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LAWRENCE BERKELEY NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

U.S. Department of Defense Vehicle-to-Grid Demonstrations in California

Douglas Black

Jason MacDonald, Nicholas DeForest, Kristina Hamachi LaCommare, and Sila Kiliccote

First Annual California Multi-Agency Update on Vehicle-Grid Integration Research

November 19, 2014

Outline

- LA Air Force Base (LA AFB) V2G project
  - Overview
  - Goals and objectives
  - Software—fleet management, DER-CAM, charge control
  - Hardware—vehicles and charging stations
  - Electricity market participation simulation
  - Risks
  - V2B as back-up power for Emergency Operations Center
  - Status and schedule
- 63rd Regional Support Command (RSC); aka “Moffett Field” project
  - Overview
  - How it differs from LA AFB
- Concluding Remarks

LA AFB Project Partners and Participants

KISENSUM

BERKELEY LAB

NISSAN

LA Air Force Base

CTC Concurrent Technologies Corporation

THE UNIVERSITY OF CALIFORNIA 1868

LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Andrews AFB

McGuire/Dix/
Lakehurst

EVAOS
ELECTRIC VEHICLE ADD-ON SYSTEMS

PRINCETON POWER SYSTEMS
Clean Power Made Simple™

CORITECH SERVICES

Akuacom

Honeywell

Fort Hood
Army Base

SOUTHERN CALIFORNIA EDISON®
An EDISON INTERNATIONAL® Company

EVI TRANSPORTATION ELECTRIFIED

PHOENIX MOTORCARS

Control Software Team

Optimization / Real-Time Charging Control
Grid Integration Group – Berkeley Lab
Sila Kiliccote (PI), Nicholas DeForest, Terry Chan, Jason MacDonald, Michael Stadler, Doug Black

Fleet Management / EVSE Network OS / Integration
Kisensum
Clay Collier, Paul Lipkin, Bob Barcklay

Real-Time Charging Control
UC Berkeley
Duncan Callaway, Matias Negrete-Pincetic, Frederik Juul

Grid Communication using OpenADR
Akuacom Honeywell
Thorsten Bach, Ed Koch

Project Objectives

- Manage 42 vehicle PEV fleet dispatch and charging
- Ensure sufficient charge to meet mobility needs
- Charge PEVs under cost-minimizing schedules
- Optimize participation in grid service markets to generate revenue
- Determine extent to which PEV fleet cost gap can be narrowed
- DoD's investment in vehicle to grid (V2G) is
  - Advancing the state of electric vehicles and charging stations
  - Advancing the state of V2G engineering and software applications
  - Providing installations with a means to reduce energy and fleet vehicle costs
  - Stimulating cooperativeness with utility operators and regulators to embrace an alternative energy solution
  - Promoting energy surety across the nation

Vehicle-Grid Integration Value

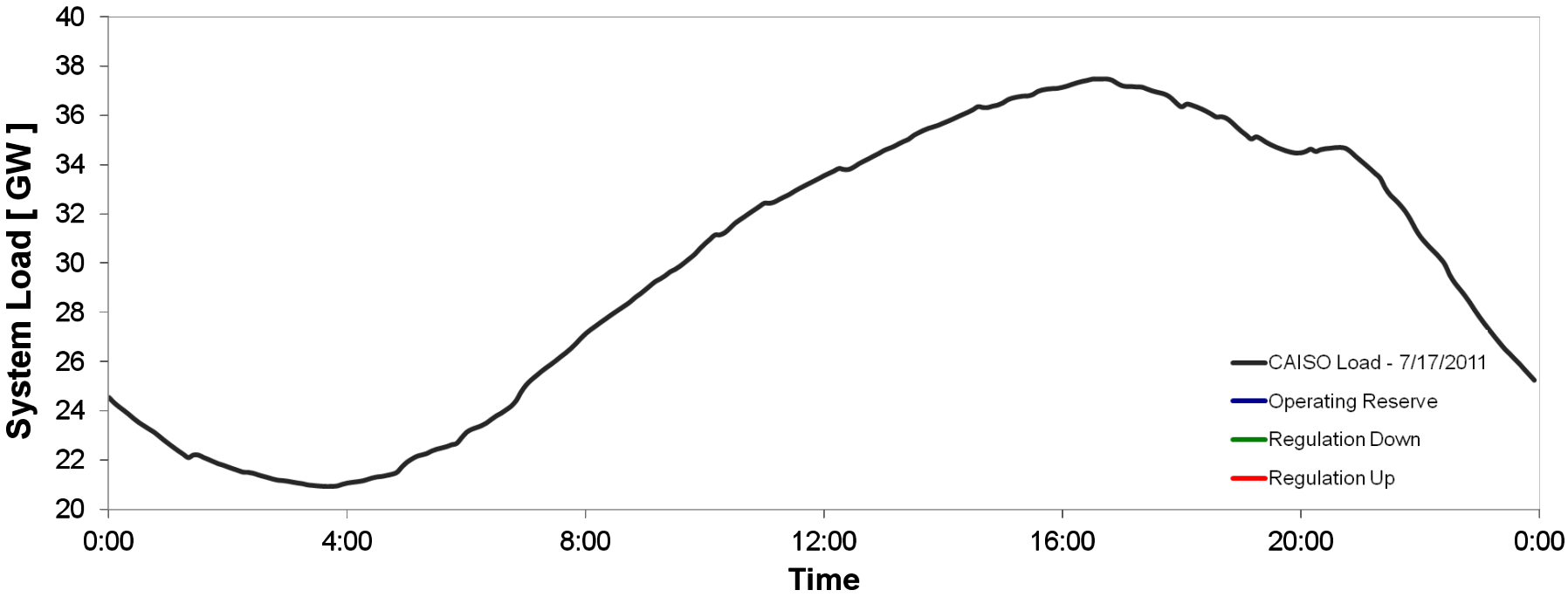
- V1G (Managed Charging)
  - ***Minimizing the cost of charging***
  - Modulated charging (demand response or ancillary services)
- V2B (Vehicle to Building)
  - ***Retail demand charge management***
  - ***Back-up generation***
  - Battery-firmed demand response
- V2G (Bi-directional Grid Services)
  - ***Ancillary services***
  - Energy arbitrage

LA Air Force Base

Los Angeles Air Force Base

- 1M sqft office complex
- 4 MW peak electrical load

Ancillary Services



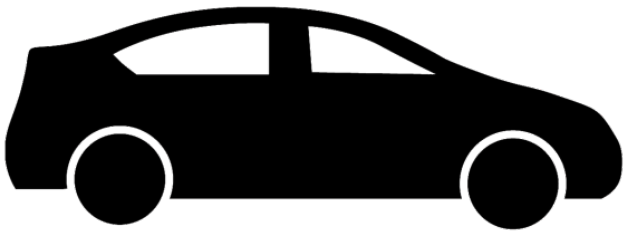
Operating Reserves respond when a contingency event occurs to restore balance.

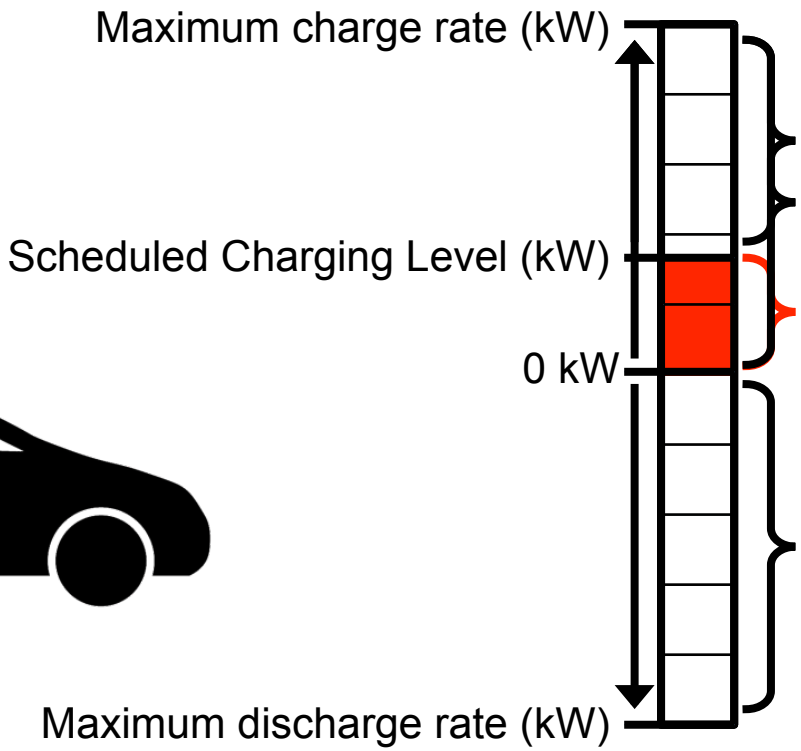
- respond within 10 minutes
- event duration typically 10-30 minutes

Regulation rectifies small discrepancies between load and 5-minute real time dispatch

- receives an operating point instruction and responds within 4 seconds
- Theoretically energy neutral, although not in practice

