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The Impact of Lithium Availability on Vehicle Electrification

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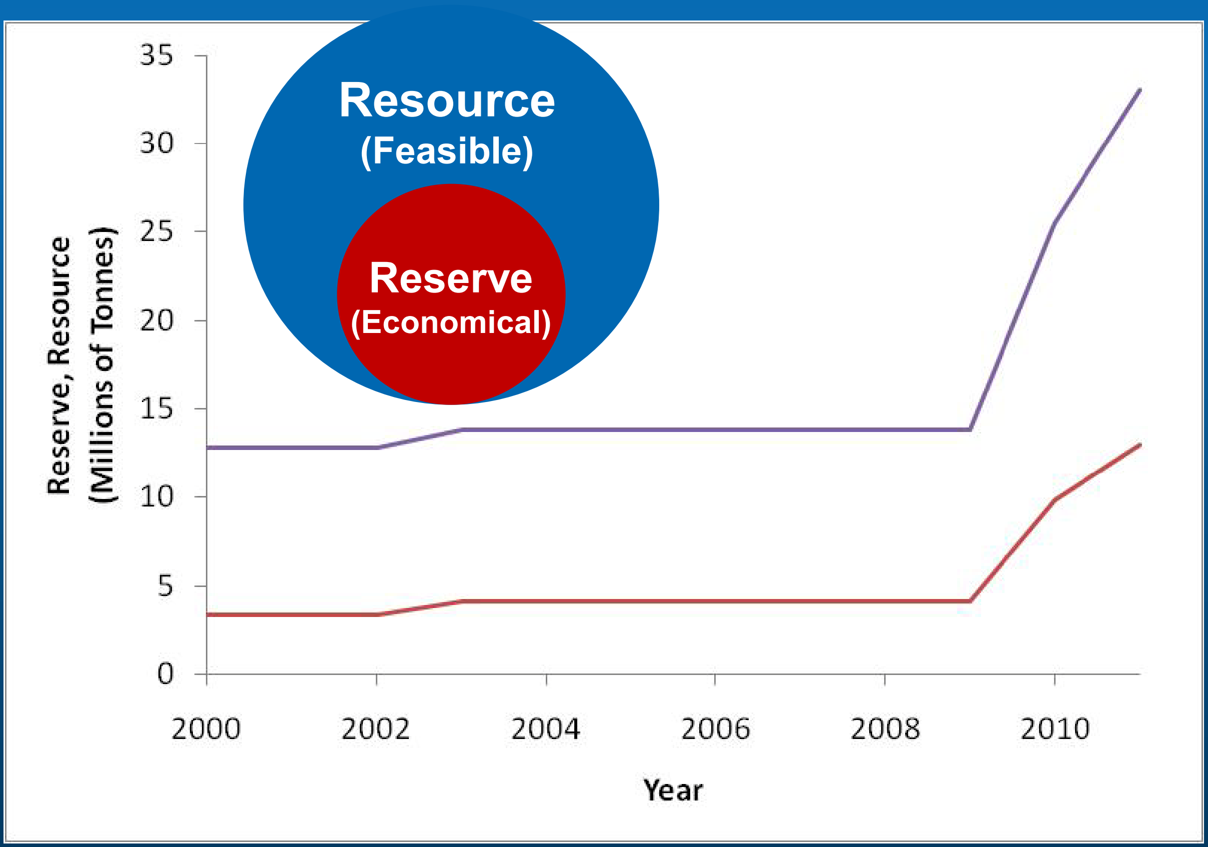
- **Objective**
  - **To use NREL modeling tools to study the relationship between electric drive vehicles (EDVs) and lithium (Li) availability**

- **Outline**
  - **Is Li Supply a Concern?**
    - Li resources and production
    - Potential EDV market demands for Li
  - **How Can We Maximize Our "Return on Lithium"?**
    - NREL modeling tools and approach
    - Vehicle performance results
    - Carbon dioxide (CO_2) and gasoline displacement per unit mass of Li
    - Effects of production limits, recycling, grid/2nd use, and cost

- **Summary**

How Much Li is There?

- Latest Li reports from the U.S. Geological Survey (USGS):
  - Global resource of 33 million metric tonnes
  - Global reserve of 13 million metric tonnes



Adapted from USGS Mineral Commodity Summaries, 2000 to 2011

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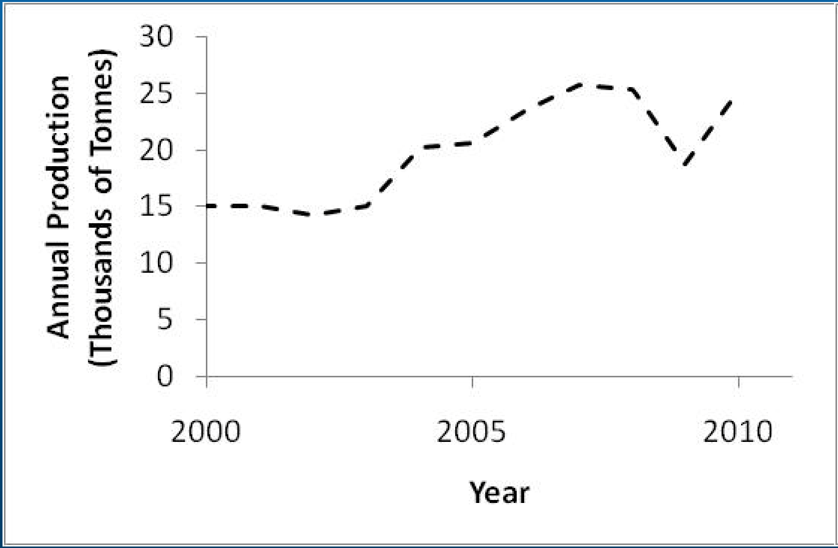
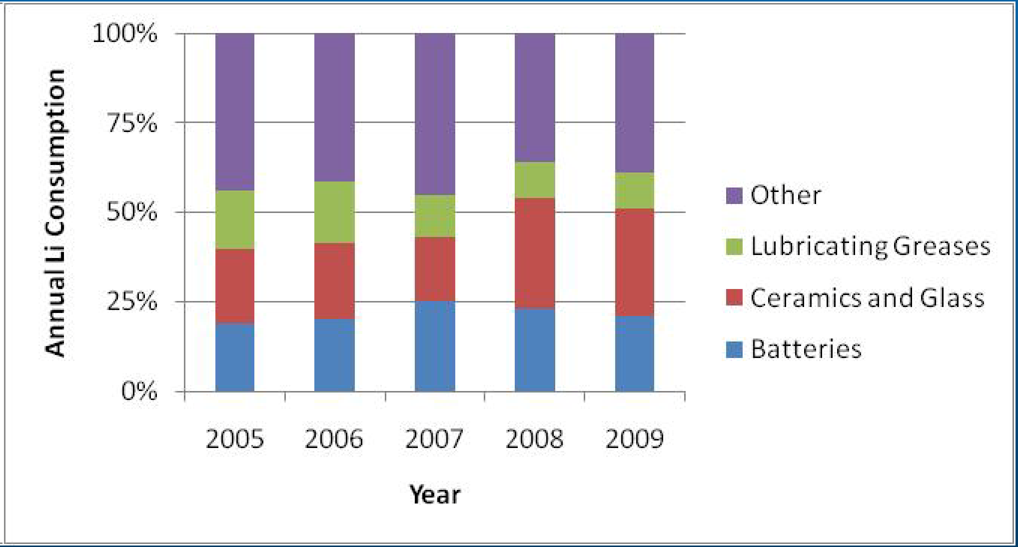
How Much Li is Produced?

