Analysis of Energy Infrastructures and Potential Impacts from an Emergent Hydrogen Fueling Infrastructure

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Overview

Timeline

- Start – Dec. 2007
- Finish – Sep. 2012
- 30% complete

Budget

- Total project funding
  - DOE $340K
- Funding received in FY08
  - $150K
- Funding for FY09
  - $190K

Barriers

- A. Future Market Behavior
- B. Stove-piped/Siloed Analytical Capability
- E. Unplanned Studies and Analysis

Targets

- Analyze issues and long term impacts related to infrastructure evolution, hydrogen fuel, and vehicles (Task 1)

Relevance / Objectives

Objectives

- Use dynamic models of interdependent infrastructure systems to analyze the impacts of widespread deployment of a hydrogen fueling infrastructure
- Identify potential system-wide deficiencies that would otherwise hinder infrastructure evolution, as well as mitigation strategies to avoid collateral effects on supporting systems

Relevance

- Transition to H2 fueling is expected to rely on distributed steam-methane reforming (SMR); we must understand the impact of hydrogen vehicles on the infrastructure

Milestones

MM / YYYY	Milestone
March / 2009	Include Plug-in hybrid electric vehicle (PHEV) adoption model to compete with hydrogen fuel cell vehicles (HFCV) in the model for California (CA) infrastructure
April / 2009	Define model of CA market economics for electricity generation, capacity and costs, to couple demand for natural gas (NG) and H2
June / 2009	Analyze impacts of PHEVs and HFCVs on demands for H2, NG, electricity in CA

Approach

- **Analysis-driven approach defined by programmatic needs**
  - Provide analysis and insight into the dynamic behavior of complex systems
- **System dynamics: Methodology**
  - Choose a region to define the system
    - Selected California as first application
  - Pose detailed questions
    - At what HFCV penetration does the demand for NG-derived H2 negatively impact NG distribution?
    - How does adoption of HFCVs affect supply limits of NG?
    - What conditions affect the competition between HFCV and plug-in hybrids?
- **System dynamics: Analysis**
  - Formulate SD models of infrastructure components and interrelations to a sufficient level of detail
  - Use Powersim software to quickly generate code

Assumptions

Infrastructure Model

- **Electric Supply**
  - NG generation adjustable
  - Other generation is "must run"
  - No elasticity in supply/demand
  - Plug-in vehicles are re-charged at night
- **Natural Gas Supply**
  - Supply elasticity for CA market
  - Imported and domestic supply
- **Gasoline Supply**
  - Oil price: linear projection
  - Elasticity for CA refinery supply
- **Hydrogen Supply**
  - 1 path: Distributed SMR

Vehicle Model

- **Conventional vehicles**
  - Gasoline fueled: 20 mpg
- **Plug-in Hybrid Electric Vehicles**
  - 48 mpg in gasoline mode
  - 0.35 kWh/mile electric mode
  - 1/3rd of miles in gasoline mode (40-mile electric range)
- **Hydrogen Fuel Cell Vehicles**
  - 65 mi/kg
- **Vehicle adoption**
  - Adjusted to Scenario #1 of Greene *et al* (ORNL, 2008)
  - 6% yearly sales rate
  - 20 year vehicle lifetime (5% scrap rate)

