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Electric Vehicle Activities at the UCLA Luskin Center for Innovation

15 November 2013

ITS-Davis Seminar

Brett Williams, MPhil (cantab), PhD
EV Initiative Director Luskin Center for Innovation
Assistant Adjunct Professor, Public Policy
University of California, Los Angeles

innovation.luskin.ucla.edu/ev

Outline

- Past and current electric-drive vehicle (EV) activities:
  - **Emerging opportunities**: Mobile Electricity (UCD) & Battery secondary use (Cal)
  - Early vehicle demonstration and analysis (Cal)
  - **Market dynamics**
  - **Regional readiness planning**
  - **Workplaces & Multi-unit dwellings** (MRPI)
    - Charging station profitability analysis
    - Driver cost of fueling comparisons
- Future research teaser:
  - Market dynamics:
    - ZEV Sales Factors analysis (ARB), Station Siting Factors and Utilization analysis, New-car buyer survey & CVRP analysis
  - Transportation Electrification Curriculum Development Roadmap (Edison)

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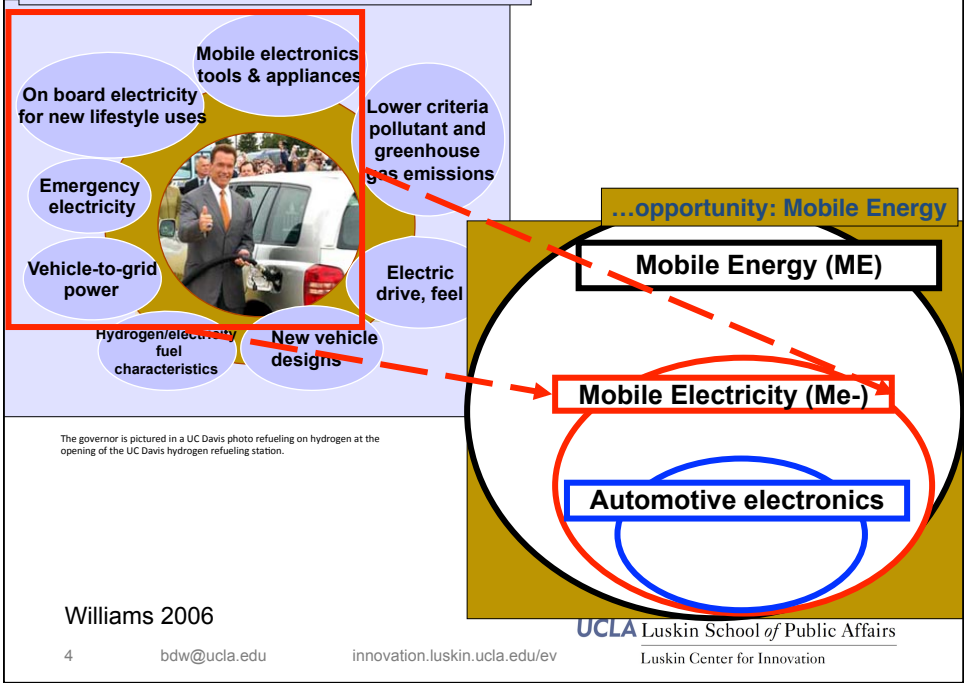
Emerging opportunities

Starting point: ZEVs as new products…



The governor is pictured in a UC Davis photo refueling on hydrogen at the opening of the UC Davis hydrogen refueling station.

Williams 2006

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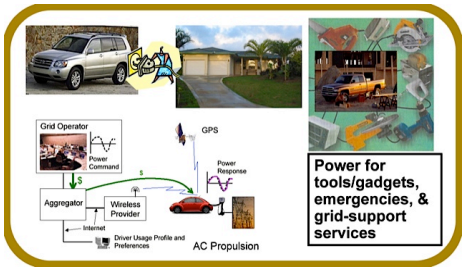
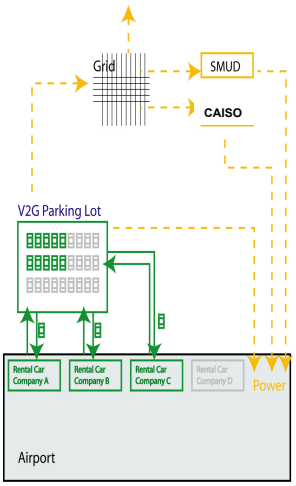
PEV battery secondary use (2U)

…in first life (Mobile Electricity) :

- Me- = mobile (untethered) power, vehicle-to building (V2B, e.g., V2Home), and vehicle-to-grid (V2G) power

  (e.g., Williams & Finkelor 2004, Williams & Kurani 2007)





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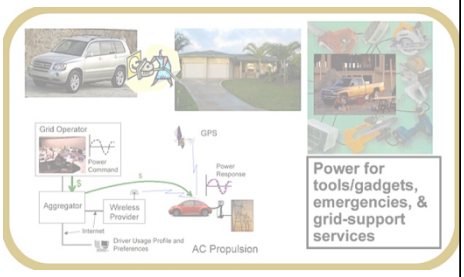
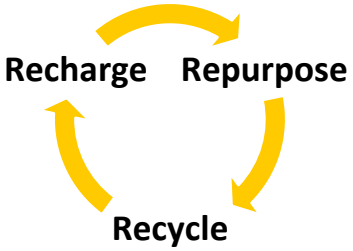


…in second life (repurposing for second use):

- e.g., vehicular cascading/ downcycling, repurposing as stationary energy storage (battery-to-grid or B2G)

  (e.g., Williams and Lipman 2009, 2011)



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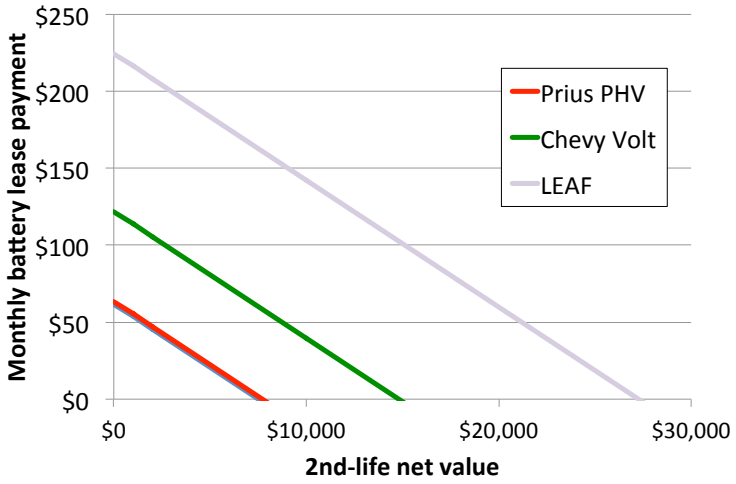
Monthly battery lease by residual value



(Williams & Lipman 2011)

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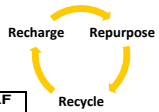
Battery second-life revenue from grid-support services

(Williams & Lipman 2011)



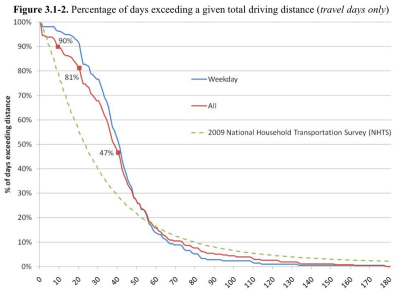
Application	PHV	Volt	LEAF
Electric Energy Time-shift	$330	$880	$1,720
Electric Supply Capacity	$320	$850	$1,670
Load Following	$800	$2,130	$4,180
Area Regulation	$8,720	$23,250	$45,610
Electric Supply Reserve Capacity	$280	$750	$1,470
Voltage Support	$2,870	$7,670	$15,040
Transmission Support	$1,200	$3,190	$6,270
Transmission Congestion Relief	$60	$150	$300
T&D Upgrade Deferral 50th percentile†	$2,390	$6,470	$12,490
T&D Upgrade Deferral 90th percentile†	$3,760	$10,020	$19,660
Substation On-site Power	$600	$1,600	$3,130
Time-of-use Energy Cost Management	$730	$1,960	$3,840
Demand Charge Management	$220	$580	$1,140
Electric Service Reliability	$3,700	$9,860	$19,340
Electric Service Power Quality	$4,170	$11,120	$21,820
Renewables Energy Time-shift	$230	$620	$1,220
Renewables Capacity Firming	$810	$2,160	$4,240
Wind Generation Grid Integration, Short Duration	$4,680	$12,480	$24,480
Wind Generation Grid Integration, Long Duration	$380	$1,000	$1,970

* lifecycle benefit over 10 years, with 2.5% escalation and 10% discount rate
† converted here to approximate 10 years of benefit to be comparable to other applications, but this is not likely at a single location

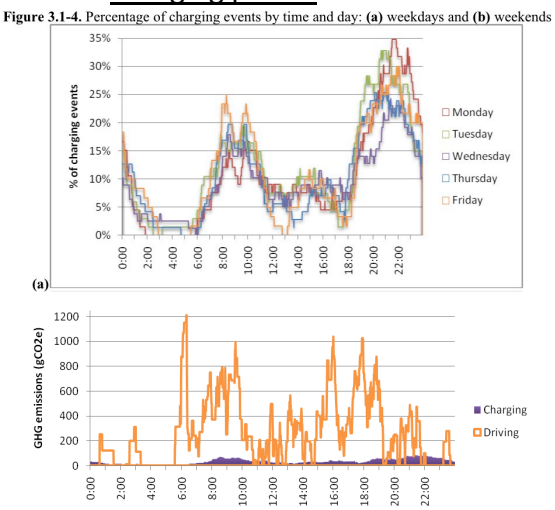
Household placements of plug-in prototypes (UCB, Toyota, ARB)

(Williams et al 2011)

