V2G-Sim | MyGreenCar

Eliminating EV Range Anxiety, Predicting Personalized Fuel Economy, and Enabling Vehicle-Grid Integration

---

Samveg Saxena, Ph.D

November 19, 2014

v2gsim.lbl.gov | powertrains.lbl.gov

Charging Ahead on Clean Transportation

- **Vehicles account for**
  - ~¼ of global GHG emissions
  - Substantial urban pollutants from tailpipe emissions

- **Transportation electrification is needed soon, at large scale to meet climate goals, but many obstacles:**
  - Range anxiety, available charging infrastructure, cost, etc.

- **If not electrification, at least need marked increases in fuel economy**

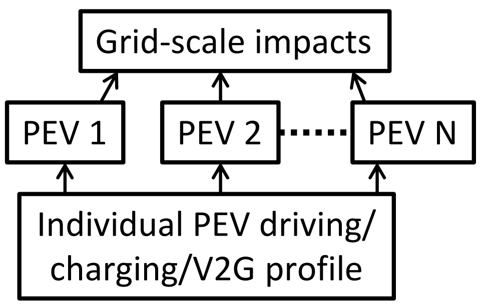
MyGreenCar

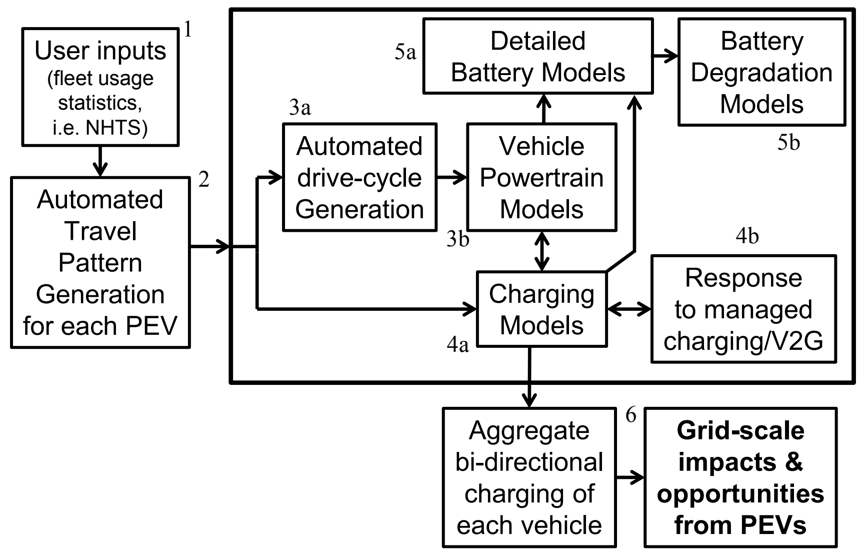
V2G-Sim: Understanding how clean transport enables a clean grid

BERKELEY LAB
Lawrence Berkeley National Laboratory

- **If ¼ US vehicles were PHEVs**
  = Grid storage for >1 hour of full US grid operations (~1,000 GWh)
  - Grid storage becomes a side-effect of deploying clean transportation
  - Enables substantial renewables integration… Clean transportation enables clean grid
  - Many coupled variables, each with large uncertainties… ⟵ ***V2G-Sim***

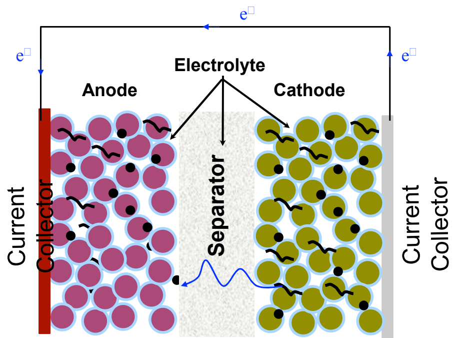
V2G-Sim **models the driving and charging behavior of individual PEVs to generate temporal and spatial grid-scale impact/opportunity predictions**





Vehicle Powertrains & Grid-Integration Research at LBNL

BERKELEY LAB
Lawrence Berkeley National Laboratory



Electrochemical Technologies

V2G-Sim development funded by laboratory directed research & development (LDRD)

Vehicle Powertrain Systems

Advanced Engine Research

Powertrain Innovations for Developing Countries

Vehicle electrification & Vehicle-grid integration

Grid Integration

Electricity Markets and Policy

LDRD: seed funding approved by Congress for high risk, high reward ideas that can transform society

Methodology: Travel Itinerary Inputs

1) Statistical approach: Categorize vehicle usage into finite number of “bins”

