Effect of Location and Driving Conditions on Plug-in Vehicle Benefits

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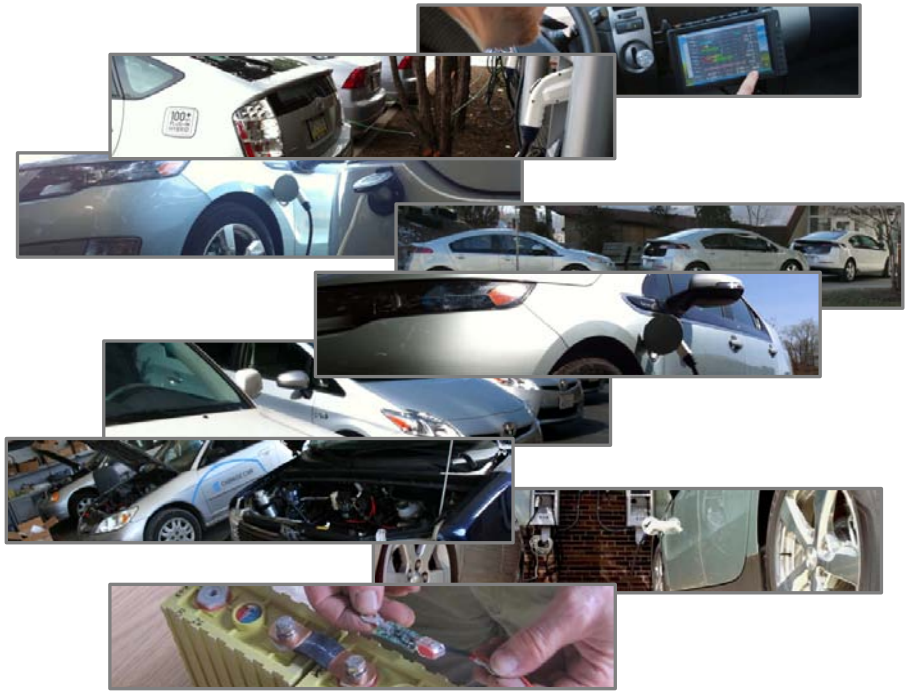
Vehicle Electrification Group



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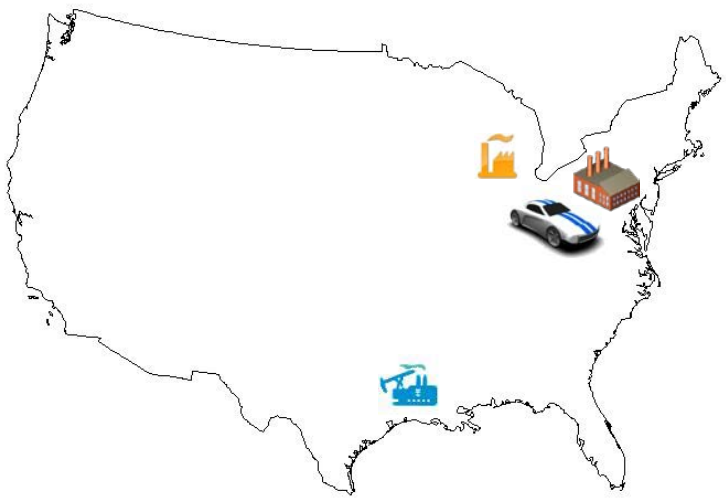
Plug-in Vehicle Benefits

- **Offset gasoline use**
  - Reduces oil dependency
- **Change air-emissions profile**
  - Fewer emissions associated with gasoline production and combustion
  - More emissions associated with battery and electricity production

Economic Value of Benefits

- **Life cycle**
  - Vehicle and battery production
  - Gasoline production & distribution
  - Electricity production & distribution
  - Vehicle operation