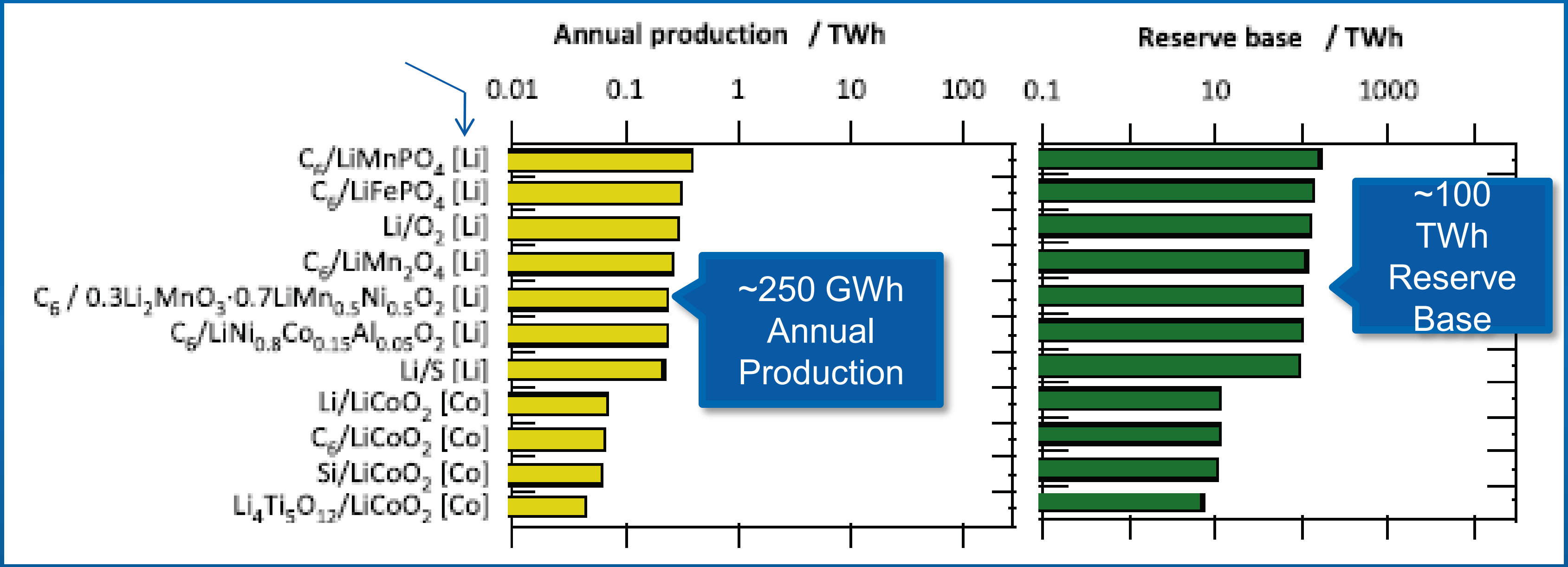
- **Consumer Li-ion batteries use ~ 20%**
- **Non-EDV markets would consume ~8% of the reserve by 2050 if held constant at 2010 levels**
- **Non-EDV markets would consume ~25% of the reserve by 2050 if increased at 5%/year**





Adapted from USGS Mineral Commodity Summaries and USGS Mineral Yearbook, 2000 to 2011
**Annual production numbers exclude U.S. production, but U.S. production is thought to be minimal*

How Many Batteries Can We Build?

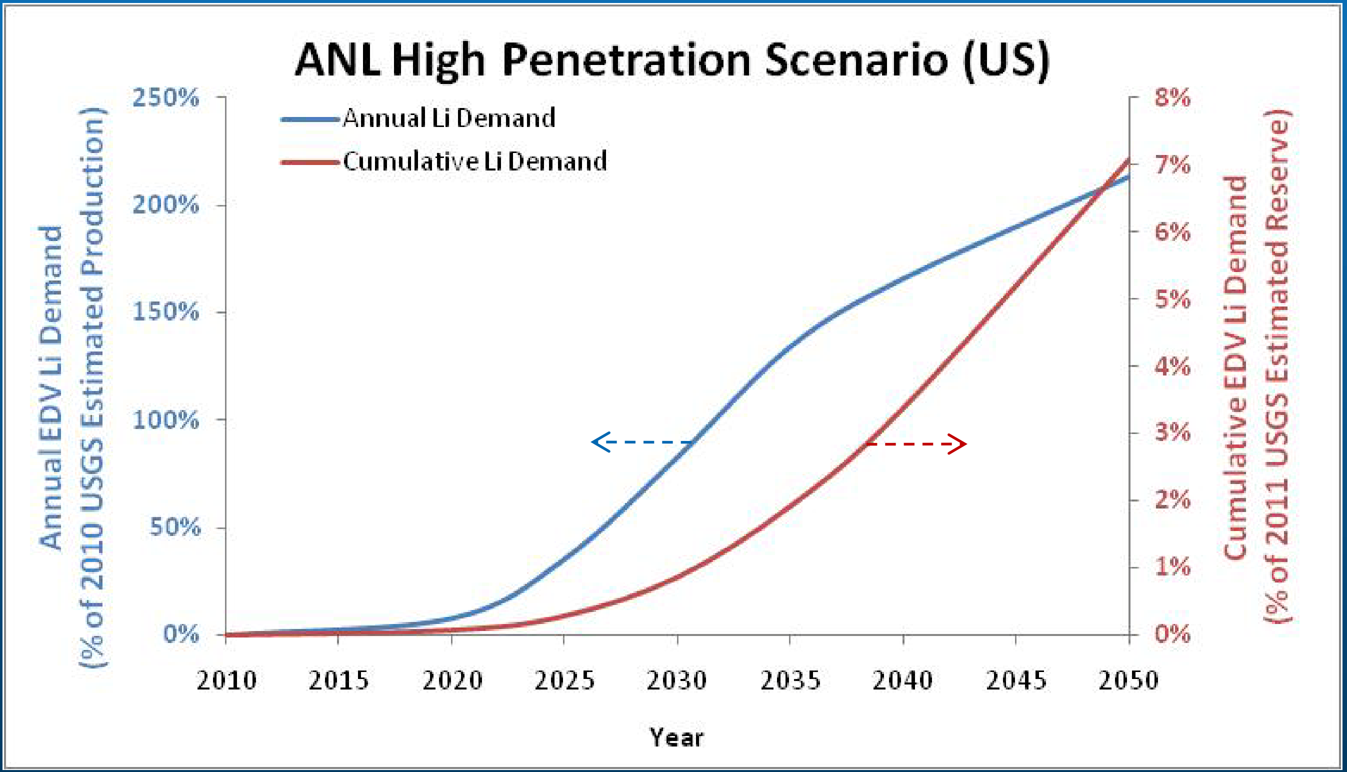


Adapted from C. Wadia et al. Journal of Power Sources *196 (1022) 593-1598*
Based on 2009 USGS reported reserve base of 11 million tons of Li

- **Cobalt (Co) is the limiting element for low volume Li-ion chemistries (*we'll ignore these*)**
- **Li is the limiting element for high volume Li-ion chemistries (*this is our focus*)**
- **We will assume $C_6/LiMn_2O_4$ moving forward**
  - Chemistry in the Nissan LEAF and Chevy Volt
  - ~8.9 Wh/g Li

How Do U.S. EV Markets Compare to Li Supply?

