Potential Impacts of High Penetration of Plug-in Hybrid Vehicles on the U.S. Power Grid

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DOE/EERE PHEV Stakeholder Workshop
Washington DC
June 2007

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Operated by Battelle for the U.S. Department of Energy

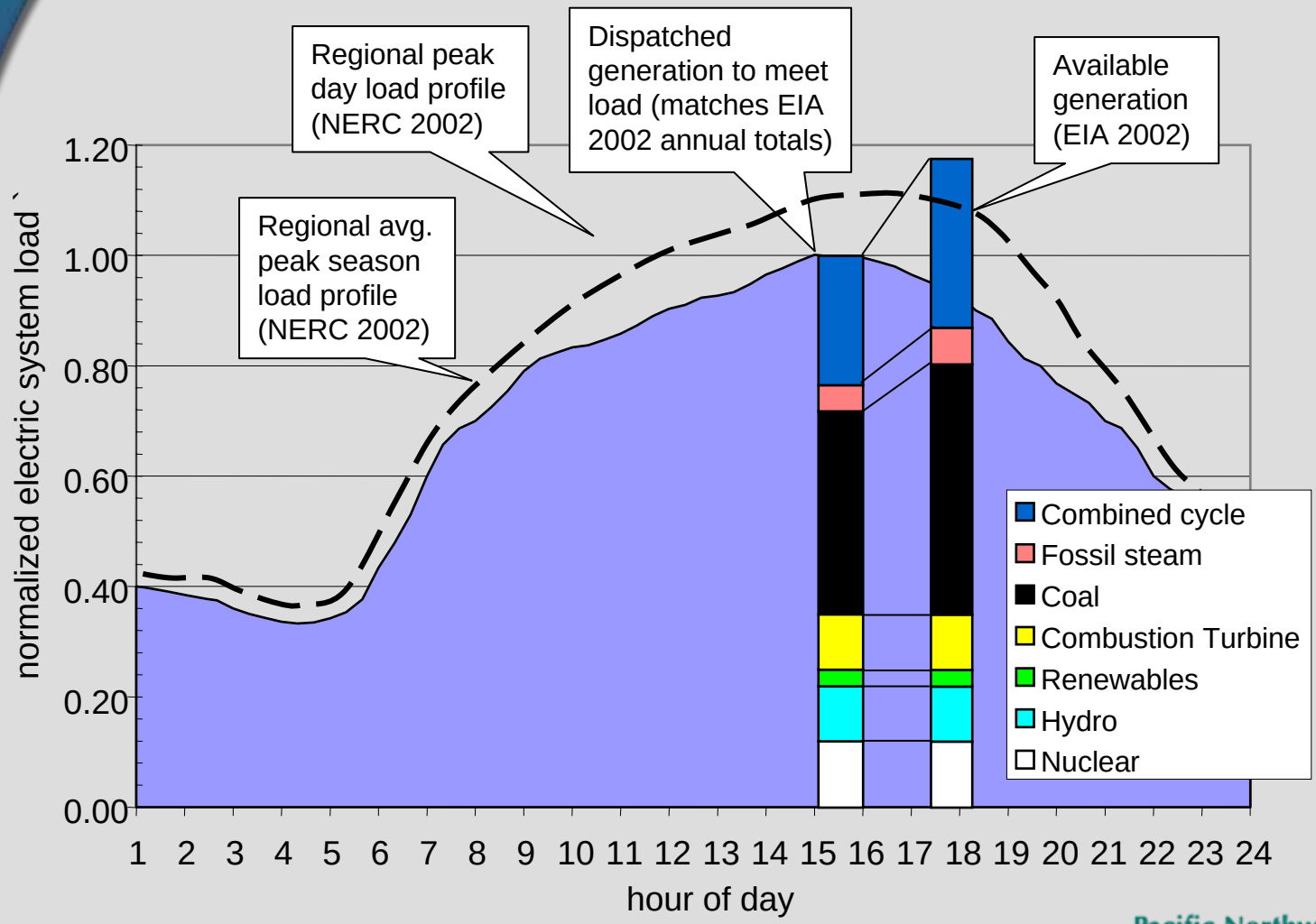
FY06 Grid Impact Study* of High Penetration Scenarios for PHEVs