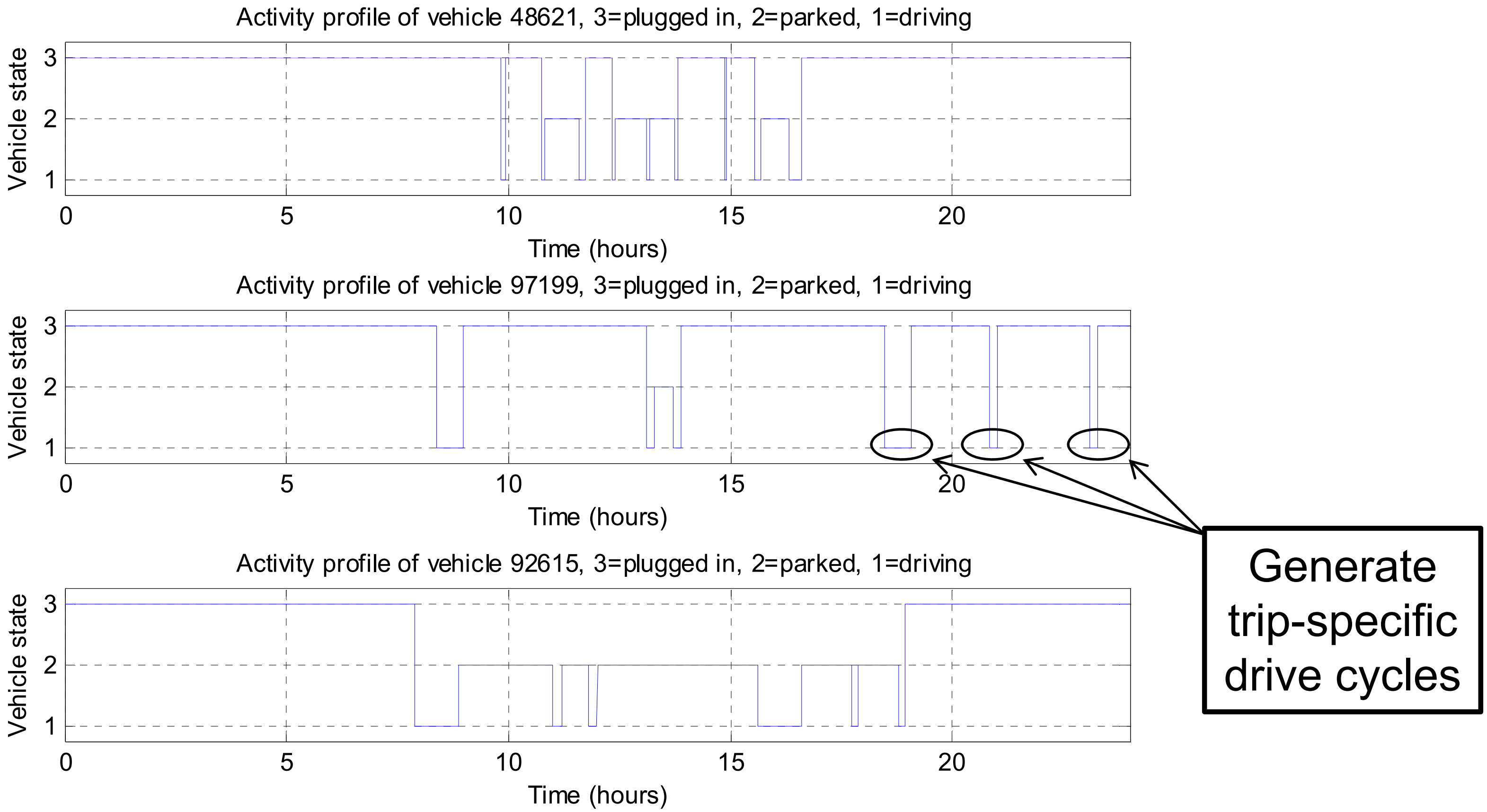
- Describe how/when vehicles are used

2) Deterministic approach: Direct simulation with actual vehicle usage data

- E.g. National Household Travel Survey / Real-time data

2.5) Automatically deriving inputs statistics from actual vehicle usage data

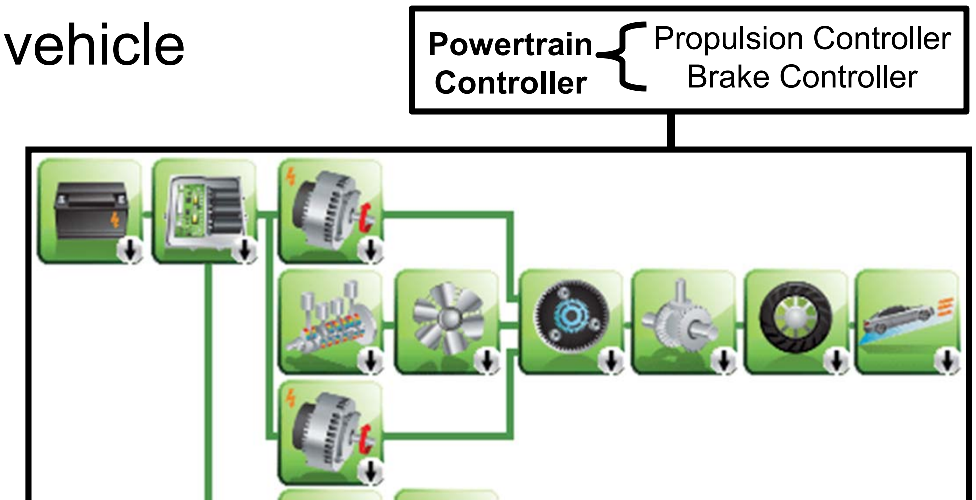
Methodology: Travel Itinerary Inputs



Methodology: Vehicle Powertrain Models

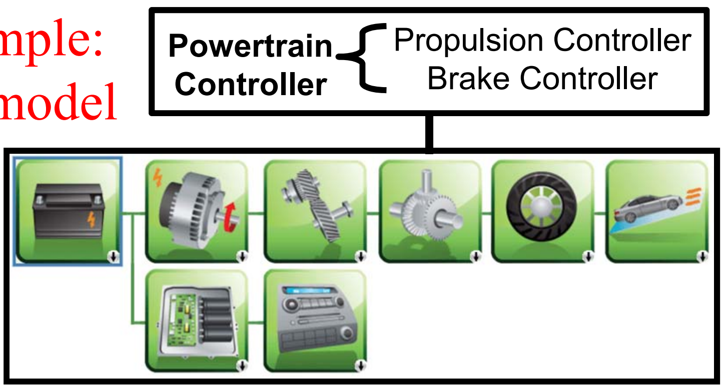
- **Methods: several possible approaches**
  - Simple: Wh/km for each vehicle
  - Detailed: Physics-based vehicle powertrain models

Example:
Powersplit PHEV



Source:
ANL, Autonomie

Example:
EV model

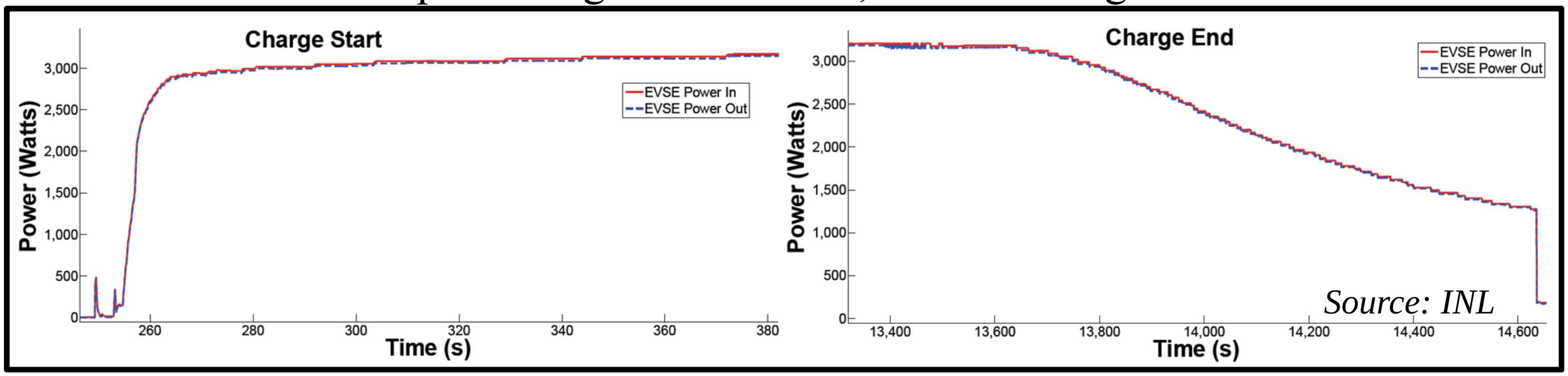


- **Output: Vehicle energy use, SOC while driving**

Methodology: Charging Models & Managed Charging/Discharging Controllers

- **Methods: charging rate with exponential decay:**
  - Simple model: $P_{charge}(t) = f\,(\,charger\ type\ ,\ SOC\ ,\ vehicle\ )$

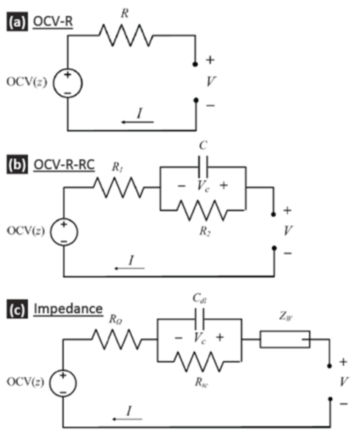
Example: ChargePoint CT503, Level 2 charger



  - Managed charging model: considers simple model + signal from managed bi-directional charging algorithms
- **Output: charging rate & SOC while charging**

Methodology: Battery Models

Equivalent Circuit Models



$$SOC = \frac{Ah_{\max} - \int \frac{I}{3600} + Ah_{init}}{Ah_{\max}}$$

$$R_{\text{int},dis} = f\left(SOC, T_{cell}\right)$$

$$R_{\text{int},chg} = f\left(SOC, T_{cell}\right)$$

$$V_{out,chg} = V_{OC} - \eta_{coul} I_{out} R_{\text{int},chg}$$

$$V_{OC} = f\left(SOC, T_{cell}\right)$$

$$V_{out,dis} = V_{OC} - I_{out} R_{\text{int},dis}$$

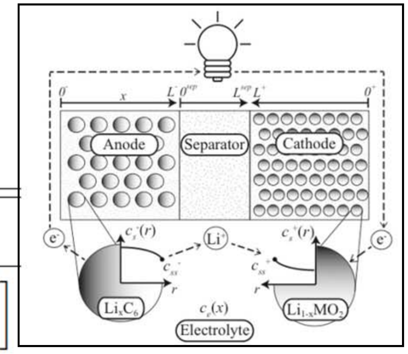
$$\dot{Q}_{gen,dis} = I_{out}^2 R_{\text{int},dis}$$

$$\dot{Q}_{gen,chg} = I_{out}^2 R_{\text{int},chg} - V_{out} I_{out}\left(1 - \eta_{coul}\right)$$

$$\dot{Q}_{cooling} = \frac{T_{\text{module air}} - T_{\text{module}}}{\text{Thermal resistance}}$$

$$T_{cell} = T_{\text{module}} = \frac{\int \left(\dot{Q}_{gen} - \dot{Q}_{cooling}\right) dt}{m_{\text{module}} C_{\text{p,module}}}$$