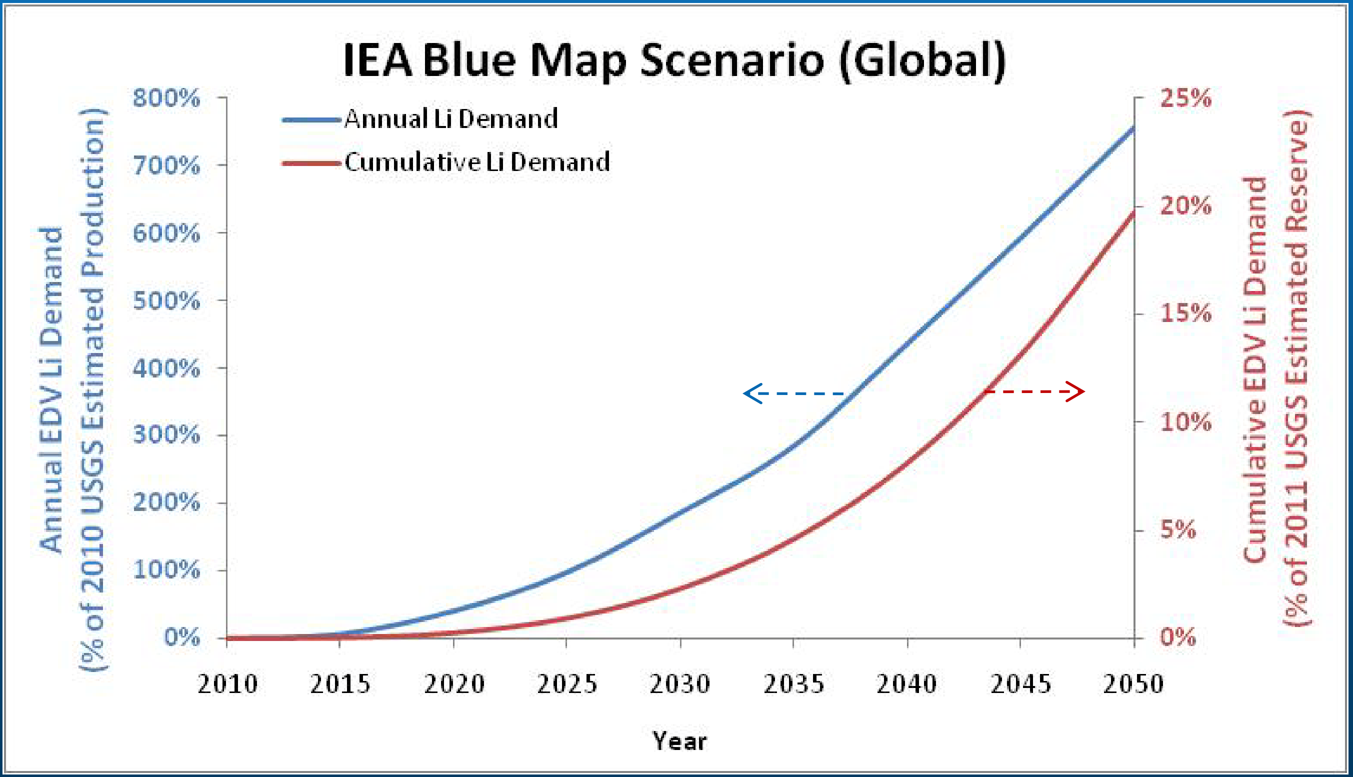
- **Argonne National Laboratory (ANL) study considers *"...the maximum percent of U.S. sales that could be accounted for by"* EDVs:**
  - Entails the sale of 465 million EDVs through 2050, reaching 90% of total light-duty vehicle sales by 2050
  - Eight vehicle types: light truck and light car versions of hybrid electric vehicles (HEVs), and plug-in hybrid electric vehicles (PHEVs), such as the PHEV20s and PHEV40s, and battery electric vehicles (BEVs), such as the BEV100s
  - Note that this is an *extreme* and *aggressive* case study, <u>*not a projection*</u>



Adapted from L. Gaines et al., "Lithium-Ion Batteries: Possible Materials Issues," ANL 2010

How Do Global EV Markets Compare to Li Supply?

- **International Energy Agency (IEA) study considers the deployment of sufficient EDVs to provide *"a 30% reduction in transport CO_2 emissions by 2050 compared to 2005"*:**
  - Entails the sale of 1.6 billion EDVs through 2050
  - Two vehicle types: PHEV25s and BEV90s
  - Note that this is a target to meet emissions goals, *not a projection*



Based upon EDV deployment targets from "Technology Roadmap: Electric and plug-in hybrid electric vehicles," IEA 2009

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Is Lithium Supply a Concern?

- **From the authors of the ANL study:**
  - *"It appears that even an aggressive program of vehicles with electric drive can be supported for decades with known supplies."*
  - Caveats: electric range, global EDV demand, non-EDV markets

- **From a look at global data and non-EDV markets:**
  - Aggressive EDV penetration and non-EDV markets growing at 5%/yr result in consumption of <50% of the 2011 Li reserve by 2050…
  - …and requires ~7%/yr increase in Li production.

- **Conclusion: the supply of Li does not appear to be an immediate or deadly threat to the EDV market**

Can the Lithium Supply Become a Concern?

- **Demand and technology are uncertain**
- **Supply of Li and its substitutes are not always indigenous**
- **Resources and reserves are dynamic**

- **Thus, within the EDV market, what is the best way to utilize Li to minimize CO_2 emissions and fossil fuel consumption?**

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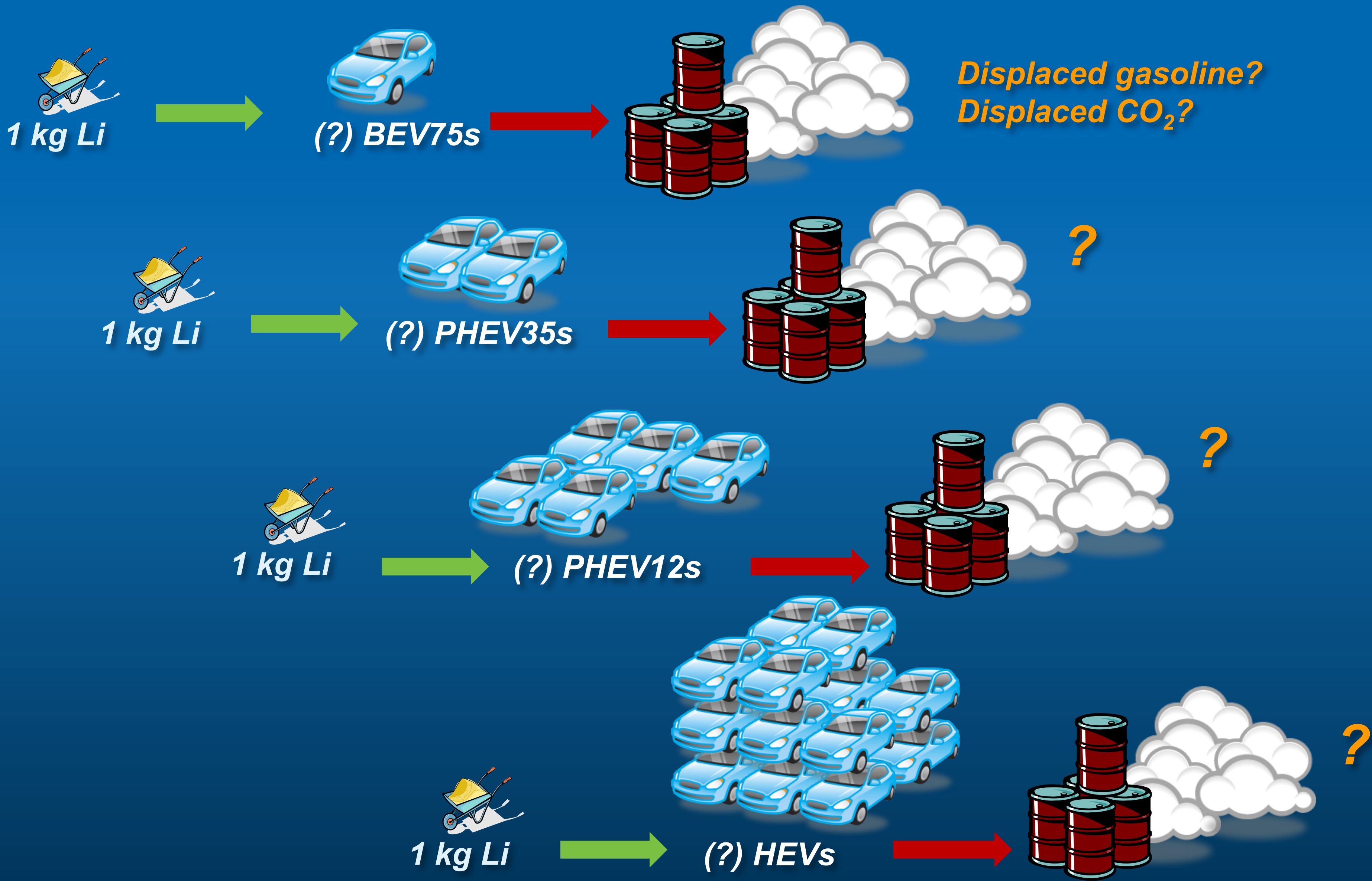
Objective: Evaluate "Return on Lithium"



