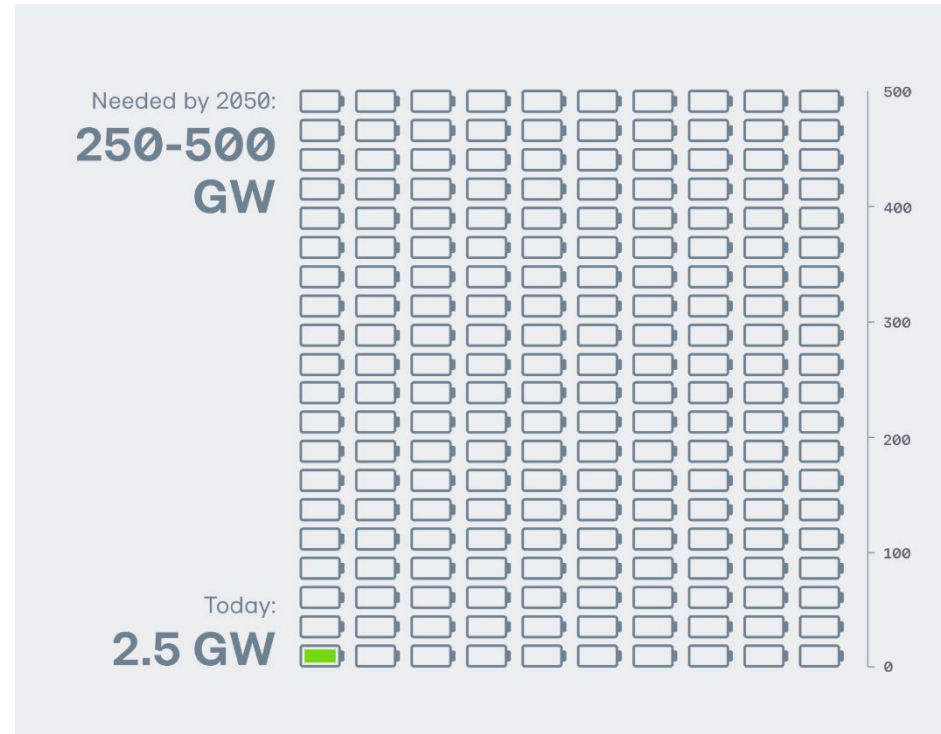


US EVs (BEV & PHEV) Sales & Sales Share Forecast: 2021 - 2030

Imminent Problems

The world is ignoring

- Zero Carbon requires ~**500 GW** (100x more than today) energy storage – slow ESS adoption due to high cost

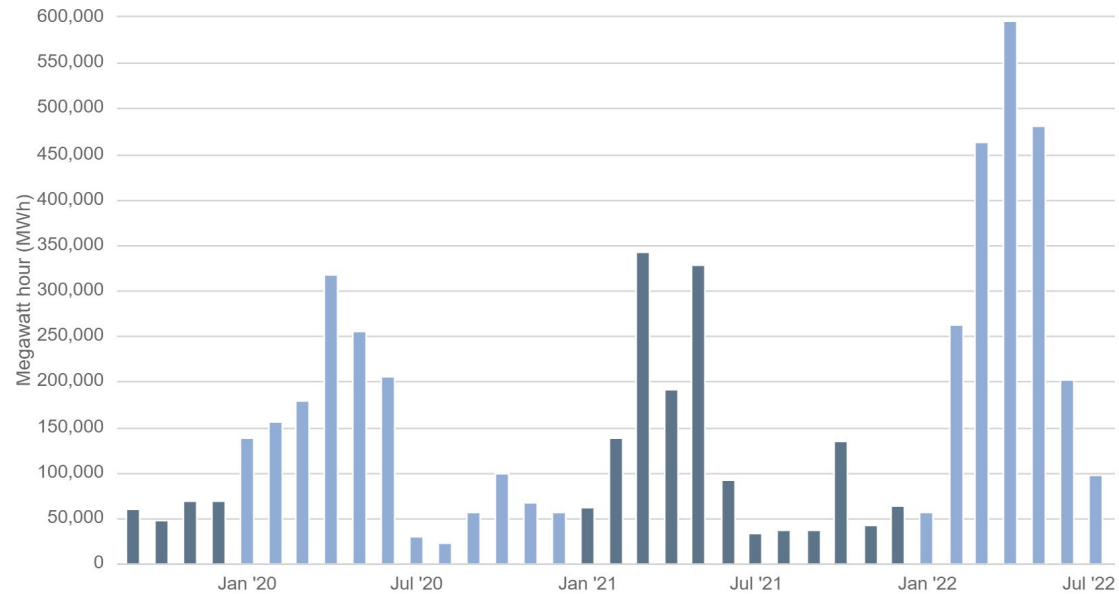


Energy Storage Needed for Carbon Neutral in the US

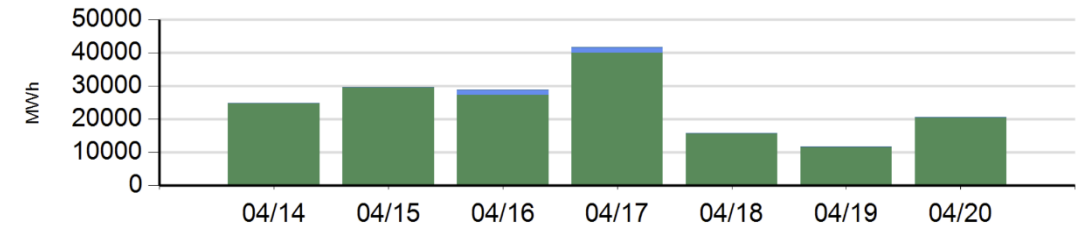
Imminent Problems

The world is ignoring

- Renewable energy is being curtailed –
Primarily due to a lack of balancing load (up to **20 GWh** curtailed daily in California in April 2022)



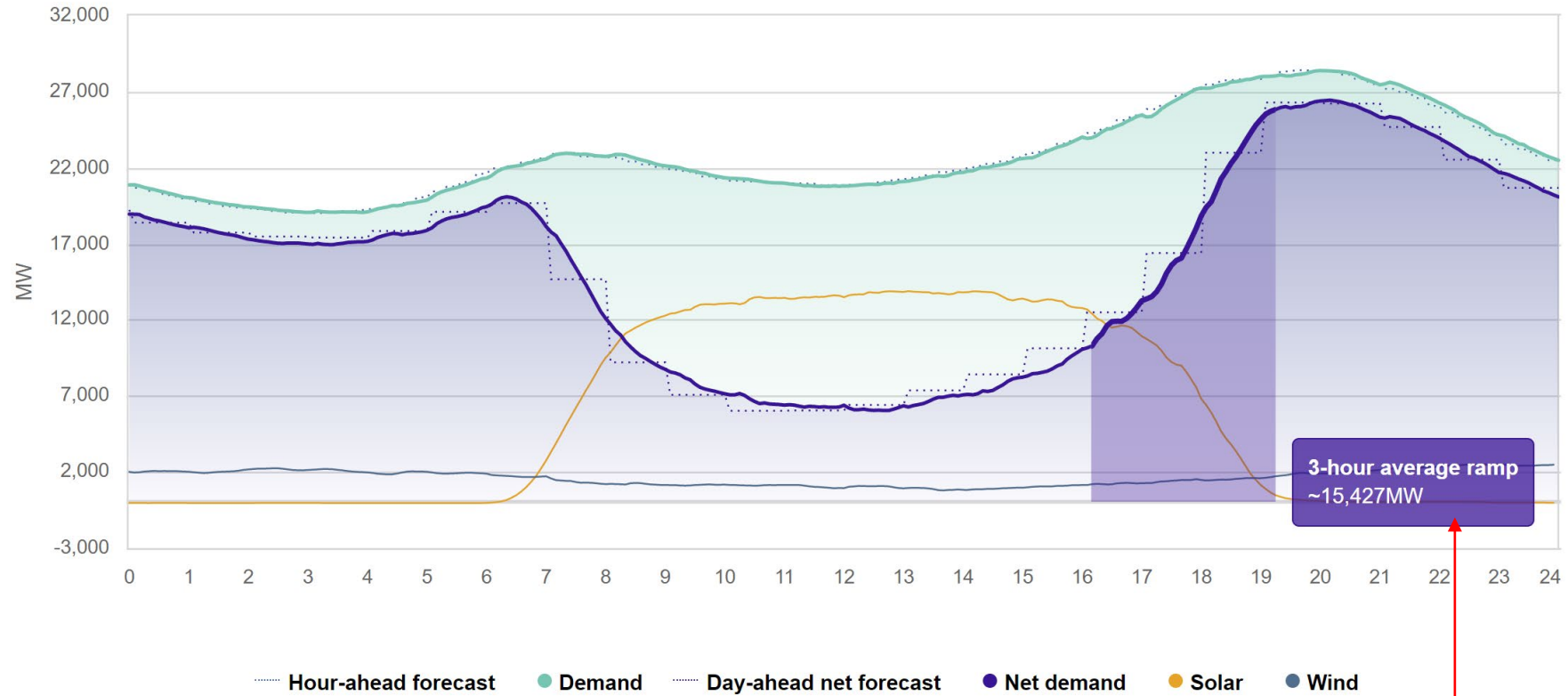
California monthly wind/solar curtailment