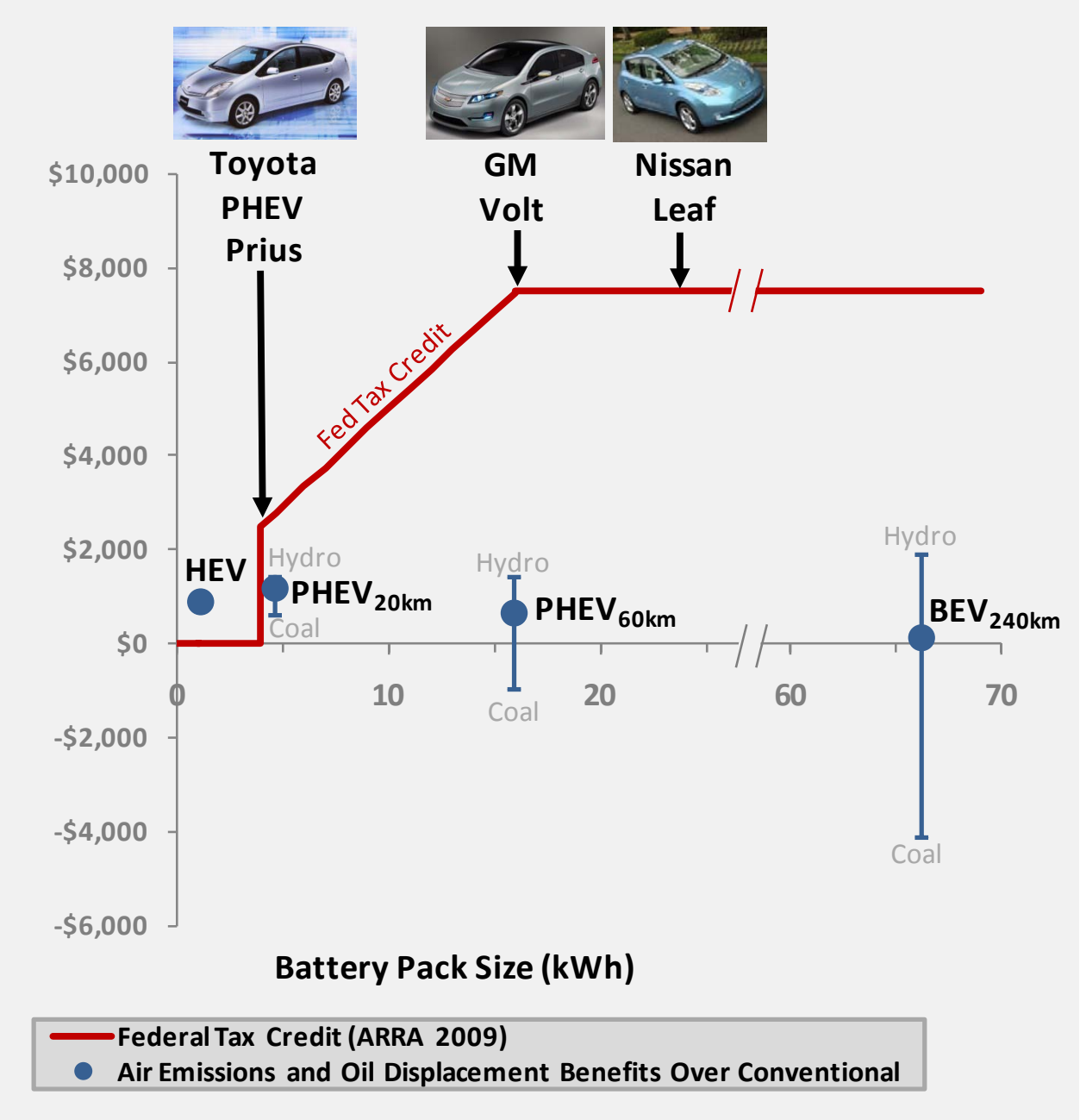


- **Air emissions**
  - Human health costs
  - Agriculture
  - Infrastructure
  - GHGs: climate change
- **Petroleum consumption**
  - Supply vulnerability
  - Monopsony premium
  - Military spending

Value of Plug-in Vehicle Benefits

Air emissions and oil premium costs

- Social benefit << $7500 fed tax credit, small compared to cost
- For batteries, bigger is not necessarily better
- To be a good value, plug-in vehicles must be cost-competitive

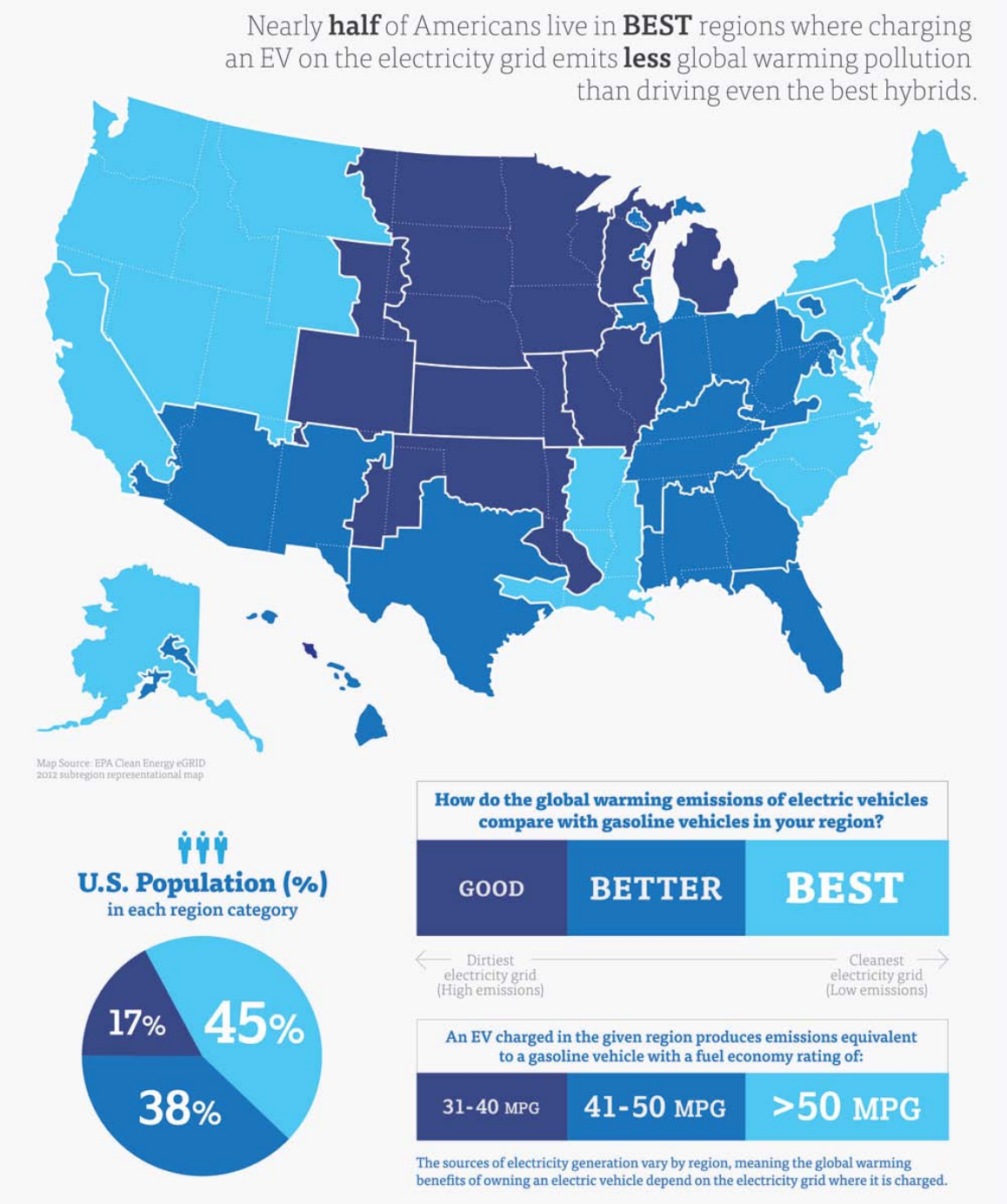


Michalek, Chester, Jaramillo, Samaras, Shiau, and Lave (2011) "Valuation of plug-in vehicle life cycle air emissions and oil displacement benefits" *Proceedings of the National Academy of Sciences*, v108 n40 p16554-16558.