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How We'll Get There

1. Simulate comparable vehicles with each powertrain to calculate amount of lithium required and fuel and electricity used per mile

2. Apply U.S. average trip distribution to each vehicle to calculate total fuel and electricity consumed

3. Calculate total CO_2 emitted from total fuel and electricity consumed using multiple electricity mix scenarios

4. Compare results to a ~32 mpg conventional vehicle using the following metrics:
   - Gallons of gasoline displaced per tonne of Li used
   - Tonnes of CO_2 displaced per tonne of Li used

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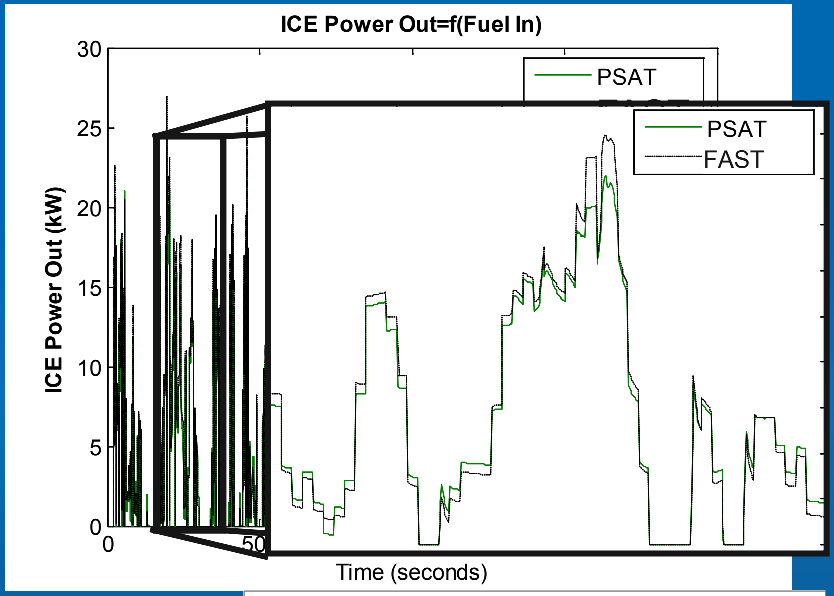
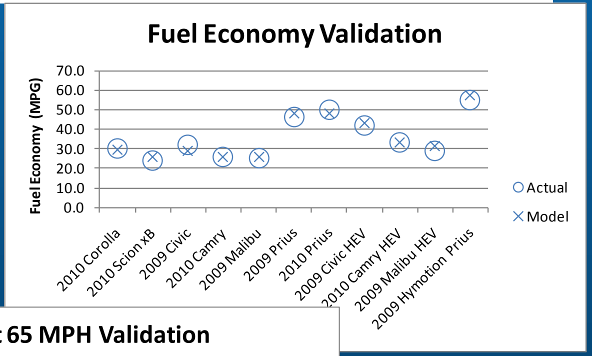
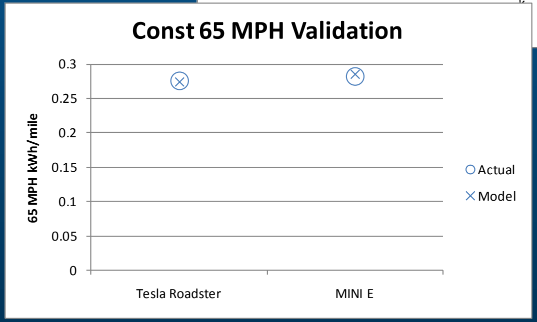
Vehicle Analysis

- **NREL Future Automotive Systems Tool**
  - *Objective:* Compare technology improvement impacts on the efficiency, performance, and cost of the leading powertrains
  - *Approach:* Include only the most important aspects
  - *Benefits:* Easy to use, fast, and captures most important performance aspects
  - *Validated:* Outputs validated against Powertrain System Analysis Toolkit (PSAT) and real-world data







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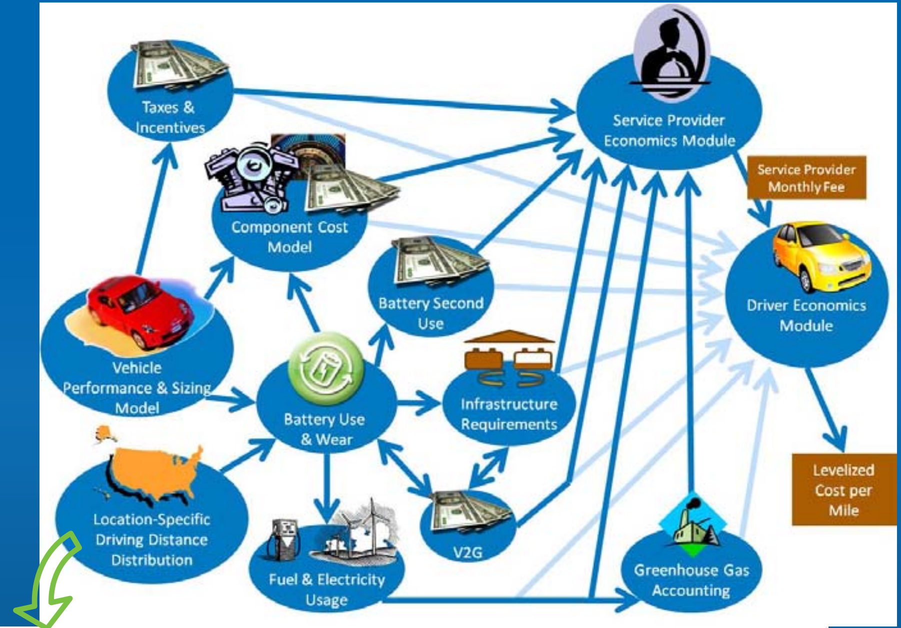
Vehicle Optimization

- Mid-size sedan platform assumed (similar to the Nissan LEAF and the Chevy Volt)
- Internal combustion engine, electric motor, and battery size optimized to provide performance in table
- Primary outputs are gal/mi and kWh/mi consumed
  - Calculated using the Environmental Protection Agency's weighted combination of highway and urban dynamometer driving schedule drive cycles

