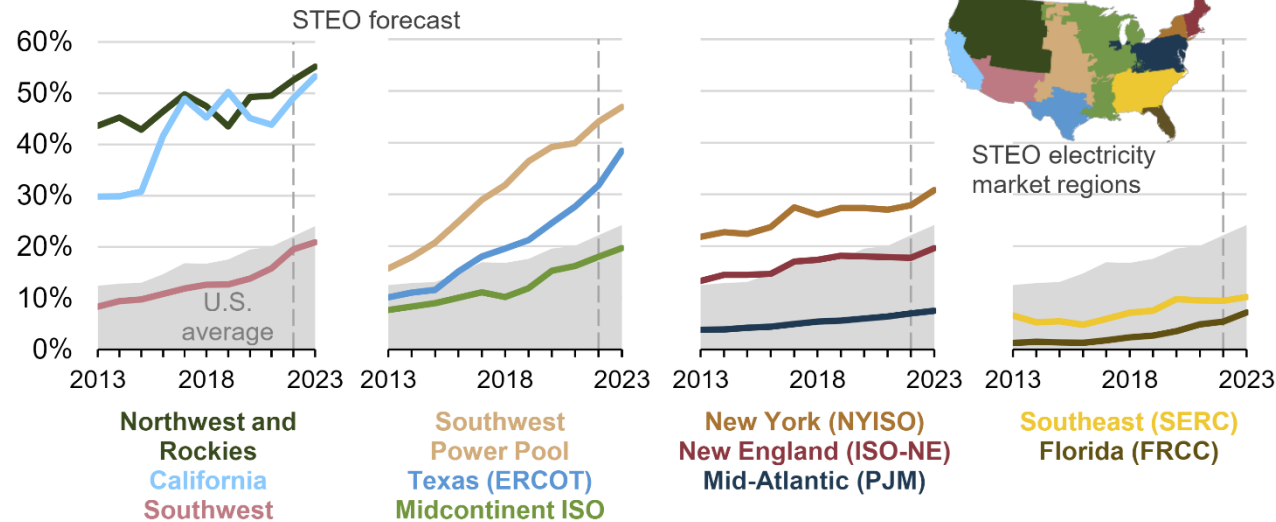# Energy Management for V2X

Dr Jiaqi Liang, Dr Matthew Gonzalez - AMP
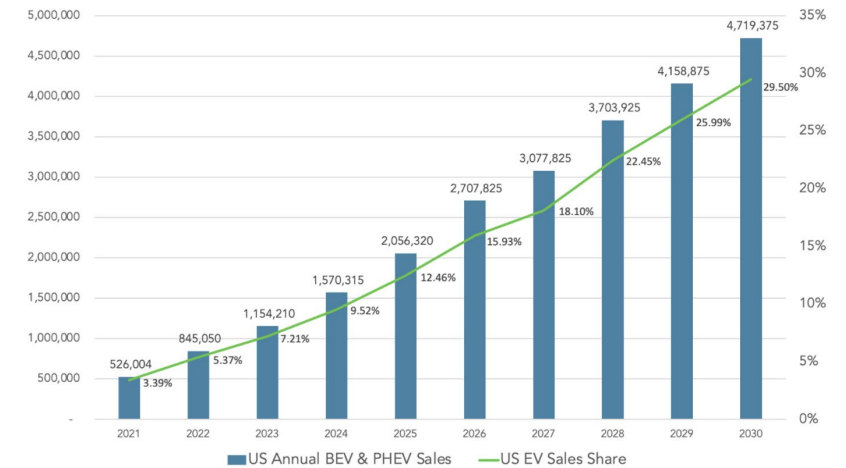
# The World Wants Zero Carbon

## 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)**
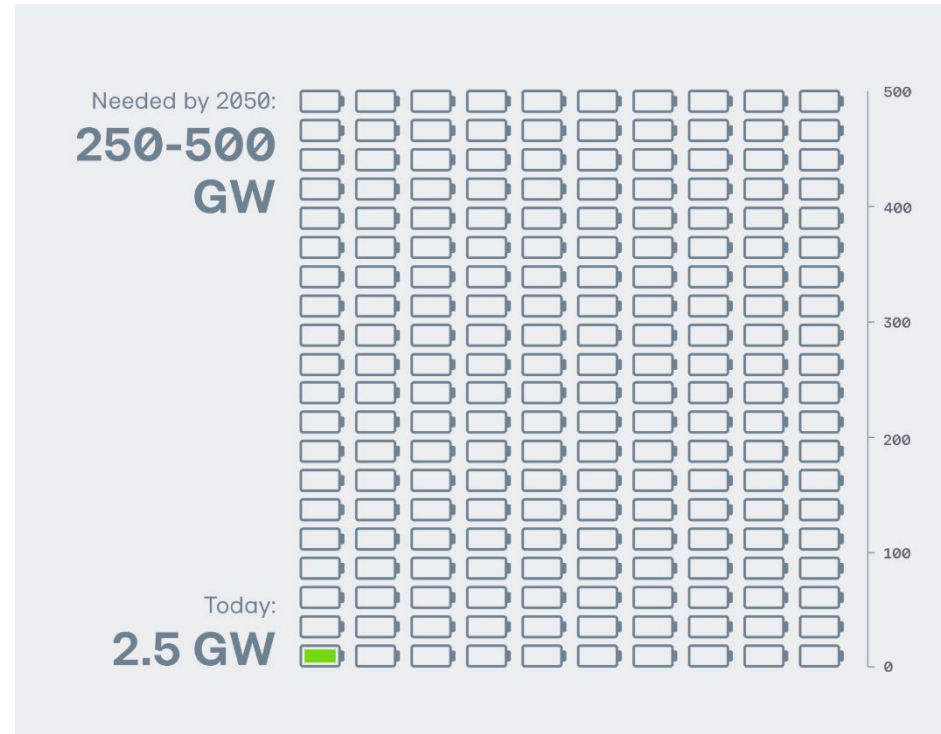Percentage of regional total electricity generation



