Hydrogen Scenarios

Presentation to the
Hydrogen Delivery Analysis Meeting

by
Frances Wood
OnLocation, Inc.
Energy Systems Consulting

May 9, 2007

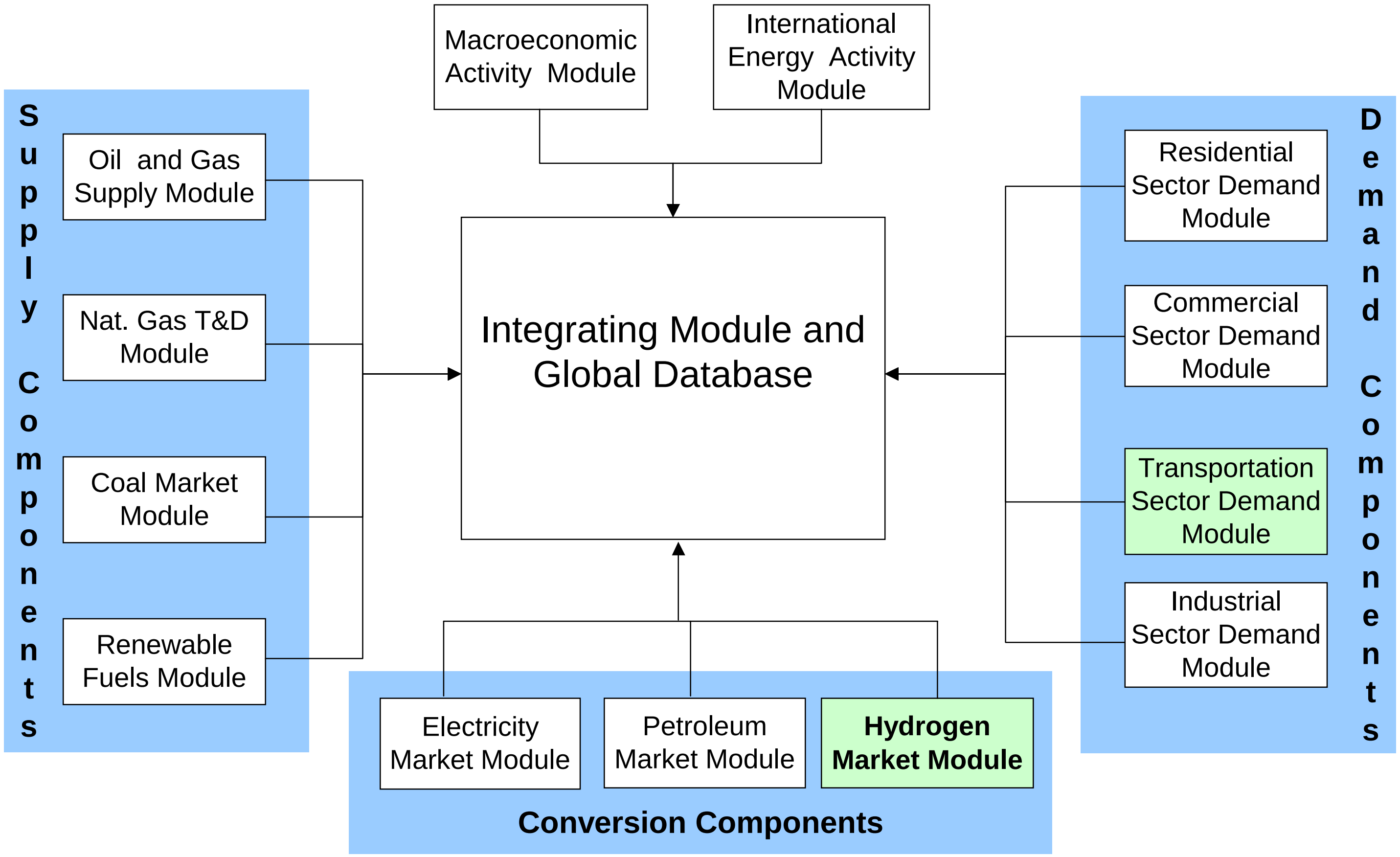
Outline

- Brief summary of NEMS-H2 model
- Representation of Hydrogen Delivery
- Hydrogen Demand Sensitivities
- Integration and Energy System Impacts - A Carbon Policy Scenario Example

