Analysis of the Effects of Developing New Energy Infrastructures

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AN002

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National Nuclear Security Administration

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Overview

Timeline

- Start – Dec. 2007
- Finish – Sep. 2012
- 80% complete

Budget

- Total project funding
  - DOE $590K
- Funding received in FY2011
  - $200 K

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)

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Relevance

Project Objective	**MYPP Systems Analysis Task 1 Activity**
Use dynamic models of infrastructure systems to analyze the impacts of widespread deployment of hydrogen technologies	Environmental impact analyses
Analyze contribution of Stationary Fuel Cells (SFC) co-produced H_2 to early market Hydrogen Fuel Cell Vehicle (HFCV) penetration	Analysis of necessary infrastructure development
Analyze competition between electric vehicles, efficient gasoline vehicles and HFCVs	Analyze the long-term impact of hydrogen fuel and vehicles

Milestones

MM / YYYY	Milestone
05 / 2011	Analyze role of SFC with H2 co-production in enabling HFCV transition. Completed.
09 / 2011	Analyze competition of HFCV and refueling to alternatives of Plug-in Hybrid Electric Vehicles (PHEV) and Battery Electric Vehicles (BEV). Ongoing.

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Collaborations

- Directly linked to IEA Task 30: Global H_2 Systems Analysis
  - Task 30 Participants:

Australia	Japan
Canada	Norway
Denmark	Spain
France	Sweden
Germany	United Kingdom
Greece	United States
Italy	

  - Modular software can be extended to other countries or regions
  - Multi-region supply, demand, and dynamics modeling to inform IEA reports
    - World Energy Outlook
    - Energy Technology Perspectives
- Collaboration with Dr. Andy Lutz at U. of the Pacific

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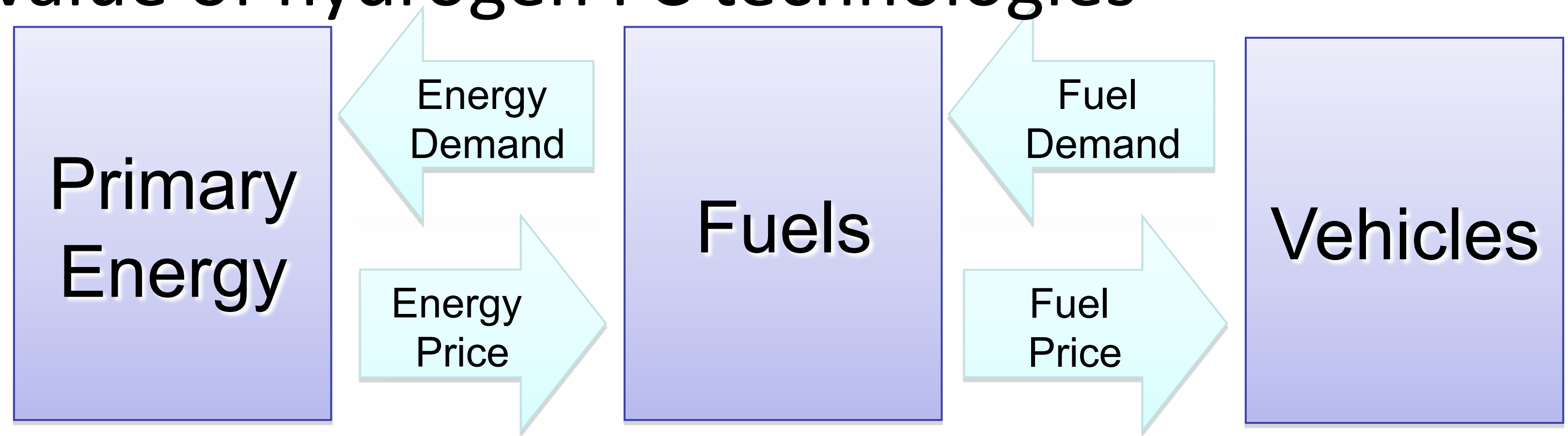
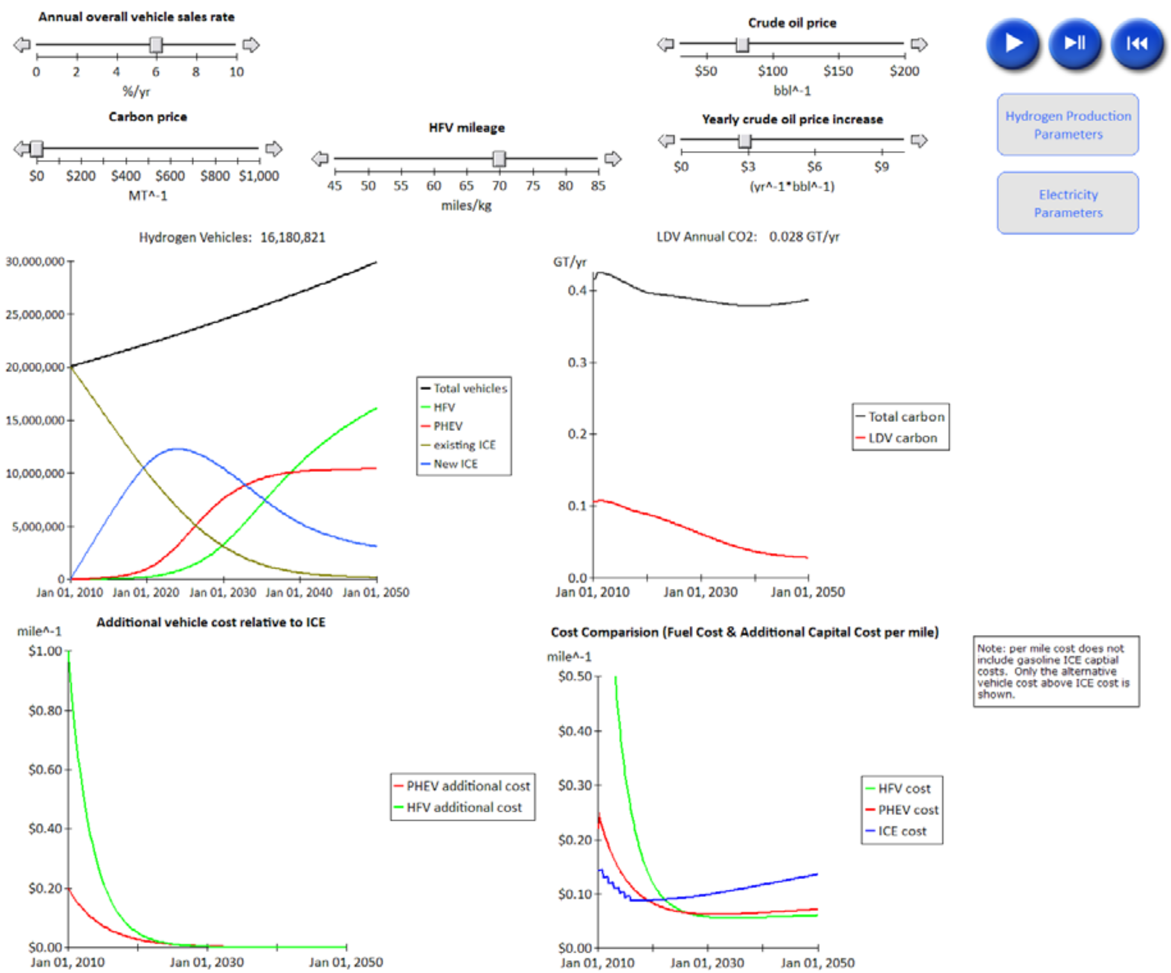
Approach: System dynamics modeling to access value of hydrogen FC technologies



