NEMS-H2: Hydrogen's Role in Climate Mitigation and Oil Dependence Reduction

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May 10, 2011

2011 Annual
Merit Review and Peer Evaluation Meeting

Project ID # AN016

Overview

Timeline	Barriers
• Start: July 2008 • Finish: June 2011 • Complete: 90%	• Future Market Behavior [4.5.A] • Stove-piped, Siloed Analytical Capability [4.5.B]
Budget	**Partners**
Total Project Funding: $280k • 100% DOE-funded • FY11 funding: none	• OnLocation, Inc.

Relevance: Hydrogen Scenarios Require Consideration of Fuel and Vehicle Markets

NEMS-H2 provides a framework for analyzing hydrogen fuel cell vehicles and hydrogen production in the context of the U.S. energy system

- Unlike in many other studies, energy supply and demand market dynamics are considered explicitly within the model
- Fuel cell electric vehicles (FCEV) market shares internally projected based on many factors including vehicle characteristics
- Relies on technology cost and performance and other data from more detailed models, such as H2A

NEMS-H2 provides a comprehensive context for analyzing hydrogen scenarios

Relevance: Project Objective

The objective is to demonstrate the potential contribution of fuel cell electric vehicles (FCEVs) to meeting national goals of reducing GHG emissions and oil imports

- Using an economic framework with competition among vehicle and hydrogen production technologies
- Analyzing the impact of alternative technology outcomes (hydrogen production, fuel cell vehicles, etc)
- Analyzing potential role and cost of policies to accelerate adoption of fuel cell vehicles

Relevance: Impact on Barriers

Barrier	***Impact***
Future Market Behavior [4.5.A]	• Performs analysis of future hydrogen vehicle deployment in the context of other hydrogen related technologies as well as other energy markets (e.g. natural gas, electricity, biomass)
Stove-piped, Siloed Analytical Capability [4.5.B]	• NEMS-H2 brings together data gathered from multiple sources on the many facets of a hydrogen based transportation system • Uses data from H2A production models, H2A Delivery Scenario Analysis Model (HDSAM), and Macro-System Model (MSM)

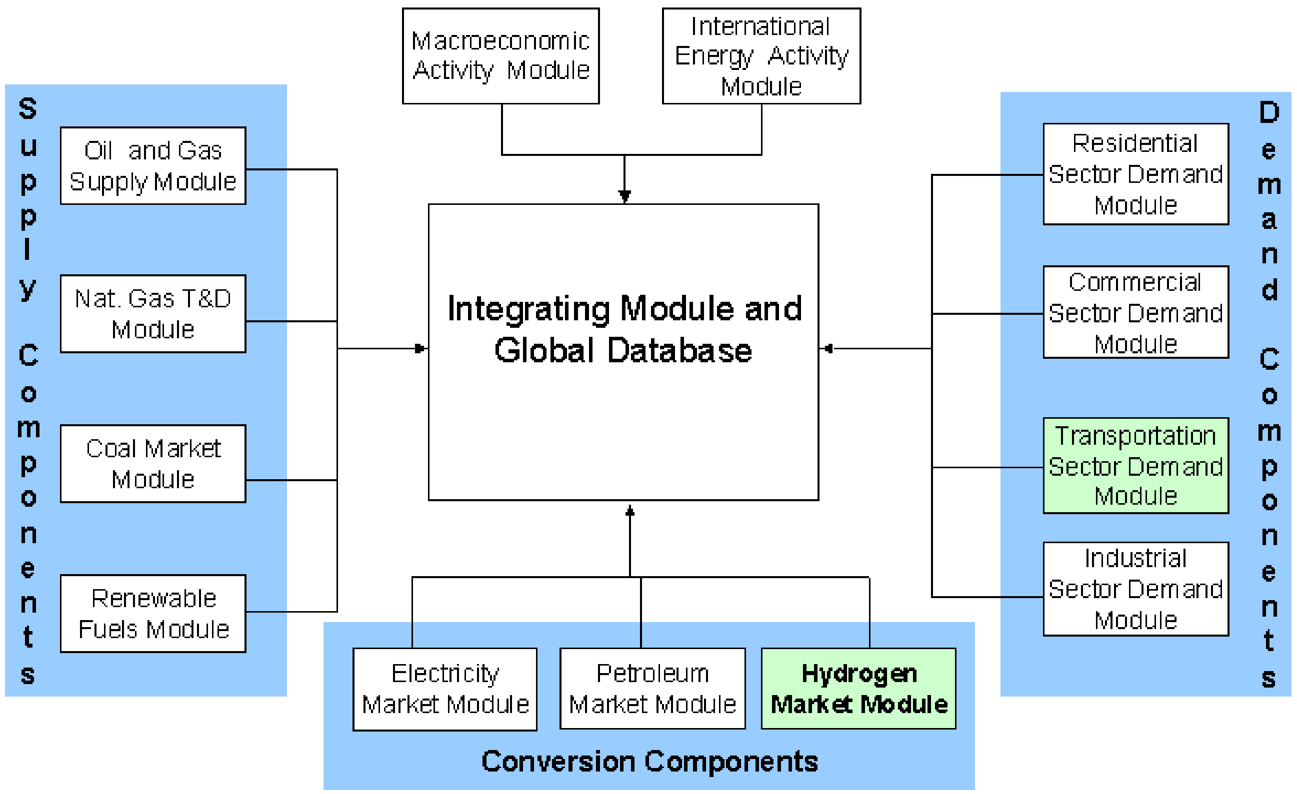
Approach: Milestones and Timeline

Milestone	*Date*	*Status*
Draft scenario report	October 2010	Completed
Final report	June 2011	On Schedule