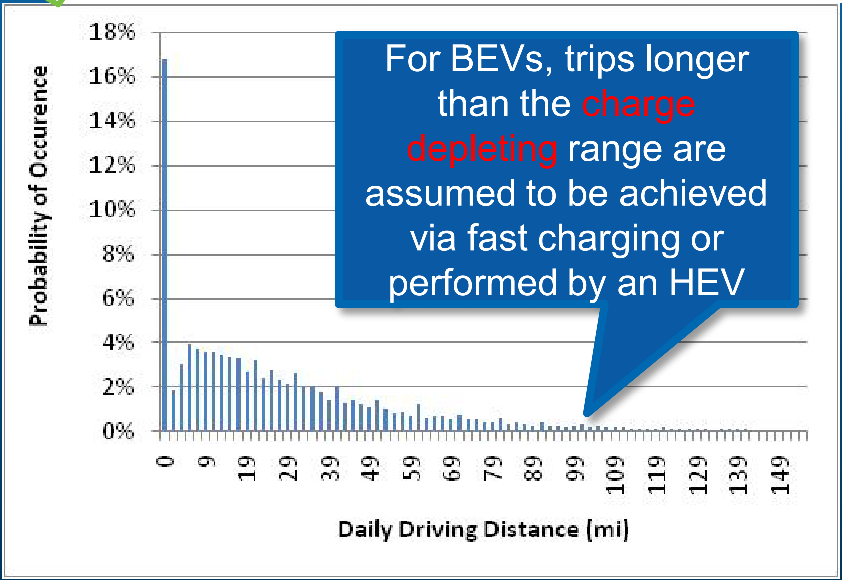
	0-60 mph time	Electric Range	Degree of Hybridization
CV	10 s	n/a	n/a
HEV	10 s	n/a	20%
PHEV12	10 s	12 mi	50%
PHEV35	10 s	35 mi	50%
BEV75	10 s	75 mi	n/a
BEV150	10 s	150 mi	n/a

Greenhouse Gas and Fuel Consumption Analysis

- **NREL Battery Ownership Model:**
  - A tool to systematically evaluate battery-related EDV business strategies
  - Detailed consideration of vehicle performance (FAST), battery wear, infrastructure, and finance at every level
  - Primary outputs are total cost of ownership, greenhouse gas (GHG) production, and fuel and electricity usage



- **Of note for this study:**
  - Vehicles applied to National Highway Traffic Safety Administration based daily drive distance probability function with 12,375 mi vehicle miles traveled (VMT) to calculate fuel and electricity consumption
  - BEV range limitations addressed via fast charging or HEV usage
  - Transmission losses and charger efficiency considered to calculate GHGs under multiple electricity mix scenarios



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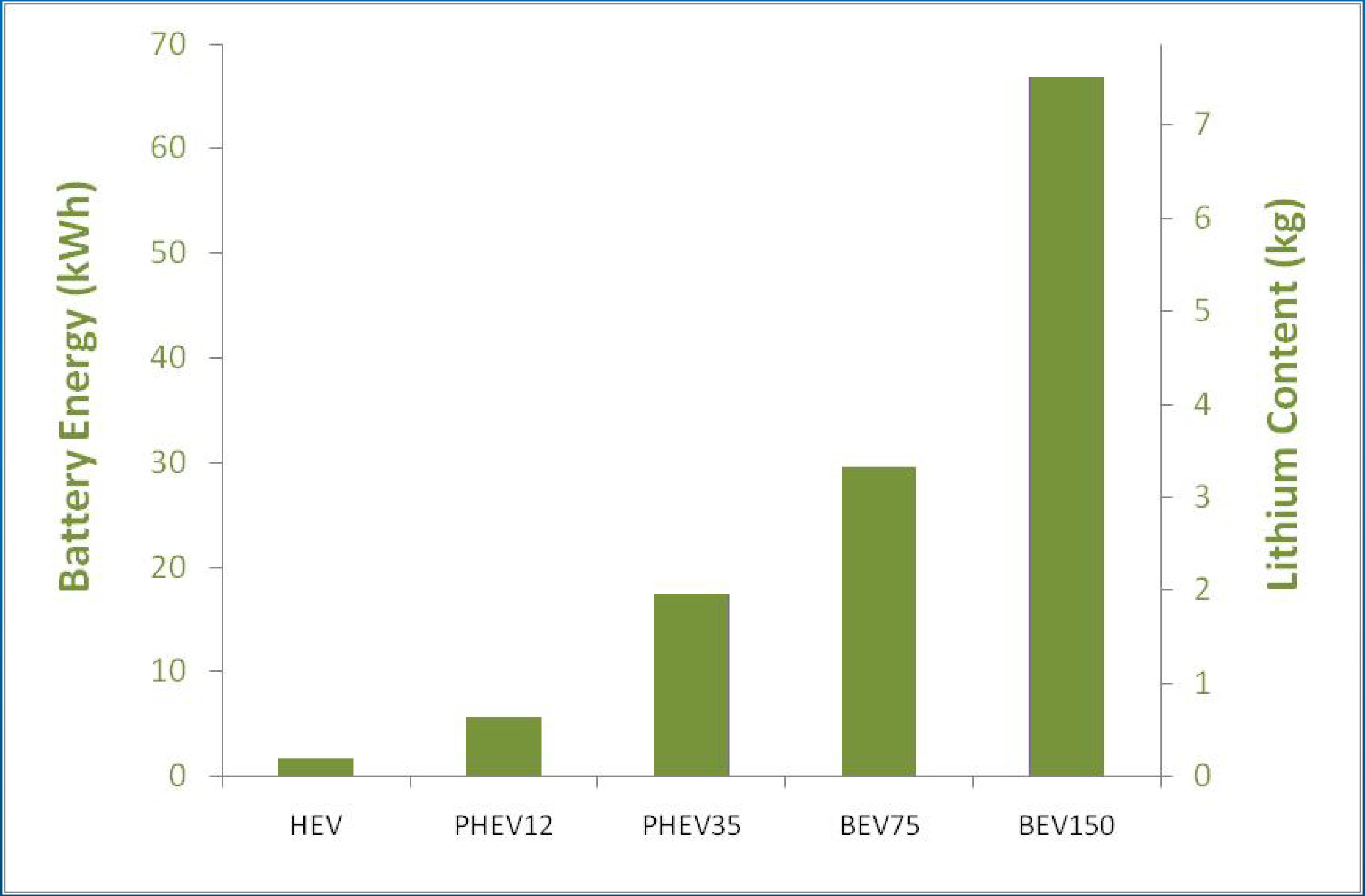
Battery Energy and Lithium Content



- **PHEVs restricted to 65% depth of discharge (DOD), BEVs to 90% DOD**
- **Battery size more than doubles between EV75 and EV150 because of efficiency decline**

