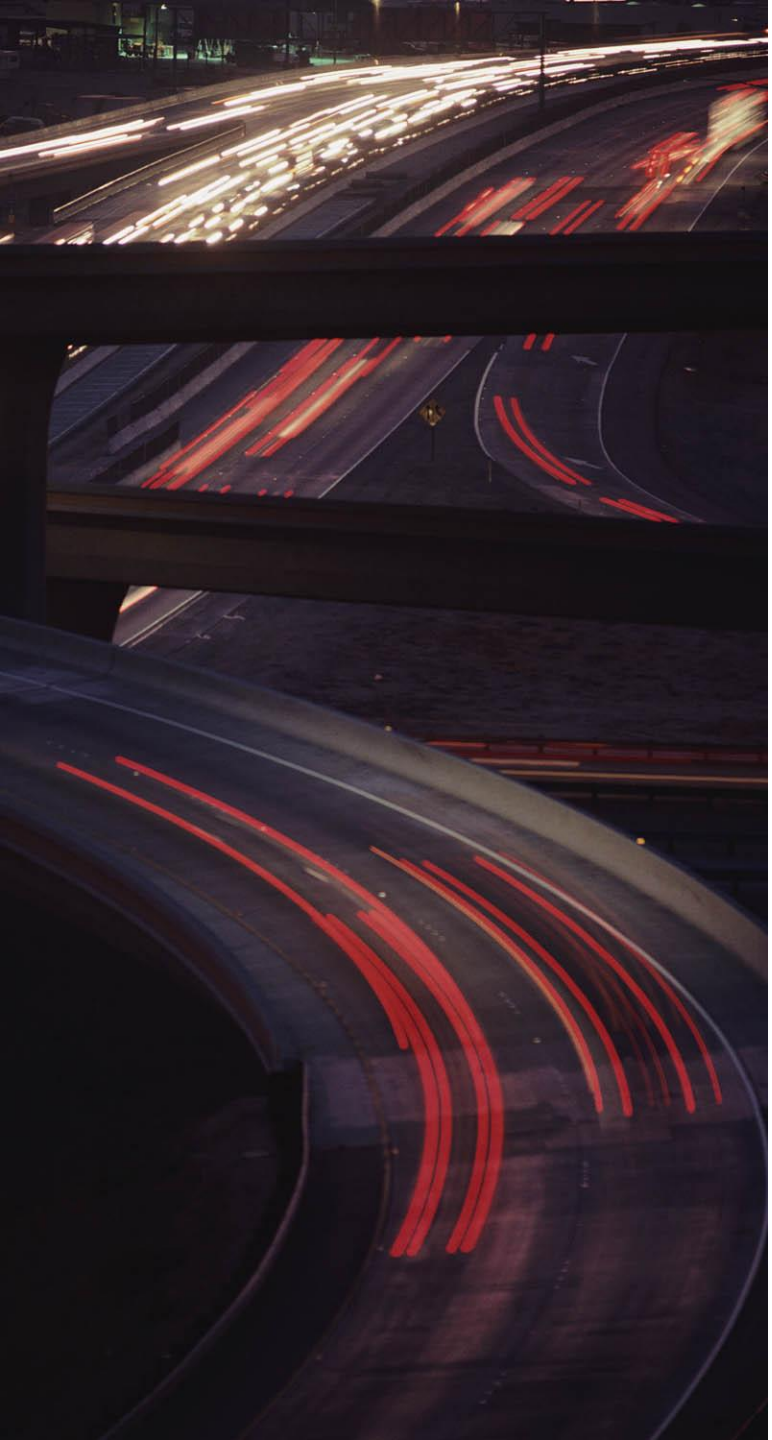

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Environmental Assessment of Plug-In Hybrid Electric Vehicles (PHEVs):

Handout to EPA Integrated Nitrogen Committee

Eladio M. Knipping, Ph.D.
Senior Technical Manager, Environment

May 14, 2009

Collaborative Study

Environmental Assessment of Plug-in Hybrid Vehicles

Volume 1: Nationwide Greenhouse Gas Emissions

Volume 2: United States Air Quality Analysis Based on AEO-2006 Assumptions for 2030

Joint report available at: www.epri.com/et

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Introduction

- **Plug-in Hybrid Electric Vehicles:**
  - Reduce net greenhouse gas emissions
  - Lower petroleum dependency
  - Improve air quality
  - Lower atmospheric deposition

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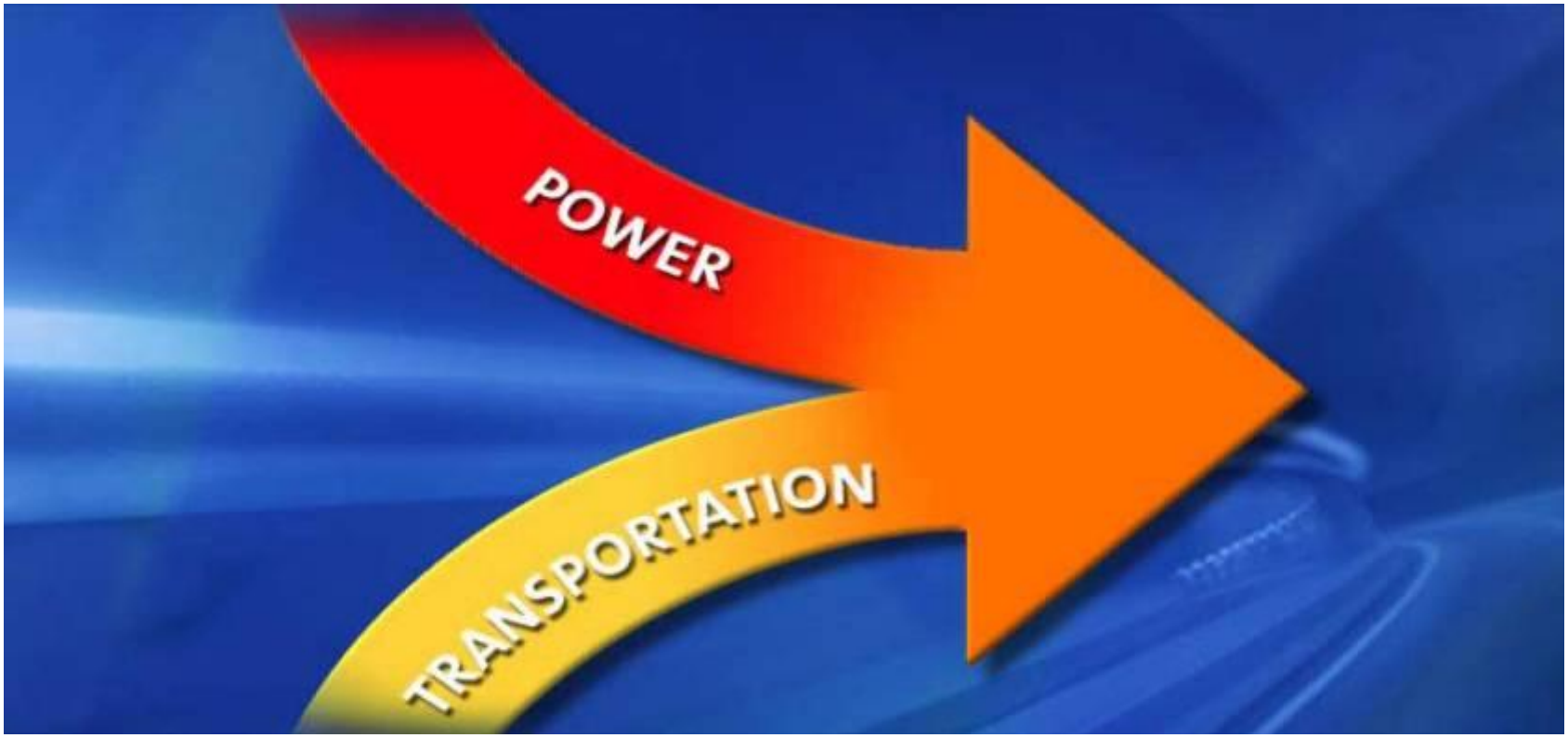
Fundamental Convergence