Approach: NEMS-H2 Modeling Framework

NEMS-H2 is an adaptation of the Energy Information Administration's (EIA) NEMS (National Energy Modeling System) to include hydrogen production, storage and delivery for use in fuel cell vehicles

- All sectors of the energy economy are represented
- Hydrogen market model was created
- Transportation model was modified



Approach: Hydrogen Market Module

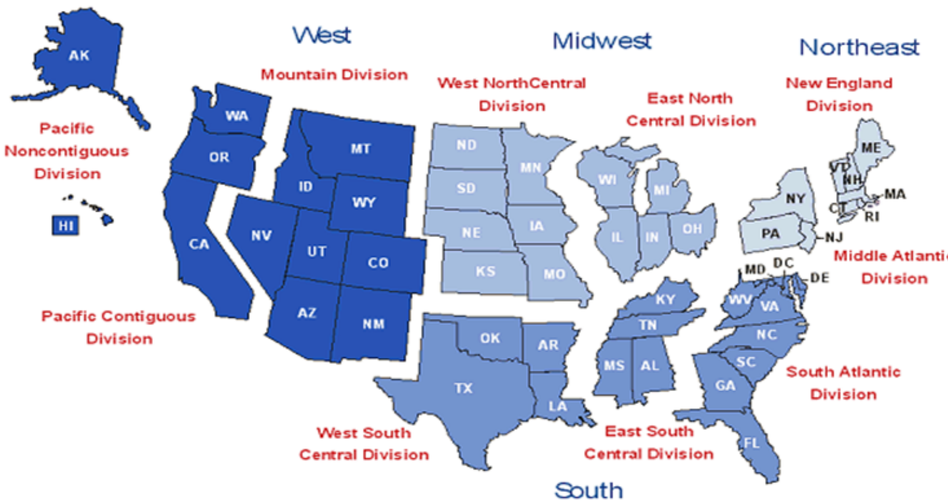
The Hydrogen Market Module (HMM) projects the lowest cost pathways to provide hydrogen at fueling stations for vehicle use

- Uses a linear programming (LP) approach
- Inputs include energy prices, production technology costs and performance, delivery costs, hydrogen demand
- Outputs include mix of hydrogen production technologies and delivery modes, fuel consumption, and retail hydrogen prices

Approach: Regional Representation and Market Segmentation

Hydrogen supply and demand analyzed by

9 geographic regions:
- Fuel costs and availability vary
- Delivery costs vary due to different demand densities, city sizes and distances



Census Regions

3 market segments:
- Large city
- Small city
- Rural

Delivery costs vary by market

Census Region	Region Number	Number of Cities	Average Population per City	Total VMT In Cities Within Region in 2002	City VMT Share %
New England	1	3	2,388,864	54,119	45%
Middle Atlantic	2	5	5,656,300	178,173	62%
East North Central	3	7	3,019,364	174,630	42%
West North Central	4	2	2,404,340	47,211	24%
South Atlantic	5	9	2,571,678	222,878	42%
East South Central	6	2	1,210,956	25,843	14%
West South Central	7	5	2,893,699	136,075	44%
Mountain	8	4	2,048,497	66,003	36%
Pacific	9	8	3,965,568	258,895	70%
U.S. Total		45	3,141,030	1,163,827	45%

Cities with a population greater than 1 million

Approach: Hydrogen Pathways

PRODUCTION TYPES

Central Production

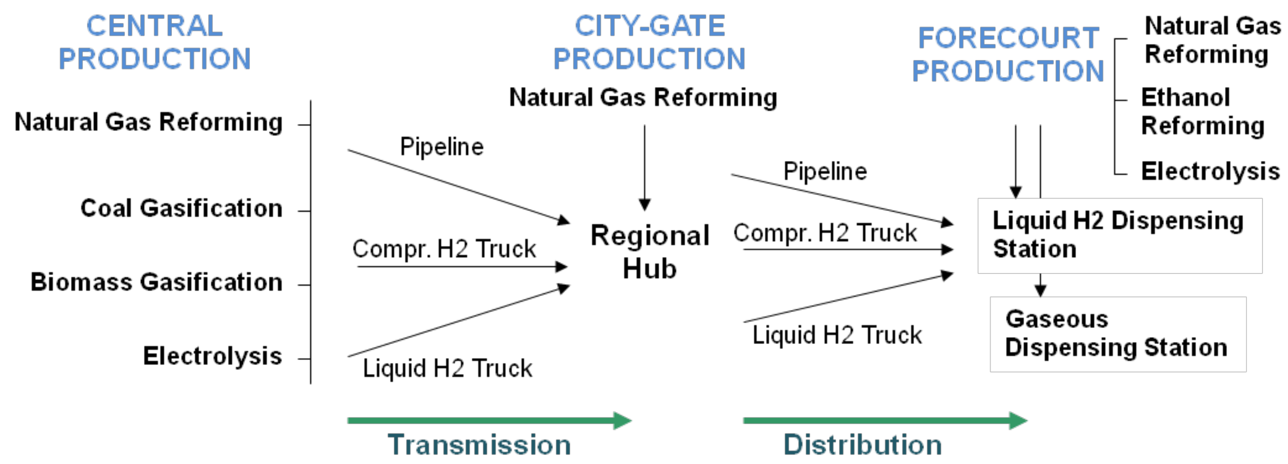
- Natural Gas Reforming without sequestration
- Natural Gas Reforming with sequestration
- Coal Gasification without sequestration
- Coal Gasification with sequestration
- Nuclear
- Biomass Gasification without sequestration
- Biomass Gasification with sequestration
- Electrolysis