California daily wind/solar curtailment

Source: [California ISO - Managing Oversupply \(caiso.com\)](https://www.caiso.com)

The Duck Curve



3-hour average ramp
~15,427MW

**Gas Turbine
Spinning Reserve!**

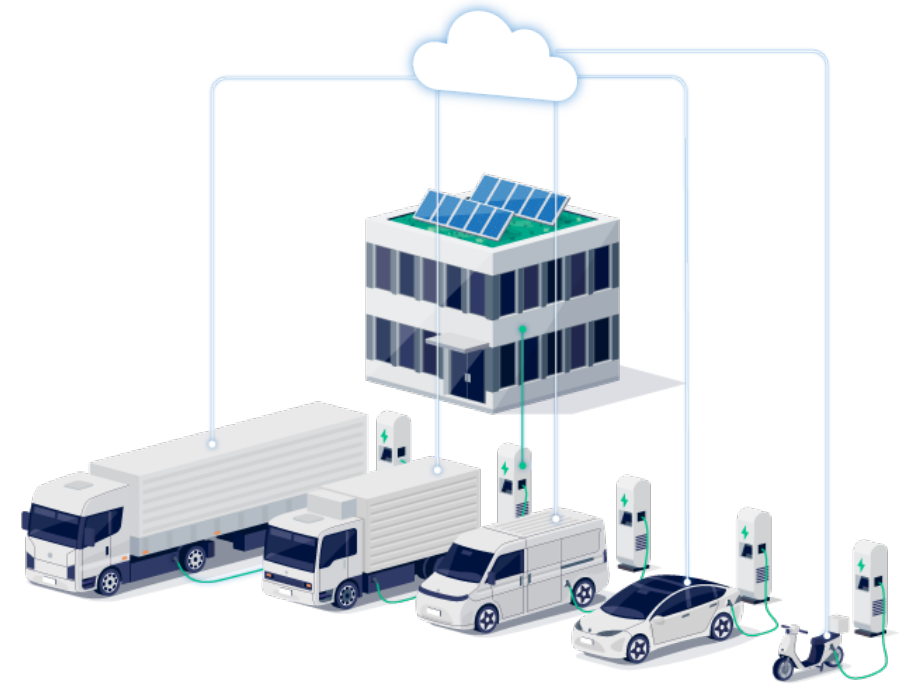
CAISO duck curve on April 25, 2022

What is V2X?

V2L – Vehicle supplies power to standalone Loads (mobile energy source)

V2H – Vehicle supplements power/load to Home, and emergency backup

V2G – Vehicle provides power back to the Grid for grid stability services



Why V2X is Needed?

Free ESS Infrastructure for carbon neutral

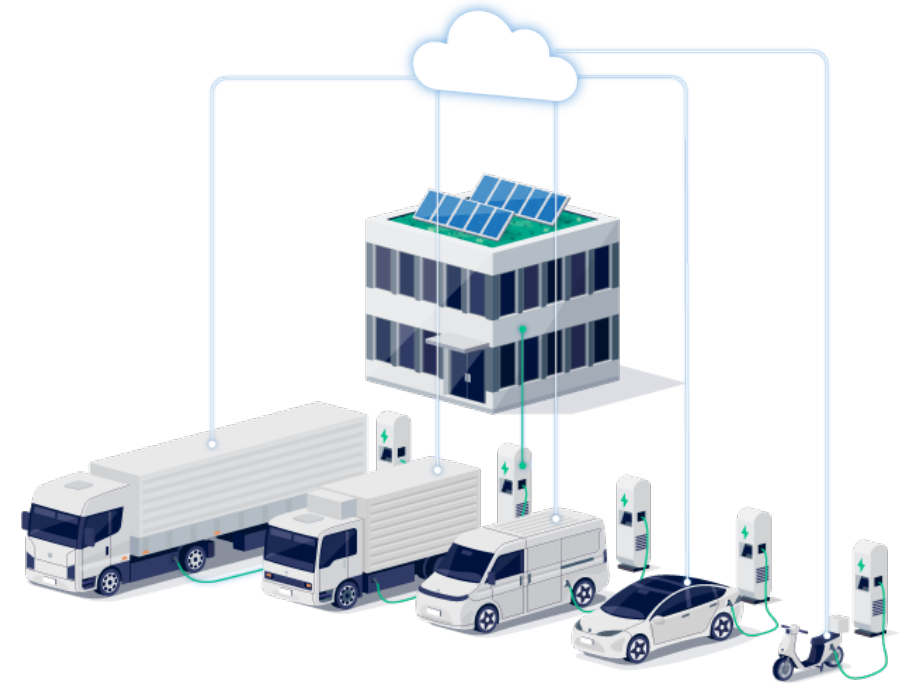
- A typical pax EV = 75kWh, 11kW OBC
- 500 GW ESS to Carbon Neutral in the US = 50 million EVs only!

Free Renewable Energy for daily driving

- US average person drives 40 miles/day = ~10 kWh/day
- California 20 GWh/day (Apr 2022) renewable curtailment = charging 2 million cars for free

More Reliable home supply & grid storage than ever

- A typical 75 kWh car battery is enough to power your home for 3+ days, and it takes only 1 hour to replenish
- Granular distributed energy storage



What's Even Better than Free Energy?

When utility pays you

California Public Utility Commission supports transportation electrification with approval of PG&E Vehicle-Grid Integration Pilot Programs

PG&E Vehicle-to-grid Residential Pilot Program for \$7.5 million



3 Year
Pilot Program
to increase
EV adoption



1000 Families
Focussed on
Light-duty EV
Adoption



\$ 2,500
Starting
Rebates
to be received



\$ 500
Additional
For ESJ
Communities



\$ 2000
Ongoing
Performance
Based Incentives

[CPUC Supports Transportation Electrification With Approval of PG&E Vehicle-Grid Integration Pilot Programs](#)

What's Needed to Enable V2X?

Bi-directional Power Flow

- DC Vs AC
- V2G: Grid Inter Connection Certification
- V2H: J1772 plug w/o dedicated neutral (North America)

Battery Utilization: up to ~50% higher daily throughput

- V2G: Grid Inter Connection Certification
- V2H: J1772 plug w/o dedicated neutral (North America)

Optimization between Vehicle and Power Grid

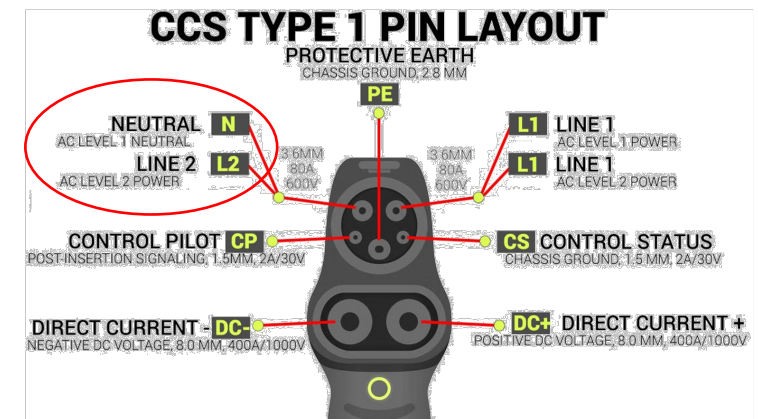
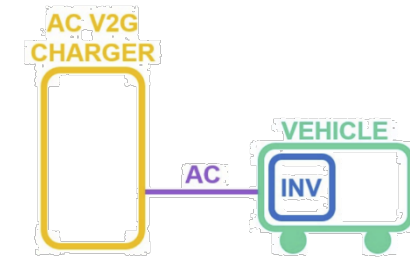
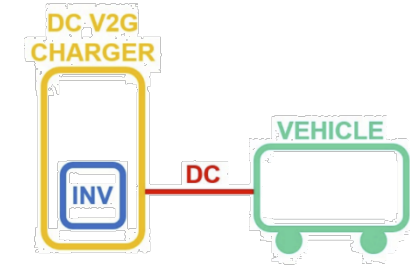
- Trade-off between vehicle usage schedule, \$/kWh, \$ of V2G services, battery availability, degradation
- Data, data, data