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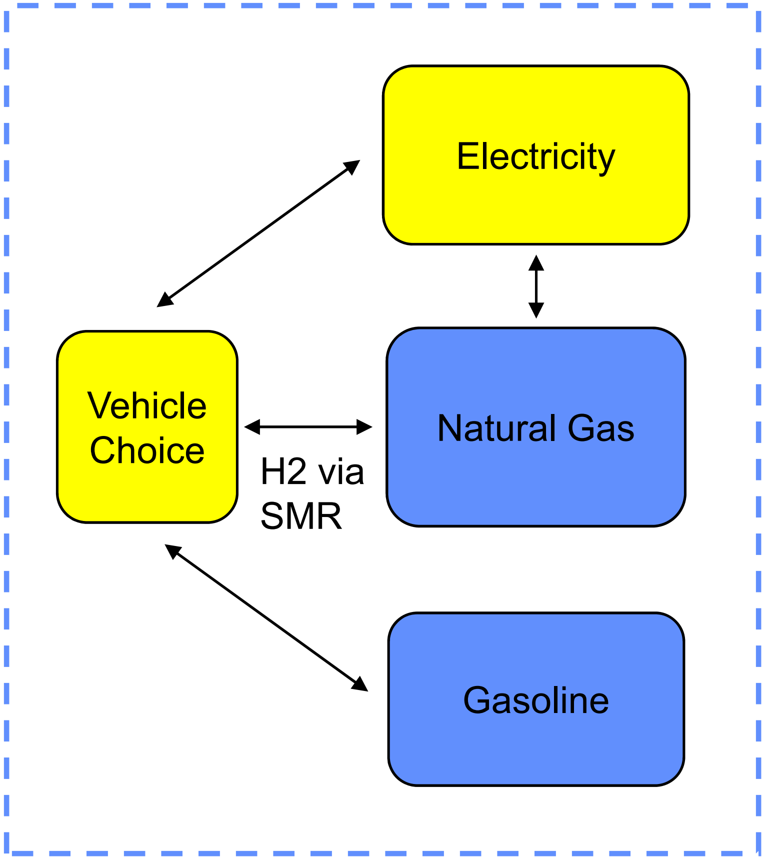
Technical Progress: add PHEVs and couple electricity market to add multiple interactions

Market Interactions

- **Compete PHEVs with HFCVs**
  - PHEVs for sale in 2010
  - Coupling PHEVs to electric & gasoline demand
- **In CA, electricity demand strongly coupled to NG supply infrastructure**

Regulatory Issues

- **Electric generation will change in CA**
  - Renewable Portfolio Std
    - 20% by 2010
    - 33% by 2020
- **Carbon tax on fossil fuels**



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Dynamic model couples energy markets to vehicle adoption model

Natural Gas

- **Supply:**
  - Imports & in-state production
- **Demand:**
  - Electric generation
  - Industrial, commercial, residential, and CNG vehicles (fixed)
  - HFCV demand from SMR
- **Price:**
  - Market elasticity
    - Long & short term
  - Determines H2 price

Electricity

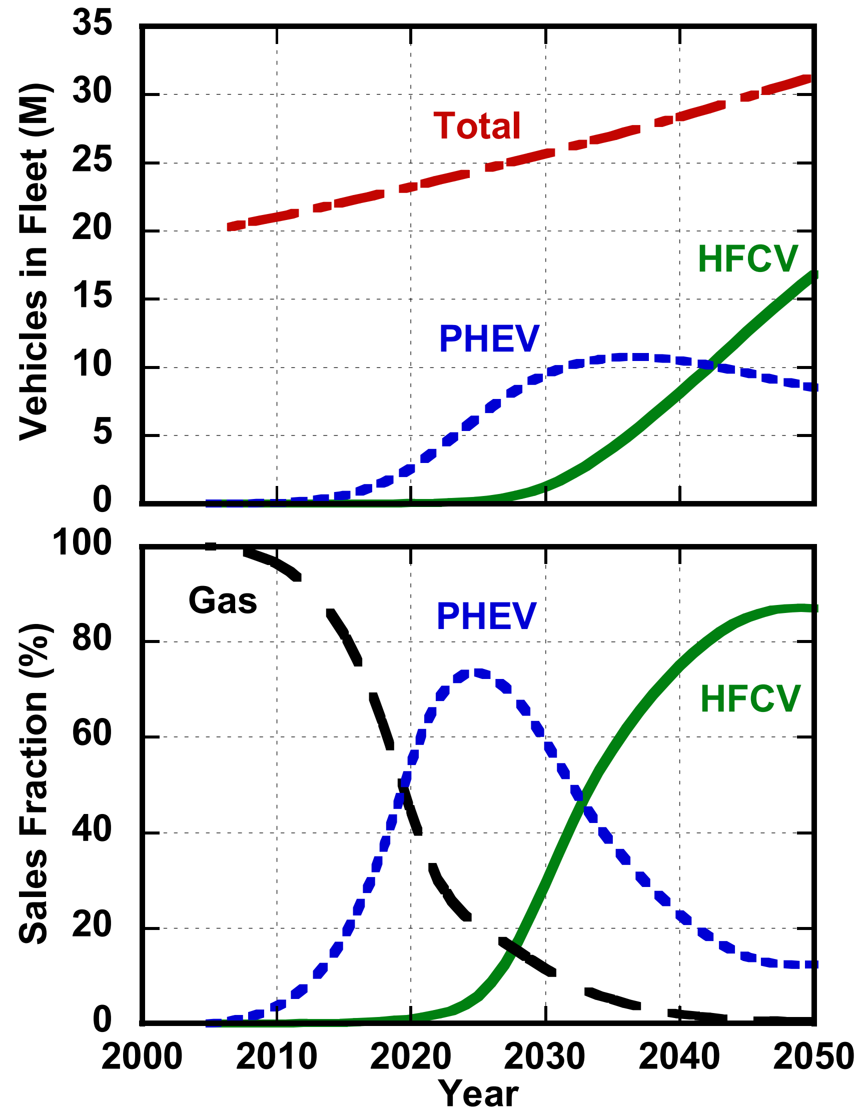
- **Supply:**
  - Imports (31% in 2007)
    - Coal (54% of imports)
  - In-state production
    - Must-run: nuclear, hydro, geo, solar, wind, biomass
    - Variable: NG
- **Demand:**
  - Historical load data with hourly resolution (Cal-ISO over 1 yr)
  - Daily PHEV charging
- **Price:**
  - Weighted average of fixed & variable generation costs
  - Fill hourly demand with must-run, then NG