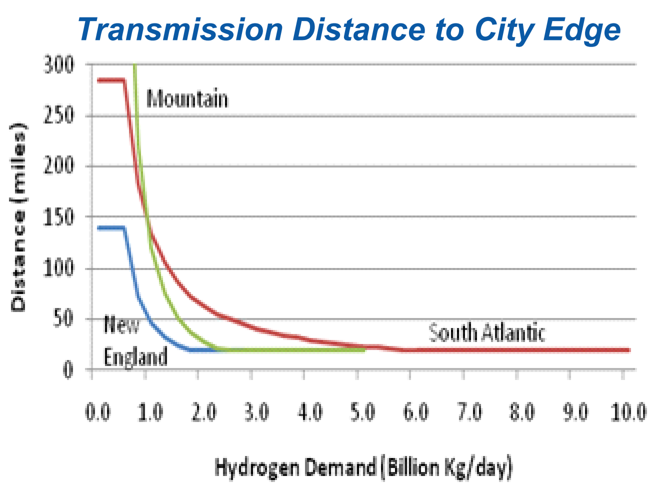
City-Gate

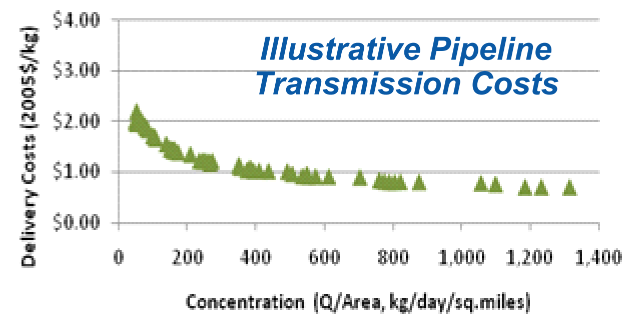
- Natural Gas Reforming

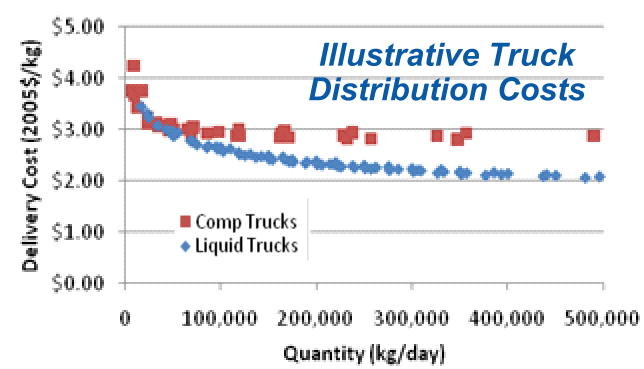
Forecourt (distributed) Production

- Natural Gas Reforming
- Ethanol Reforming
- Electrolysis









Approach: The NEMS-H2 Transportation Model

The NEMS Transportation Model uses a multi-attribute logit choice algorithm in determining market shares for vehicles by size class (6 cars and 6 light truck sizes)

16 vehicle technologies are arranged in 5 groups

- **Conventional**: gasoline, diesel, flex-fuel ethanol, CNG bi-fuel, and LPG bi-fuel
- **Hybrid Electric Vehicle (HEV):** gasoline, diesel, and gasoline plug-in hybrids (PHEV10 and PHEV40)
- **Dedicated Alternative Fuel**: ethanol, CNG, and LPG
- **Fuel Cell**: Hydrogen and plug-in hydrogen; FC-PHEV added in NEMS-H2
- **Dedicated Electric**

Market shares are computed based on consumer preferences for multiple attributes, including vehicle cost, driving cost (based on efficiency and fuel price), fuel availability, range, maintenance costs, acceleration, and model availability

In NEMS-H2, there are 3 market segments in each region

Approach: Multiple Scenario Runs

Scenarios include conditions in which a transition to hydrogen is sensible – relatively high oil prices and penalties on carbon dioxide emissions along with successful FCEV R&D

Multiple sensitivity cases were constructed to capture the uncertainty of key technology and other assumptions

- Fuel cell and other advanced vehicle prices and efficiencies
- Cost and efficiency of hydrogen production
- Refueling station sizes and fuel availability
- Treatment of biomass CO_2 emissions

Several policy were examined for their effectiveness

- 3 levels of fuel cell vehicle subsidies with alternative designs
- Fueling station subsidies
- Hydrogen price subsidies

Multiple scenarios were examined to look at the impact of key assumptions and effectiveness of policies

Approach: Key Baseline Assumptions Are Favorable to FCEVs

Economic Conditions

- Crude oil prices rise to $115 by 2030 and $150 by 2050 (real 2006 dollars)
- Wellhead natural gas prices rise to $7 per mmBtu by 2030 and $14 by 2050
- Carbon emissions are penalized starting in 2015 at $30 per metric ton CO2 and increases at 5% real per year, resulting in a price of $62 in 2030 and $165 in 2050

Vehicle and Hydrogen Supply Technologies

- FCEVs achieve the FY10 Fuel Cell Program R&D cost and performance goals (30 $/kW); other advanced vehicle R&D is successful as well
  - FCEVs reach vehicle price parity to conventional vehicles in most vehicle size classes by 2050
- Hydrogen production technologies improve as projected by H2A