Regulation Capacity for a PEV





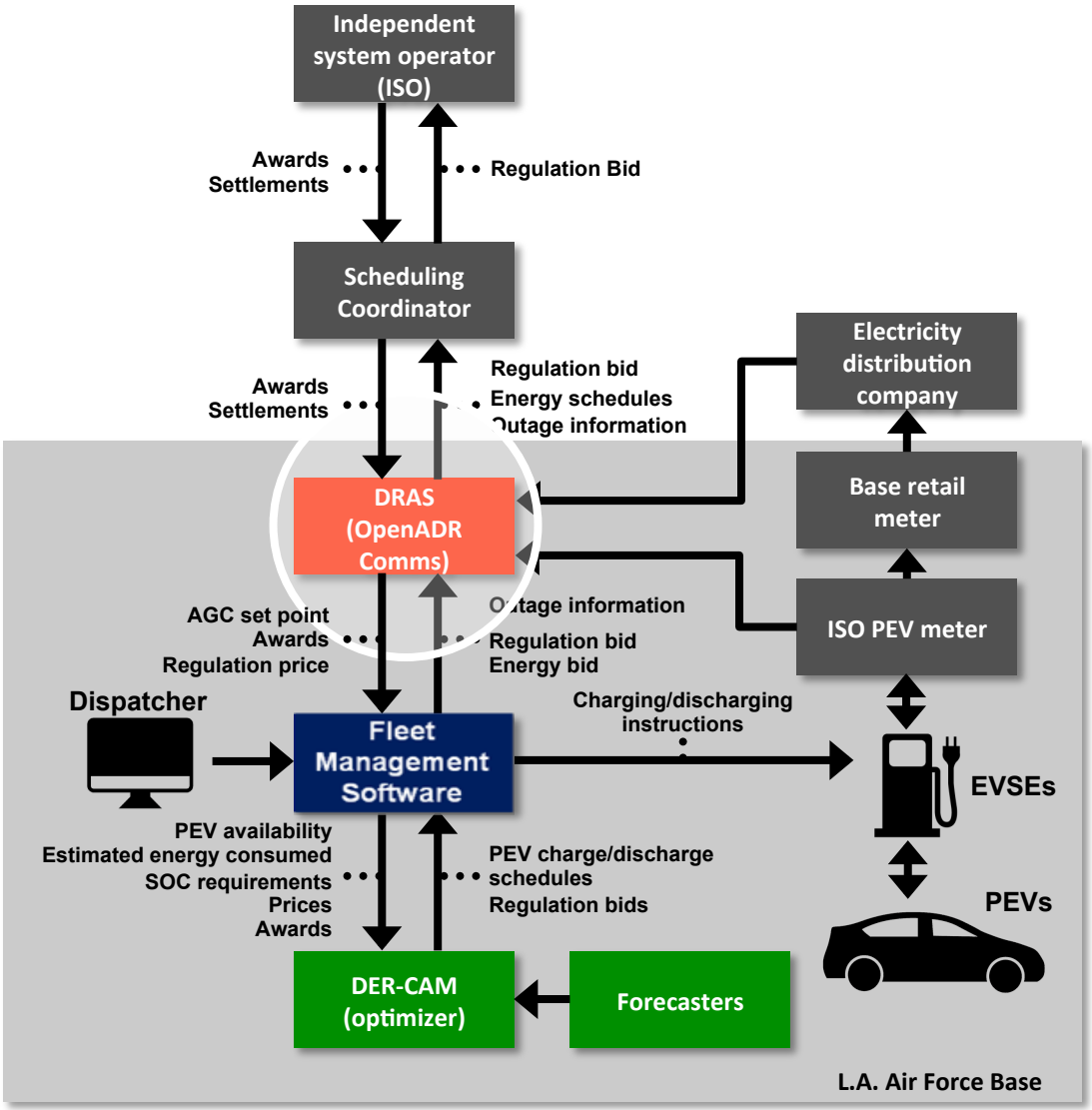
Regulation Down Capacity: limited by max charge rate, empty battery capacity and current charging level

Regulation Down Capacity: limited by max charge rate and empty battery capacity

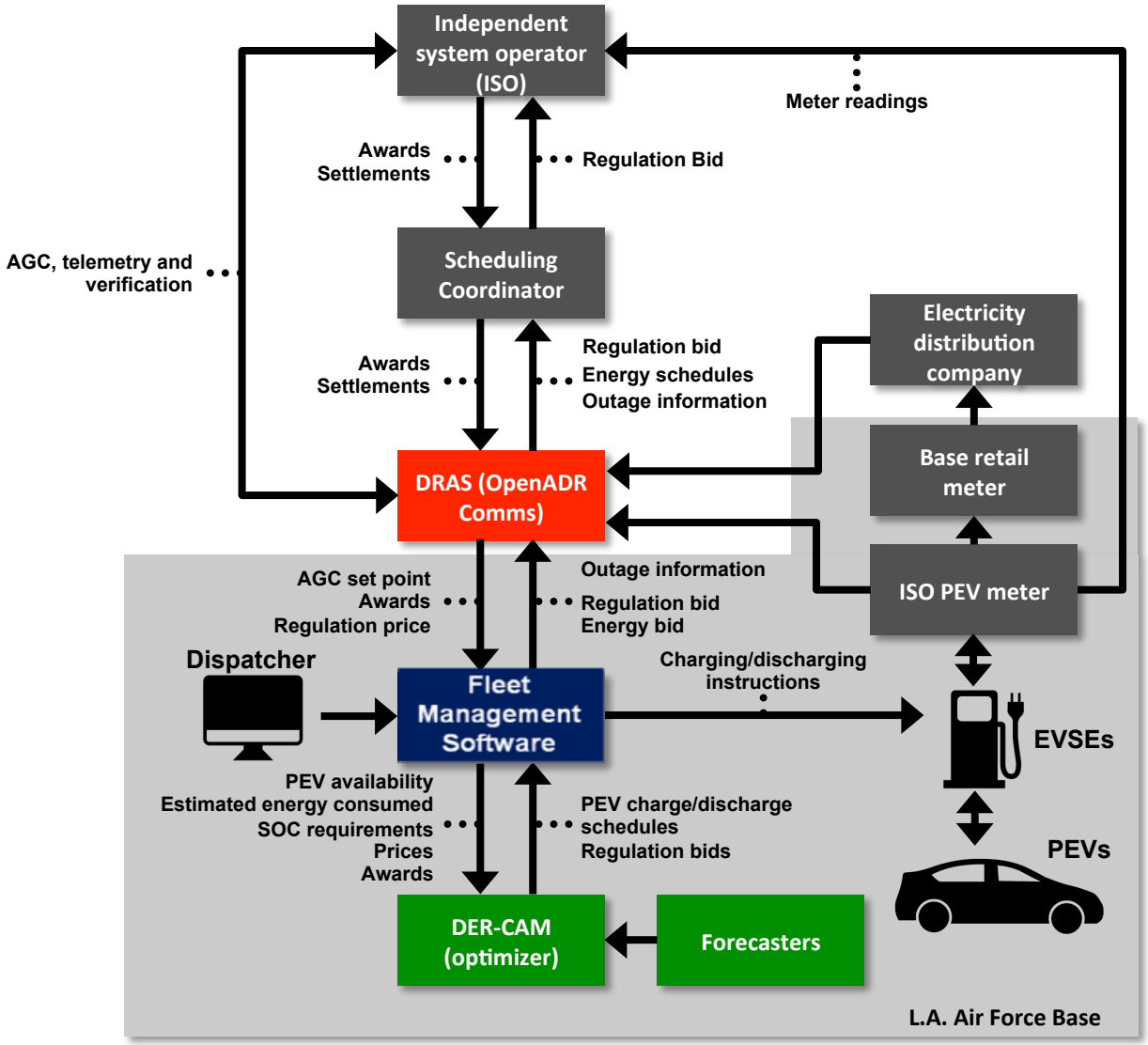
Scheduled charging may be shed to increase **Regulation Up** bid if trip constraints allow

Regulation Up Capacity: limited by max discharging capacity and energy stored in battery

LA AFB System Architecture: Regulation Bidding

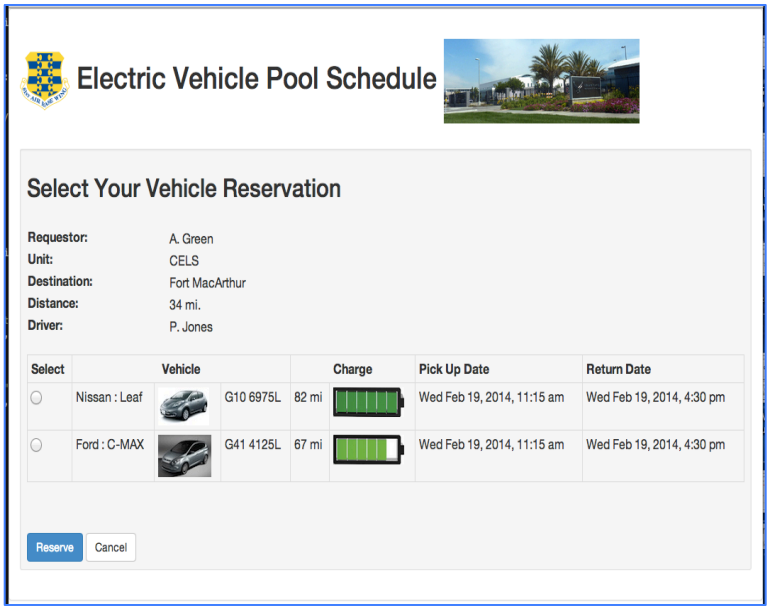


LA AFB System Architecture



Fleet Management System

- Vehicle reservation system
- Software interface with Base personnel
- Determines expected battery energy needs for vehicle trips and vehicle availability
- Outputs are hard constraints in the optimization model