Benefits vary by region

Study: Union of Concerned Scientists

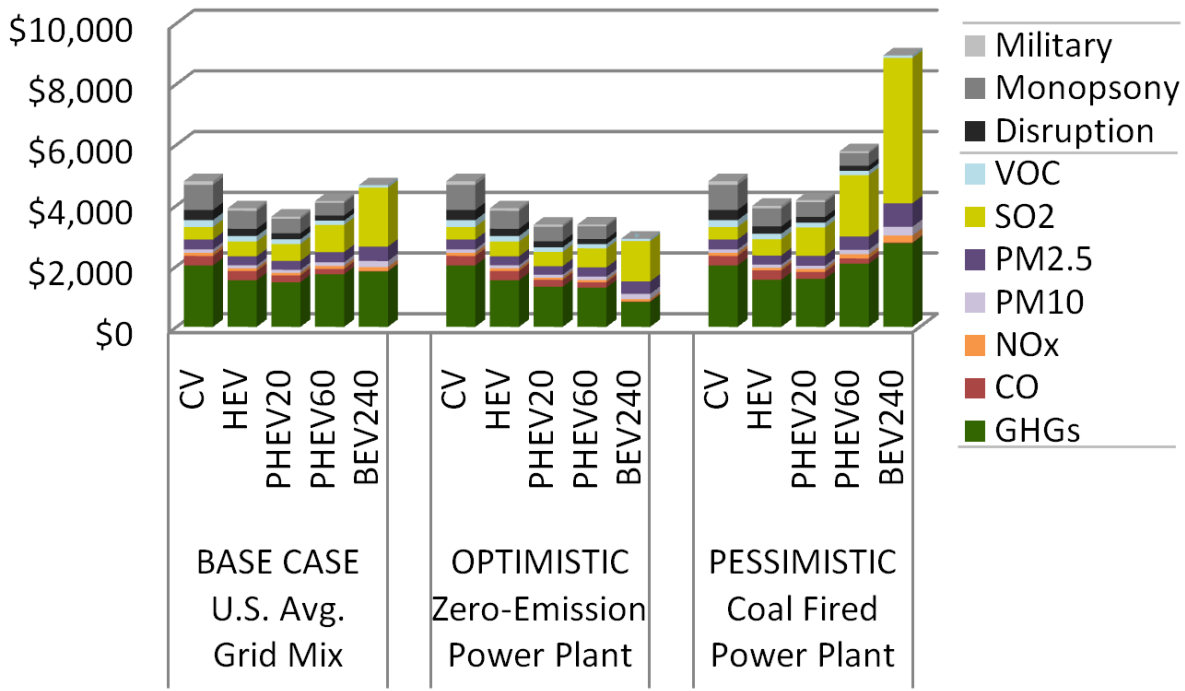
- Highlights regional differences in plug-in vehicle benefits based on grid mix
- But…
  - Not life cycle (ignores production emissions – big for batteries)
  - Sensitive to regional definition (based on primary utility serving city, Weber et al. 2010)
  - Uses average rather than marginal emissions
  - Ignores other emissions
  - Ignores other sources of regional variation…

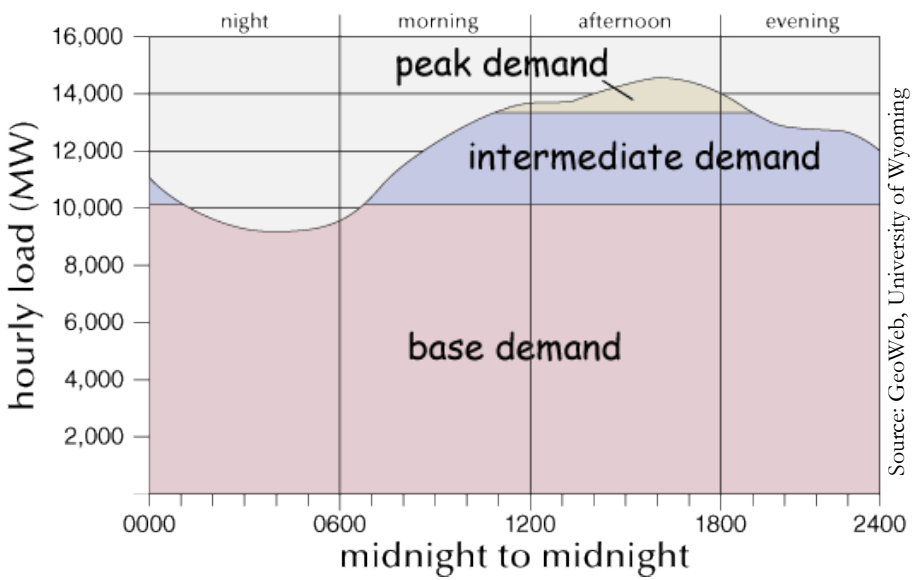


Anair and Mahmassani (2012) "State of charge: electric vehicles' global warming emissions and fuel-cost savings across the United States," Report, Union of Concerned Scientists.

Grid Mix

- **Marginal Grid Mix**
  - Depends on charge timing, fleet, feedstock prices, load profile.
  - In many regions coal is on the margin at night.





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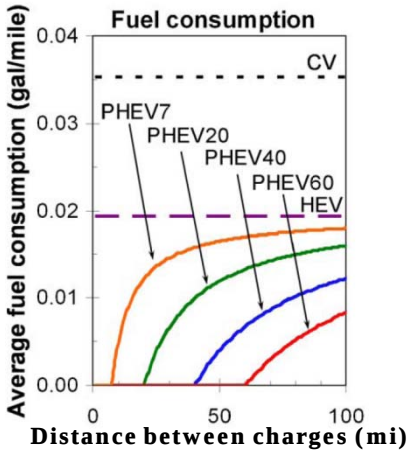
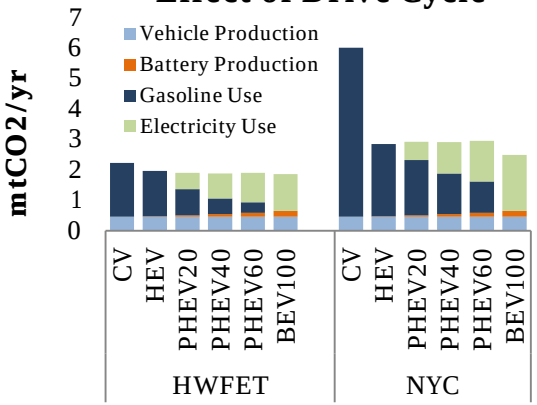
Fuel Consumption