Approach: Scenario Key

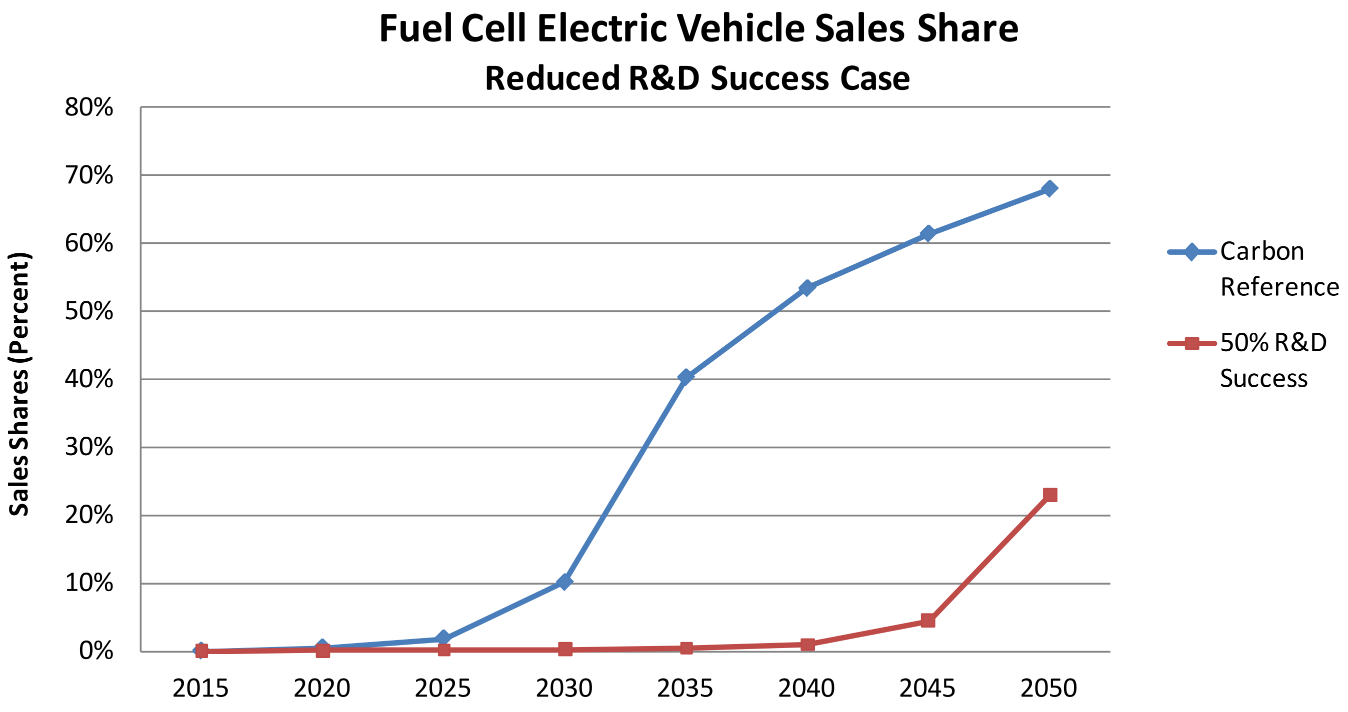
- Below is a description of the sensitivity and policy cases along with corresponding reference cases
  - The vehicle subsidy cases were also run in combination with the lower vehicle R&D success assumptions

Case Abbreviation	Description
Reference Cases	
BAU No H2	BAU Case without FCEVs
BAU Ref	BAU Case with FCEVs
Carbon No H2	Carbon Policy Case without FCEVs
Carbon Ref	Primary Reference Case including Carbon Penalty
No H2 Bio Taxed	Carbon Reference Case without FCEVs with Biomass assessed carbon penalty of 1/3 its carbon content
Ref Bio Taxed	Carbon Reference Case with FCEVs with Biomass assessed carbon penalty of 1/3 its carbon content
Sensitivity Cases	
FCEV Delay	10 year delay in meeting FCEV R&D goals
50% Vehicle R&D	Lower achievement of vehicle R&D success (FCEV and other advanced vehicle)
Biomass Taxed	Biomass assessed a carbon penalty for 1/3 of its carbon content rather than being carbon neutral
H2 R&D	Successful hydrogen production, storage, and delivery R&D
H2 R&D No Seq	Successful hydrogen R&D except for sequestration
No Seq Bio2X	Case above with twice the amount of biomass resources
Large Stations Only	Assume only large fueling stations (1500 kg/day) rather than smaller initial stations (300 kg/day)
FY12 Vehicle Goals	Use FY12 R&D goals rather than the FY10 goals used in Reference
Policy Cases	
Station Subsidy	Subsidy for fueling stations that reduces their cost by 50 percent
H2 Price Subsidy	Hydrogen price subsidy of $1 per kg
$5k to 2030	FCEV subsidy of $5000/vehicle until 2030
$8k til Parity	FCEV subsidy of the greater of $8000/vehicle or difference between FCEV and conventional vehicle
$10 to 1 million	FCEV subsidy of $10,000/vehicle until 1st million vehicles are sold