FMS- Choose Vehicle

KISENSUM

Unit	POOL	**Reservation Start:**	2014-11-14	13	00	**Reservation End:** 2014-11-14 17 00

Vehicle Class	Reserved	Available	Actions
EV Compact Sedan	3	15	Reserve EV Compact Sedan
Vans	None	7	Reserve Vans
Compact Sedan	None	7	Reserve Compact Sedan
EV Vans	None	2	Reserve EV Vans
EV Forklift	None	2	Reserve EV Forklift
2 Ton Stake Truck	None	2	Reserve 2 Ton Stake Truck
Pickup Truck	None	1	Reserve Pickup Truck
LSV	None	1	Reserve LSV
2 Ton Box Truck	None	1	Reserve 2 Ton Box Truck
1 Ton Box Truck	None	1	Reserve 1 Ton Box Truck

FMS - Reservation

KISENSUM

Reserve:
EV Compact Sedan

From: 2014-11-14 — 13 — 00

To: 2014-11-14 — 17 — 00

Paste

***Requestor** Abeyta, Felix Capt

***Operator** Abeyta, Felix Capt

Chauffeur ---------

Phone 3-3705

Project Code 01:Electric Vehicle Dispatch

***Purpose** Shuttle Service

Vehicle Type Nissan Leaf

Req. Other

Op. Other

Op. Unit

Cargo Weight 0

Passenger Count 1

Notes

Pick up Camron Gorguinpour

***Type** Round Trip

Pickup Loc. V/Ops (LAAFB)

Other

***Dest.** Applied Minds Inc. (27 miles one-way)

Other

***Est Miles** 54

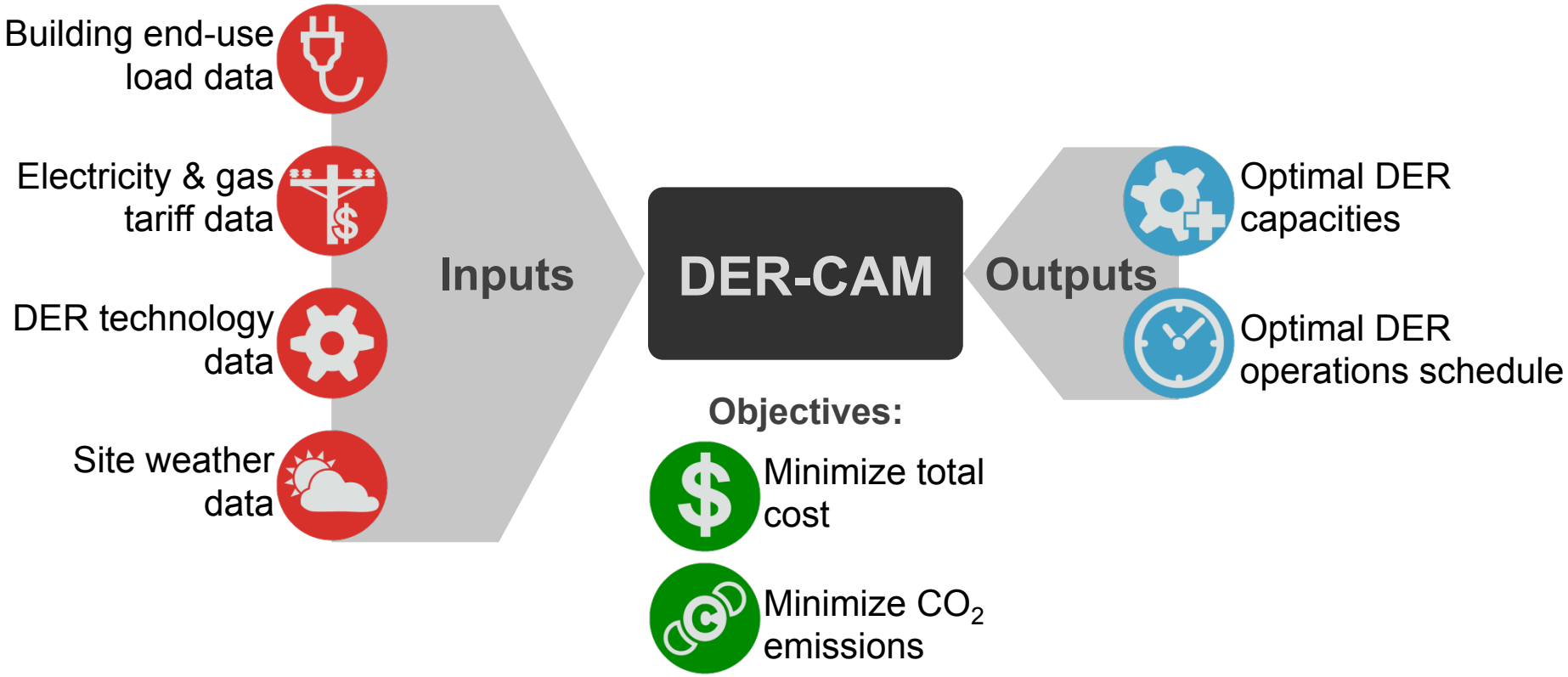
PAX Miles 54

Calculate Miles

Cancel

Confirm

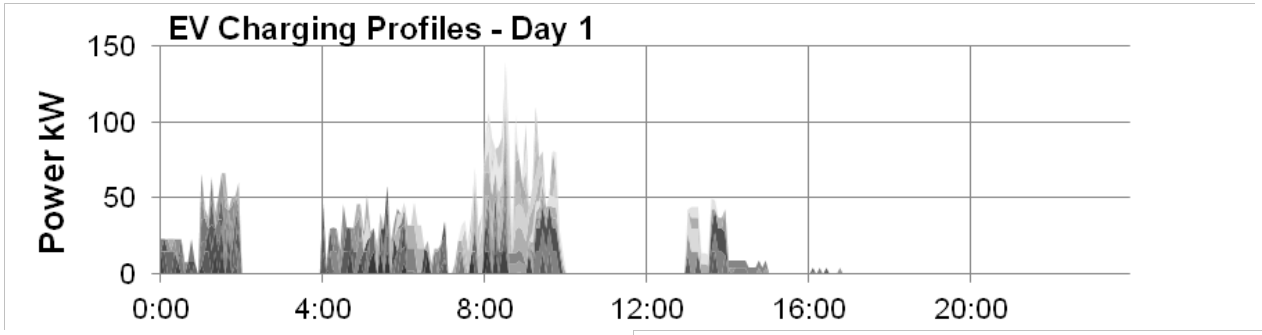
Distributed Energy Resources Customer Adoption Model

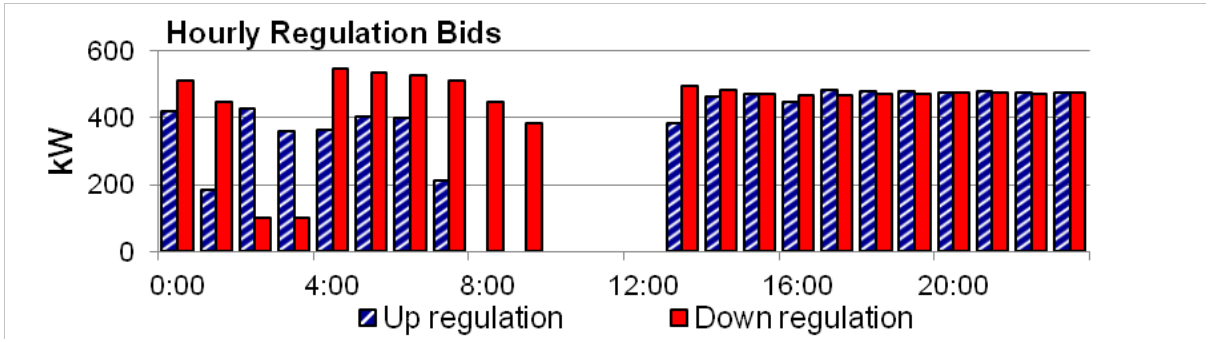


- **Investment & Planning:** determines optimal equipment combination and operation based on *historic* load data, weather, and tariffs
- **Operations:** determines optimal week-ahead scheduling for installed equipment and *forecasted* loads, weather and tariffs