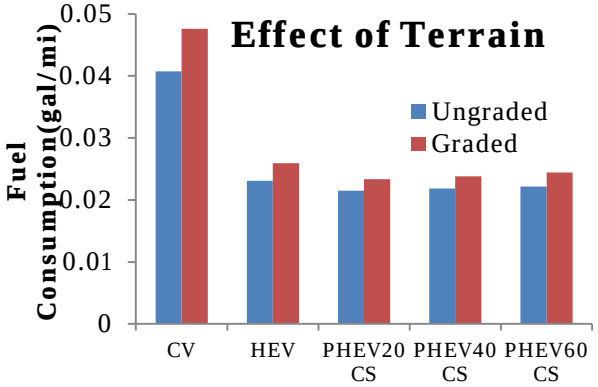
- **Driving Distance & Charging Patterns**
  - Short trip drivers can displace gasoline with small AER
  - Yet drivers with high VMT have best chance to pay off capital investment
  - Faster rate charging, workplace and retail charging, service station rapid charging or battery swapping enable more electric miles (at a cost)
- **Driving Style**
  - In highway conditions, xEVs cost more for low benefit
  - In NYC conditions, xEVs can cut cost 20% and emissions 50%
- **Terrain**
  - xEVs regen on hills, but Atkinson engine works hard in HEVs
- **Weather**
  - Heater cuts Leaf range by 15%, starts engine in Volt
  - Batteries die faster in Phoenix than Miami due to peak temperatures

Effect of Driving/Charging Pattern



Effect of Drive Cycle



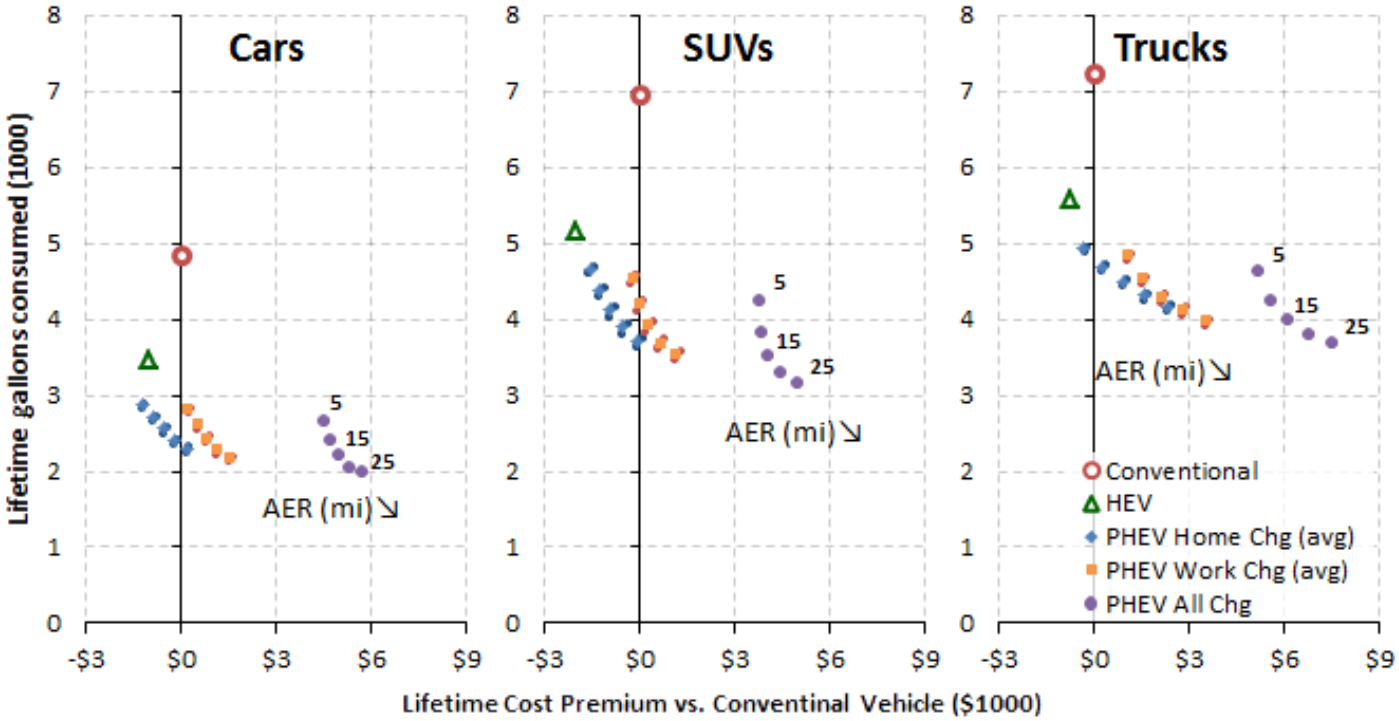


•Karabasoglu and Michalek (2012) "Influence of driving patterns on life cycle benefits of hybrid and plug-in vehicles," in review, *Energy Policy*.
•Peterson and Michalek (2013) "Cost effectiveness of plug-in hybrid electric vehicle battery capacity and charging infrastructure investment for reducing US gasoline consumption," *Energy Policy*, v52 p429-438.
•Shiau Samaras, Hauffe and Michalek (2009) "Impact of battery weight and charging patterns on the economic and environmental benefits of plug-in hybrid vehicles," *Energy Policy* v37 p2653-2663.
•Traut, Hendrickson, Klampfl, Liu and Michalek (2012) "Optimal design and allocation of electrified vehicles and dedicated charging infrastructure for minimum life cycle greenhouse gas emissions and cost," *Energy Policy*, v51 p524-534.
•Yuksel and Michalek (2012) "Evaluation of the effects of thermal management on battery life in plug-in hybrid electric vehicles," *Battery Congress*

Fleet

- **Displaced Fuel**
  - Benefit depends on whether displacing gasoline, diesel, E10, E85

