Electrification of Transportation from the Electricity Supply's Perspective

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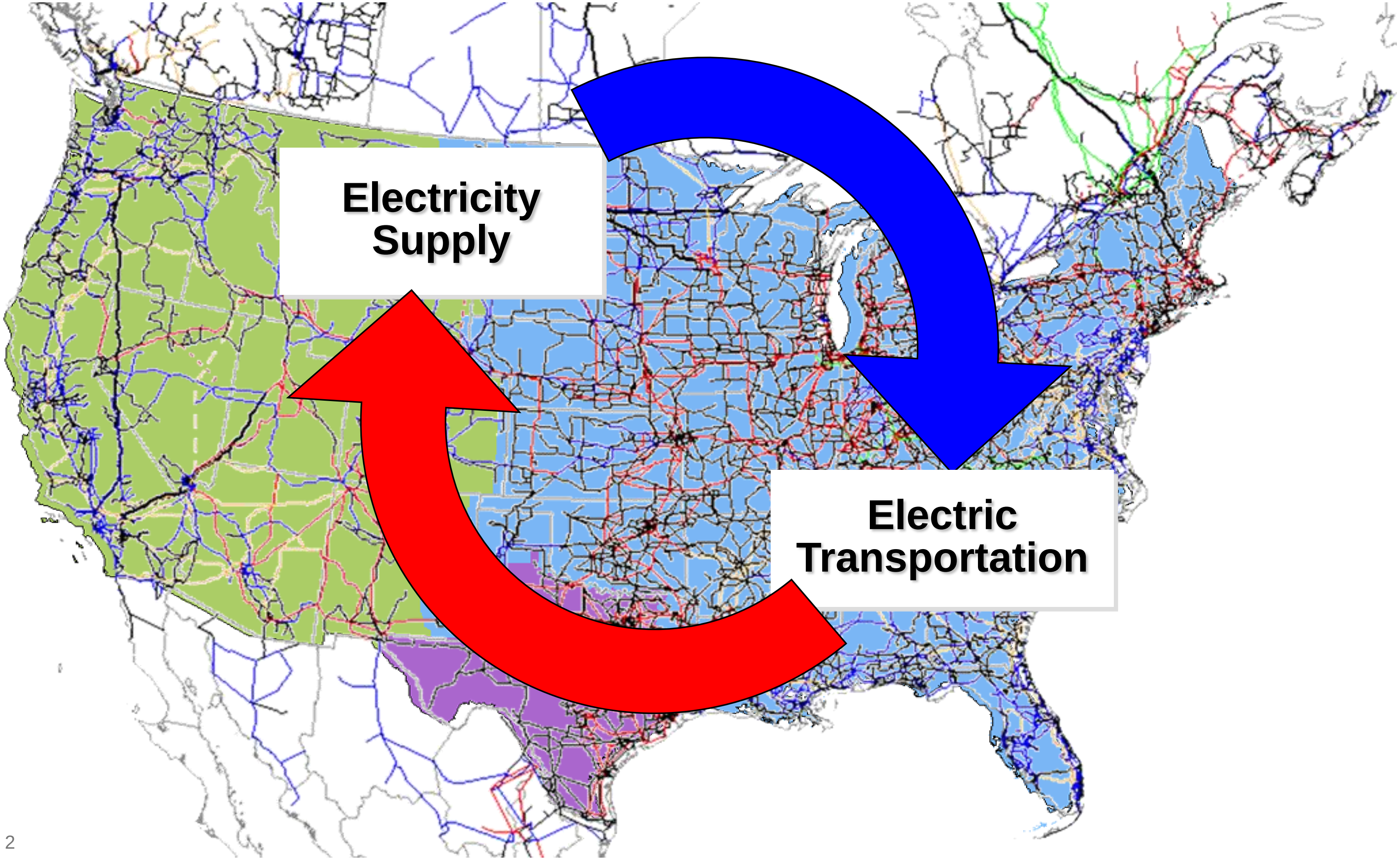
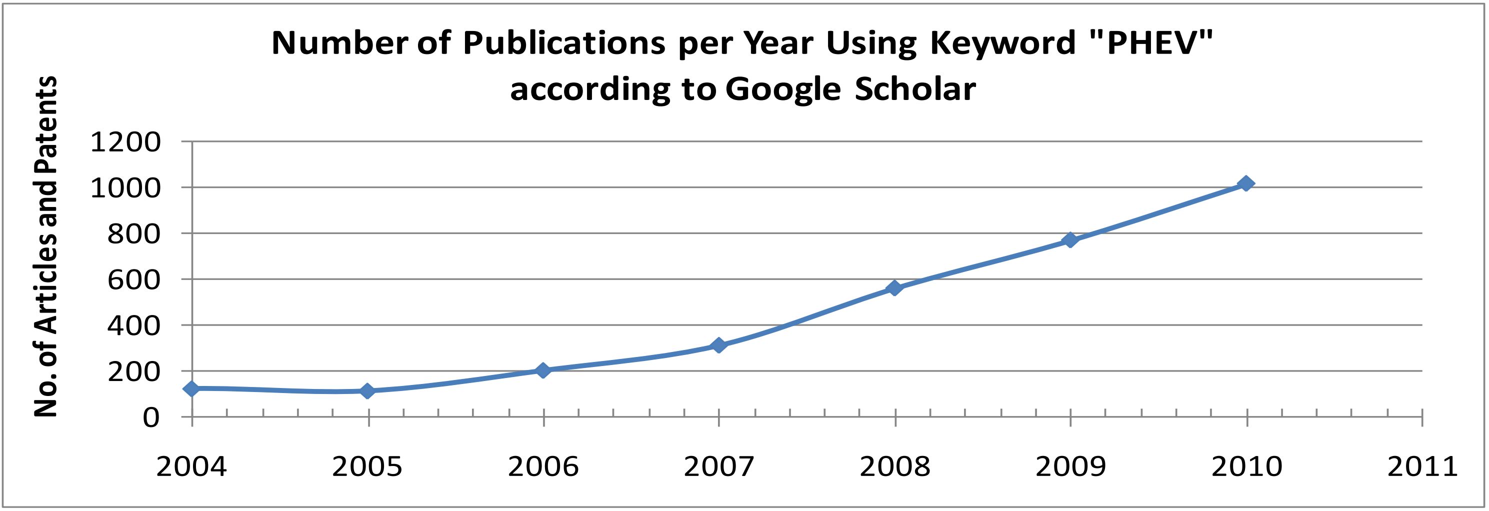
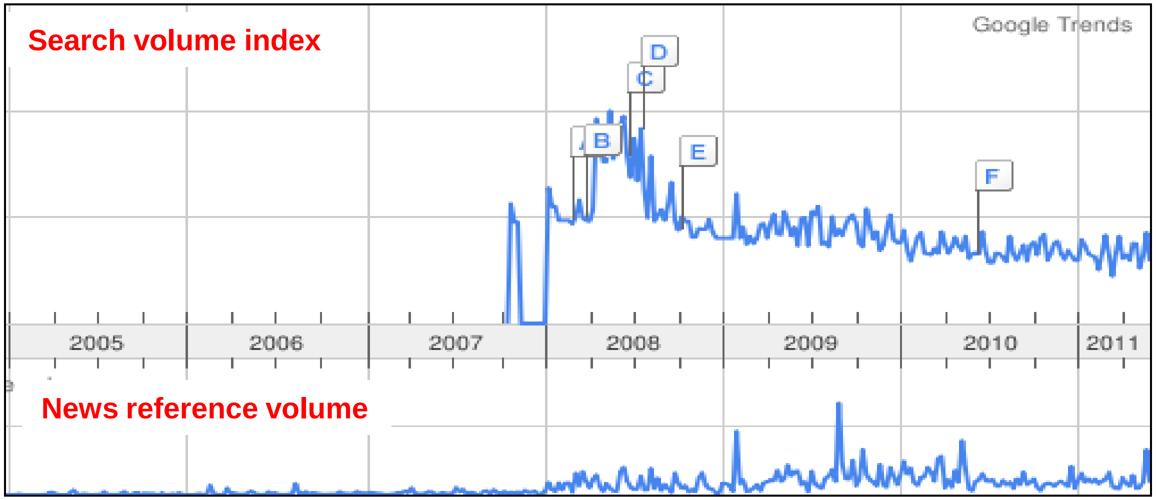
What are the Synergies Between Electric Transportation and the Electric Infrastructure?



Significant Uptake on Research and General Public Interest on PHEVs Starting in 2006



Scholarly Articles and Patents acc. Google Scholar in English



Public Interests according to Google Searches

Source: Google Searches keyword "PHEV" in June 5th, 2011

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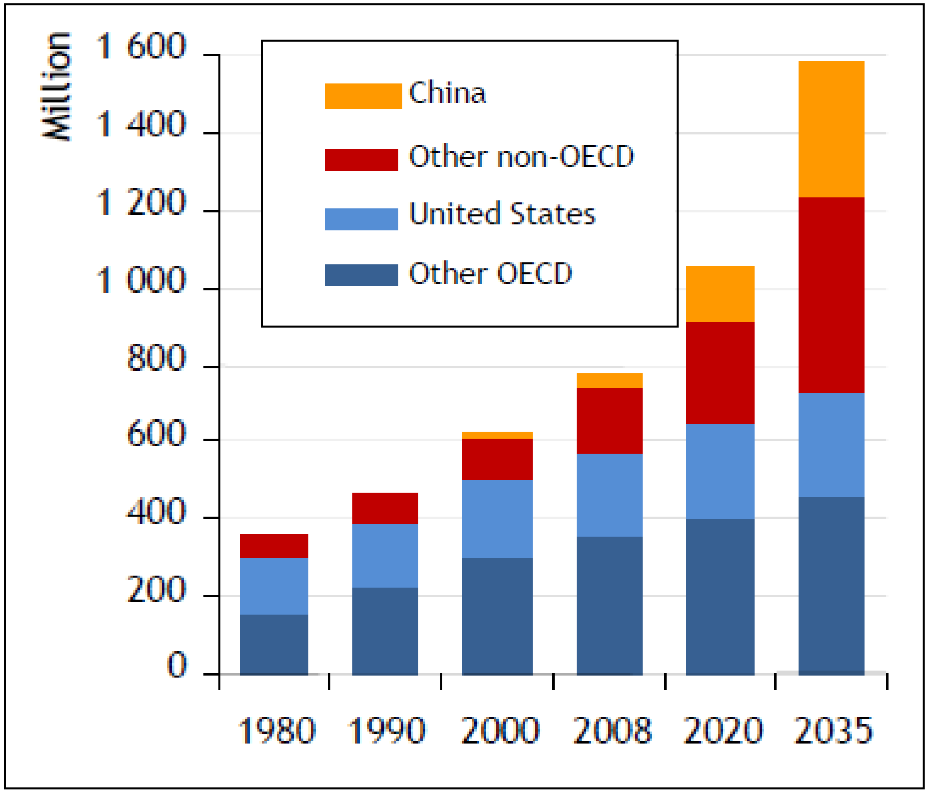
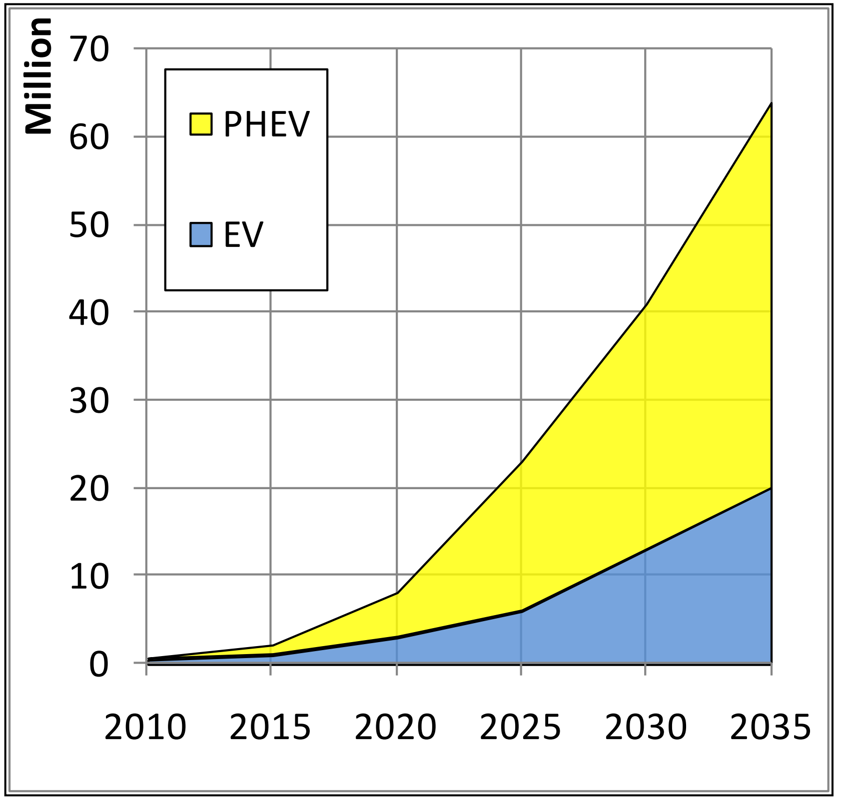
Continued Surge of Global Car Fleet –
as China and Emerging Economies Buy Cars

Projections of Global Passenger Car Fleet[1]



Projections of Global Annual Sales[2]



PHEVs and EVs may reach 39% of new sales in 2035

[1]Source: World Energy Outlook 2010, New Policy Case, IEA, Nov. 9, 2010

[2]Source: World Energy Outlook 2010, 450 Scenario, IEA, Nov. 9, 2010

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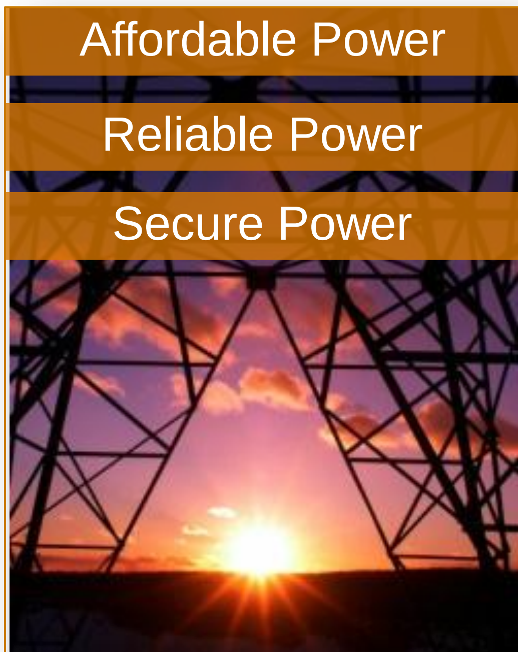
The Challenge Ahead is Complex
The grid must meet new expectations

The energy industry is highly regulated, capital intensive, risk averse, innovation poor and highly fragmented

Historical Expectations



Emerging Expectations

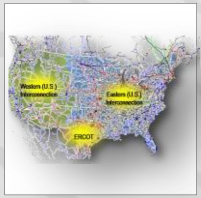
Delivering 300 GW of renewable generation by 2025