Can the electric power grid become a strategic national asset for addressing U.S. 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*

Fundamental Approach 1: Determine Available Marginal Generation

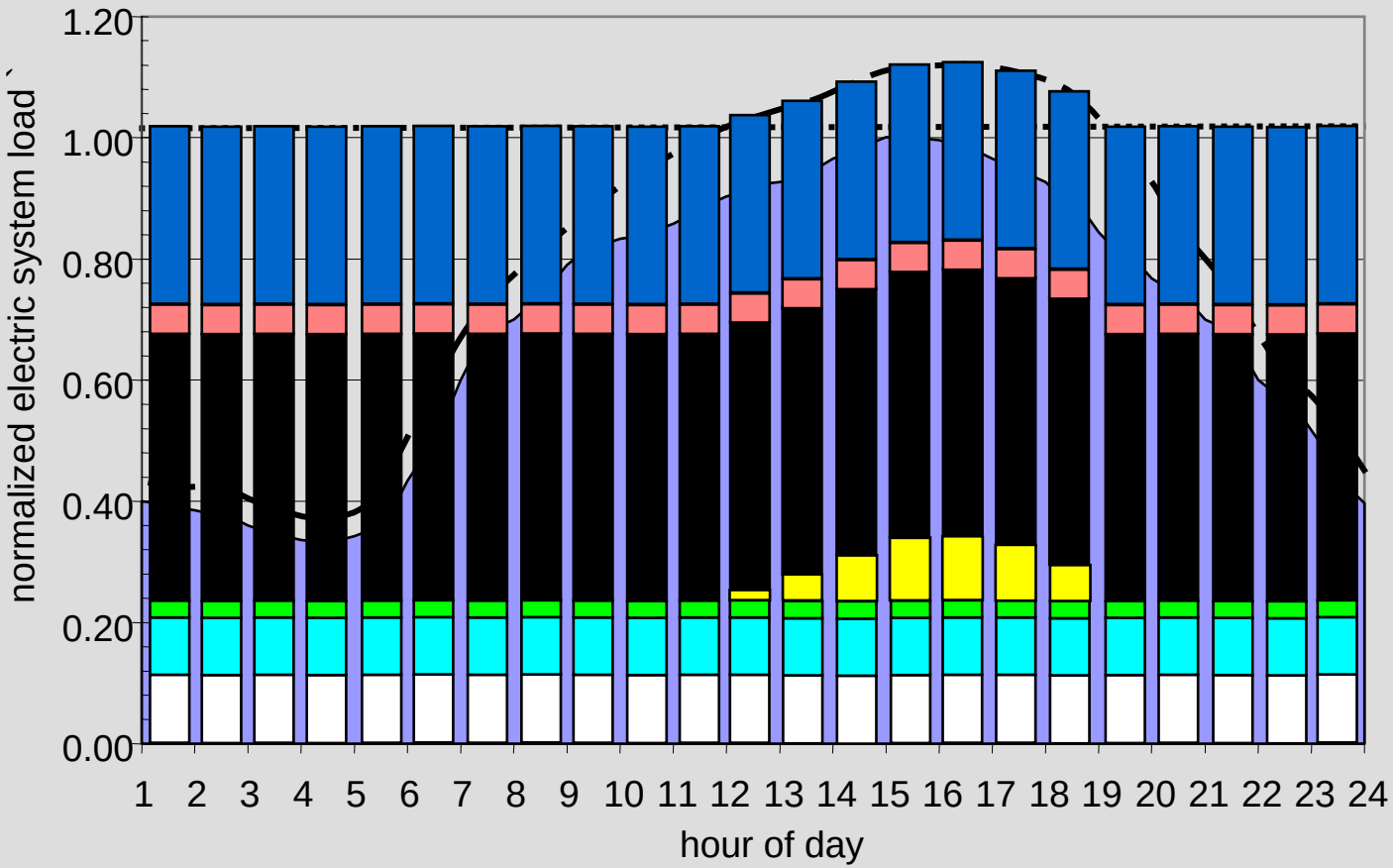


Assumptions:

No additional generation from existing:

- *Nuclear*
- *Hydro*
- *Renewables*
- *Combustion Turbines (peaking plants)*

Fundamental Approach 2: "Fill the Valley" in the Load Shape

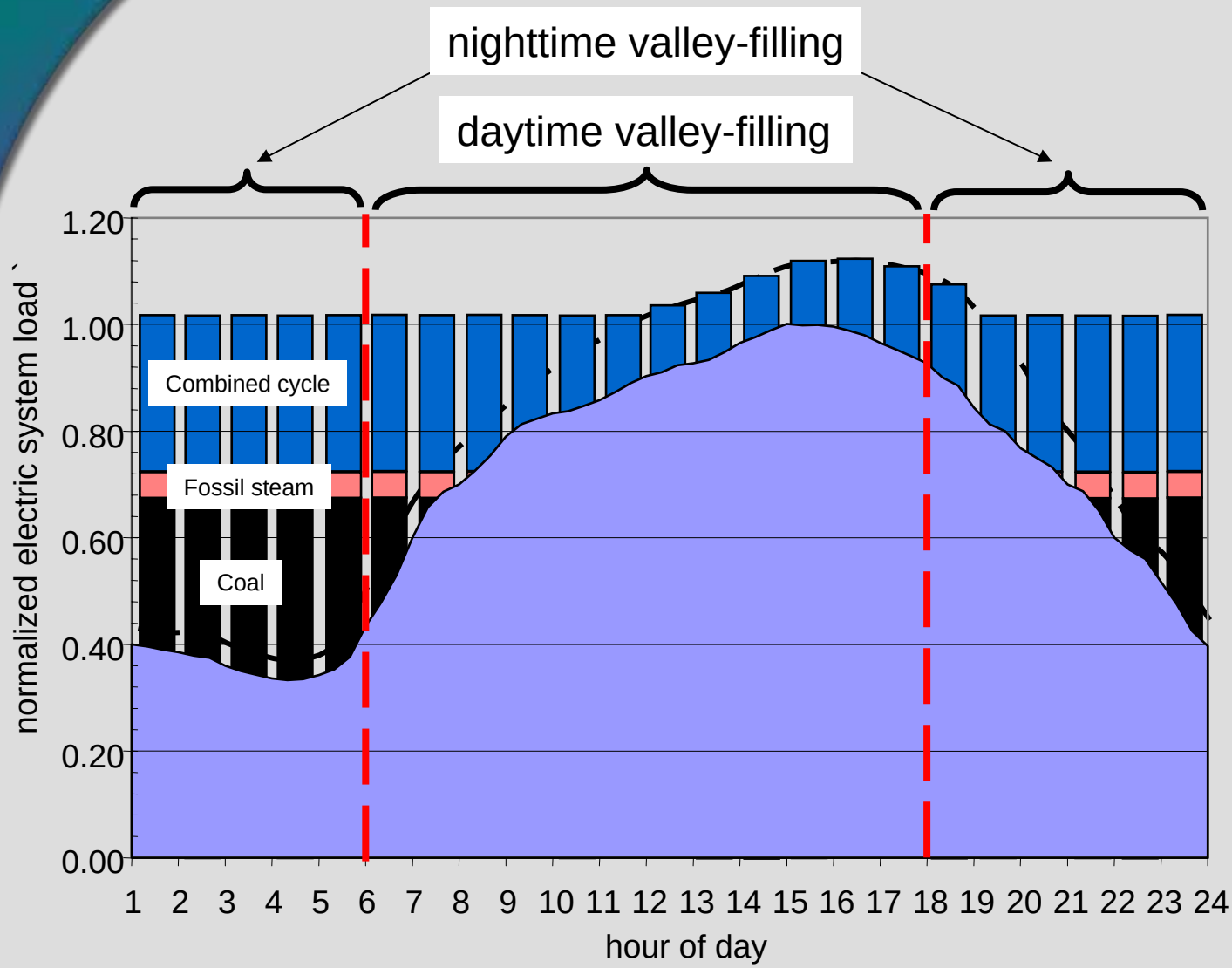


Assumption:

Additional valley-filling generation constrained to lesser of:

- *Available marginal generation @ 85% capacity factor*
- *Peak load*

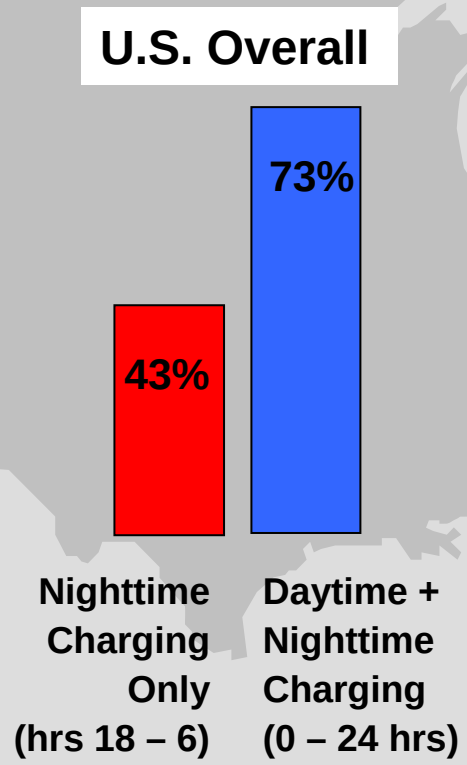
Coal, Nat. Gas Power Plants Fill the Valley



Summary

- Determine size of valley in MWh
  - Floor: average day in the peak season
  - Ceiling: lesser of available marginal generation @ 85% or peak load
- No marginal added generation in valley from:
  - Hydro
  - All other renewables
  - Nuclear
  - Peaking plants