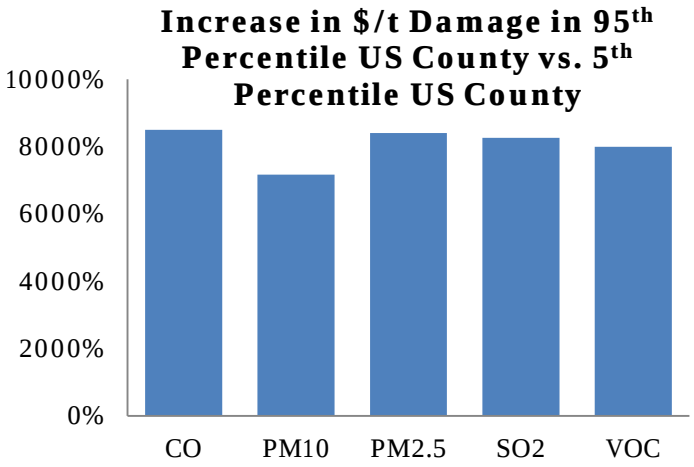
- **Vehicle Size/Class**
  - EV costs and benefits differ for large/small cars/trucks

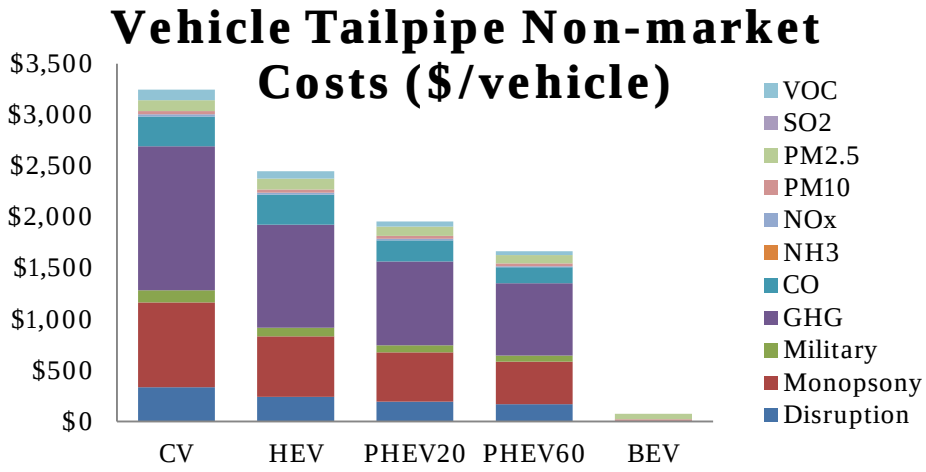


Peterson, S. and J.J. Michalek (2013) "Cost effectiveness of plug-in hybrid electric vehicle battery capacity and charging infrastructure investment for reducing US gasoline consumption," *Energy Policy*, v52 p429-438.

Impact

- **Population Density**
  - Emissions in dense areas do more damage
- **Pollutant Transport & Ambient Air Quality**
  - Marginal air pollutants do about 80× more damage in some dirty urban regions than in clean rural regions
- **Value of Statistical Live**
  - VSL is measured relative to a population's observed willingness to take risk for treasure, which varies by wealth of region (utilitarian ethical issues)
- **Oil Dependency Costs**
  - The non-market costs of oil consumption (e.g.: military costs) vary by nation





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Other Key Sources of Variability

	Variable	Importance
Grid	**Marginal grid mix**	Depends on charge timing, fleet, feedstock prices, load profile. In many regions coal is on the margin at night.
Fuel Consumption	**Driving distance**	Short trip drivers can displace much gasoline with small AER Yet drivers with high VMT have best chance to pay off capital investment
	Parking / charging infrastructure	Faster rate charging, workplace and retail charging, service station rapid charging or battery swapping enable more electric miles (at a cost)
	Driving style	In highway conditions, xEVs cost more for low/no benefit In NYC conditions, xEVs can cut cost 20% and emissions 50%
	Terrain	xEVs regen on hills, but Atkinson engine works hard in HEVs
	Weather	Heater cuts Leaf range by 15%, starts engine in Volt Batteries die faster in Phoenix than Miami due to peak temperatures
Fleet	**Displaced fuel**	Benefit depends on whether displacing gasoline, diesel, E10, E85
	Vehicle size/class	EV costs and benefits differ for large/small cars/trucks
Impact	**Population density**	Emissions in dense areas do more damage
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Vehicle Electrification

	Conventional	Hybrid-Electric	Plug-in Hybrid Electric	Battery Electric
	CV	HEV	PHEV	BEV
Power Convertor	Engine	Engine & Motor	Engine & Motor	Motor
Battery Pack	-	Small	Medium	Large
Gasoline	✓	✓	✓	
Electricity			✓	✓