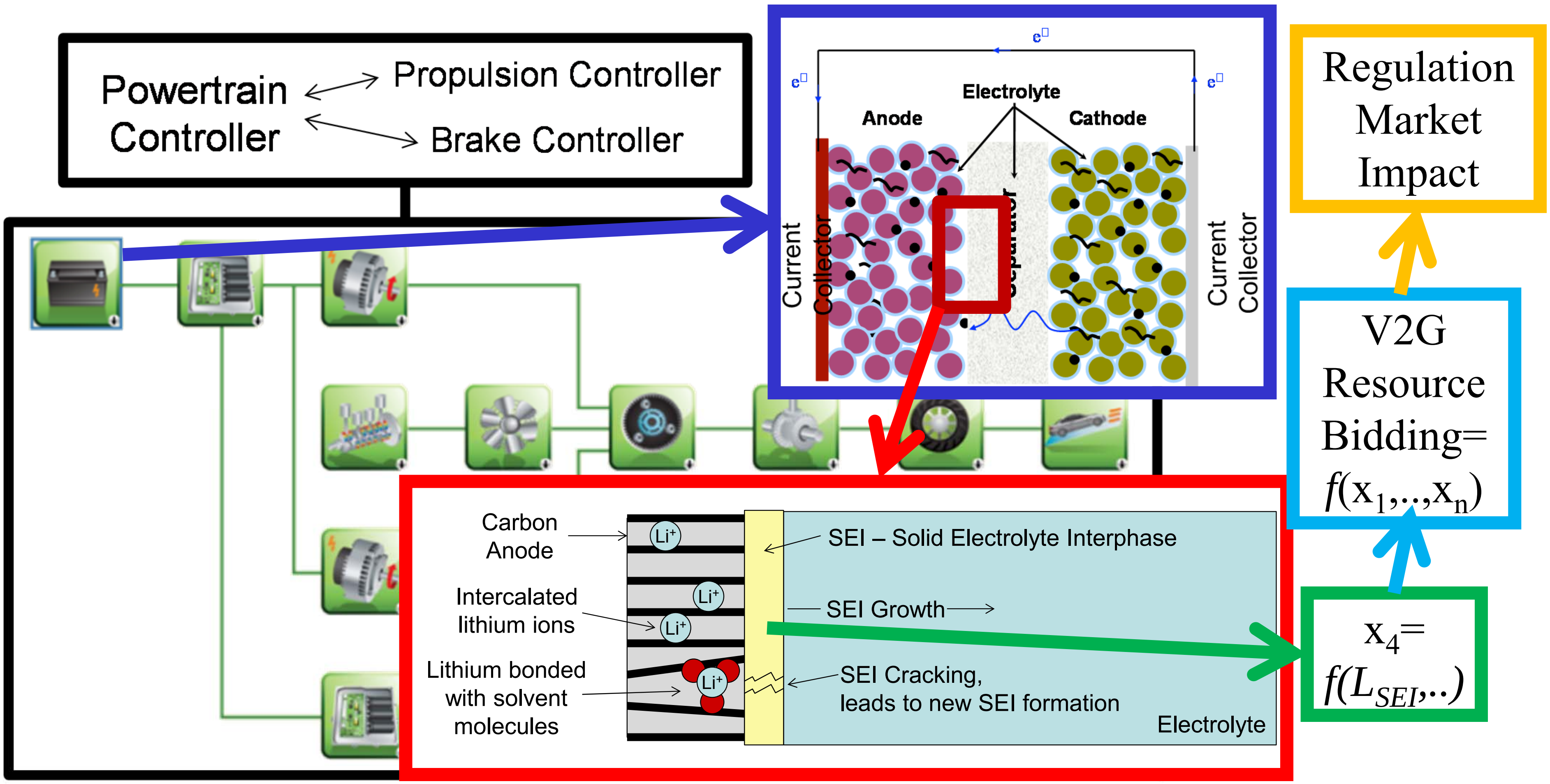
Electrochemical Models



Description	Equation
Solid phase Li concentration	$\frac{\partial c_s^\pm}{\partial t}(x,r,t) = \frac{1}{r^2}\frac{\partial}{\partial r}\left[D_s^\pm r^2 \frac{\partial c_s^\pm}{\partial r}(x,r,t)\right]$
Electrolyte Li concentration	$\varepsilon_e \frac{\partial c_e}{\partial t}(x,t) = \frac{\partial}{\partial x}\left[\varepsilon_e D_e \frac{\partial c_e}{\partial x}(x,t) + \frac{1-t_c^0}{F} i_e^\pm(x,t)\right]$
Solid potential	$\frac{\partial \phi_s^\pm}{\partial x}(x,t) = \frac{i_e^\pm(x,t)-I(t)}{\sigma^\pm}$
Electrolyte potential	$\frac{\partial \phi_e}{\partial x}(x,t) = -\frac{i_e^\pm(x,t)}{\kappa} + \frac{2RT}{F}(1-t_c^0)\left(1+\frac{d\ln f_{c/a}}{d\ln c_e}(x,t)\right)\frac{\partial \ln c_e}{\partial x}(x,t)$
Electrolyte ionic current	$\frac{\partial i_e^\pm}{\partial x}(x,t) = a_s F j_n^\pm(x,t)$
Molar flux btw phases	$j_n^\pm(x,t) = \frac{1}{F} i_0^\pm(x,t)\left[e^{\frac{\alpha_a F}{RT}\eta^\pm(x,t)} - e^{-\frac{\alpha_c F}{RT}\eta^\pm(x,t)}\right]$
Temperature	$\rho c_P \frac{dT}{dt}(t) = h\left[T^0(t)-T(t)\right] + I(t)V(t) - \int_{0^-}^{0^+} a_s F j_n(x,t)\Delta T(x,t)dx$

Prof. Scott Moura, UC Berkeley

Applications: Cross-disciplinary research

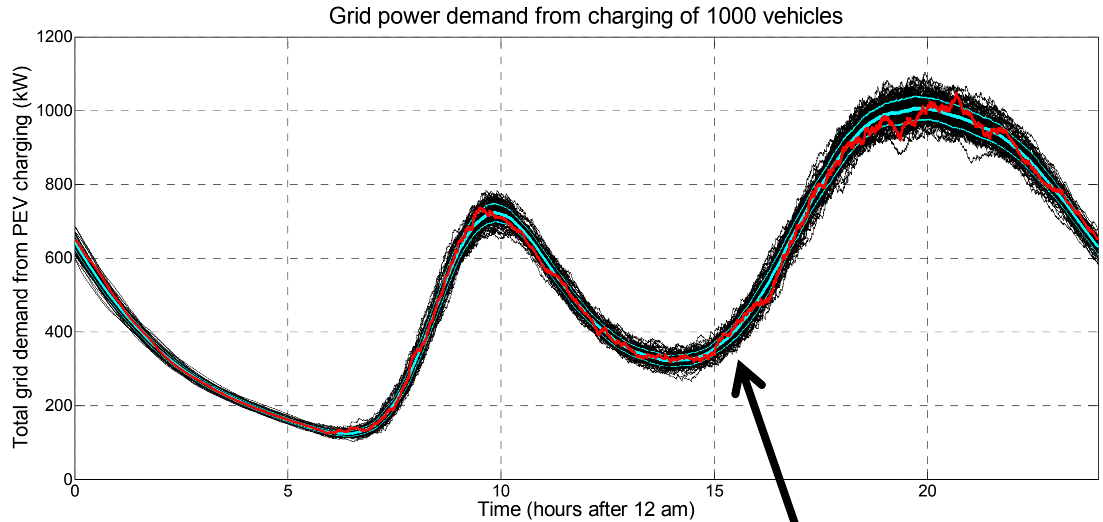


V2G-Sim Demonstration Cases

1. Predicting PEV charging demand & uncertainty
2. Spatial resolution of grid impacts
3. Battery degradation from driving & grid services
4. PEVs for renewables integration
5. EVs for demand response
6. Adequacy of inexpensive charging infrastructure
7. Redefining the Useful Lifetime of EV Batteries

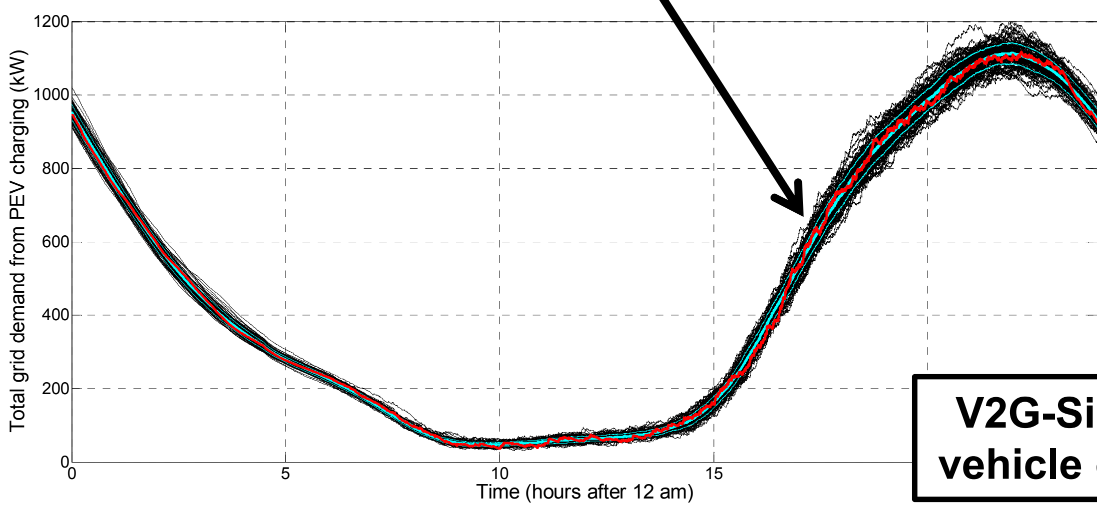
Case 1: Forecasting PEV Charging Demand from Stochastic Inputs

V2G-Sim forecasts PEV loads second-by-second with uncertainty estimates (enabler for PEV aggregation)



Case 1a

- 1,000 EVs
- Mix of L1 & L2 charging
- Favoring evening charging



Case 1b

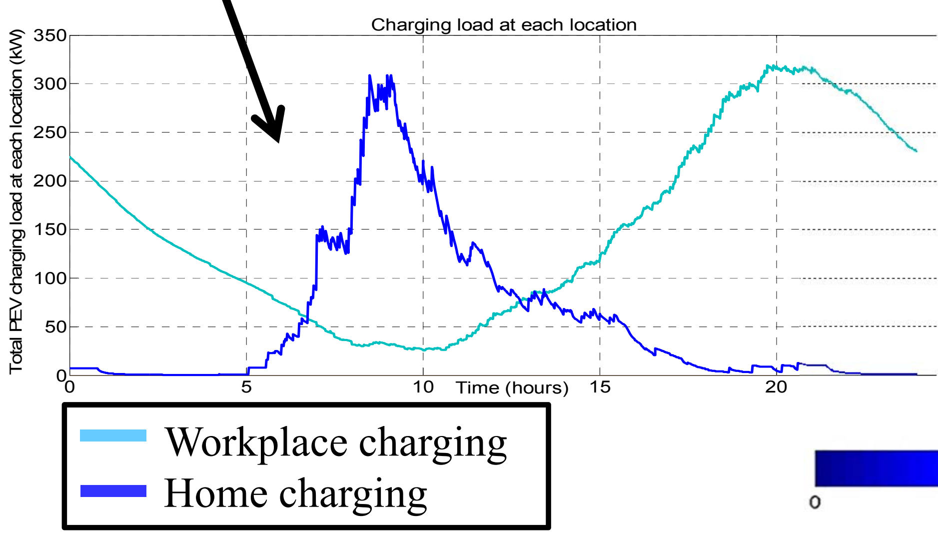
- 1,000 EVs
- Mix of L1 & L2 charging
- Day and evening charging

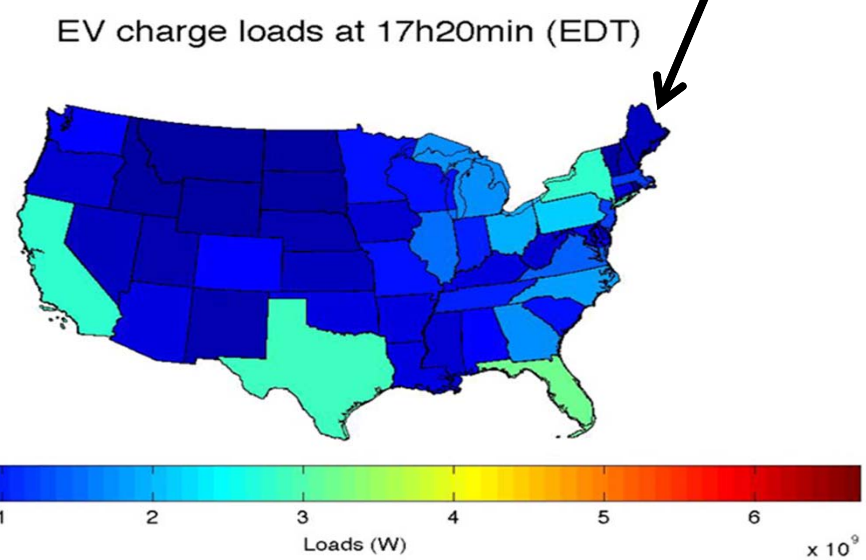
V2G-Sim allows any number of different vehicle or charger types to be considered