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Understanding Environmental Impacts of Plug-In Hybrid Electric Vehicles

- Environmental impacts of shifting vehicle energy supply from petroleum to electricity

- Location and characteristics of vehicle and power plant emissions are different
  - Temporal, spatial, chemical
- Electricity supplied by diverse mix of fuels and plant technologies
- New technologies take time to penetrate vehicle fleet
- Generation capacity and economics evolve over time
  - Energy pathway analyses (e.g., GREET) are insufficient to appropriately model these changes

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Scope and Methodology Climate Task

- Nationwide greenhouse analysis
  - Based on EPRI electric system model (NESSIE)
    - Electric sector evolves over time
    - Least-cost economics
      - Monetization of emission allowances
      - Capital and O&M costs of technology options
    - Capacity expansion and retirement
    - Production simulation (dispatch modeling)

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Scope and Methodology Climate Task

- Cross-scenario matrix = 9 evaluations
  - Different transportation sector & PHEV technology/adoption scenarios
  - 2010 to 2050 timeframe

2050 Annual CO_2e Reduction (million metric tons)		**Electric Sector CO_2 Intensity**		
		High	Medium	Low
PHEV Fleet Penetration	Low			
	Medium			
	High			

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The Future of the Electric Sector
Three Possible Scenarios

Key Parameters

- Value of CO_2 emissions allowances
- Plant capacity retirement and expansion
- Technology availability, cost and performance
- Electricity demand

Scenario Definition	High CO_2	Medium CO_2	Low CO_2
Cost of CO_2 Emissions Allowances	Low	Moderate	High
Power Plant Retirements	Slower	Normal	Faster
New Generation Technologies	Unavailable: Coal with CCS New Nuclear New Biomass	Normal Technology Availability and Performance	Available: Retrofit of CCS to existing IGCC and PC plants
	Lower Performance: SCPC, CCNG, GT, Wind, and Solar		Higher Performance: Solar
Annual Electricity Demand Growth	1.56% per year on average	1.56% per year on average	2010 - 2025: 0.45% 2025 - 2050: None

SCPC – Supercritical Pulverized Coal
GT – Gas Turbine (natural gas)
CCNG – Combined Cycle Natural Gas
CCS – Carbon Capture and Storage

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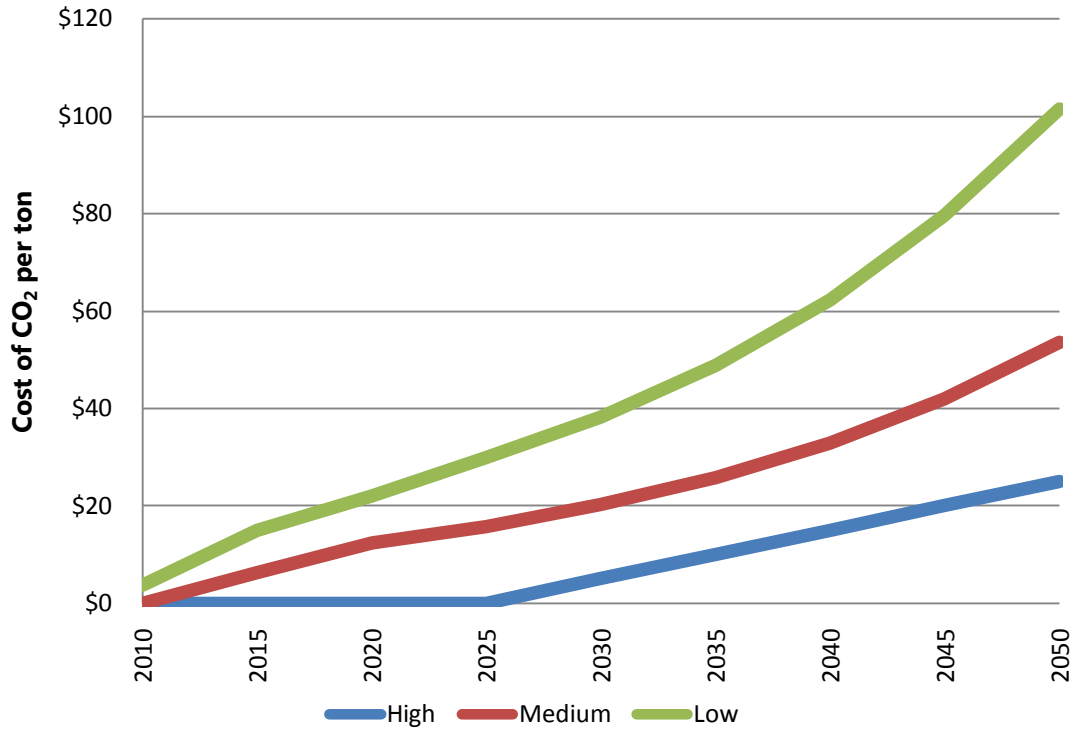
Value of CO_2 Emission Allowances

- CO_2 emissions in model controlled by applying a cost to emit on power plant fuel and stack emissions
- Higher CO_2 costs increase cost of power from higher emitting technologies
- Model calculates CO_2e includes CO_2, N_2O, and CH_4 emissions from upstream fuels



Carbon Dioxide Equivalents:

$CO_2e = CO_2 + 23 \times CH_4 + 296 \times N_2O$

Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis*

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PHEV Assumptions

- Base vehicles derived from EPRI 2001 and 2002 consensus studies on benefits and impacts of HEVs
- PHEVs available up to Class 5 vehicles (19,500 lb GVW)
- Technology options include PHEV 10, 20 and 40
  - No PHEV-60, no BEVs or FCVs

- Vehicle assumptions coordinated with MOBILE6 and EMFAC mobile emissions databases
  - PHEV and HEV have same fuel economy on gasoline
  - PHEV electricity usage dependent on battery size, annual vehicle miles travelled (VMT)
  - Electric VMT (eVMT) reduces on-road emissions and gasoline consumption