Size Matters

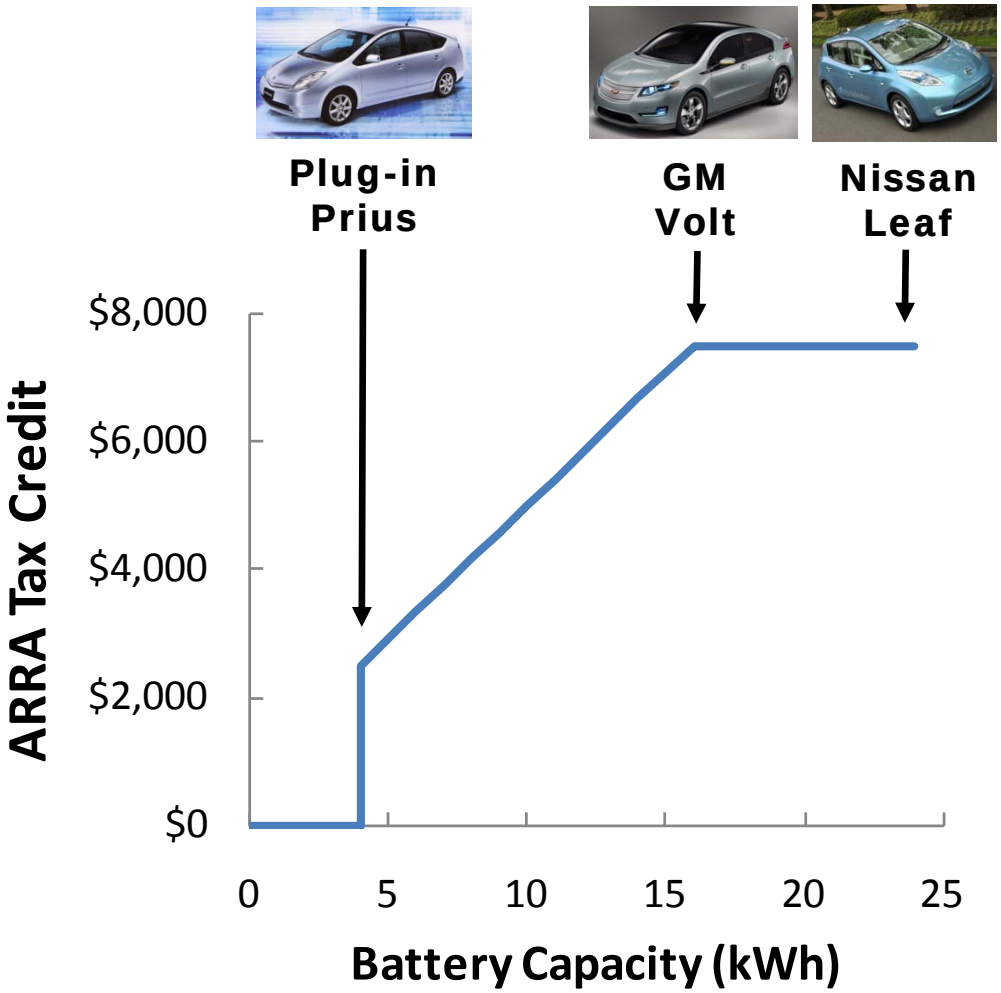
Adding more batteries
(all else being equal) means

- **Longer distance** traveled on electricity before needing gasoline
- **More expensive**
- **Heavier** (less efficient)
- **More manufacturing** emissions and resource consumption

	Vehicle	Range	Battery
	Toyota PHEV Prius	PHEV-12	4kWh
	GM Volt	PHEV-40	16kWh
	Fisker Karma	PHEV-32	20kWh
	Ford Focus Electric	BEV-76	23kWh
	Nissan Leaf	BEV-73	24kWh
	Tesla Roadster	BEV-244	53kWh

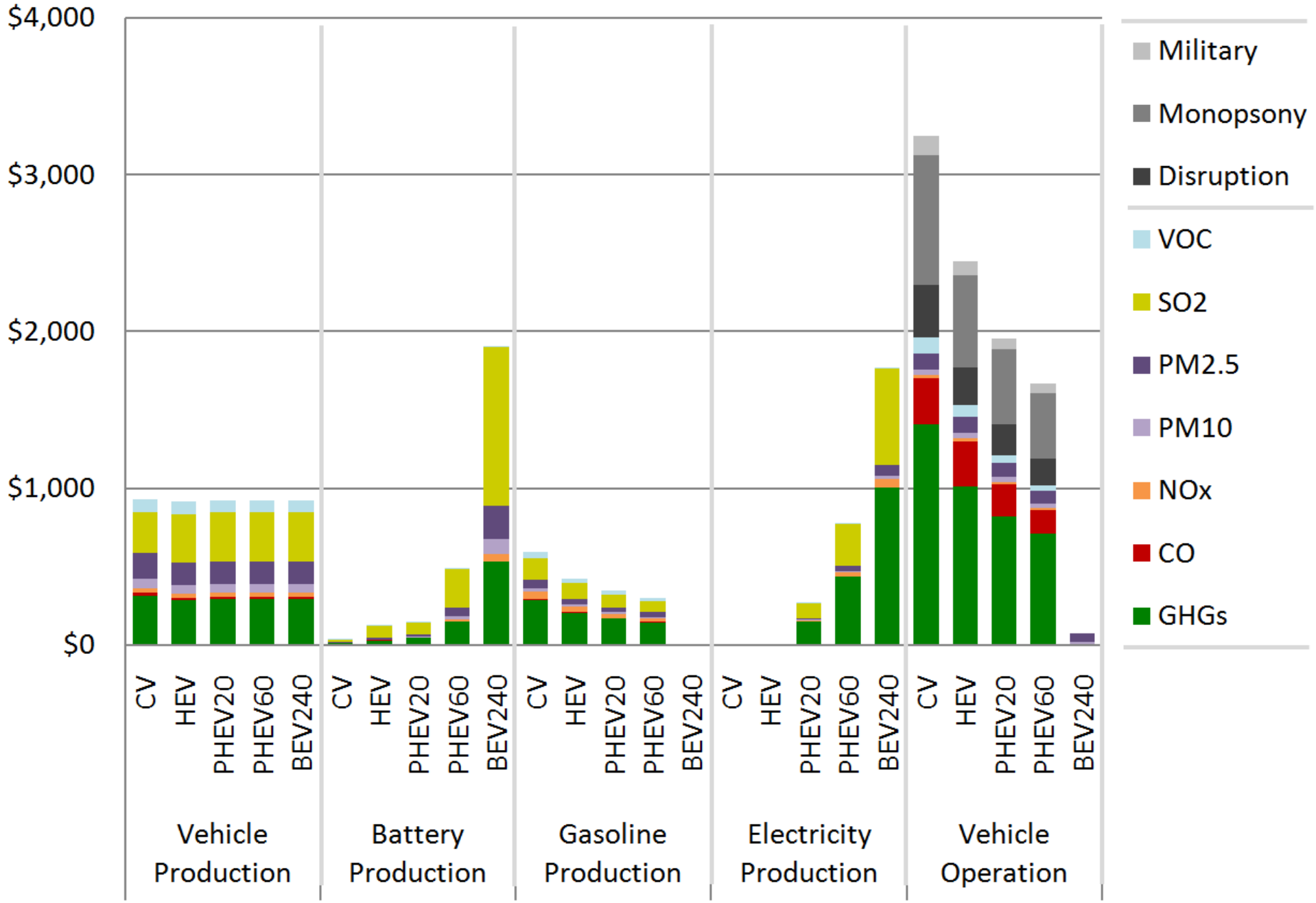
U.S. Federal Policy

- **American Recovery and Reinvestment Act of 2009**
  - $2500 tax credit for PHEV with at least 4kWh battery capacity
  - $417 additional per kWh battery capacity, up to $7500