Maximize benefits of end-use efficiency and storage

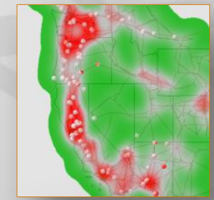
Electrify transportation sector to reduce dependence on imported oil

Meet future carbon and emissions constraints

Key Elements for Transforming the U.S. Energy System



System Transparency – *Seeing and operating the grid as a national system in real-time*



Analytic Innovations - *Leveraging High-Performance Computing and new algorithms to provide real-time situational awareness and models for prediction and response*

EV

Demand Response – *Making demand an active tool in managing grid efficiency and reliability.*

EV

Renewable Integration – *Addressing variability and intermittence of large-scale wind generation and the complexities of distributed generation and net metering*

EV

Energy Storage – *Defining the location, technical performance, and required cost of storage; synthesizing nanofunctional materials and system fabrication to meet requirements*

EV

Cyber Security and Interoperability – *Defining standards for secure, two-way communication and data exchange*

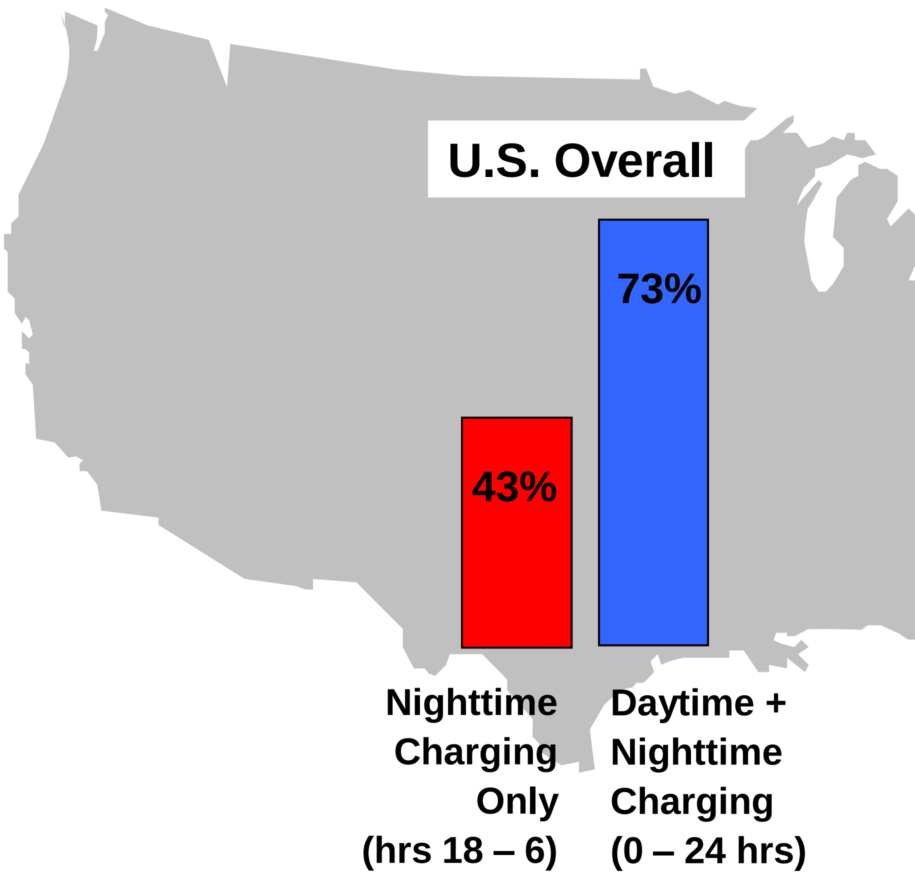
Technical Potential Analysis of Today's Grid

Can the US electric grid become a strategic national asset for addressing our dependence on foreign oil?

- How much energy could the idle capacity of the grid deliver for the U.S. light- duty vehicle fleet (cars, pickups, SUVs, vans)?
  - assume grid looks much like today's (worst case; likely to be cleaner)
  - assume vehicle mix is unchanged (worst case; likely to be lighter)
  - i.e., don't allow outcome to be driven by assumptions about the future power plant mix or vehicle fleet
- What would be some of the impacts be on
  - gasoline/crude oil displacement
  - emissions
  - utility revenue requirements

** funded by Office of Electricity Delivery and Energy Assurance*

Over 70% of the existing U.S. light-duty vehicle fleet (if PHEVs) could be fueled with available off-peak electric capacity



Assumptions

- PHEV specific energy requirements (EPRI 2004):
  - Compact 0.26 kWh/mi
  - Mid-size 0.30 kWh/mi
  - Mid-size SUV/Vans 0.38 kWh/mi
  - Full-size SUV 0.46 kWh/mi
- 87% charger efficiency
- 85% battery efficiency
- 8% T&D loss

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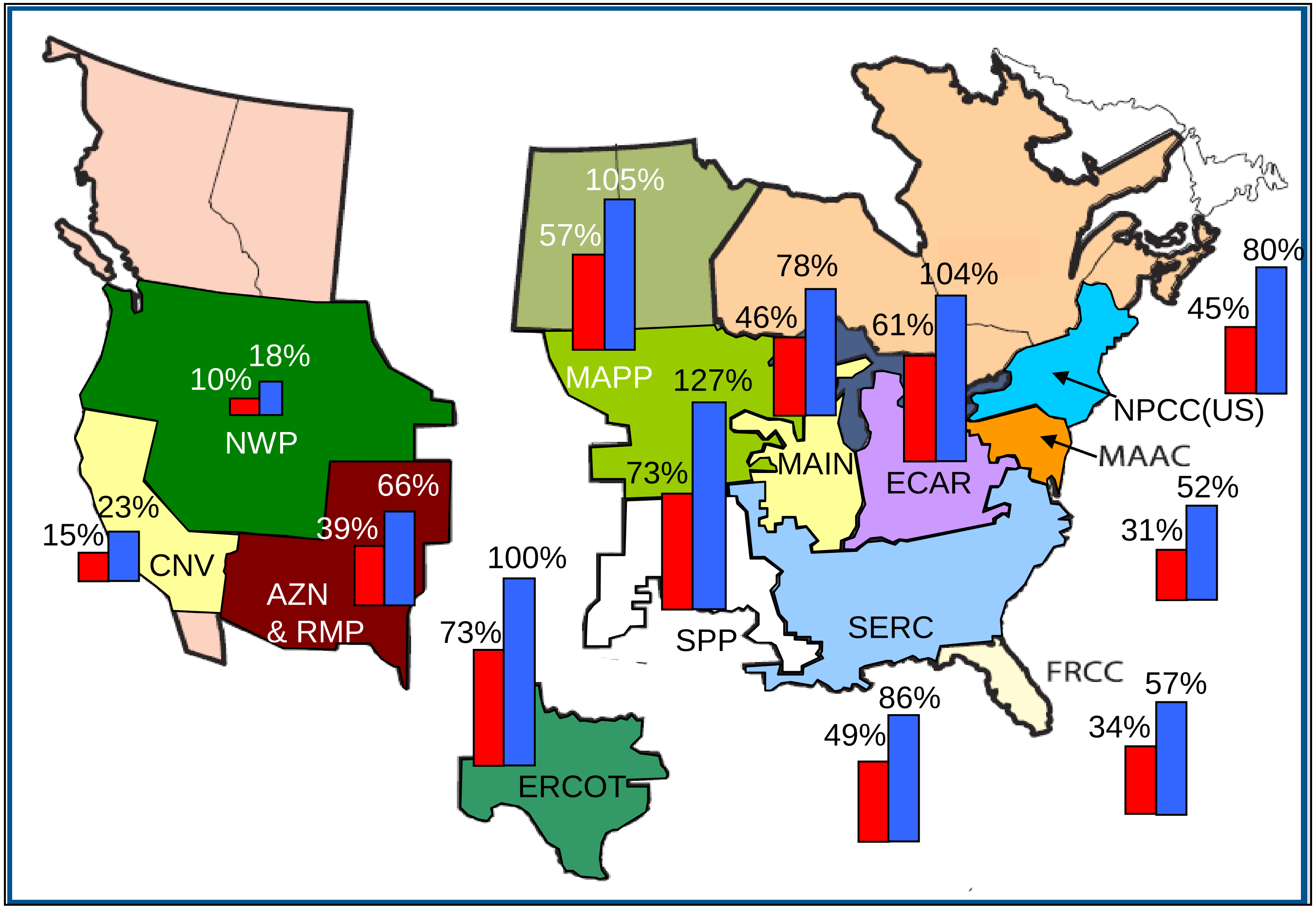
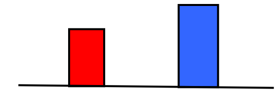
Analysis by North American Electric Reliability Corporation (NERC) Region





Summary

- Midwest: support almost the entire LDV fleet
- East: somewhat smaller potential
- West: supports fewer vehicles

% figures denote the percentage of LDV fleet supported by idle electric capacity

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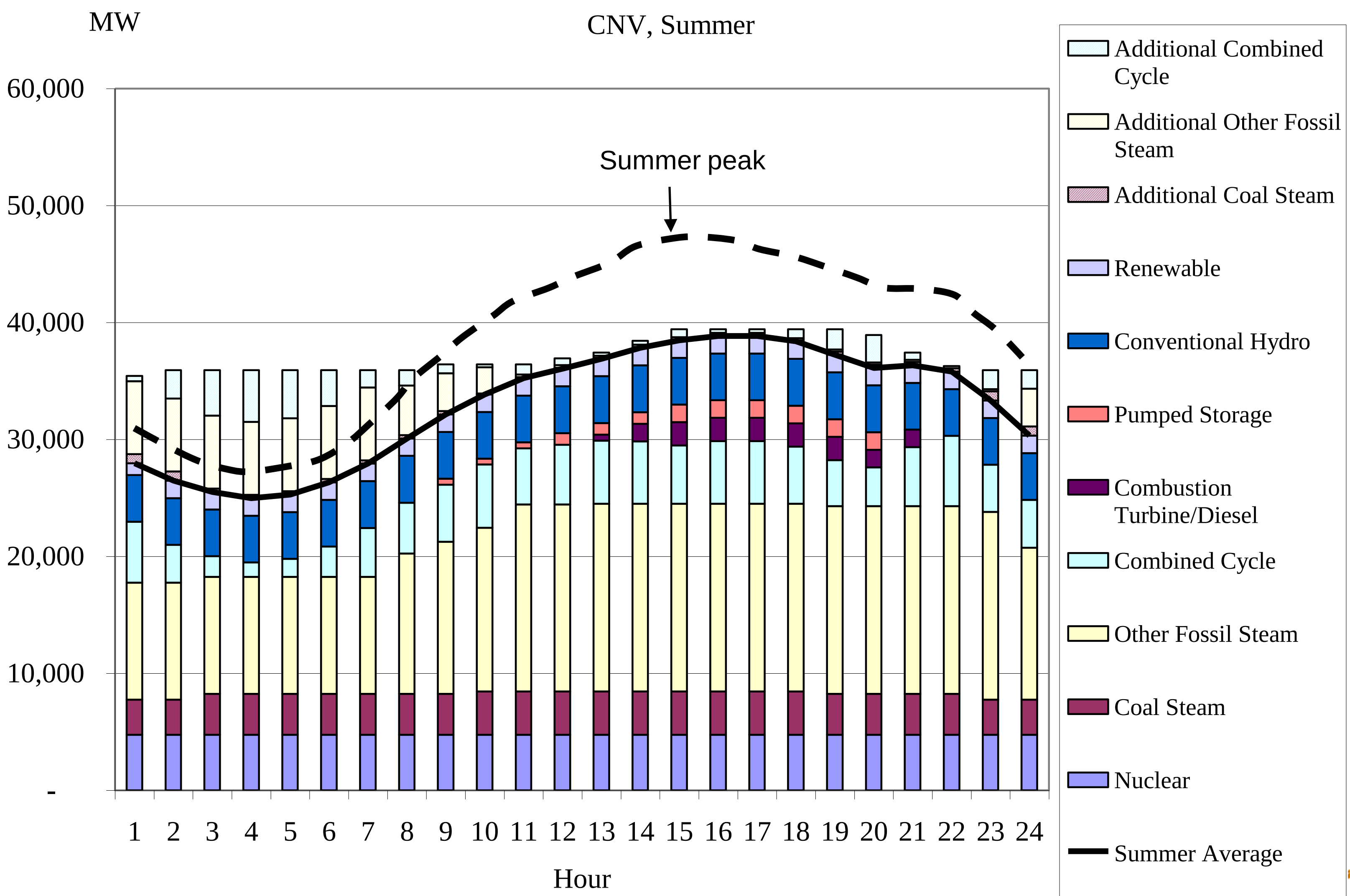
Current Generation and "Valley-Filling" CNV, Summer



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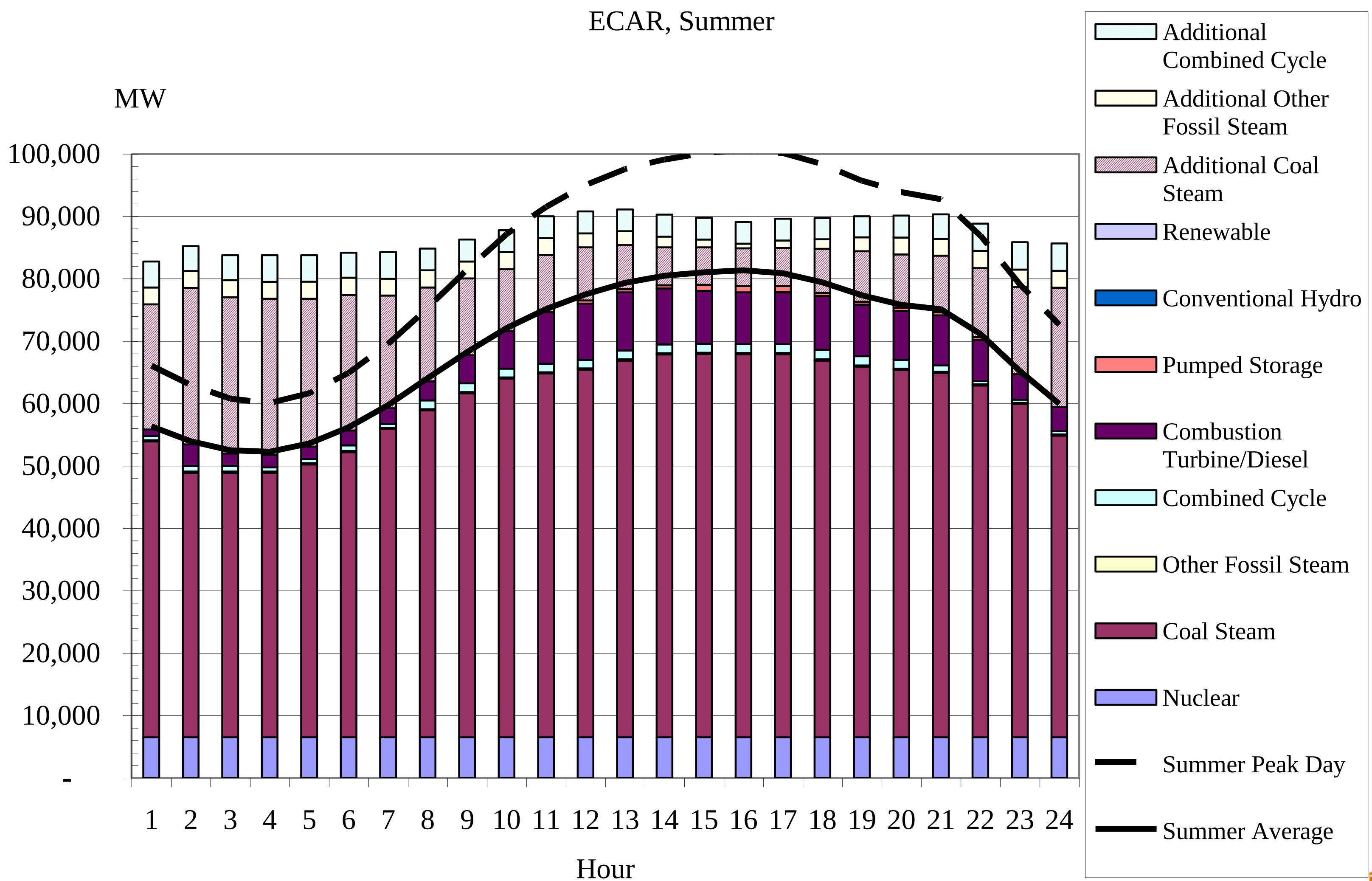
Current Generation and "Valley-Filling" ECAR, Summer