NEMS-H2 Overview

NEMS-H2 Overview

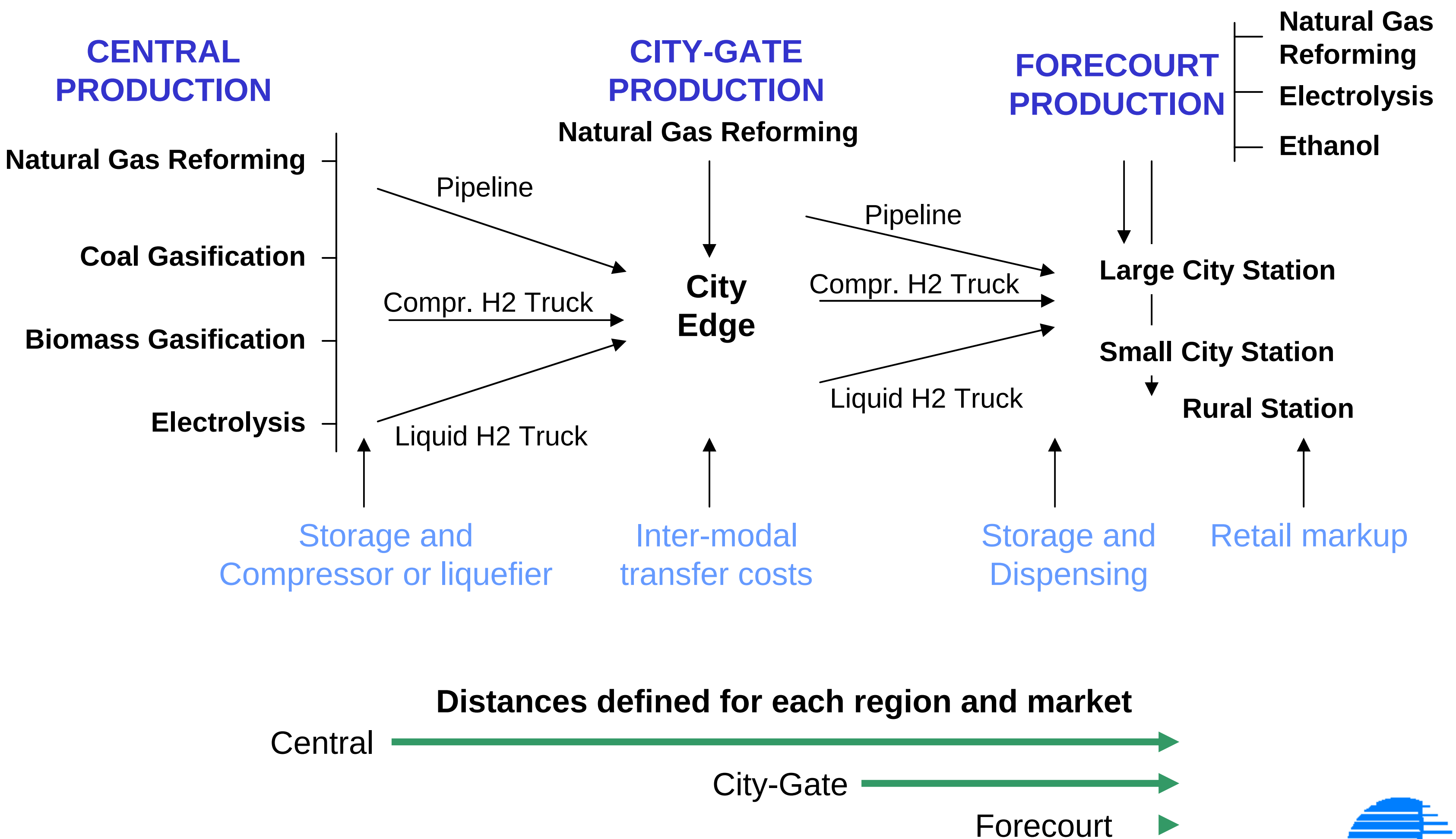
- NEMS-H2 is a modification of EIA's NEMS model which simulates energy production, consumption, and conversion sectors – including hydrogen.