Vehicle Electronics: Up-time increases by 2-3 times

- Minimize waking up unnecessary electronics & components

Coordinate with Offboard Devices

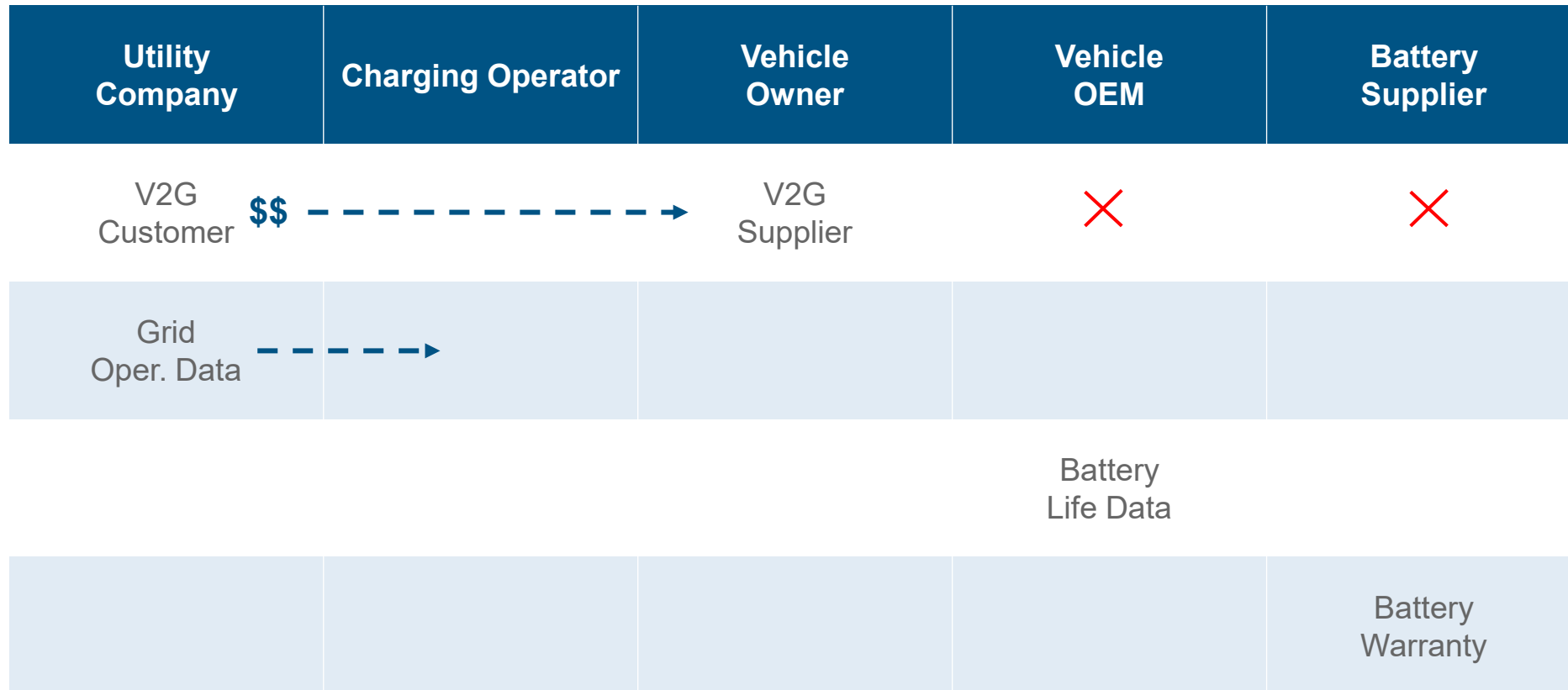
- Communication with EVSE, distribution panel, transfer switch
- Standard DC (PLC ISO15118) vs AC (low-level PWM), lack of detailed battery info exchange



V2G Business Wars

Who should be part of the V2G value chain?

Who decides between providing V2G service and warranting battery life?

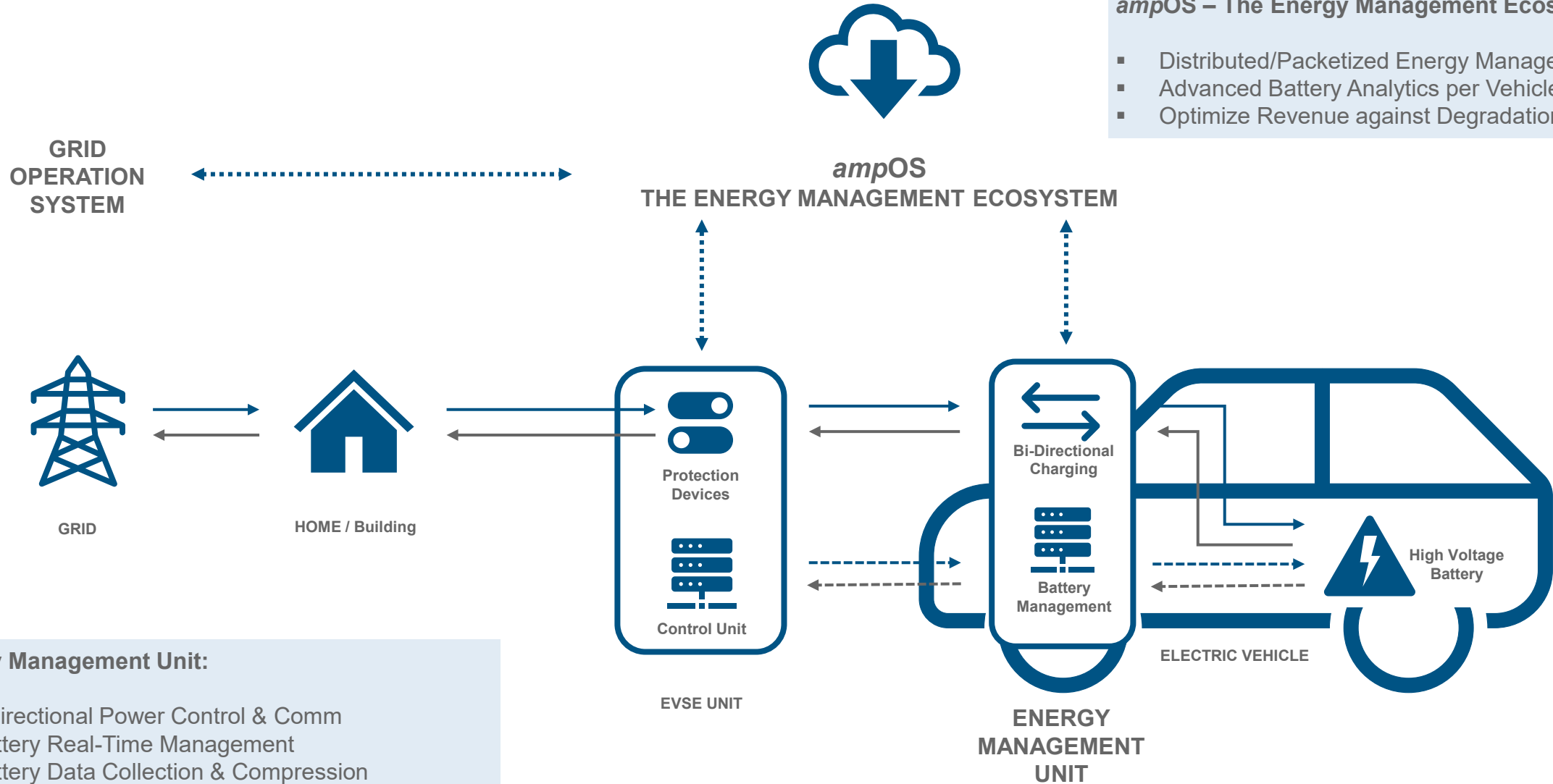


End-to-End Energy Management for V2X

'Power Wall on Wheels'

ampOS – The Energy Management Ecosystem:

- Distributed/Packetized Energy Management
- Advanced Battery Analytics per Vehicle
- Optimize Revenue against Degradation