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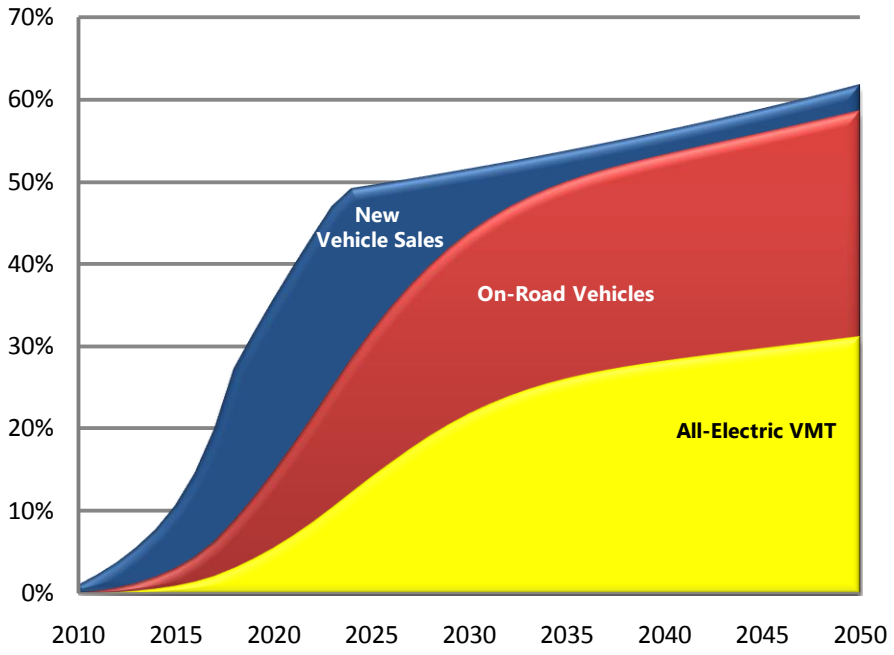
PHEV Market Share and Electric VMT Fraction
Medium Scenario

- Low, Medium, High PHEV market penetration scenarios
- Corresponds to 20%, 60%, and 80% peak market share by 2050
- New vehicles take time to penetrate fleet



Growth of PHEVs and eVMT

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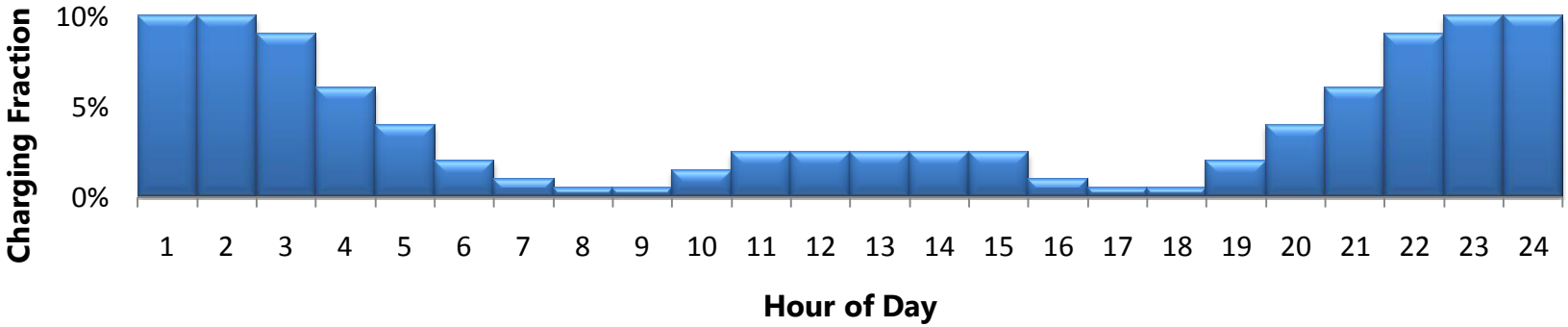
PHEV Charging Profile Assumptions

- Base Case represents 74% of energy delivered from 10:00 pm to 6:00 am, 26% between 6:00am and 10:00 pm
- Vehicle charged primarily, but not exclusively, at each vehicle's "home base"
- Owners incentivized or otherwise encouraged to use less expensive off-peak electricity
- Charge onset delays built into near-term vehicles—allow battery system rest and cooling before recharge
- Long-term with large PHEV fleets, utilities will likely use demand response or other programs to actively manage the charging load



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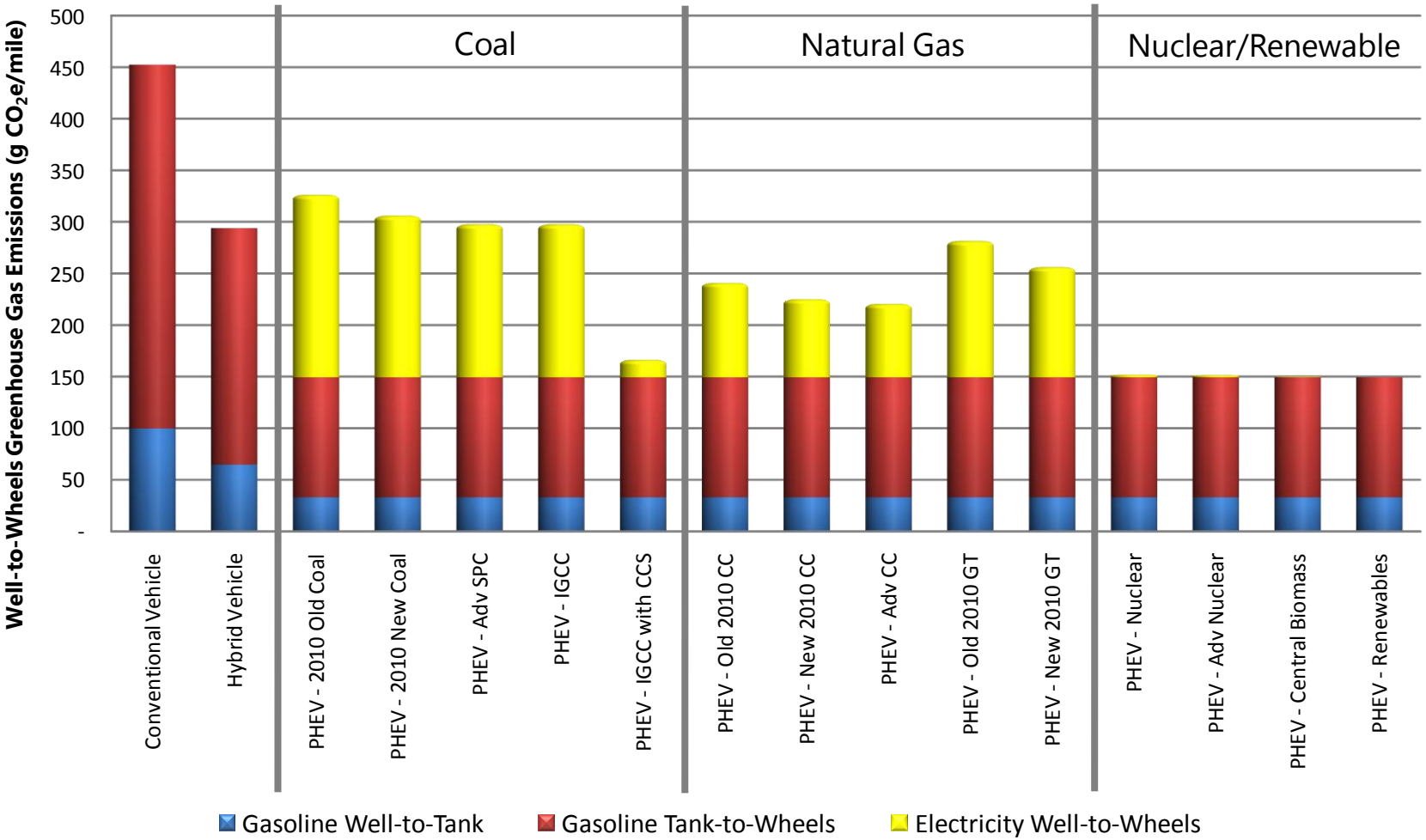
Power Plant-Specific PHEV Emissions in 2010
PHEV 20 – 12,000 Annual Miles