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Regional Emissions Impacts (Well-to-Wheel*) with Today's Generation Mix

**** Argonne National Laboratory's GREET well-to-wheel model***

Plant mix for valley fill	ECAR	ERCOT	MACC	MAIN	MAPP	NPCC	FRCC	SERC	SPP	PNW	AZ RMP	CNV	US total
	Power Generation Composition												
Natural Gas	32%	94%	74%	42%	1%	91%	69%	57%	78%	43%	63%	93%	
Coal	68%	6%	26%	58%	99%	9%	31%	43%	22%	57%	37%	7%	
Emissions	**Emissions Ratio (Electric Vehicle/Gasoline Vehicle)**												
Greenhouse gases	0.87	0.60	0.69	0.83	1.01	0.61	0.71	0.76	0.66	0.84	0.73	0.61	0.73
VOC: Total	0.11	0.04	0.06	0.10	0.14	0.04	0.07	0.08	0.06	0.10	0.07	0.04	0.07
CO: Total	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
NOx: Total	1.02	0.38	0.59	0.93	1.35	0.41	0.64	0.76	0.54	0.93	0.71	0.39	0.69
Particulates	1.55	0.81	1.06	1.45	1.94	0.86	1.13	1.26	0.99	1.46	1.19	0.84	1.18
SOx	3.94	0.42	1.68	3.59	5.96	0.64	2.05	2.67	1.34	3.77	2.35	0.53	2.25
Urban: VOCs	0.00	0.01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.01	0.01	0.01
CO	0.00	0.01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00	0.00	0.00	0.00	[illegible]	0.00
NOx	0.10	0.11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.10	0.11	0.10	[illegible]	[illegible]	0.10
Particulates	0.60	0.62	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.61
SOx	0.35	0.04	0.14	0.30	0.51	0.05	0.17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.19

Existing coal plants break even on greenhouse gases

Nationally, greenhouse gases reduced 27% despite increased reliance on coal

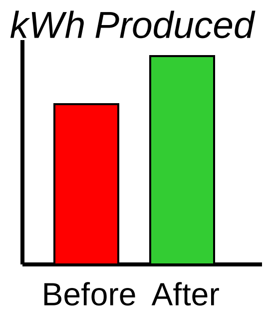
SOx from vehicles doubles: cap-and-trade will require investment in cleaner plants

Urban air quality emissions greatly reduced:
VOCs/CO/NOx > 90%
SOx = 80%
Particulates = 40%

- Moving emissions from tailpipes to smokestacks:
  - solves an intractable problem for CO_2 capture
  - improves cost effectiveness for other emissions

Increased Sales of Electricity from PHEVs Produce Downward Pressure on Electricity Rates*

Increased sales



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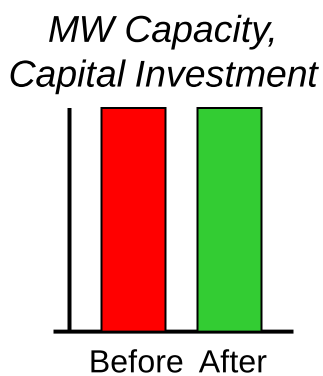
Same infrastructure, same capital investment



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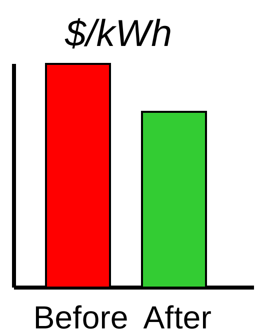
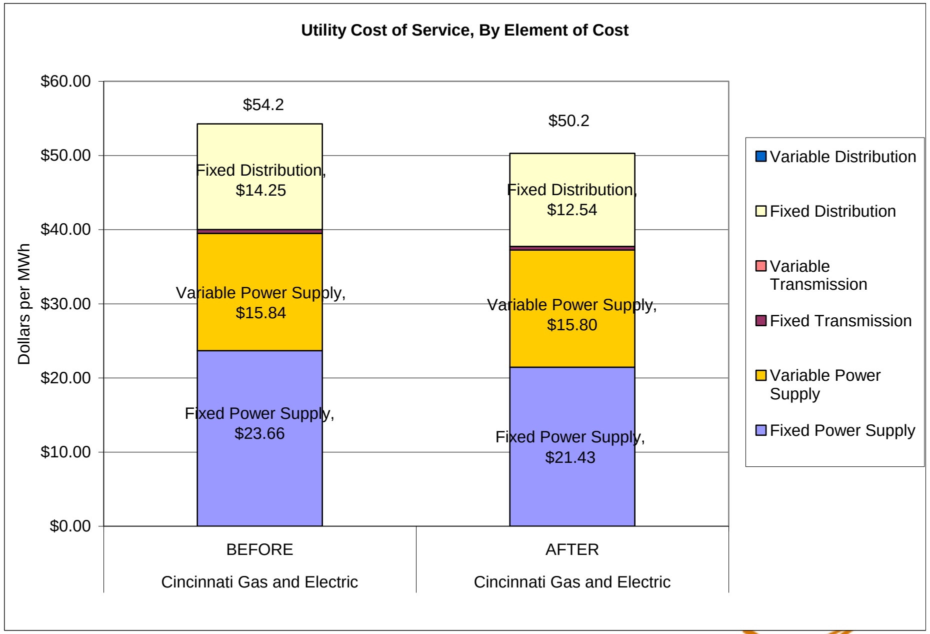
Lower electricity rates



* analysis of Cincinnati Gas & Electric and San Diego Gas & Electric

Cincinnati Gas & Electric Costs/MWh with PHEV Valley Filling



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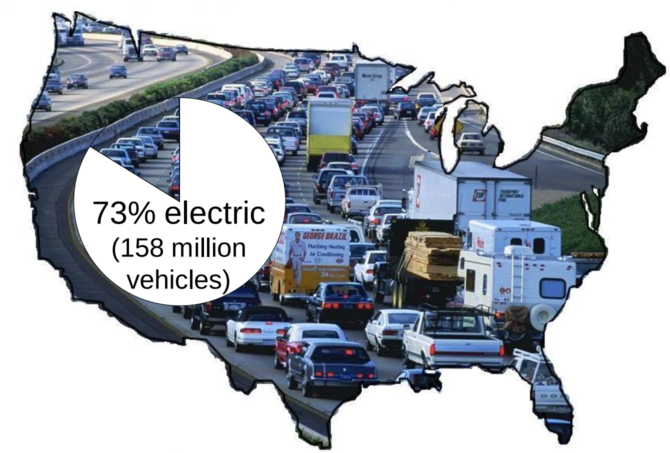
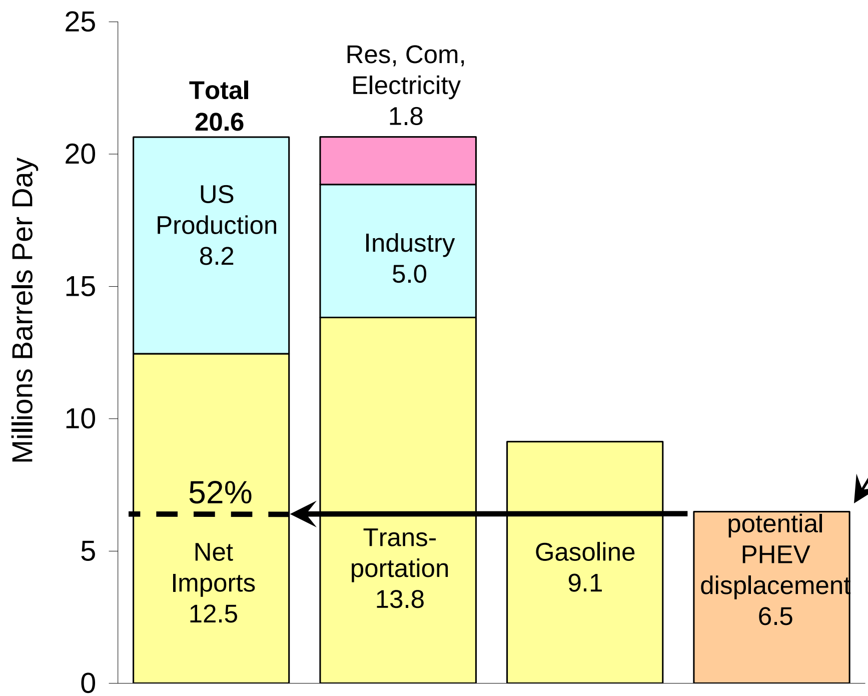
Summary

The idle capacity of the U.S. grid **could supply 73%** of the energy needs of <u>today's</u> cars, SUVs, pickup trucks, and vans…

without adding generation or transmission
<u>if charging of vehicles is managed</u>





Source: EIA, Annual Energy Review 2005

- Potential to displace 52% of net oil imports (6.7 MMbpd)
- More sales + same infrastructure = downward pressure on rates
- Reduces CO_2 emissions by 27%
- Emissions move from tailpipes to smokestacks (and base load plants) … cheaper to clean up
- Introduces vast electricity storage potential for the grid

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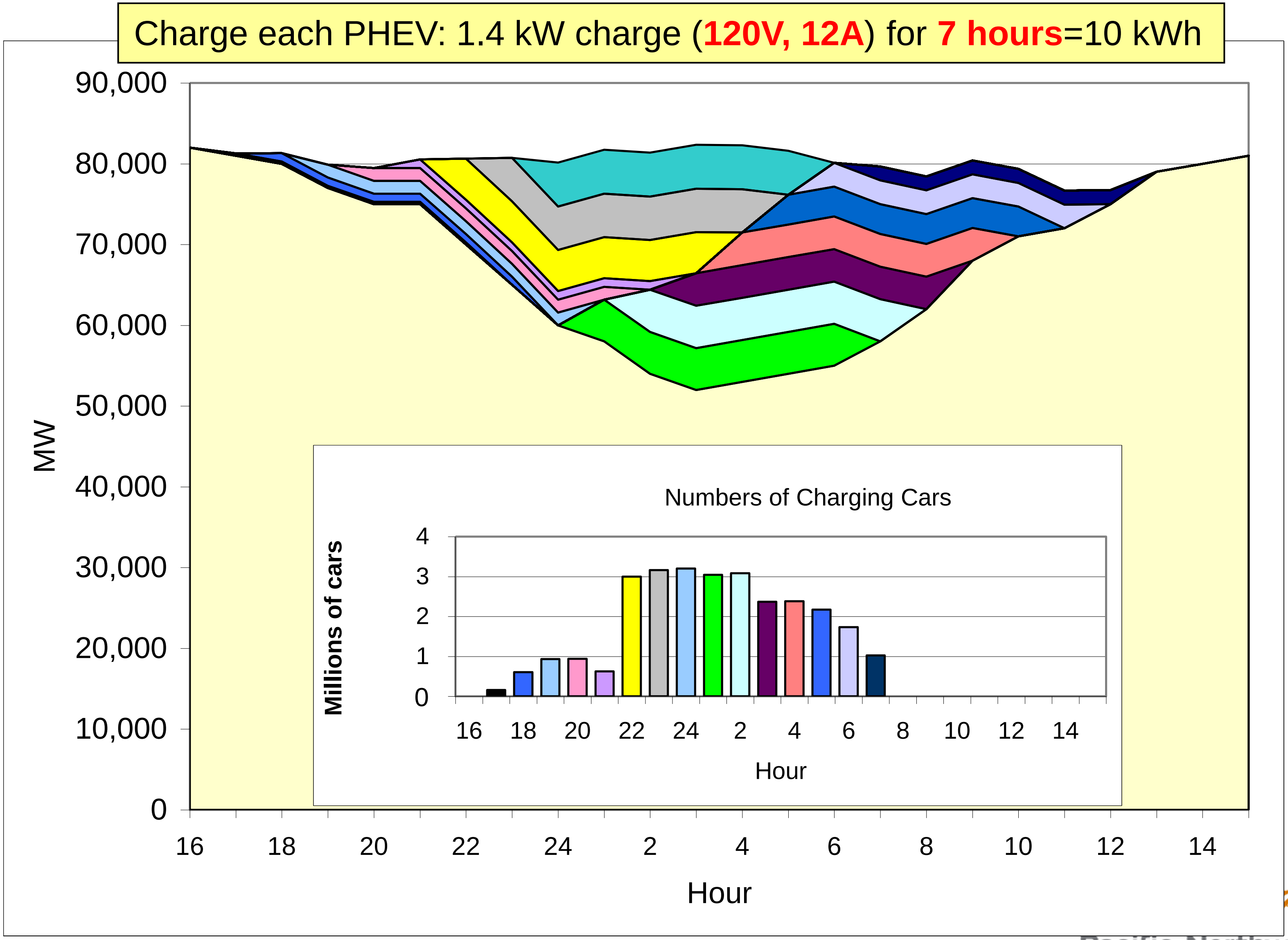
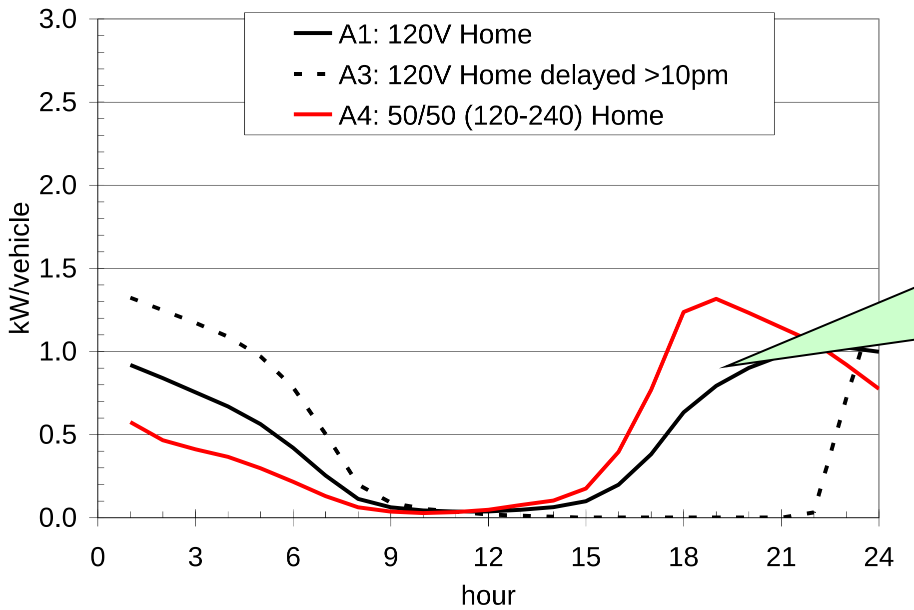
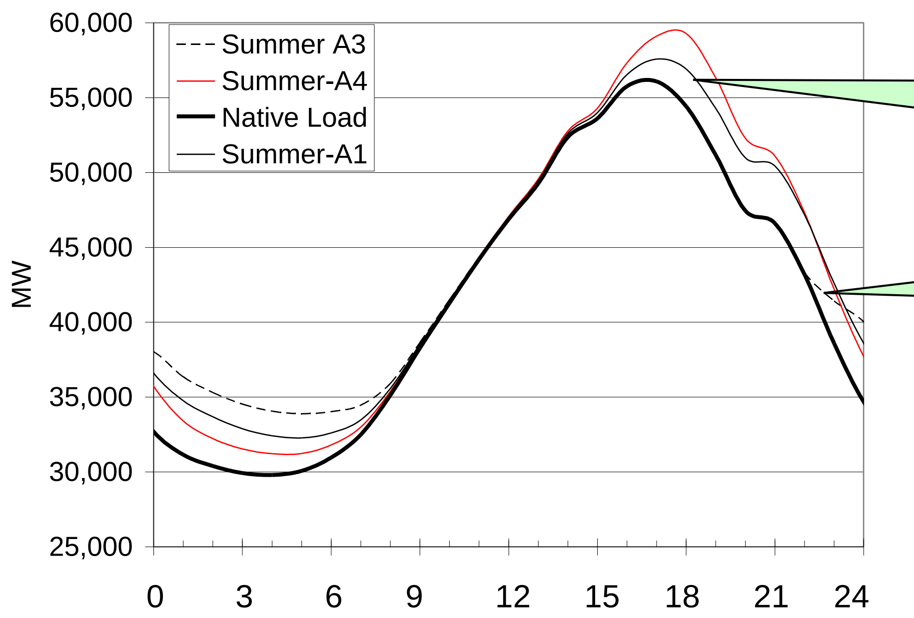
Perfect Valley Filling

