NREL
Transforming ENERGY

Autonomous Energy Systems: Transportation

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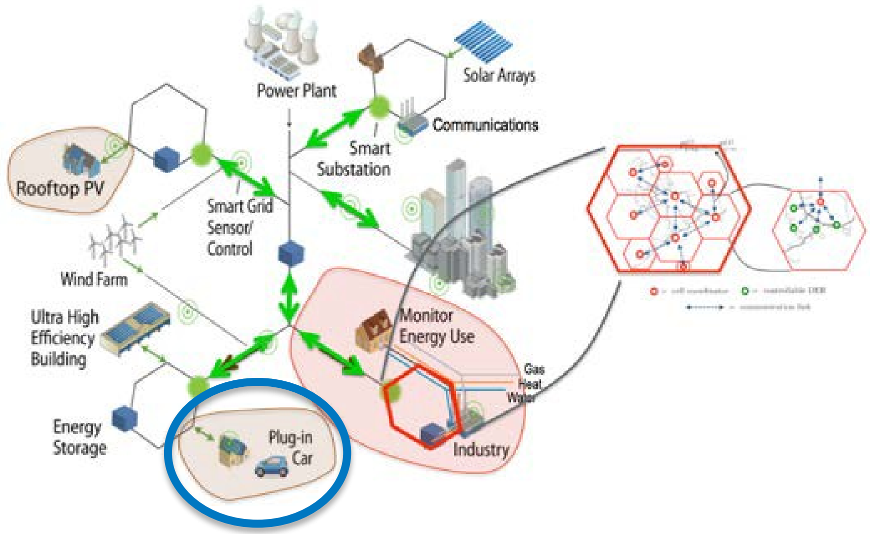
Presentation Overview

- Overview of two research areas related to **transportation and grid impacts**
  - Learned ride-hailing fleet control, load management
  - Consensus charging overview



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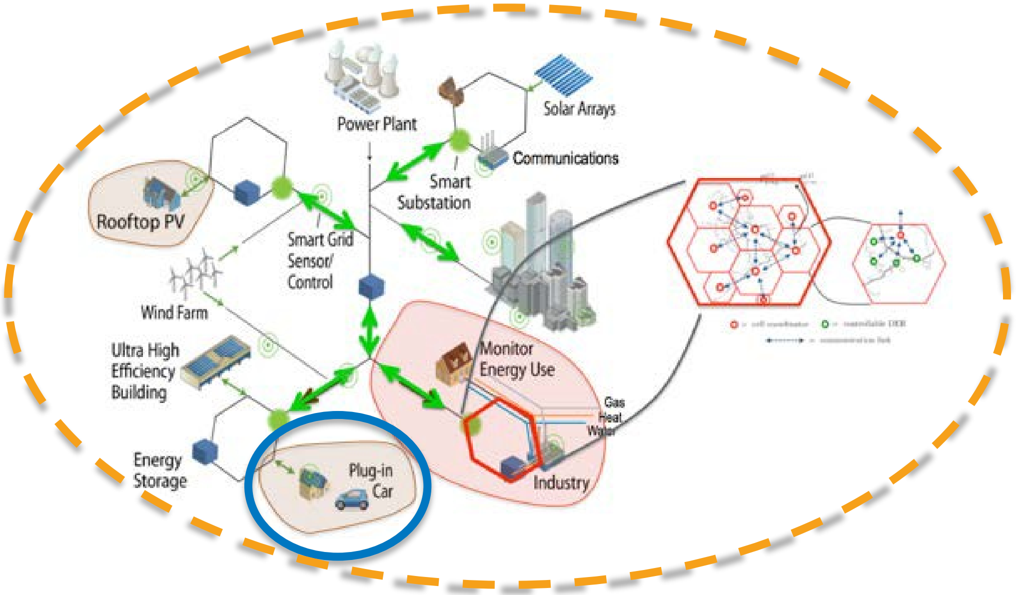
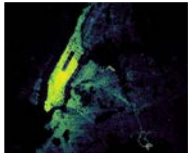
  - Consensus charging overview
- Integration into **broader AES simulation framework**



Ride Hailing Modeling, Managed Loads

Model Overview, Inputs and Outputs

- Battery size
- Fleet size
- Occupancy, etc.



- O-D locations
- Pickup times

- $/kWh by TOD

- Passenger pooling willingness

- Station power levels
- Locations, plugs, etc.

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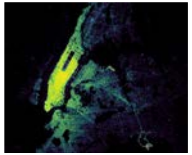

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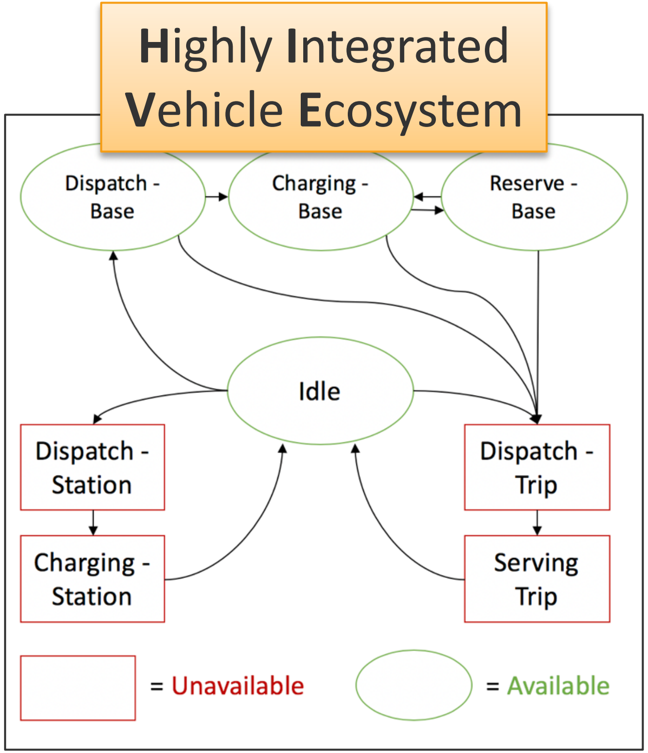

Broad Outputs:

- Vehicle utilization
- Fleet performance
- Station economics
- … and many more!