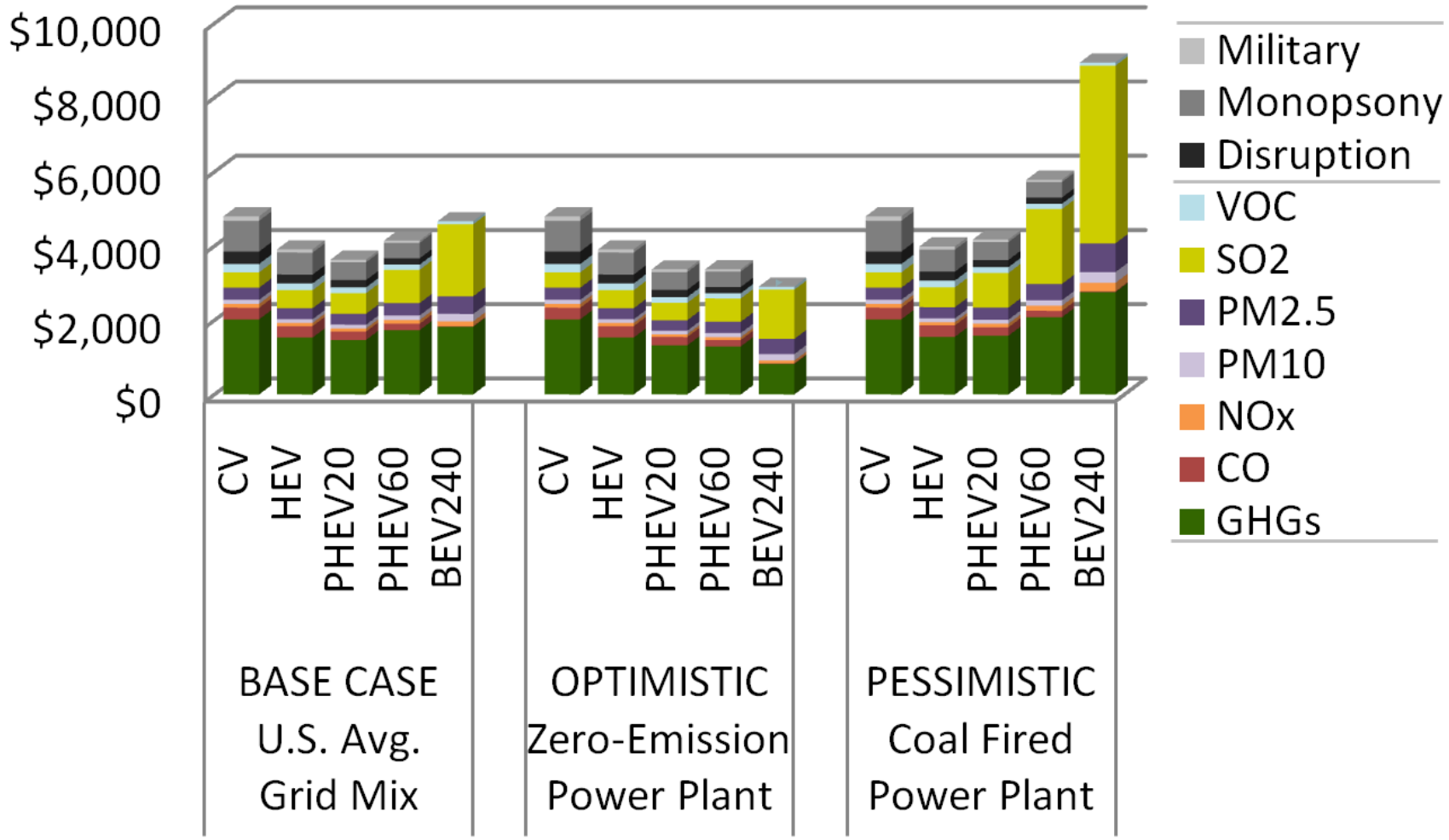
The larger the battery, the more taxpayers subsidize