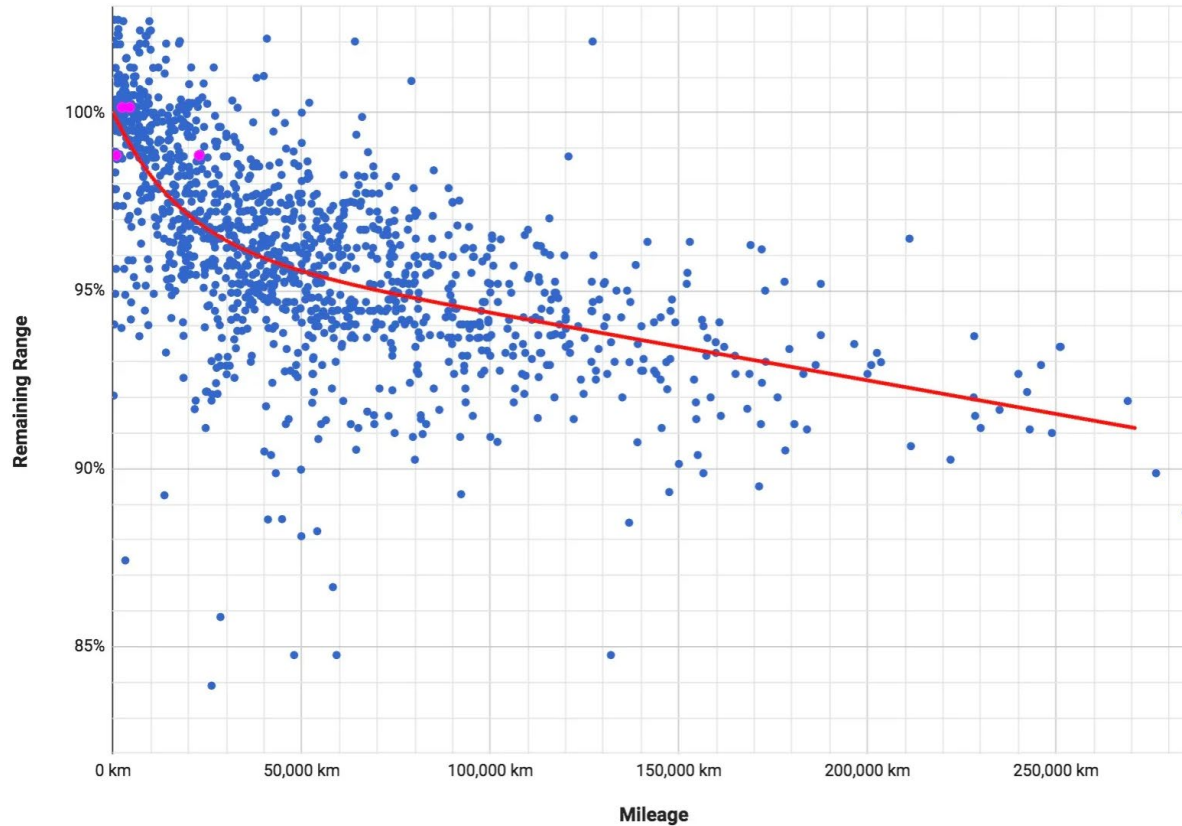
Energy Management Unit:

- Bidirectional Power Control & Comm
- Battery Real-Time Management
- Battery Data Collection & Compression

Won't V2X Age My Battery?

Short Answer: Yes, it does.

Tesla Model S/X Mileage vs Remaining Battery Capacity



Fighting
'Range Anxiety'

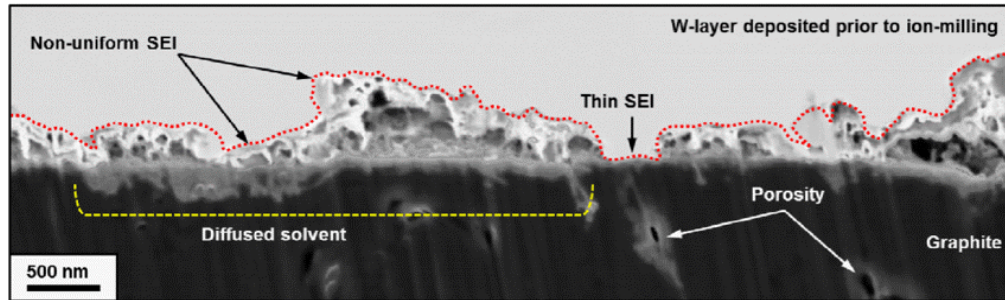


- Charging and discharging to the grid is effectively like driving extra miles
- Up to 50% more battery energy throughput to provide V2X service
 - 200,000 km \approx 300,000 km

Understanding Battery Degradation

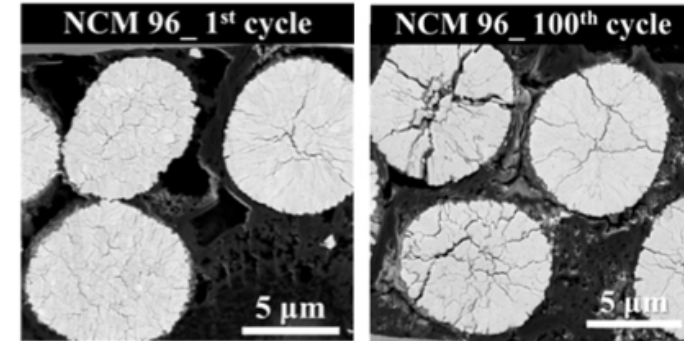
Know your enemy to avoid impact on performance and cycle-life

1. SEI growth and non-uniformity

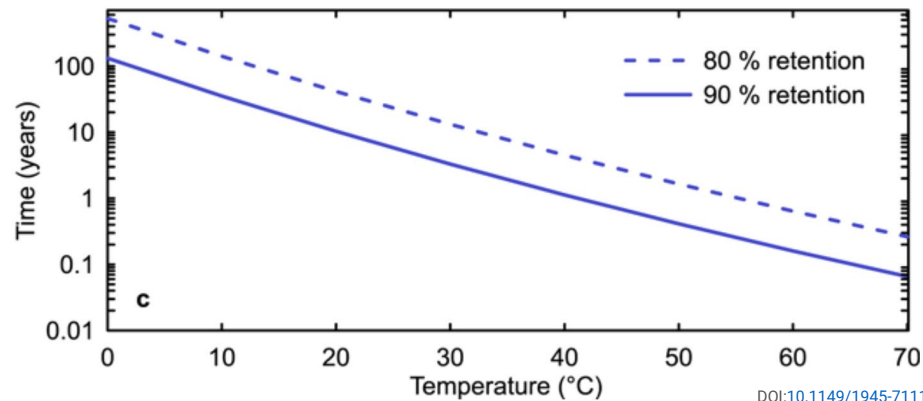


DOI: [10.1016/j.carbon.2013.10.032](https://doi.org/10.1016/j.carbon.2013.10.032)

2. Chemo-mechanical damage to active materials

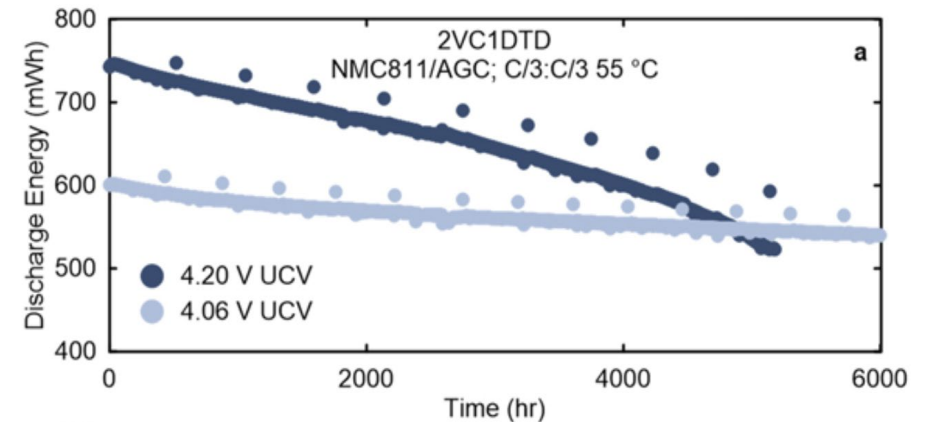


Operate in the proper thermal environment



DOI: [10.1149/1945-7111/ac42f1](https://doi.org/10.1149/1945-7111/ac42f1)

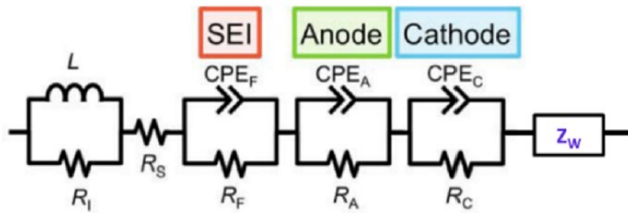
Operate in the proper voltage window



Determining the Proper Operating Parameters

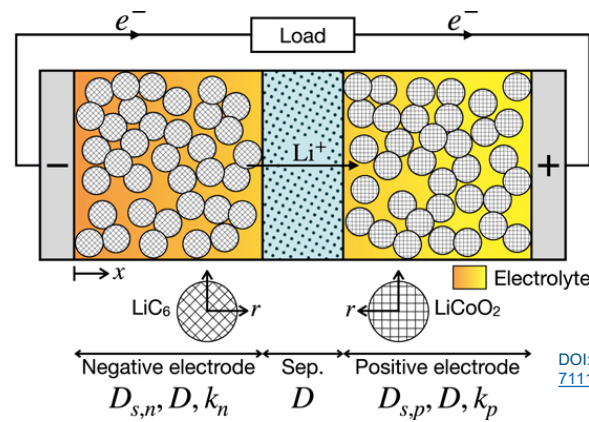
Physical modeled informed failure analysis