Fleet Visualization (Austin, TX)

Trip Demand:

Ride Austin TNC Data

[Animation Web link]

HIVE 0.4.0+ Model Structure

Data-Driven Fleet Control

- Version: 0.1.0, heuristic based decision making
- Version: 0.4.0: Refactored HIVE in an “RL gym” to enable model training
- Exploring opportunities for improved performance beyond heuristics

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Environment

Agent
“Fleet Manager”

State

- Current & upcoming requests
- Current & upcoming prices to charge
- Fleet average SOC
- Fleet composition by state

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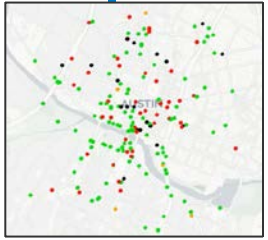

Environment

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Action
- % Fleet Charging
- % L2 vs DCFC

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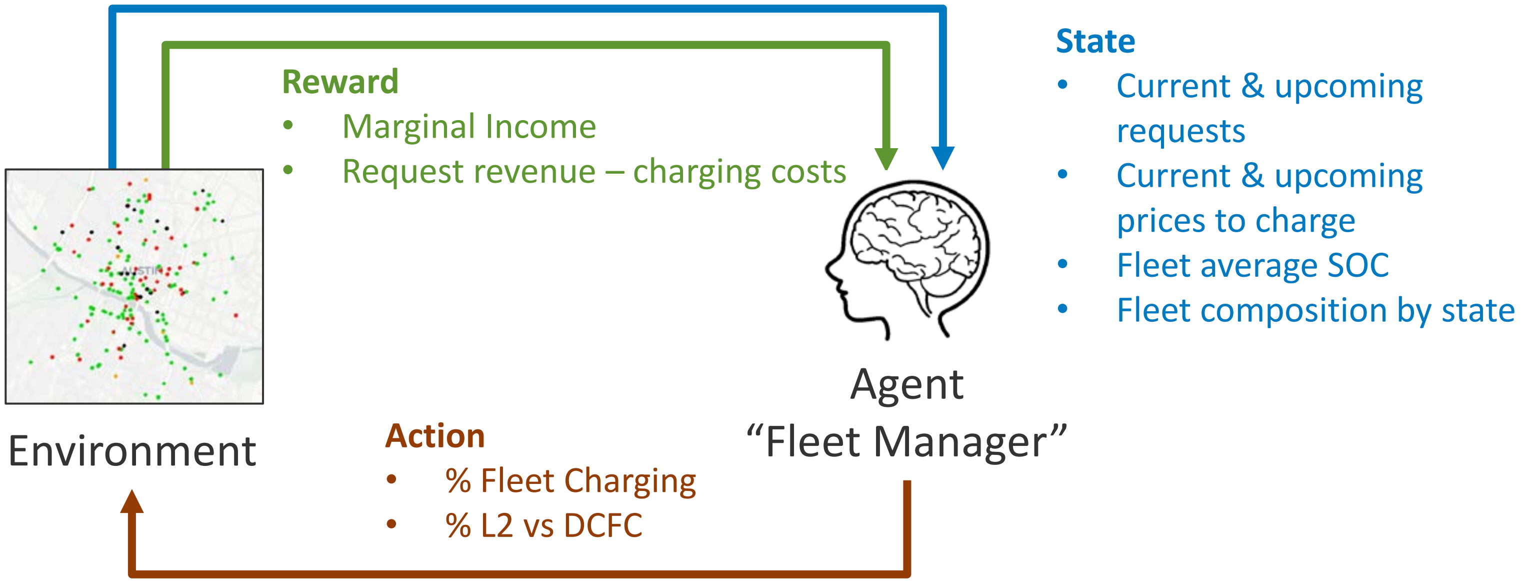

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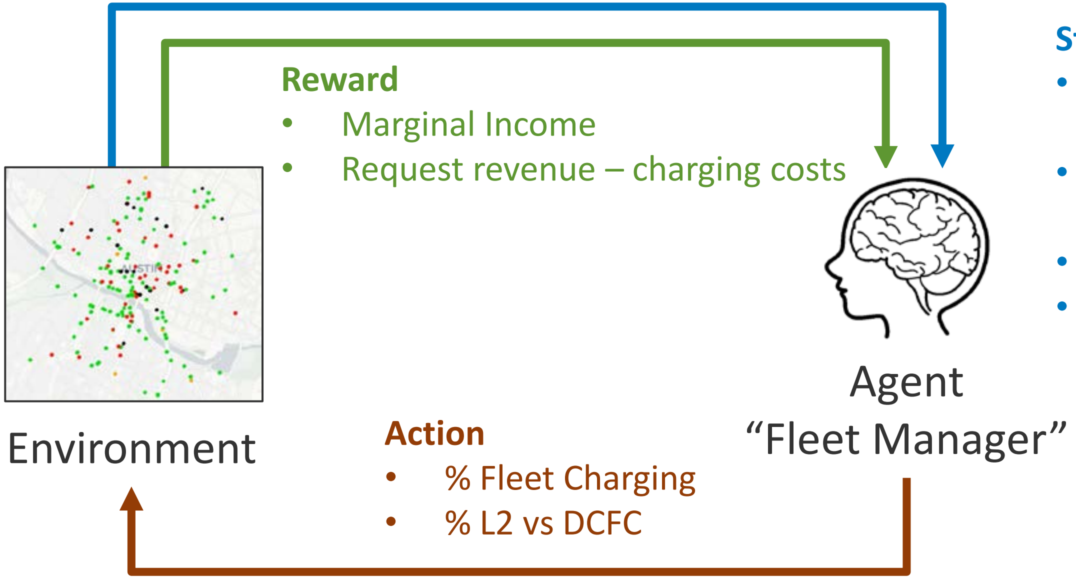
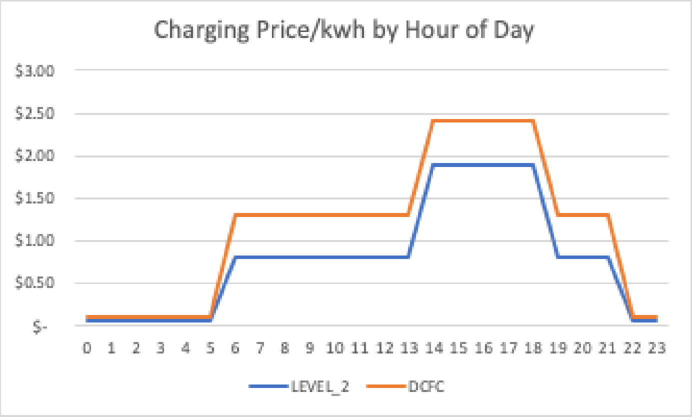
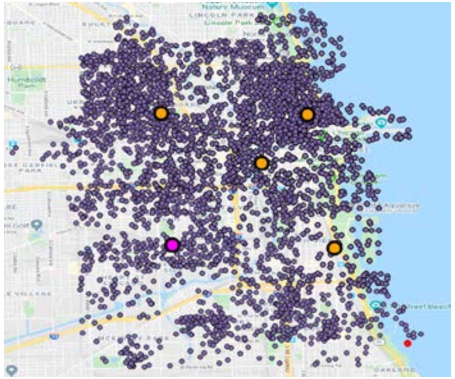