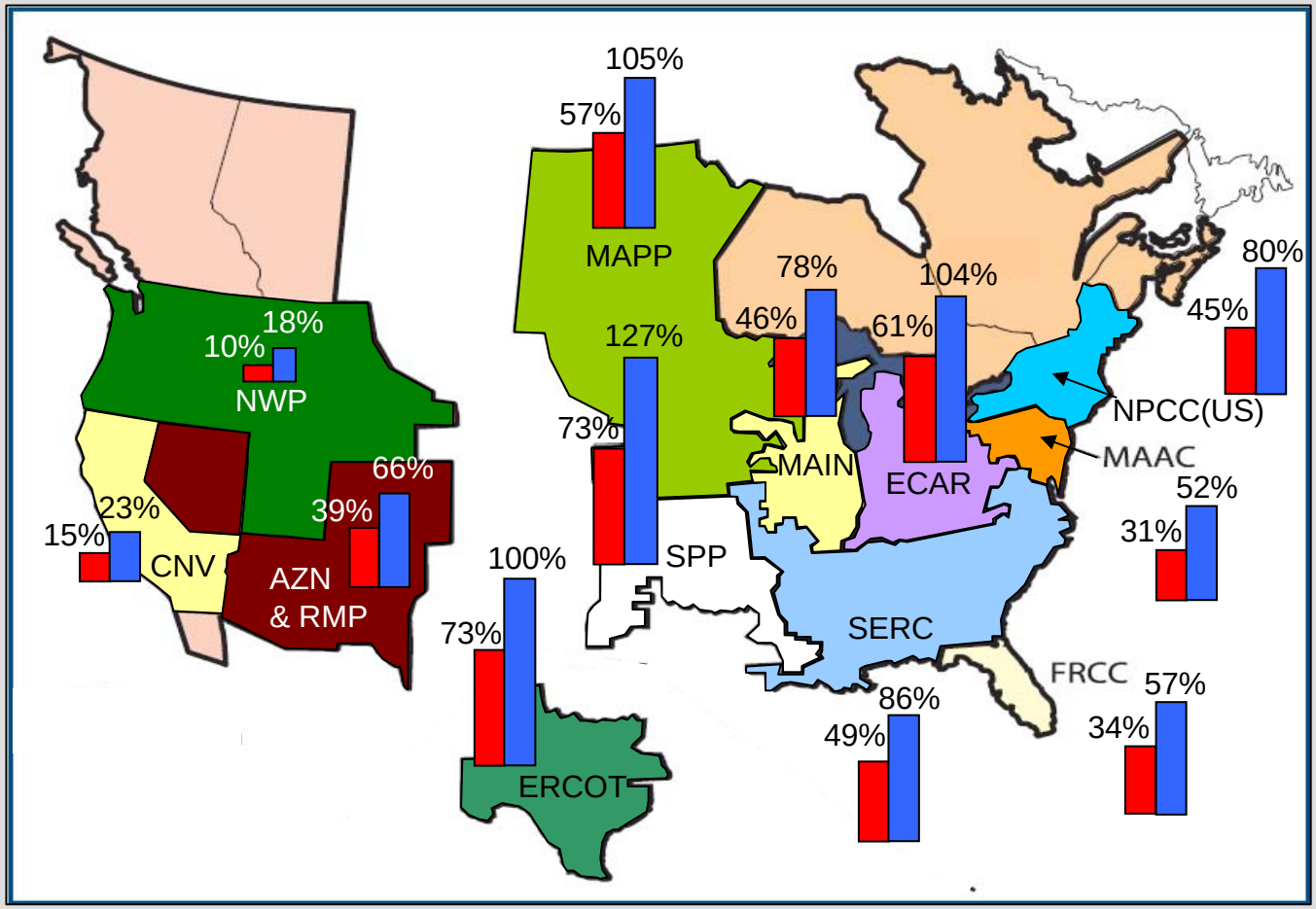
Over 70% of the existing U.S. light-duty vehicle fleet (if PHEVs) could be fueled with available off-peak electric capacity

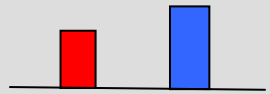


Assumptions

- 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

Analysis by NERC Region*





Nighttime Charging Only (hrs 18 – 6)

Daytime + Nighttime Charging (0 – 24 hrs)

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

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

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

Existing coal plants break even on greenhouse gases

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

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									0.01	0.01	0.01
CO	0.00	0.01						0.00	0.00	0.00	0.00		0.00
NOx	0.10	0.11						0.10	0.11	0.10			0.10
Particulates	0.60	0.62											0.61
SOx	0.35	0.04	0.14	0.30	0.51	0.05	0.17						0.19

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

+

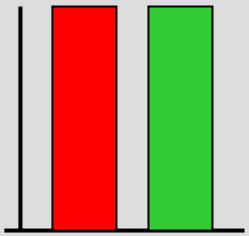
Same infrastructure, same capital investment