**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
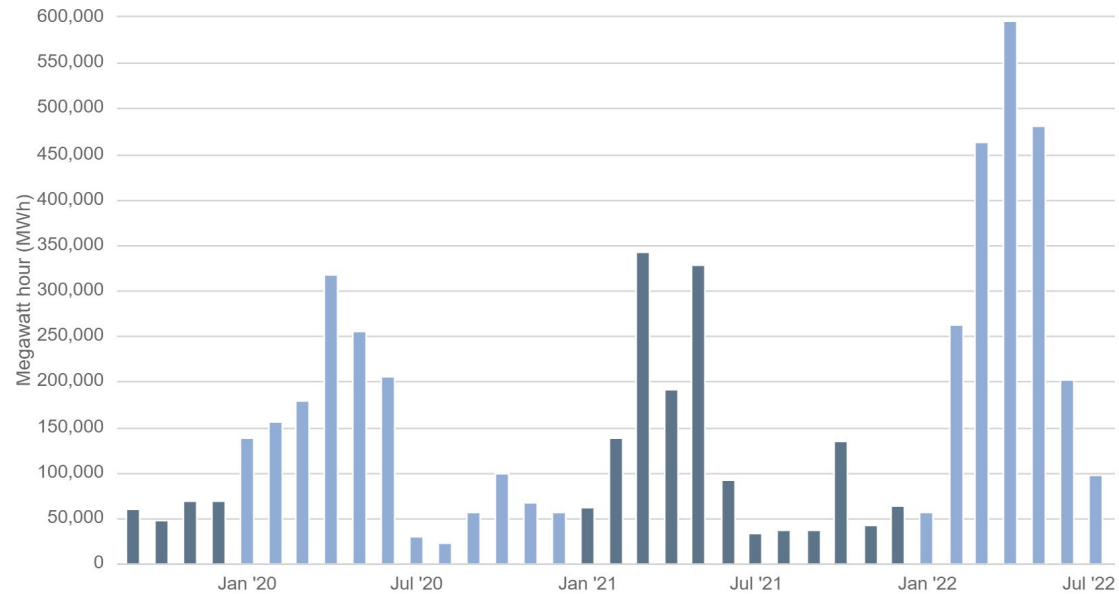


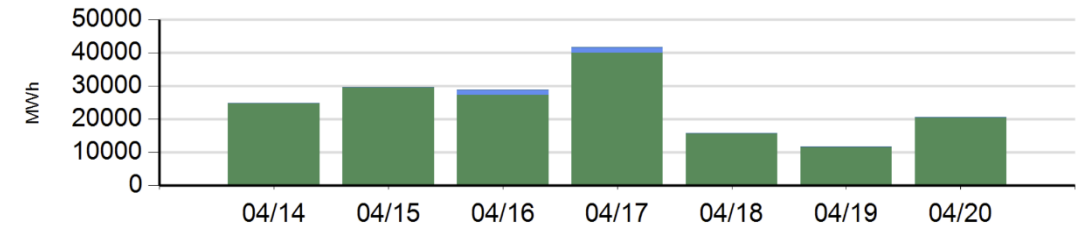Energy Storage Needed for Carbon Neutral in the US

# 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)
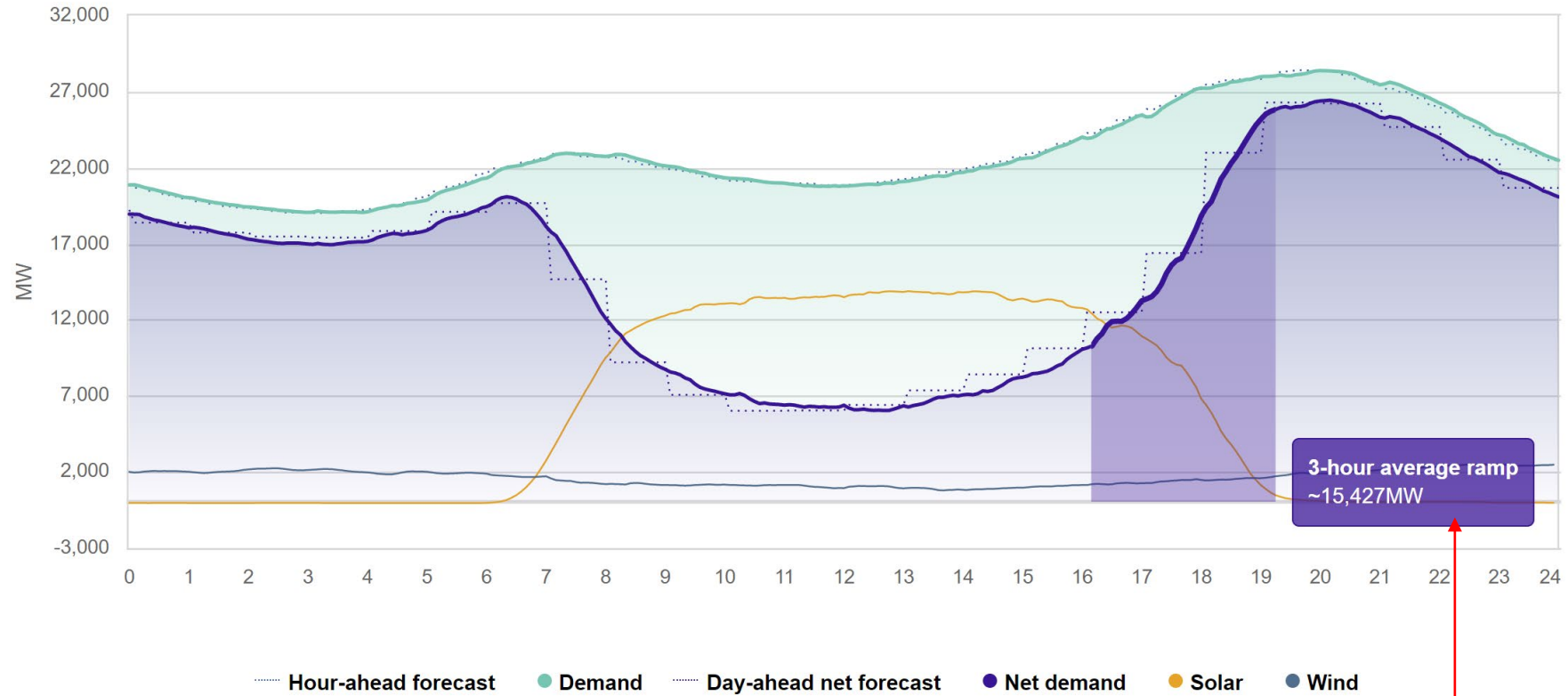


California monthly wind/solar curtailment



California daily wind/solar curtailment

Source: California ISO - Managing Oversupply (caiso.com)
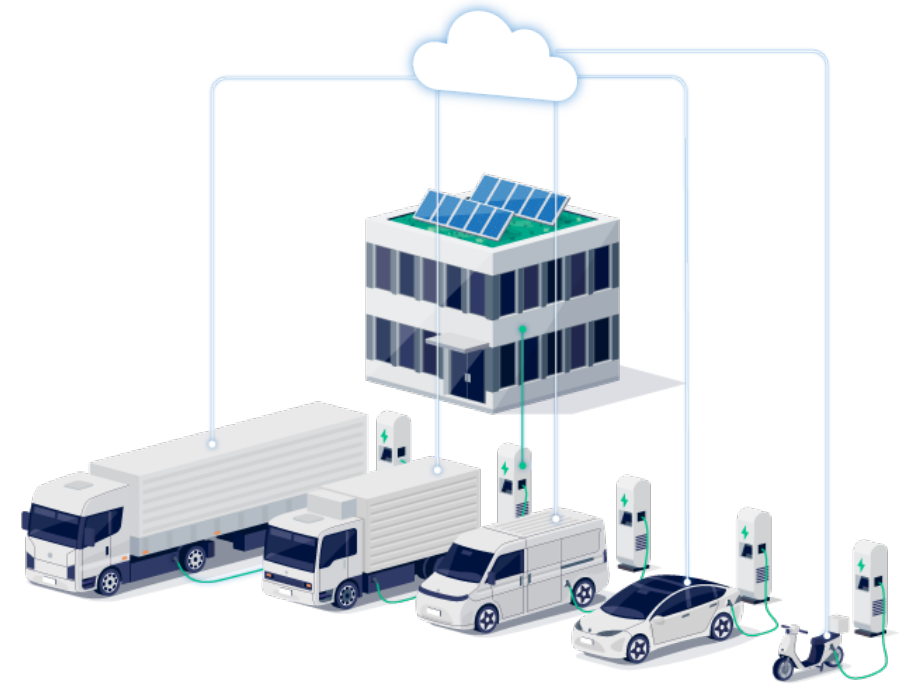
# The Duck Curve