ECAR Summer Load Profile



Why Is It Important to Manage the Charging?





"Dumb" charging profiles based on 37,000 observations from US National Household Travel Survey (2001)

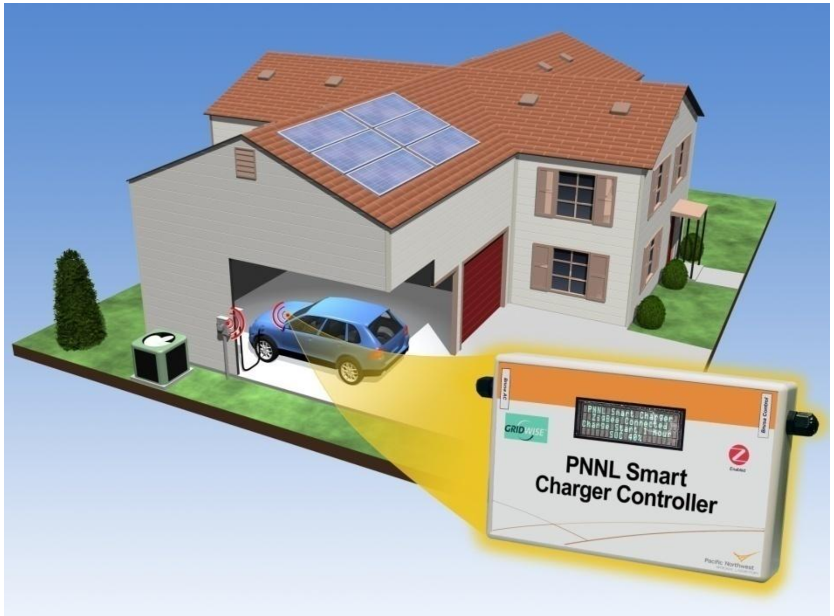
"Dumb" charging at home exacerbate system peak

Delayed charging moves majority of load into low-load conditions

Based on 6 mill. PHEVs in CAISO footprint for 2030

Smart Charging for a Smart Grid

Smart Home Application



- Smart grid services:
  - **Price-based** charging to perform majority of charging during off-peak, enabling customers to optimize between cost and convenience
  - **Demand response** services (direct load control)
  - **Regulation** services by modulating load

Public Charging Stations

- Mobile billing
  - Enable 'roaming' transaction concepts for
- Smart battery services
  - Diagnostics and Maintenance
  - Determining state-of-health of battery

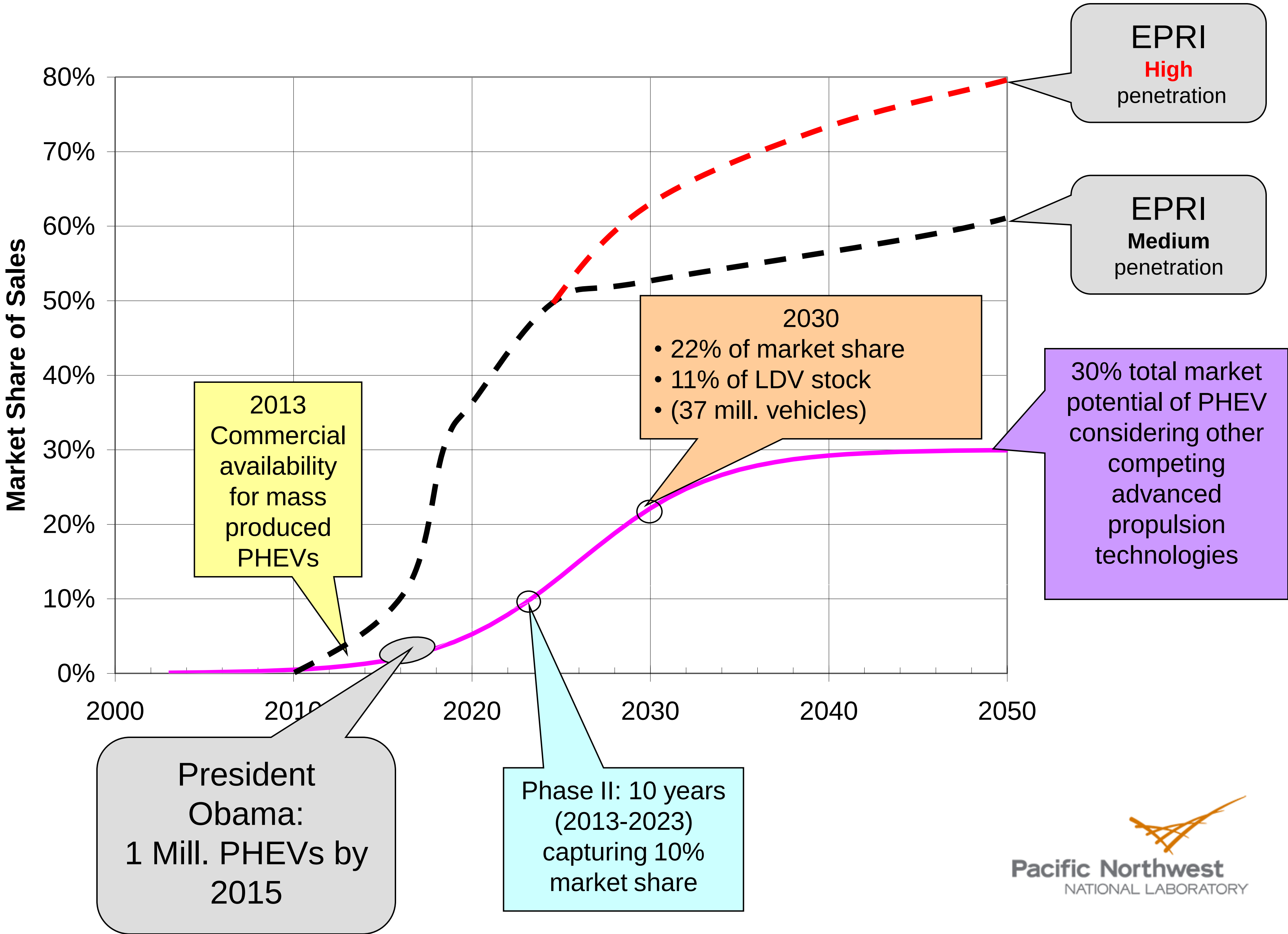
Communication Standards are enabling Vehicle-to-Grid interactions

- Society of Automotive Engineers (North America)
- JSAE (Japan)
- International Electrotechnical Commission (primarily Europe)

What are Electricity Cost Impacts of Electric Transportation from a National Perspective?

- Key assumptions:
  - Time horizon of the study (2030)
  - Grid: What will the grid look like for the time horizon of the study?
  - Transportation
    - How many vehicles? -> penetration rates
    - When are they charged?
    - How are they charged?
- Methodology
  - Complex economic dispatch model of thousands of generators and transmission network representation

Penetration results



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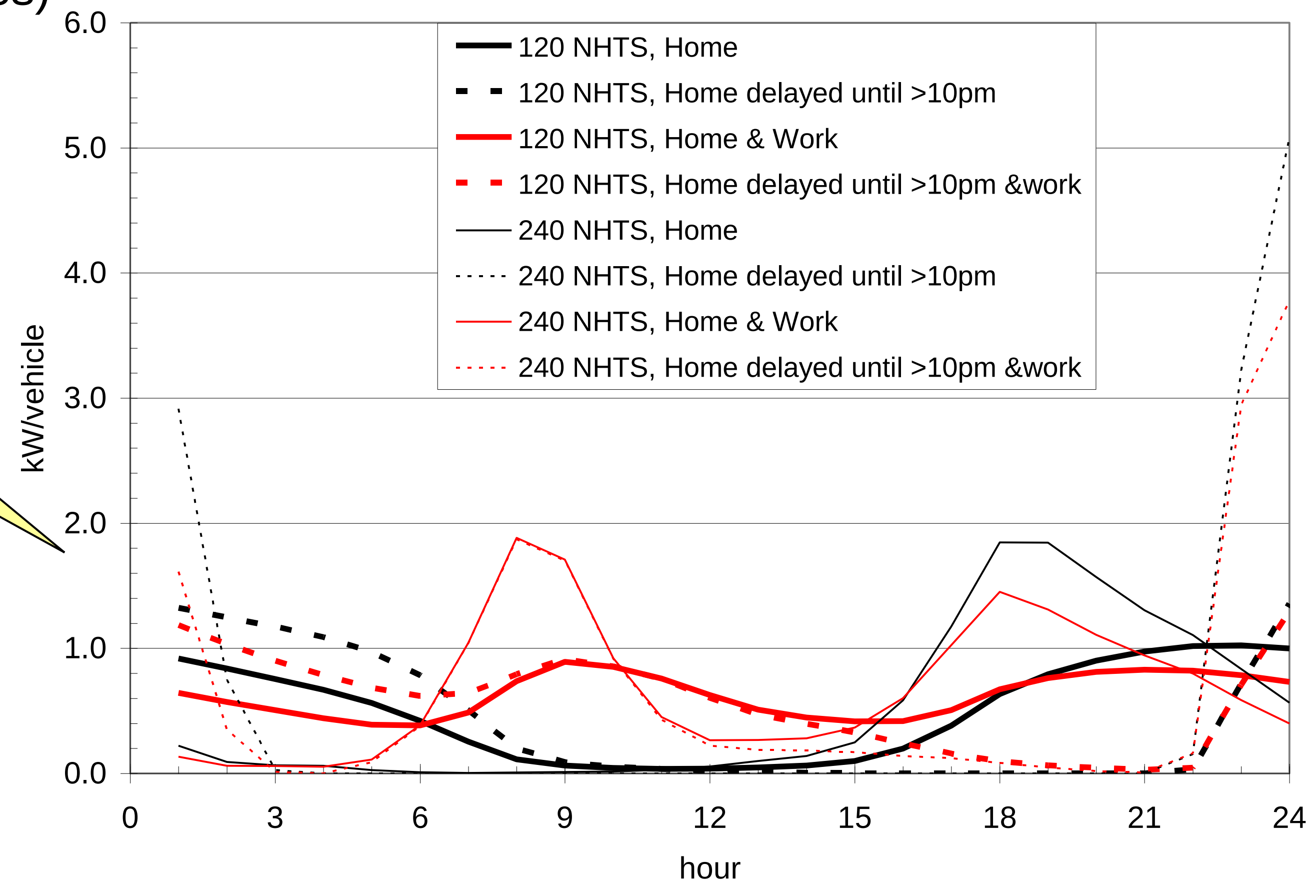
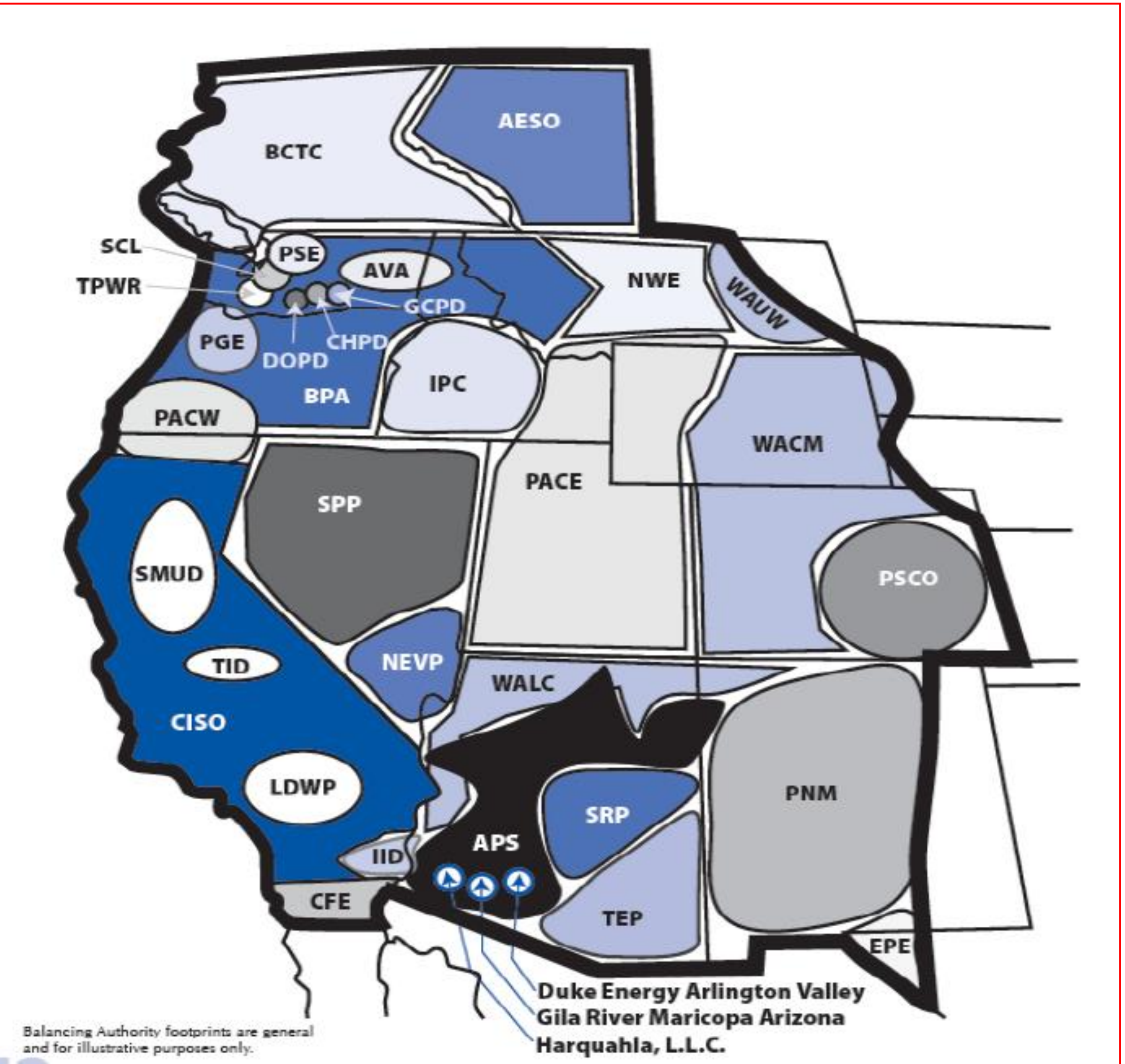
Developed Plausible PHEV Charging Profiles