Driving profile

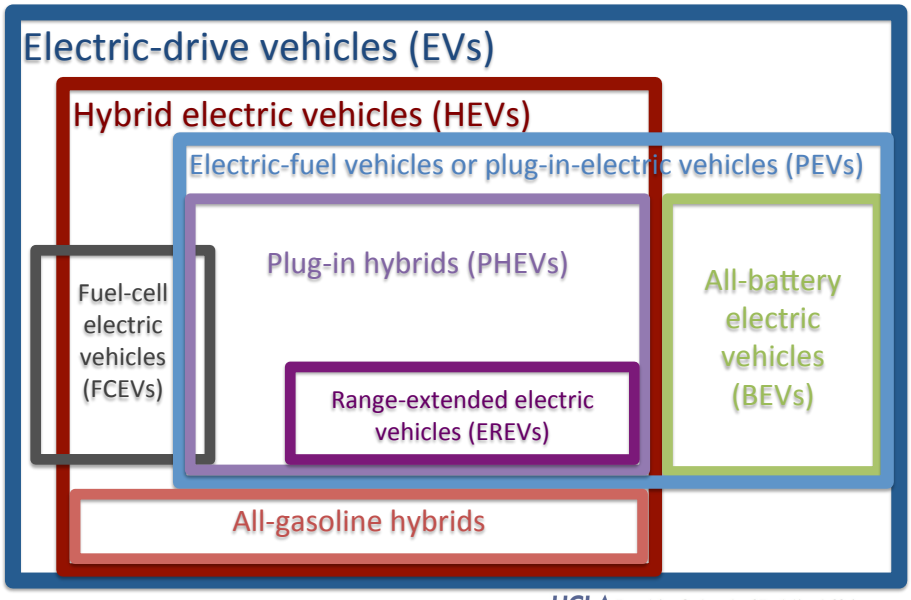


Charging profile



GHG profile

"Electric vehicles" (Williams 2013)



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PEV market analysis

1) Market status
2) Future Luskin work

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U.S. Plug-in Electric Vehicle (PEV) Sales Trends & Analysis

Dec 2010 — Oct 2013

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07-Nov-13

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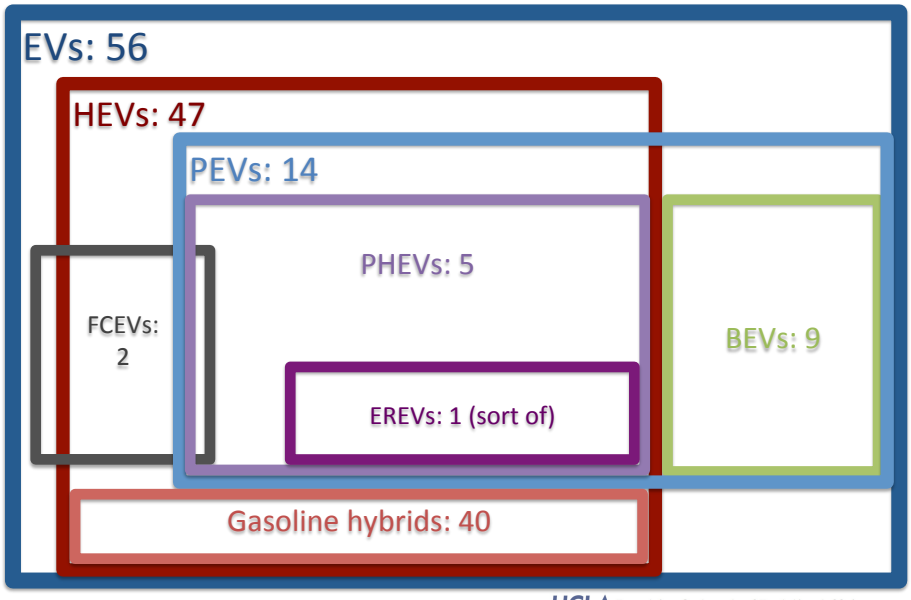
What kinds of "electric vehicles" are on the market?

EV typology and acronym soup

of models on the market in Oct '13 (Williams 2013)



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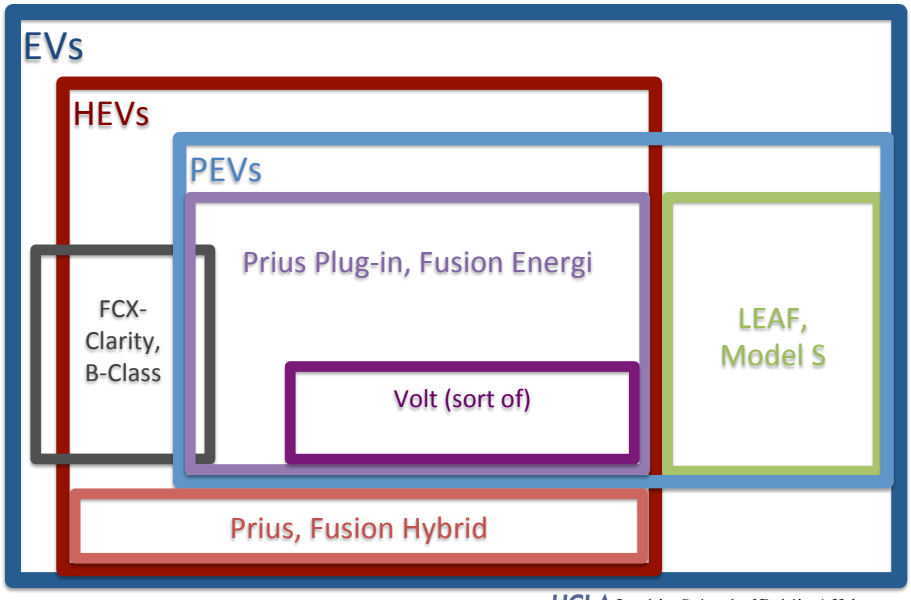
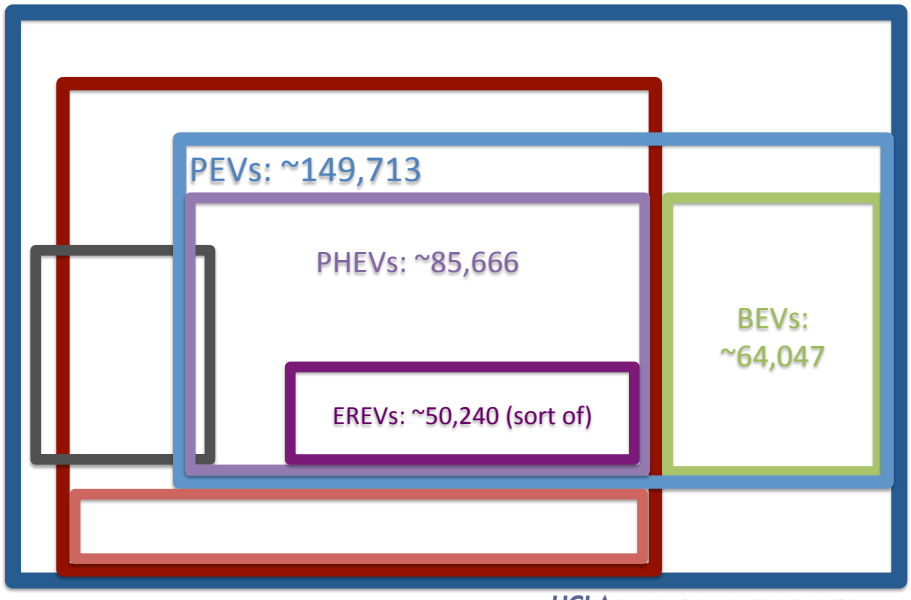
EV light-duty examples

(Williams 2013)



of U.S. vehicles sold thru Oct 2013

(Williams 2013)



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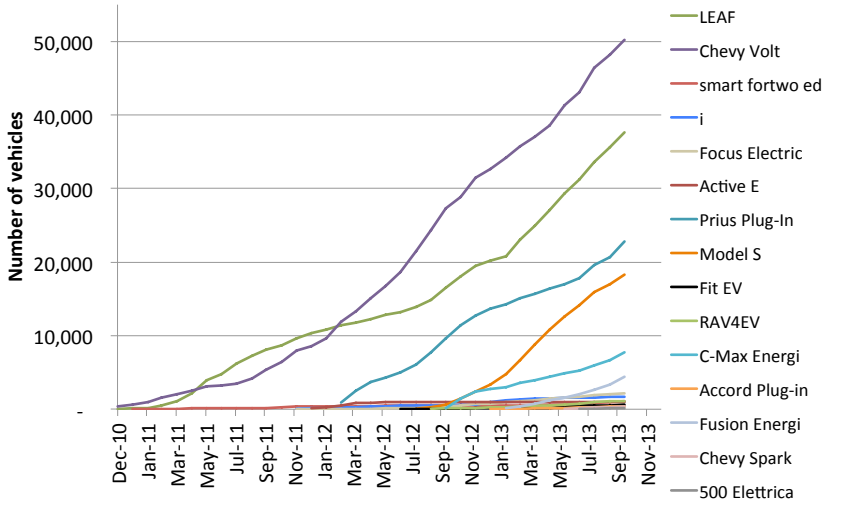
Where are we with PEVs?

Cumulative U.S. sales

Cumulative U.S. sales by PEV model



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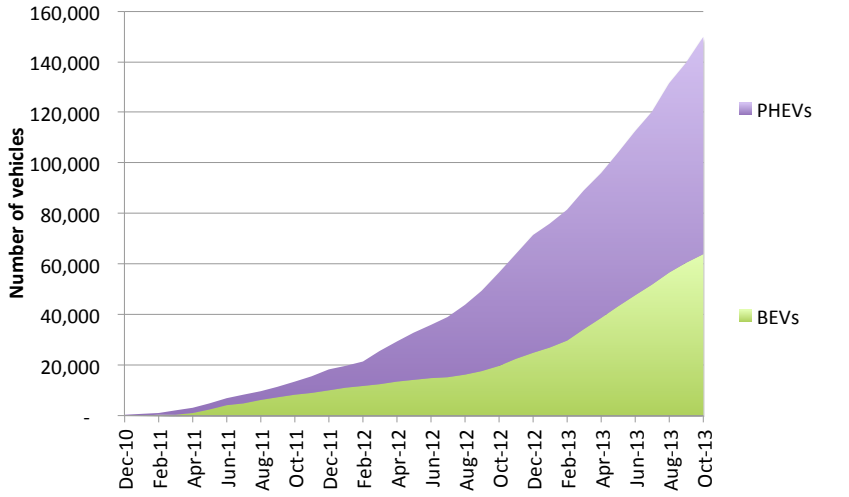
Cumulative U.S. sales by PEV type



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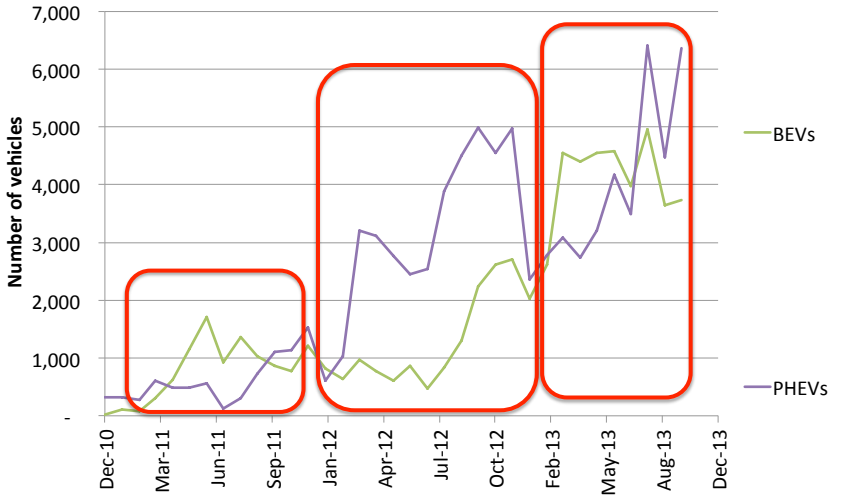
How is the rate changing over time?