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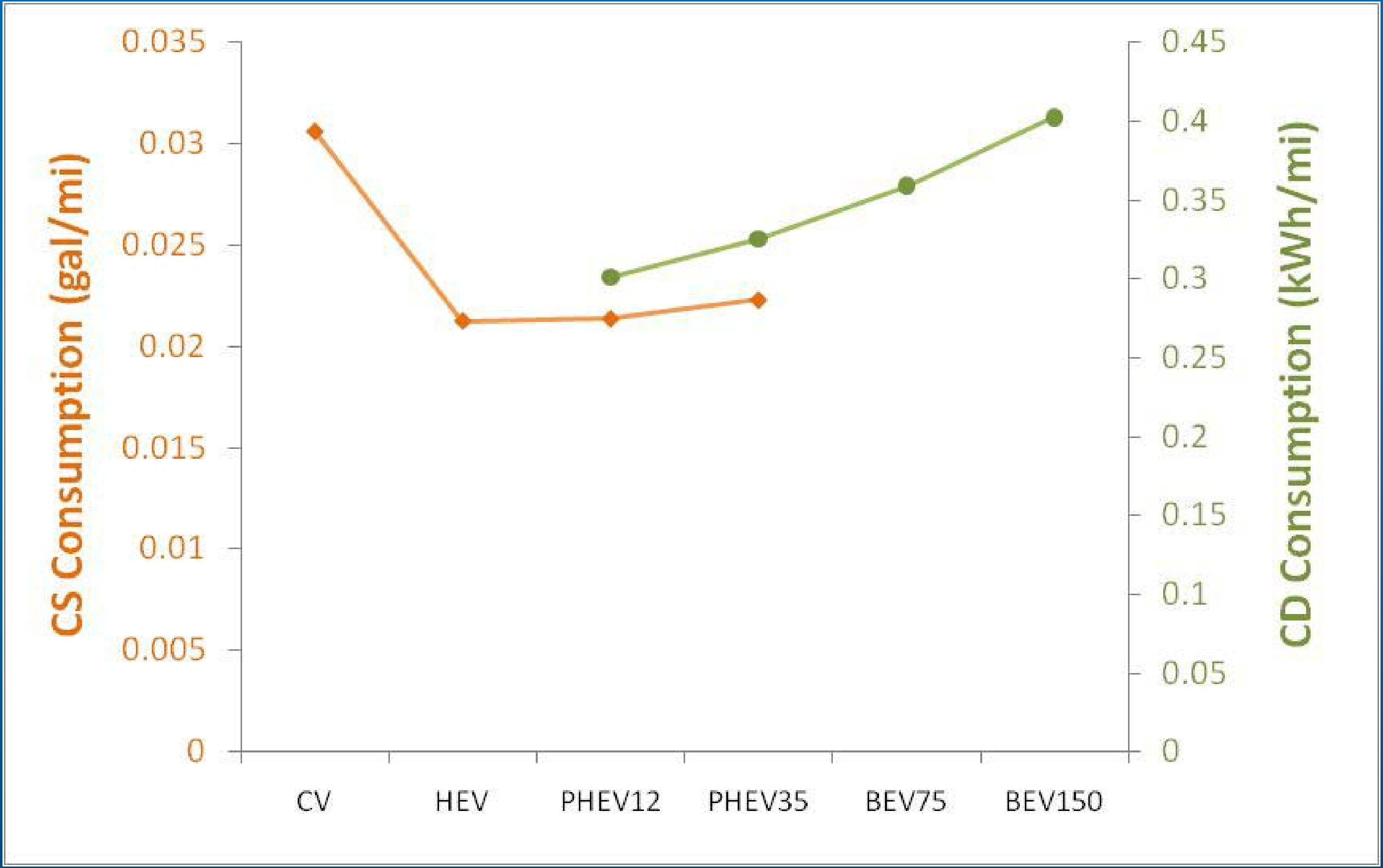
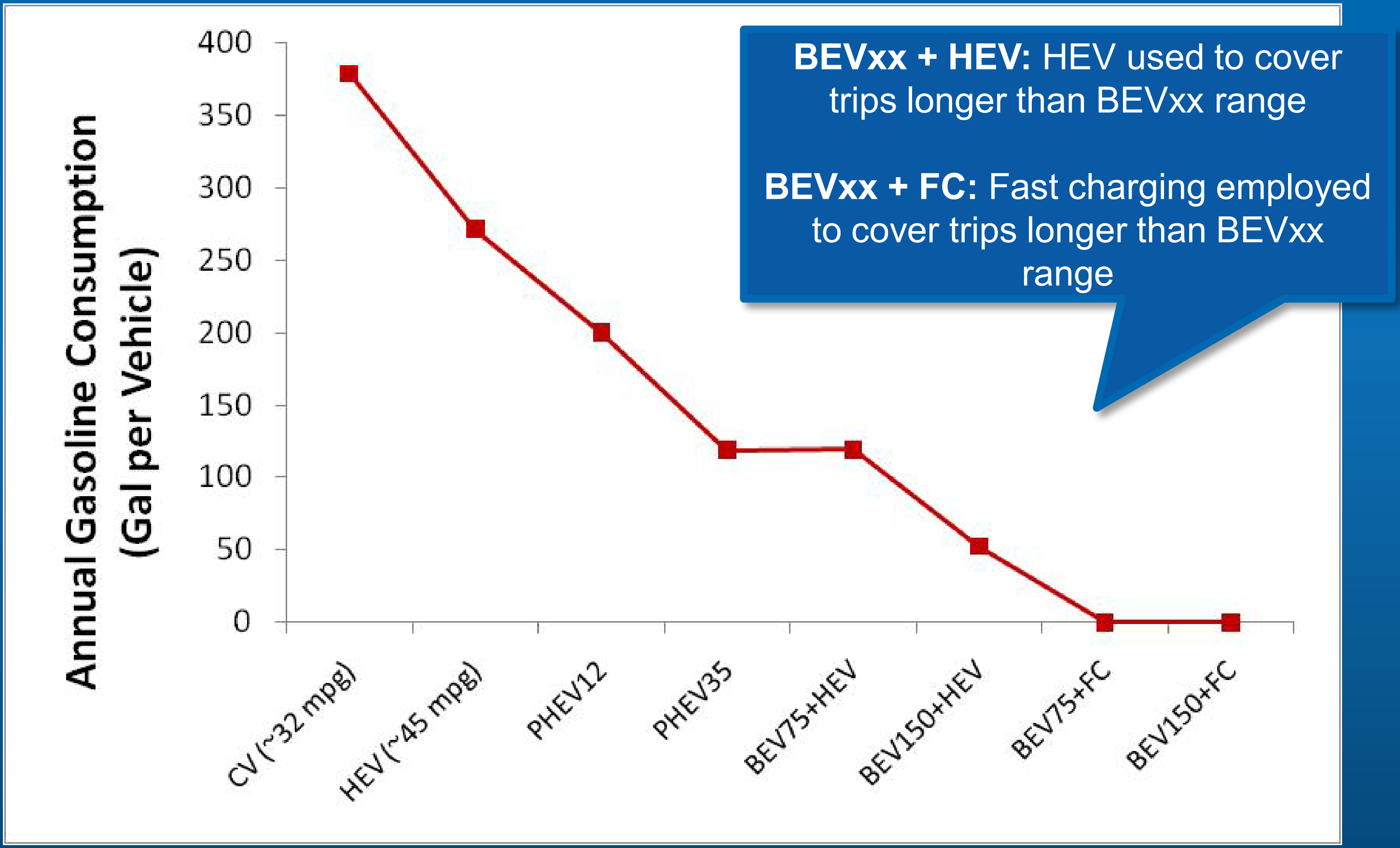
Vehicle Efficiency