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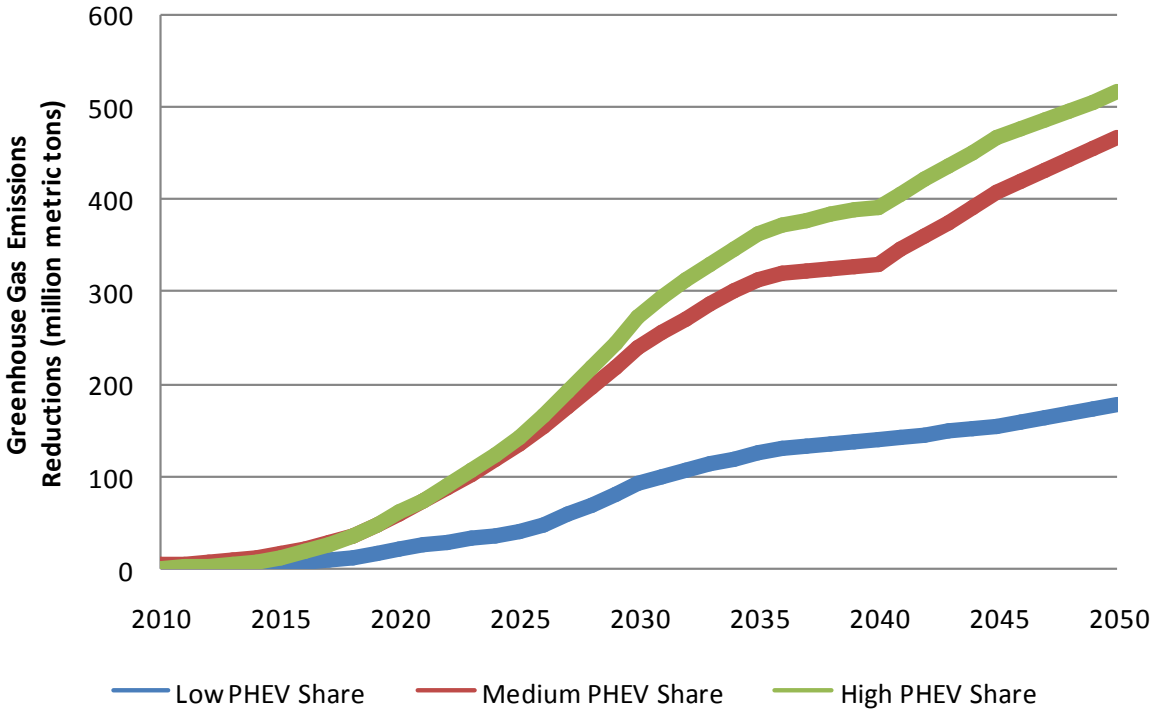
Greenhouse Gas (GHG) Emissions

- Electricity grid evolves over time
- Nationwide fleet takes time to renew itself or "turn over"
- Impact would be low in early years, but could be very high in future
- A potential 400-500 million metric ton annual reduction in GHG emissions



Annual Reduction in GHG Emissions due to PHEV Adoption

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Overall CO_2e Results

- All nine scenarios resulted in CO_2e reductions from PHEV adoption
- Every region of the country will see reductions
- In the future, PHEVs charged from new coal (highest emitter) w/o CCS roughly equivalent to HEV, superior to CV
  - There is unlikely to be a future electric scenario where PHEVs do not return CO_2e benefit

2050 Annual CO_2e Reduction (million metric tons)		**Electric Sector CO_2 Intensity**		
		High	Medium	Low
PHEV Fleet Penetration	Low	**163**	**177**	**193**
	Medium	**394**	**468**	**478**
	High	**474**	**517**	**612**

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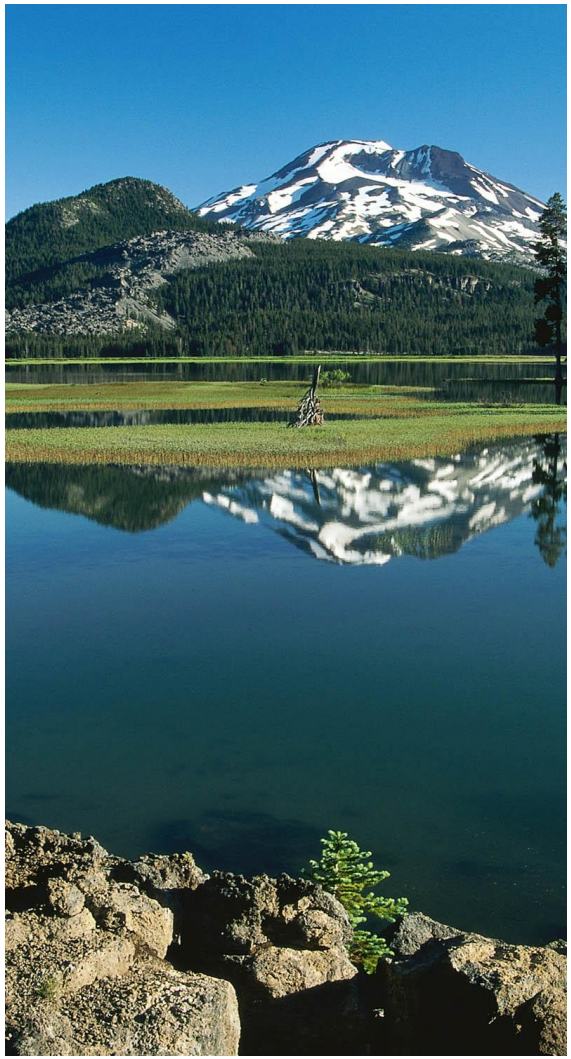
Scope and Methodology Air Quality Task



- **Consistent with U.S. Department of Energy's 2006 Annual Energy Outlook (AEO)**
- **Two Scenarios in 2030:**
  - 0% and Medium PHEV Penetration
    - >50% Sales Penetration
    - >40% Fleet Penetration; >20% eVMT
  - Model power-plant capacity expansion, generation and emissions using North American Electricity and Environment Model (NEEM)
    - Renewable Portfolio Standards (RPS)
    - California Million Solar Roofs Initiative
    - Includes EPA regulations
  - Full-year air quality analysis using three-dimensional air quality model