Monthly U.S. PEV sales

Monthly U.S. sales by PEV type



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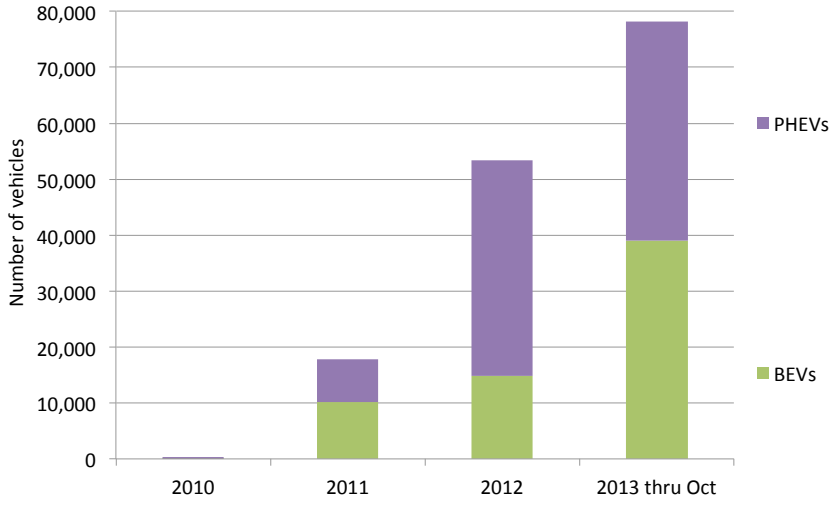
Yearly U.S. sales by PEV type



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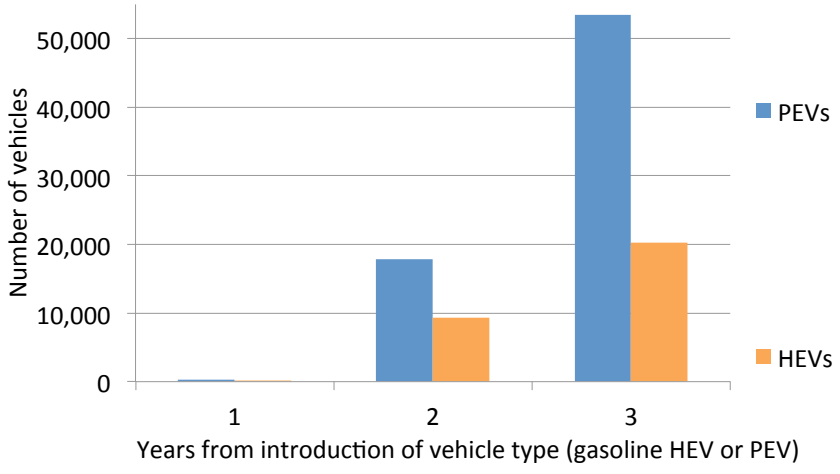
How do PEVs compare to gasoline-only hybrids?

U.S. sales from introduction of vehicle type

Managing EV Expectations

(Williams 2013)



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What does the market look like?

Market share

Sales-weighted average characteristics

U.S. PEV market share

Model	Type	Share thru '11	Share thru '12	Share of CA thru '12	CA share of U.S. thru '12	Cumulative share
LEAF MY'11	BEV	53%	27%	29%	40%	14%
Chevy Volt	PHEV	44%	44%	33%	28%	34%
smart fortwo ed MY'11	BEV	2%	1%	2%	82%	0%
i	BEV	0%	1%	1%	22%	1%
Focus Electric	BEV	0%	1%	2%	65%	1%
Active E	BEV	0%	1%	2%	47%	1%
Prius Plug-In	PHEV	0%	18%	26%	53%	15%
Model S 85kWh	BEV	0%	3%	5%	52%	2%
Fit EV	BEV	0%	0%	0%	90%	0%
RAV4EV	BEV	0%	0%	0%	63%	1%
C-Max Energi	PHEV	0%	3%	1%	10%	5%
Model S 60kWh	BEV	0%	0%	0%	0%	11%
Accord Plug-in	PHEV	0%	0%	0%	0%	0%
Fusion Energi	PHEV	0%	0%	0%	0%	3%
LEAF S MY'13	BEV	0%	0%	0%	0%	11%
smart electric drive MY'13	BEV	0%	0%	0%	0%	0%
Chevy Spark	BEV	0%	0%	0%	0%	0%
500 Elettrica	BEV	0%	0%	0%	0%	0%
BEVs		56%	35%	41%	43%	43%
PHEVs		44%	65%	59%	57%	57%
PEVs		100%	100%	100%	37%	100%

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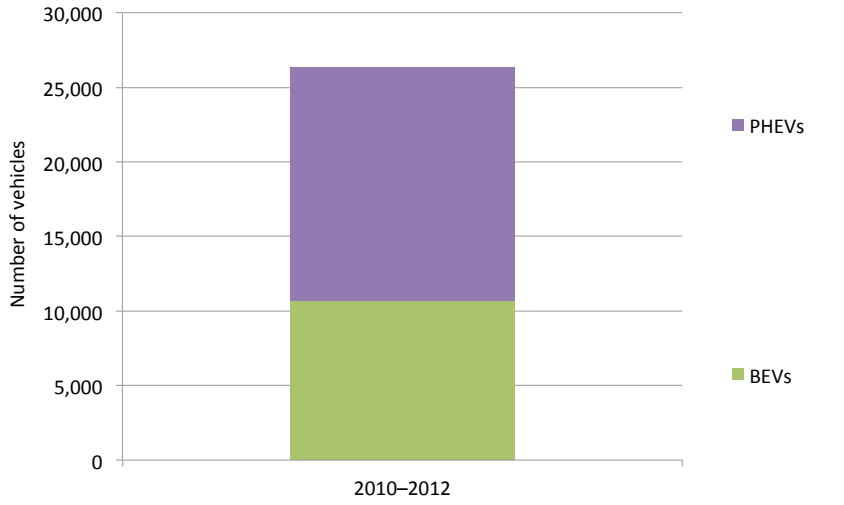
Cumulative California registrations by PEV type



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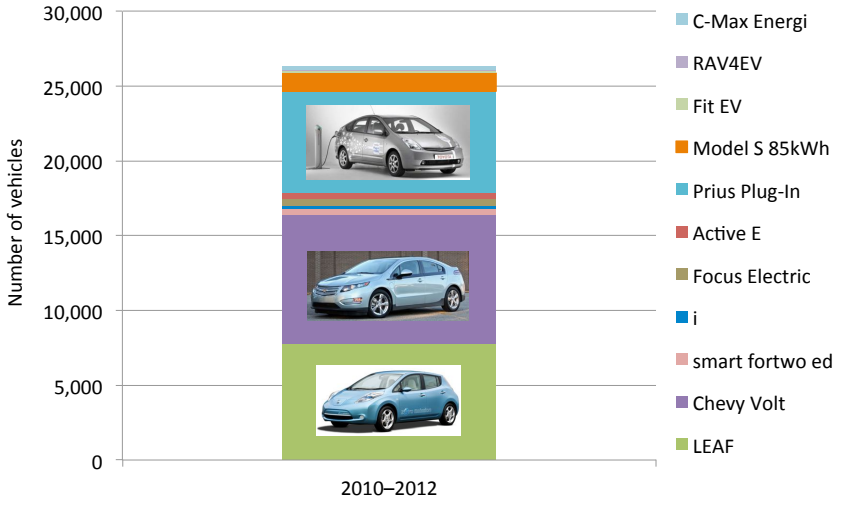
Cumulative CA registrations by PEV model



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U.S. PEV sales-weighted average characteristics

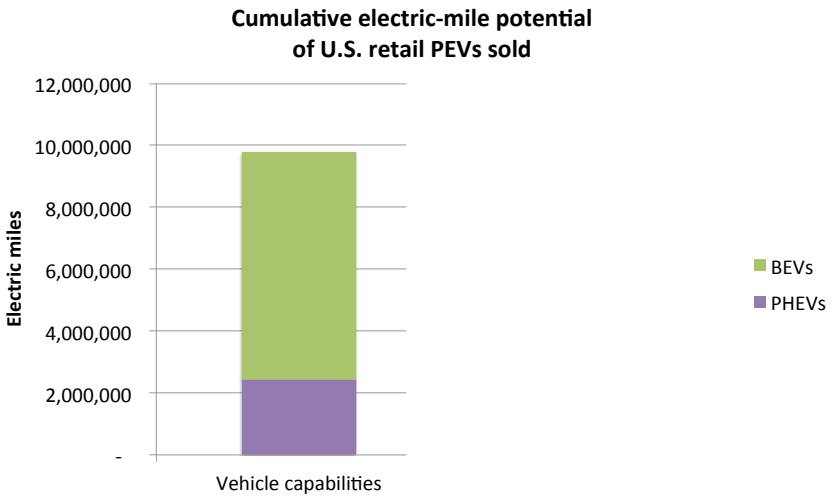
	Motor (kW)	Battery (rated kWh)	Gasoline econ. (mi/gal)	Electric econ. (mpge)	Electric fuel cons. (kWh/100mi)	Electric range (EPA mi)	Range, gasoline (EPA mi)	Range, total (mi)
BEV average	124	35	-	103	33	115	-	115
PHEV average	91	12	41	97	35	27	431	459
PEV average	105	22	-	100	34	65	-	312

Based on revenues (from base MSRP)x(# of vehicles sold):

PEVs are a ~$6 billion industry

- The Volt is a ~$2 billion product.