Gasoline

- **Supply:**
  - Refinery capacity for CA compliant gasoline
- **Demand:**
  - Conventional and PHEV consumption
- **Price:**
  - Oil price specified in time
  - Refining margin modeled with market elasticity
    - Short-term elasticity for supply
    - Long-term elasticity identifies major capacity additions

Vehicle adoption model competes PHEV and HFCV with conventional vehicles

- **Adoption follows elements of Struben & Sterman model (MIT)**
  - Willingness to adopt parameterized by marketing and word-of-mouth
  - Affinity of vehicle choice depends on
    - Fuel cost, vehicle incremental cost, efficiency (mileage)
- **Adjusted to penetration Scenario #1 of Greene *et al* (ORNL) 2008 study**
  - On-road HFCV 1% of fleet by 2025
  - Plug-in vehicles replace hybrids
- **Vehicle penetrations are sensitive to**
  - HFCV:
    - H2 price (from NG price)
    - HFCV mileage: reference = 65 mile/kg
  - PHEV:
    - Electricity price



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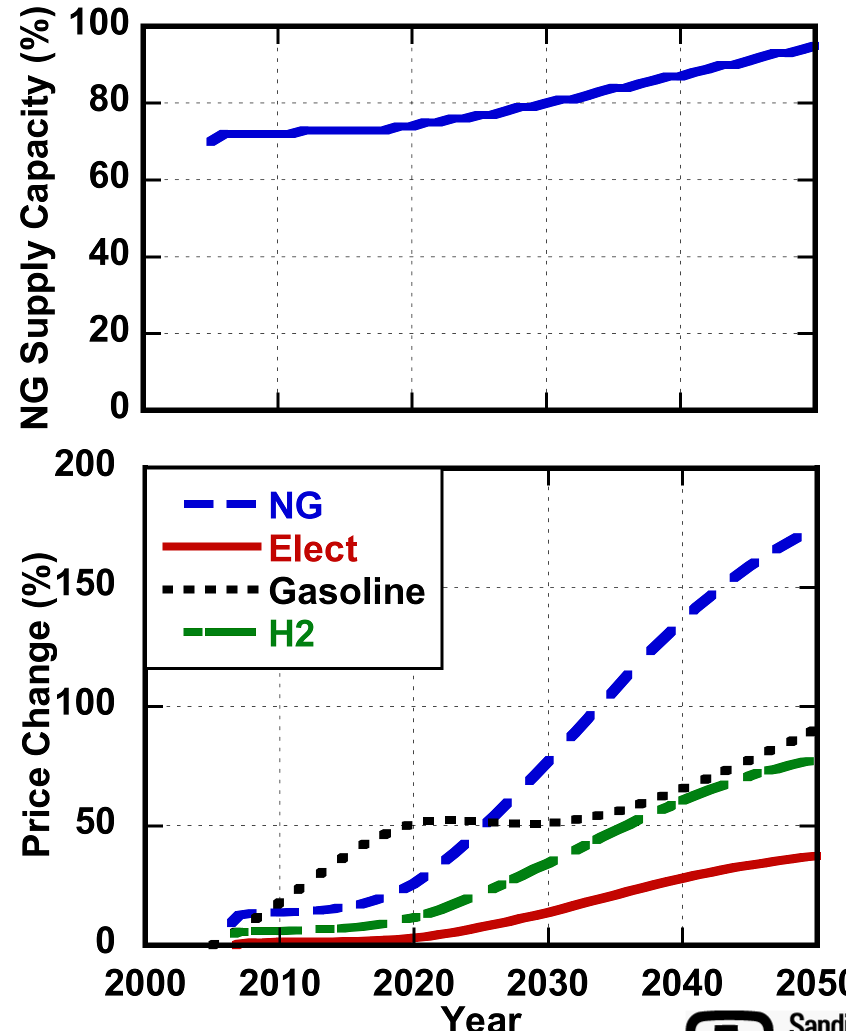
Penetration of PHEV and HFCV increases H2 and NG costs