- Choose appropriate regions and vehicle segments to define the system
  - Resources and demand vary by region
  - Alternative vehicle technologies have different performance/capabilities
- Cost will drive decisions
  - Choice factors (e.g. vehicle range) can be converted to cost penalty
- Model legislated and potential improvements to gasoline vehicles
- Pose detailed questions
  - What are the potential reductions of CO_2 emissions and gasoline consumption due to HFCV adoption?
  - What is the value of HFCV in comparison to battery electric vehicles?
  - What effect does stationary FC H_2 co-production have on HFCV penetration?

Approach: Model provides user interface and sensitivity analysis

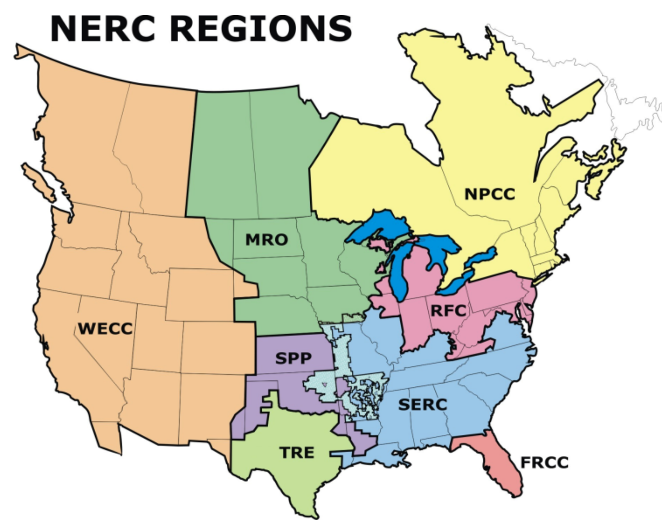
- Easy-to-use model front end
- Allows sensitivity analysis using Latin hypercube sampling
- Results are displayed on-screen as well as sent to Excel spreadsheet



Technical Progress: More detail for vehicles & fuels to analyze impact of changing vehicle technologies

- Added powertrain and vehicle size to model to analyze up to 15 vehicle subtypes
- Expanded model from 1 geographic region to 8 regions
- Enhanced modeling of future energy sources to include low-carbon options

<u>Powertrains:</u> Conventional ICE, HFCV, PHEV10, PHEV40, BEV	<u>Vehicle size/class:</u> Small Car, Large Car, Truck
<u>Energy sources:</u> Coal, Natural gas, Oil, Wind	<u>Fuels:</u> Gasoline, Hydrogen, Electricity



North American Electric Reliability Corporation regions are not geographic regions; our regions approximate NERC regions.

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Vehicle Fuel Economy Assumptions

MPGe in 2010/2016/ 2035	Gasoline ICE	HFCV	PHEV10 Gas (77%) Elect (23%)	PHEV40 Gas (37%) Elect (63%)	BEV
Small Car	36/42/45	69/71/76	41/45/56 84/102/136	30/34/47 94/110/148	99/110/148
Large Car	18/30/39	69/71/76	35/39/47 72/87/116	25/29/40 80/94/126	N/A
Truck	18/30/39	69/71/76	20/23/28 42/51/68	N/A	N/A

- Vehicle fuel economy interpolated between points and is fixed at the last value after 2035
- Used EPA vehicle class definitions (not CAFE) - SUVs classified as “large cars”
- Some powertrain/size combinations assumed to be unlikely
- Gasoline internal combustion engine (ICE) powertrain includes hybrids
- Current HFCV values based on Toyota Highlander FCHV-adv report (Wipke *et al*)

Assumptions

Fuel Model

Electric Supply

- Marginal electricity mix for regions calculated from EPA eGrid2009 data by selecting fossil generation units at 0.3-0.6 capacity factor
- Option to fix marginal generation, convert generation to natural gas, or convert to least cost new generation option.