Case 2: Spatially resolving PEV loads and resources

Case 2a
- 659 vehicles, SF Bay data from NHTS
- L1 at home, L2 at work

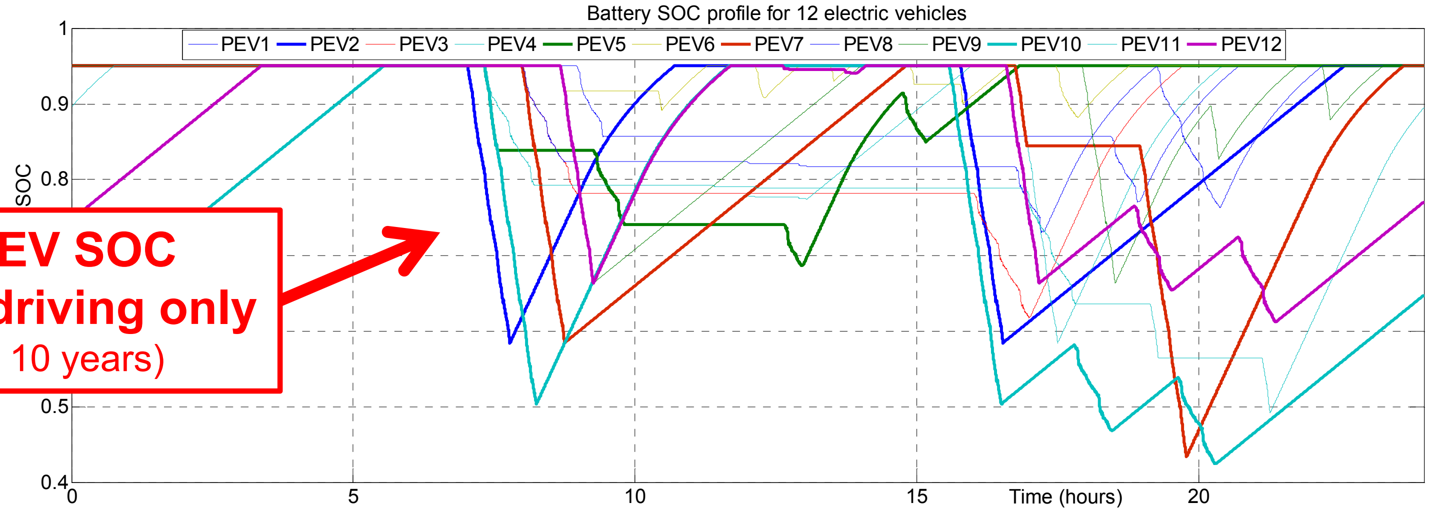
Case 2b
- 80% PEV adoption uniformly across U.S.
- L1 at home, L1 at work





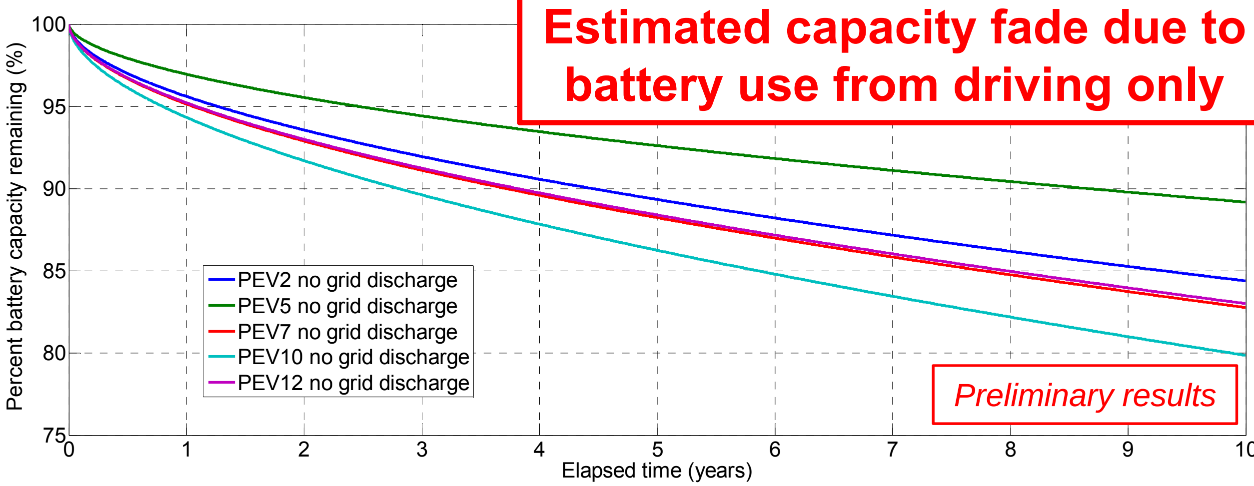
Alternatively, can spatially-resolve down to distribution level, neighborhood, GPS coordinate, etc.

Case 3: Predicting battery degradation from driving vs. vehicle-grid services



Individual EV SOC profiles from driving only
(Repeated for 10 years)

Estimated capacity fade due to battery use from driving only

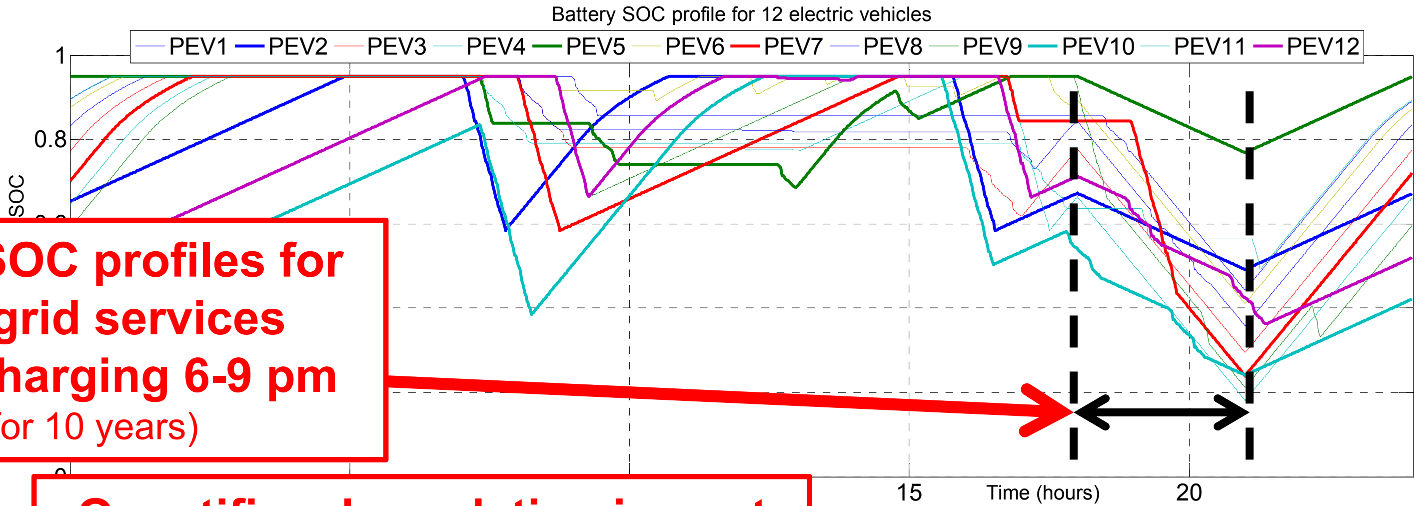


Preliminary results

Case 3a

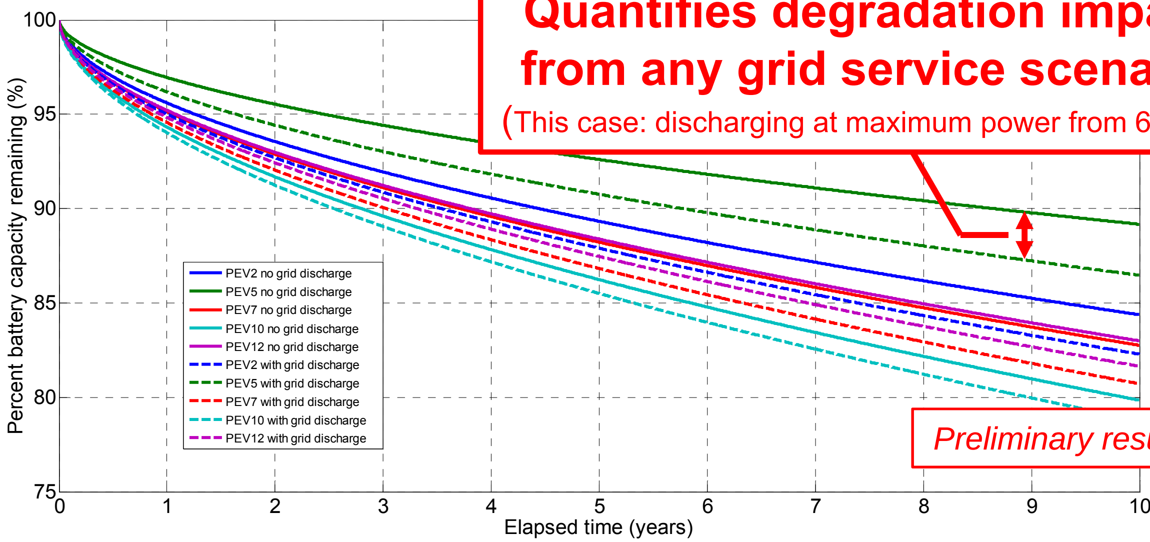
- **12 EVs**
- **Capacity fade of a $LiFePO_4$ battery pack (driving only)**