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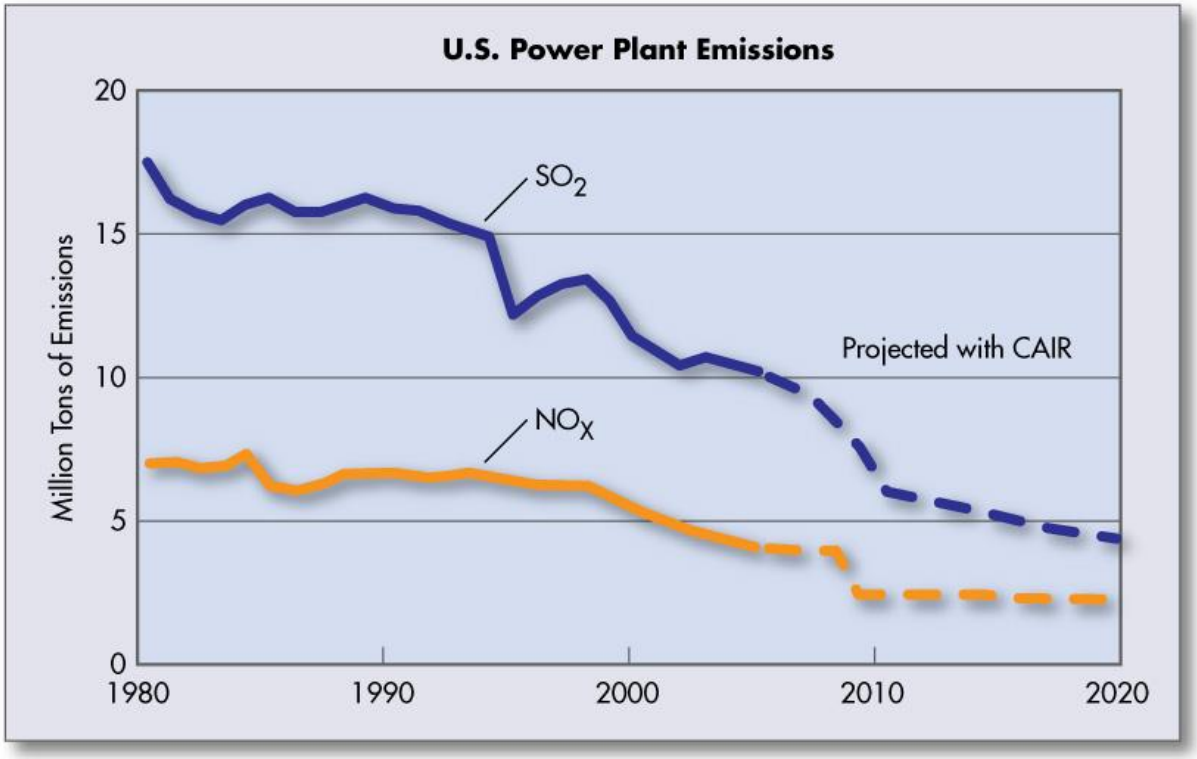
U.S. Power Plant Emissions Trends



- Power plant emissions of SO_2 and NOx will continue to decrease due to tighter federal regulatory limits (caps) on emissions
- Additional local and national regulations further constrain power plant emissions
- Air quality is determined by emissions from all sources undergoing chemical reactions within the atmosphere

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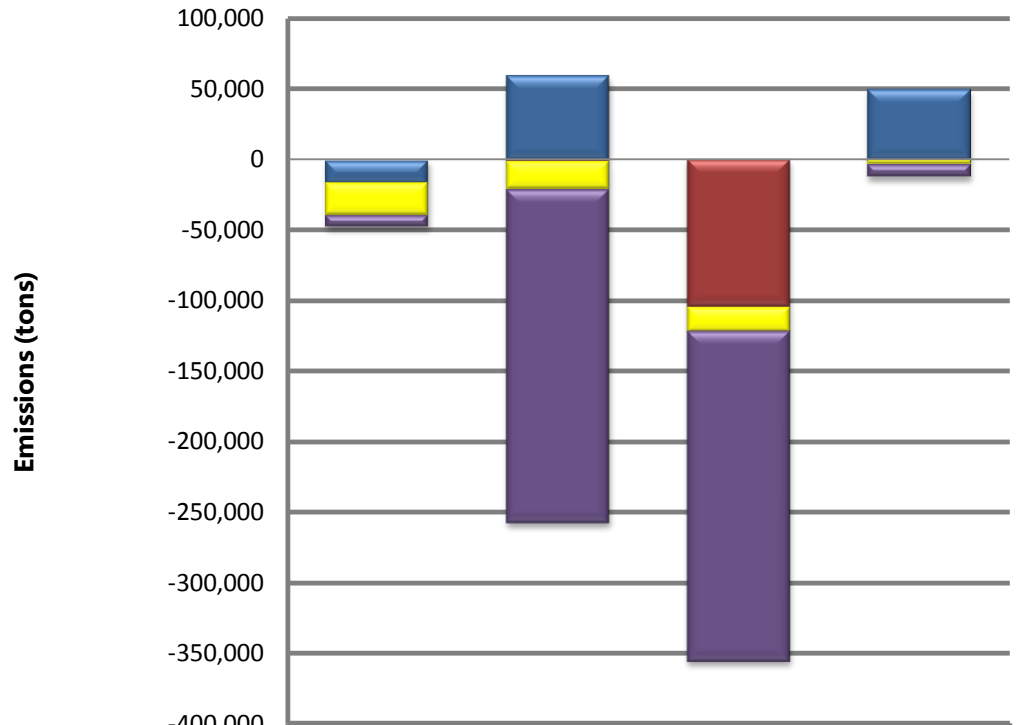
Net Changes in Criteria Emissions Due to PHEVs

Power Plant Emissions

- Emissions under caps (SO_2, NOx, Hg) are essentially unchanged
- Primary PM emissions increase (defined by a performance standard)

Vehicle Emissions

- NOx, VOC, SO_2, PM all decrease
- Significant NOx, VOC reductions at vehicle tailpipe
- Reduction in refinery and related emissions



	SOx	NOx	VOC	PM
On-Road Vehicle	-7,716	-236,292	-234,342	-9,255
Refinery and Other Stationary	-23,549	-20,076	-17,804	-3,282
Distributed Upstream	0	-1,293	-103,323	-101
Power Plant	-16,284	58,916	0	49,434
	-47,549	**-198,745**	**-355,469**	**36,796**