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
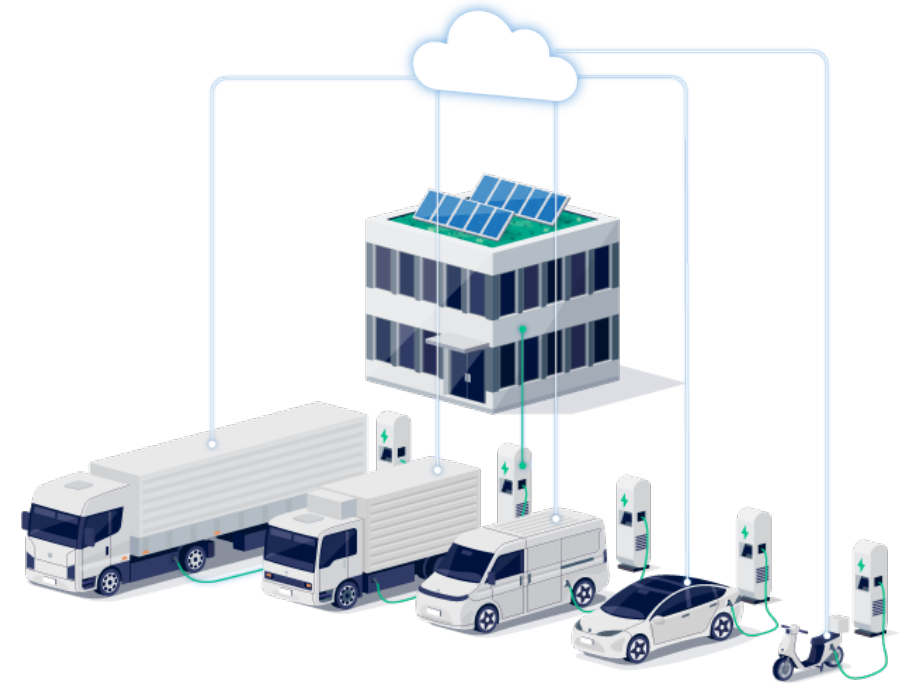
# What's Even Better than Free Energy?

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
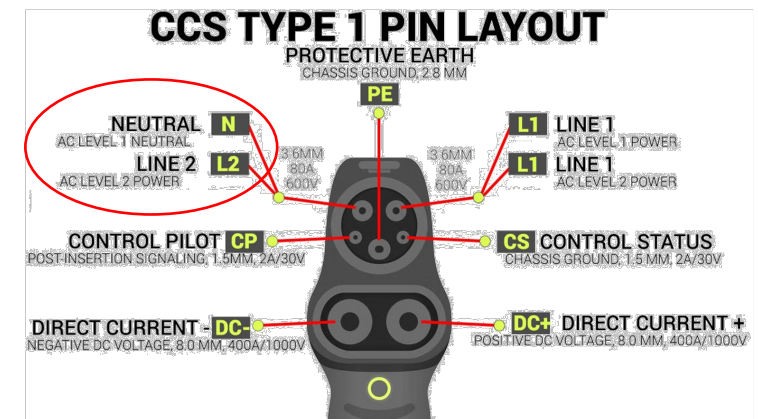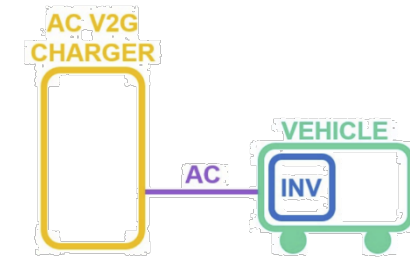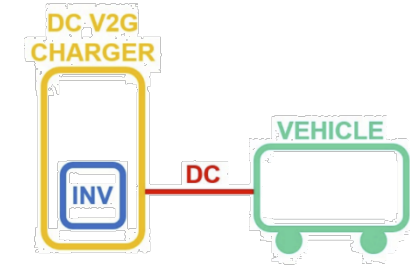
# V2G Business Wars

Who should be part of the V2G value chain?

Who decides between providing V2G service and warranting battery life?

| Utility Company | Charging Operator | Vehicle Owner | Vehicle OEM | Battery Supplier |
|---|---|---|---|---|
| V2G Customer  $$ - - - - - → | | V2G Supplier | ✕ | ✕ |
| Grid Oper. Data  - - - → | | | | |
| | | | Battery Life Data | |
| | | | | Battery Warranty |
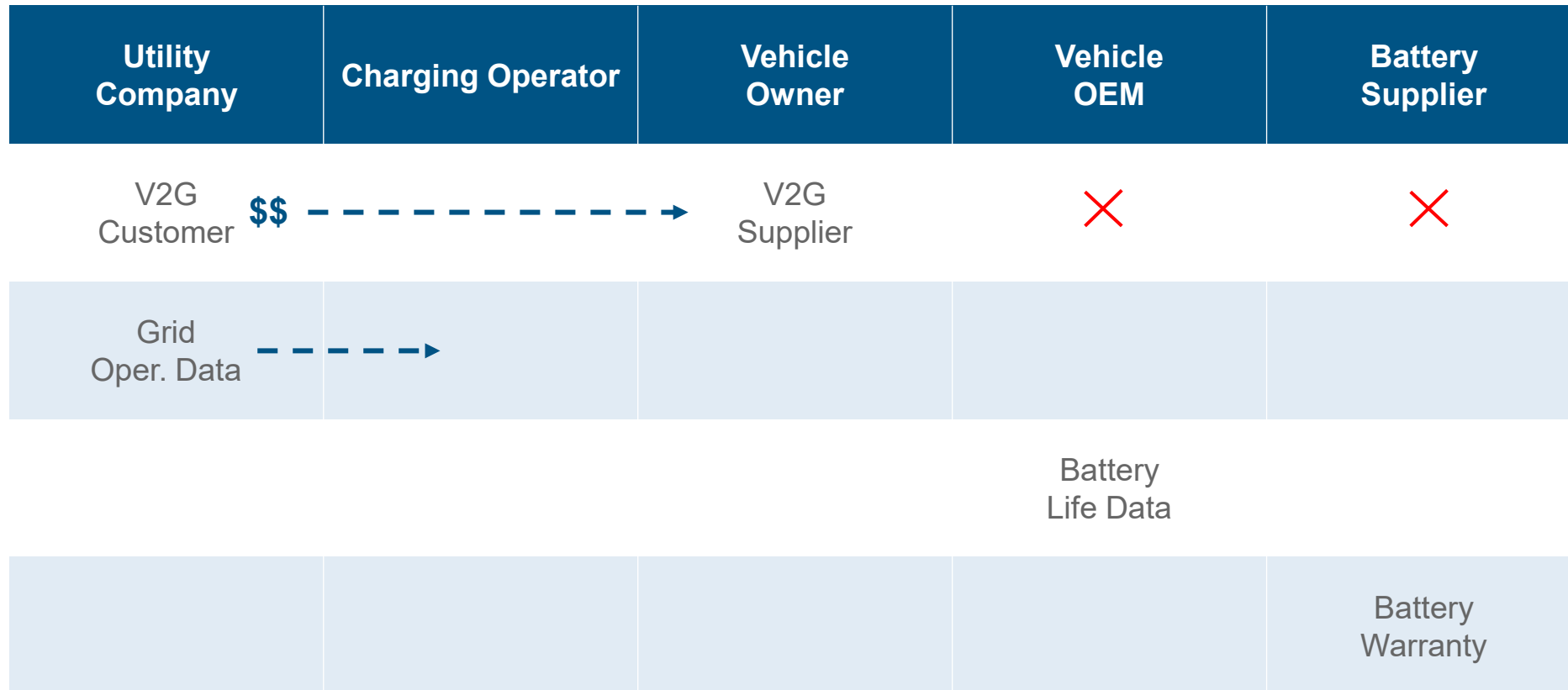
# End-to-End Energy Management for V2X