Case 3: Predicting battery degradation from driving vs. vehicle-grid services



Individual EV SOC profiles for driving and grid services Example: Discharging 6-9 pm
(Repeated for 10 years)

Quantifies degradation impact from any grid service scenario
(This case: discharging at maximum power from 6-9 pm)



Preliminary results

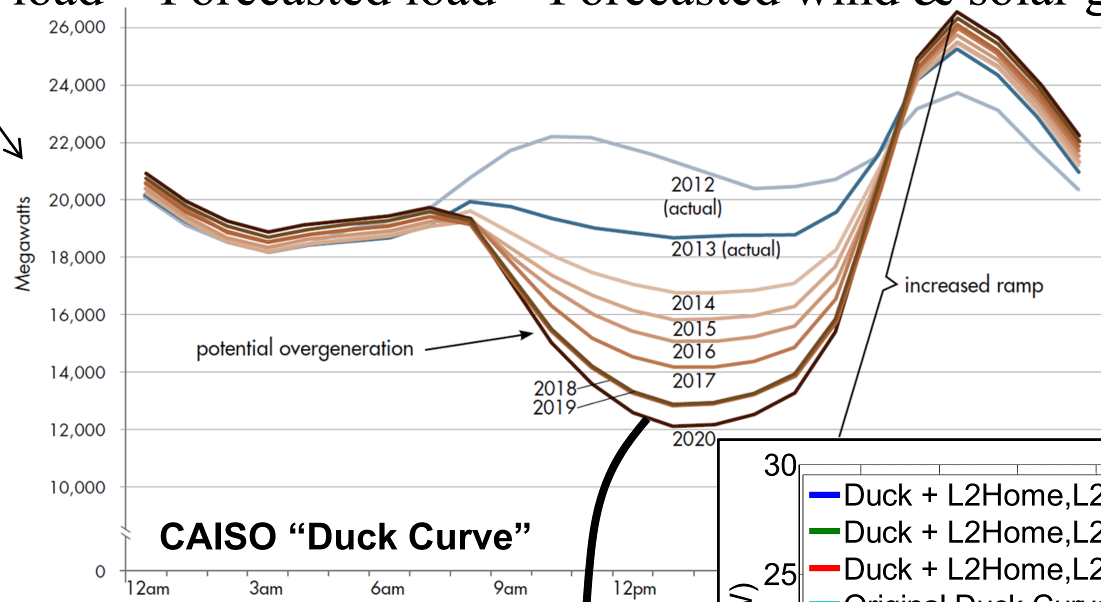
Case 3b

- **12 EVs**
- **Capacity fade of a $LiFePO_4$ battery pack (driving + grid service)**

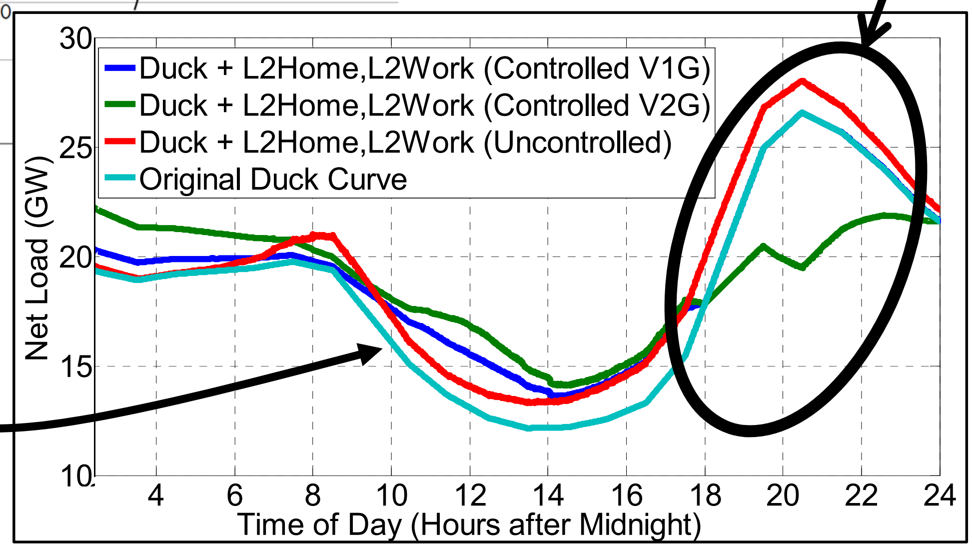
Case 4: PEVs for Renewables Integration

BERKELEY LAB

Net load = Forecasted load – Forecasted wind & solar generation



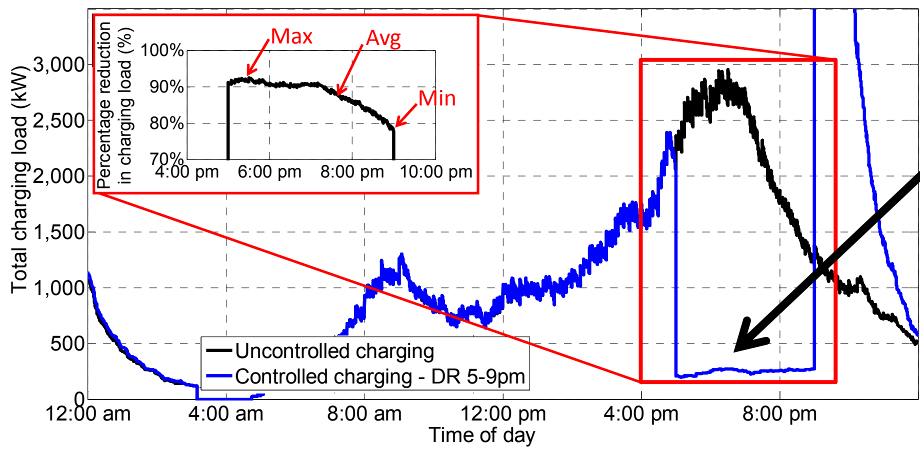
V2G-Sim results for ~3M PEVs (mostly PHEVs)



Plug-in vehicles can alleviate challenges from large-scale renewables integration

Case 5: Flexibility of EVs to vary charging to offer demand response

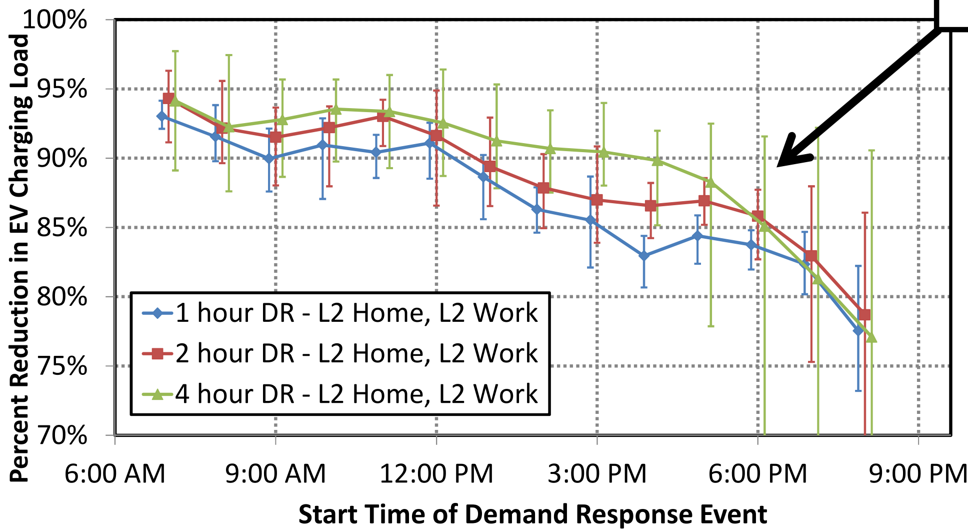
Charging load from 3,166 EVs



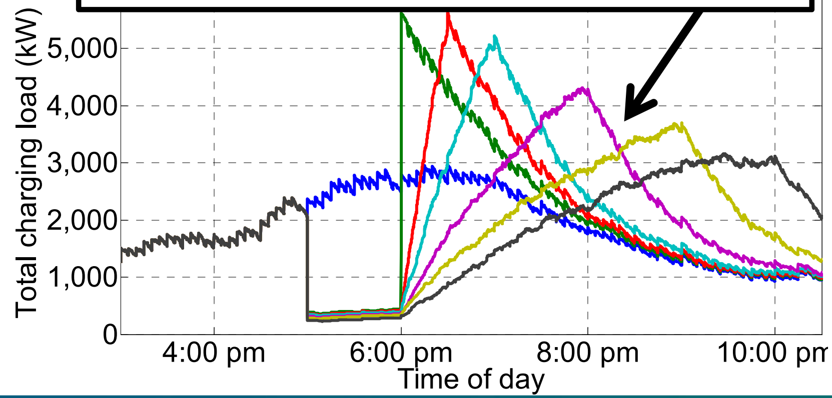
Managed charging controller in V2G-Sim set up to reduce PEV charging during demand response events
(without interfering with any drivers' mobility needs)

Parametrically simulate DR events for different durations, at different times of day

75-95% EV charging can be shed during DR event without interfering with driver needs