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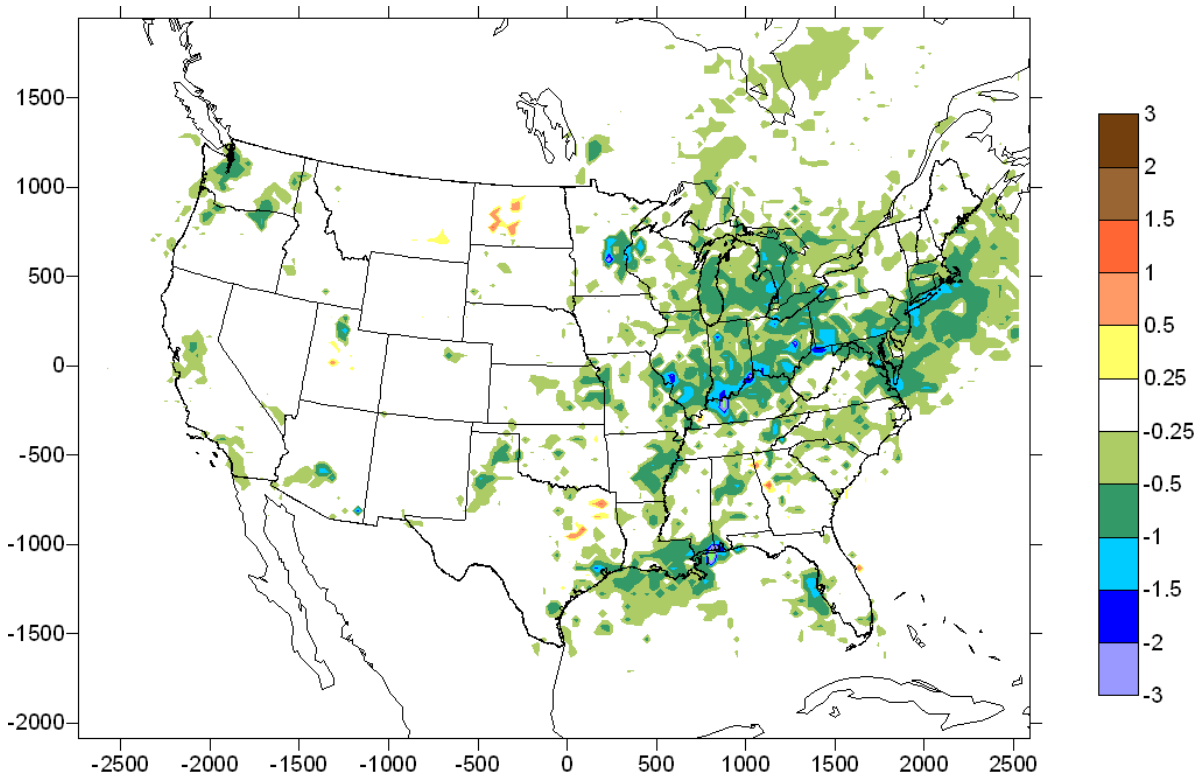
PHEVs Improve Overall Air Quality
Reduced Formation of Ozone

- Air quality model simulates atmospheric chemistry and transport
- Lower NOx and VOC emissions results in less ozone formation particularly in urban areas



Change in 8-Hour Ozone Design Value (ppb)
PHEV Case – Base Case

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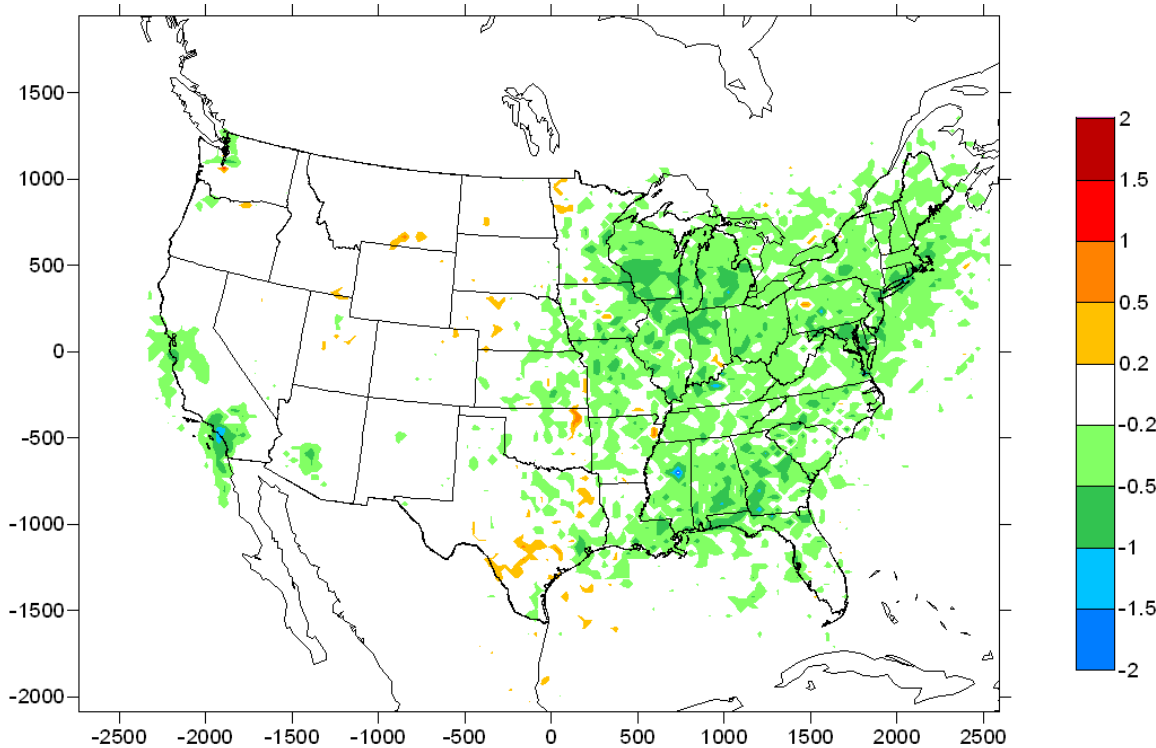
PHEVs Improve Overall Air Quality

Reduced Formation of Secondary $PM_{2.5}$

- $PM_{2.5}$ includes both direct emissions and secondary PM formed in the atmosphere
- PHEVs reduce motor vehicle emissions of VOC and NOx
- VOCs emissions from power plants are not significant
- Total annual SO_2 and NOx from power plants capped
- The net result of PHEVs is a notable decrease in the formation of secondary $PM_{2.5}$