Natural Gas Supply

- EIA price data used to initialize model
- Current distribution system assumed to be at 80% capacity

Gasoline Supply

- Oil price: linear projection, ability to program periodic price spikes. Default oil price is $90/bbl with $3/bbl/year increases

Hydrogen Supply

- Distributed steam-methane reforming (SMR)
- Zero-carbon H_2 from wind with central electrolysis
- Cost of distribution decreases as number of vehicles increases
- Choice of energy source based on price inclusive of carbon price

Vehicle Model

- Purchase costs adapted from National Academies reports, " Transitions to Alternative Vehicle Technologies" (2008,2010). Long-term incremental vehicle costs (above conventional) are $2100 for PHEV10 and HFCV, and $5500 for PHEV40 and BEV.
- Vehicle age distribution and scrap rate from Department of Transportation (DOT) data
- Sales rate 6.8%, scrap rate 5.9%. Fleet grows at 0.9% per annum, equal to US census bureau projections
- Multinomial logit model based on purchase cost, fuel cost, and penalty factor to determine sales

SFC Model

Large Scale: 500 MW

- High Temp FC system
- Natural Gas (NG) operation with internal reforming
- 50% NG to electric efficiency
- 24% to H2 in co-production mode
- Performance parameters from FuelCell Energy publications

Penetration extent from California Energy Commission report extrapolated to US

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Model provides a tool for examining a range of scenarios

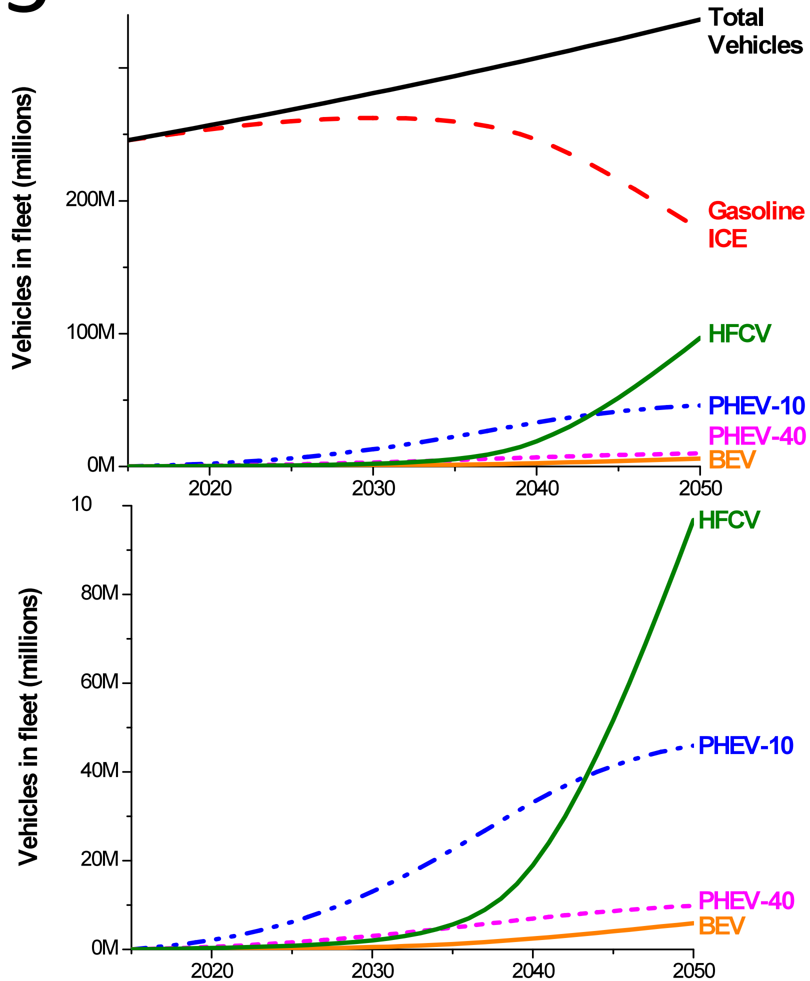
- Key input parameters
  - Vehicles:
    - Fuel economy as a function of time; cost of alternative technologies, learning curve for vehicle cost; sales/discard rates, payback period for additional purchase cost, availability of powertrain options
  - Electricity:
    - Changes in marginal electric mix, rate of change of marginal electric mix, non-transport demand for electricity
  - Energy Sources:
    - NG price elasticity, Supply curves for zero-carbon energy sources, Availability of inter-regional transport, Crude oil initial price and rate of increase
  - SFC:
    - Electric efficiency; H_2 co-production efficiency, fixed & variable costs of H_2 production; penetration rate of SFC units
  - Other: carbon price

Base case: HFCV dominate alternative vehicle fleet by 2045

- With moderate increases in petroleum price ($3/bbl/yr) and without carbon price, gasoline ICE vehicles are the majority for the first half of this century

- PHEV-40 and BEV are hampered by costs and market segment limitations

- Smaller batteries in PHEV-10 reduce vehicle cost, allowing earlier penetration



- Hydrogen-fueled vehicles are the dominant alternative vehicle after 2045
- Fleet is half alternative vehicles at 2050
- Hydrogen-fueled vehicles reach 1 million vehicles by 2026