Key Attributes of NEMS-H2

- Designed to analyze interactions of hydrogen markets with other energy markets
  - Focus is on economic, not engineering, aspects of hydrogen production, delivery, and consumption
- Hydrogen is represented for 3 market segments within 9 Census Divisions
- In the Hydrogen Market Module (HMM) hydrogen supply options compete based on delivered cost in each market
  - Multiple production and delivery pathways
  - Integration of NEMS fuel and electricity supply inputs
- Light duty vehicle choice within NEMS modified to address multiple market segments
- Extended to 2050

H2 Production and Delivery Pathway Representation



NEMS-H2 Light Duty Vehicle Representation

- Fuel price and availability varies among 3 markets in 9 Census Divisions
- Vehicle selection is made for 6 car and 6 truck classes
- Within each, there are 16 vehicle technologies arranged in 5 groups
  - Conventional: gasoline, diesel, flex-fuel methanol, flex-fuel ethanol, CNG bi-fuel, and LPG bi-fuel
  - Hybrid Electric Vehicle (HEV): gasoline and diesel
  - Dedicated Alternative Fuel: ethanol, methanol, CNG, and LPG
  - Fuel Cell: gasoline and hydrogen fuel cells
  - 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

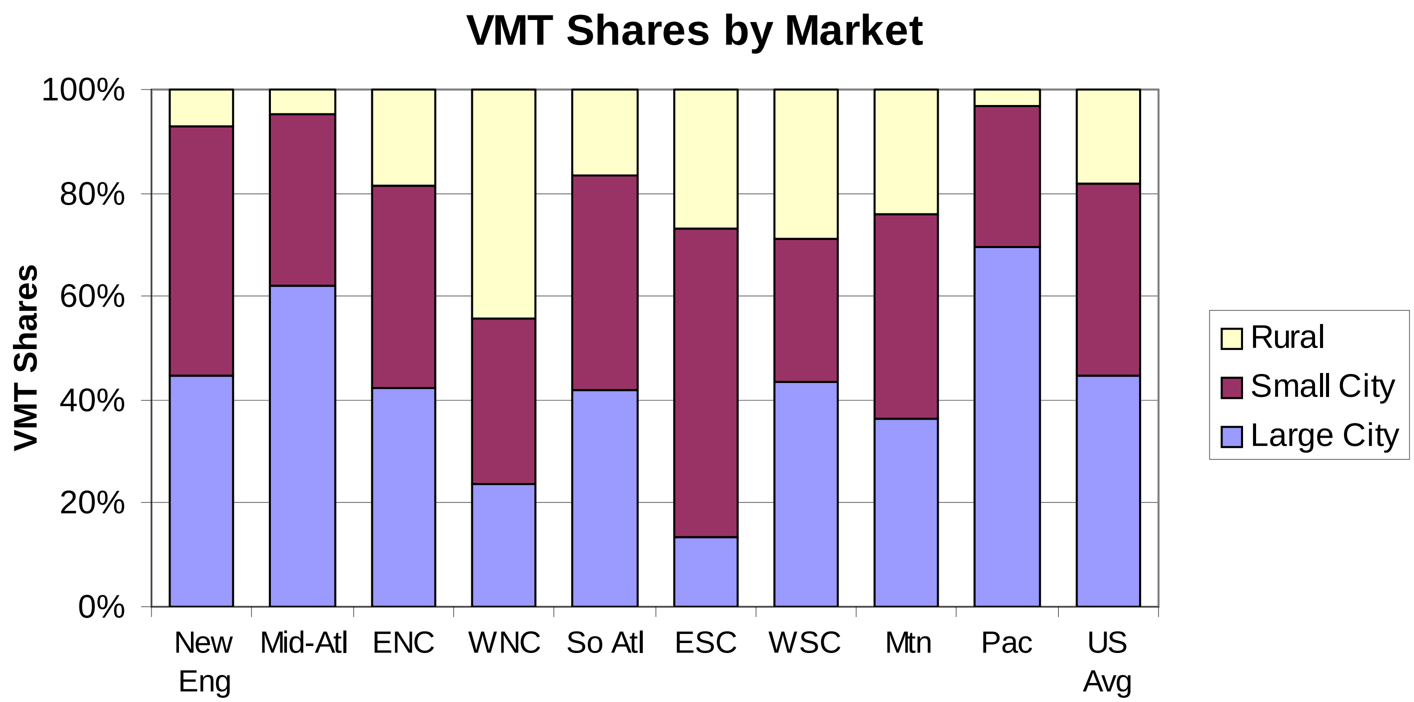
Representation of Hydrogen Delivery

Regions and Markets