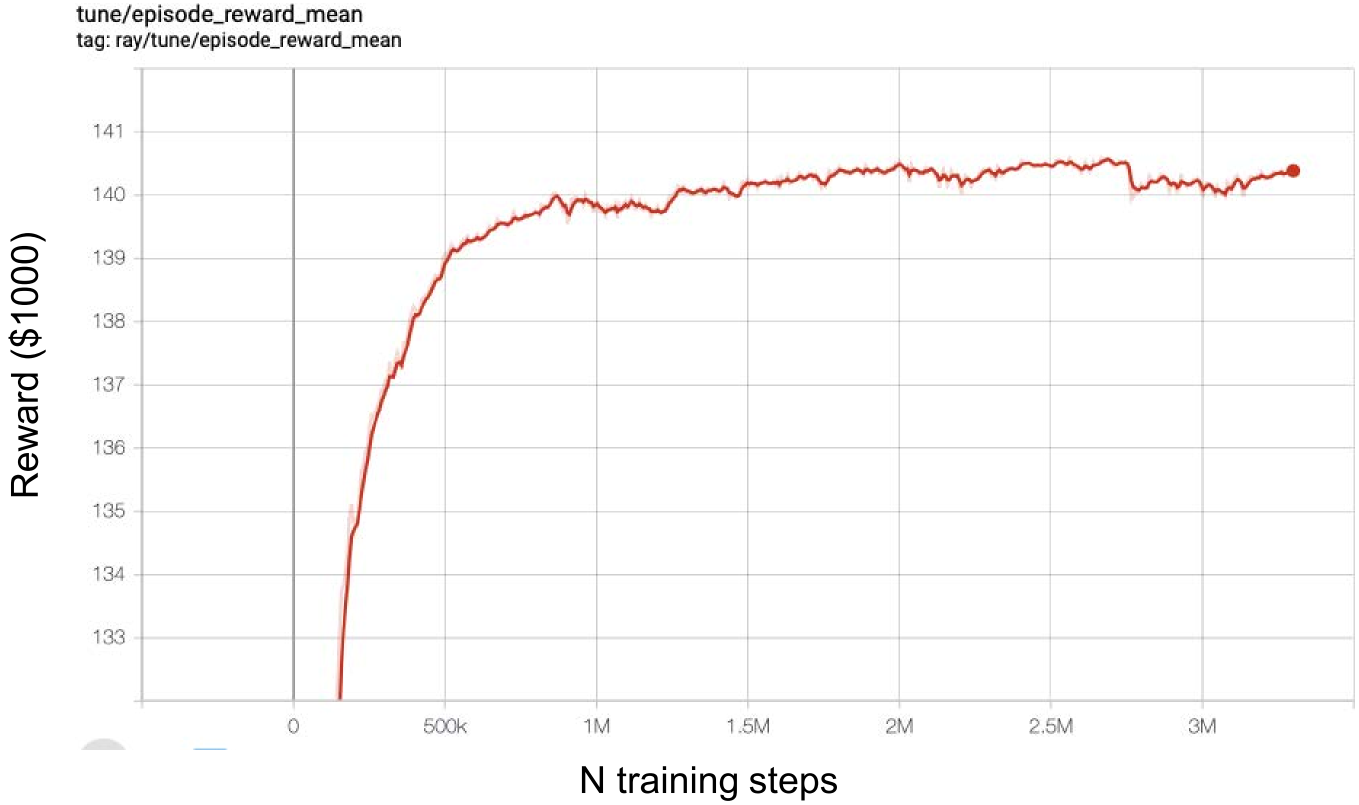
Sample Scenario, Downtown Chicago

- **Requests:** Two days of request data - one for training, one for test
- **Fleet:** 350 fleet vehicles with 50 kwh battery
- **Infrastructure** 4 fast charging stations, 1 base with slow charging
- **Charging Costs:** variable by time of day, based on data from ComEd
- **Forecasting:** perfect for upcoming prices and requests

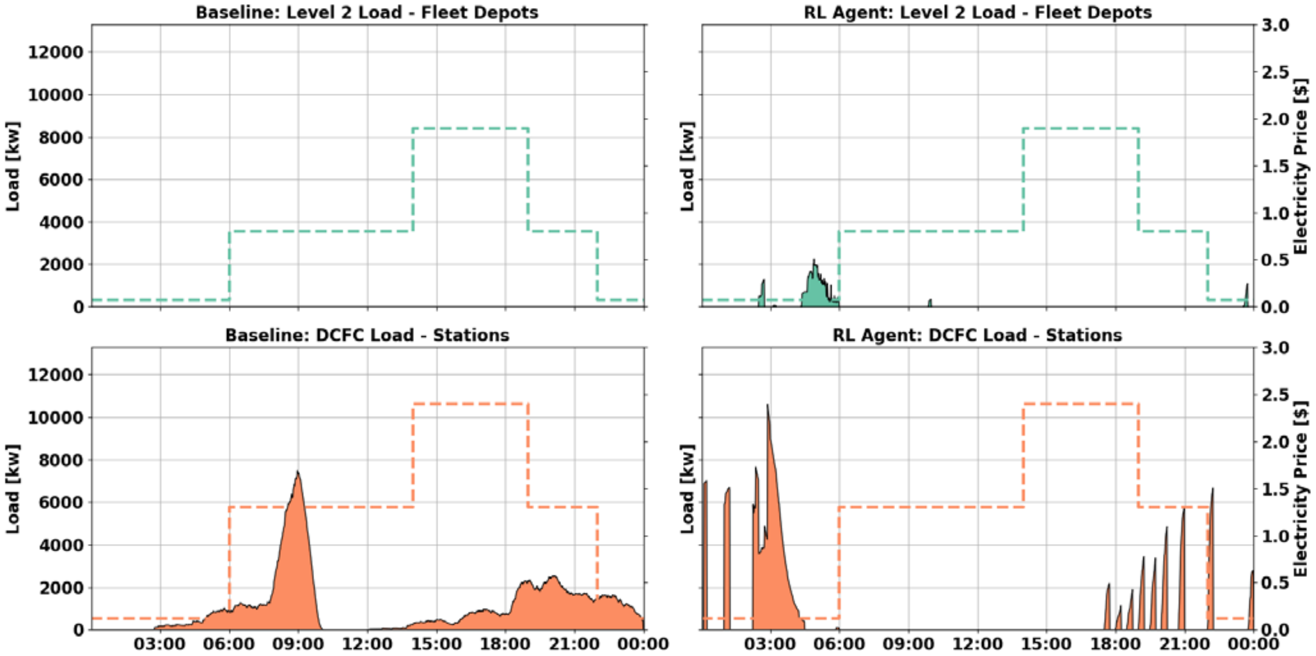




Results, RL-Trained Fleet Manager



Results, RL-Trained Fleet Manager, cont.