AMP

'Power Wall on Wheels'

**ampOS – The Energy Management Ecosystem:**

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

**GRID OPERATION SYSTEM**

***amp*OS**
**THE ENERGY MANAGEMENT ECOSYSTEM**

**GRID**

**HOME / Building**

Protection Devices

Control Unit

**EVSE UNIT**

Bi-Directional Charging

Battery Management

**ELECTRIC VEHICLE**

High Voltage Battery

**ENERGY MANAGEMENT UNIT**
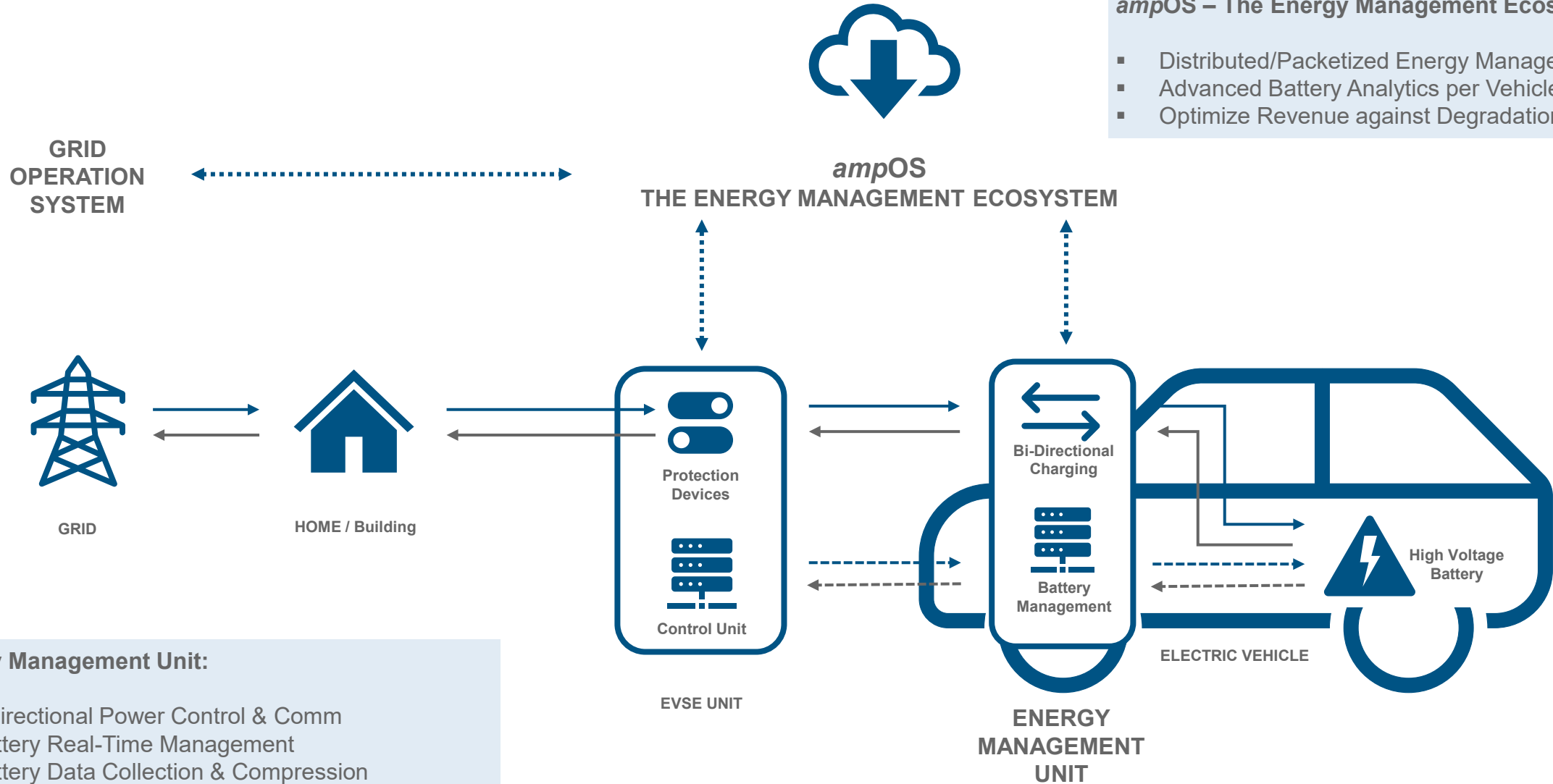
**Energy Management Unit:**

- 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
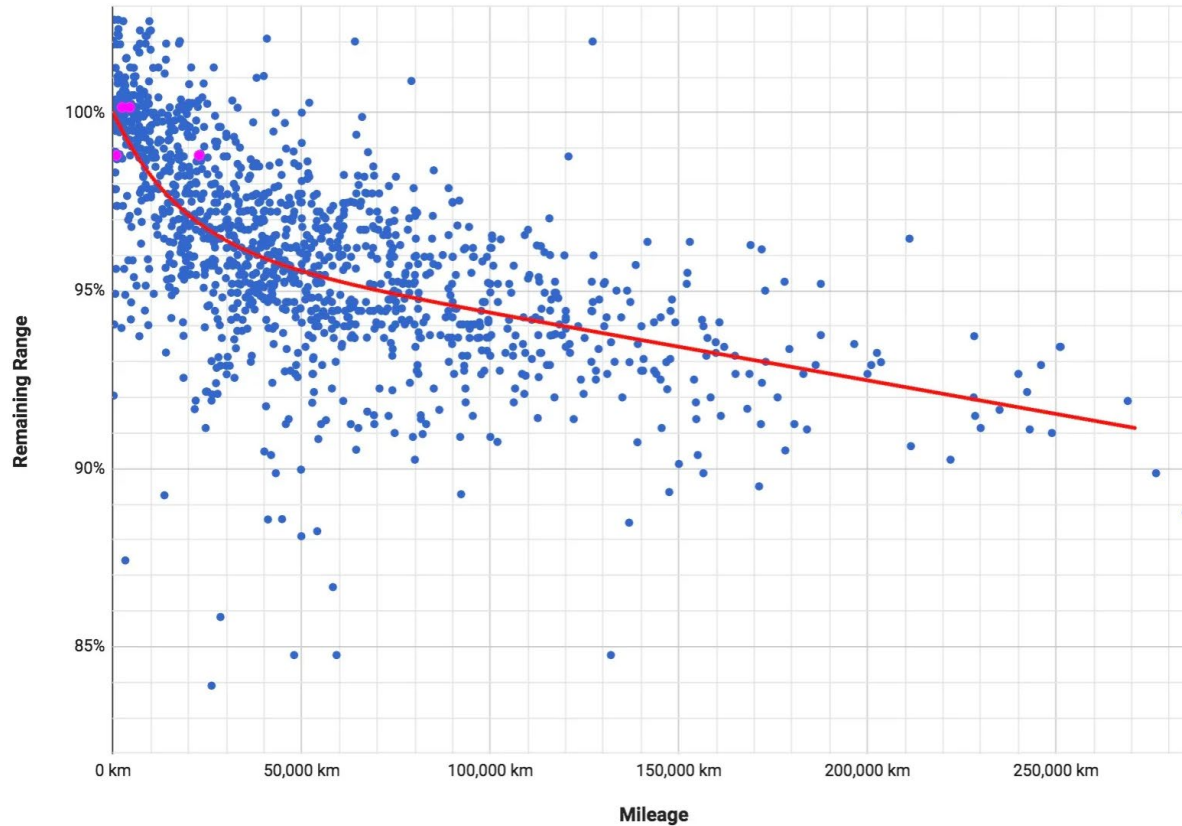
Fighting
'Range Anxiety'