- NEMS demand models use Census Divisions for regional detail. Hydrogen market module was designed around this same regional breakdown.
- Census Divisions are employed to capture the potential impact of variations in fuel input prices throughout the country.
- Market segments are used to capture relative demand density and associated delivery costs within the regions.
  - Three market segments are defined based on population
  - Market segment definitions constructed from county level data and Core Base Statistical Areas (CBSA's)
    - Large City (>= 1,000,000 population)
    - Small City (> 50,000 and < 1,000,000 population)
    - Rural (remaining counties)

Hydrogen Market Segment Shares

- The shares of vehicle miles traveled (VMT) within the markets segments vary considerably by Census Division.



H2 Production and Delivery Costs

- Delivery to Large Cities is comprised of inter-city transport and intra-city distribution, while other markets just have distribution.

Central/City Gate Production – Large City Markets

Production	Transport	Distribution	Dispensing
F(Q)	F(Q,D-L)	F(Q,D-S)	F(Q)

Central – Small City and Rural Markets

Production	Distribution	Dispensing
F(Q)	F(Q,D-S)	F(Q)

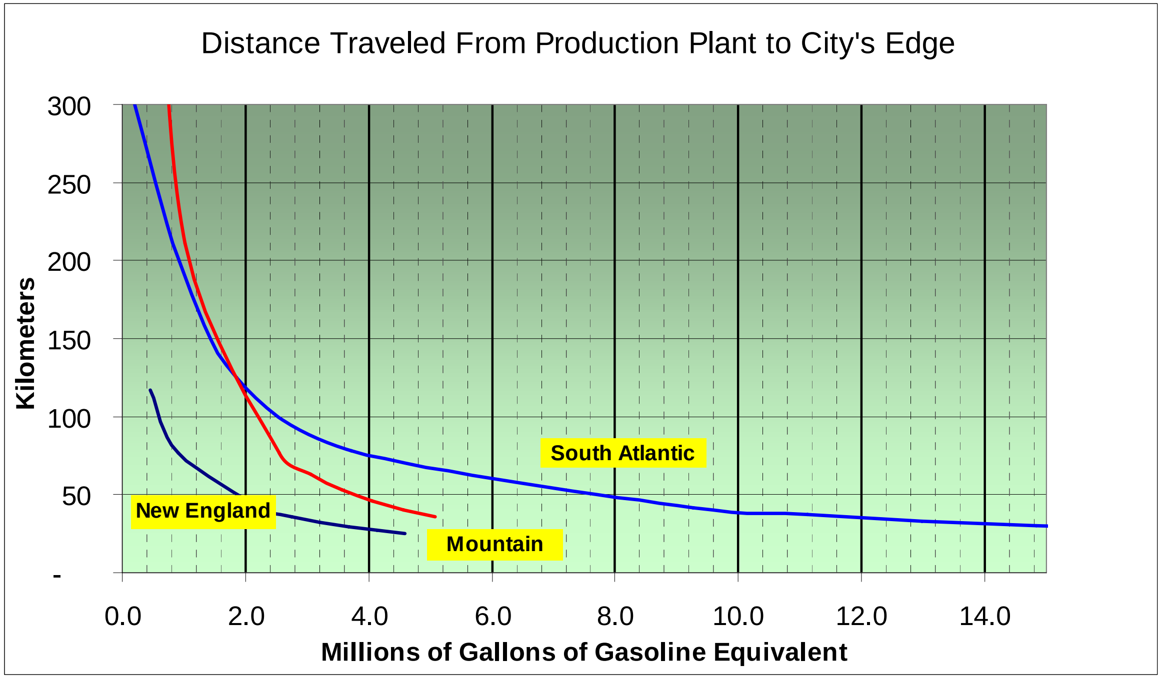
Q	**Quantity**
D-L	**Linear Distance**
D-S	**Spacial Distributed Distance**