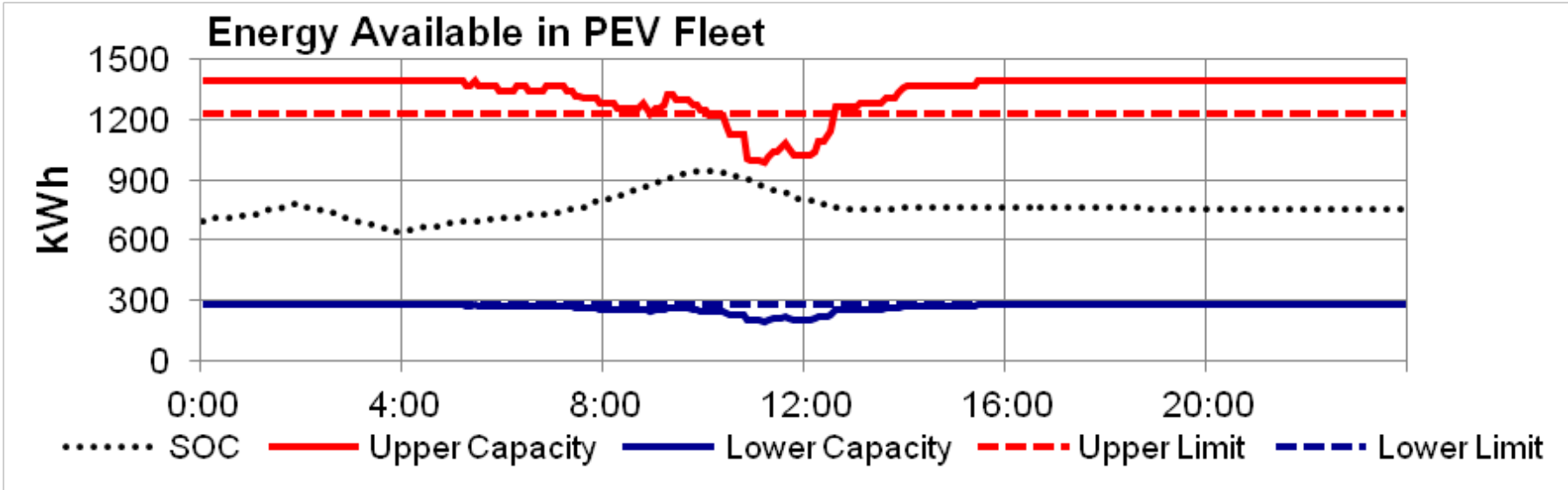
Charging and Market Participation Optimization

- Economic optimization is accomplished through LBNL's DER-CAM.
  - Minimizes retail energy and demand charges
  - Maximizes regulation revenue, based on forecasted AS Prices
  - Constrained by travel requirements for each vehicle





How DER-CAM does it



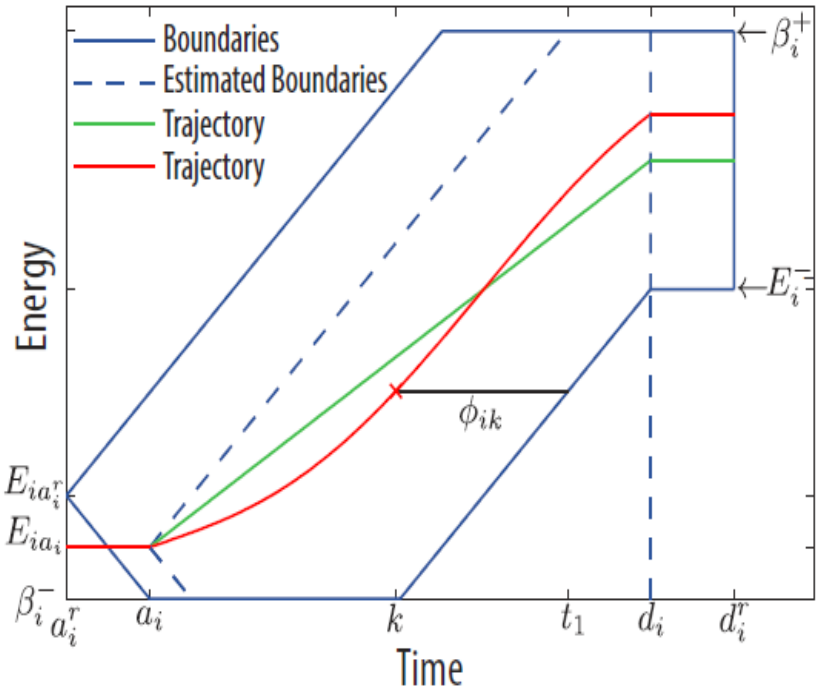
- Calculates vehicle SOC for entire day.
- Resource available capacity is determined as the sum of available capacity from each individual vehicle.
- The upper and lower energy limits scale with the number of vehicles plugged in.
- Upper and Lower Limits (part of daily bid) prevent us from bidding available capacity during some hours in order to maximize participation through the day.

Real-Time Charging Controller

- Distributes charge/discharge commands among connected vehicles
- Attempts to minimize deviation from optimal charging pattern developed in DER-CAM (charging trajectory)
- Calculate optimal charging and discharging trajectories for both operational requirements and market participation
- Manage the aggregated state of charge across the entire fleet
- Controls the EV Charging Stations (EVSE) through industry standard protocols

Green is DER-CAM Optimal

Red is Actual



Charge Control

KISENSUM

Total EVSEs: 12

Active EVSEs: 11

Current Dispatch (kw): 0.0

Total Power (kw): 0.0

Total Connected Vehicles: 9

Below SOC Plan with insufficient time: 0

Below SOC Plan with slack: 7 **above SOC Plan:** 1

At Target SOC (TSOC): 1

Updated:
Nov. 13, 2014, 2:15 p.m.

Update | Export

Dispatch Simulation

kW: 80

Space #	Vehicle	Status	Setpoint (kW)	Power (kW)	SOC (kWh)	SOC %	TSOC (kWh)	Next Trip
0002	Nissan Leaf (12B80020)	Connected	0.0	0.0	20.68		24.00	5 hours, 44 minutes
0003	Nissan Leaf (12B80023)	Connected	0.0	0.0	23.17		24.00	2 days, 21 hours
0004	Nissan Leaf (12B80011)	Offline	0.0	0.0			24.00	44 minutes
0005	Nissan Leaf (12B80012)	Connected	0.0	-0.0	23.73		24.00	1 hour, 14 minutes
0006	Nissan Leaf (12B80015)	Connected	0.0	-0.0	21.41		24.00	2 hours, 44 minutes
0007	Nissan Leaf (12B80016)	Connected	0.0	0.0	21.31		24.00	3 hours, 4 minutes
0008	Nissan Leaf (12B80017)	Connected	0.0	-0.0	23.92		24.00	3 hours, 14 minutes
0009	Nissan Leaf (12B80018)	Connected	0.0	0.0	19.59		24.00	3 hours, 44 minutes
0010	Nissan Leaf (12B80021)	Connected	0.0	-0.0	20.38		24.00	6 hours, 44 minutes
0011	Nissan Leaf (12B80022)	Connected	0.0	0.0	24.00		24.00	3 days, 21 hours
0012	Nissan Leaf (12B80013)	Disconnected	0.0	0.0			24.00	1 hour, 44 minutes
0013	Nissan Leaf (12B80019)	Disconnected	0.0	0.0			24.00	4 hours, 44 minutes

Charge Control—Up Regulation

KISENSUM

Total EVSEs: 12

Active EVSEs: 11

Current Dispatch (kw): -80.0

Total Power (kw): -80.0

Total Connected Vehicles: 9

Below SOC Plan with insufficient time: 0

Below SOC Plan with slack: 9 **above SOC Plan:** 0

At Target SOC (TSOC): 0

Updated:
Nov. 13, 2014, 2:19 p.m.

Update | Export

Dispatch Simulation

kW:

Space #	Vehicle	Status	Setpoint (kW)	Power (kW)	SOC (kWh)	SOC %	TSOC (kWh)	Next Trip
0002	Nissan Leaf (12B80020)	Connected	-11.5	-11.5	15.57		24.00	5 hours, 40 minutes
0003	Nissan Leaf (12B80023)	Connected	-5.5	-5.7	9.99		24.00	2 days, 21 hours
0004	Nissan Leaf (12B80011)	Offline	0.0	0.0			24.00	40 minutes
0005	Nissan Leaf (12B80012)	Connected	-6.6	-6.6	10.97		24.00	1 hour, 10 minutes
0006	Nissan Leaf (12B80015)	Connected	-10.7	-10.6	14.80		24.00	2 hours, 40 minutes
0007	Nissan Leaf (12B80016)	Connected	-9.0	-9.0	13.25		24.00	3 hours
0008	Nissan Leaf (12B80017)	Connected	-10.7	-10.7	14.81		24.00	3 hours, 10 minutes
0009	Nissan Leaf (12B80018)	Connected	-8.5	-8.5	12.84		24.00	3 hours, 40 minutes
0010	Nissan Leaf (12B80021)	Connected	-6.1	-6.1	10.51		24.00	6 hours, 40 minutes
0011	Nissan Leaf (12B80022)	Connected	-11.4	-11.3	15.52		24.00	3 days, 21 hours
0012	Nissan Leaf (12B80013)	Disconnected	0.0	0.0			24.00	1 hour, 40 minutes
0013	Nissan Leaf (12B80019)	Disconnected	0.0	0.0			24.00	4 hours, 40 minutes