- **Gasoline price flattens with reduced demand**
  - Linear increase in oil price
    - From 65 $/bbl to 140 $/bbl at 2030
  - Refining margin decreases, eventually to point where model becomes artificial at low demand
- **Electricity price grows due to PHEV demand**
- **NG price increases due to both PHEV and HFCV demand**
  - Consumption at 2050 approaches existing pipeline capacity
    - Major capacity increase necessary by 2040
- **H2 price tracks NG for SMR**
  - SMR is only path to H2



Price change relative to 2005

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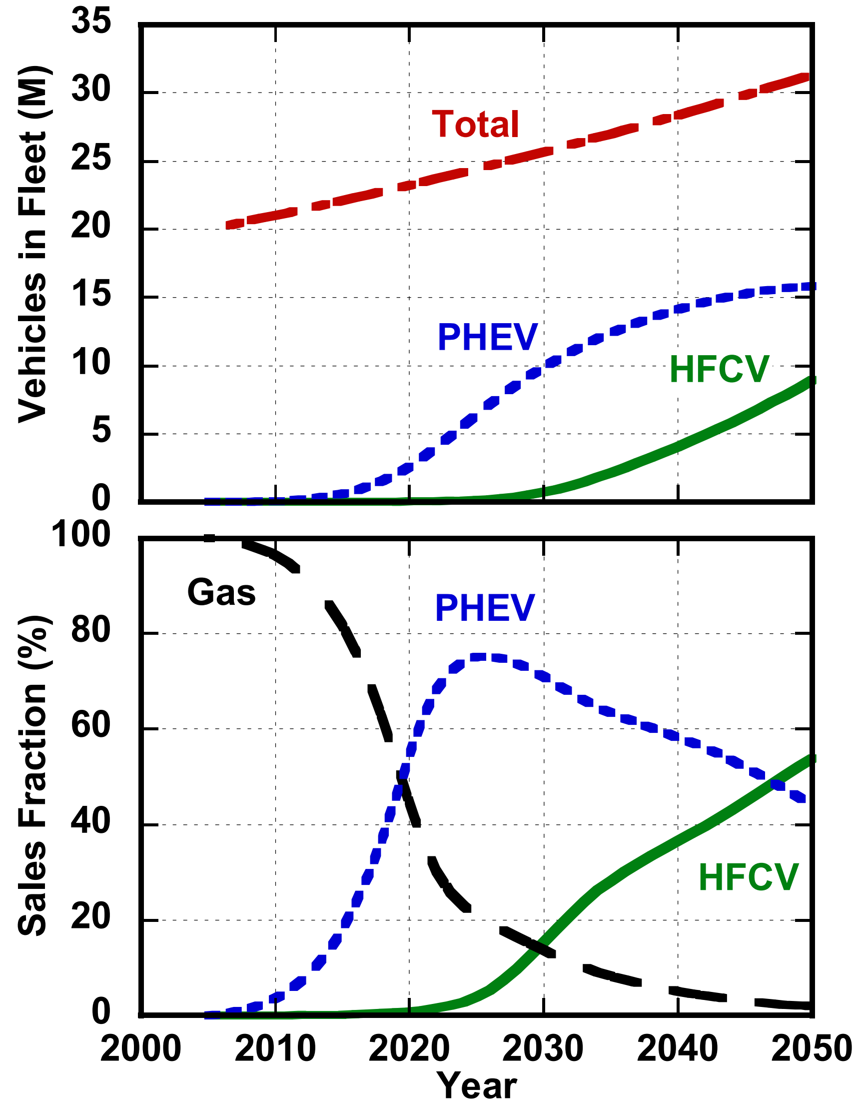
HFCVs must achieve high mileage to overcome plug-in vehicles