Equivalent Circuit Models



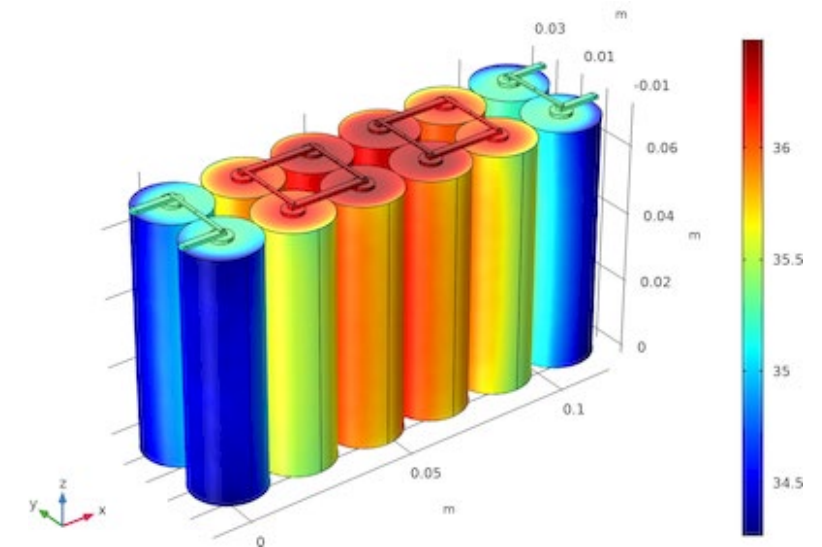
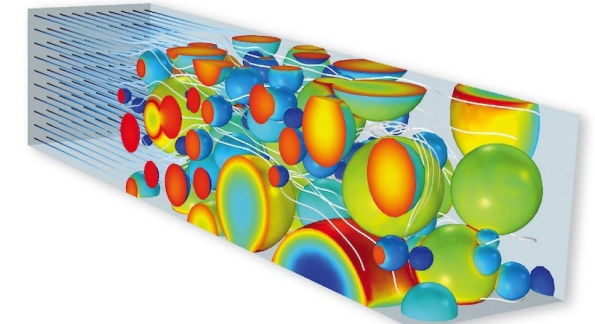
DOI:10.3390/batteries5010012

Pseudo-2D Newman Models



DOI:10.1149/1945-7111/ac26b1

3D Multiphysics Models



<https://www.comsol.com/>

Increasing model accuracy...but increasing computational cost

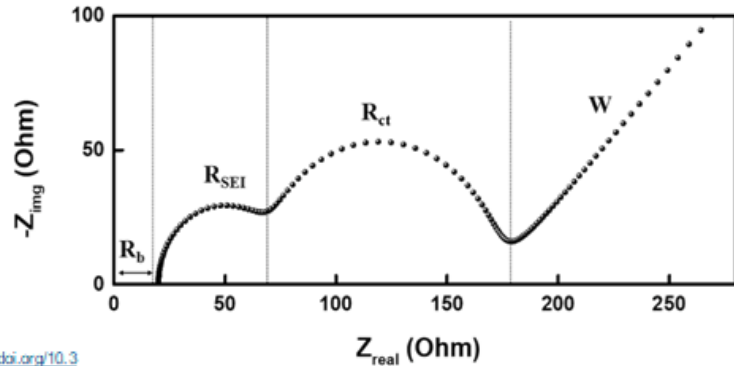
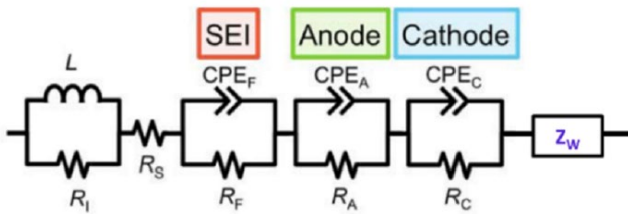


Battery Pack Performance Characterization

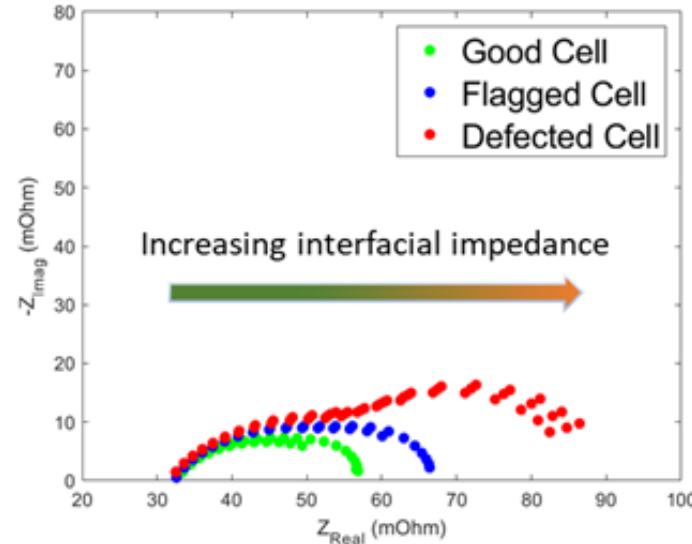
Measure the health of your battery pack

AMP: Onboard EIS for battery pack health check-ups and diagnostics

Electrochemical Impedance Spectroscopy (EIS) & Nyquist analysis



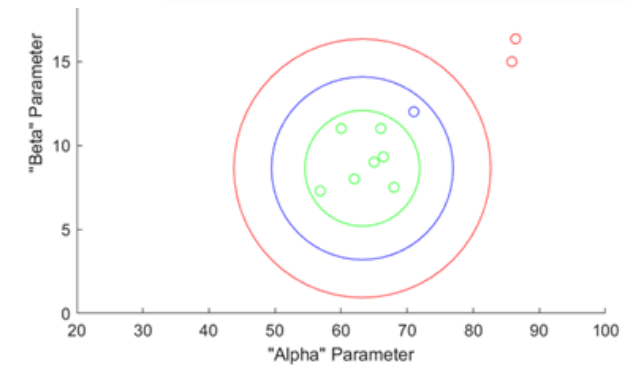
DOI: <https://doi.org/10.33961/rect.2019.00528>



Cell Diagnostics

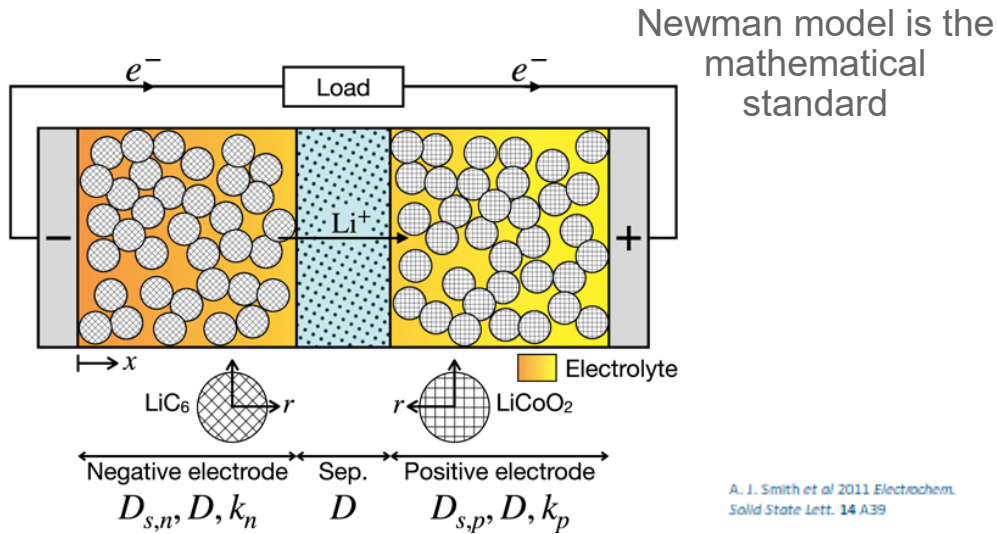
Cell 04 has been flagged for potential defect!
Check Engine Light. Defect detected in Cell 07! Please Examine!
Check Engine Light. Defect detected in Cell 09! Please Examine!