Charging Stations

Qty	Vendor	Vehicles to Charge	Size / Type	Comm. Type	V2G Status
4	Eaton	Ford C-MAX Energis, Chevy Volt, VIA	15 kW AC	OCPP	Non-V2G
13	Princeton Power Systems	Nissan LEAFs	15 kW DC	OCPP	V2G
16	Coritech	VIA/EVAOS	15 kW AC	SAE	V2G
5	Coritech	EVI/Phoenix	50 kW DC	SAE	V2G

Princeton Power DC charging station (V2G using CHAdeMO)

Eaton AC charging station

AC (V2G using SAE)

Coritech Services

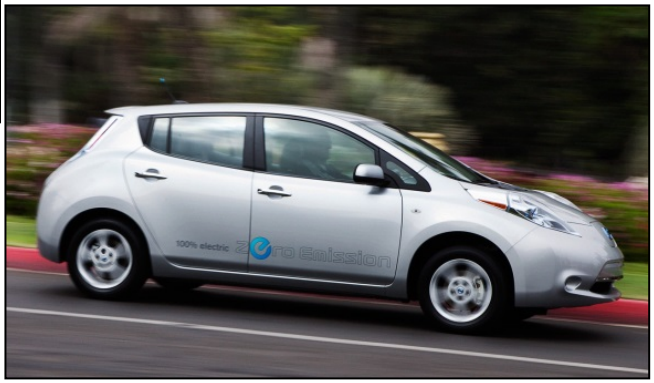
DC (V2G using SAE Combo)

LA AFB Electric Vehicles

EVAOS –
Uses Ford F150,
F250 and F350

EVI Stake Bed
(also Box Truck)

VIA Vans – Use
Chevrolet Express
van chassis



2012 Nissan LEAF
(with bi-directional firmware)

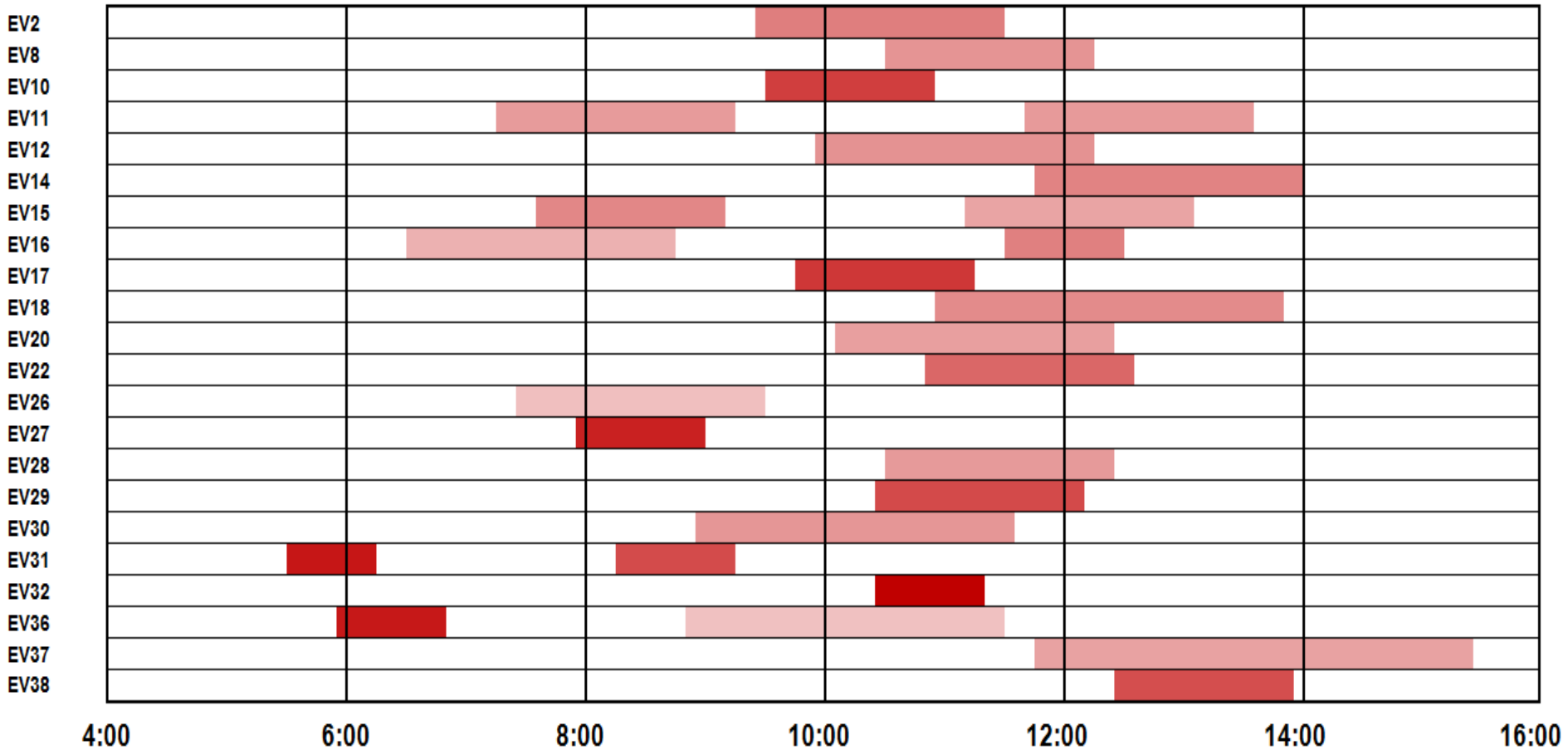
Phoenix Shuttle Bus

LA AFB Vehicle Fleet--Simulated

Qty	Vendor	Model	Capacity (kWh)	Charge/ Discharge Rate (kW)	V2G Capable
4	Ford	C-MAX Energi	8	3.3	Non-V2G
2	Chevy	Volt	15	3.3	Non-V2G
13	Nissan	LEAF	24	15 (DC)	V2G
4	VIA	Van	24.4	15	Non-V2G
9	VIA	Van	24.4	15	V2G
4	EVI	2 Stake-bed Trucks 2 Box Trucks	120	50 (DC)	V2G
5	EVAOS	5 Kits for Ford trucks	27	15	V2G
1	Phoenix	Surrey Bus	120	50 (DC)	V2G
Total Charge / Discharge (kW)				**722 / 642**	
Total Capacity			**1426**		

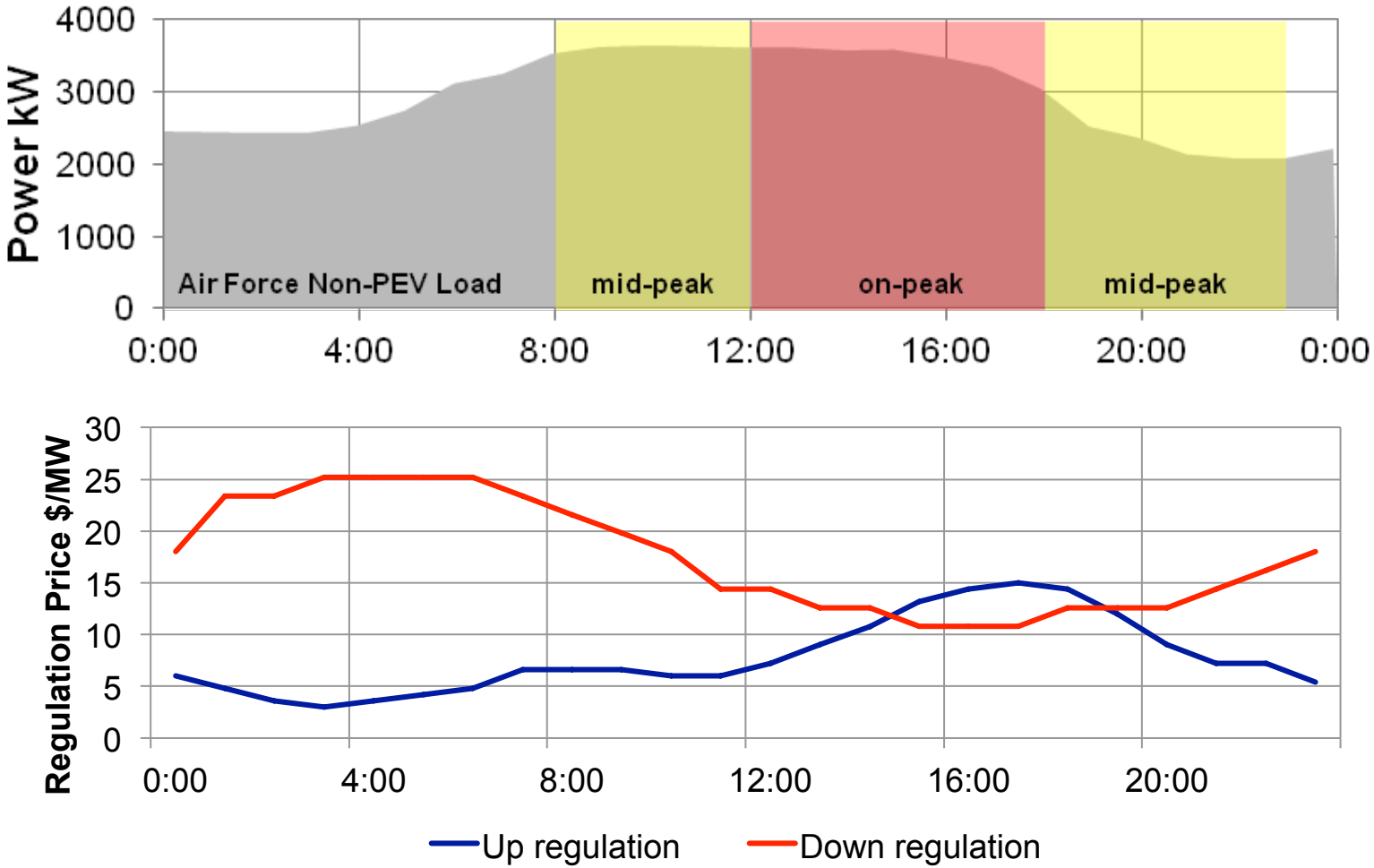
Minimum resource size: 500 kW; bid: 100 kW; bid increment: 10 kW