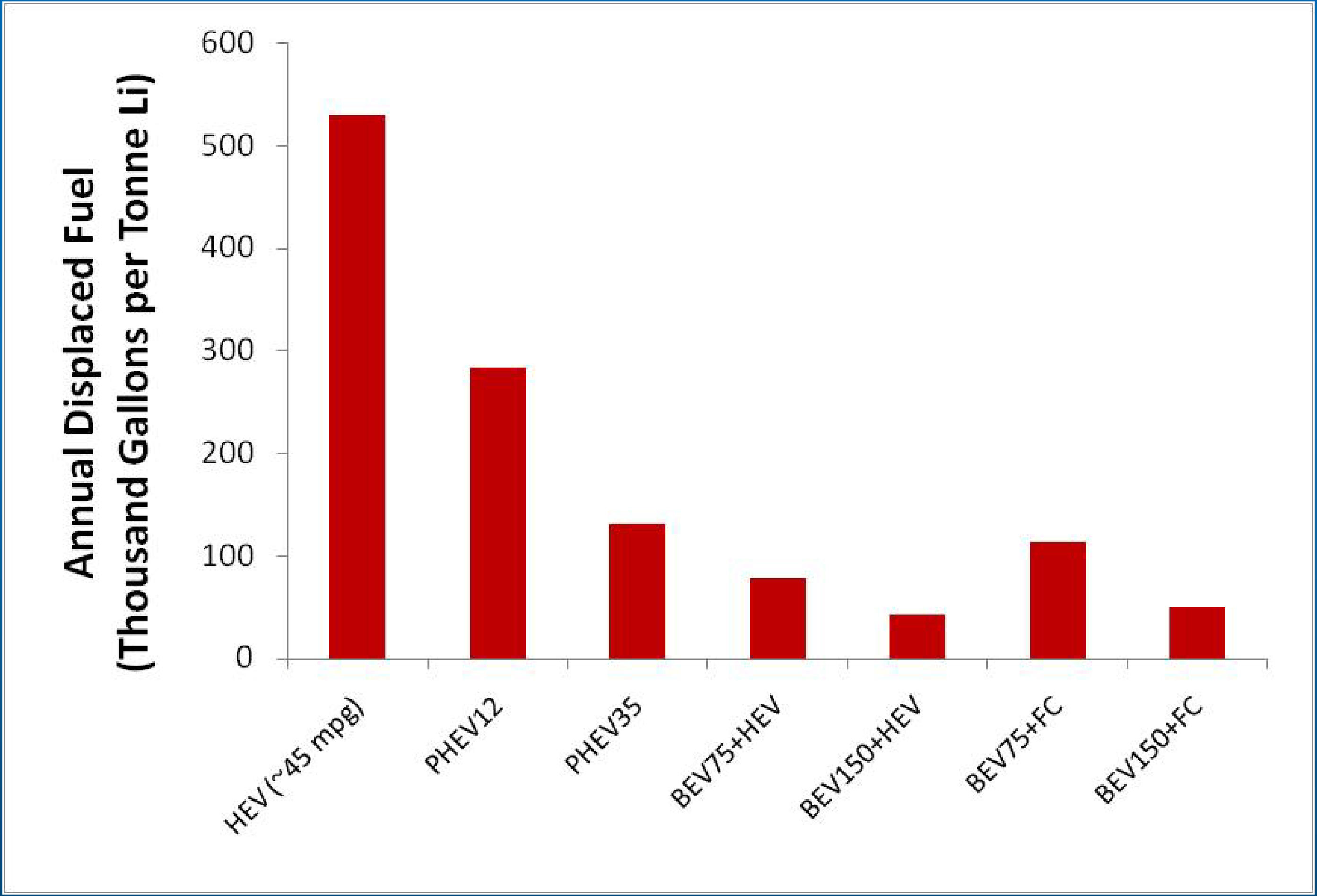
- **Conventional gasoline-powered vehicle (CV) efficiency is considerably improved with the addition of a small battery to make it an HEV**
- **EDVs decrease in efficiency as battery mass increases**

Gasoline Consumption



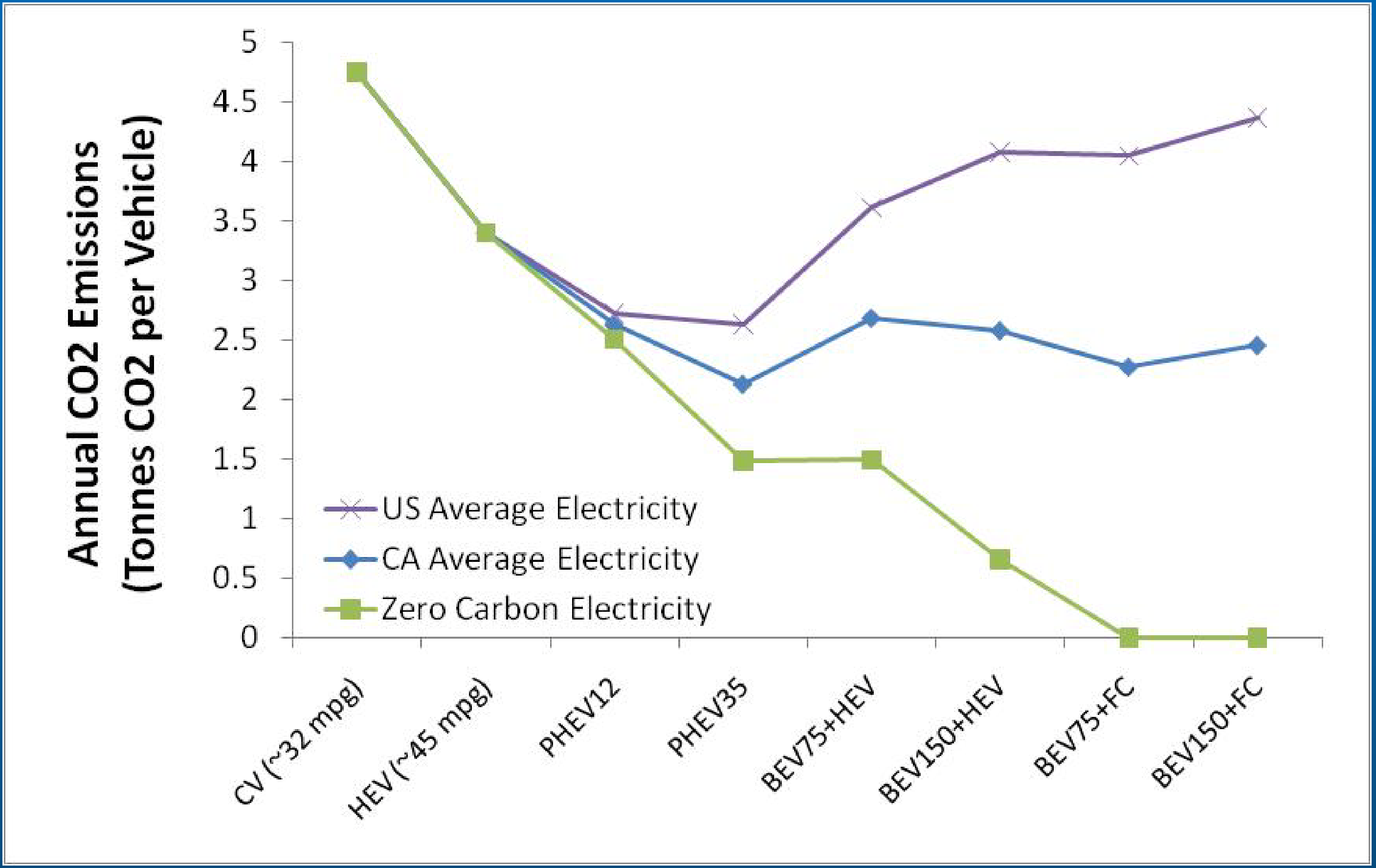
- **Fuel usage falls strongly across this powertrain spectrum *on a per vehicle basis***
- **The PHEV35 and BEV75 have nearly identical utility factors**