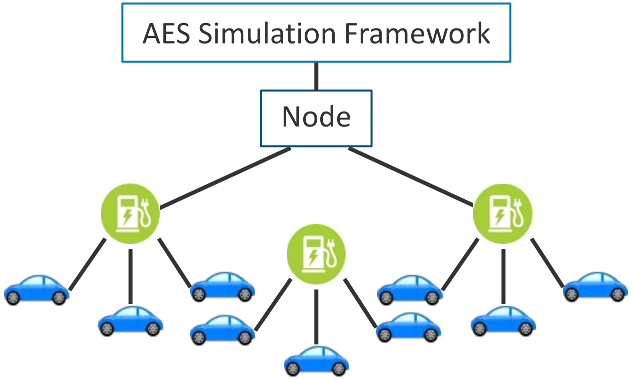
Future Work, HIVE

- Extended study over 10+ days of request data
- Expose fleet manager to more complicated rate structures (demand charges)
- Simulate more constrained scenarios – limited infrastructure, larger geographic area
- Expand scope of state/action space to include control of more than just charging
  - Fleet rebalancing

Consensus Charge Control

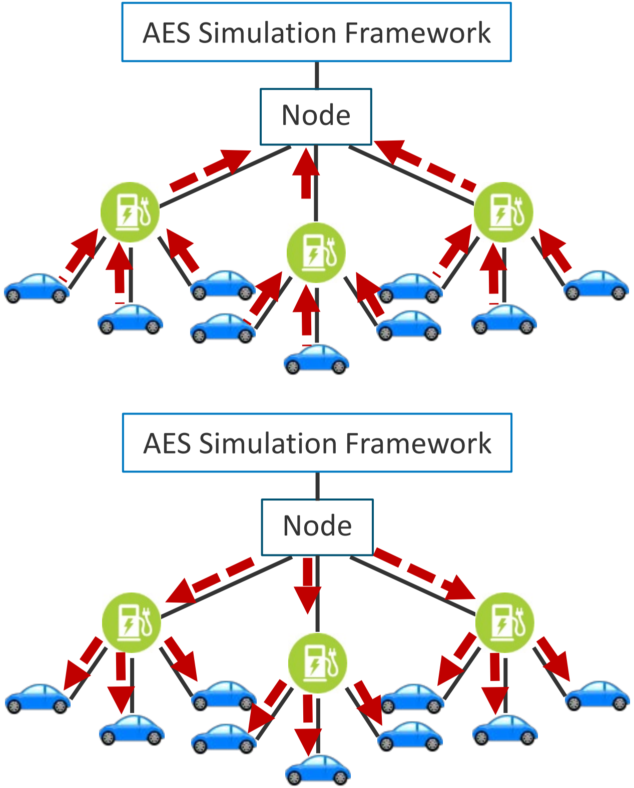
Background – Typical Control Hierarchies

A) No Control



All vehicles permitted to charge as demanded

B) Centralized Control



Centralized data acquisition from vehicles

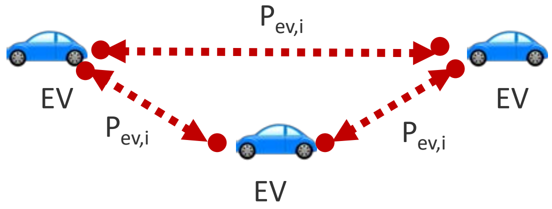
Optimized charge profiles passed to EVs from centralized node

Proposed: Consensus-Based Control

C) Consensus-based Distributed Control

Rather than communicating with a centralized node, vehicles communicate amongst each other to develop a charging profile through consensus

Step 1: Communication among EVs

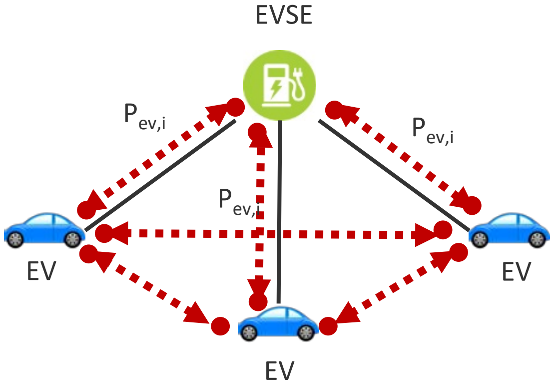


Node objective minimize $\sum_{i \in \mathcal{V}} f_i(x_i)$

Where, $f_i(x_i)$ = *min.* $P_{ev,i}$

$P_{ev,i}$ - Charging profile for each EV

Step 2: Aggregate optimized charge profiles from individual EVs

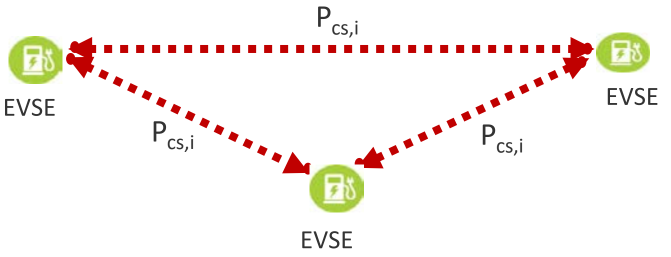


Consensus Control – Deeper Dive

C) Consensus-based Distributed Control

In addition to vehicles communicating amongst each other to optimize profiles at the station-level, additional communication amongst stations to consider grid supply / capacity