Technical Accomplishments: FCEV Market Growth is Highly Sensitive to R&D Success

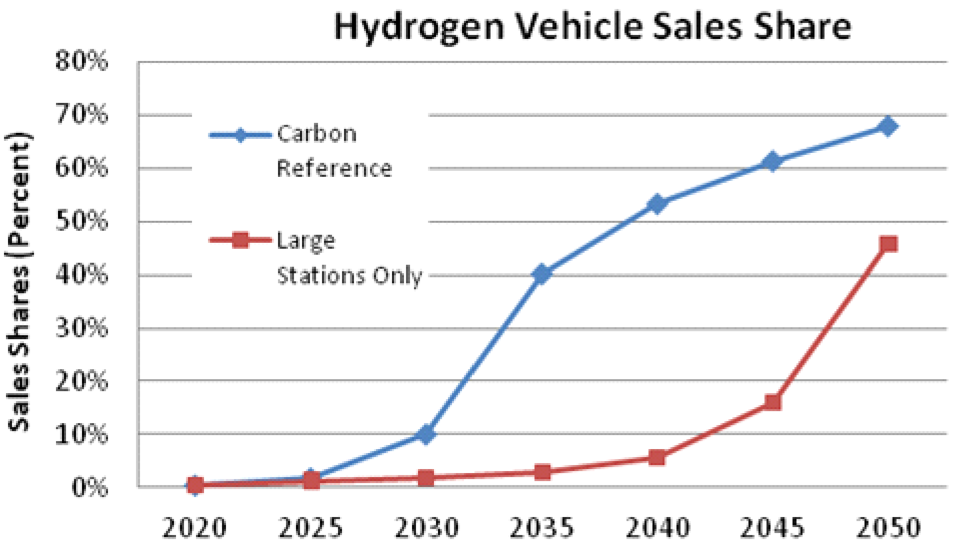
If R&D goals are met as in the Reference case, FCEV shares are projected to increase to almost 70 percent of sales by 2050

With less optimistic vehicle R&D success (50% case), FCEV sales might reach only 25 percent by 2050



Technical Accomplishments: Market Adoption Rates Are Very Sensitive to Station Availability (Size)

If only large, and hence fewer, hydrogen fueling stations are developed, the share of FCEVs could be hampered by reduced attractiveness to consumers due to low fuel availability

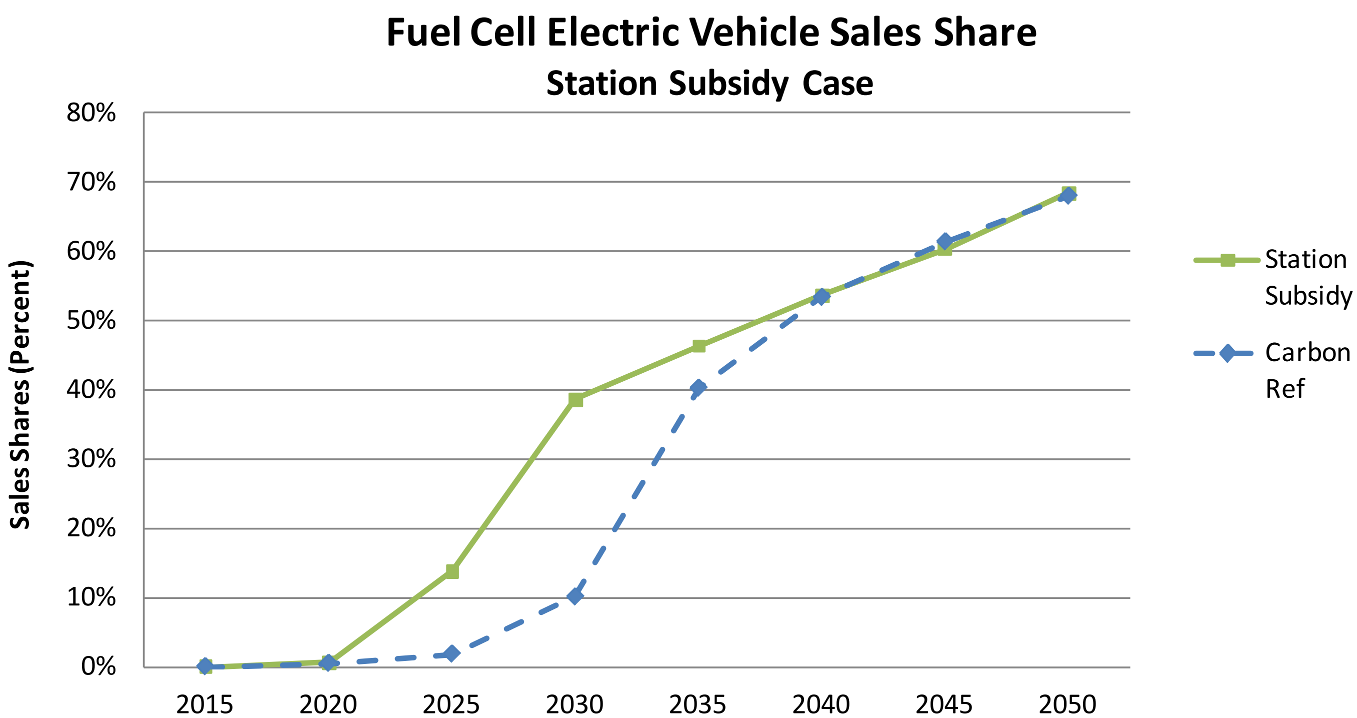


The Reference case assumes initial stations are sized at 300 kg per day, while the Large Stations Only case assumes all are 1500 kg per day