- 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 ≈ 300,000 km

https://electrek.co/2020/06/06/tesla-battery-degradation-replacement/

# Understanding Battery Degradation

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

## 1. SEI growth and non-uniformity
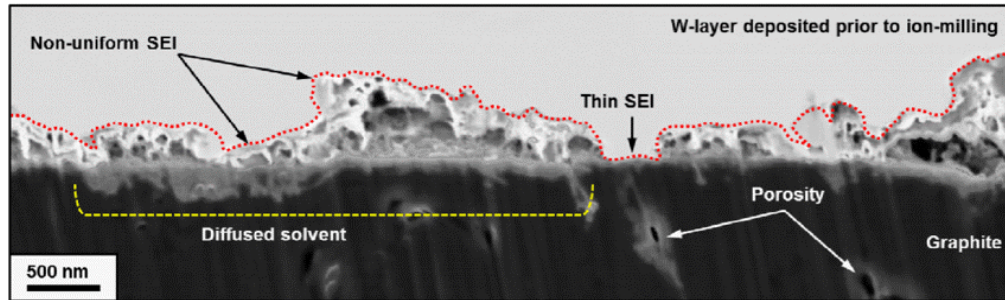


DOI:10.1016/j.carbon.2013.10.032

### Operate in the proper thermal environment
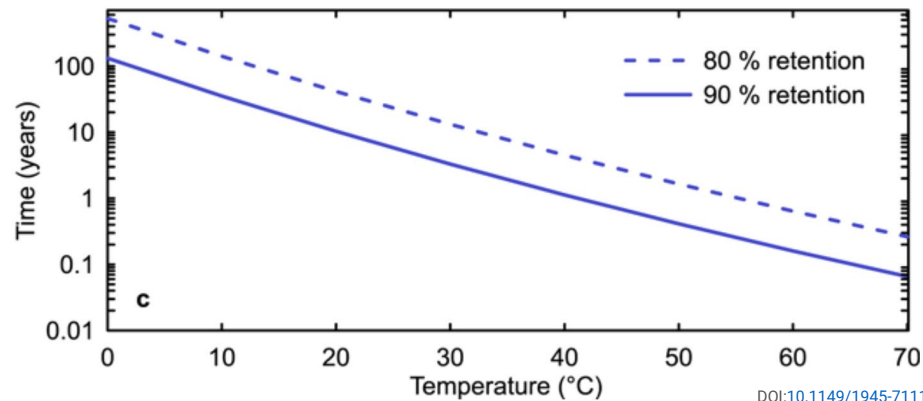


DOI:10.1149/1945-7111/ac42f1

## 2. Chemo-mechanical damage to active materials



### Operate in the proper voltage window
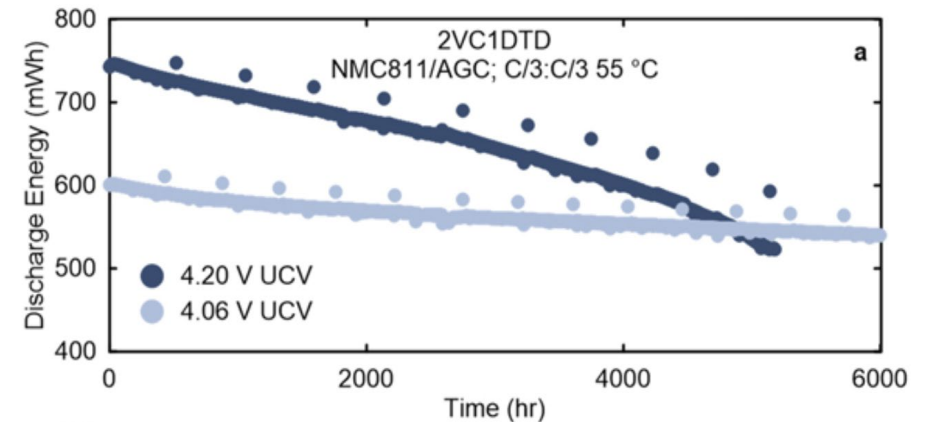
# Determining the Proper Operating Parameters

Physical modeled informed failure analysis

3D Multiphysics Models

Pseudo-2D Newman Models

Equivalent Circuit Models
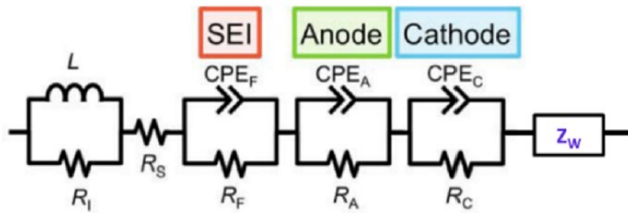
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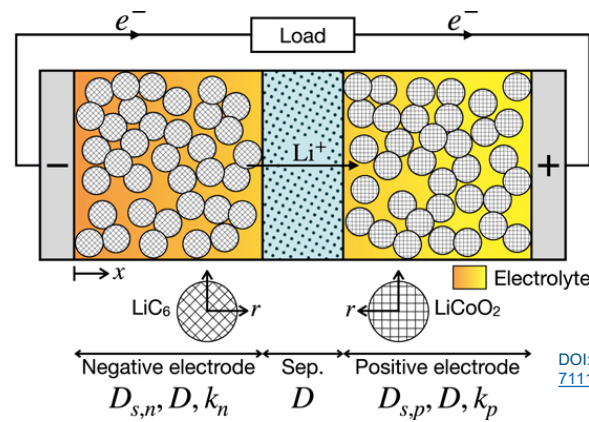
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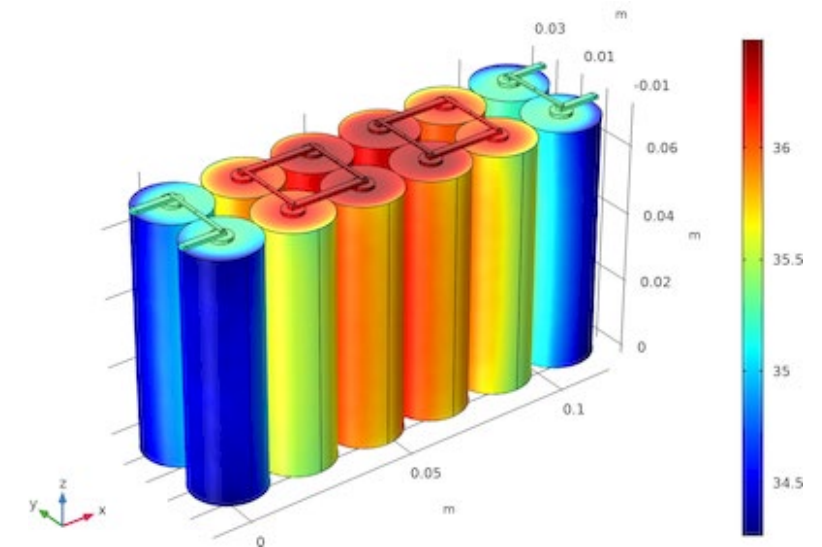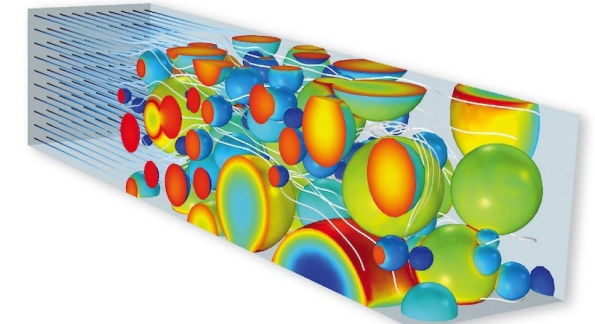
Increasing model accuracy...but increasing computational cost