OK

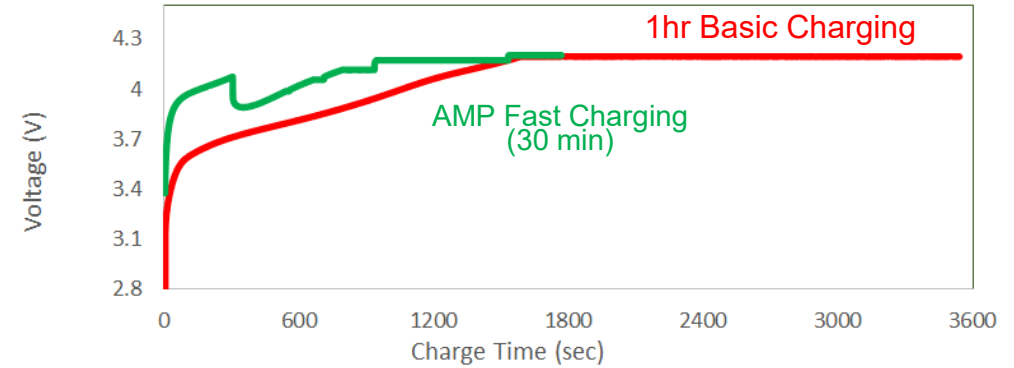


Analyzing Chemistry and Kinetics

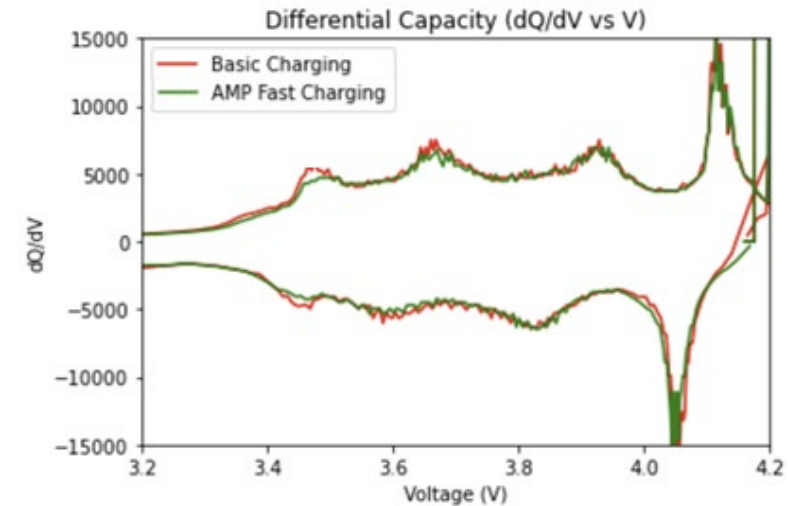
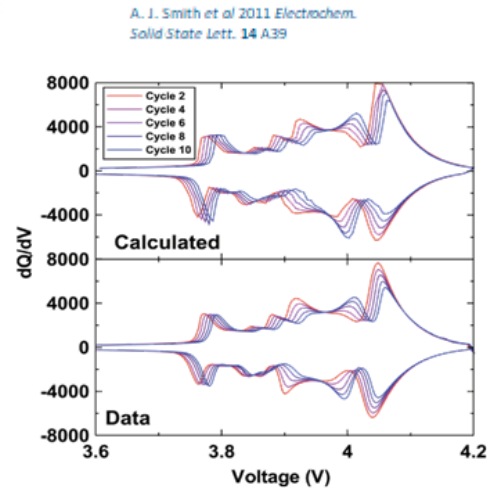
Informed decision making based on established techniques



AMP: First principals based operating protocols



Differential analysis provides deep insights into governing physics



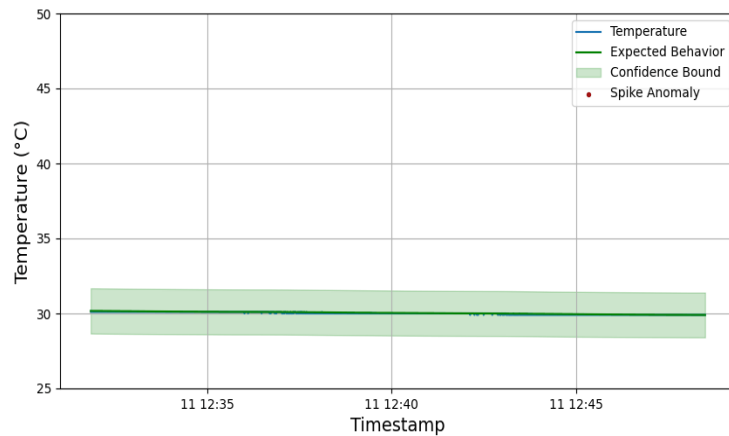
Accounting for Anomalies and New Data

Expect the Unexpected

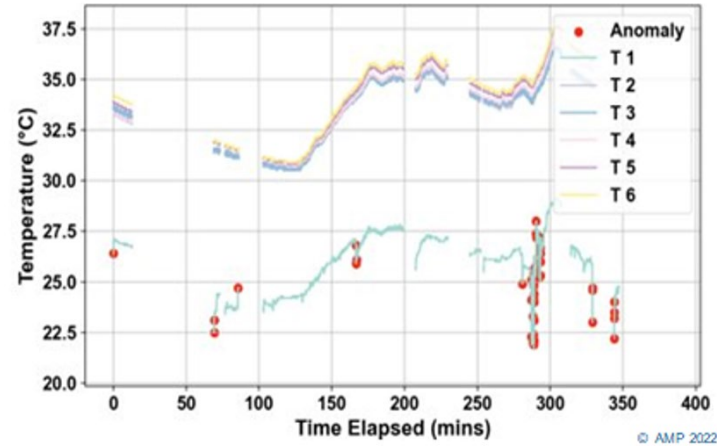
AMP: Machine learning based data analytic tools and cloud-enable data management



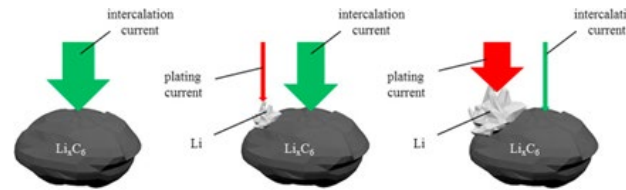
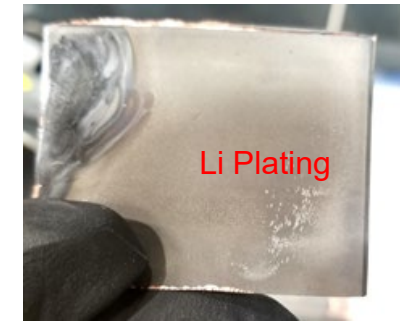
Basic models don't track anomalies



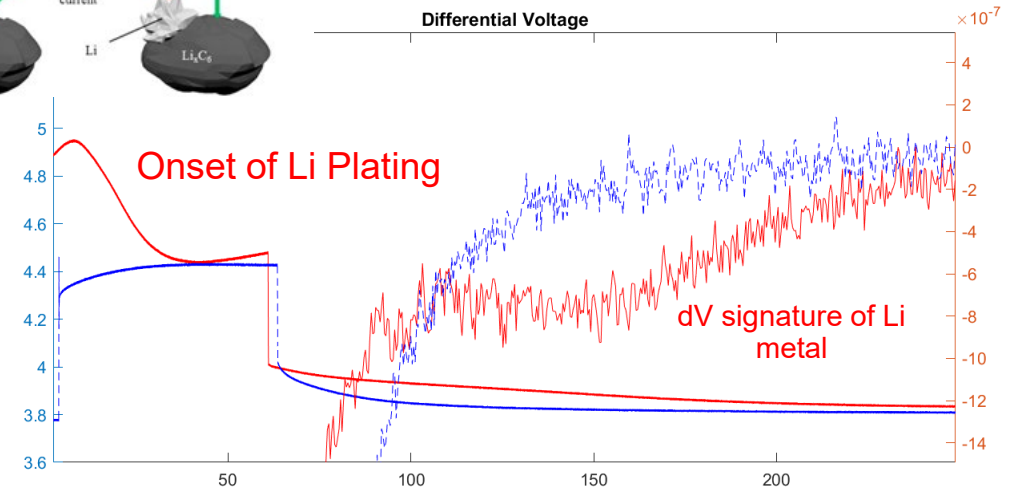
Normal vs. Abnormal



Feed newly discovered data back into model for **continuous improvement**



DOI: [10.1039/C6RA19482F](https://doi.org/10.1039/C6RA19482F)