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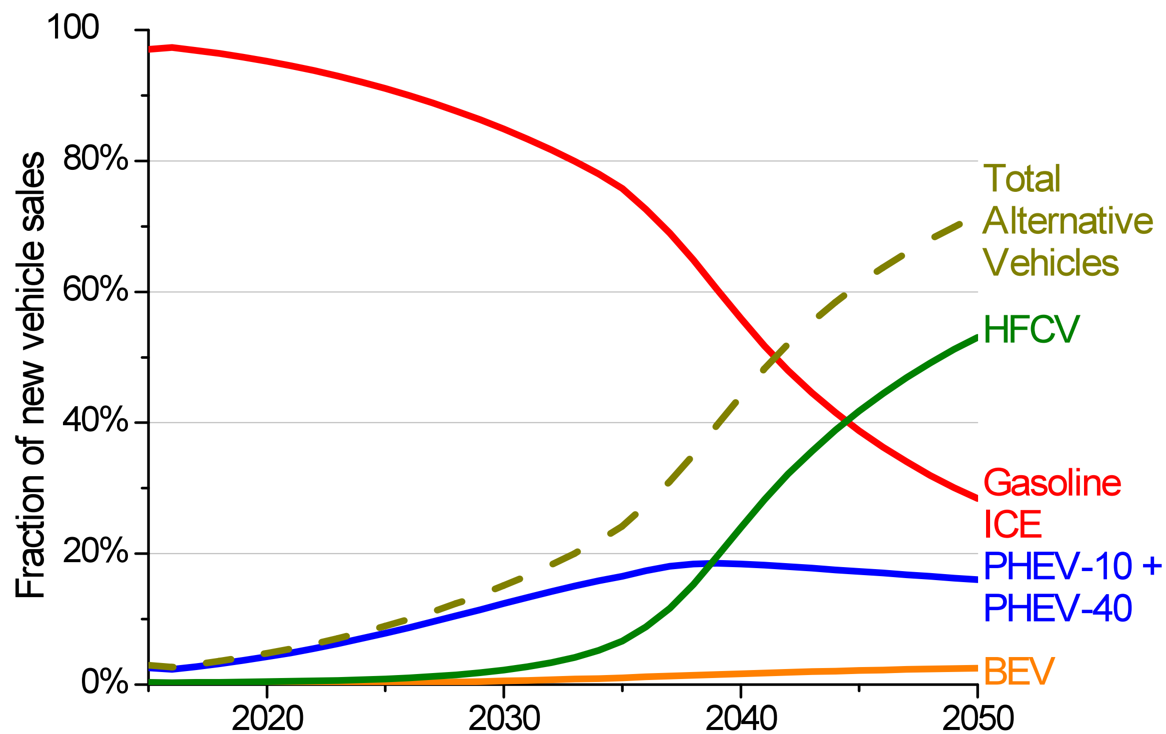
Base case: Alternative fuel vehicle sales accelerate after 2030

Assumptions:
- Improvements in fuel economy for all vehicles
- Reductions in the cost of alternative vehicles
- Carbon policy not considered

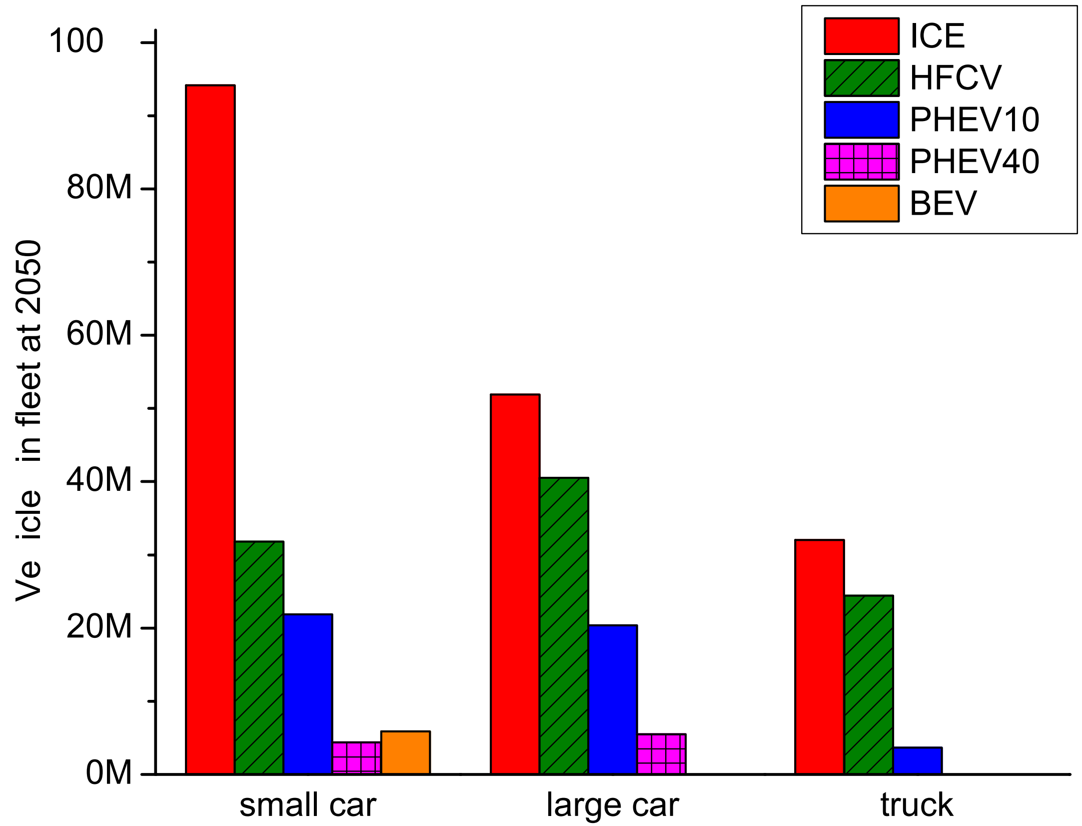
Shape and timing of HFCV sales rate is consistent with HyTrans results (Greene *et al*, ORNL 2008)



- Gasoline ICE sales fall below 50% in 2040
- Alternative vehicles make up 75% of new vehicle sales at mid-century (~17 M vehicles/year)