https://www.comsol.com/

# 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
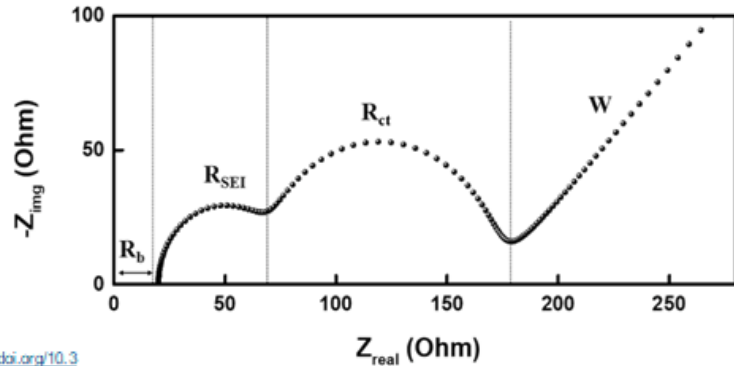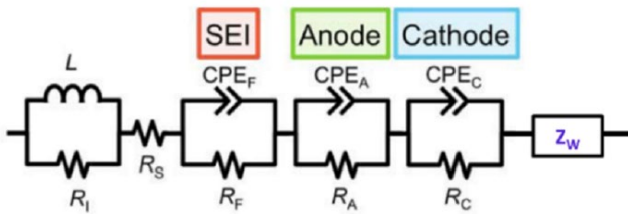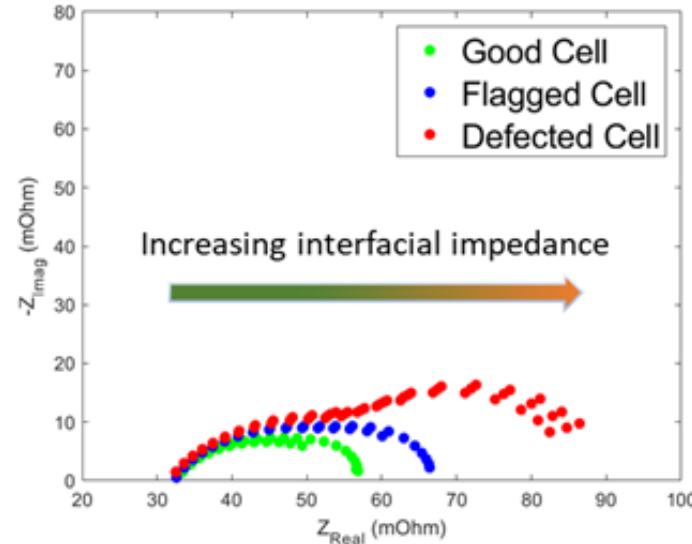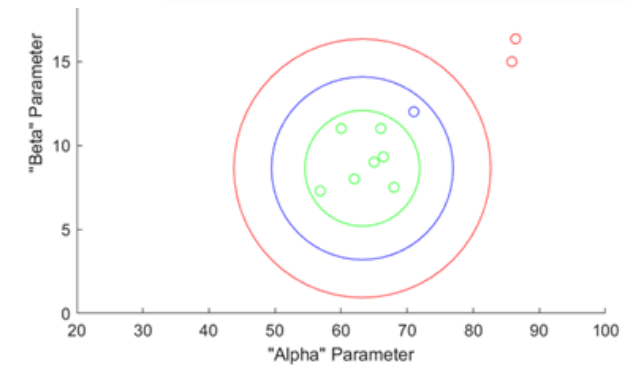
# Analyzing Chemistry and Kinetics

Informed decision making based on established techniques



Newman model is the mathematical standard

Differential analysis provides deep insights into governing physics

## AMP: First principals based operating protocols
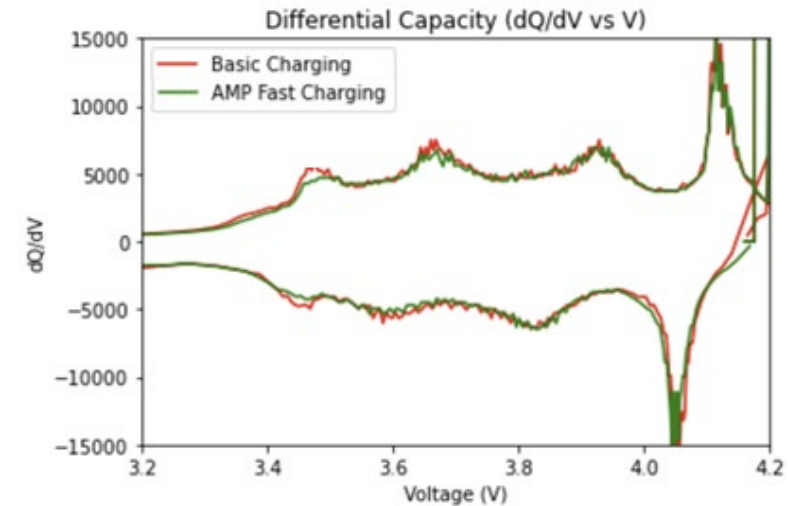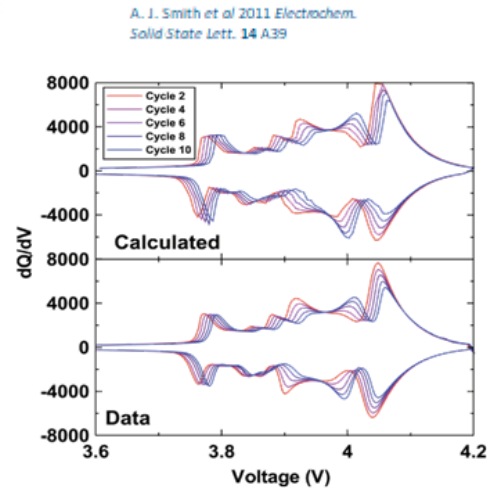
# Accounting for Anomalies and New Data

Expect the Unexpected

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

Normal vs. Abnormal



© AMP 2022
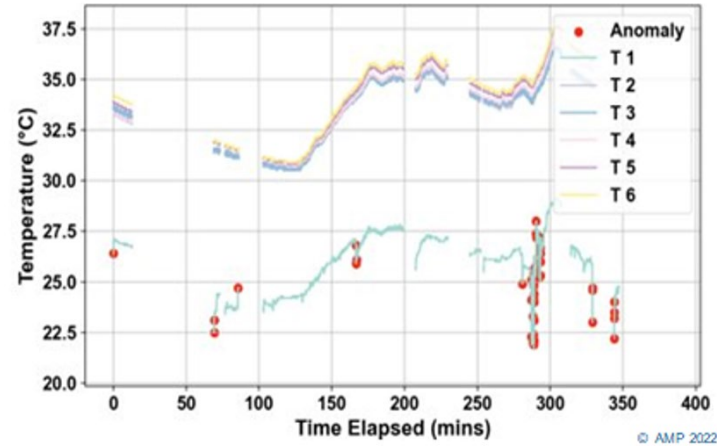
Feed newly discovered data back into model for **continuous improvement**