Step 3: Communication among Charging Stations

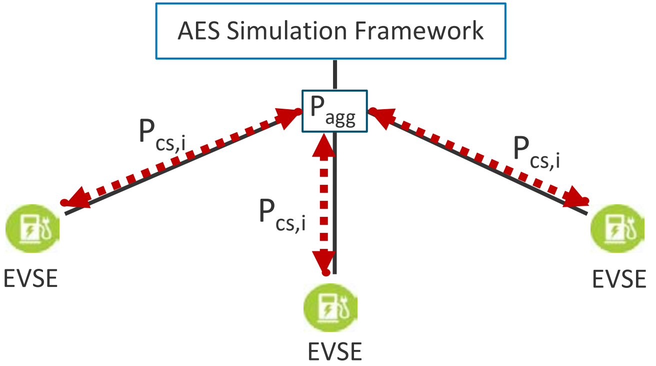


Node objective minimize $\sum_{i \in \mathcal{V}} f_i(x_i)$

Where, $f_i(x_i)$ = *min.* $P_{cs,i}$

$P_{cs,i}$ – Aggregated load profile at charging station

Step 4: Aggregate optimized load profile from individual charging stations



Step 5: If Pagg<= Plim, Stop. Else, repeat.

P_{lim} = Grid supply/capacity constraint

Consensus Control: Parameters Assumed

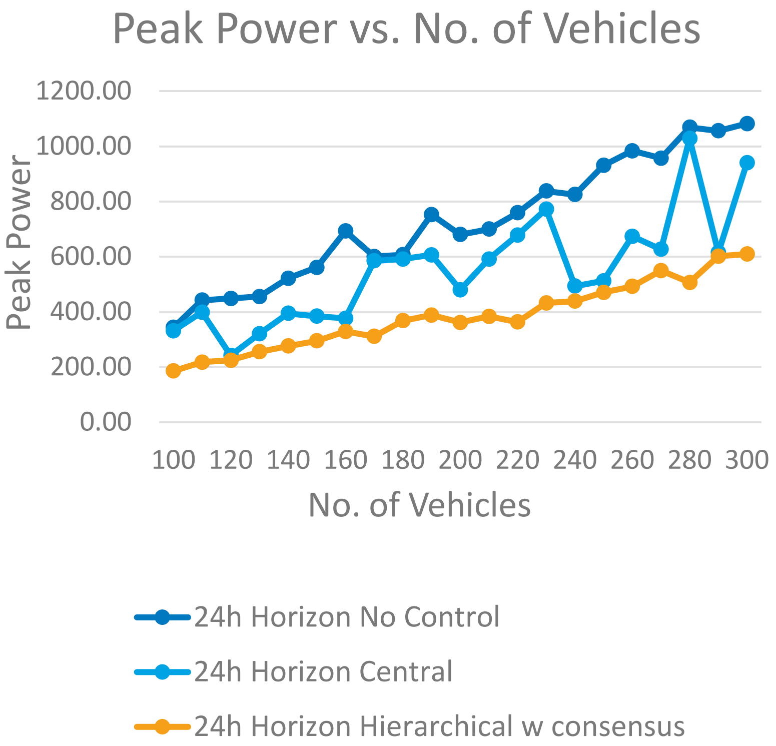
Focus: **Demand charge mitigation, by flattening the charging profile**

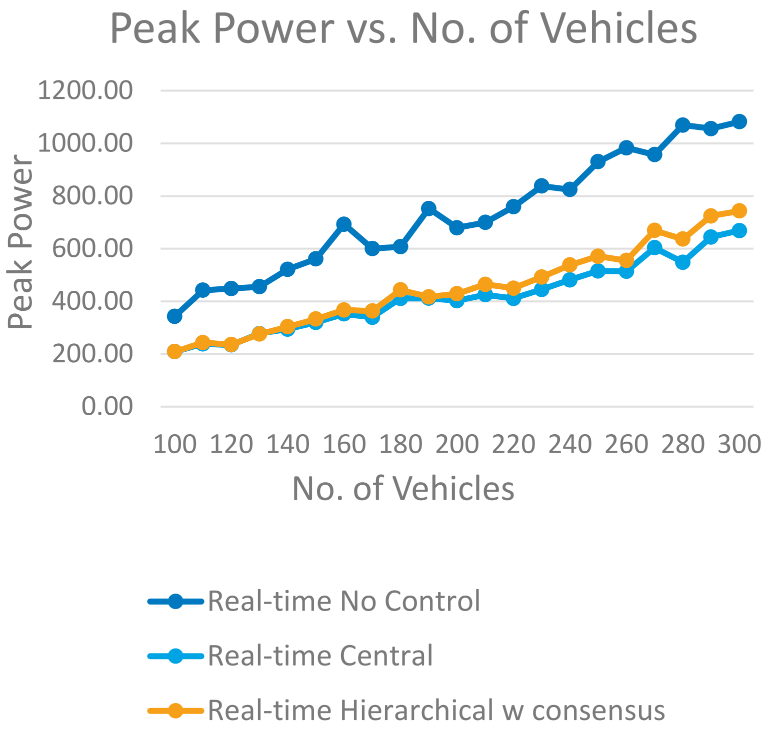
Parameters:

- EV_i is the vector specified by (a_i, d_i, e_i, $P_{max,i}$)
- a_i is the arrival time of EV_i.
- d_i is the departure time of EVi.
- e_i is the charging energy demand of EV_i. $e_i\ (t) = 0$ if $t < a_i$ or $t \geq d_i$
- $P_{max,i}$ is the peak charging rate of EV_i.
- $r_i(t)$ is the instantaneous charging rate of EV_i. $r_i\ (t) = 0$ if $t < a_i$ or $t \geq d_i$.
- $P_{cs}\ (t)$ is the instantaneous aggregated power at charging station

Approach: **ADMM based distributed control**

Consensus Control: Performance Evaluation, cont.