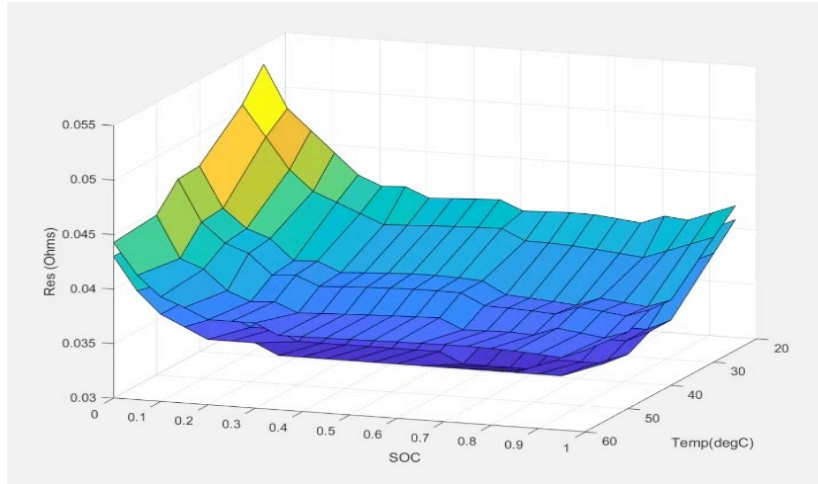


Online Battery Characterization & Optimization



Closed loop characterization-based updates throughout battery lifetime

Adaptive Battery System Controls



Deployable Firmware Code

```

amp_cal_datac {
    .timeabovethresholdinticks = 1000,
    .timebelowthresholdinticks = 0,
    .event_callback_idx = eDiag_ApDiagEventSetAboveThreshold_cb,
    .nms_on_set = true,
    .tx_on_set = true,
    .freeze_frame = eEventLogEvent_Overcurrent,
    .dtc_id = #eM30C00,
    .uds_priority = #eM30C_PriorityWarning,
    .uds_group = #eM30C_GroupB,
    .snapshot_category = #eM30C_SnapName,
},
[eDiag_OvercurrentMv] = {
    .del = #eM32S,
    .fal = ACTION_INHIBIT_CHARGE|ACTION_INHIBIT_CHARGE_ENTRY|ACTION_INHIBIT_DRIVE|ACTION
    .enable = true,
    .persist = false,
    .event_threshold_hi_val = 1.0,
    .event_threshold_lo_val = 0.0,
    .timeabovethresholdinticks = 100,
    .timebelowthresholdinticks = 500,
    .event_callback_idx = eDiag_ApDiagEventSetOnHigh_cb,
    .nms_on_set = true,
    .tx_on_set = true,
    .freeze_frame = eEventLogEvent_Battery,
    .dtc_id = #eM30S000,
    .uds_priority = #eM30C_PriorityStop,
    .uds_group = #eM30C_GroupC,
    .snapshot_category = #eM30C_SnapName,
},
[eDiag_ShortCircuitCountlatch] = {
    .del = #eM32S,
    .fal = ACTION_INHIBIT_CHARGE|ACTION_INHIBIT_CHARGE_ENTRY|ACTION_INHIBIT_DRIVE|ACTION
    .enable = true,
    .persist = true,
    .event_threshold_hi_val = 15.0,
    .event_threshold_lo_val = 0.0,
    .timeabovethresholdinticks = 0,
    .timebelowthresholdinticks = 0,
    .event_callback_idx = eDiag_ApDiagEventSetAboveThreshold_cb,
    .nms_on_set = true,
    .tx_on_set = true,
    .freeze_frame = eEventLogEvent_Battery,
    .dtc_id = #eM30S,
    .uds_priority = #eM30C_PriorityNone,
    .uds_group = #eM30C_GroupNone,
    .snapshot_category = #eM30C_SnapName,
},
[eDiag_OvercurrentDischarge] = {
    .del = #eM32S,
    .fal = ACTION_INHIBIT_CHARGE|ACTION_INHIBIT_CHARGE_ENTRY|ACTION_INHIBIT_DRIVE|ACTION
    .enable = true,
    .persist = false,
    .event_threshold_hi_val = -1.0,
    .event_threshold_lo_val = -0.0,
}
    
```

Auto-generation & Online Adaptation



Calibrations

OCV (V)	-15	2	5	10	15	25	27	45	50	55	60
0	3.2386	3.2386	3.2354	3.0967	3.1023	3.1133	3.0921	2.9494	2.9446	2.9296	2.9146
0.05	3.3402	3.3402	3.3355	3.2277	3.3276	3.3273	3.3263	3.3192	3.319	3.3187	3.3184
0.1	3.3805	3.3805	3.3737	3.3625	3.3611	3.3585	3.3575	3.352	3.3524	3.355	3.3576
0.15	3.3901	3.4391	3.4347	3.4275	3.4262	3.4236	3.4219	3.4111	3.4112	3.4124	3.4137
0.2	3.437	3.4972	3.4951	3.4918	3.4905	3.4879	3.4864	3.4764	3.4765	3.4774	3.4782
0.25	3.482	3.5436	3.5435	3.5333	3.5322	3.5312	3.5311	3.5262	3.5248	3.5255	3.5267

Configurations

Event ID	Event Name	Event Type	Event Severity	Event Action	Event Status
00001	Brk Undercharge Warning	Warning	Low	None	Active
00002	Brk Undercharge Warning	Warning	Low	None	Active
00003	Brk Undercharge Warning	Warning	Low	None	Active
00004	Brk Undercharge Warning	Warning	Low	None	Active
00005	Brk Undercharge Warning	Warning	Low	None	Active
00006	Brk Undercharge Warning	Warning	Low	None	Active
00007	Brk Undercharge Warning	Warning	Low	None	Active
00008	Brk Undercharge Warning	Warning	Low	None	Active
00009	Brk Undercharge Warning	Warning	Low	None	Active
00010	Brk Undercharge Warning	Warning	Low	None	Active
00011	Brk Undercharge Warning	Warning	Low	None	Active
00012	Brk Undercharge Warning	Warning	Low	None	Active
00013	Brk Undercharge Warning	Warning	Low	None	Active
00014	Brk Undercharge Warning	Warning	Low	None	Active
00015	Brk Undercharge Warning	Warning	Low	None	Active
00016	Brk Undercharge Warning	Warning	Low	None	Active
00017	Brk Undercharge Warning	Warning	Low	None	Active
00018	Brk Undercharge Warning	Warning	Low	None	Active
00019	Brk Undercharge Warning	Warning	Low	None	Active
00020	Brk Undercharge Warning	Warning	Low	None	Active
00021	Brk Undercharge Warning	Warning	Low	None	Active
00022	Brk Undercharge Warning	Warning	Low	None	Active
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00032	Brk Undercharge Warning	Warning	Low	None	Active
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00099	Brk Undercharge Warning	Warning	Low	None	Active
00100	Brk Undercharge Warning	Warning	Low	None	Active

Diagnostic Events

Energy Management Unit (EMU)

Consolidated vehicle electronics for seamless V2X

Optimized Microprocessor Architecture:

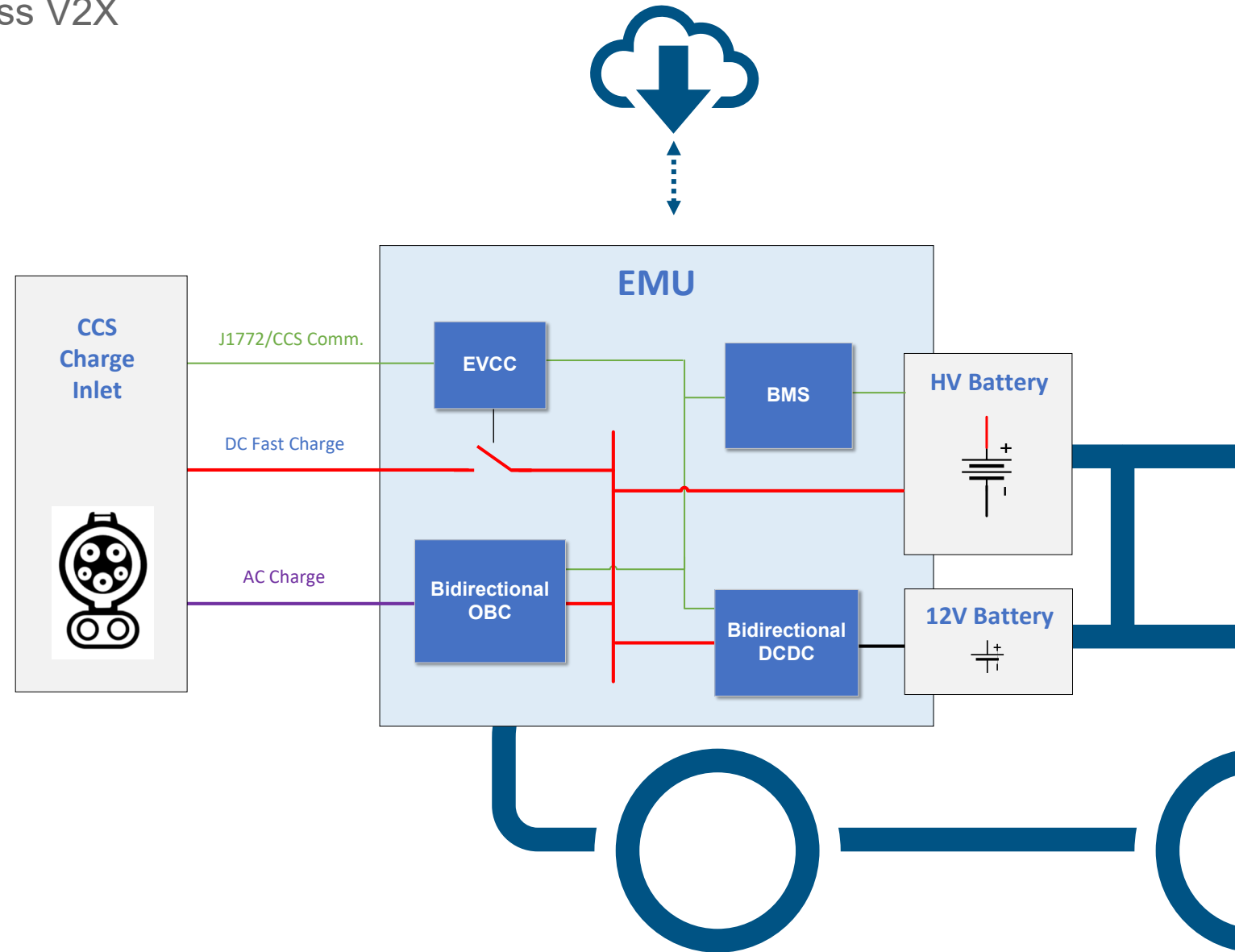
- Real-time control
- Safety critical functions
- Rich battery data collection
- V2X decision making with *ampOS* (adaptive to each vehicle)