Change in Daily $PM_{2.5}$ Design Value ($\mu g\ m^{-3}$)
PHEV Case – Base Case

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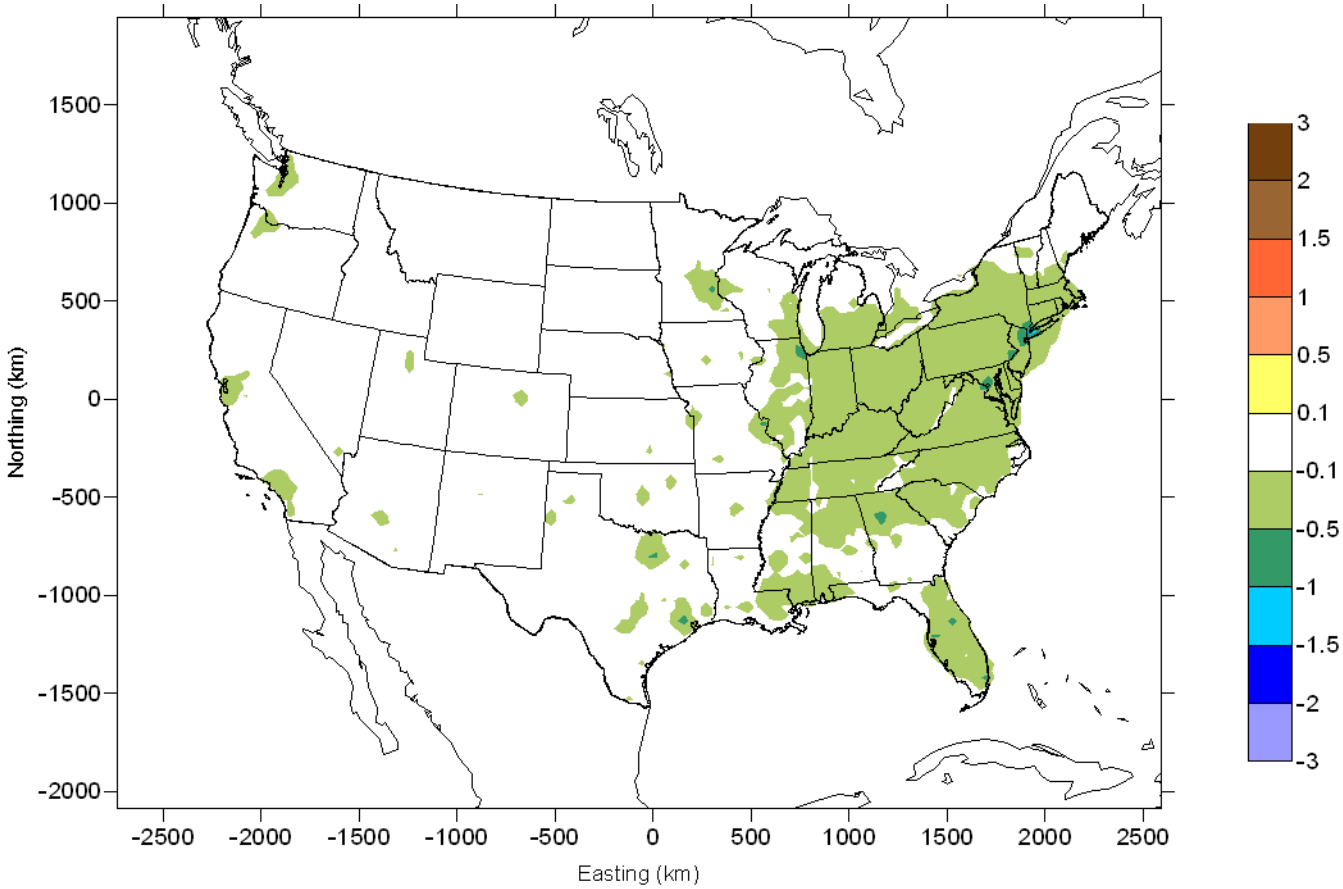
Nitrogen Deposition Impacts



Annual: Difference in Nitrogen deposition kg/hectare
PHEV - Base, 2030 - 36km domain

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Nitrogen Deposition Impacts

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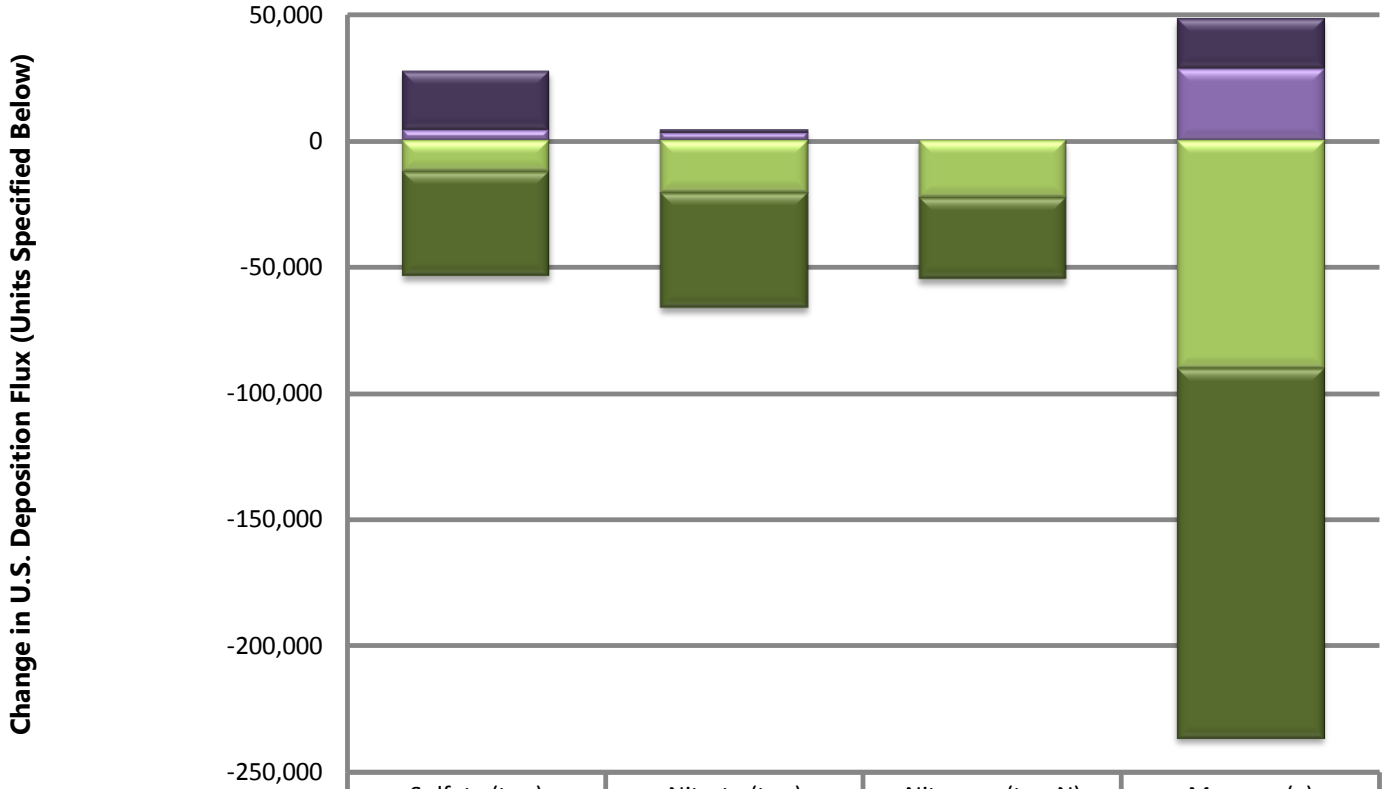
PHEVs Improve Overall Air & Water Quality

Reduced Deposition of Sulfates, Nitrates, Nitrogen, Mercury



	Sulfate (ton)	Nitrate (ton)	Nitrogen (ton N)	Mercury (g)
Benefit above Threshold	-41,472	-45,490	-32,413	-146,370
Benefit below Threshold	-12,416	-20,995	-22,784	-90,202
Disbenefit above Threshold	23,211	1,581	0	19,712
Disbenefit below Threshold	4,562	3,396	233	28,693
	-26,114	**-61,508**	**-54,963**	**-188,166**

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Environmental Conclusions

- The electric sector is resilient and responsive to technological and environmental challenges

- Plug-in hybrid electric vehicles represent a convergence of the electric and transportation sectors that provides solutions to several environmental issues

  - Reduce greenhouse gas emissions
  - Lower petroleum dependency
  - Improve air quality
  - Enable the use of strategies to ease stress on water resources
  - Decrease acid deposition and nutrient (nitrogen) loadings to sensitive waterbodies