Can mitigate post-DR peak by gradually resuming EV charging

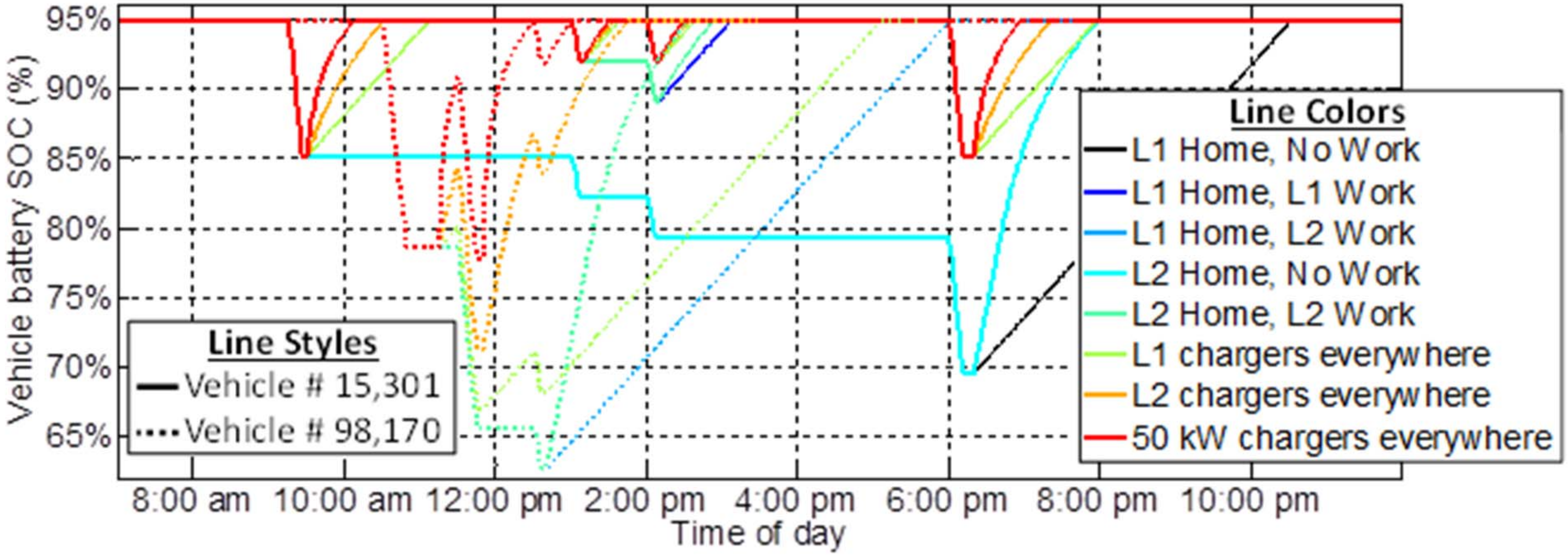


Case 6: Quantifying the adequacy of EVs to meet driver needs

- **Travel patterns from NHTS for the entire United States**
  (2009 data – indicative of how people want to drive if they had no range limitations)
  - o # Samples: 120,495 weekday drivers, 39,349 weekend drivers

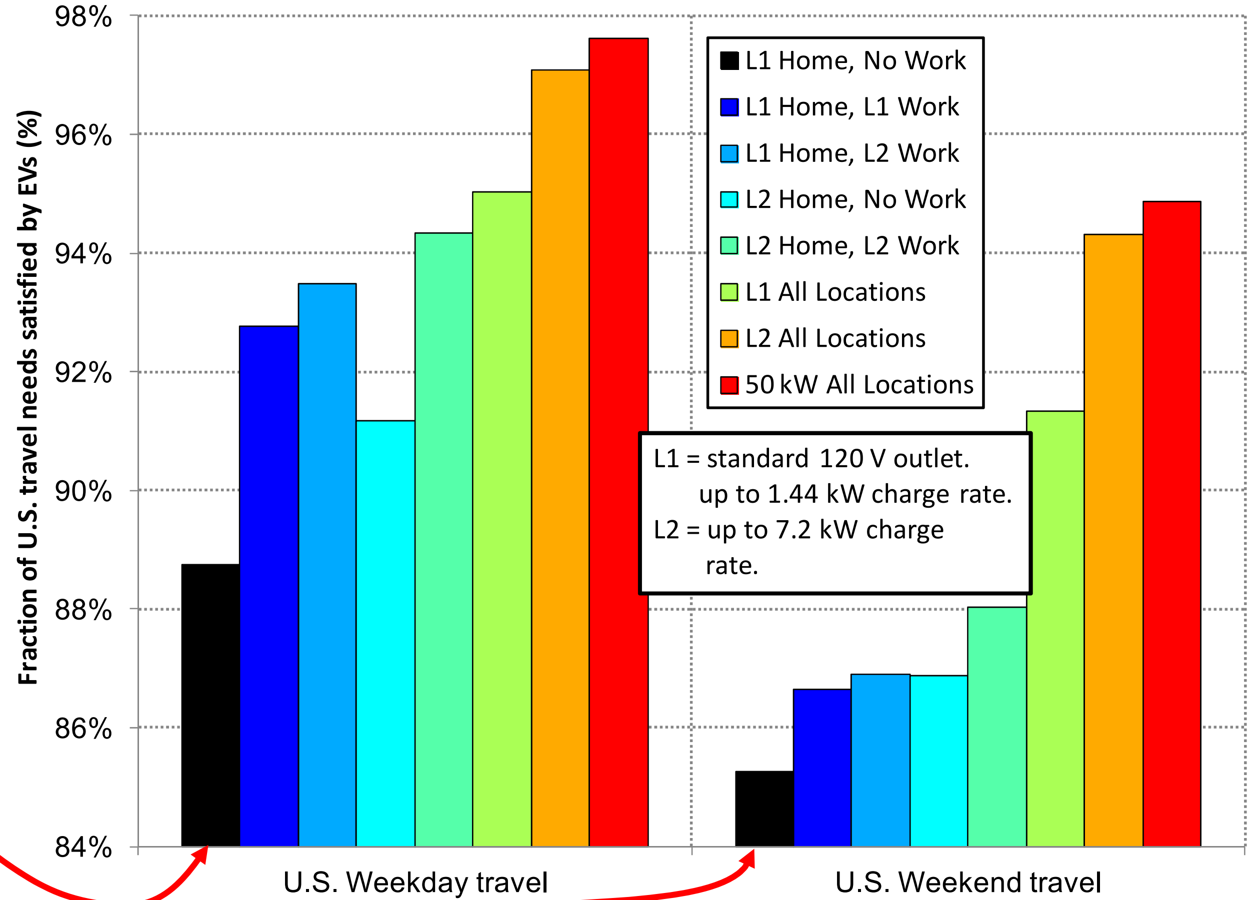
- **Model vehicles with Nissan Leaf specs in V2G-Sim**

V2G-Sim predicts SOC profile of each vehicle in each charging scenario



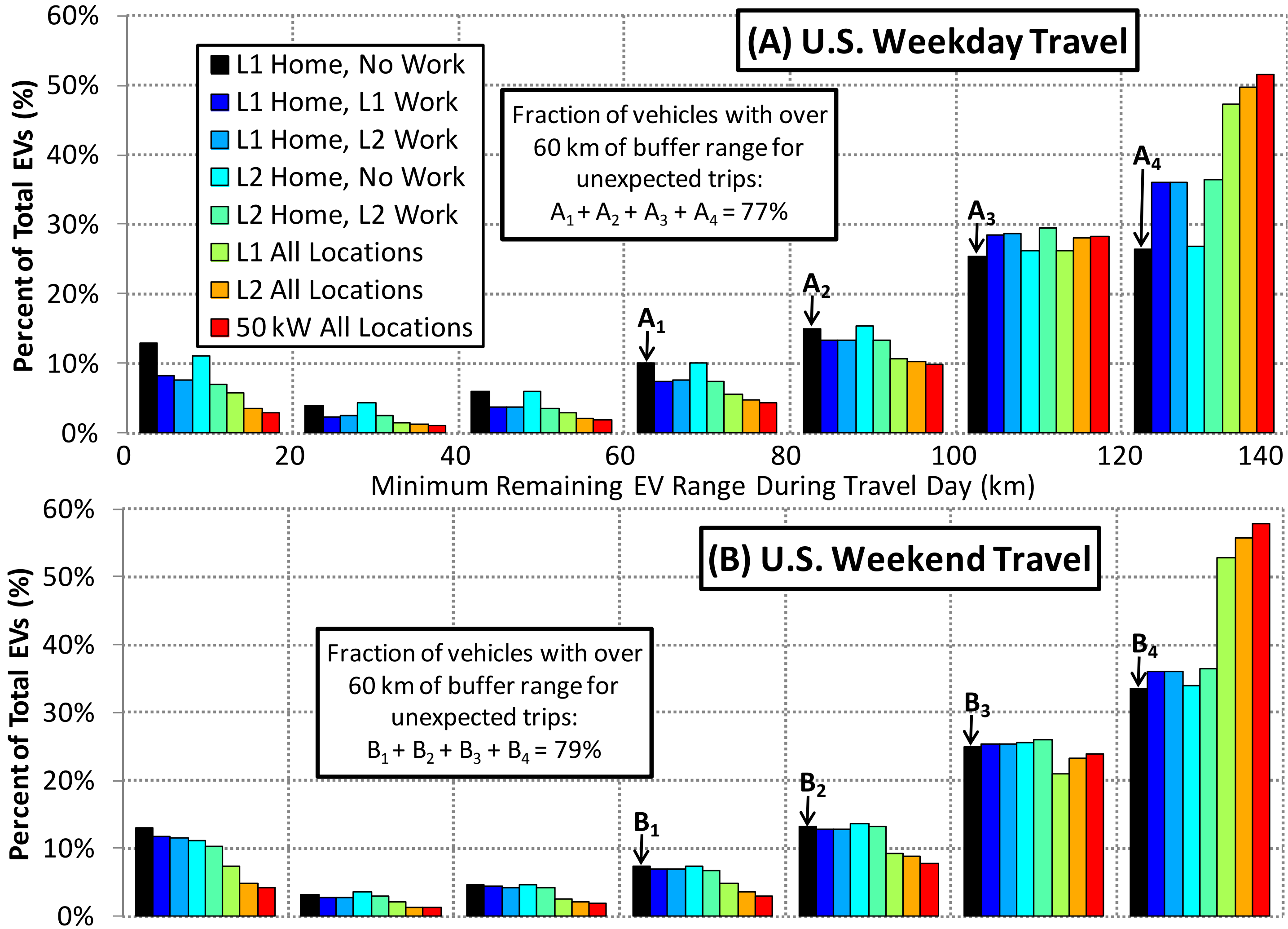
Case 6: Quantifying the adequacy of EVs to meet driver needs