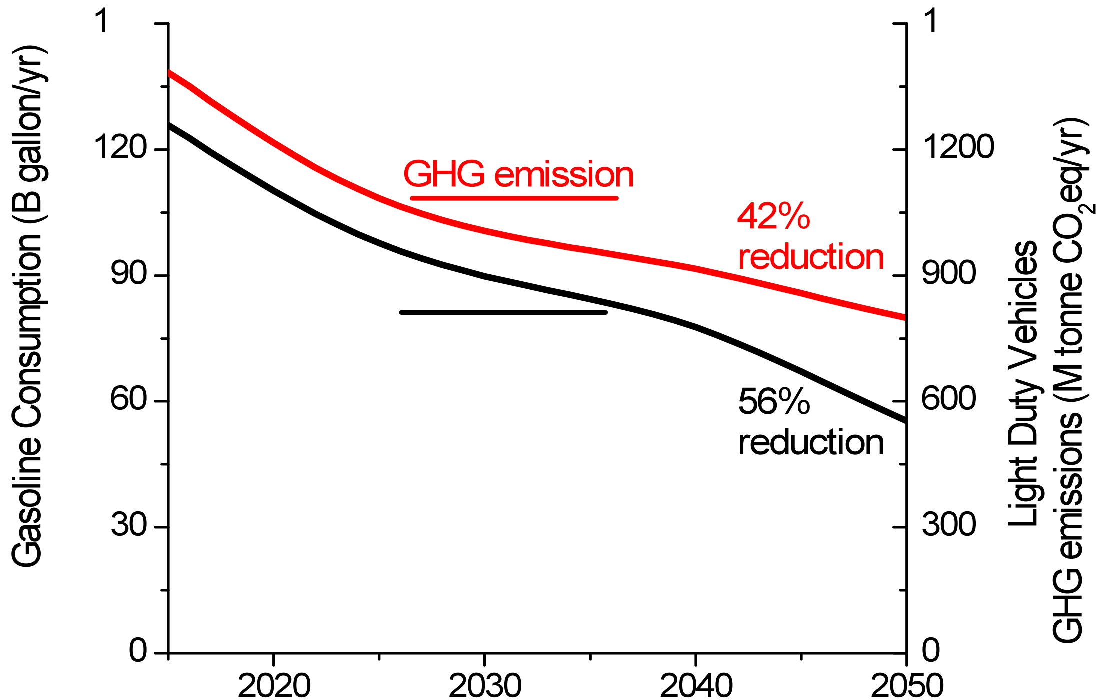
Base case: Powertrain choice varies with size of vehicle

- Large car segment
  - Higher proportion of alternative vehicles due to larger difference in fuel consumption
- Small car segment
  - Small ICEs already efficient
  - Fuel savings of alternative vehicles is small compared to additional purchase costs
- Changing vehicle cost or gasoline price assumptions changes both the penetration and distribution of hydrogen vehicles



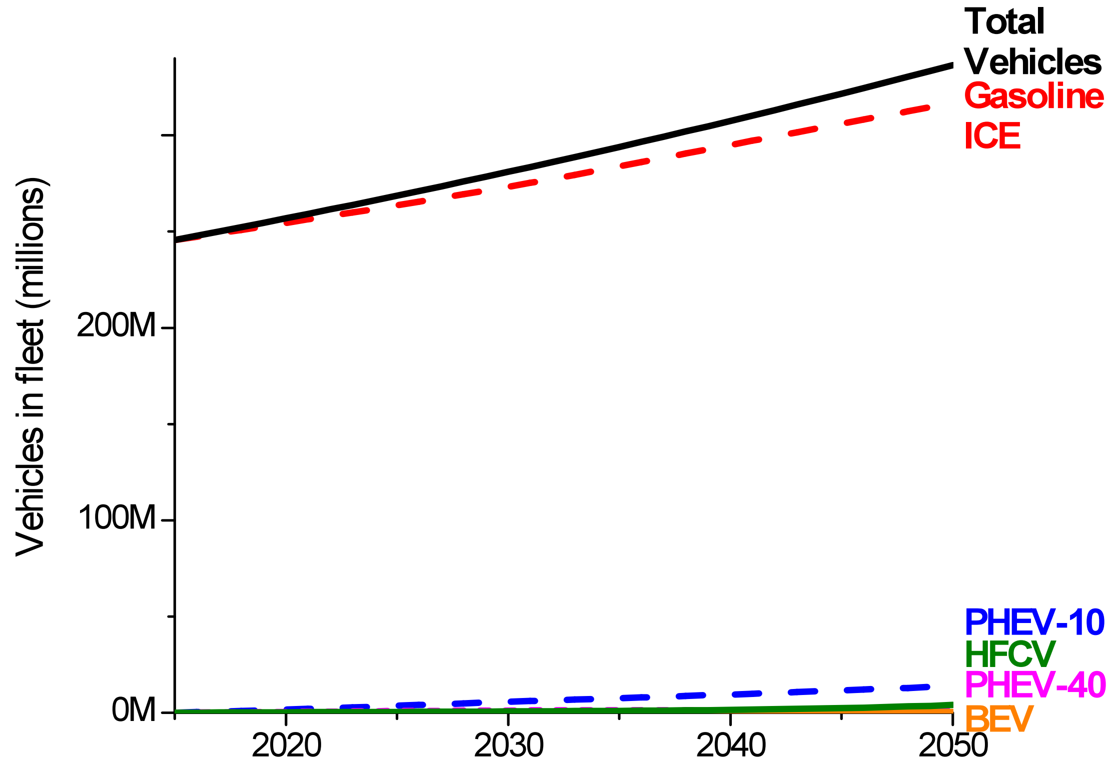
Base case: Large reductions in both gasoline use and GHG emissions from new vehicle technologies

- Significant gasoline use reduction, despite increase in population & vehicles
  - Increases 0.9% per year, total increase 37% from 2015 to 2050
- Gasoline demand in 2050 is within the technical limit of domestic biofuel production
  - About 60 B gallon gasoline equivalent (GGE) per year
- Gasoline ICE improvements alone would achieve 25% reduction in GHG emissions and gasoline use (relative to 2015)