Does size matter? (Williams 2013)
Per-charge and per-day e-mile potential



Does size matter?
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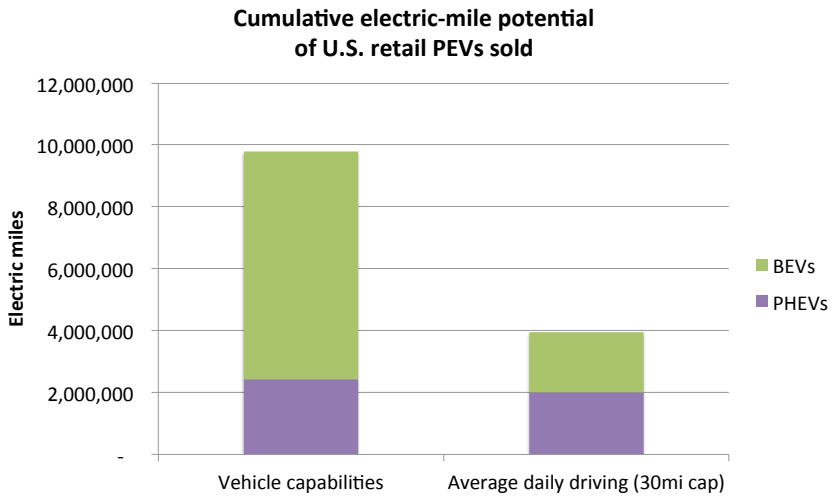
(Williams 2013)



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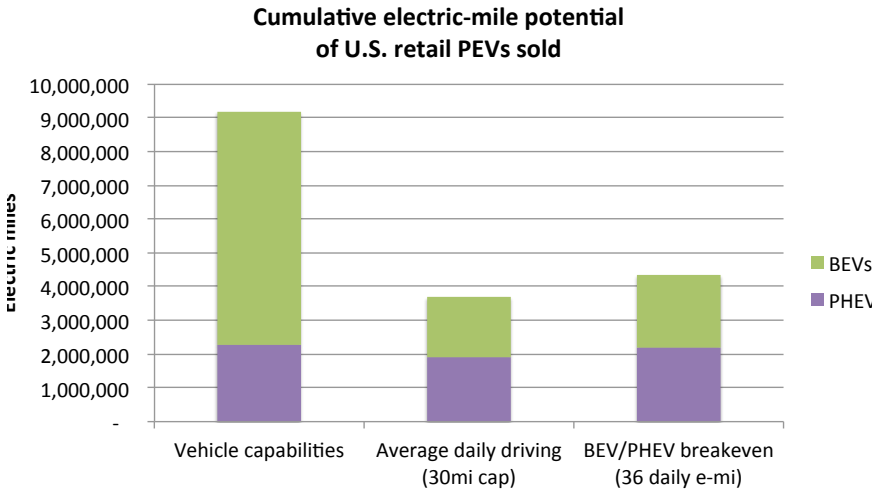
E-mi breakeven: 36 daily miles



(Williams 2013)

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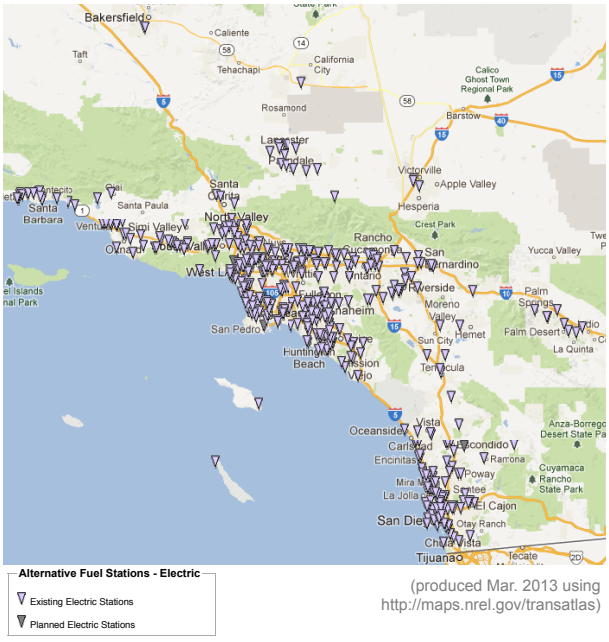
Illustrative e-mile cost effectiveness (assuming $500 per rated kWh across the board)

Model		Battery cost/e-mi range
LEAF MY'11	BEV	$163
Chevy Volt	PHEV	$217
smart fortwo ed MY'11	BEV	$131
i	BEV	$129
Focus Electric	BEV	$151
Active E	BEV	$170
Prius Plug-In	PHEV	$200
Model S 85kWh	BEV	$160
Fit EV	BEV	$122
RAV4EV	BEV	$203
C-Max Energi	PHEV	$181
Model S 60kWh	BEV	$144
Accord Plug-in	PHEV	$258
Fusion Energi	PHEV	$181
LEAF S MY'13	BEV	$158
smart electric drive MY'13	BEV	$129
Chevy Spark	BEV	$128
500 Elettrica	BEV	$138

(Williams 2013)

LA-region charge stations



(produced Mar. 2013 using http://maps.nrel.gov/transatlas)

CA charging and hybrid densities

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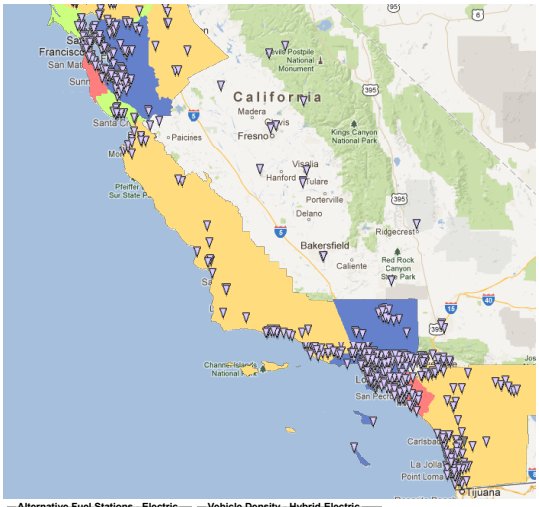

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Market dynamics: future analysis

1) ZEV sales factors

2) CVRP analysis

Examining Factors that Affect ZEV Sales in CA

- Project approved by the California Air Resources Board (ARB), in contracting, hope to start by October
- Will examine monthly ZEV sales throughout California over time by census tract
- Test the effect/importance/relationship between ZEV sales and:
  - Supportive polices (rebates, carpool lane access)
  - Consumer socio-demographics
  - Access to public infrastructure
  - Characteristics of the built environment
  - Fuel prices (gasoline and electricity)
  - PEV model types and their variety
- Produce statistical models useful for predictive analysis of future changes in ZEV markets

Clean Vehicle Rebate Project (CVRP) analysis

- Pre-2010 project experienced 75% of its total applications in last 12 months, facing periodic and worsening funding shortfalls
- UCLA Luskin is writing a proposals to help the ARB and CCSE:
  1. Provide context about the market externalities (both environmental and innovation) the program helps to address
  2. Assess potential project design changes that might improve cost effectiveness of inducing additional PEV sales
  3. Assemble the requirements of a more sustainable, long-term plan

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Regional PEV readiness planning

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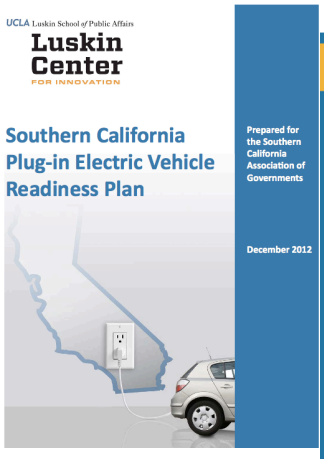
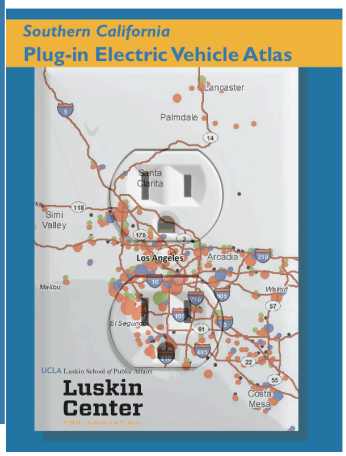
Policies and planning guidance to facilitate charging installation and operation





Prioritize *locations* for charging

Southern California PEV Readiness Plan and Atlas

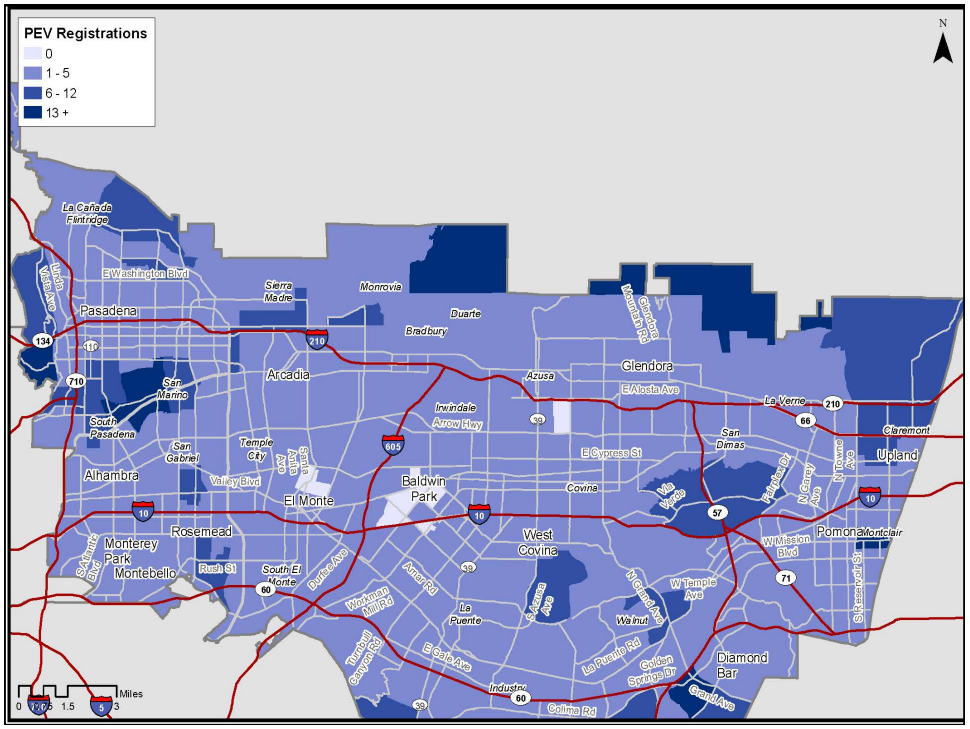
(DeShazo, Ben-Ayuda, et al. 2012)