Li Plating

Basic models don't track anomalies



DOI: 10.1039/C6RA19482F

Differential Voltage

Onset of Li Plating

dV signature of Li metal
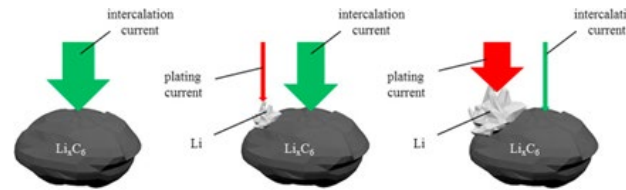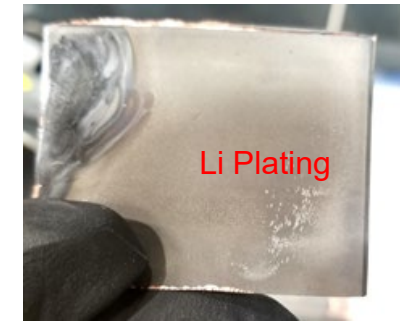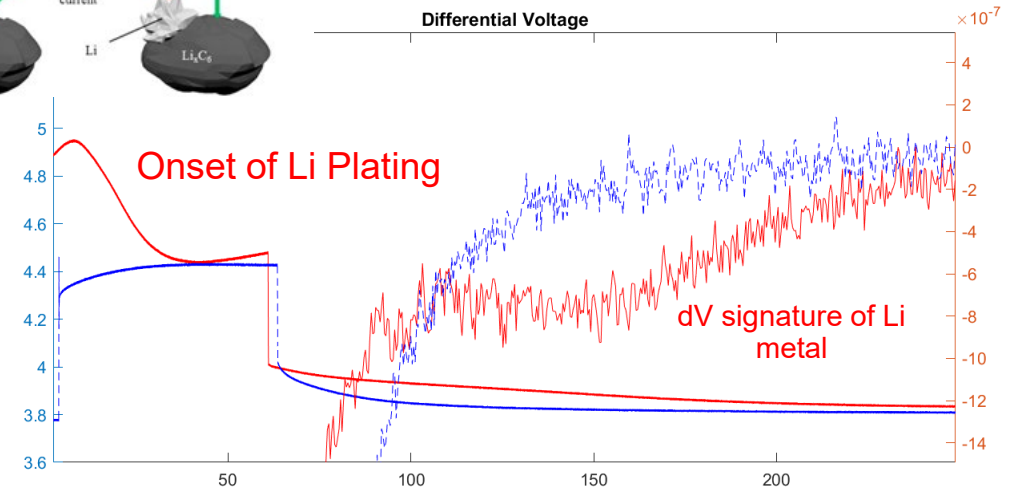
# Online Battery Characterization & Optimization

Closed loop characterization-based updates throughout battery lifetime

**Deployable Firmware Code**

Adaptive Battery System Controls

**Auto-generation & Online Adaptation**

Calibrations

Configurations

Diagnostic Events

# Energy Management Unit (EMU)

Consolidated vehicle electronics for seamless V2X

**AMP**

Optimized Microprocessor Architecture:

- Real-time control
- Safety critical functions
- Rich battery data collection
- V2X decision making with *amp*OS (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

# AMP Gen 1 EMU
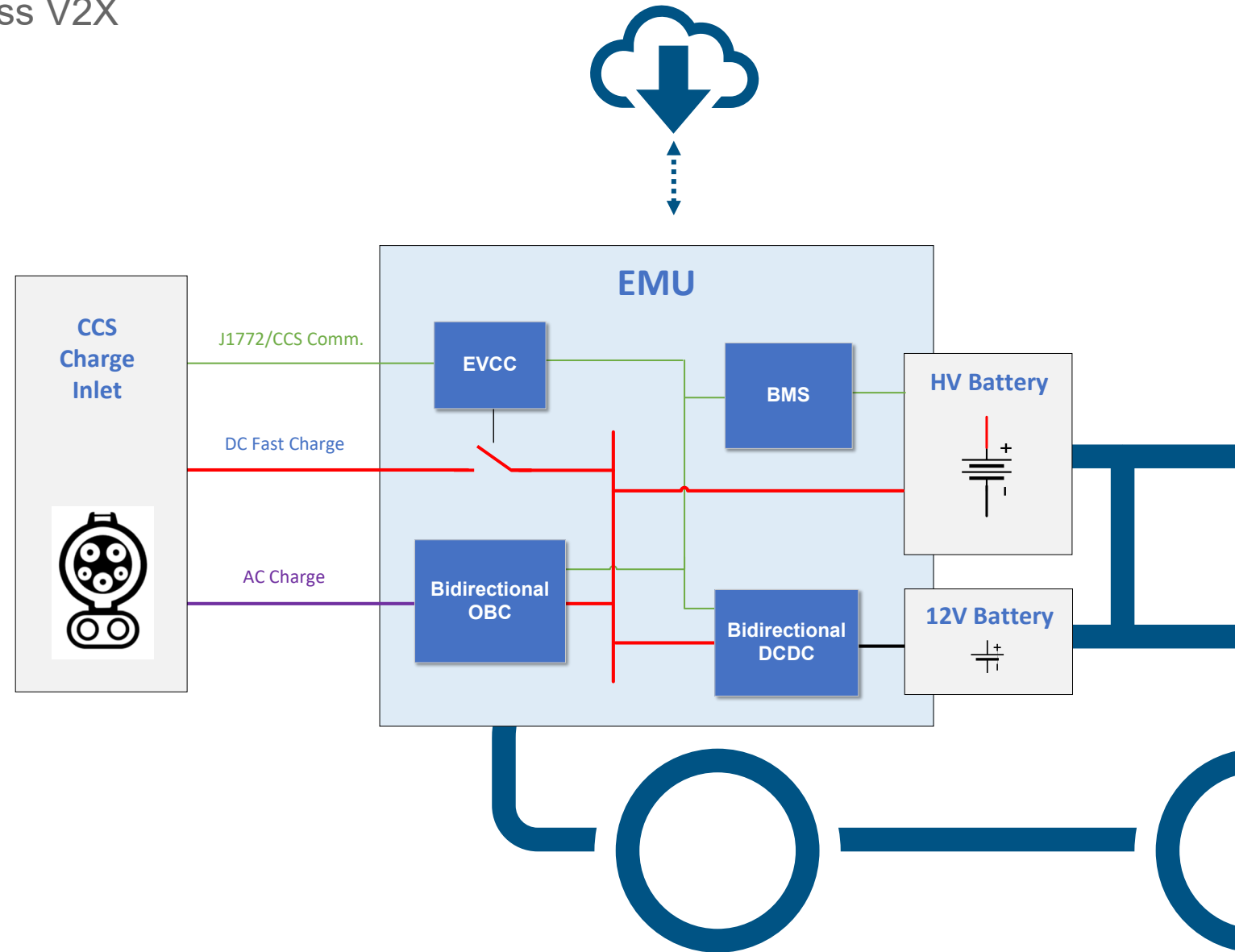
- 400V Architecture
- 11 kW OBC
- 3 kW DCDC
- 500 A DC fast charge
- EVCC ISO15118 S/W stack
- Integrated PDU for e-motors, heater, compressor