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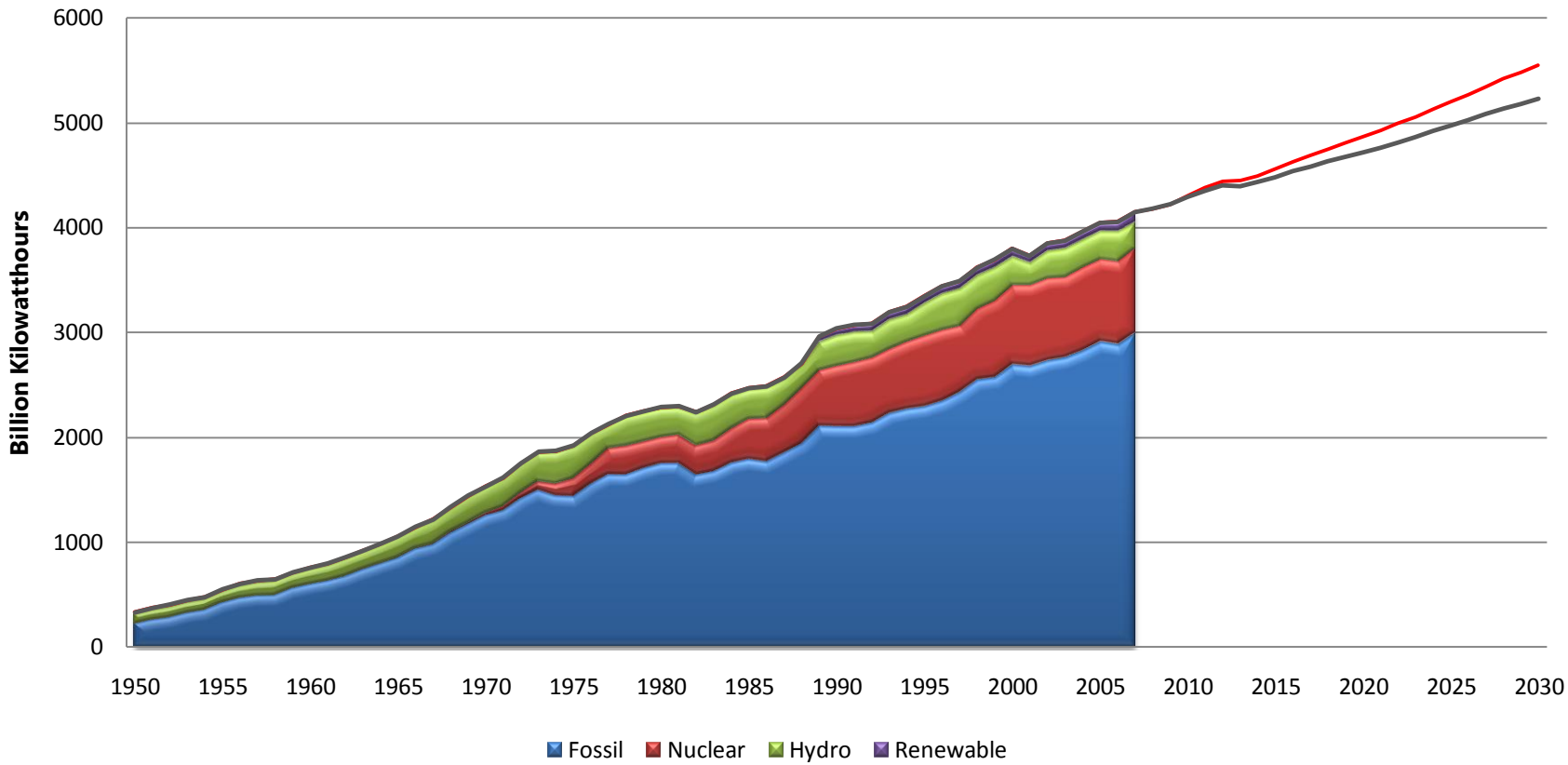
Power Generation in the United States



- Moderate electricity demand growth: ~8%
- Capacity expansion required: ~3%
- **3-4 million barrels per day in oil (Medium PHEV Case, 2050)**

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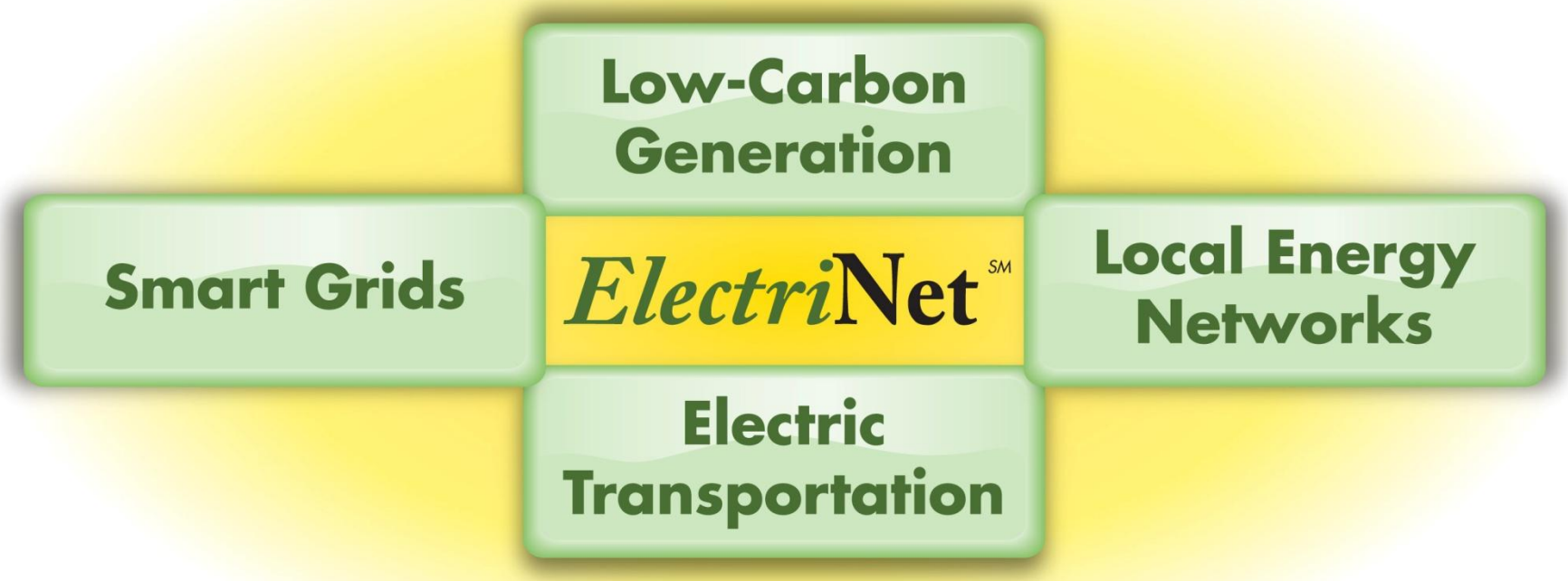
Action Framework… Four Evolving Infrastructures



Creating the Electricity Network of the Future

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