=

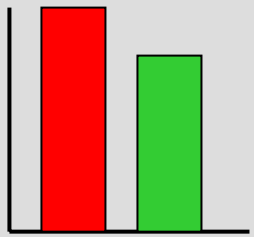
Lower avg. cost of electricity

kWh Produced

MW Capacity, Capital Investment

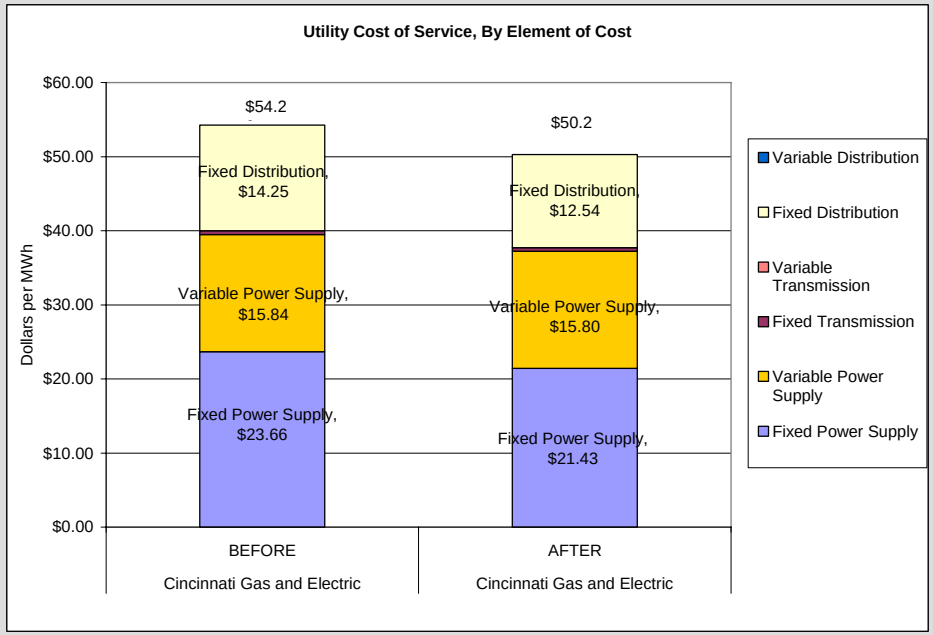


$/kWh



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

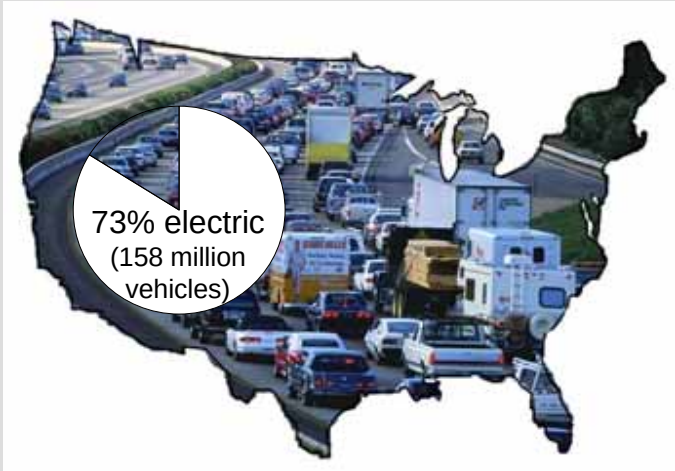
Cincinnati Gas & Electric Costs/MWh with PHEV Valley Filling