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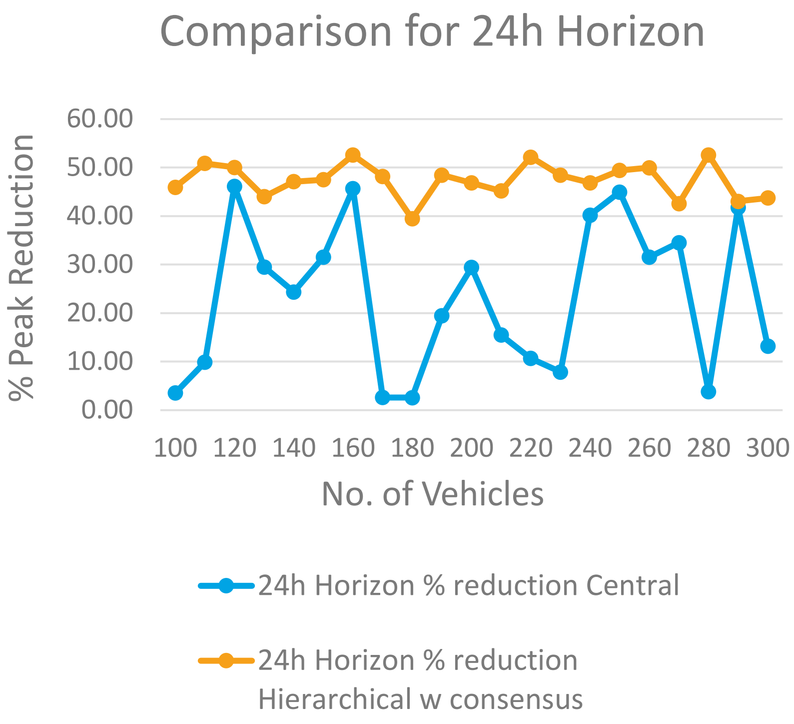

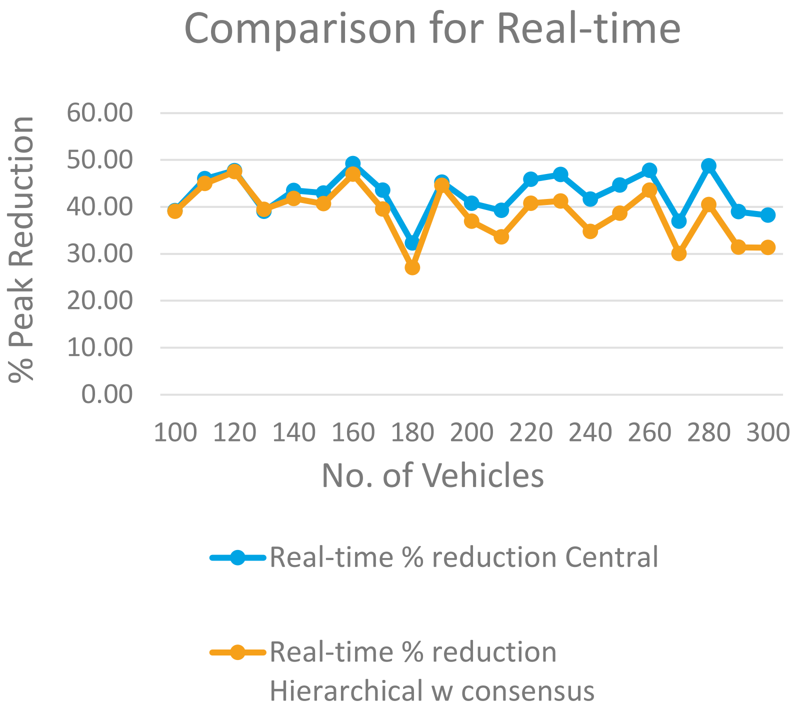

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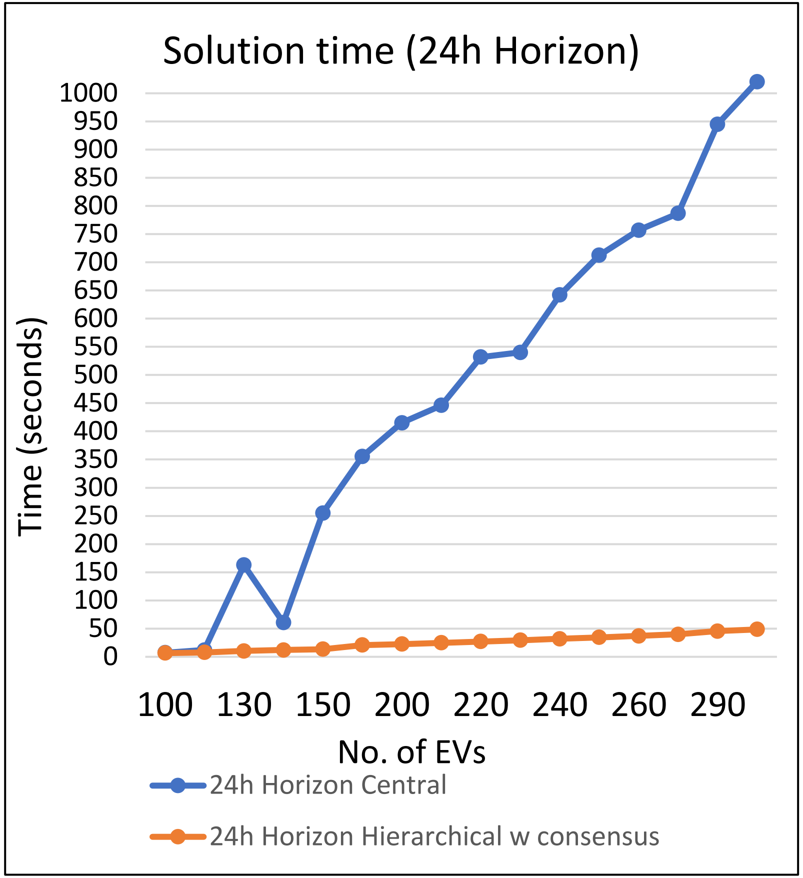
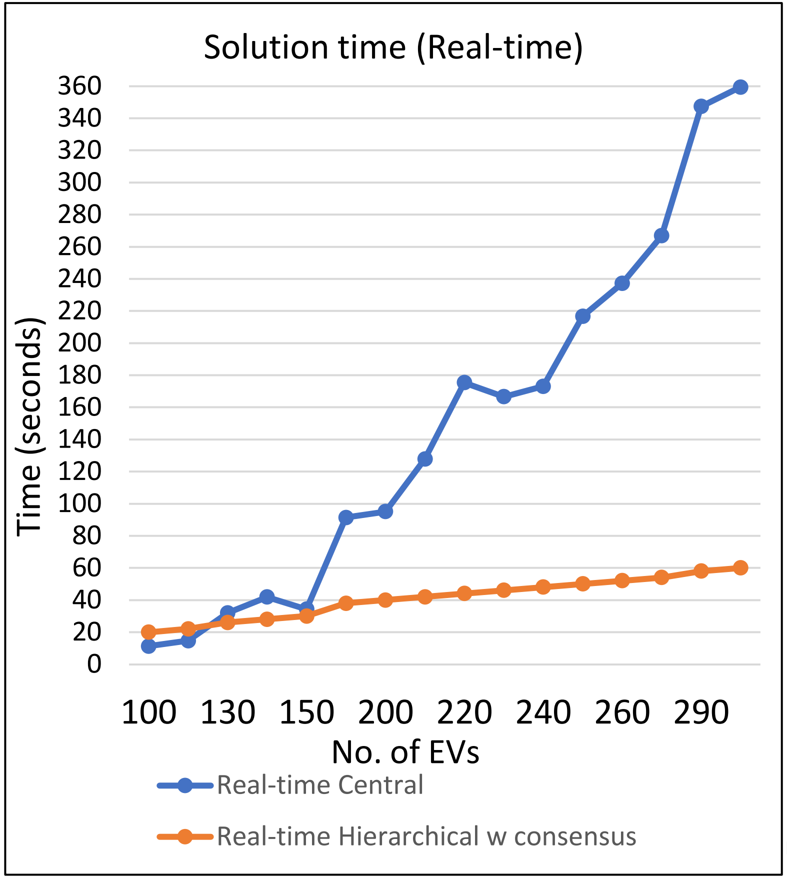