Base Case Life Cycle Emissions & Oil



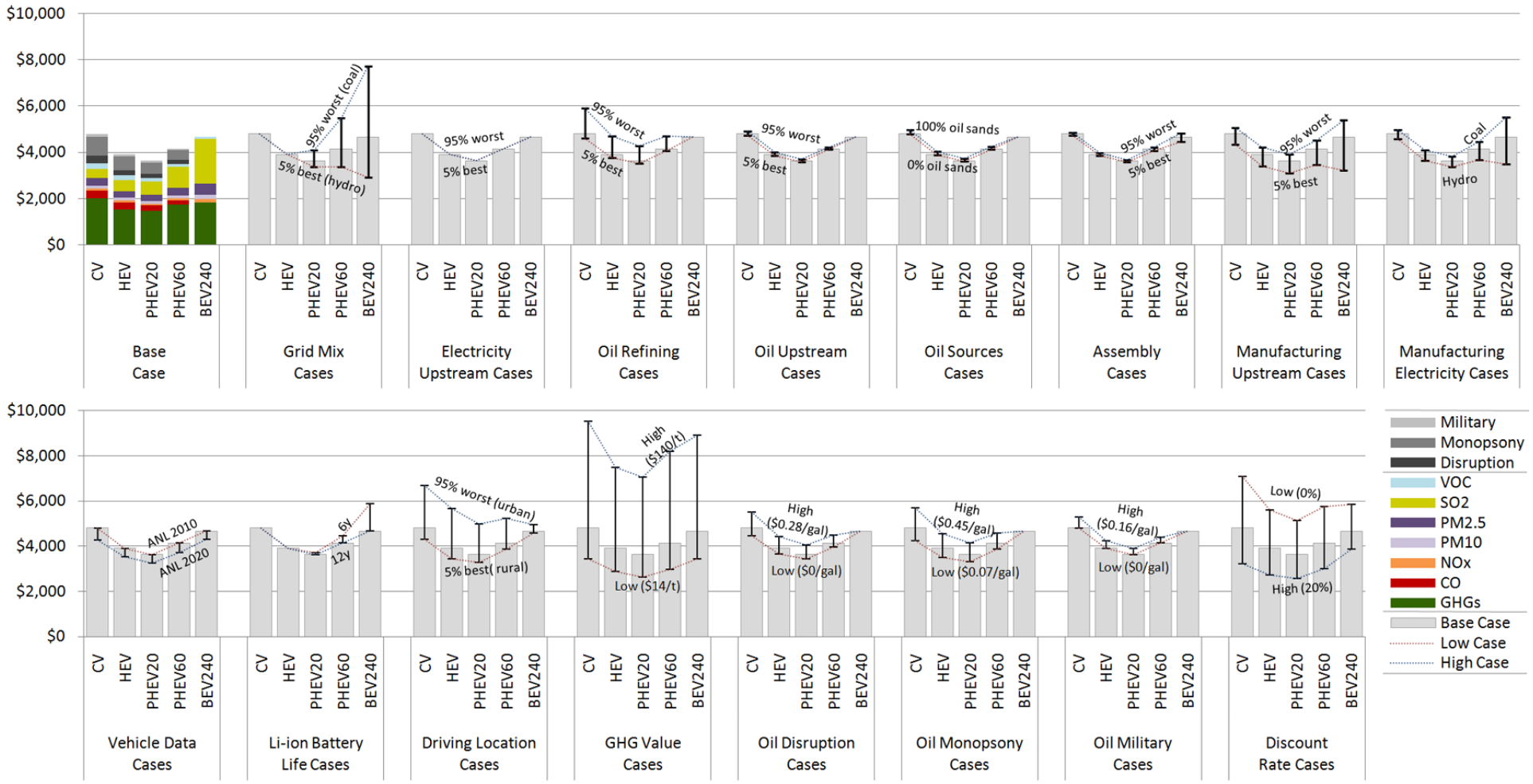
Air Emissions & Oil Premium Costs

- Damage reduction potential of plug-in vehicles
  - HEV & PHEV20 reduce damages vs. conventional vehicle
  - PHEV60 & BEV may increase or decrease damages



Sensitivity Analysis

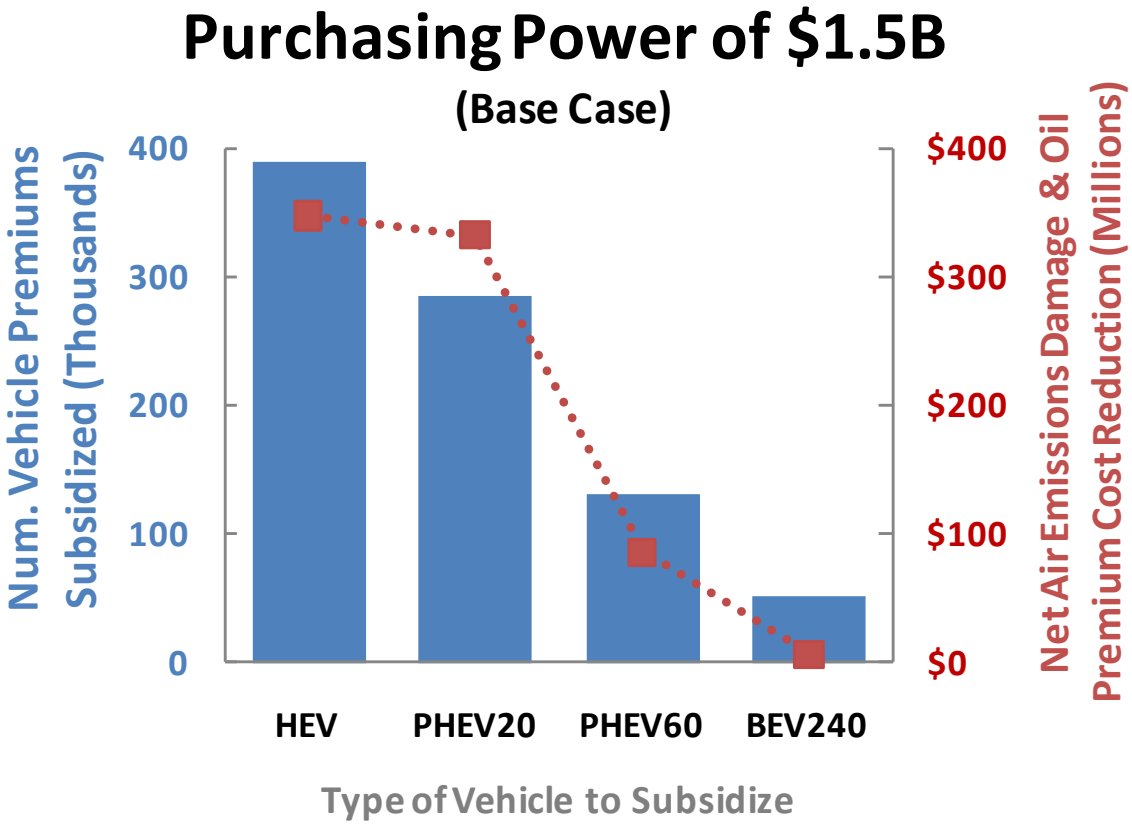
- Life cycle air emissions externalities and oil premium



Take Away

In the near term, HEVs and PHEVs with small battery packs offer more benefits per dollar spent

- Large battery packs may eventually be best if we achieve
  - cheap batteries
  - expensive gasoline
  - clean electricity
  - long battery life
  - overcome range issues



Dissemination

- **Policy briefs (Capitol Hill)**
  - Congressional Budget Office
  - Congressional Research Service
  - Senate Energy and Natural Resources Committee
  - Senate Commerce, Science and Transportation Committee
  - Several offices in the House of Representatives

- **Automakers**
  - Ford
  - Toyota
  - Chrysler

- **National Petroleum Council** Study of Future Transportation Fuels (Chu)

- **Magazine article**: Issues in Science and Technology

- **Media:** Washington Post, Bloomberg, Greenwire, U.S. News & World Report, CNN Money