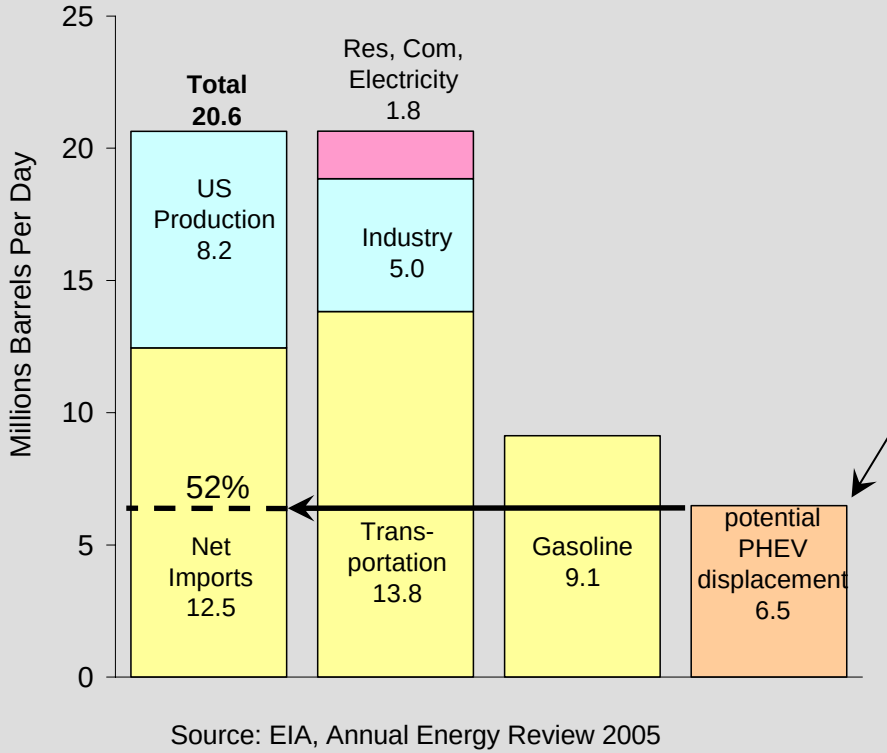


Summary

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

without adding generation or transmission if vehicles are charged off peak





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

But, If Charged at Peak Times Electricity May Not be Affordable for PHEVs

- Value proposition works for vehicle & utility customers only when off-peak power is used
  - off-peak, retail: 7 ¢ /kWh electricity - > \$0.77/gal_e*
  - on-peak, retail: 33 ¢ /kWh electricity - > \$3.63/gal_e*

    * Southern Calif. Edison: TOU-EV1 electric vehicle time-of-use rate
  - adding generation, transmission, & distribution to meet new peak loads will drive rates higher not lower
- Smart charger as an element of a smart grid can:
  - communicate price signals to charger
  - enforce contract terms for cheap power
  - mitigate reliability concerns

Smart PHEV Chargers Help Keep the Lights On: Vehicle-to-Grid and Vehicle-to-Home

- Storage has long been the "Holy Grail" for the grid
  - Batteries in today's cars (fully charged) could supply the entire U.S. for 20 minutes!
  - Batteries in the analyzed fleet of PHEVs could supply the U.S. for 5 hours!!!
  - Electric vehicles are the highest value use for batteries
- Smart charger & smart grid can mitigate stress of running grid near capacity
  - Grid Friendly™ chargers can be interrupted when grid is in trouble – "no harm/no foul" – *near term*
  - Vehicle-to-Home: PHEV powers a home in emergencies, take it "off line" when prices are high – *mid term*
  - Vehicle-to-Grid: PHEV feeds power back into the grid, selling reliability services (regulation, spinning reserve) at a profit – *long term?*