Encouraging hydrogen fueling stations will likely be important in stimulating consumer interest in FCEVs

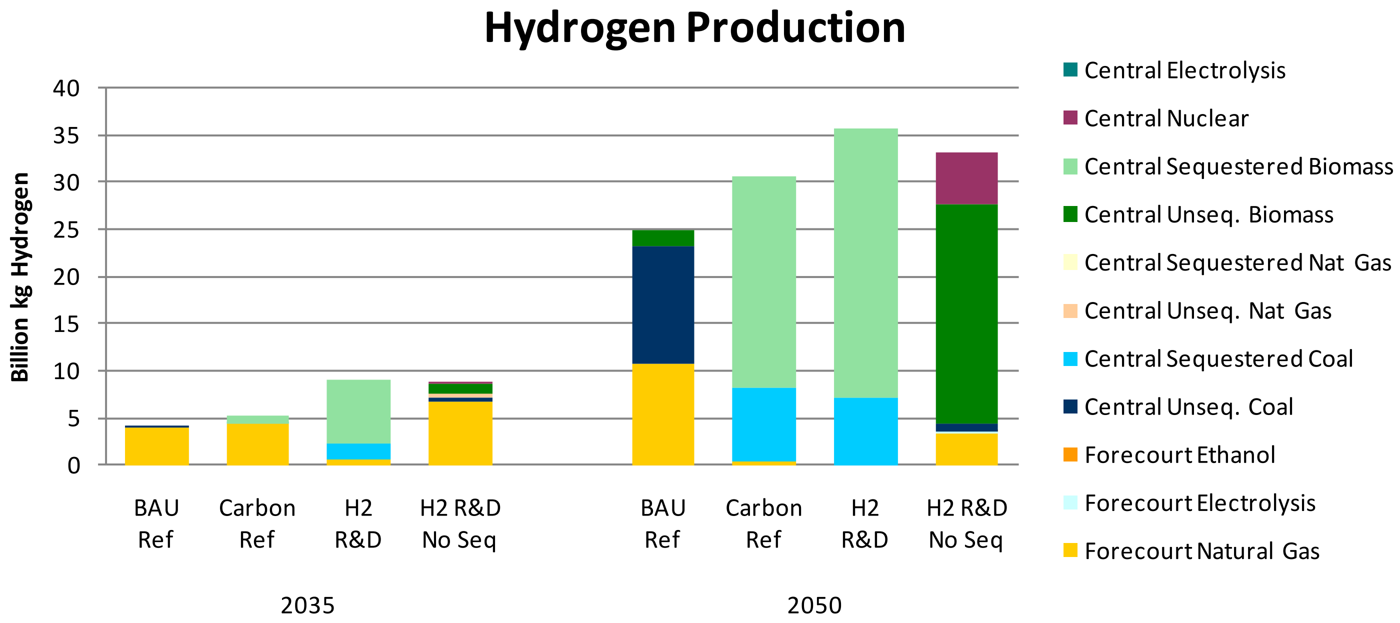
Technical Accomplishments: Market Adoption Rates are Accelerated with Station Subsidies

Subsidies for fueling stations that reduce the cost by 50% and increase their initial number could accelerate the transition to FCEVs and the subsidy can be phased out.



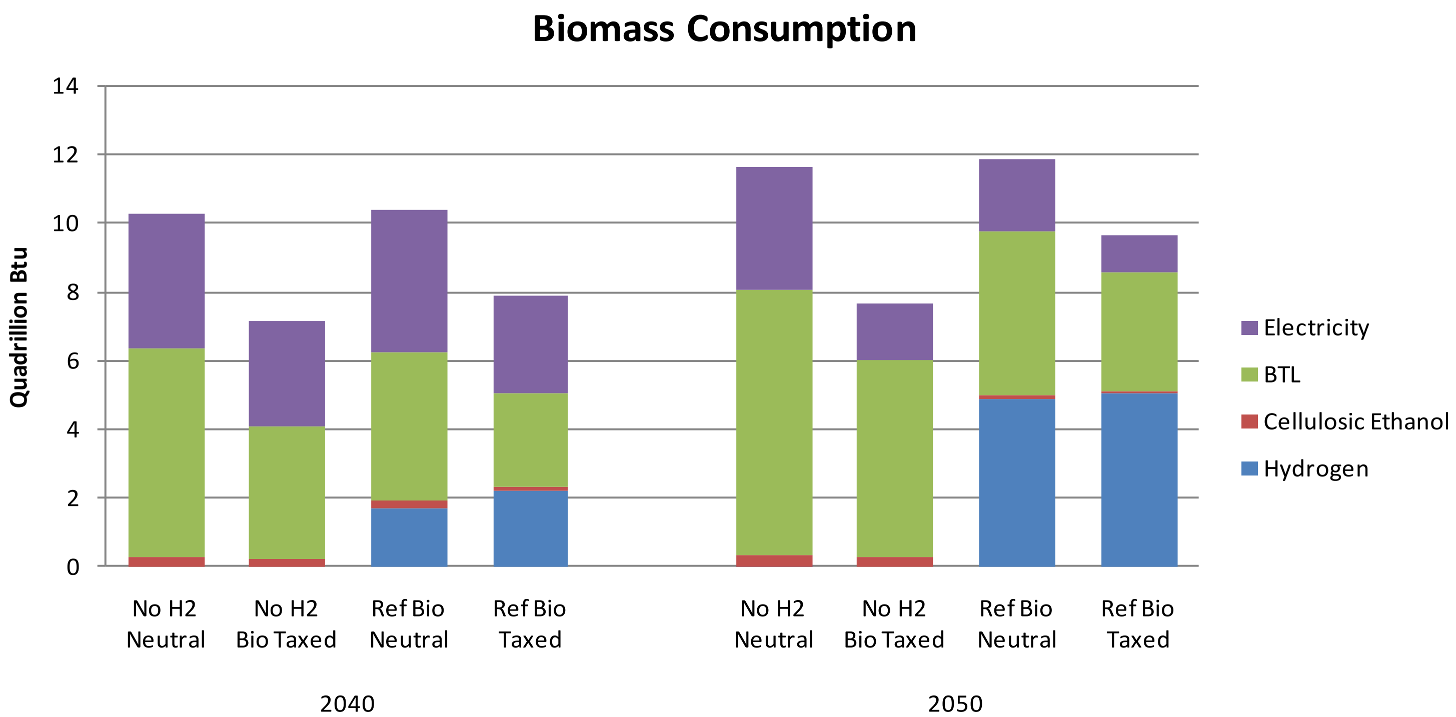
Technical Accomplishments: Production Type Depends on R&D and Carbon Policy