- **HFCV mileage**
  - Reference case: 65 mi/kg
  - At 55 mi/kg, affinity for HFCV is less than affinity for PHEV
- **PHEV mileage**
  - 48 mpg in gasoline mode
  - 0.35 kWh/mile electric mode
  - 1/3rd of miles in gasoline mode
    - Based on National Household Travel Survey
    - 40 mile electric range



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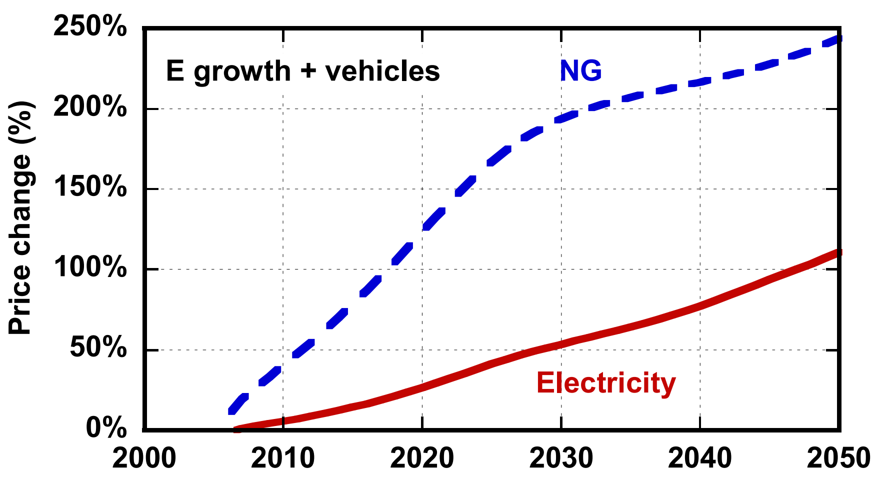
Growth in average electric load causes NG capacity to exceed existing infrastructure by 2025

- **Electric load grows at 1% / year**
  - Growth alone increases NG price 170% and electricity price 40%
- **Vehicle choice**
  - Higher average electric loads drive up NG price faster than electricity, favoring PHEVs over HFCVs



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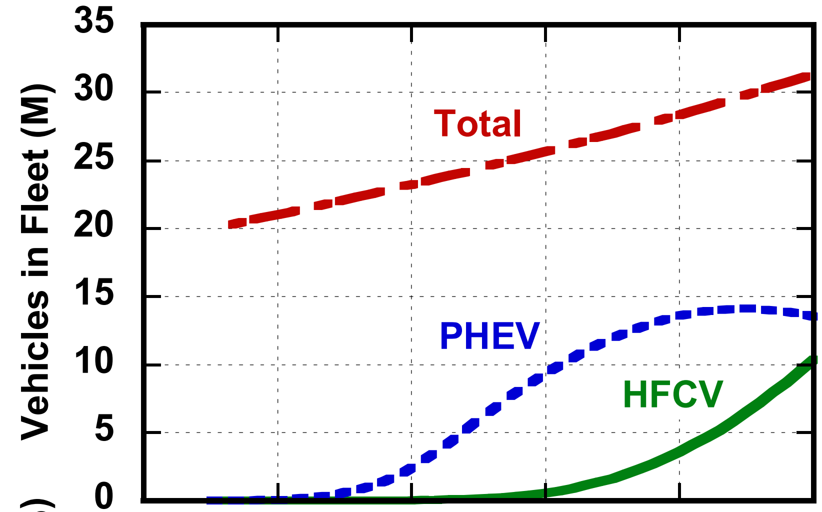