Inter-City Distance Function

- For the current model where we assume demand must be met uniformly within a region, we have developed a distance function used to in computing transport costs
- Several key factors are combined to create a representative distance function that has a reasonable shape and form.
  - Hydrogen demand
  - Area served (region size)
  - Number of cities in region
  - Standard hydrogen plant size
- When demand is less than the output of a single plant, the distance is set to the average radius from the region's centroid
- When demand is sufficient to allow a standard plant at each city market, then the distance is set to the NIMBY distance

Inter-City Delivery Distances

- For each region, the delivery distance function will vary based on number of large cities and size of the regional area.
  - New England and Mountain regions have similar market sizes, but Mountain has greater distances due to its cities being dispersed over a larger spatial area.
  - South Atlantic is overall a much larger region with more city markets.

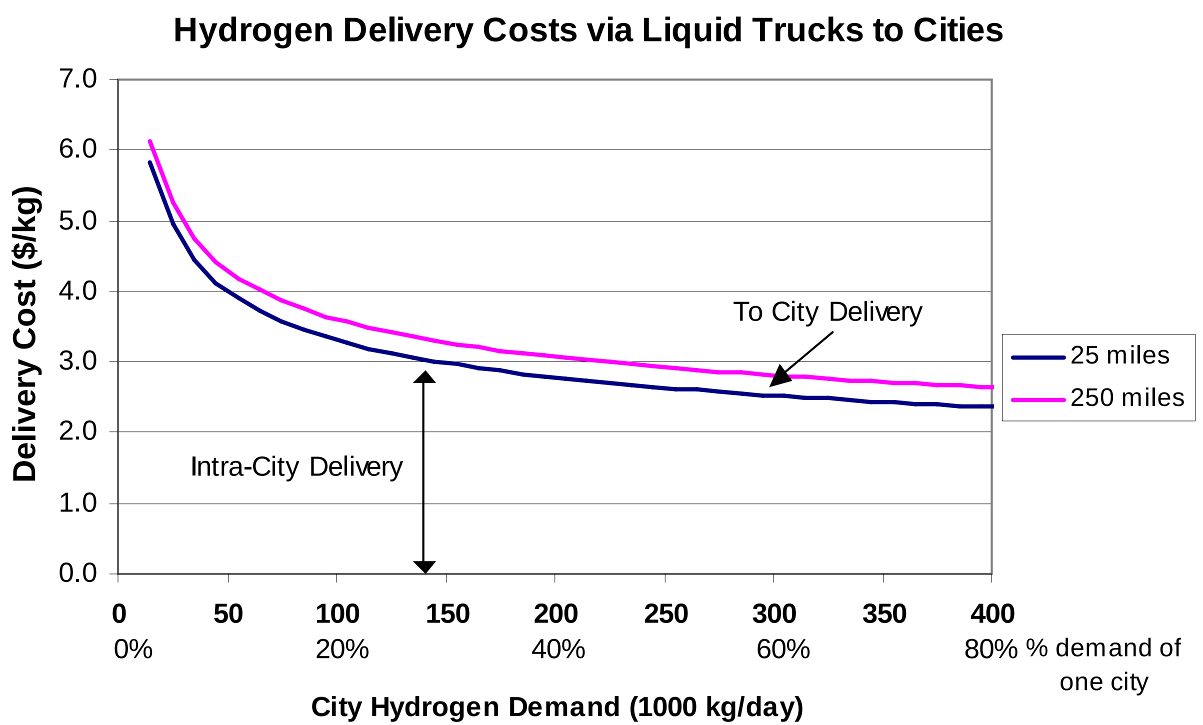


Delivery Cost Representation