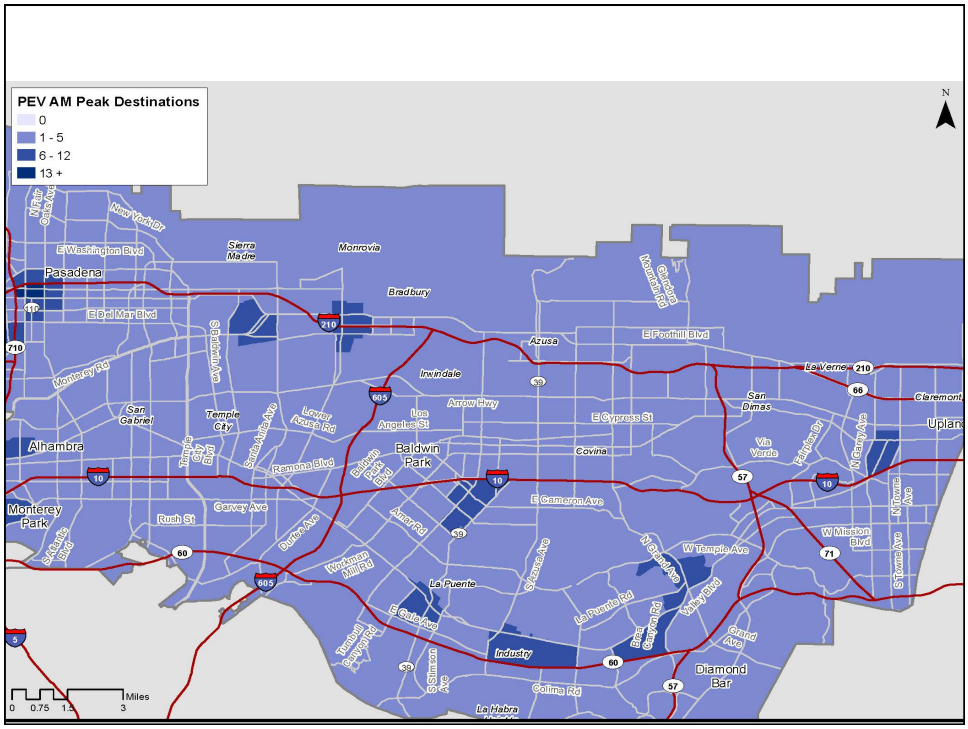
Download at innovation.luskin.ucla.edu/ev

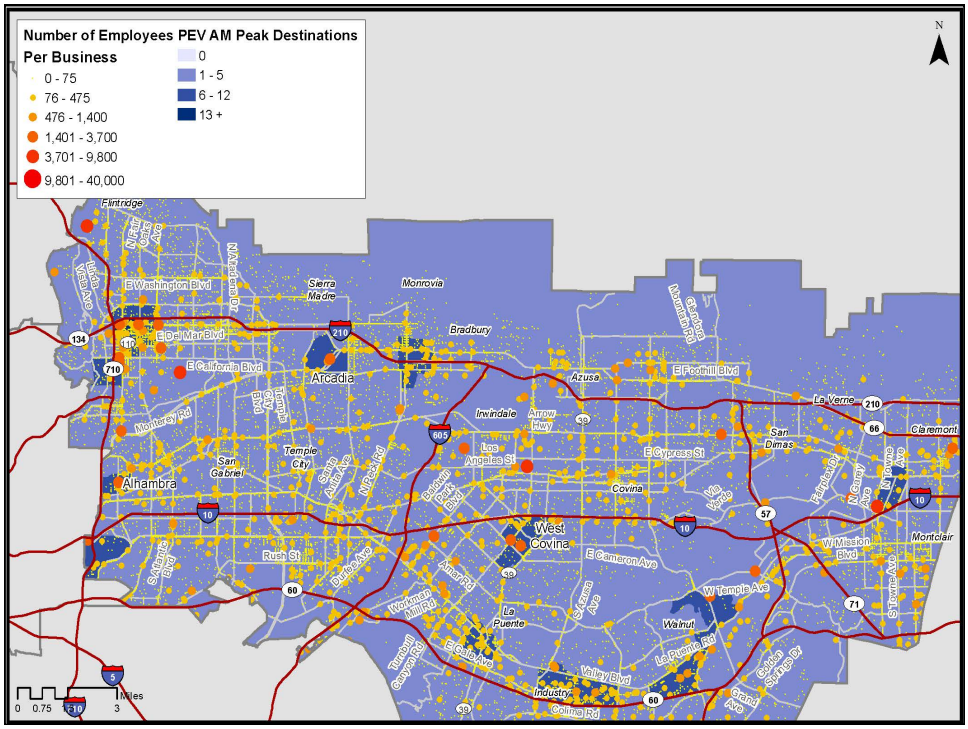
SCAG Planning Region

 bdw@ucla.edu

SCAG is made up of 6 Counties which are divided into 14 subregions.




PEV AM Peak Destinations
0
1 - 5
6 - 12
13 +
N
Pasadena
Sierra Madre
Monrovia
Bradbury
Azusa
Duarte
Irwindale
La Verne
Claremont
San Dimas
Alhambra
San Gabriel
Temple City
Baldwin Park
Covina
Monterey Park
Rush St
Carvey Ave
E Cameron Ave
W Temple Ave
W Mission Blvd
La Puente
Industry
Diamond Bar
Colima Rd
Miles
0 0.75 1.5 3


Number of Employees Per Business
0 - 75
76 - 475
476 - 1,400
1,401 - 3,700
3,701 - 9,800
9,801 - 40,000
PEV AM Peak Destinations
0
1 - 5
6 - 12
13 +
N
Flintridge
Sierra Madre
Monrovia
Bradbury
Arcadia
Azusa
Irwindale
La Verne
Claremont
San Dimas
Alhambra
San Gabriel
Temple City
Covina
West Covina
Monterey Rd
Rush St
E Cameron Ave
W Temple Ave
W Mission Blvd
La Puente
Walnut
Industry
Colima Rd
Miles
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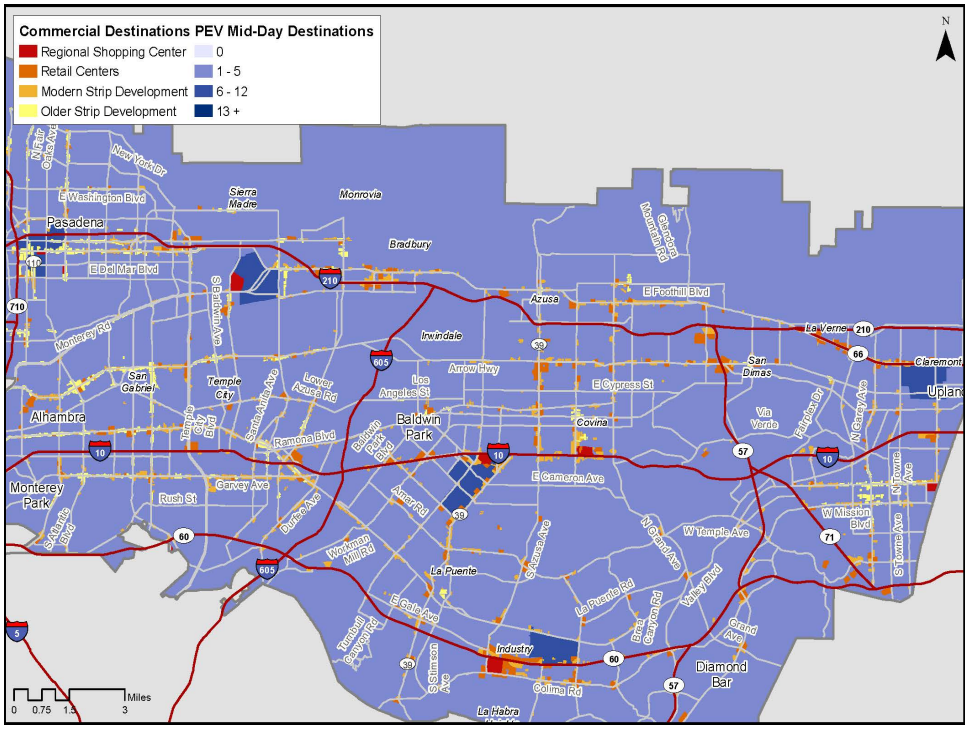
Commercial Destinations
Regional Shopping Center
Retail Centers
Modern Strip Development
Older Strip Development
PEV Mid-Day Destinations
0
1 - 5
6 - 12
13 +
N
Pasadena
Sierra Madre
Monrovia
Bradbury
Azusa
Irwindale
Arrow Hwy
E Foothill Blvd
La Verne
San Dimas
Claremont
E Cypress St
San Gabriel
Temple City
Alhambra
Baldwin Park
Covina
Monterey Park
Rush St
Garvey Ave
E Cameron Ave
W Temple Ave
W Mission Blvd
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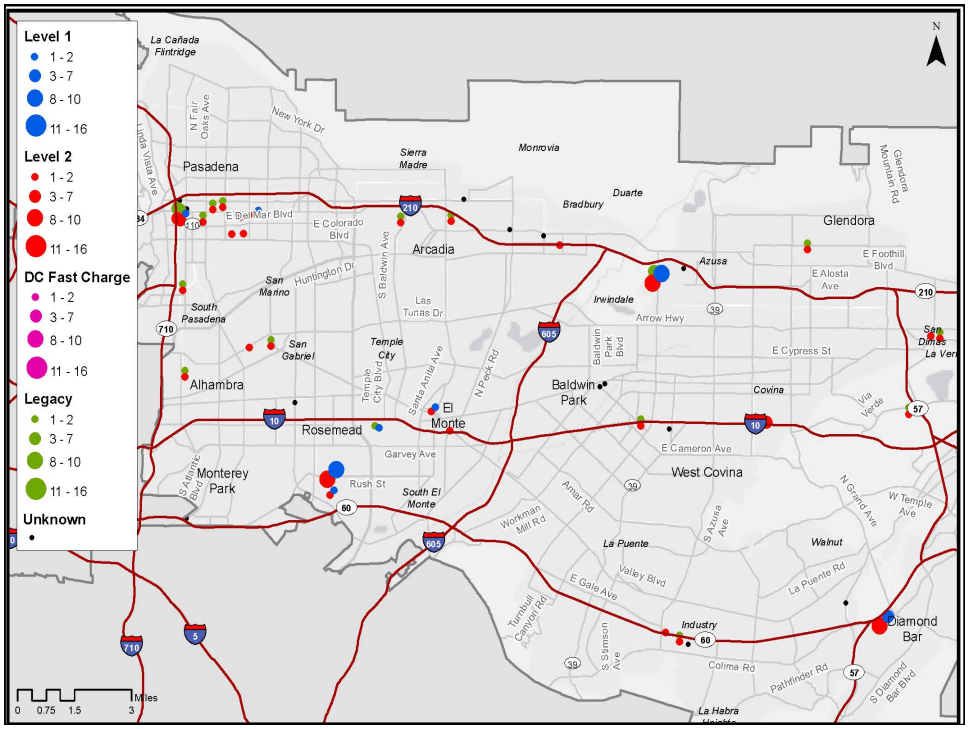
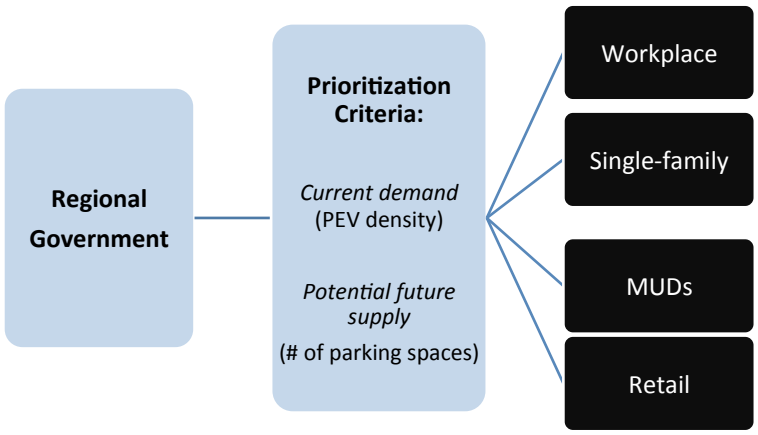
Diamond Bar
Colima Rd
Miles
0 0.75 1.5 3