- Need for PHEV charging profile
  - Most researchers use EPRI "W" shaped profile based on notion of 120V/12A charging
- Refined PHEV profile with DOT 2001 National Household Travel Survey to reflect "resting periods" of vehicles
- Considered both 120V and 240V charging (automakers announced 240V charging capabilities)

Diversified average charging profiles for PHEVs



Detailed Electricity Market Impact Analysis for WECC



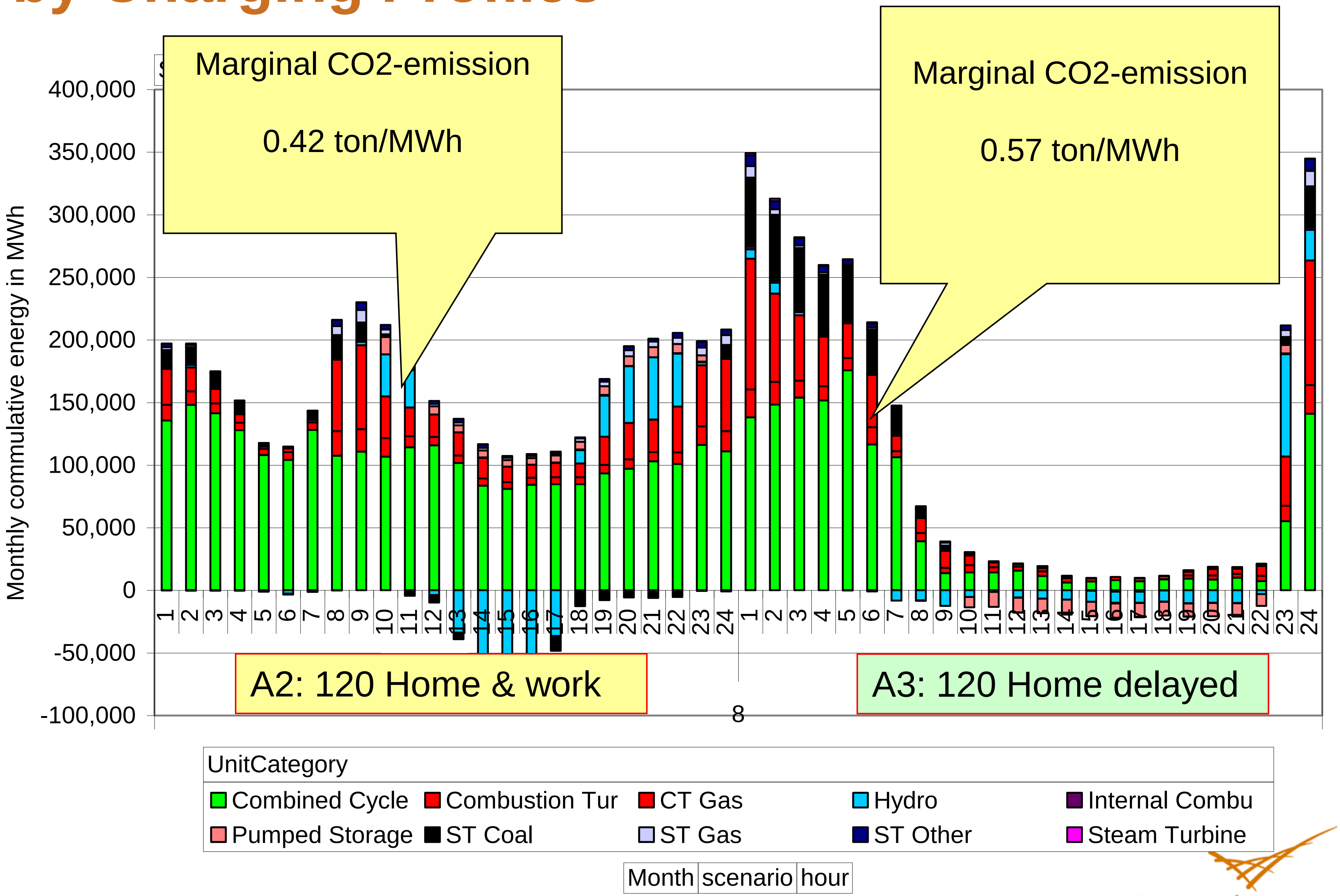
Impacts to the grid

- 9.2 Million PHEVs in WECC in 2030
- Majority of PHEVs in California

Grid Analysis

- Production cost model
- 1900+ generator units
- 64 balancing zones
- EIA's capacity additions to 2030
- Meeting regional RPS
- Additional capacity for PHEVs
- Determine
  - Cost impacts
  - Emissions impacts

Comparison of WECC's Marginal Generation by Charging Profiles



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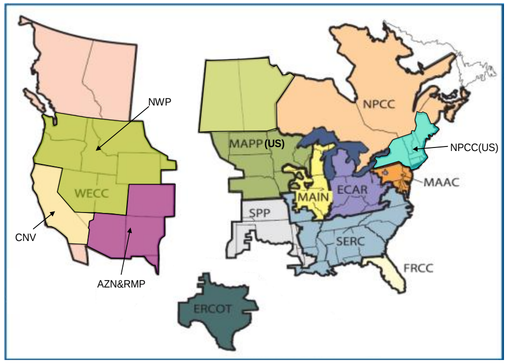
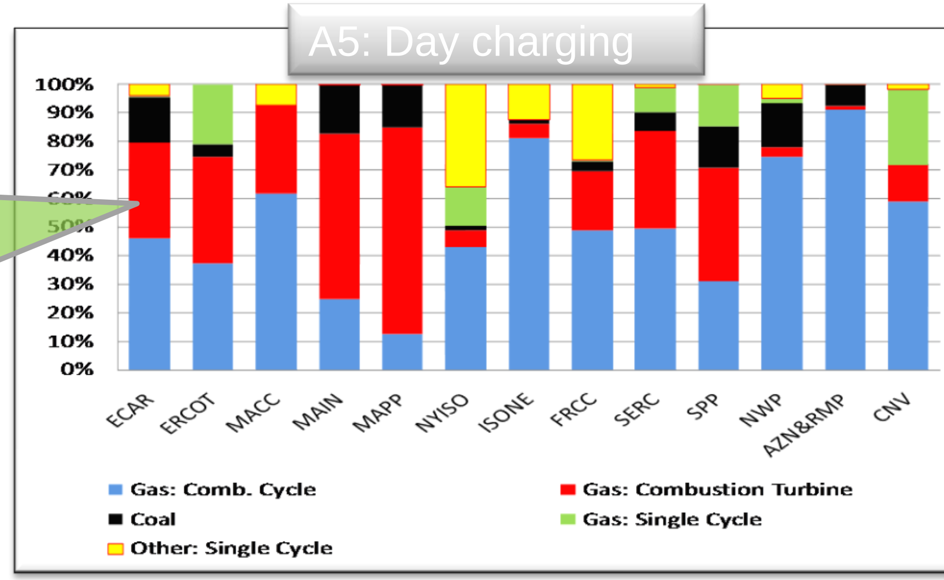
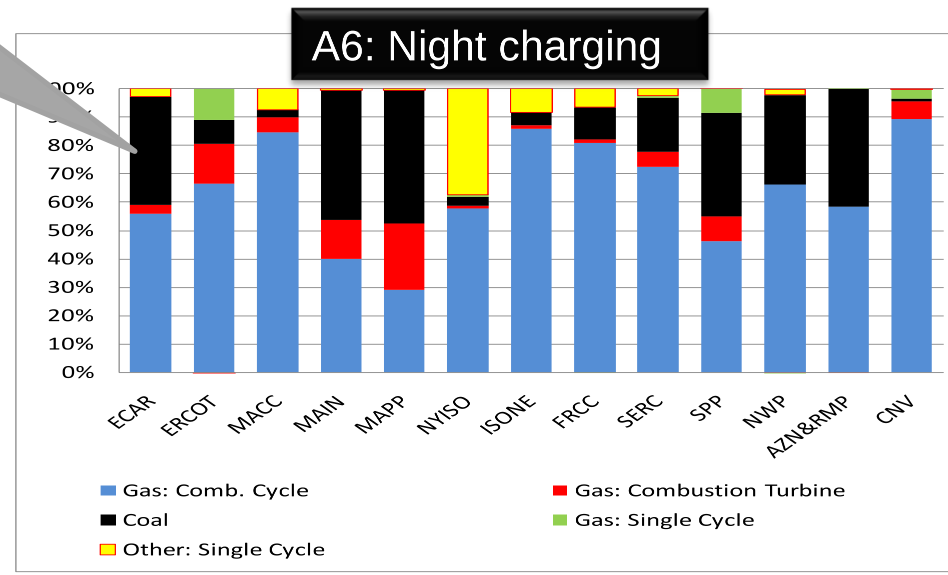
Results: Marginal generation mix depends on the regions and the time of day when vehicles are charged



Natural gas primary fuel for day-charging

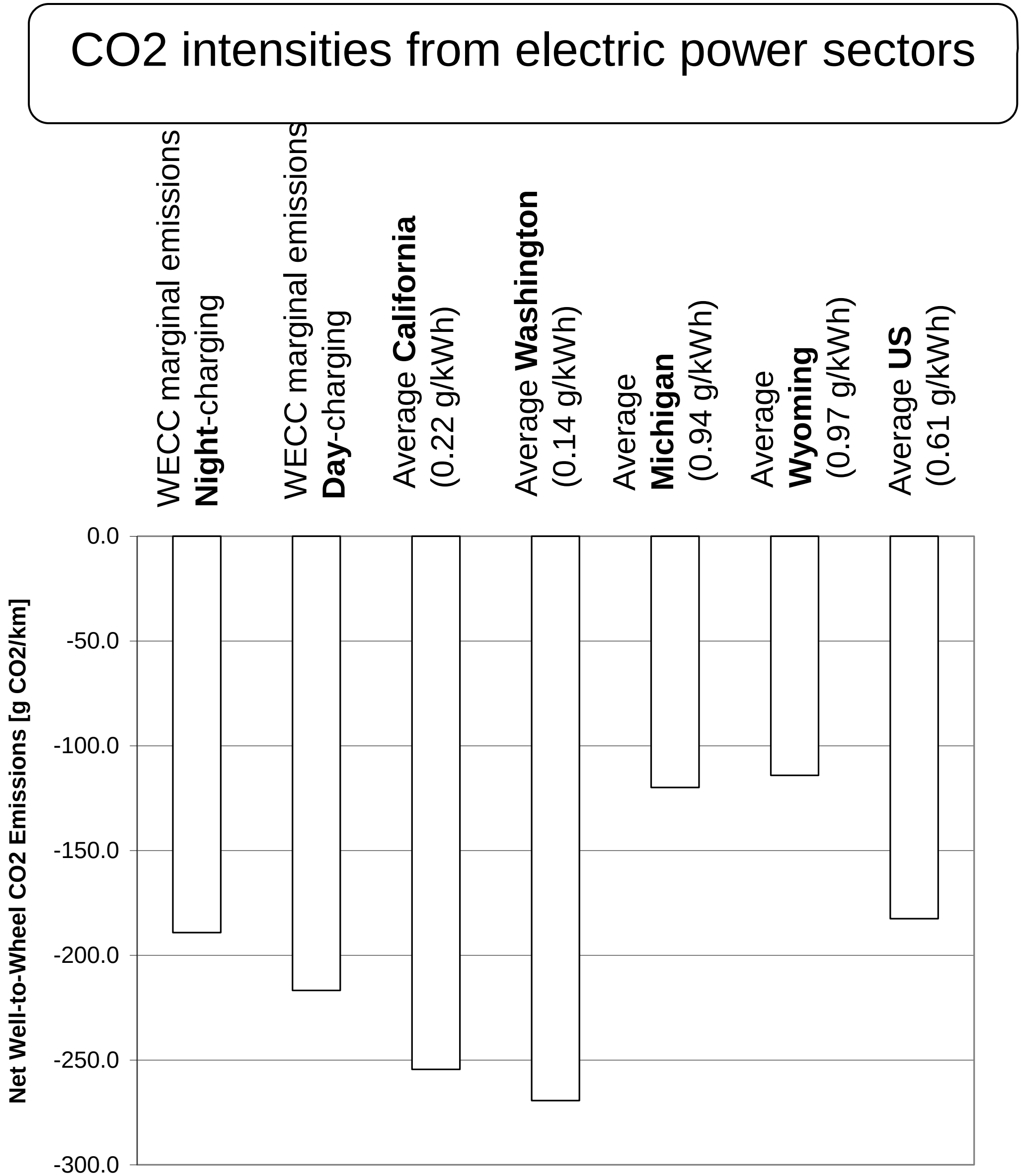


Significant coal resources available for night-charging



Economics suggest to charge at night, resulting in about ½ of the cost increases compared to day-charging

Net Well-to-Wheel* CO_2 Emissions Comparisons



- Assume mid-sized PHEV electric mode (0.35 kWh/mile)
- For Well-to-Wheel, conventional gasoline vehicle, assume 20% contribution for Well-to-Pump
- Average Michigan and US electric power CO_2 intensity from EIA source