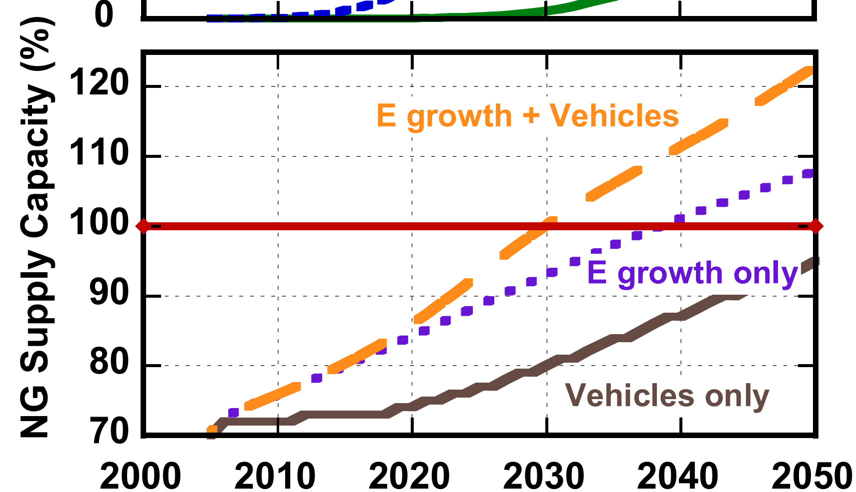

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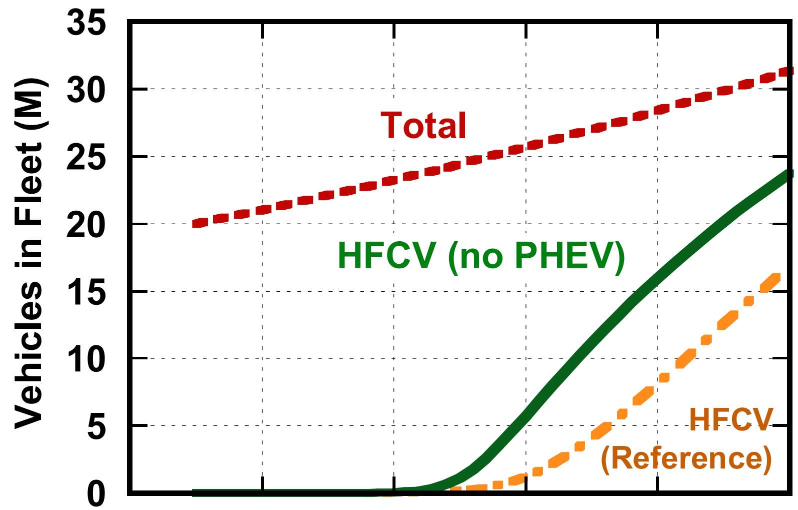
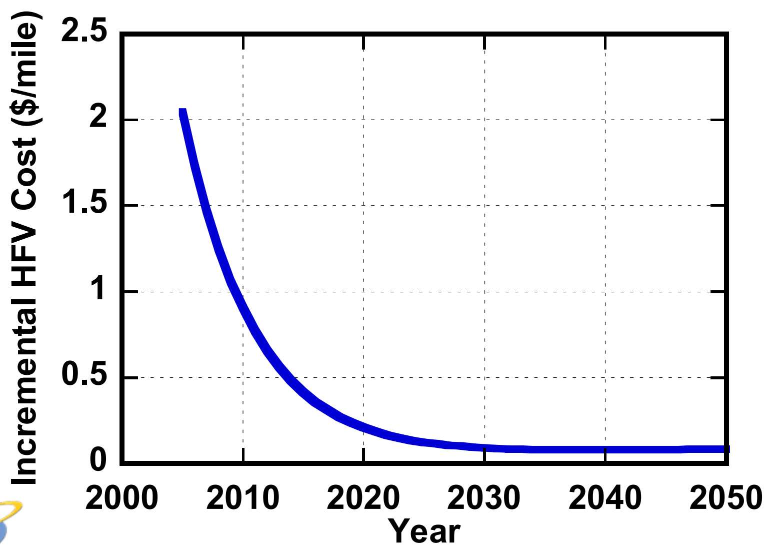
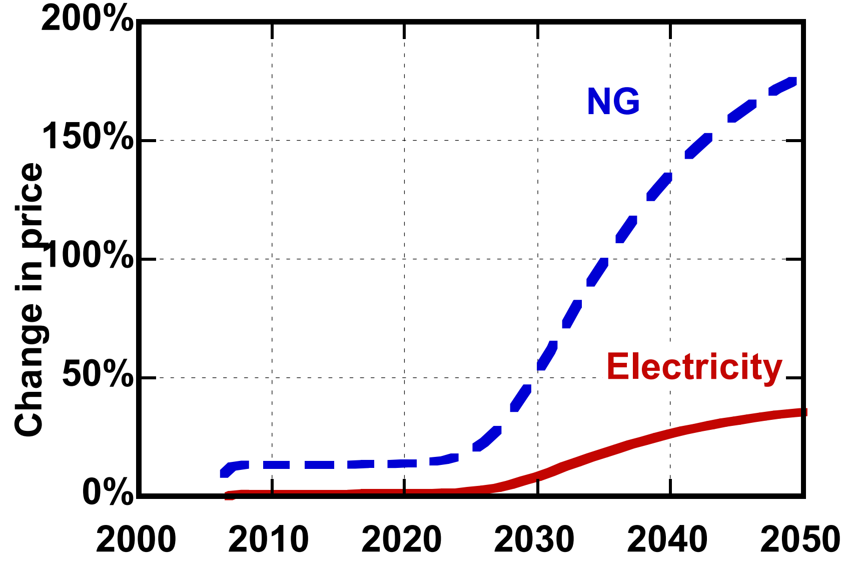
Absence of PHEVs allows earlier HFCV growth