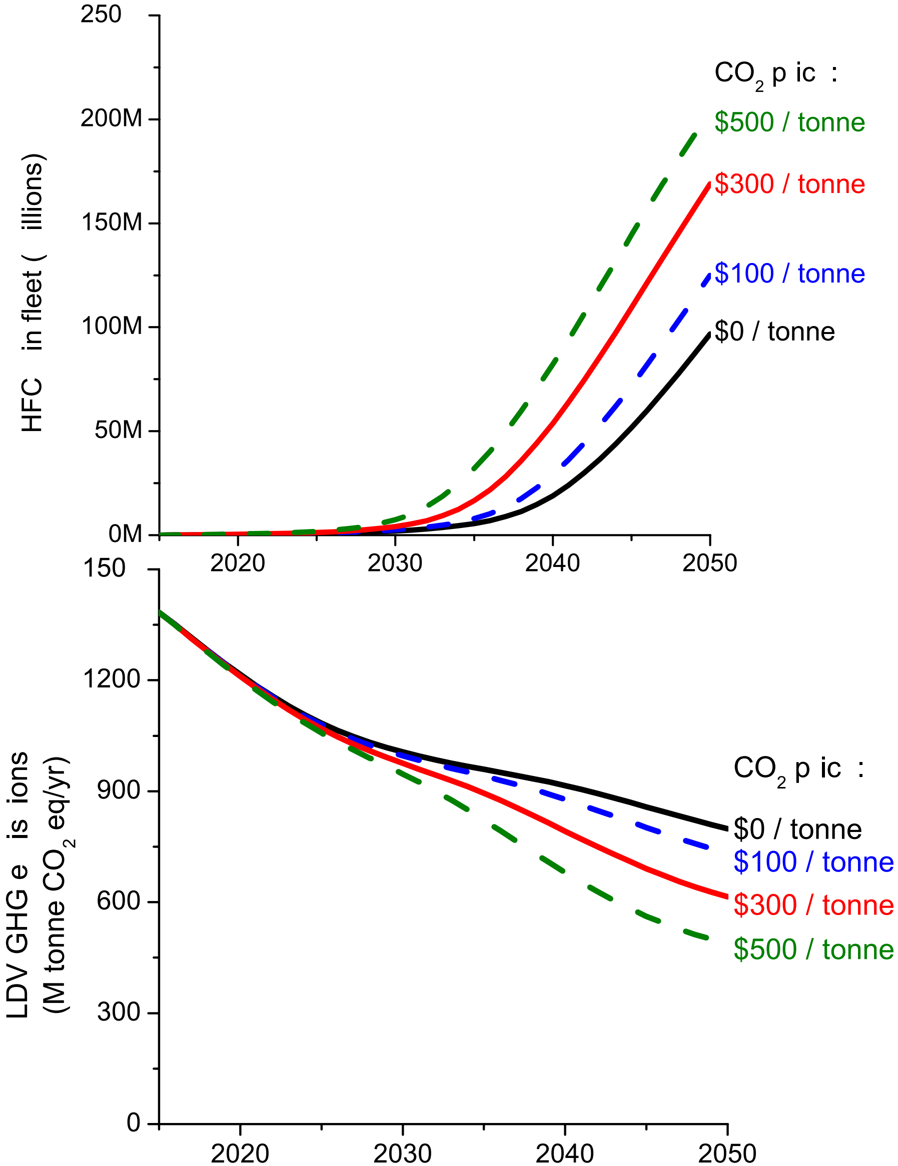
Without higher gasoline costs, alternative vehicles are minor portion of fleet

- Oil price constant at $90/bbl
- No carbon price
- Gasoline ICE continue to improve
- Fuel savings is not sufficient to support purchase of alternative-fueled vehicles
- Model does not presuppose success of alternative vehicles



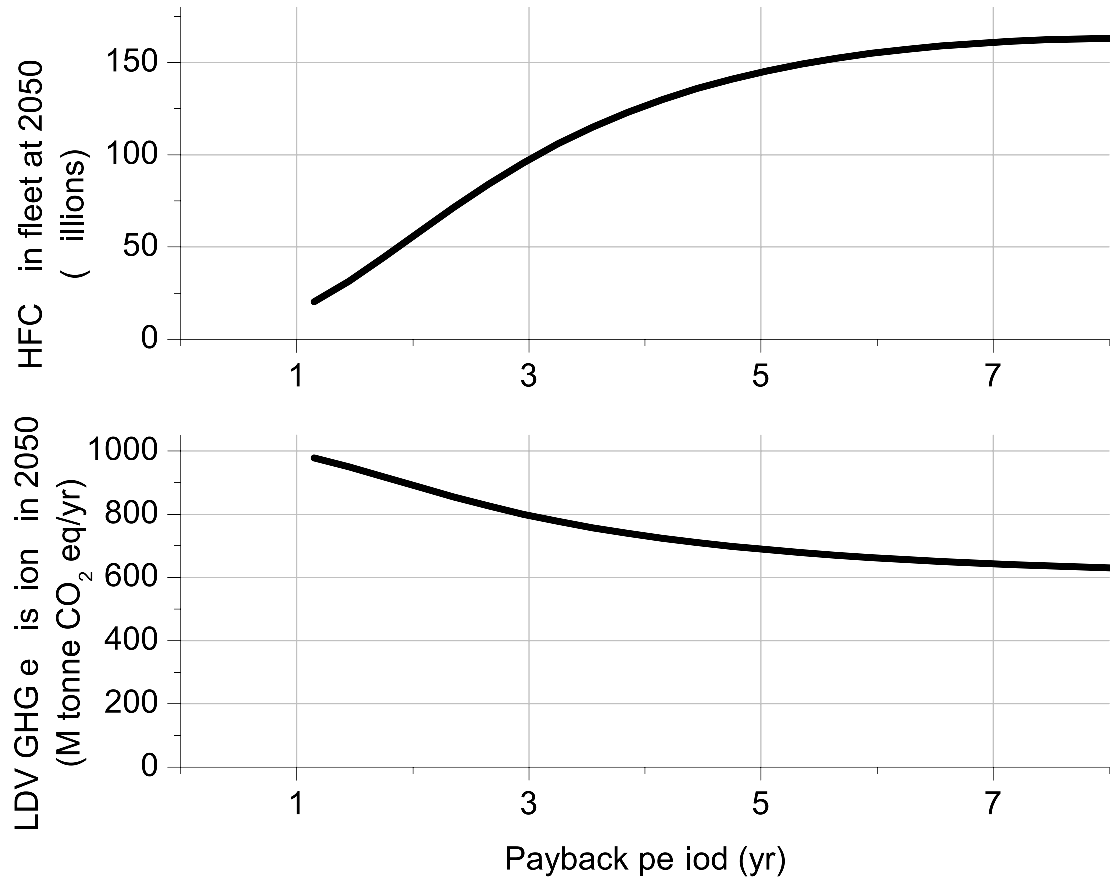
High carbon price increases hydrogen vehicle penetration

- Model allows hydrogen production from natural gas or wind electricity
- Carbon price increases the total number of HFCV and causes earlier introduction
- However, significant carbon price is required to have large impact on hydrogen vehicle sales



Payback period is a critical parameter for HFCV sales and GHG emissions

- Greene reports consumers use 1.5 to 2.5 year payback period
- Baseline assumption: 3 year period for consumer choice
- Changing from 3 to 5 years to recoup purchase price increases HFCV by 50% and saves >100 M tonne CO_2/year
- Achieving the same reduction with carbon price requires $175/ tonne price.