PEV Test Day Trip Schedule

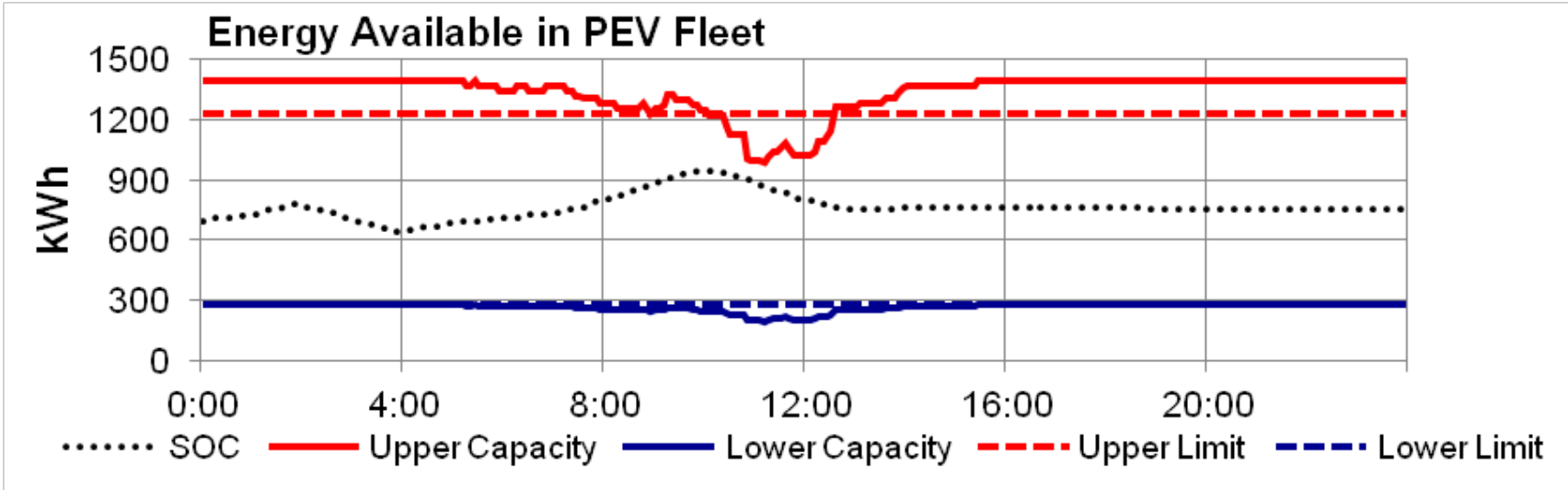


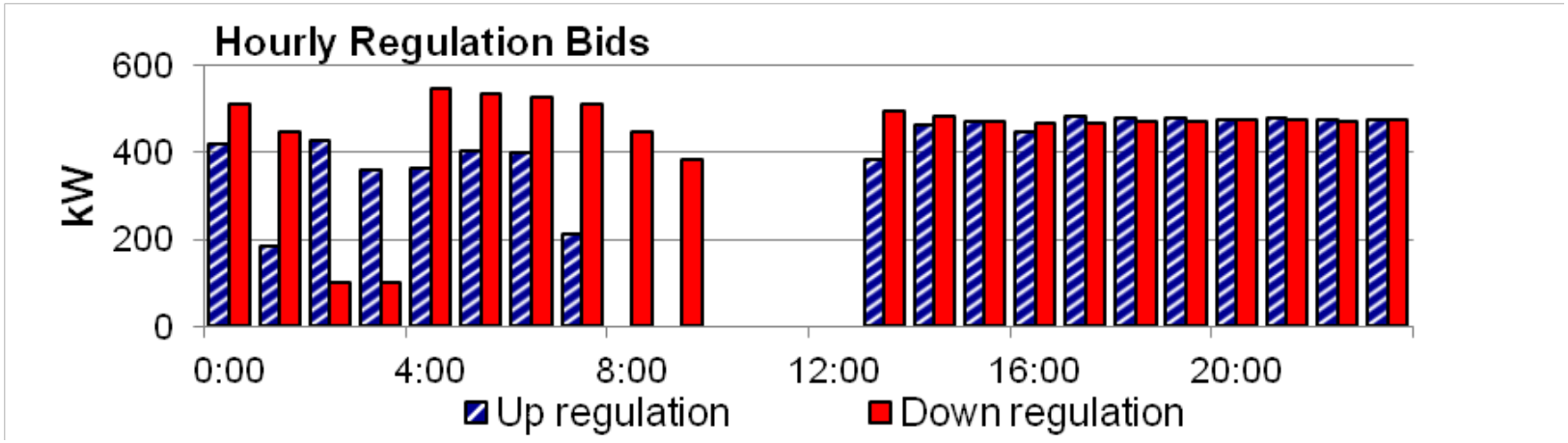
Note: All other EVs unused during simulated day

Test Day Conditions

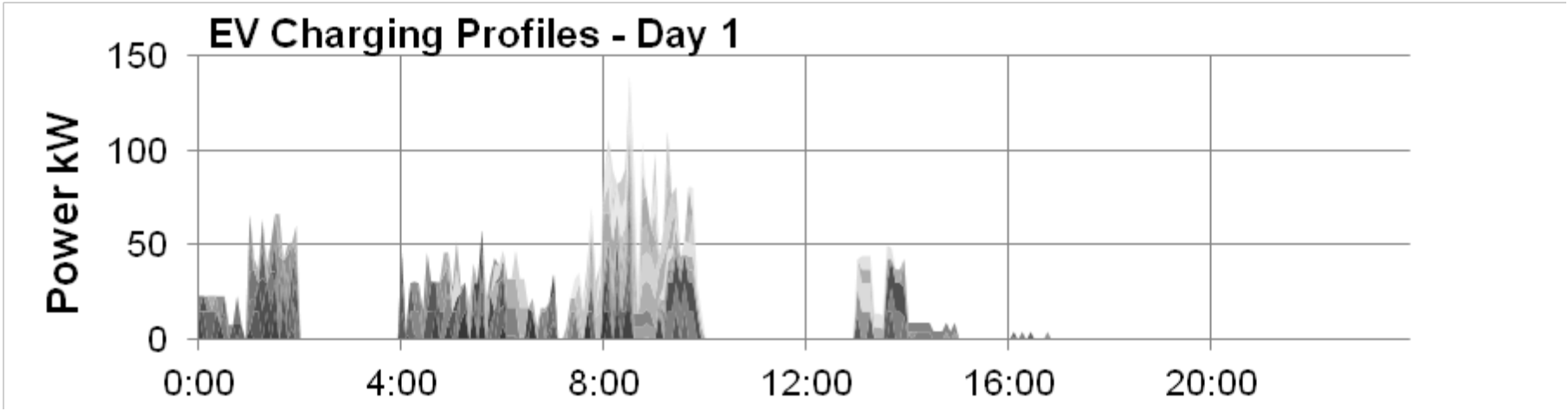


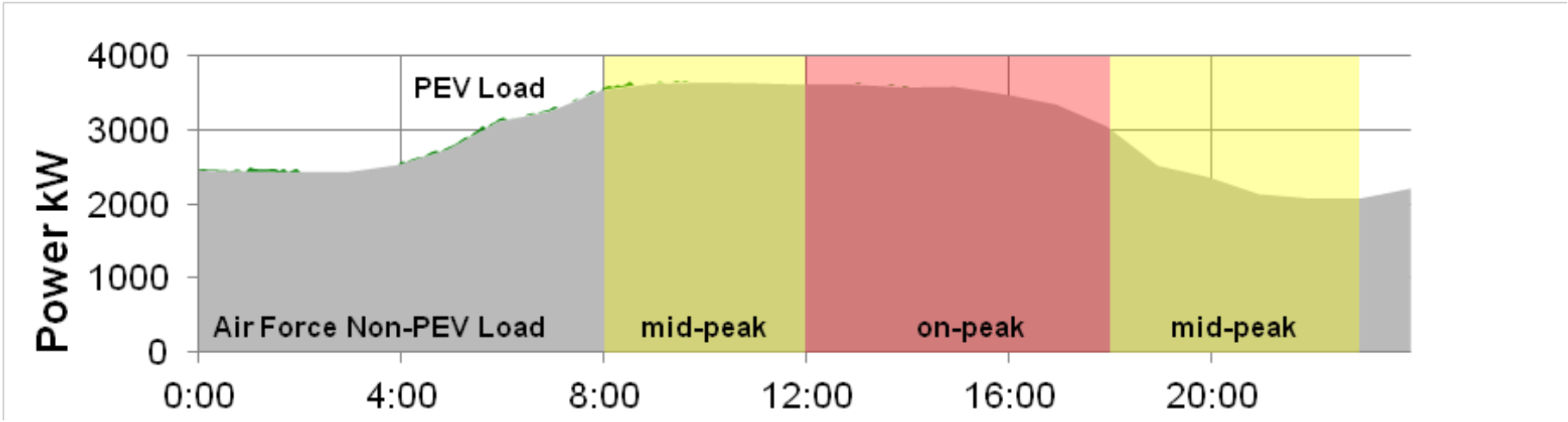
Resource Availability & Bids





Impact of EV Charging





Summary of Daily Results

Energy Costs		$ 41.17
Power Costs		$ 0.00
Regulation Revenue	**Up**	$ 69.15
	Down	$ 169.66