Level 1
1 - 2
3 - 7
8 - 10
11 - 16
Level 2
1 - 2
3 - 7
8 - 10
11 - 16
DC Fast Charge
1 - 2
3 - 7
8 - 10
11 - 16
Legacy
1 - 2
3 - 7
8 - 10
11 - 16
Unknown
N
Pasadena
Sierra Madre
Monrovia
Duarte
Bradbury
Glendora
Arcadia
Azusa
Irwindale
Alhambra
San Gabriel
Temple City
South Pasadena
San Marino
Baldwin Park
Covina
El Monte
Rosemead
Monterey Park
South El Monte
West Covina
La Puente
Walnut
Industry
Diamond Bar
Miles
0 0.75 1.5 3

Sub-regional PEV Planning Process



Potential Charging Supply: South Bay Cities Example

	Employee Count	Rank	% Employee	Rank	Multi-Family Count	% Multi-Family	Single-Family Count	% Single-Family
Torrance	114,489	1	68%	4	24,343	15%	28,482	17%
Carson	75,483	2	76%	2	5,634	6%	17,928	18%
Inglewood	42,231	3	55%	6	22,626	30%	11,448	15%
Gardena	34,307	4	65%	5	10,011	19%	8,329	16%
El Segundo	30,799	5	82%	1	4,071	11%	2,587	7%
Hawthorne	24,791	6	48%	9	20,260	39%	6,653	13%
Redondo Beach	23,084	7	46%	10	18,888	37%	8,485	17%
Manhattan Beach	16,582	8	53%	7	4,654	15%	9,793	32%
Lawndale	7,599	9	50%	8	5,467	36%	2,112	14%
Hermosa Beach	7,419	10	45%	11	5,700	35%	3,289	20%
Rolling Hills Estates	6,416	11	69%	3	127	1%	2,727	29%
Rancho Palos Verdes	5,942	12	27%	14	3,247	15%	12,573	58%
Lomita	5,341	13	40%	12	4,981	37%	2,966	22%
Palos Verdes Estates	2,052	14	27%	13	349	5%	5,095	68%

Torrance Workplace-Charging Example

PEV Density	
High (H)	3
Moderate (M)	2
Other	0

Own/Lease	
Owned (O)	1
Leased (L)	0
Unknown (U)	0

High Tech	
Yes (Y)	1
No (N)	0

White Collar	
50% of more	1
Less than 50%	0

	Torrance															
	Company	Address	City	ST	ZIP	Type	Employees	PEV	Points	Own/Lease	Point	High Tech	Points	Wht Collar	Points	Total Points
1	Little Company of Mary Hosp	4101 Torrance Blvd	Torrance	CA	90503	Hospitals	3,500	M	2	U	0	N	0	88	1	3
2	Westbay Water Co	1606 Crenshaw Blvd	Torrance	CA	90501	Water Companies-Bottled, Bulk, Etc	2,500	M	2		0	N	0	71	1	3
3	Torrance City Hall	3031 Torrance Blvd	Torrance	CA	90503	City Government-Executive Offices	2,000	M	2	O	1	N	0	0	0	3
4	Alcoa Fastening Systems	3000 Lomita Blvd	Torrance	CA	90505	Fasteners-Industrial (Wholesale)	1,500	M	2	U	0	N	0	73	1	3
5	Motorcar Parts of America Inc	2929 California St	Torrance	CA	90503	Alternators & Generators-Automotive-Mfrs	833	M	2	L	0	N	0	27	0	2
6	Virco Mfg Corp	2027 Harpers Way	Torrance	CA	90501	Furniture-Manufacturers	800	H	3	U	0	N	0	27	0	3
7	Real Estate Group-Escrow	3480 Torrance Blvd	Torrance	CA	90503	Real Estate	650		0		0	N	0	70	1	1
8	L-3 Electron Technologies Inc	3100 Lomita Blvd	Torrance	CA	90505	Aerospace Industries (Mfrs)	600	H	3		0	Y	1	79	1	5
9	Robinson Helicopter Co Inc	2901 Airport Dr	Torrance	CA	90505	Aircraft-Manufacturers	600	H	3	O	1	Y	1	52	1	6
10	Lisi Aerospace Hi-Shear Corp	2600 Skypark Dr	Torrance	CA	90505	Automobile Parts & Supplies-Mfrs	500	H	3	O	1	N	0	26	0	4

Total Points
4
5
6

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Workplace & MUD charging

1) Station profitability
2) Driver cost-of-fueling comparisons

(Williams & DeShazo, forthcoming)

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Station profitability

10-year present value of net revenues (NPV)

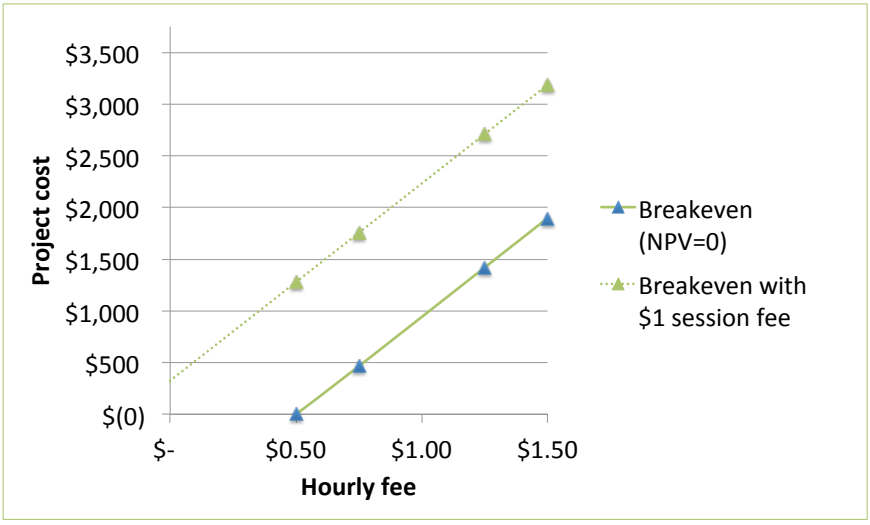
(Williams & DeShazo, forthcoming)

Workplace charging baseline scenarios

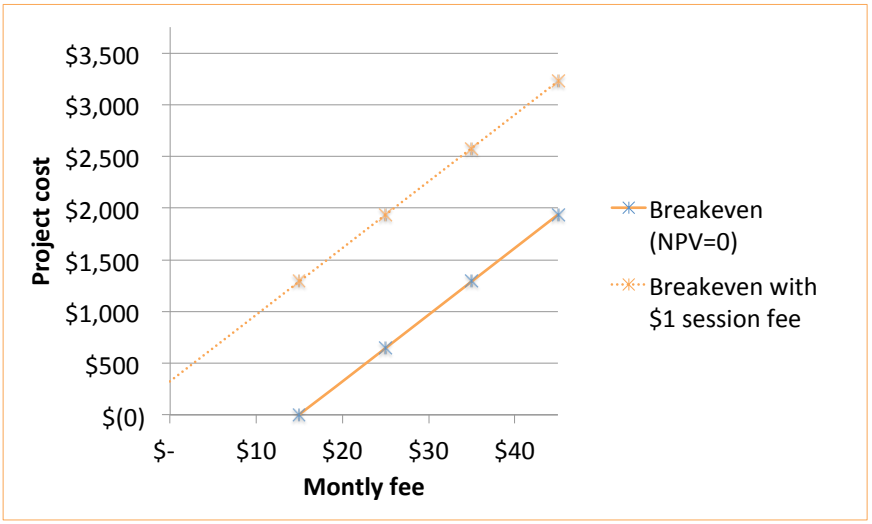
Fee structure:	Per-hour, per-kWh, or per-month	**1-way commute (mi):**	15	**Electricity (/kWh):**	$0.1275
Session fee:	$0	**kWh purchased:**	5.2	**Discount rate:**	5%
Charger (kW):	3.5 (Level 2)	**Utilization (h/d):**	1.5	**Days/year:**	240