- Without a carbon penalty, the lowest cost method of hydrogen production is likely coal-based without sequestration
- A carbon policy would incentivize a shift to sequestering carbon if the technology is available at a reasonable cost
- Successful R&D, including delivery technologies, could speed the transition to larger-scale central production with lower emissions



Technical Accomplishments: Hydrogen Might Use a Significant Share of Biomass Resources

Hydrogen production will compete with other uses of biomass even if biomass is assessed a partial carbon penalty



Increased use of biomass for hydrogen production will likely decrease its use elsewhere which reduces its emission savings

Technical Accomplishments: Vehicle Subsidies Vary in Effectiveness

The size of a vehicle subsidy and its duration impact FCEV sales and the subsidy's cost-effectiveness in reducing emissions and oil imports

- The policy that pays a subsidy of the greater of $8000 per vehicle or the difference between the FCEV price and the conventional vehicle price is the most expensive but yields the greater emission and oil reductions
- The $10,000 subsidy that expires after 1 million vehicles are sold is the most cost-effective, but leads to the lowest savings

In general these subsidies are more expensive than the fueling station subsidy examined ($5 billion)

	Cumulative Subsidies (billion $)	Cumulative CO2 Reductions (MMTCO2)	Cumulative Import Reductions (Billion Barrels)	Subsidy Cost for CO2 Reductions $/Ton CO2	Subsidy Cost for Reduced Imports $/barrel
$5k to 2030	103.6	3340	5.30	31.0	19.5
$8k til Parity	329.0	4724	7.80	69.7	42.2
$10k to 1 million	12.3	1859	2.59	6.6	4.8

The most effective policies are ones that can stimulate additional sales and create momentum without being permanent

Technical Accomplishments: Vehicle Subsidies Effectiveness Depends on FCEV Prices

The cost of various subsidy designs depends on future FCEV prices (i.e. R&D success)

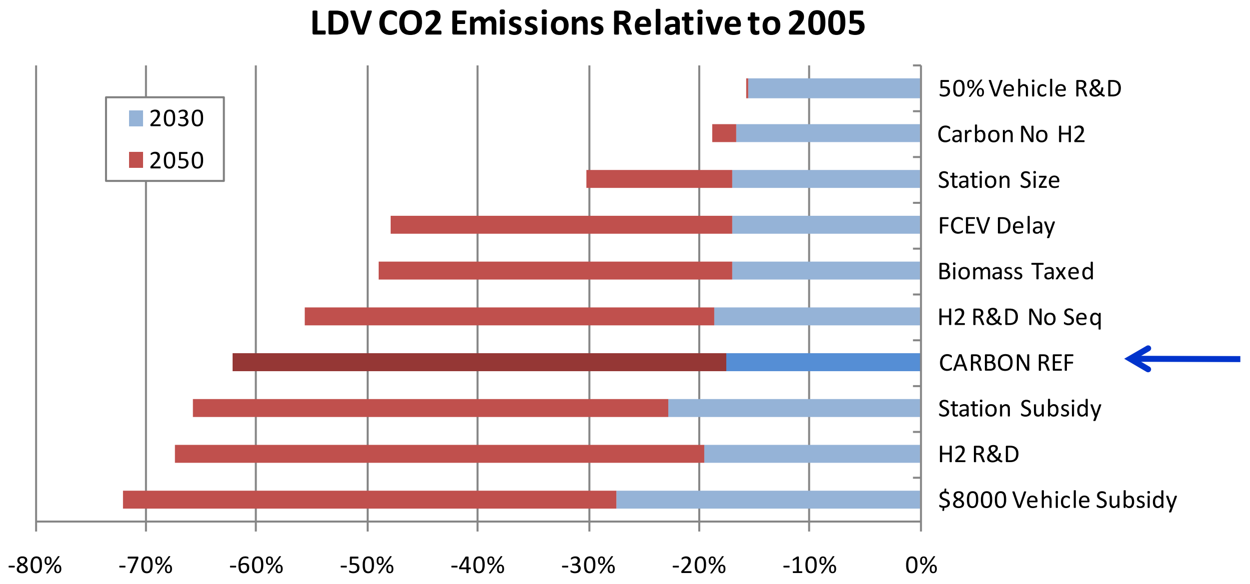
- The $5000 subsidy until 2030 is effective if FCEV prices are declining but largely ineffective if not (lower R&D success)
- The $8000 subsidy until parity with conventional vehicles is much more expensive if FCEV prices remain high