# AMP Gen 1 EMU

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**
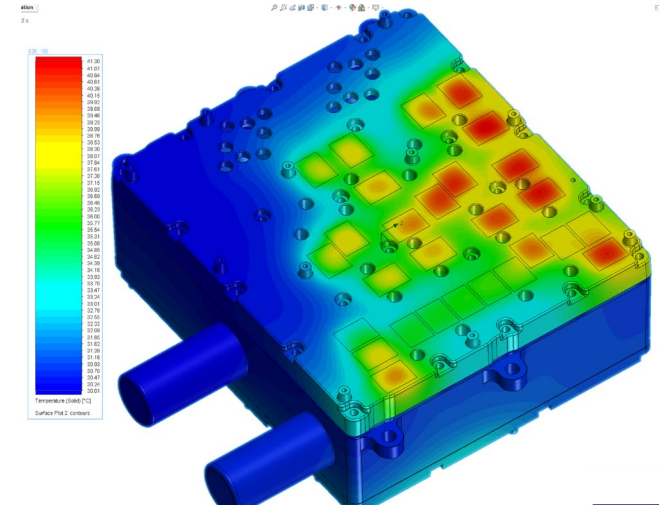
# EMU Operation Waveforms

**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

# AMP EMU Roadmap

**AMP**
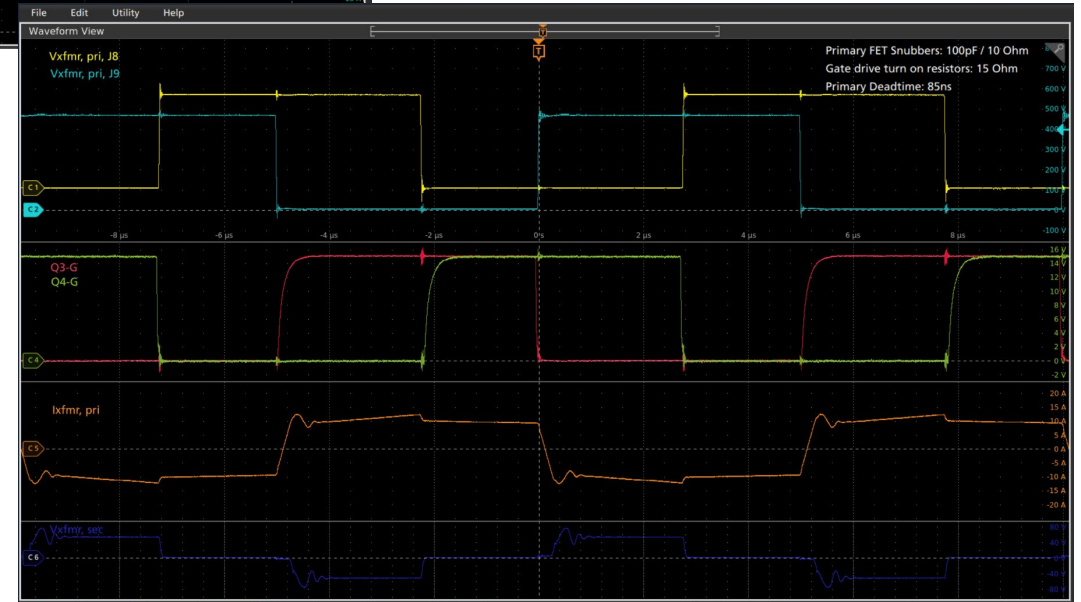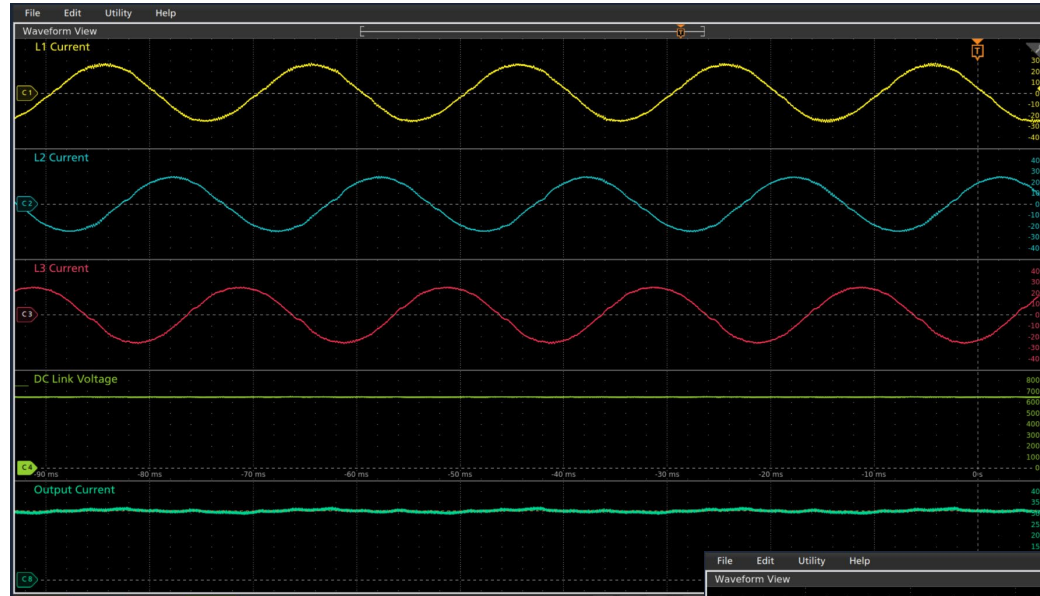
## Gen 1



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

**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.
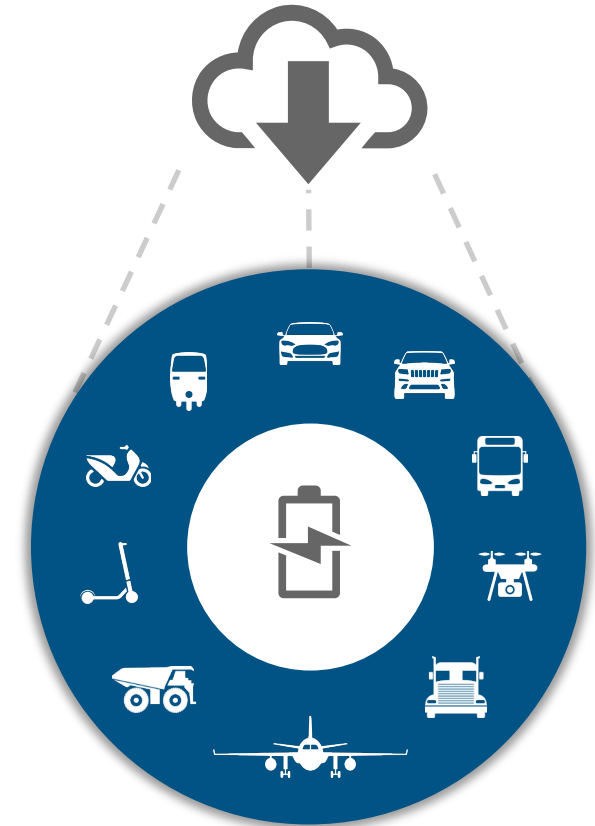
| Battery Runtime | Reduce recalls |
| Battery Lifetime | Lowers service cost |
| Faster Charging | Faster to Market |



TESLA　RIVIAN　Virgin hyperloop　ZOOX　SPACEX　DAIMLER　HONDA　Toyota　gm

# THANK YOU

# VISIT US AT

Dr Jiaqi Liang, Dr Matthew Gonzalez

**Auto Motive Power, Inc.**
11643 Telegraph Road, Santa Fe Springs, CA 90670

Booth
# #1205

✉ jiaqi.liang@amp.tech

  Matthew.Gonzalez@amp.tech

www.amp.tech