Workplace charging breakeven pricing: per-hour

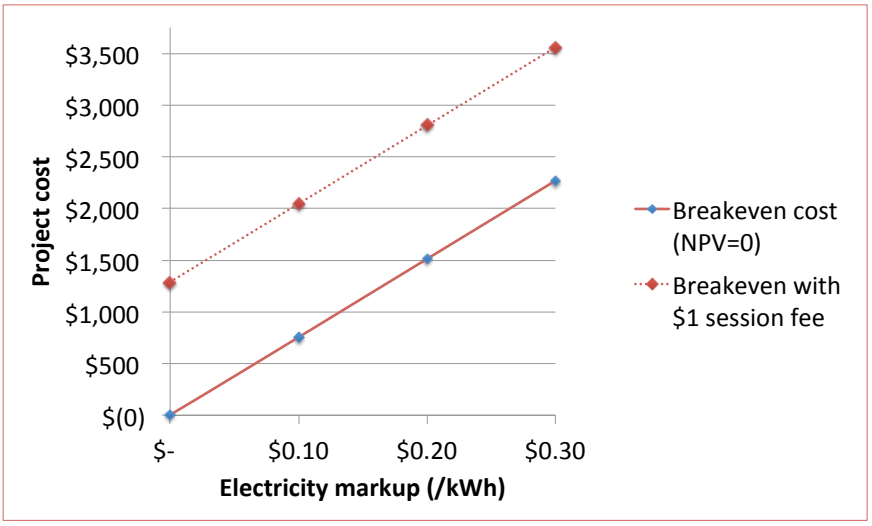
Workplace charging breakeven pricing: per-hour



Workplace charging breakeven pricing: per-month



Workplace charging breakeven pricing: per-kWh



Workplace charging profitability: per-kWh price

Fee structure	per-kWh	**1-way commute (mi)**	15	**Electricity (/kWh)**	$0.1275
Session fee	$0.00	**kWh purchased**	5.2	**Discount rate**	5%
Charger (kW)	3.5 (Level 2)	**Utilization (h/d)**	1.5	**Days/year**	240

a)

Project Cost \ Electricity markup	$-	$0.10	$0.20	$0.30
$-	$-	$1,087	$2,174	$3,261
$1,000	$(1,437)	$(350)	$737	$1,824
$2,000	$(2,875)	$(1,788)	$(701)	$386
$3,000	$(4,312)	$(3,225)	$(2,138)	$(1,051)
$4,000	$(5,750)	$(4,662)	$(3,575)	$(2,488)
$5,000	$(7,187)	$(6,100)	$(5,013)	$(3,926)
$6,000	$(8,624)	$(7,537)	$(6,450)	$(5,363)
$7,000	$(10,062)	$(8,975)	$(7,887)	$(6,800)
$8,000	$(11,499)	$(10,412)	$(9,325)	$(8,238)

MUD charging profitability: per-kWh price

Fee structure	per-kWh	**Daily driving (mi)**	30	**Electricity (/kWh)**	$0.1640
Session fee	$0.00	**kWh purchased**	10.2	**Discount rate**	5%
Charger (kW)	3.5 (Level 2)	**Utilization (h/d)**	2.9	**Days/year**	350

Project Cost \ Electricity markup	$-	$0.10	$0.20	$0.30
$-	$(0)	$2,763	$5,526	$8,289
$1,000	$(1,437)	$1,326	$4,089	$6,852
$2,000	$(2,875)	$(112)	$2,652	$5,415
$3,000	$(4,312)	$(1,549)	$1,214	$3,977
$4,000	$(5,750)	$(2,986)	$(223)	$2,540
$5,000	$(7,187)	$(4,424)	$(1,661)	$1,103
$6,000	$(8,624)	$(5,861)	$(3,098)	$(335)
$7,000	$(10,062)	$(7,299)	$(4,535)	$(1,772)
$8,000	$(11,499)	$(8,736)	$(5,973)	$(3,210)

Recharging station profitability (workplace charging case)

Pricing structure

a) Fee structure: per-kWh; Session fee: $0.00

Electricity markup

Project Cost	$ -	$ 0.10	$ 0.20	$ 0.30
$ -	$ -	$ 1,087	$ 2,174	$ 3,261
$ 1,000	$ (1,437)	$ (350)	$ 737	$ 1,824
$ 2,000	$ (2,875)	$ (1,788)	$ (701)	$ 386
$ 3,000	$ (4,312)	$ (3,225)	$ (2,138	$ (1,051)
$ 4,000	$ (5,750)	$ (4,662)	$ (3,575	$ (2,488)
$ 5,000	$ (7,187)	$ (6,100)	$ (5,013	$ (3,926)
$ 6,000	$ (8,624)	$ (7,537)	$ (6,450	$ (5,363)
$ 7,000	$ (10,062)	$ (8,975)	$ (7,887	$ (6,800)
$ 8,000	$ (11,499)	$ (10,412)	$ (9,325	$ (8,238)

c) Fee structure: per-hour; Session fee: $0.00

Hourly fee

Project cost	$ 0.50	$ 0.75	$ 1.25	$ 1.50
$ -	$ (15)	$ 670	$ 2,041	$ 2,727
$ 1,000	$ (1,453)	$ (767)	$ 604	$ 1,289
$ 2,000	$ (2,890)	$ (2,205)	$ (834)	$ (148)
$ 3,000	$ (4,327)	$ (3,642)	$ (2,271)	$ (1,586)
$ 4,000	$ (5,765)	$ (5,079)	$ (3,708)	$ (3,023)
$ 5,000	$ (7,202)	$ (6,517)	$ (5,146)	$ (4,460)
$ 6,000	$ (8,639)	$ (7,954)	$ (6,583)	$ (5,898)
$ 7,000	$ (10,077)	$ (9,391)	$ (8,021)	$ (7,335)
$ 8,000	$ (11,514)	$ (10,829)	$ (9,458)	$ (8,773)

e) Fee structure: per-month; Electricity fee: $0.00

Monthly fee

Project cost	$ 15	$ 25	$ 35	$ 45
$ -	$ 4	$ 930	$ 1,857	$ 2,784
$ 1,000	$ (1,433)	$ (507)	$ 420	$ 1,346
$ 2,000	$ (2,871)	$ (1,944)	$ (1,018)	$ (91)
$ 3,000	$ (4,308)	$ (3,382)	$ (2,455)	$ (1,528)
$ 4,000	$ (5,746)	$ (4,819)	$ (3,892)	$ (2,966)
$ 5,000	$ (7,183)	$ (6,256)	$ (5,330)	$ (4,403)
$ 6,000	$ (8,620)	$ (7,694)	$ (6,767)	$ (5,841)
$ 7,000	$ (10,058)	$ (9,131)	$ (8,205)	$ (7,278)
$ 8,000	$ (11,495)	$ (10,569)	$ (9,642)	$ (8,715)

Utilization

a) $0.30/kWh markup

Utilization per day

Project cost	1 PEV 15 e-mi 5.2 kWh	2 PEVs 30 e-mi 10.4 kWh	3 PEVs 45 e-mi 15.5 kWh	4 PEVs 60 e-mi 20.7 kWh
$ -	$ 3,261	$ 6,522	$ 9,784	$ 13,045
$ 1,000	$ 1,824	$ 5,085	$ 8,346	$ 11,608
$ 2,000	$ 386	$ 3,648	$ 6,909	$ 10,170
$ 3,000	$ (1,051)	$ 2,210	$ 5,472	$ 8,733
$ 4,000	$ (2,488)	$ 773	$ 4,034	$ 7,295
$ 5,000	$ (3,926)	$ (664)	$ 2,597	$ 5,858
$ 6,000	$ (5,363)	$ (2,102)	$ 1,159	$ 4,421
$ 7,000	$ (6,800)	$ (3,539)	$ (278)	$ 2,983
$ 8,000	$ (8,238)	$ (4,977)	$ (1,715)	$ 1,546
$ 9,000	$ (9,675)	$ (6,414)	$ (3,153)	$ 109
$ 10,000	$ (11,113)	$ (7,851)	$ (4,590)	$ (1,329)

(Williams & DeShazo)

Monte Carlo uncertainty analysis: Inputs

Input parameter	*Min.*	***Best guess***	*Max.*
One-way commute distance (mi)	10	**15**	20
Maintenance costs (% of all-in costs)	1%	**5%**	10%
Discount rate	3%	**5%**	10%
PEV electric fuel economy (kWh/100mi)	30.1	**34.5**	38
Escalation of markup	1%	**3%**	5%
Commute days per year	235	**240**	260
Maintenance cost escalation	**1%**	**uniform (3%)**	**5%**
Charging power (kW)	1.4	**3.5**	7.2
Electricity cost (/kWh)	$0.0901	**$0.1275**	$0.30
Electricity cost escalation	1%	**3%**	12%

Workplace-charging case

Monte Carlo uncertainty analysis: Importance

	+$0.30/kWh	$1.50/hour	$45/month
Point estimate	$386	($148)	($91)
Monte Carlo mean	$264	($1,387)	($910)
95% confidence interval	($829) to $1,460	($3,426) to $2,517	($2,535) to $300
Input parameter	***Uncertainty Contribution[a]***		
One-way commute distance (mi)	54%	2%	-14%
Maintenance costs (% of all-in costs)	-27%	-6%	-19%
Discount rate	-8%		-1%
PEV electric fuel economy (kWh/100mi)	6%	0.2%	2%
Escalation of markup	3%		
Commute days per year	1%	0.1%	-0.3%
Maintenance cost escalation	-1%	-0.2%	-0.3%
Charging power (kW)		-73%	
Electricity cost (/kWh)		-16%	-56%
Electricity cost escalation		2%	-7%

[a] Described in the text, this is a metric based on normalized rank correlation coefficients

Workplace-charging case

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Cost of fueling

(Williams & DeShazo, forthcoming)

PEV cost of refueling (workplace charging case)