Daily travel needs of 85-89% of U.S. drivers are satisfied with EVs charging on 120V wall outlets at homes only



Case 6: Quantifying the adequacy of EVs to meet driver needs

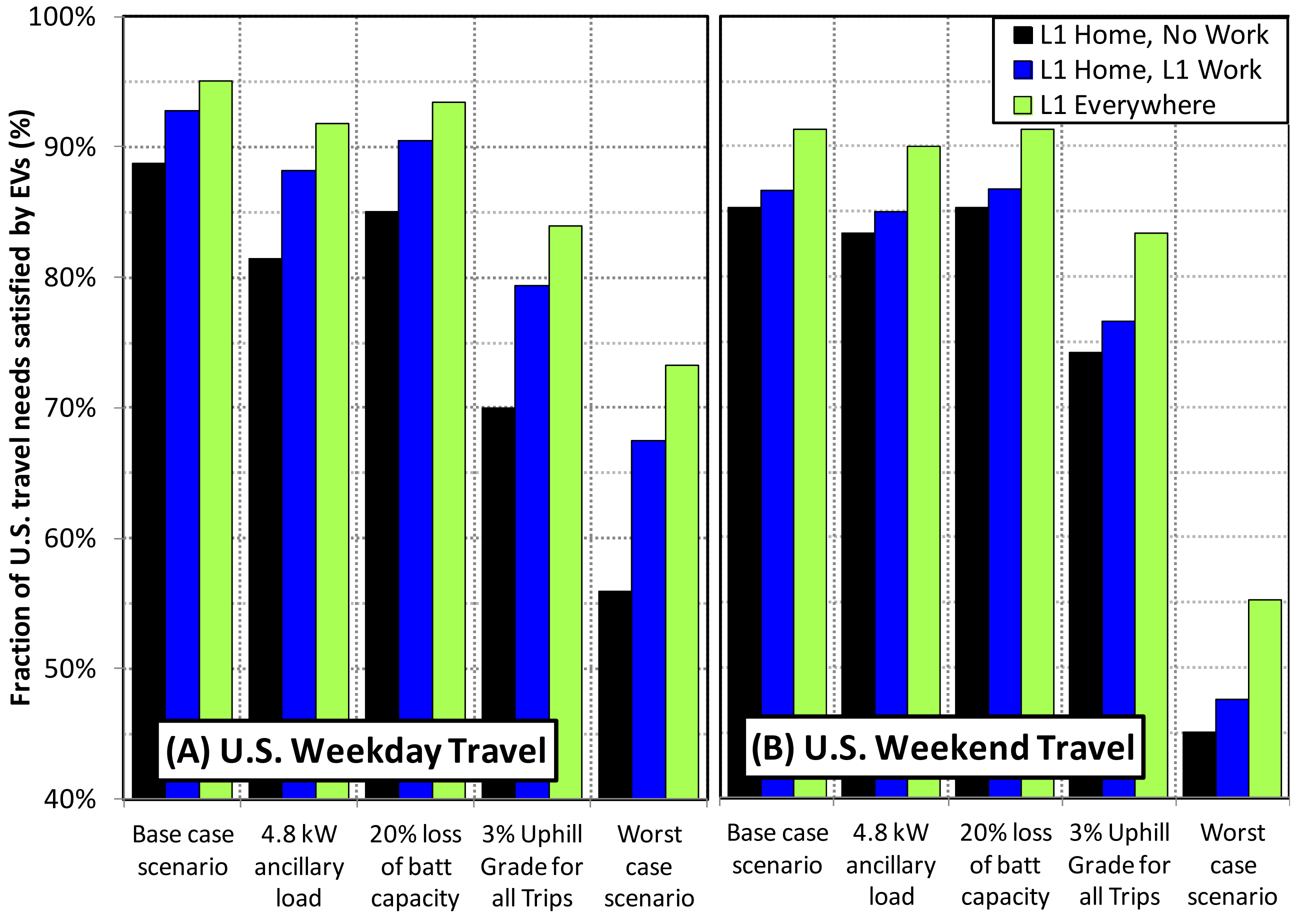
BERKELEY LAB



Samveg Saxena

v2gsim.lbl.gov

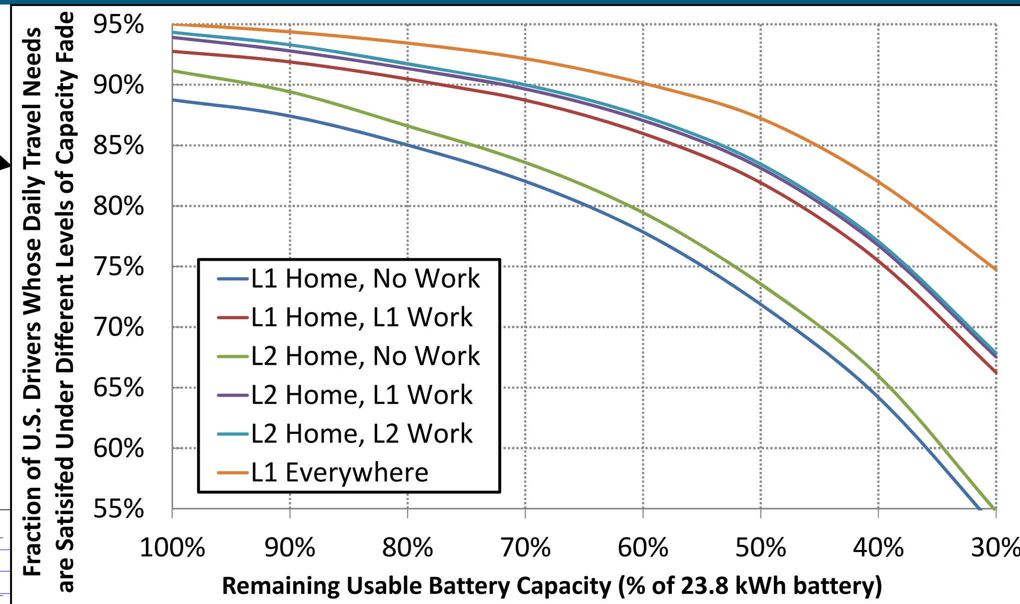
Case 6: Quantifying the adequacy of EVs to meet driver needs



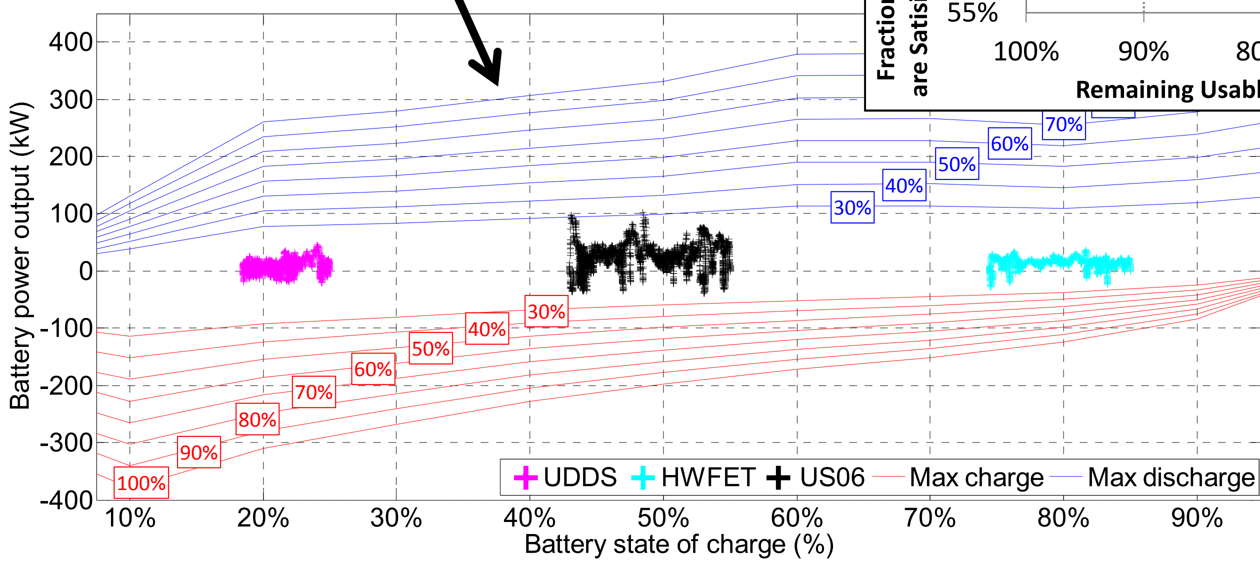
Case 7: Redefining the useful lifetime of EV batteries and the start of second life