Compared to conventional gasoline vehicle with **22 MPG**

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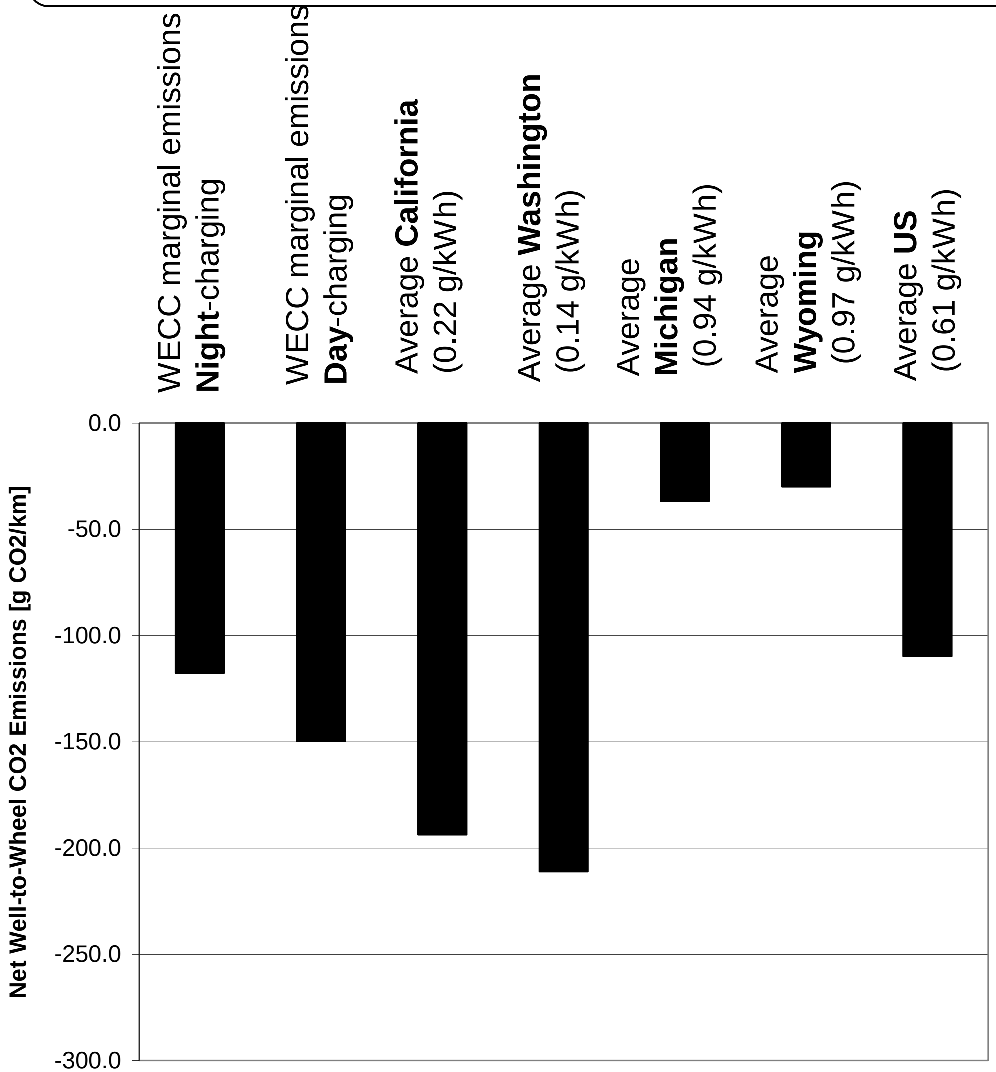
Net Well-to-Wheel* CO2 Emissions Comparisons

CO2 intensities from electric power sectors



- Assume mid-sized PHEV electric mode (0.35 kWh/mile)
- For Well-to-Wheel, conventional gasoline vehicle, assume 20% contribution for Well-to-Pump
- Average Michigan and US electric power CO2 intensity from EIA source

Compared to conventional gasoline vehicle with **27 MPG**

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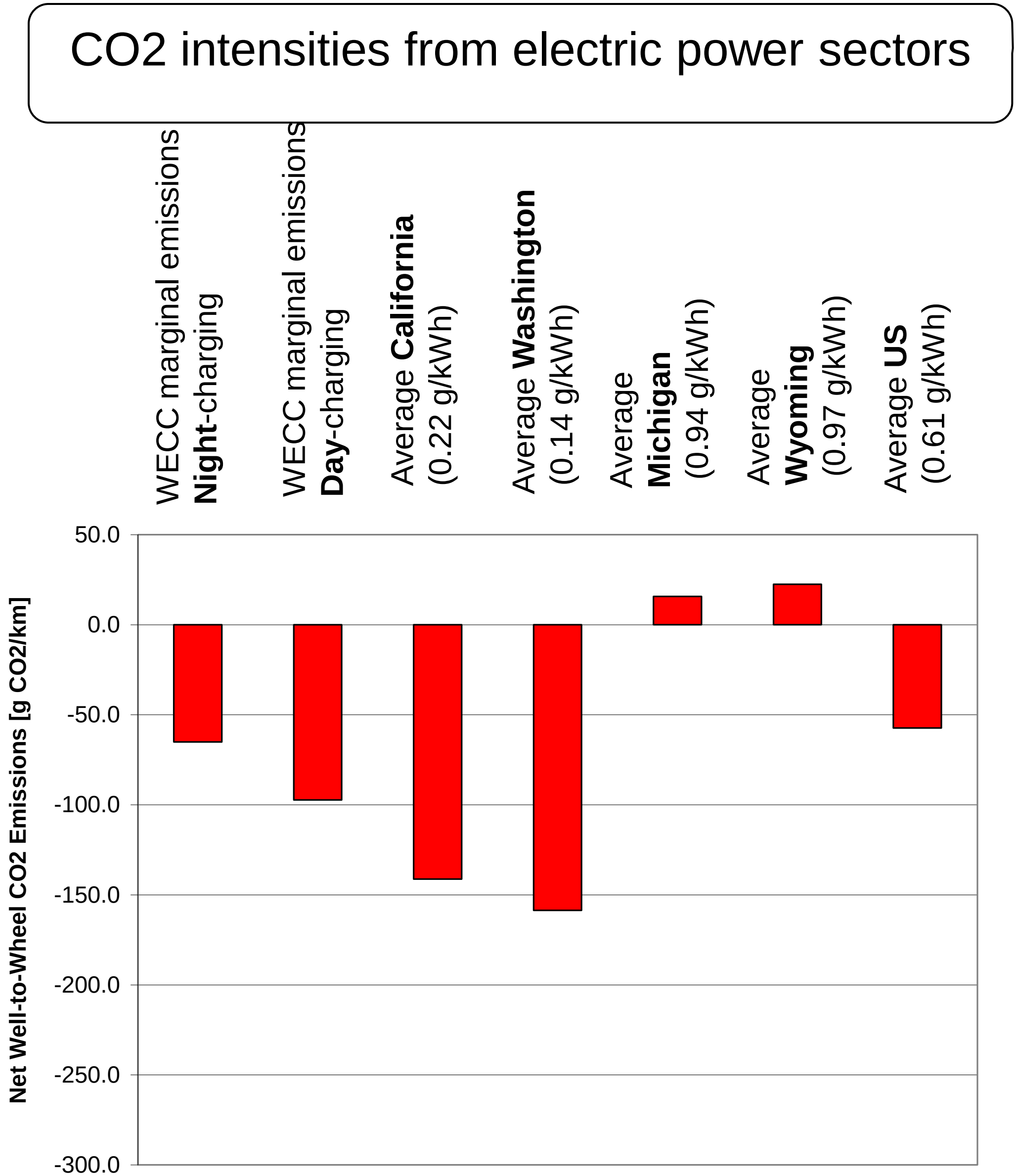
Net Well-to-Wheel* CO2 Emissions Comparisons



- Assume mid-sized PHEV electric mode (0.35 kWh/mile)
- For Well-to-Wheel, conventional gasoline vehicle, assume 20% contribution for Well-to-Pump
- Average Michigan and US electric power CO_2 intensity from EIA source

Compared to conventional gasoline vehicle with **35 MPG**

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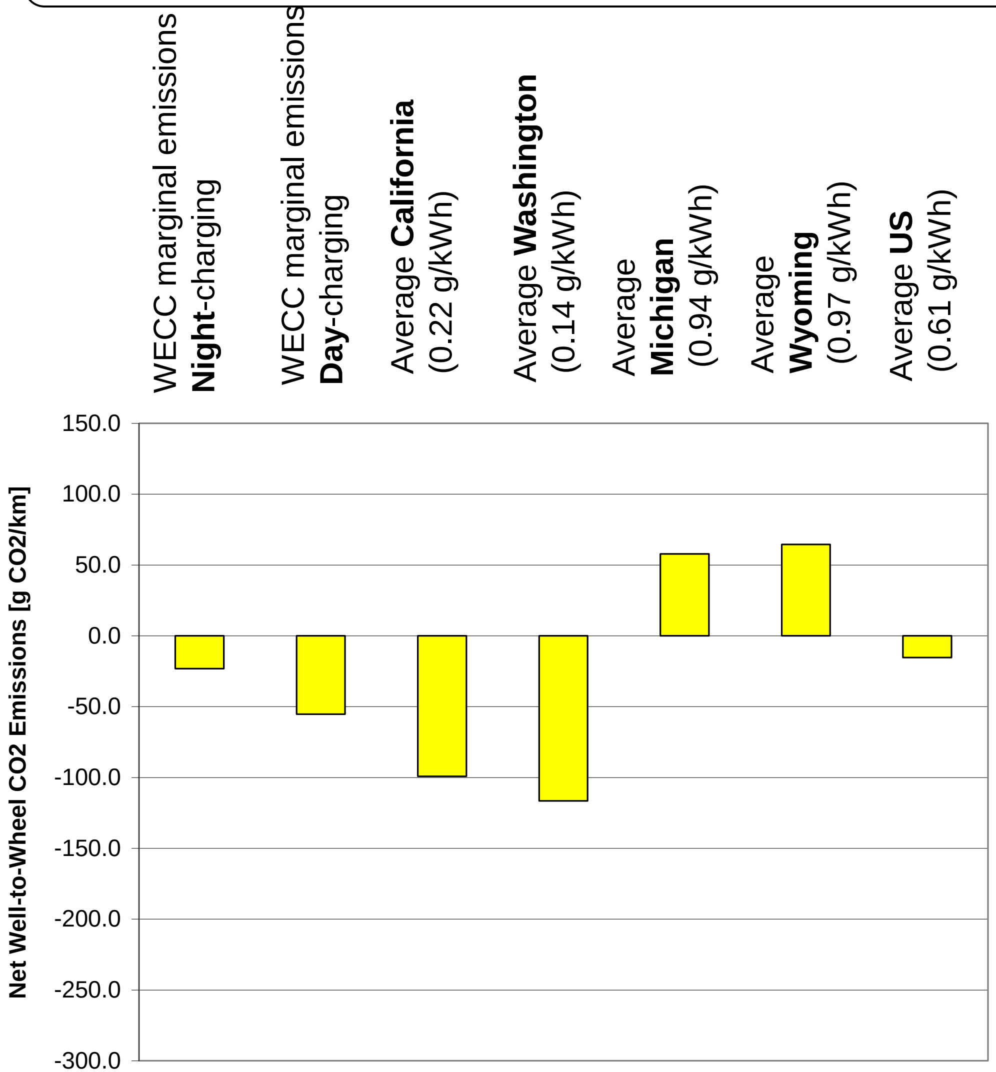
Net Well-to-Wheel* CO_2 Emissions Comparisons

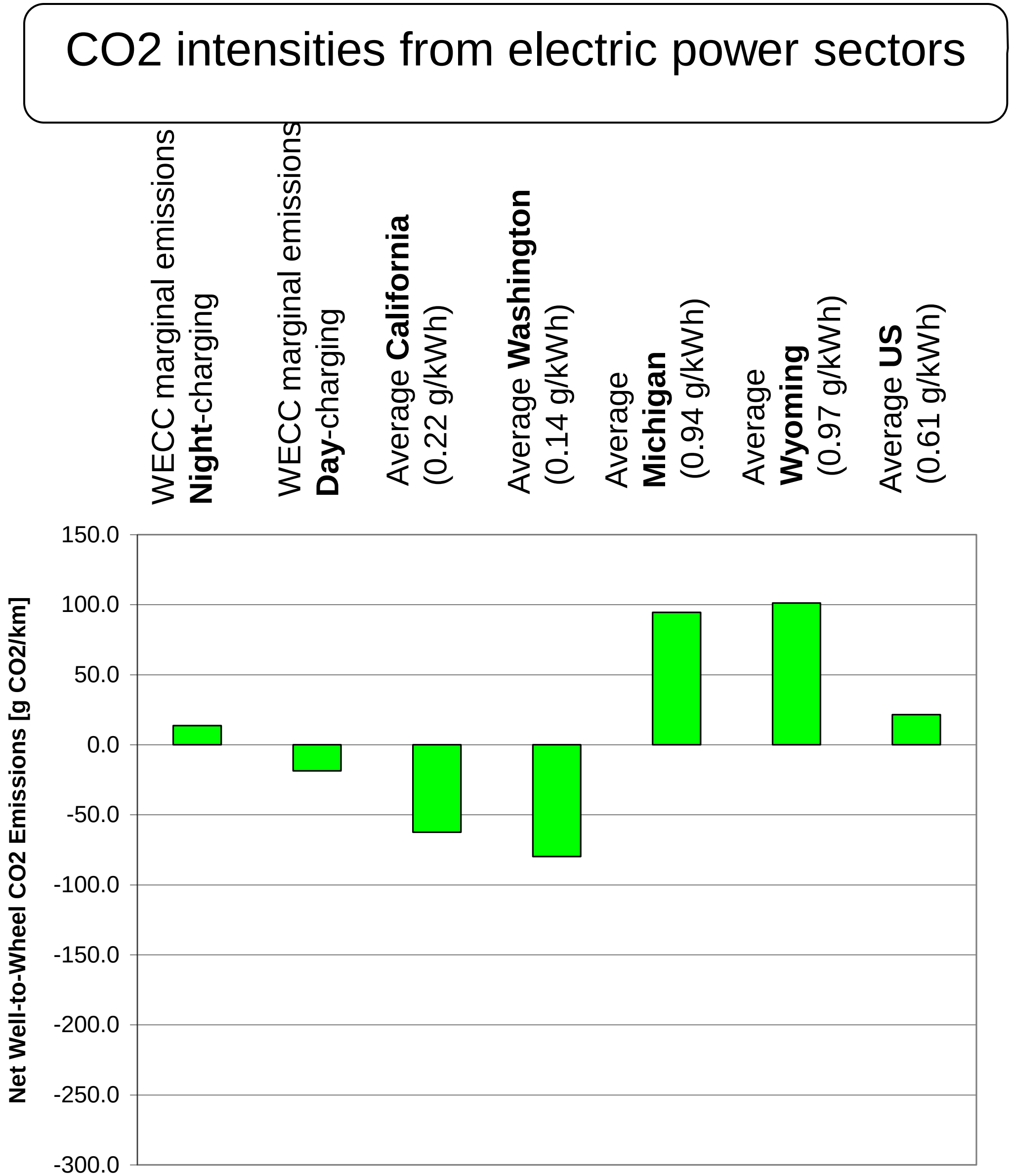
CO2 intensities from electric power sectors