For test-day prices and usage schedule:

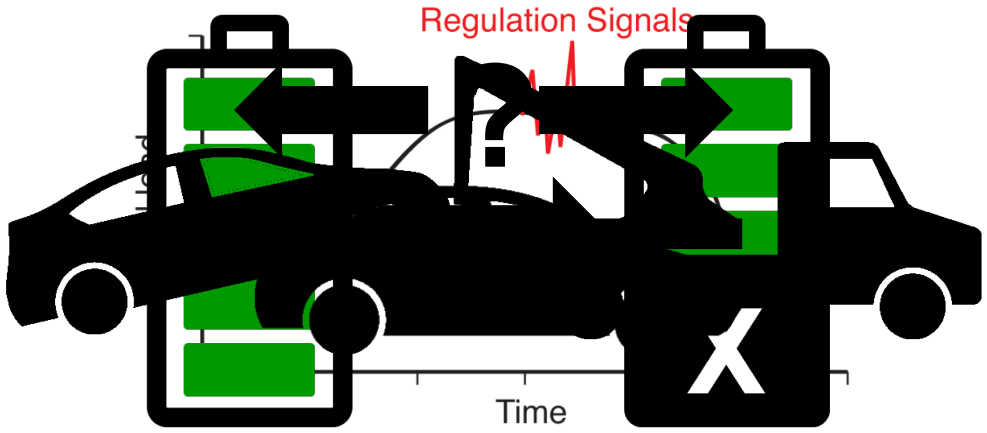
Daily energy cost: $1.08 per PEV

Daily regulation revenue: $6.28 per PEV

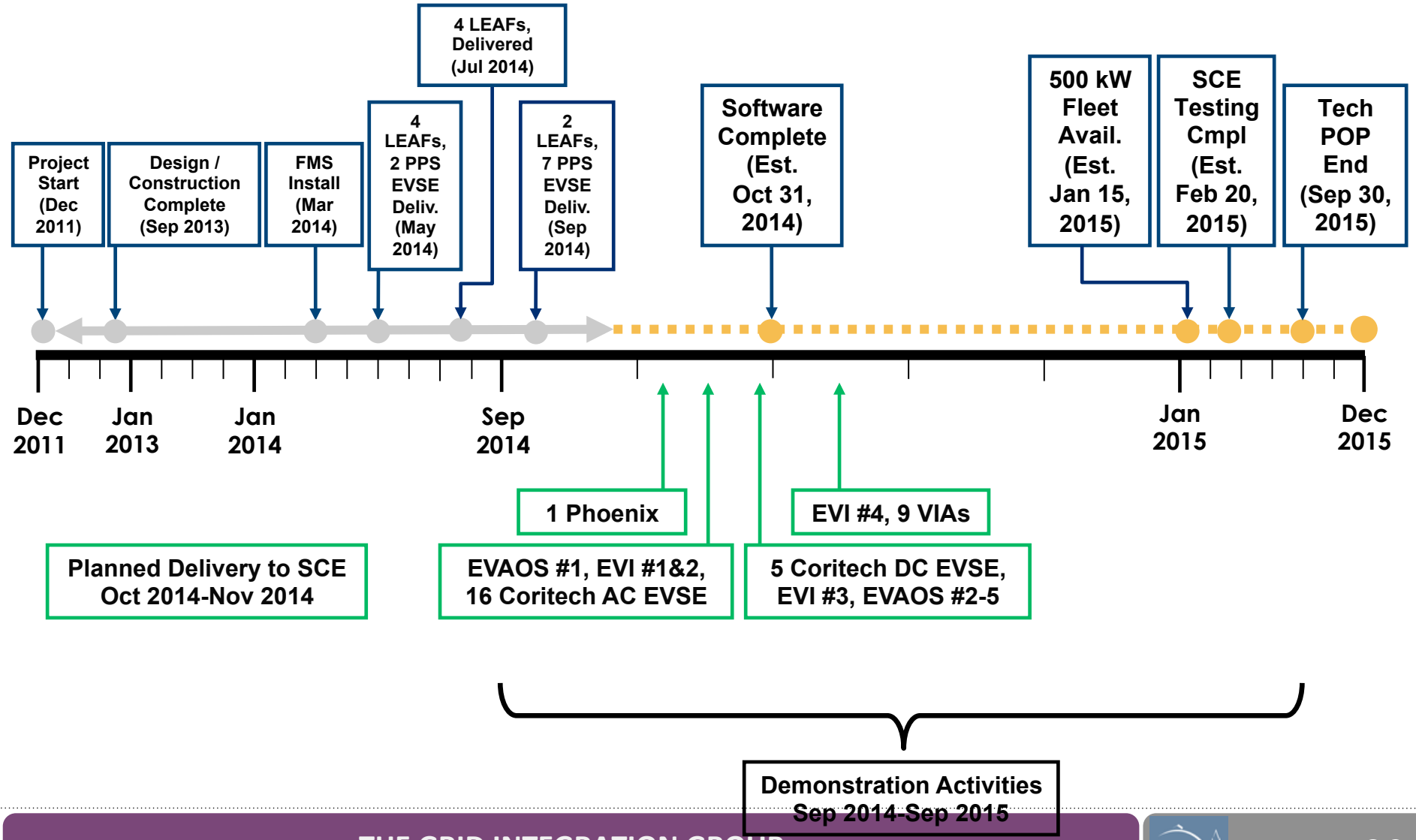
Note: This result is for one random sample day and may not be representative of future market prices

Incorporating risks

- Tariff demand spikes
- AGC signals depleting batteries
- Uncertainty in schedules
- Battery degradation



Schedule (DOD Program Management Review 9/24/14)



Vehicle-to-Building

- Emergency back-up power; building 229 Emergency Operation Center
- Battery-firmed demand response
- Manage charging to minimize peak demand and utility bills when not called to participate in AS regulation
- V2B DR/AS scenarios to be studied via simulation:

Simulation Scenario	Demand Response	Ancillary Service	Current Capability
S1	Real-Time Price	Regulation / Participating Load	Yes
S2	Demand Bidding Program	Regulation / Participating Load	Planned for Spring 2015
S3	Load Shaping	Supply Side	TBD

LA AFB V2G Status

- All PEV sedans and associated EVSEs are operating
- PEV trucks and bus and EVSEs to be installed and functional by Feb 2015
- DER-CAM Day Ahead Optimization functioning
- Fleet management software installed and operating
- Communications between DRAS and external entities established
- Battery health monitoring currently being installed
- Wholesale market participation expected in March 2015

Overview of 63rd RSC Pilot

- The overall technical goal is to demonstrate an all-electric non-tactical fleet at the 63rd that has the ability to provide economic energy resources to the wholesale electricity market.
- Demonstrate and evaluate the use of the proxy demand resource (PDR).
- Participate in the wholesale electricity market with the demand response resources of the RSC-HQ's building loads.
- Examine the impacts of smart charging on battery cycling and, potentially, battery life.
- Apply and evaluate the technology and capabilities developed for the L.A. AFB in a different market with a different set of rules and time scale of transactions.