- **Higher HFCV sales rate after 2025 increases the final market share**
  - HFCV price learning curve restricts early adoption
- **NG price increases with HFCV rollout as demand approaches current infrastructure capacity**







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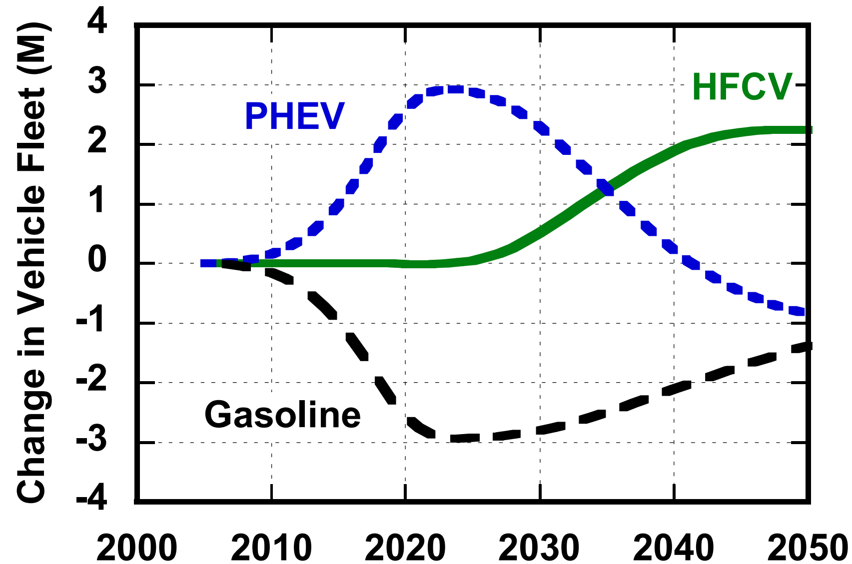
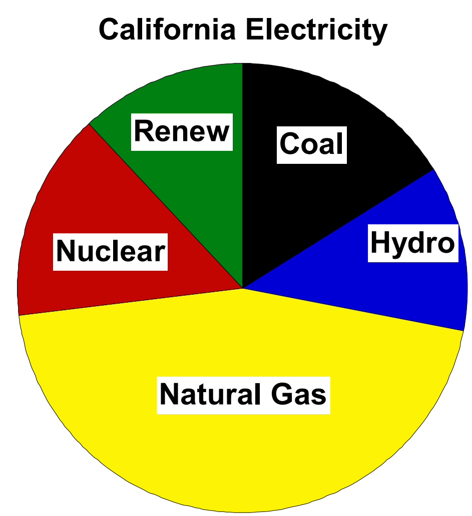
Carbon tax increases both PHEV and HFCV - at least for CA

- **Change in vehicle fleet compared to non-taxed reference case**
- **Additional CA electricity generated from NG**
- **Conclusion not likely true for other regions!**
- **Carbon Tax at 200 $ / tonne**
  - 1.76 $/gal gasoline
  - 1.85 $/kg H2
  - 0.11 $/kWh electricity
- **Tax influence on fuel cost**
  - PHEV ~ 4 ¢ / mile tax
  - HFCV ~ 3 ¢ / mile tax
  - Gasoline ~ 9 ¢ / mile tax