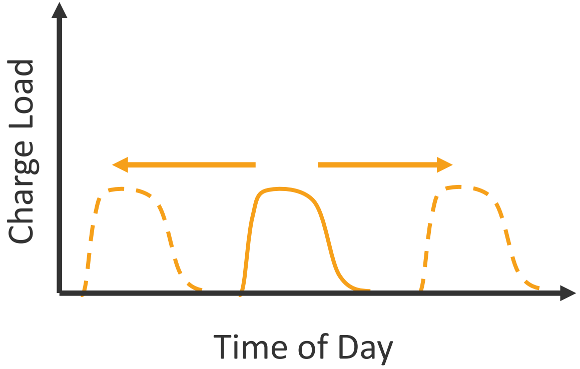


Transportation Topics, AES Simulation Framework

Load Shifting Strategy, Comparison

HIVE: “Plug” control

- HIVE has no formal charge control, but can load shift by controlling when vehicles are sent to charge
- Fleetwide charging peaks are controlled through strategic dispatch & charge instructions
- Main incentive is to recharge vehicles quickly so additional passengers may be served



No grid feedback, static decision-making

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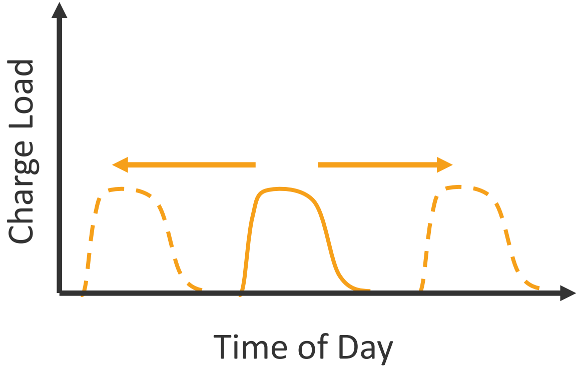

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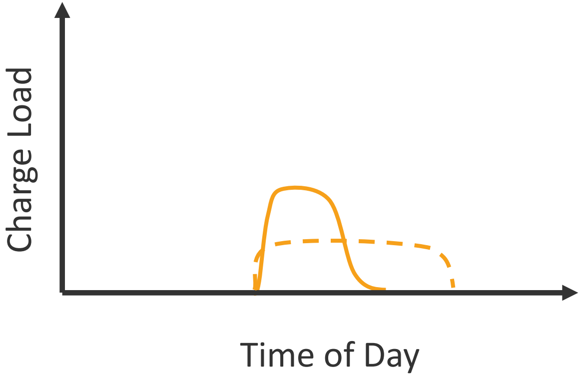
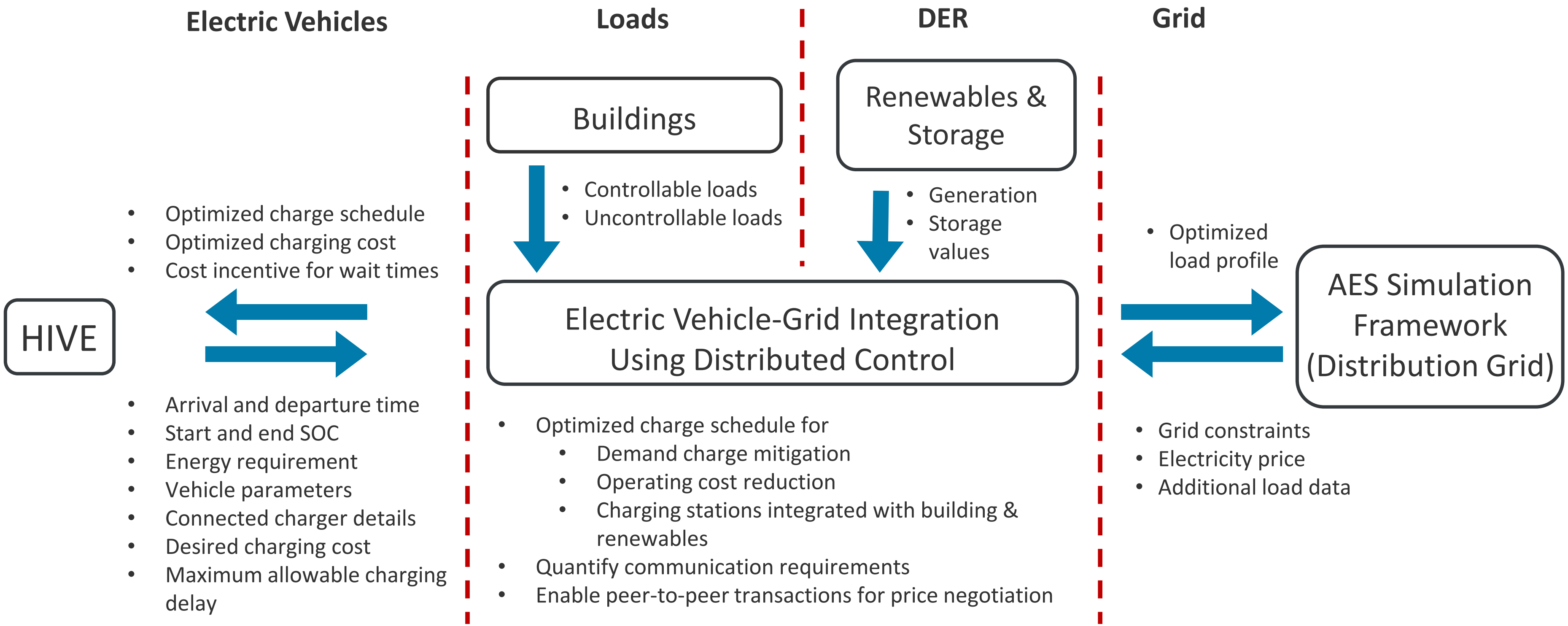
Consensus: "Charge" control