63rd RSC Partners

KISENSUM

BERKELEY LAB

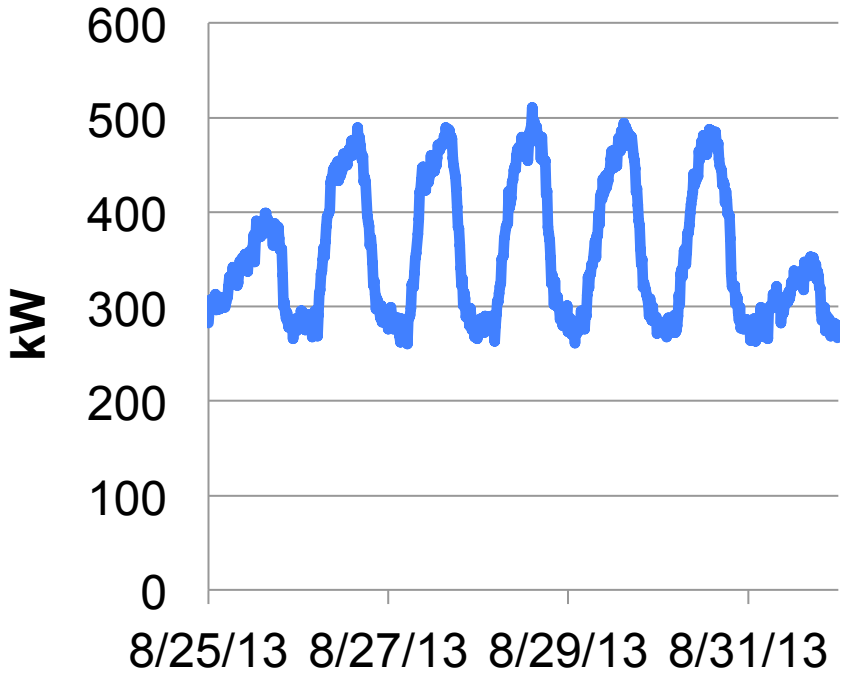
olivine
demand responsible

PG&E

63rd Regional
Support Command

63rd Regional Support Command (aka "Moffett Field")

- Mission is to provide support for all Reserve personnel in the seven-state Southwest Region
- Three buildings—main office/training, vehicle maintenance shop, and warehouse



CAISO Demand Models

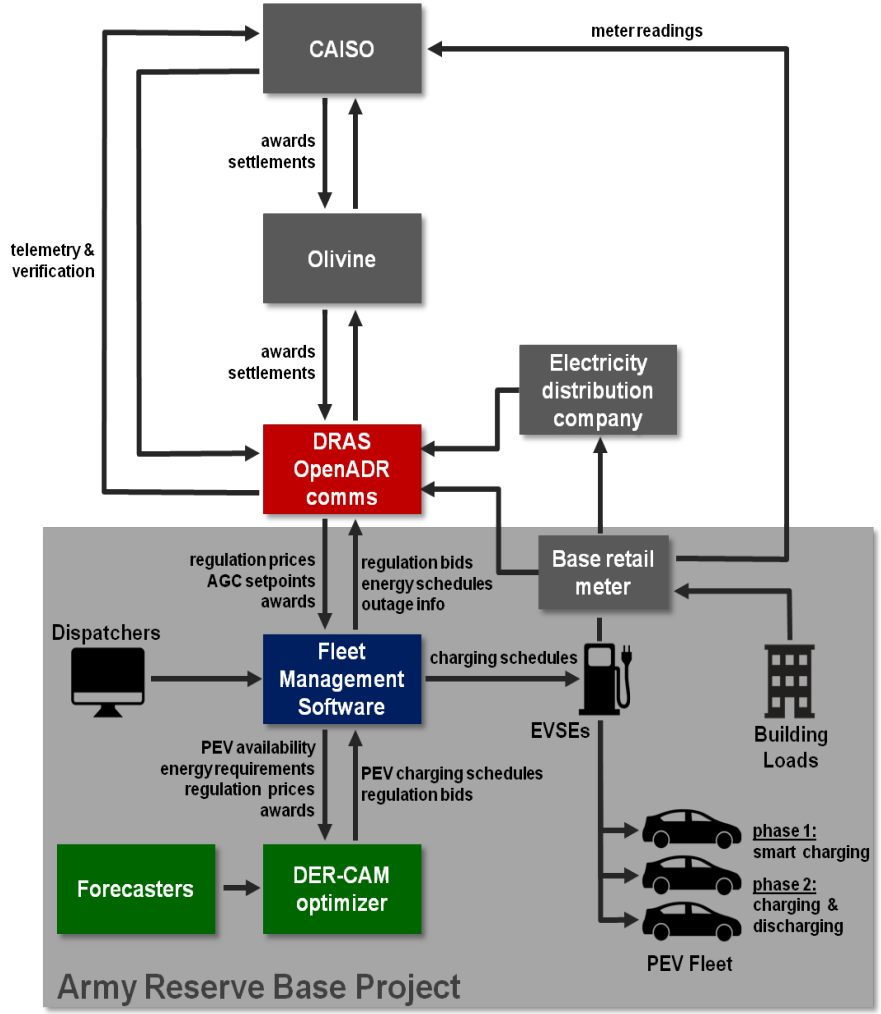
63rd RSC →

LA AFB →

MODEL	INCEPTION	ELIGIBLE MARKET SERVICES	DRP/LSE RELATIONSHIP
Participating load	1999	Non-spinning reserves	DRP and LSE must be the same entity
Proxy demand resource (PDR)	2010	Day-ahead and real-time energy, non-spinning reserves, and spinning reserves*	DRP can be a separate entity than the LSE
Non-generator resource (NGR)	2012	Day-ahead and real-time energy, non-spinning reserves, spinning reserves,* and regulation*	DRP and LSE must be the same entity
Reliability DR resource (RDRR)	To be re-filed at FERC	Day-ahead and real-time energy	DRP can be a separate entity than the LSE
NGR/PDR	Under consideration in 2013 stakeholder initiatives catalog	Day-ahead and real-time energy, spinning reserve, non-spinning reserve, and regulation service	DRP can be a separate entity than the LSE

Source: Demand Response and Energy Efficiency Roadmap: Maximizing Preferred Resources. CAISO. December 2013.

63rd RSC System Architecture



Differences Between 63rd RSC and LA AFB Projects

- The LA AFB PEVs will be bid into the CAISO regulation markets and the 63rd RSC PEVs will participate in the CAISO Proxy Demand Response program and bid into the Day Ahead energy markets.
- The 63rd RSC fleet will be combined with site loads behind the same meter so that PEVs and building loads can be bid as an integrated system
- The 63rd RSC fleet charging will be controlled to maximize revenue considering the impacts of the site's baseline load on demand response program settlements

Concluding Remarks

- Critical hardware and software system components are in place at LA AFB and functioning awaiting full fleet resource implementation
- LA AFB V2G market participation simulation indicates economic benefit, but magnitude depends on uncertainties of actual fleet and market behavior
- LA AFB project has brought together diverse major stakeholders to create a V2G-enabling market and regulatory structure
- 63rd RSC project aims to demonstrate a market-ready approach for vehicle grid integration that is combined with building loads as a single resource

Thanks!

- Any questions: drblack@lbl.gov

- The LA AFB project is funded jointly by the Department of Defense's Environmental Security Technology Certification Program (ESTCP) and the California Energy Commission
- The 63rd RSC project is funded jointly by the California Energy Commission, the Department of Defense, and Pacific Gas & Electric

Additional Slides

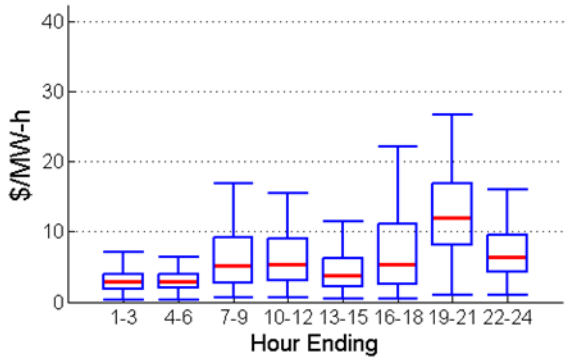
Grid Communications using OpenADR 2.0b

- Akuacom provides the grid communication using their Demand Response Automation Server, employing the OpenADR 2.0b data format.
- DRAS is connected to the ECN
  - Sends and receives all telemetry
  - Receives and translates AGC signals
  - Connects to ADS through SCE's systems
  - Passes availability for bidding to SCE systems

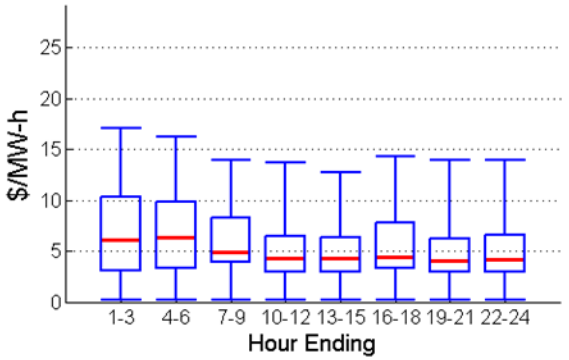
Value of Regulation

Market Clearing Prices by Season

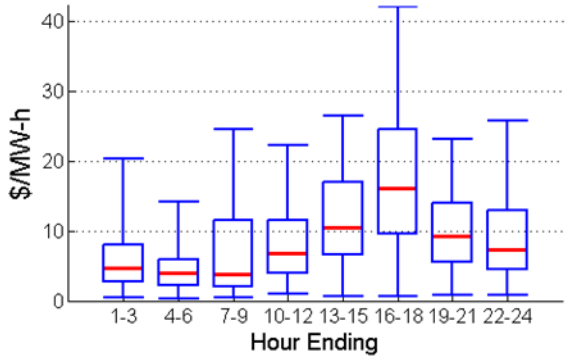
Up Regulation - Winter



Down Regulation - Winter



Up Regulation - Summer



Down Regulation - Summer