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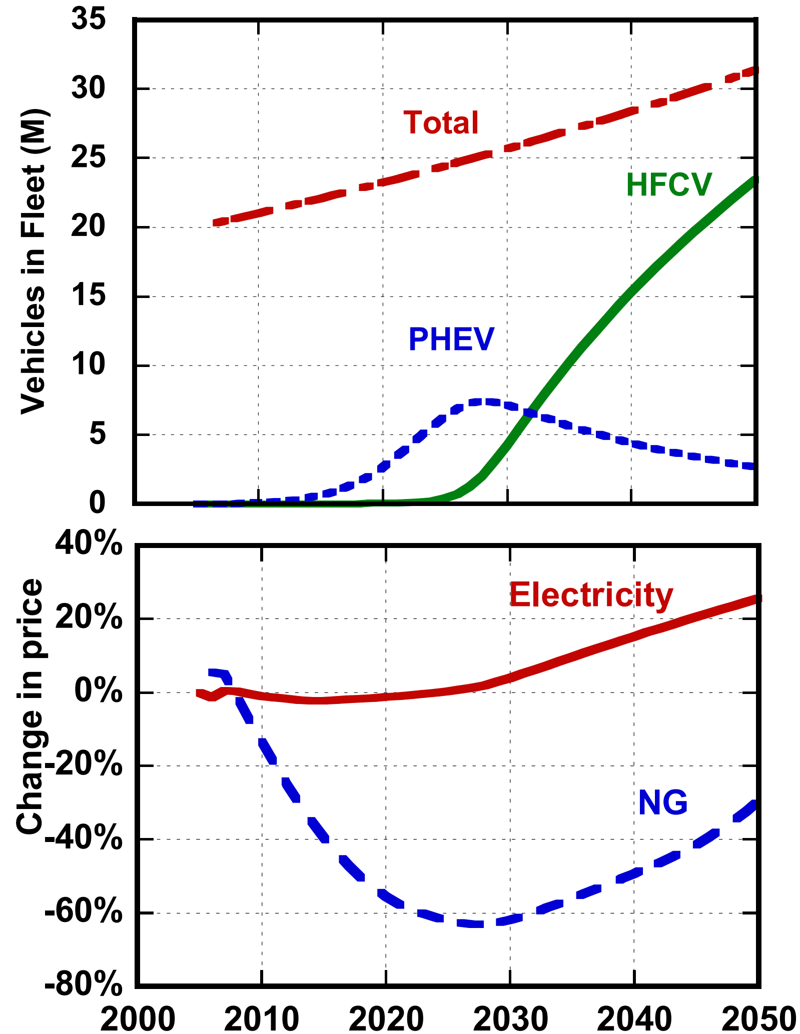
Aggressive renewable electricity frees NG supply and increases HFCVs

- **Increasing renewable power**
  - reduces NG demand
  - increases electricity price
  - HFCVs sales rise quickly in response to low NG price
- **California's goal of 33% renewable electricity by 2020 requires over 1000 MW/yr of new renewable capacity**
  - At linear rate of capacity increase, would result in 78% renewable power in 2050
- **Caveat: model does not consider limits to potential for renewable power!**



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Summary

- **System dynamics approach allows analysis of energy infrastructures**
  - Model describes market behavior of interconnected infrastructures
  - HFCV market adoption varies with costs of NG, gasoline, electricity
- **Simulations suggests that a transition to PHEV will increase NG price through electricity demand**
  - Since model assumes SMR to H2 only, HFCV competes with PHEV
- **Electric load growth (alone) is enough to stress CA's NG market**
  - Capacity to import gas from will be exceeded by 2035
  - Aggressive HFCV scenario based on H2 from reforming will move the NG capacity problem up a decade
- **Carbon tax will favor the adoption of both PHEV and HFCV**
- **Renewable power will free up NG for supplying HFCV**

Future Work

- **Remainder of FY09:**
  - Dynamics of NG pipeline and storage system
    - Canadian NG demand in winter reduces flow to California
    - Flow to CA in fall fills storage for winter
    - Weekday / weekend demand changes
  - Electrolysis option for H2 production
    - Compete off-peak H2 production with PHEV charging
    - Enable renewable H2 with growth in solar/wind
  - Model construction of additional electric generation capacity
  - Peer Review:
    - Local connections with UC Davis ITS and CA-Fuel Cell Partnership
- **FY10:**
  - Extend SD approach to another region in US
  - Modify electrical generation model for regional mix