	Cumulative Subsidies (billion $)	Cumulative CO2 Reductions (MMTCO2)	Cumulative Import Reductions (bil barrels)	Subsidy Cost for CO2 Reductions $/Ton CO2	Subsidy Cost for Reduced Imports $/barrel
Vehicle Subsidies with Reference Case R&D Success					
$5k to 2030	104	3340	5.30	31	20
$8k til Parity	329	4724	7.80	70	42
$10k to 1 million	12	1859	2.59	7	5
Vehicle Subsidies with Lower R&D Success					
$5k to 2030	3	510	0.74	7	4
$8k til Parity	1553	9890	15.08	157	103
$10k to 1 million	21	1070	1.56	20	14

Policies need to be robust under a range of FCEV prices.

Technical Accomplishments: Scenarios Achieve a Range of GHG Reductions

- The greatest emissions reductions occur with successful hydrogen production and delivery R&D along with FCEV and advanced vehicle R&D or include subsidies
- Savings are reduced if vehicle R&D is not as successful or FCEV adoption is delayed due to a low number of fueling stations

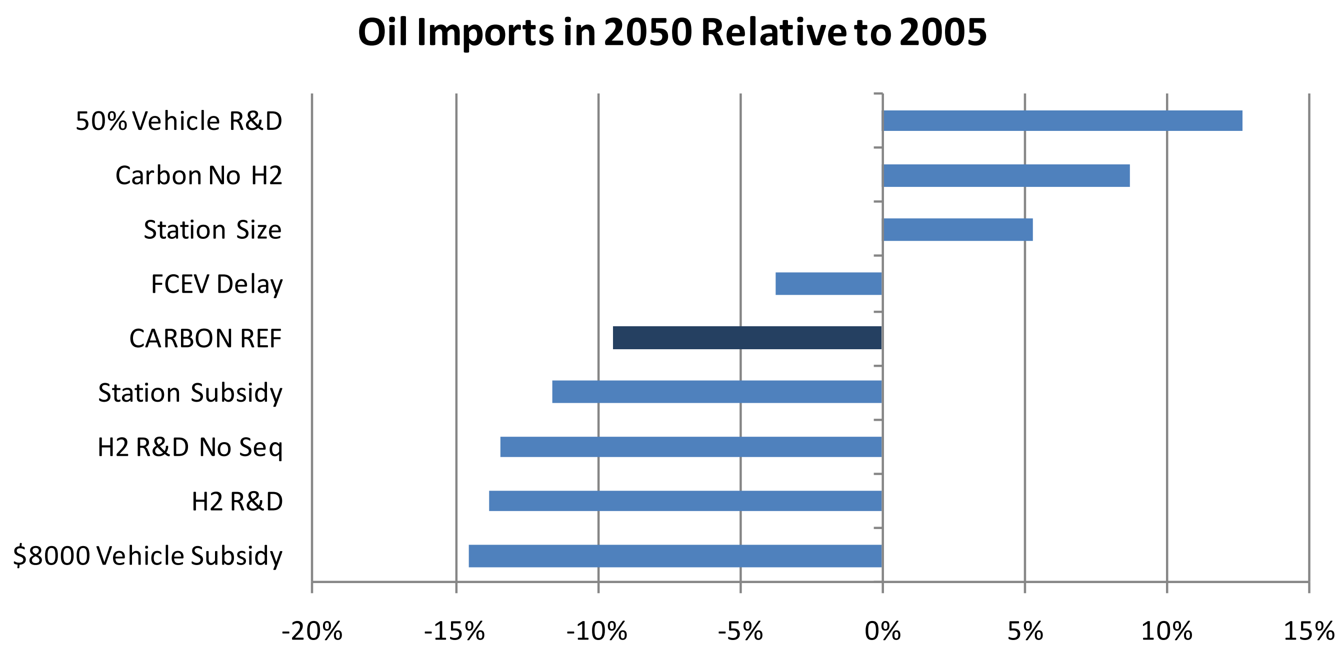


Successful policies lead to an over 70 percent reduction in CO_2 emissions from the LDV sector

Technical Accomplishments: Scenarios Achieve a Range of Petroleum Import Reductions

Without hydrogen or less successful vehicle R&D, imports are projected to rise above 2005 levels by 2050 due to reduced domestic production and rising oil demand from freight and aircraft

Oil imports are reduced in scenarios with greater FCEV adoption rates



Collaborations and Future Work

Collaborations

- NEMS-H2 makes use of data developed by other DOE activities, such as the H2A production models and HDSAM
- The systems integration team provided data from MSM that was used in developing the NEMS-H2 delivery cost curves

Future Work

- Final report is in review

Summary

Relevance	• NEMS-H2 provides a context for analyzing FCEVs and hydrogen within the U.S. energy system and their ability to reduce CO_2 emissions and oil imports
Approach	• Use of an integrated energy system model to analyze alternative FCEV scenarios
Accomplishments	• Multiple scenarios were analyzed that demonstrate key uncertainties impacting the potential of FCEVs to reduce CO_2 emissions and oil imports and the effectiveness of a range of policies to accelerate FCEV adoption rates
Collaborations	• NREL and other analysts
Proposed Future Work	• Final report is in review