BERKELEY LAB
Lawrence Berkeley National Laboratory

Impact of energy capacity fade on ability to satisfy drivers' daily travel needs



Impact of power fade on ability to meet drive cycle requirements



EV batteries continue to meet driver needs far longer than expected…

…battery useful life is much longer than expected

MyGreenCar: Leveraging V2G-Sim to accelerate deployment of clean vehicles

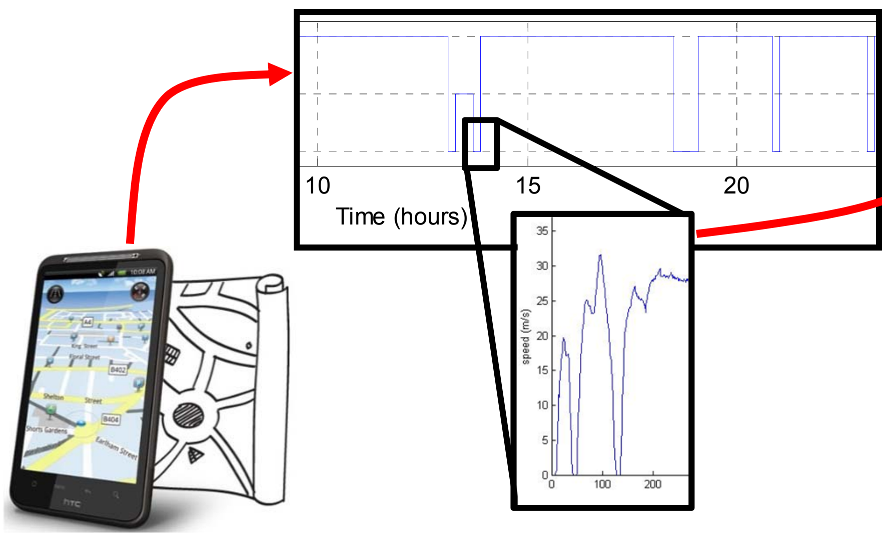
- **Drivers and fleet managers are often unaware of the benefits of clean vehicles**

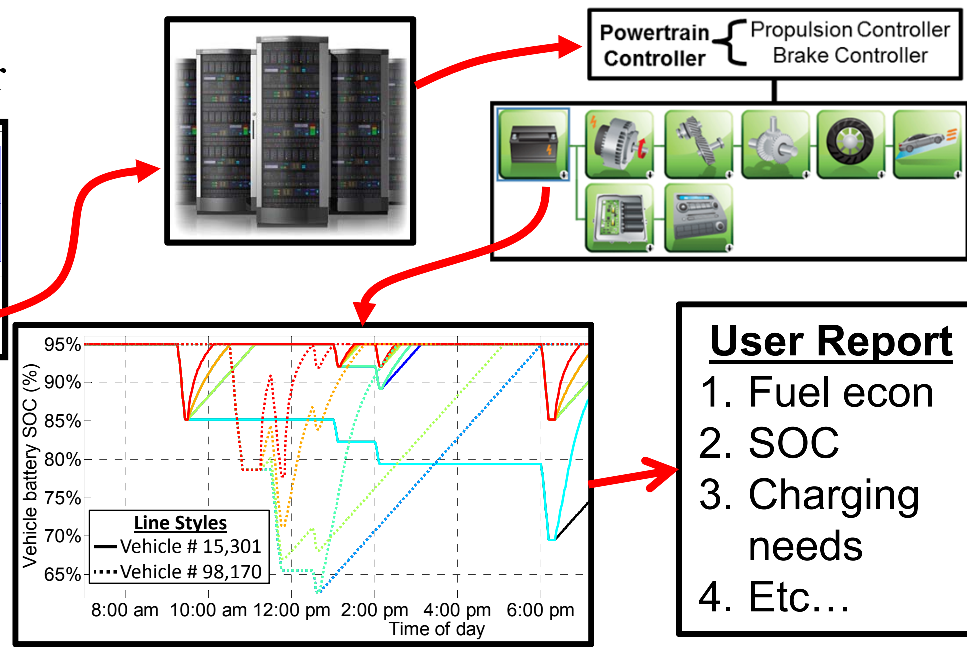
- **Many are unaware whether these vehicles even meet their individual needs**
  - E.g. range anxiety is a key obstacle for EV adoption

- **MyGreenCar is an end user application of V2G-Sim that provides drivers with personalized information on how clean vehicles meet their needs**

How MyGreenCar Works

1. Users record their travel patterns and personalized drive cycles for any duration (e.g. 3 weeks, 3 months, etc.)
    2. User chooses vehicle types and data is transmitted to a V2G-Sim server that uses physics-based powertrain models to predict SOC, charging needs, fuel consumption, etc.
        - Models consider important factors such as traffic, terrain, ancillary power consumption, etc.
3. Analysis results are reported to the user





MyGreenCar Application 1: Eliminating range anxiety for prospective car buyers

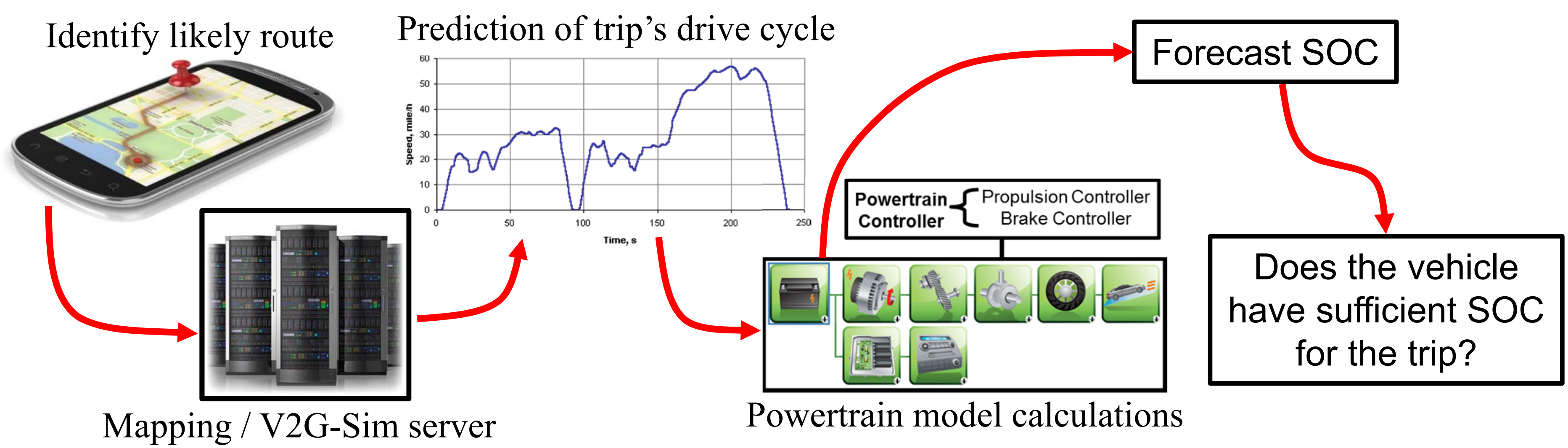
BERKELEY LAB
Lawrence Berkeley National Laboratory

- **Accelerating EV adoption by eliminating range anxiety for prospective EV owners**
  - Does an EV provide the range requirements for my normal travel patterns? Am I ever in danger of running out of charge?
  - How much range will I have if I need to make an unexpected trip?
  - Do I need a level 2 charger at home, or is level 1 sufficient?
  - Do I need a charger at work or other locations?

  - How much will I pay for electricity? How does this compare to what I will pay for gasoline in a comparable conventional car?
  - What incentives are available?

MyGreenCar Application 2: Eliminating EV range anxiety for current EV owners

- **Eliminating range anxiety for current EV owners**
  - At my car's current SOC, do I have enough charge to make my next trip? (when considering traffic, terrain, ancillary power consumption, etc.)
  - If not, how much do I need to charge my car? How long will this charging take on different types of chargers?



Application 3: Personalized fuel economy estimates for any driver in any car

- **Enabling drivers to compare fuel economy across vehicles for their own driving style**

  (i.e. personalized EPA fuel economy label)
  - How do these cars compare in terms of fuel economy and operating costs for my personal driving patterns and style?
  - Are there comparable cars available that will offer greater fuel economy for my driving style?

vs.

My Personal Fuel Economy	<u>Compare several cars</u> Conventional models vs. hybrid models vs. plugin models, etc.

MyGreenCar Application 4: Guiding fleet vehicle purchasing

- **Enabling fleet managers to quantify the benefits of clean vehicles and deploy them to capture the greatest benefits**
  - How much fuel savings will an advanced vehicle get in comparison to a conventional vehicle on our routes?
  - How long will it take to recoup the added capital cost of an advanced vehicle?
  - Which routes should I deploy the advanced vehicle on to capture the greatest fuel savings benefits?

vs.

Diesel vs. natural gas vs. diesel hybrid vs. etc. ?

Which routes?

More applications of MyGreenCar…

- **Schedule a test drive within the MyGreenCar App**
- **Enable drivers to understand economic benefits of clean vehicles**
  - Fuel savings, incentives, time-of-use rates for charging, etc.
- **Research dataset – more detail & samples than any other travel survey**
- **Spatially forecasting PEV deployment for grid infrastructure planning**
- **Enabling real-time data collection to enable vehicle-grid integration**
  - MyGreenCar as interface to an aggregator – specify planned travel activity
  - PEV owners + MyGreenCar + V2G-Sim forecasting + aggregation server = grid services
- **Utilities: a tangible tool for outreach and accelerating PEV adoption**
- **And more…**

Transformative applications spanning disciplines

BERKELEY LAB
Lawrence Berkeley National Laboratory

MyGreenCar | V2G-Sim

Samveg Saxena
ssaxena@lbl.gov
v2gsim.lbl.gov

Eliminating EV range anxiety

Accelerating clean vehicle deployment

Predicting personalized fuel economy

Optimize powertrain control systems for VGI

Understand, quantify, and avoid battery degradation from VGI

Develop and understand impacts of managed charging algorithms

Develop VGI business models & understand their impacts

Understand distribution & transmission system impacts

Plan future infrastructure

Forecast PEV loads

Quantify impact of VGI for many grid applications and markets

V2G-Sim Analysis planned release: Nov-Dec 2014