- The H2A Delivery Model cost information was used to produce a simplified formulaic representation of delivery costs
- The H2A model was run iteratively to create the regression data set by varying:
    1. Metropolitan area (Los Angeles, Houston, etc.)
    2. Mode of transport and delivery (pipeline, gas truck, liquid truck)
    3. Production distance from city edge (0 to 500 miles in 100 mile increments)
    4. Hydrogen penetration percentages for each city (1, 2, 3, 5, 10,15, 35, 50, 75 percent)
- Reduced form represented by regressing key cost drivers (quantity, distance, etc.) against sub-elements of costs (e.g., capital costs, operations and maintenance costs, etc.)
    - Capital costs estimated on total cost basis
    - O&M, energy, fuel, etc., estimated on unit cost basis
- Drivers tied to information available to NEMS or derivable from information contained in NEMS.

Liquid Truck Delivery Costs

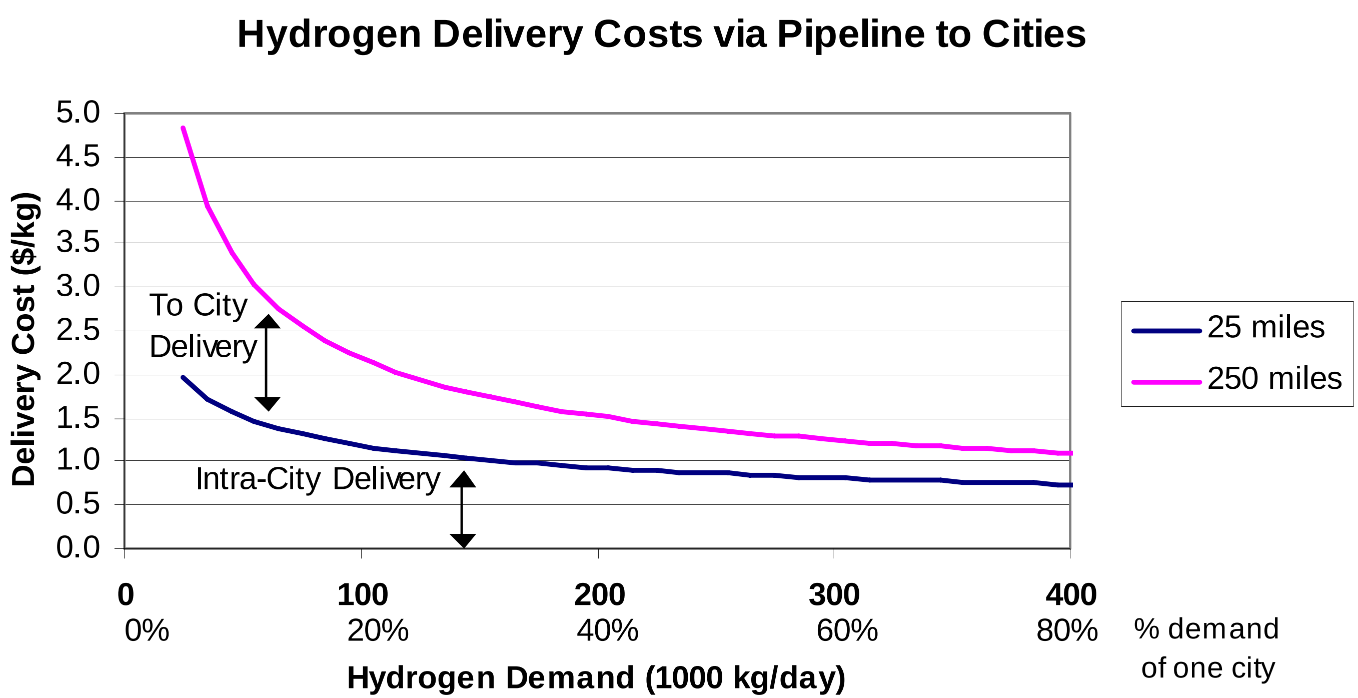
- The incremental cost to transport hydrogen by liquid truck from a central plant to a city is relatively small compared to the full cost of delivery to fueling stations and is not sensitive to demand levels.