Reduced BOM Cost, Weight & Volume:

- Fewer silicon
- Fewer cable harness
- Shared thermal management
- Shared IP enclosure

Simplified Vehicle Integration:

- Abstracted charging & V2X interface



- 400V Architecture
- 11 kW OBC
- 3 kW DCDC
- 500 A DC fast charge
- EVCC ISO15118 S/W stack
- Integrated PDU for e-motors, heater, compressor



World Class Power Density and Efficiency:

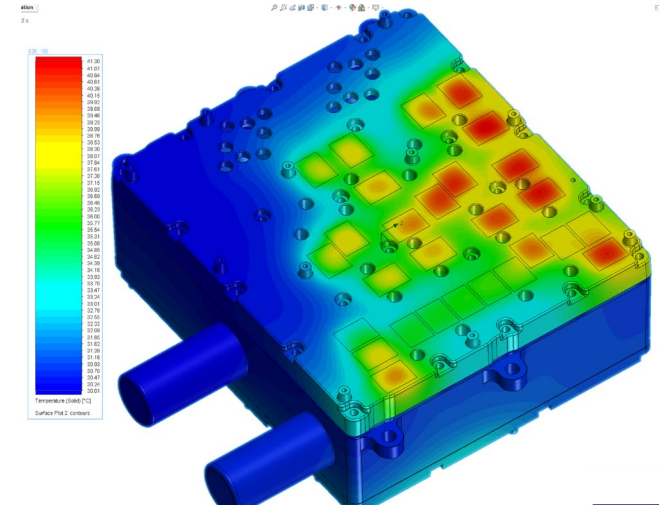
- 7L power conversion stage, 2kW/L
- OBC up to 95% efficient
- DCDC up to 97% efficient

Technologies:

- SiC power electronics
- Liquid-cooled magnetics
- 3D cooling cold block
- No electrolytic capacitors



Proprietary integrated OBC/DCDC cold block



EMU Operation Waveforms

OBC Input:

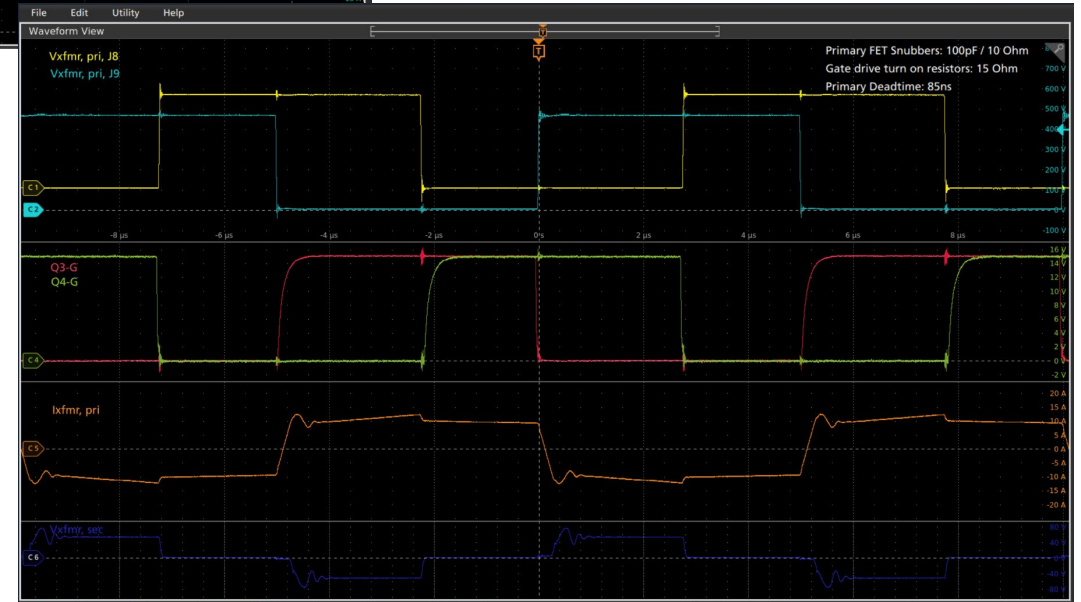
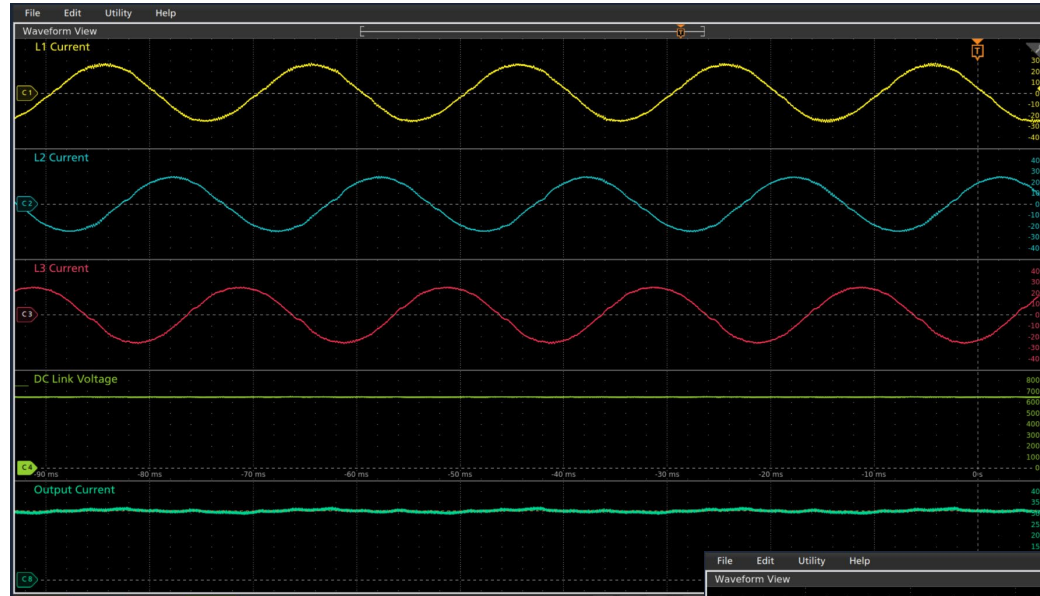
- 380 Vac L-L 3 phase
- 0.997 power factor
- 3% current THD

OBC Output:

- 367 Vdc
- 30 A
- 11 kW

DCDC Output:

- 14 Vdc
- 180 A
- 2.5 kW



Gen 1



SOP

Passenger cars: May 2022

Commercial vehicles: Q3 2023

400V

11 kW OBC, 3 kW DCDC

Paralleling for 22 kW OBC

500A peak DC fast charge

EVCC ISO15118 S/W stack

Ultra-compact – proprietary integrated cold block

Gen 2

SOP 2024

800V and 400V

Bidirectional OBC for V2X

Bidirectional DCDC for bus precharge

400V to 800V dc buck/boost mode

EVCC ISO15118-20 extension for V2X

Top-side cooled SMT SiC MOSFET

We are AMP



Managing **energy** for e-mobility with the best-in-class solutions

We produce connected electronics and software that control both the battery and charging.

With more than 150 years of experience, the AMP team has been integral in the development of energy management solutions at leading E-OEMs.

Battery Runtime

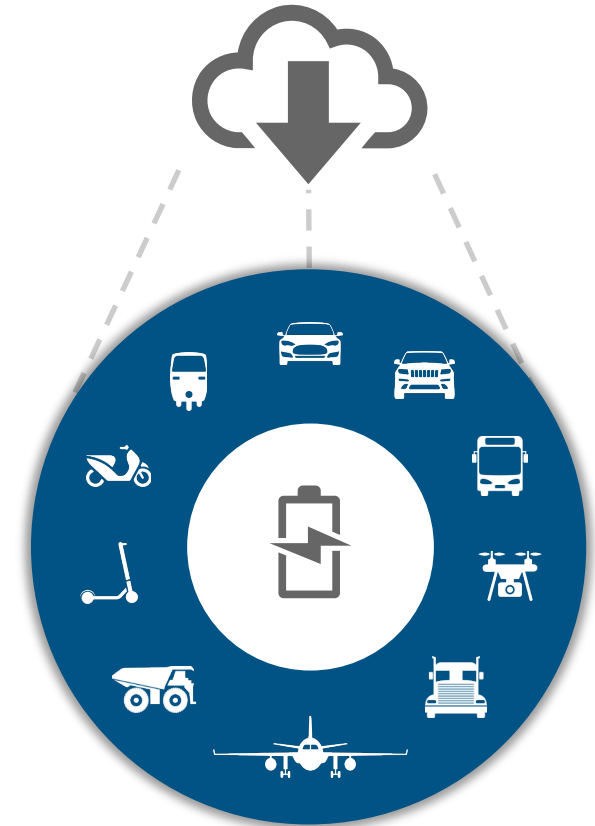
Reduce recalls

Battery Lifetime

Lowers service cost

Faster Charging

Faster to Market



ZOOX

SPACEX

DAIMLER



THANK YOU

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