- Assume mid-sized PHEV electric mode (0.35 kWh/mile)
- For Well-to-Wheel, conventional gasoline vehicle, assume 20% contribution for Well-to-Pump
- Average Michigan and US electric power CO_2 intensity from EIA source

Compared to conventional gasoline vehicle with **45 MPG**

Net Well-to-Wheel* CO2 Emissions Comparisons



- Assume mid-sized PHEV electric mode (0.35 kWh/mile)
- For Well-to-Wheel, conventional gasoline vehicle, assume 20% contribution for Well-to-Pump
- Average Michigan and US electric power CO2 intensity from EIA source

Compared to conventional gasoline vehicle with **60 MPG**

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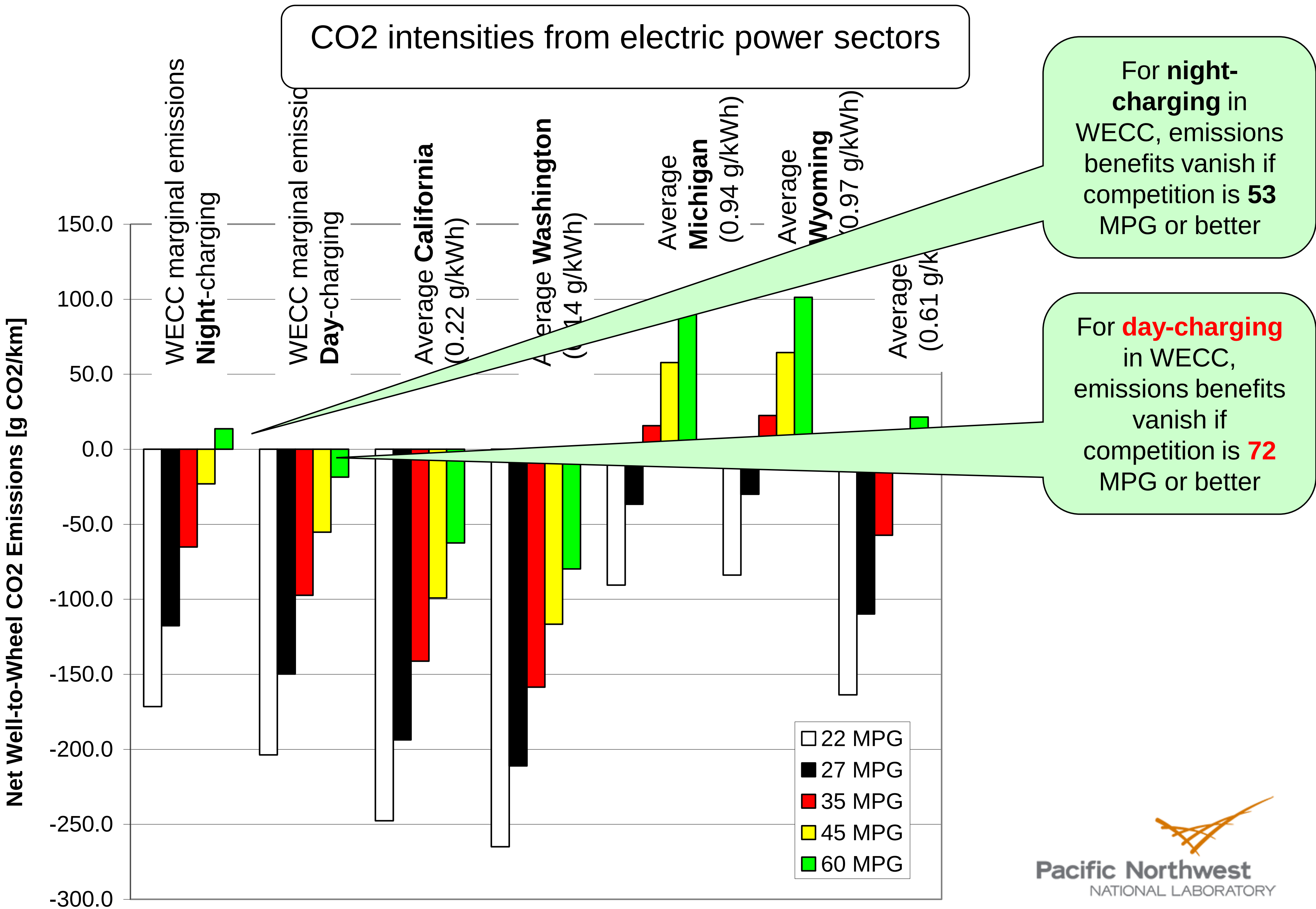
Net Well-to-Wheel* CO2 Emissions Comparisons



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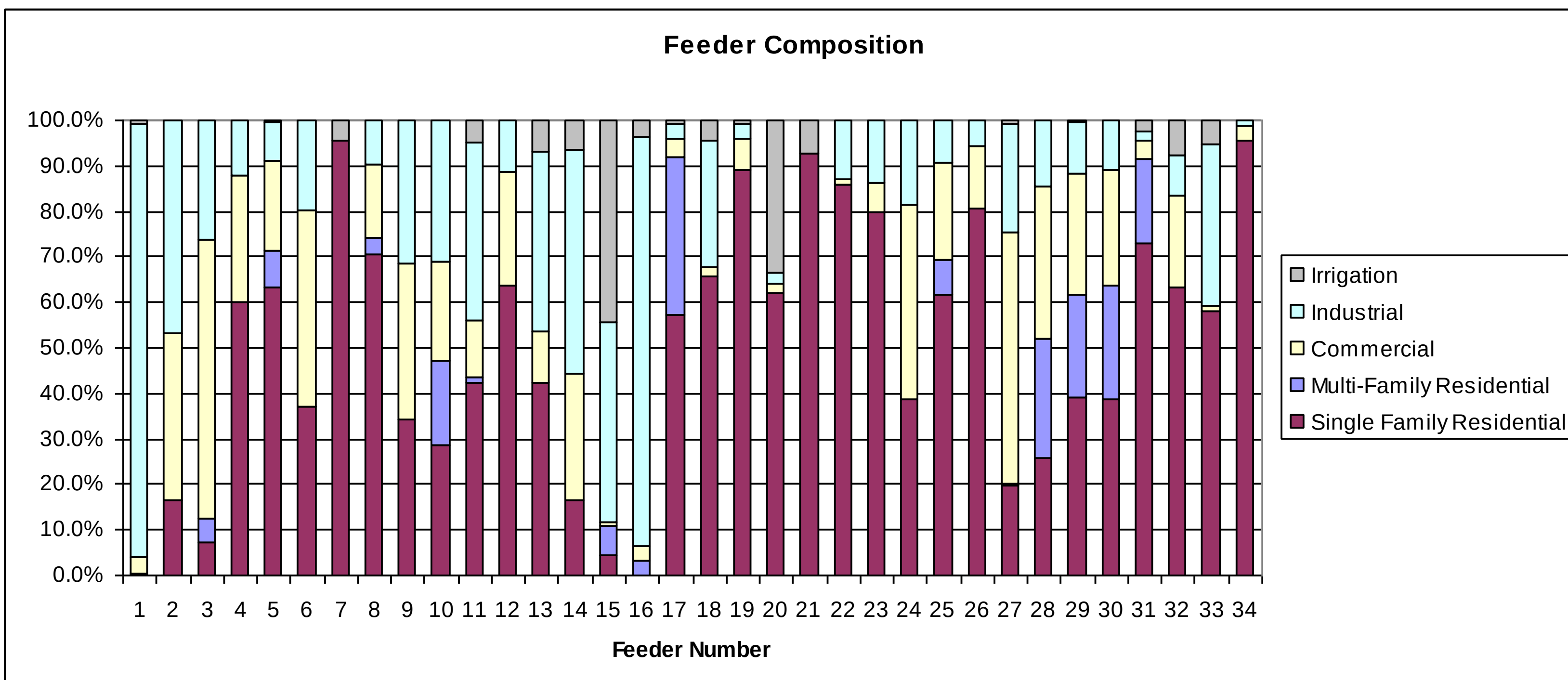
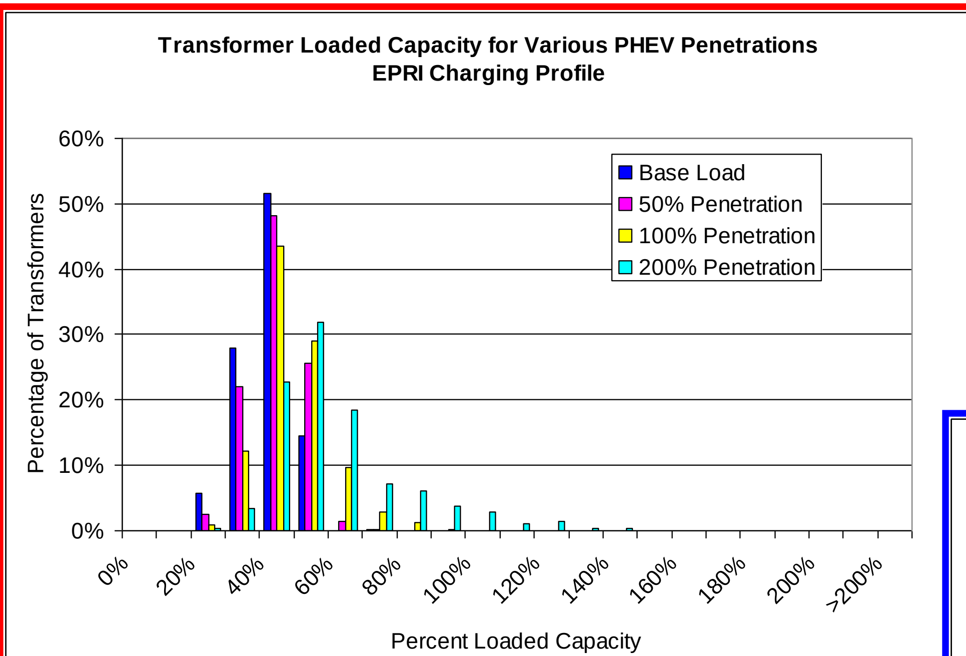
Impacts on the Distribution System

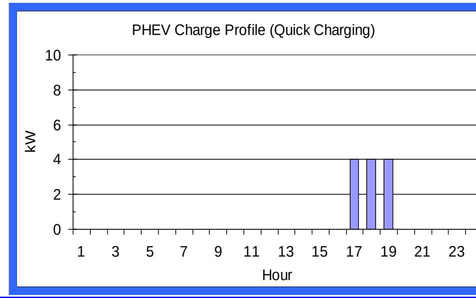
- Issues:
  - How do PHEV impact my capital budget for distribution upgrades?
  - How different is a PHEV load from, say plasma TV or Air-conditioning?
  - Are there any reliability impacts with this new load?
- Methodology
  - Distribution system planning tools
  - Probabilistic Risk Assessment

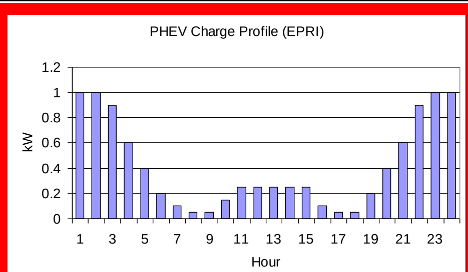


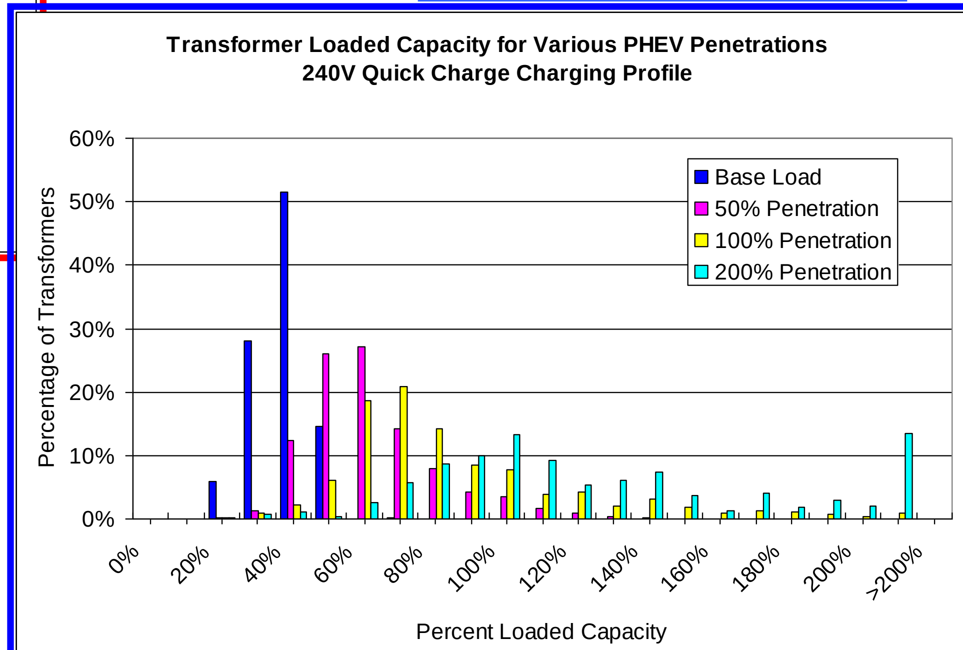
Secondary Transformer Loading (Selected Utilities in PNW)



Level 2 (240V) Charging







Level 1 (120V) Charging

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Selected Feeder in the NW

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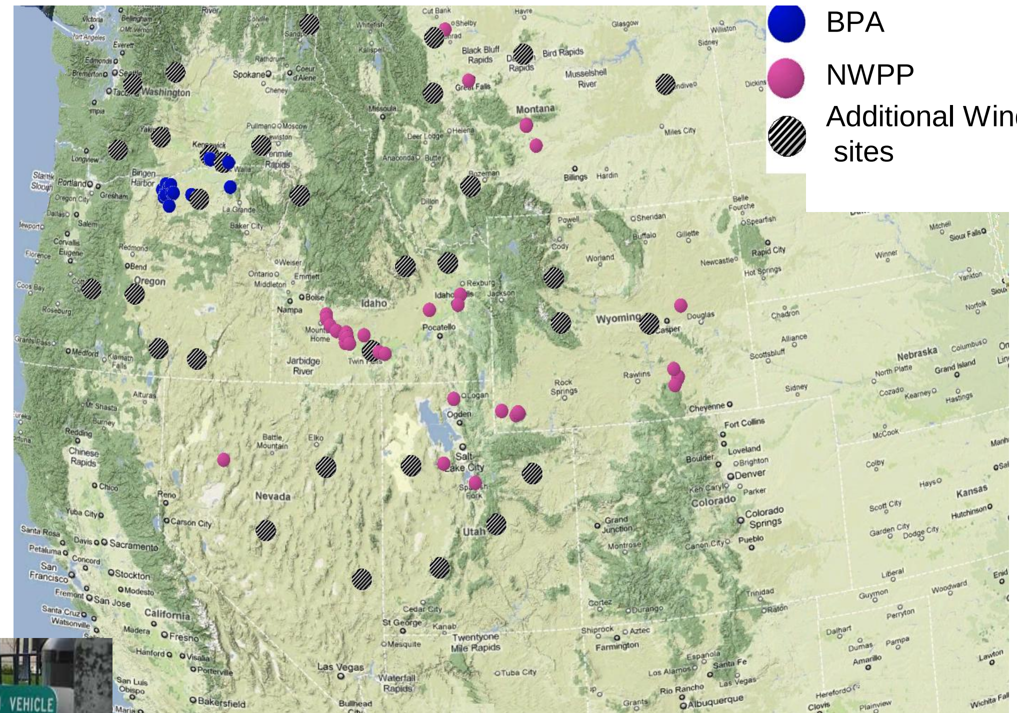
Benefits of PHEVs for Integrating Renewable Energy Resources