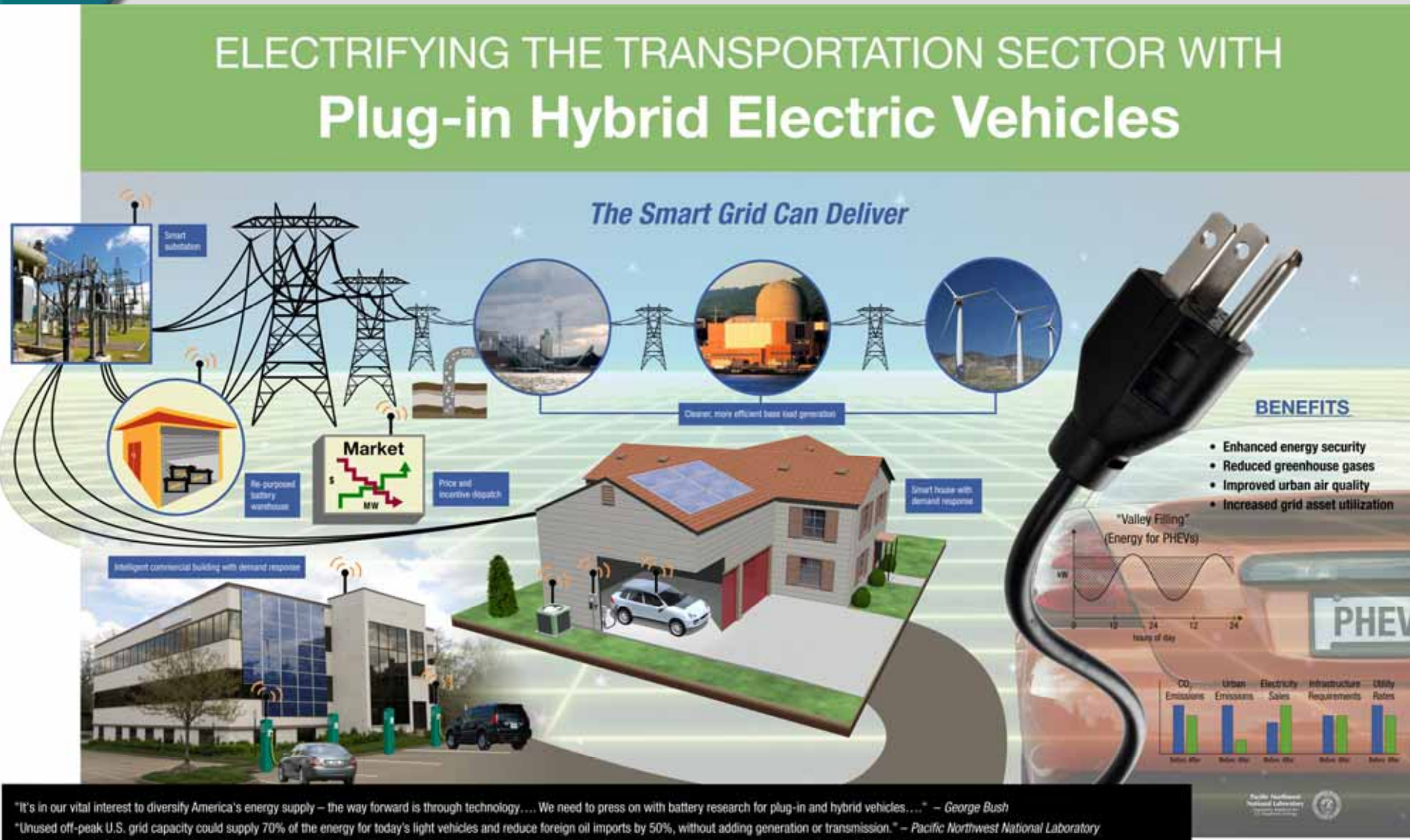
FY07/08: Follow-on Study*

- University of Michigan, working with auto industry, using their consumer research & automotive competency to:
  - determine validated market penetration scenarios for PHEVs
  - establish PHEV charging load shapes (preferred, price-influenced, etc.)
- PNNL will apply expertise in grid analysis to
  - distribution system bottlenecks (with Detroit's DTE Energy)
  - effects of PHEV load on
    - coal and natural gas prices impacts
    - future power plant mix, including: nuclear, renewable portfolio requirements, emissions caps

  … and hence electricity prices and emissions

** jointly funded by Offices of Electricity and Energy Efficiency*

Smart Grid Can Deliver the Electricity for Millions of PHEVs



"It's in our vital interest to diversify America's energy supply – the way forward is through technology…. We need to press on with battery research for plug-in and hybrid vehicles…." – *George Bush*

"Unused off-peak U.S. grid capacity could supply 70% of the energy for today's light vehicles and reduce foreign oil imports by 50%, without adding generation or transmission." – *Pacific Northwest National Laboratory*

"Nationwide adoption of plug-in hybrids will increase the use of domestically produced electricity and can ultimately reduce greenhouse gas emissions by up to 800 million tons per year." – *EPRI*

"Rarely in history has an emerging technology offered such an attractive opportunity … as both a new load and resource, to enhance overall performance of the electric power infrastructure." – *National Renewable Energy Laboratory*

"Working with automakers and local utilities, we need to understand how large numbers of PHEVs will be used, and their effect on the grid." – *University of Michigan*