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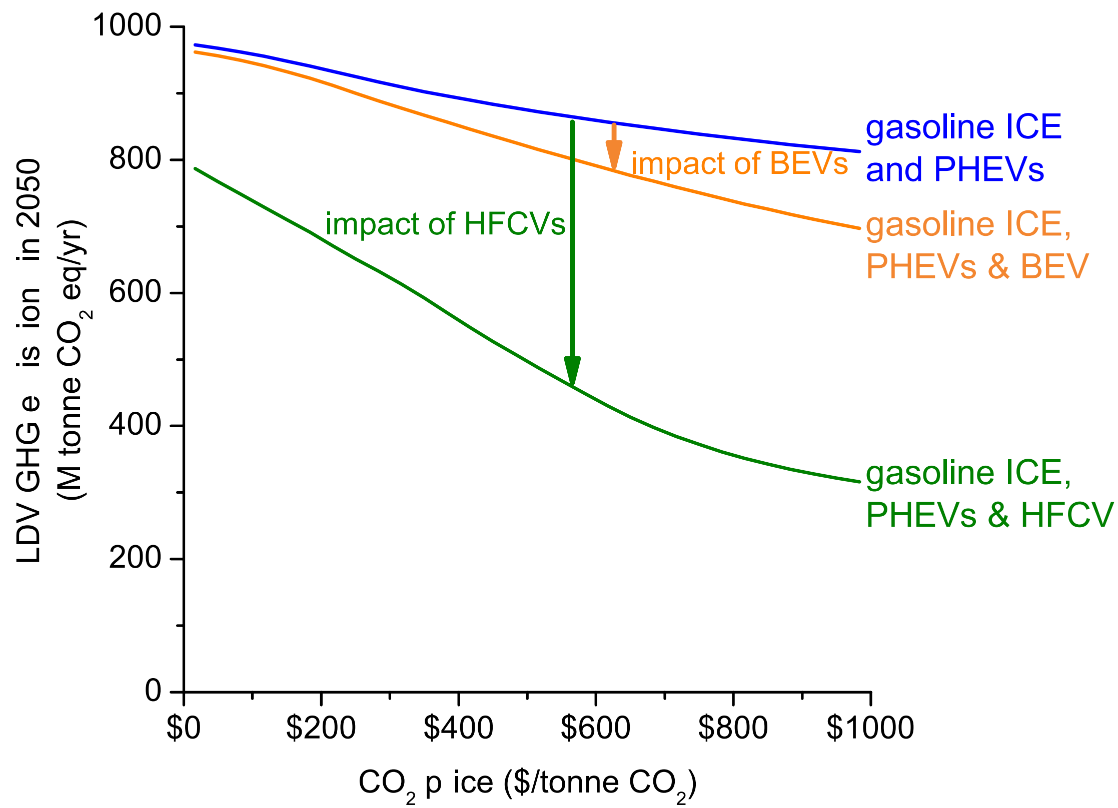
Hydrogen vehicles have a larger impact on emissions & oil use than battery electric vehicles

- Large-scale use of hydrogen or battery electric vehicles will require infrastructure investment and R&D progress.
- However, the impact of these technologies is not equal.