Table 3-7: Illustrative fueling cost benchmarks: Per-hour workplace charging

Pricing Level	$ per electric mile	Electricity equivalent	Gasoline equivalent (CV)	Gasoline equivalent (PHEV)
H1. $0.50/hour actively charging	$0.05/e-mi	$0.14/kWh	$1.34/gal	$2.02/gal
H2. $0.75/hour actively charging	$0.07/e-mi	$0.21/kWh	$2.01/gal	$3.03/gal
H3. $1.25/hour actively charging	$0.12/e-mi	$0.36/kWh	$3.35/gal	$5.05/gal

(Williams & DeShazo)

TABLE 3-4 Alternative Fueling Cost Benchmarks: Workplace Charging Baseline and Gasoline

Pricing Level	$ per electric mile	Electricity equivalent	Gasoline equiv. (CV)	Gasoline equivalent (PHEV or hybrid)
1. breakeven prices			*"A Steal"*	*"Incentivizing"*
Electricity cost=$0.1275/kWh (in year 1)	$0.04/e-mi	*$0.13/kWh*	$1.20/gal	$1.80
$0.50/hour actively charging	$0.05/e-mi	$0.14/kWh	$1.34/gal	$2.02
$15/month	$0.05/e-mi	$0.14/kWh	$1.36/gal	$2.05
2. low prices			*"Incentivizing"*	*"Cheap"*
$0.75/hour actively charging	$0.07/e-mi	$0.21/kWh	$2.01/gal	$3.03
Electricity cost + $0.10/kWh	$0.08/e-mi	*$0.23/kWh*	$2.14/gal	$3.22
$25/month	$0.08/e-mi	$0.24/kWh	$2.27/gal	$3.42
3. medium prices			*"Cheap"*	*"Uncompetitive"*
Electricity cost + $0.20/kWh	$0.11/e-mi	*$0.33/kWh*	$3.08/gal	$4.64
$35/month	$0.12/e-mi	$0.34/kWh	$3.17/gal	$4.78
$1.25/hour actively charging	$0.12/e-mi	$0.36/kWh	$3.35/gal	$5.05
Low gasoline price	$0.13/e-mi	$0.37/kWh	*$3.50/gal*	
Gasoline price (~CA 2012 average)	$0.15/e-mi	$0.43/kWh	*$4.00/gal*[a]	
4. high prices			*"Equivalent"*	*"Forget about it"*
Electricity cost + $0.30/kWh	$0.15/e-mi	*$0.43/kWh*	$4.01/gal	$6.05
$1.50/hour actively charging	$0.15/e-mi	$0.43/kWh	$4.02/gal	$6.07
$45/month	$0.15/e-mi	$0.43/kWh	$4.08/gal	$6.13
High gasoline price	$0.16/e-mi	$0.48/kWh	*$4.50/gal*	

[a] http://articles.latimes.com/2013/jan/01/business/la-fi-gas-prices-20130101
CV=conventional vehicle, PHEV=plug-in-hybrid electric vehicle

(Williams & DeShazo, forthcoming)

Driver refueling cost benchmarks: MUD

Pricing Level[a]	$ per electric mile	Electricity equivalent	Gasoline equiv., CV[b]	Gasoline equiv., (plug-in) hybrid[c]
1. Breakeven prices			*"A Steal"*	*"Incentivizing"*
Electricity cost ($0.164/kWh, yr 1)	$0.06	$0.16/kWh	$1.52/gal	$2.30/gal
$55/month	$0.06	$0.18/kWh	$1.71/gal	$2.58/gal
$0.65/hour charging	$0.06	$0.19/kWh	$1.72/gal	$2.60/gal
2. Low prices			*"Incentivizing"*	*"Cheap"*
Electricity cost + $0.10/kWh	$0.09	*$0.26/kWh*	$2.45/gal	$3.70/gal
$85/month	$0.10	$0.29/kWh	$2.64/gal	$3.99/gal
$1.00/hour charging	$0.10	$0.29/kWh	$2.65/gal	$4.00/gal
3. Medium prices			*"Cheap"*	*"Uncompetitive"*
Electricity cost + $0.20/kWh	$0.12	*$0.36/kWh*	$3.37/gal	$5.10
$115/month	$0.13	$0.39/kWh	$3.57/gal	$5.40/gal
$1.35/hour charging	$0.13	$0.39/kWh	$3.58/gal	$5.41/gal
Gasoline price (~CA 2012 average)	$0.15	$0.43/kWh	*$4.00/gal*[d]	
4. High prices			*"Equivalent"*	*"Forget it"*
Electricity cost + $0.30/kWh	$0.16	*$0.46/kWh*	$4.30/gal	$6.50
$1.70/hour charging	$0.17	$0.49/kWh	$4.50/gal	$6.81/gal
$145/month	$0.17	$0.49/kWh	$4.51/gal	$6.81/gal

[a] Each pricing level (1–4) provides the same amount of cost-recovery potential (Table 3-1)

[b] CV=conventional vehicle = 27.2 mpg [10]

[c] (plug-in) hybrid = 41.1 mpg [9]

[d] http://articles.latimes.com/2013/jan/01/business/la-fi-gas-prices-20130101

Conclusions: workplace & MUD charging

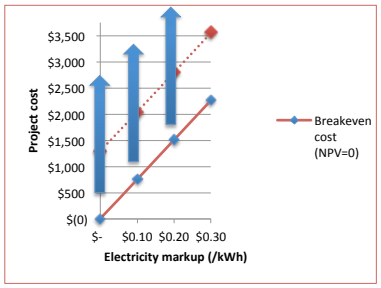
- Pricing levels likely motivating to employee drivers might provide limited opportunity for employer station cost recovery
  - E.g., $0.33/kWh (incl. markup) may be uncompetitive to hybrid drivers but only covers ~$1,500 in all-in facility investment costs per PEV served
    - Similarly, employee-drivers may balk at prices at or exceeding $1.25/hour or $35/month
- The differential, "discriminatory" impact of different pricing structures may be important.
- Constraints may limit ability to Increase facility utilization—key to cost recovery
  - "Multiplexed," perhaps lower-power facilities might help
- Monte Carlo simulation highlights key uncertainties of both station profitability and refueling costs
  - E.g., maintenance costs need to be better understood
  - Employers' choice of pricing structure will differentially affect their ability to remain financially viable in the face of input-assumption uncertainty

Back to the Future: Smart Charging Grid-Support Value?

- Given the limited cost-recovery potential of workplace charging, some employers may want additional value
- How might secondary use of charging facilities help?
  - Control (and aggregation) of recharging timing and rate (i.e., smart charging) to provide grid-support services

Application	PHV	Volt	LEAF
Electric Energy Time-shift	$330	$880	$1,720
Electric Supply Capacity	$320	$850	$1,670
Load Following	$800	$2,130	$4,180
Area Regulation	$8,720	$23,250	$45,610
Electric Supply Reserve Capacity	$280	$750	$1,470
Voltage Support	$2,870	$7,670	$15,040
Transmission Support	$1,200	$3,190	$6,270
Transmission Congestion Relief	$60	$150	$300
T&D Upgrade Deferral 50th percentile†	$2,390	$6,470	$12,490
T&D Upgrade Deferral 90th percentile†	$3,760	$10,020	$19,660
Substation On-site Power	$600	$1,600	$3,130
Time-of-use Energy Cost Management	$730	$1,960	$3,840
Demand Charge Management	$220	$580	$1,140
Electric Service Reliability	$3,700	$9,860	$19,340
Electric Service Power Quality	$4,170	$11,120	$21,820
Renewables Energy Time-shift	$230	$620	$1,220
Renewables Capacity Firming	$810	$2,160	$4,240
Wind Generation Grid Integration, Short Duration	$4,680	$12,480	$24,480
Wind Generation Grid Integration, Long Duration	$380	$1,000	$1,970

† converted here to approximate 10 years of benefit to be comparable to other applications, but this is not likely at a single location



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…to be continued?

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Thank you for your attention!

Thanks also to:
Prof. JR DeShazo, Luskin Center Director
Ayala Ben-Yehuda, PEV Readiness Planning Project Manager

Additional slides, references follow…

Notes about the PEV sales slides

- EV = electric-drive vehicle = HEVs + PEVs + FCEVs
  - HEVs = hybrid EVs (aka "hybrids")
  - FCEVs = fuel-cell EVs
  - PEVs = plug-in electric vehicles (aka "plug-ins") = BEVs + PHEVs
    - BEVs = all-battery EVs (aka "all-electric")
    - PHEVs = plug-in hybrid EVs (aka "plug-in hybrids")
- Figure legend order reflects sequence of vehicle introduction.
- No single source used contained a complete and/or accurate list of sales data, so multiple sources were compiled by the National Renewable Energy Laboratory (gasoline-only hybrid data) and UCLA Luskin Center (PEV data, most of which were compiled from monthly reports at hybridcars.com).
- Data for the Tesla Roadster, Cooper MINI-E, Th!nk City, Azure Transit Connect Electric, Fisker Karma, and Coda Sedan are not included.
- Tesla Model S sales are estimates and increasingly overestimate U.S. sales as the vehicle is marketed globally. Further, for simplification, it is assumed that all 2012 sales are the 85kWh model and 2013 sales are the 60kWh model.

Notes about the CA PEV sales slides

- EV = electric-drive vehicle = HEVs + PEVs + FCEVs
  - HEVs = gasoline-only hybrid EVs (aka "hybrids")
  - FCEVs = fuel-cell EVs
  - PEVs = plug-in electric vehicles (aka "plug-ins") = BEVs + PHEVs
    - BEVs = all-battery EVs (aka "all-electric")
    - PHEVs = plug-in hybrid EVs (aka "plug-in hybrids")
- CA = California
- Data presented for 11 models described herein only. Also excludes low-speed/neighborhood-electric and medium-/heavy-duty vehicles
- Figure legend order reflects sequence of vehicle introduction.
- Calculations based on PEV vehicle registration data from R&L Polk & Co.

Some terms (others defined within)

AB	assembly bill
AQMD	air quality management district
CA	California
CARB	California Air Resources Board
CEC	California Energy Commission
CO_2e	carbon-dioxide-equivalent (greenhouse-gas emissions)
EPA	Environmental Protection Agency
EV	electric-drive vehicle (hybrid, plug-in-hybrid, all-battery and fuel-cell EVs)
GHG	greenhouse gas
NHTSA	National Highway Traffic Safety Administration
ZEV	zero-tailpipe-emission vehicle (plug-in and fuel-cell EVs)

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