- Question to answer:
  - How many electric vehicles are necessary to meet new balancing requirements for integrating wind generation in the PNW (2020)?
- Assumptions
  - Balancing requirements for wind capacity to increase from 4.2 to 14.4 GW (RPS of 12%)
  - Basic assumptions from PNNL report on storage integration into NWPP[(1)]



[(1)]: Source: PNNL-19300. Energy Storage for Power Systems Applications: A Regional Assessment for the Northwest Power Pool (NWPP)

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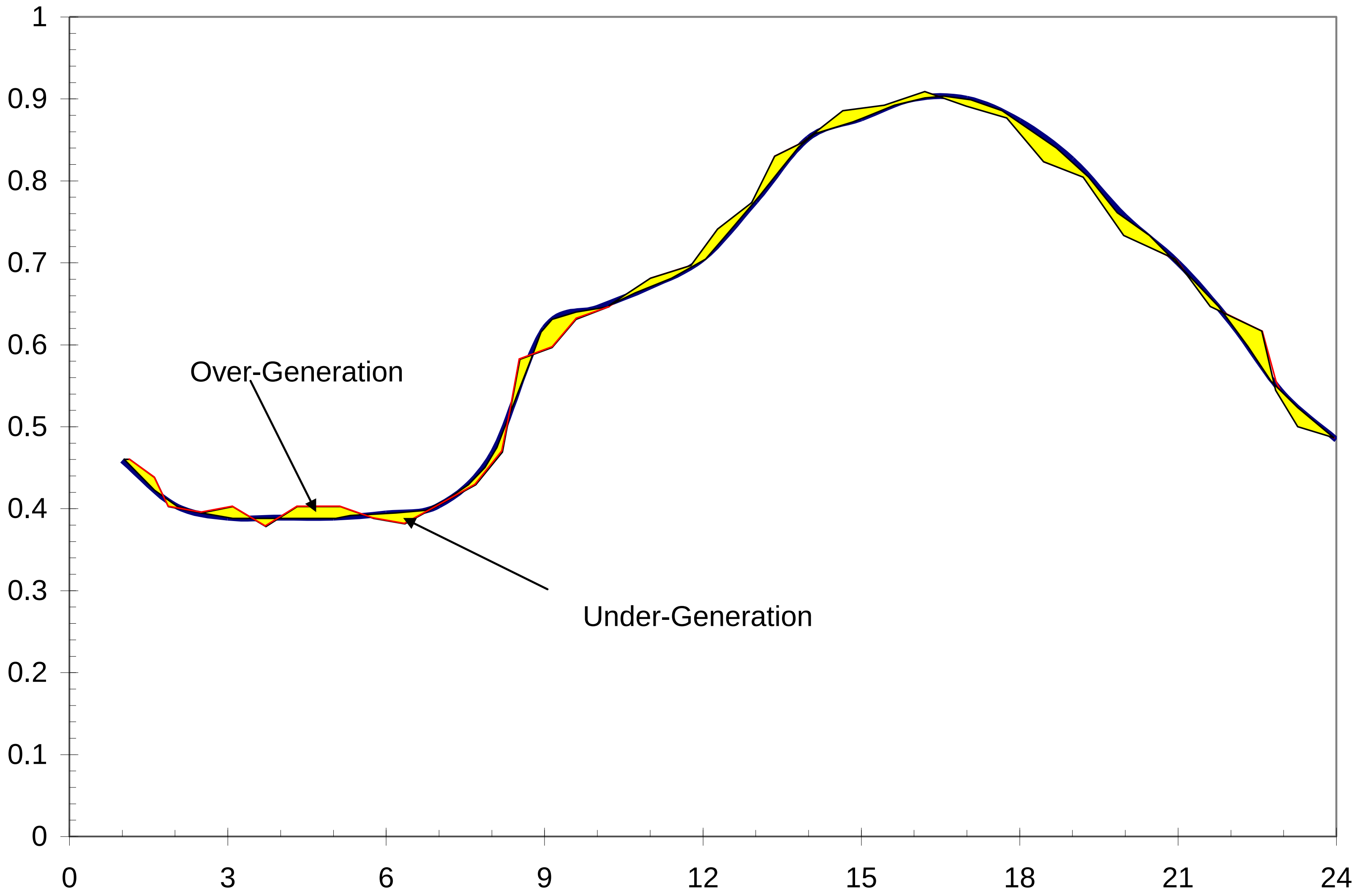
Approach for Determining Balancing Requirements



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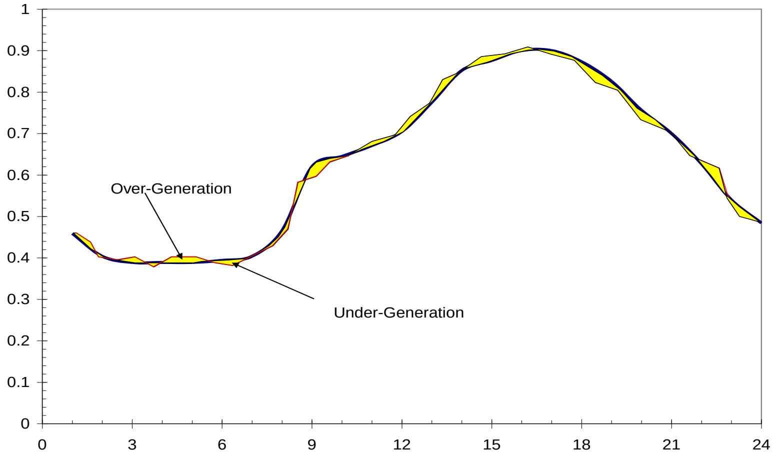
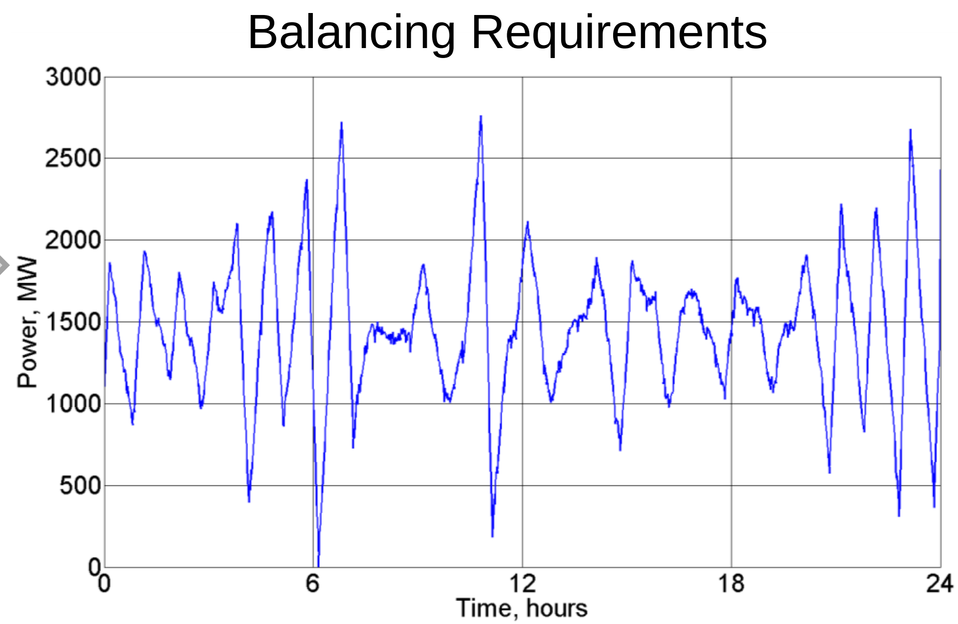
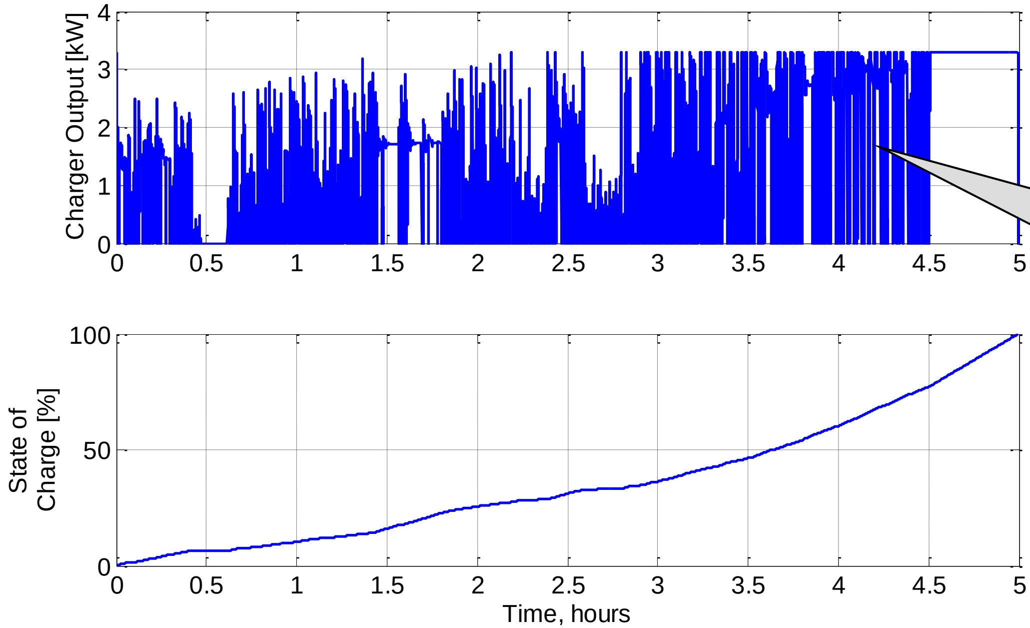
Meeting Balancing Requirements with Smart Charging







Modulation of charging between 0 – full charging rate (3.3 kW)

Capacity value regulation services to the grid-operator = 3.3 kW for duration of charging

Electric Vehicles as a Resource for Renewable Integration

- Light duty vehicle stock in NWPP (ID, WA, OR, UT,MT): 16.5 Million
- Assumptions
  - 110 mile all-electric range
  - Half of all charging stations (public/private) are 240 VAC-capable
  - Utilize 2001 NHTS Data for driving patterns

Charging Infrastructure		No. of Vehicles	% of Vehicle Stock
Home	Public		
100%	0%	>16 mill	> 100%
100%	5%	6 mill	36%
100%	20%	3 mill	20%
100%	100%	2 mill	12%

Electric Vehicles could provide a significant portion of the future balancing requirements
And thus contribute to the integration of Renewable Energy Resources

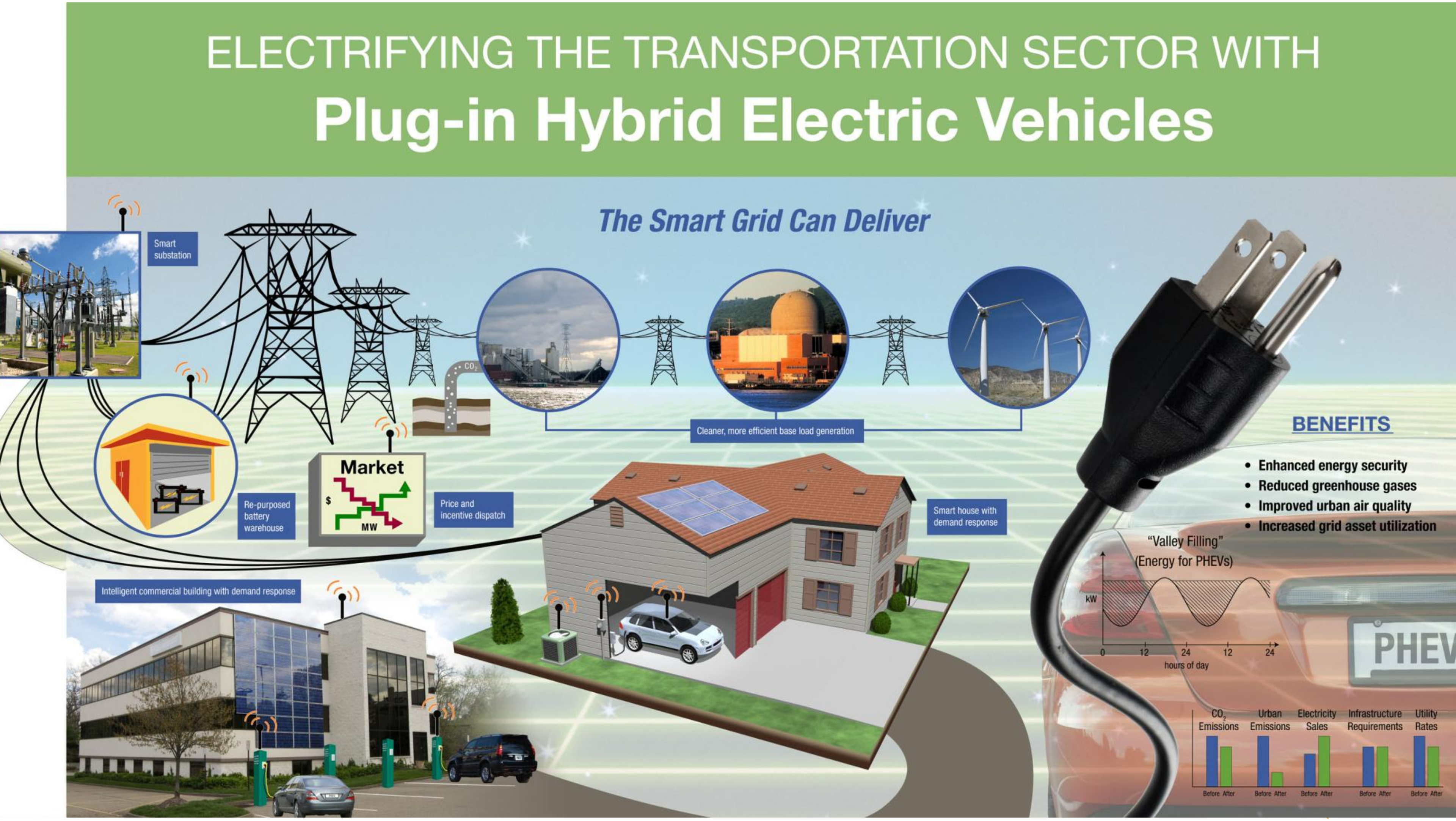
Challenge: What is the reward system and how do we verify?

Demonstrate Smart Charging Technologies

PNNL's Toyota Prius

17 charging stations with PV

Smart Grid with Smart Chargers Can Deliver the Electricity for Millions of PHEVs



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