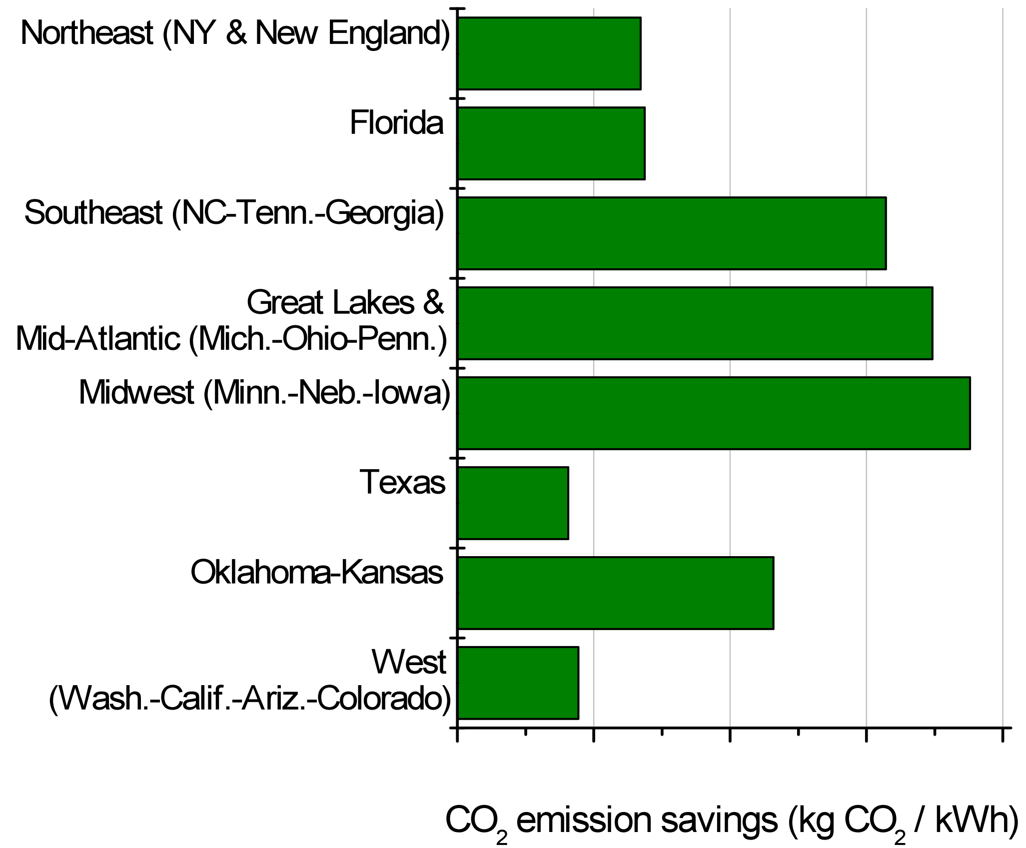
Gasoline use

Oil Price	ICE +PHEV	ICE +PHEV +BEV	ICE +PHEV +HFCV	ICE +PHEV +HFCV +BEV
$90/bbl, no increase	92.7 B gal/yr	92.6 B gal/yr	91.4 B gal/yr	91.3 B gal/yr
$90/bbl → $195/bbl	84.5 B gal/yr	82.6 B gal/yr	56.2 B gal/yr	55.3 B gal/yr
$90/bbl → $265/bbl	79.6 B gal/yr	75.6 B gal/yr	40.5 B gal/yr	39.2 B gal/yr



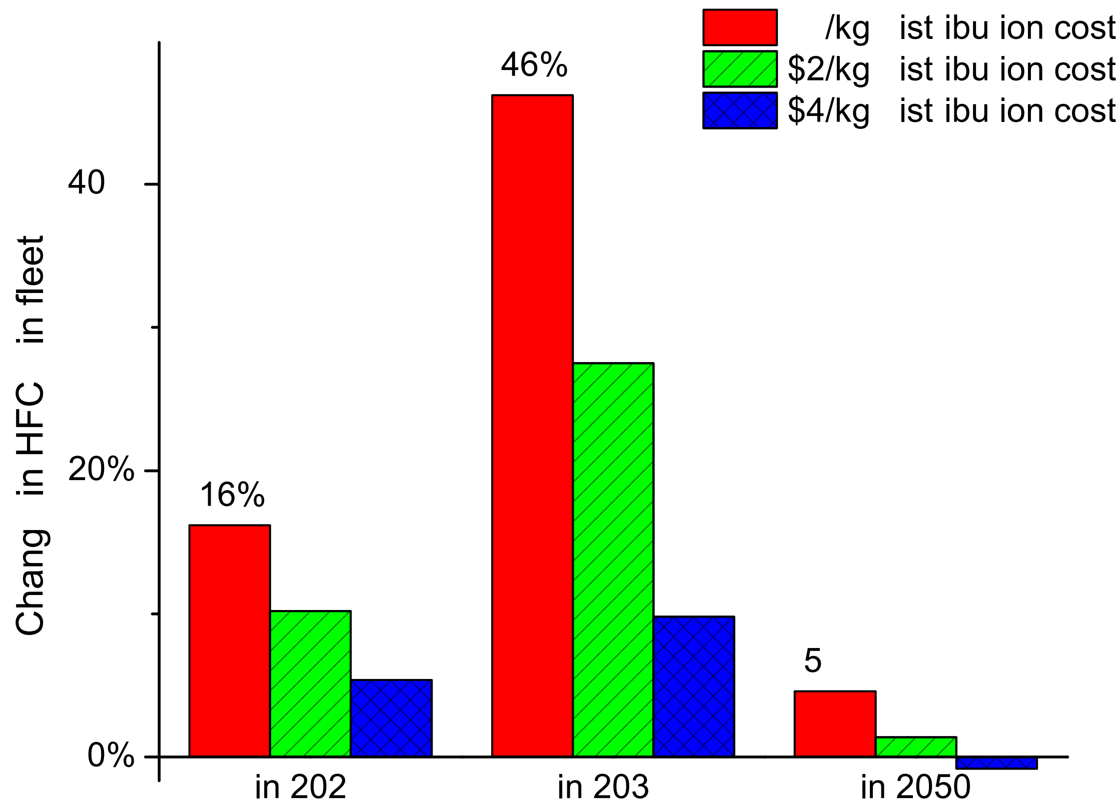
Emissions benefits from SFC for distributed generation vary by region

- Benefits are significant in regions with coal-fired marginal generation
- Absolute value of emissions reduction depends on SFC penetration rate



SFC hydrogen availability could change early adoption behavior

- SFC hydrogen co-production increases initial HFCV penetration
- Effect is significant if filling station capital and maintenance costs are subsidized or otherwise reduced



Baseline: 0.84M 5.6M 96.7M

Summary

- Increasing oil prices and/or policies that give a price to carbon are needed for significant numbers of HFV to penetrate the light duty vehicle fleet.
  - At moderate oil price increases, our analysis predicts 50% hydrogen and electric vehicles by 2050.
- Hydrogen vehicles would allow significant GHG emission and gasoline use reductions.
  - Over 50% decrease in gasoline use in 2050 (relative to 2015 levels)
  - Hydrogen vehicles are predicted to have much larger effect than battery electric vehicles.
  - Our model shows a high sensitivity to the payback period used for consumer vehicle choice. Policies that address the consumer's view of fuel saving and purchase price could have significant effect on emissions.
- H_2 co-produced from SFC could have impact on early vehicle adoption rates.
  - Up to 46% increase in H_2 vehicles in 2035

Future Work

- Remainder of FY11:
  - Increase the number of hydrogen production pathways modeled
  - Incorporate higher resolution energy source data
- FY12:
  - Consider coupling of system dynamics tools to Macro-System Model
  - Include detail on inter-regional energy and fuel transport
  - Examine infrastructure costs, such as natural gas transportation and distribution networks
  - Include ability to examine more complex carbon policies