- Consensus control can affect the charging rate during an event, but has no control over plug-in / plug-out times
- Charging peaks are controlled within the confines of a dwell. Greater dwell time correlated with greater flexibility
- Likely to be best integrated at fleet depots where vehicles have long overnight stays

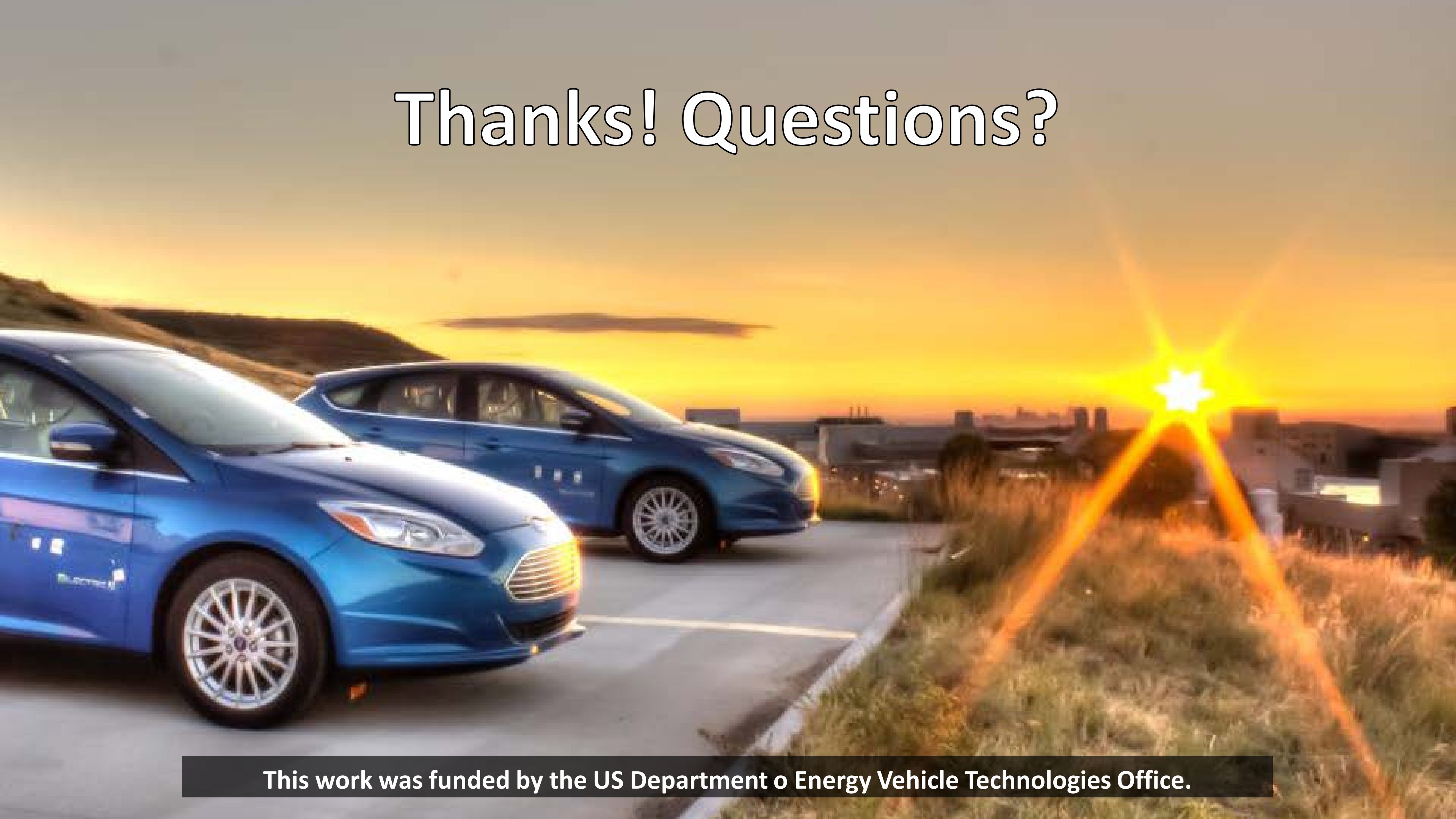


Direct integration with AES framework

Proposed Electric Vehicle-Grid Integration Framework



Thanks! Questions?



This work was funded by the US Department o Energy Vehicle Technologies Office.

Consensus Control: Performance Evaluation

No. of Evs	24h Horizon			Real-time		
	No Control	Central	Hierarchical w consensus	No Control	Central	Hierarchical w consensus
100	343.20	331.06	185.62	343.20	208.60	209.08
110	442.20	398.55	217.31	442.20	238.80	243.35
120	448.80	241.78	224.23	448.80	234.62	235.71
130	455.40	320.99	255.11	455.40	277.45	275.70
140	521.40	394.34	275.94	521.40	294.59	303.52
150	561.00	384.12	294.62	561.00	319.98	332.87
160	692.99	376.78	328.82	692.99	352.09	367.62
170	600.60	584.93	311.22	600.60	339.24	363.19
180	607.20	591.54	367.80	607.20	411.00	443.04
190	752.40	606.23	387.94	752.40	411.69	417.10
200	679.80	480.04	361.56	679.80	402.70	428.77
210	699.60	591.25	383.65	699.60	425.21	464.45
220	759.00	678.15	363.33	759.00	410.95	449.66
230	838.20	772.26	432.38	838.20	445.34	492.35
240	825.00	493.36	438.41	825.00	481.70	538.06
250	930.60	512.44	470.79	930.60	515.44	571.15
260	983.40	673.42	491.98	983.40	513.60	554.92
270	957.00	626.71	549.64	957.00	603.40	669.20
280	1069.20	1028.20	506.77	1069.20	548.33	636.35
290	1056.00	615.27	601.80	1056.00	644.58	724.34
300	1082.4	939.98	609.24	1082.4	668.66	743.17