Gasoline Displacement



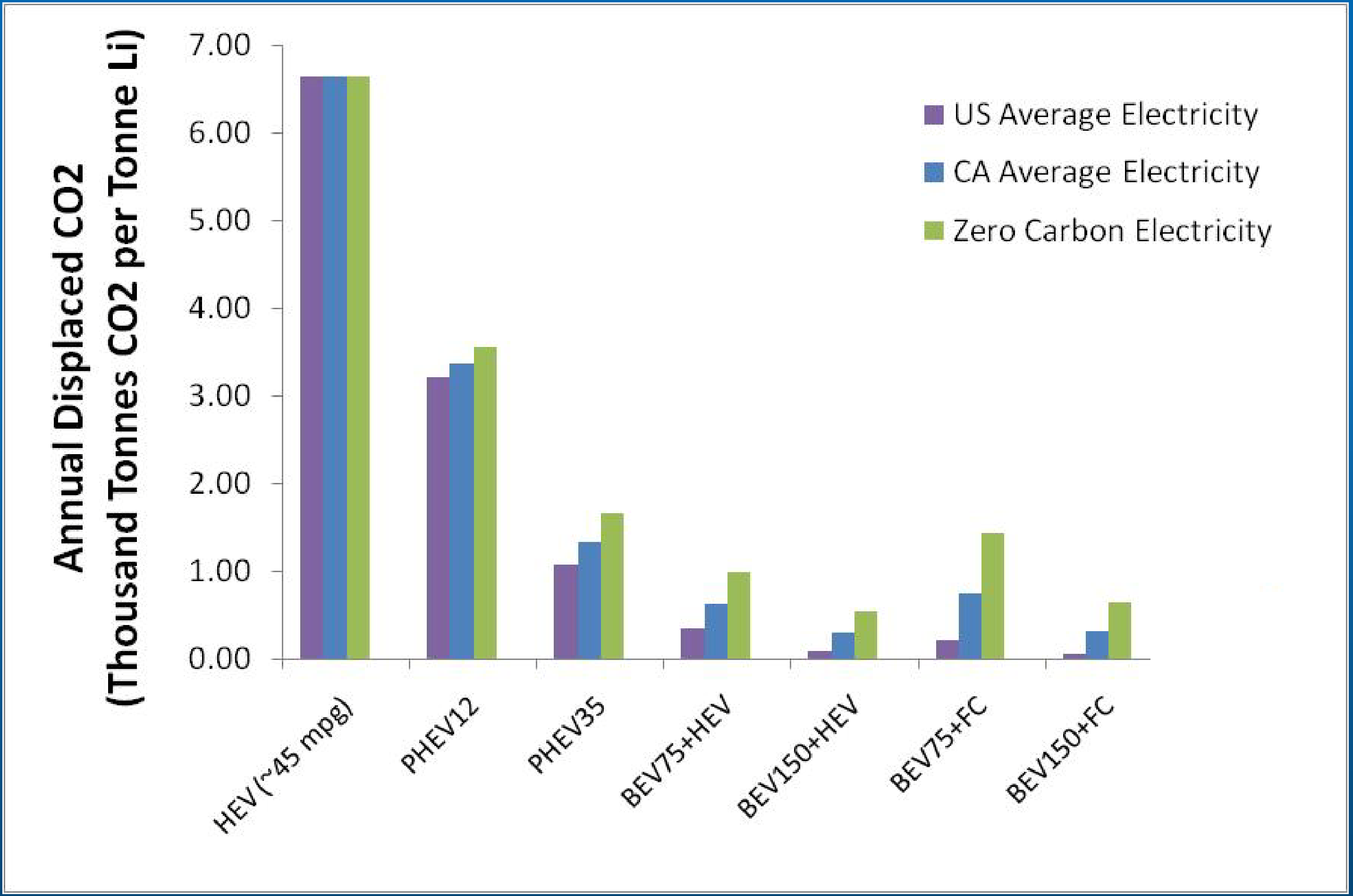
- **Displacement relative to 32 mpg CV**
- **Under our assumptions, HEVs offer the best ability to displace gasoline *on a per-unit-mass-of-Li basis***

CO_2 Emissions



- CO_2 emissions per vehicle are very sensitive to the charging electricity mix
- Higher degrees of vehicle electrification are not always better

CO_2 Displacement



- **Displacement relative to 32 mpg CV**
- **Under our assumptions, HEVs offer the best ability to displace CO_2 on *a per-unit-mass-of-Li basis***

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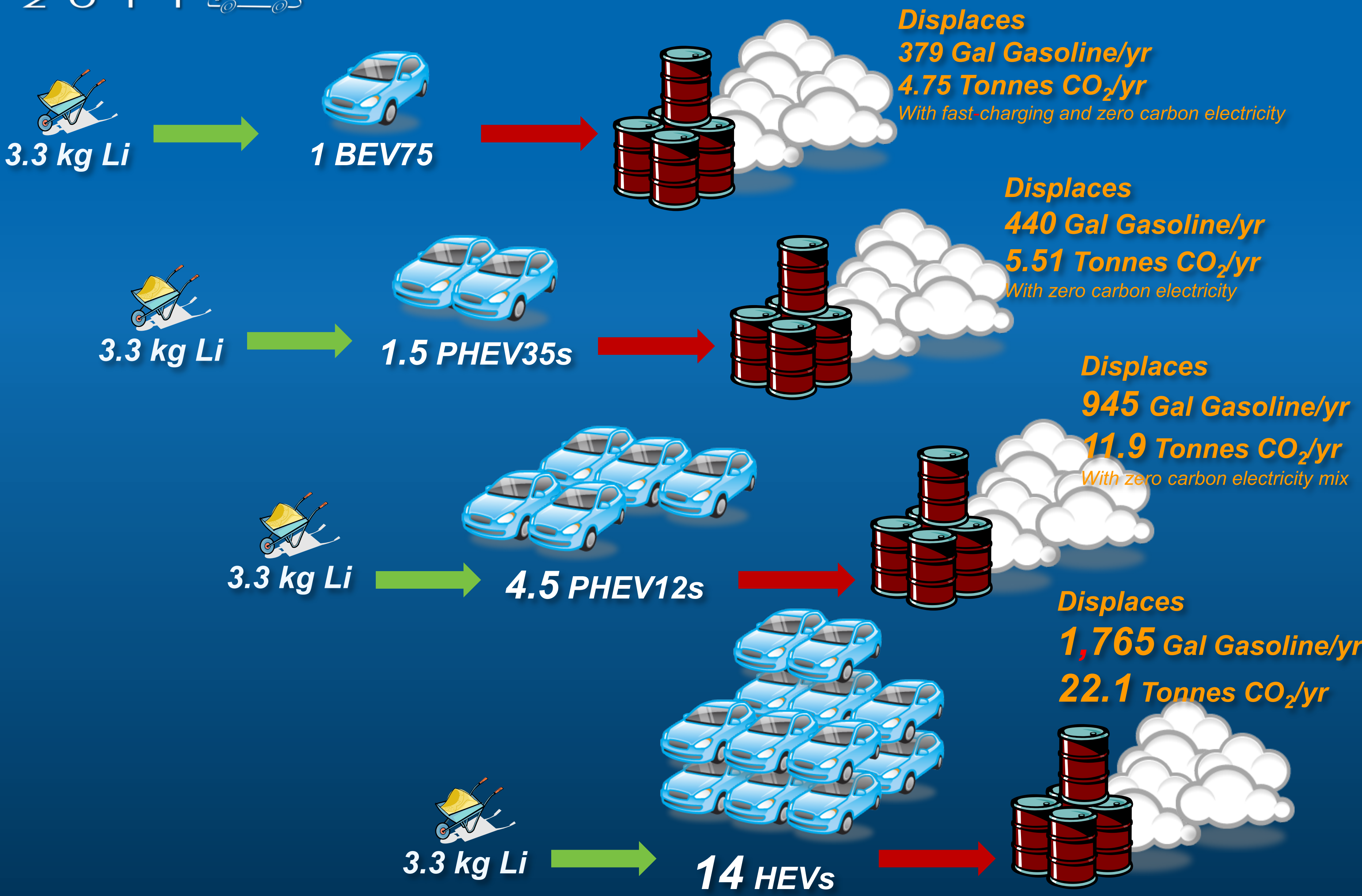
"Return on Lithium" Evaluated



Summary

- **Li supply does not appear to be a problem given today's reserve and production quantities, even under aggressive expectations for EDV deployments**
  - BEVs offer the largest gasoline displacement capability
  - BEVs are not always the best at CO_2 displacement - heavily dependent on electricity mix
- **Were Li supply to become a concern under changing conditions in the short or long term...**
  - HEVs offer the best "return on lithium" for both gas and CO_2 displacement, but mass deployment may be demand limited
  - Under our assumptions, short-range PHEVs may have the maximum impact in a limited Li market
  - Li recycling yields near those of lead in lead acid batteries would likely alleviate any envisioned Li supply stress
- **Our FAST and Battery Ownership Model computational tools are capable of exploring these trades and optimizing resource utilization.**

Acknowledgments

- This activity is funded by the U.S. Department of Energy's (DOE) Vehicle Technologies Program, Energy Storage Technology

- We appreciate the support provided by DOE program managers David Howell and Brian Cunningham