Note: Excludes Forecourt Costs

Pipeline Delivery Costs

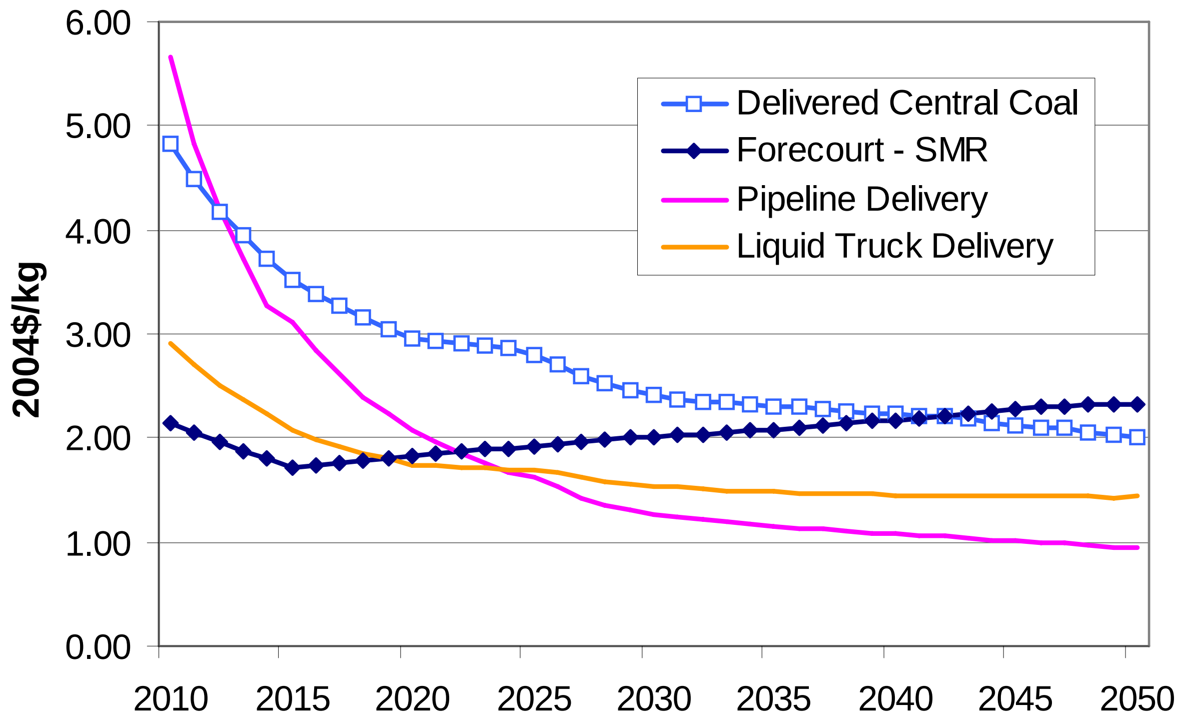
- For pipelines, delivery costs to cities are very high when demand is low. Costs to and within cities are reduced significantly as demand rises.



Note: Excludes Forecourt Costs

Sample Resulting Delivery Costs

- Central hydrogen production does not become cheaper than forecourt production until there is sufficient demand to lower delivery costs.



NEMS-H2 Demand Sensitivities

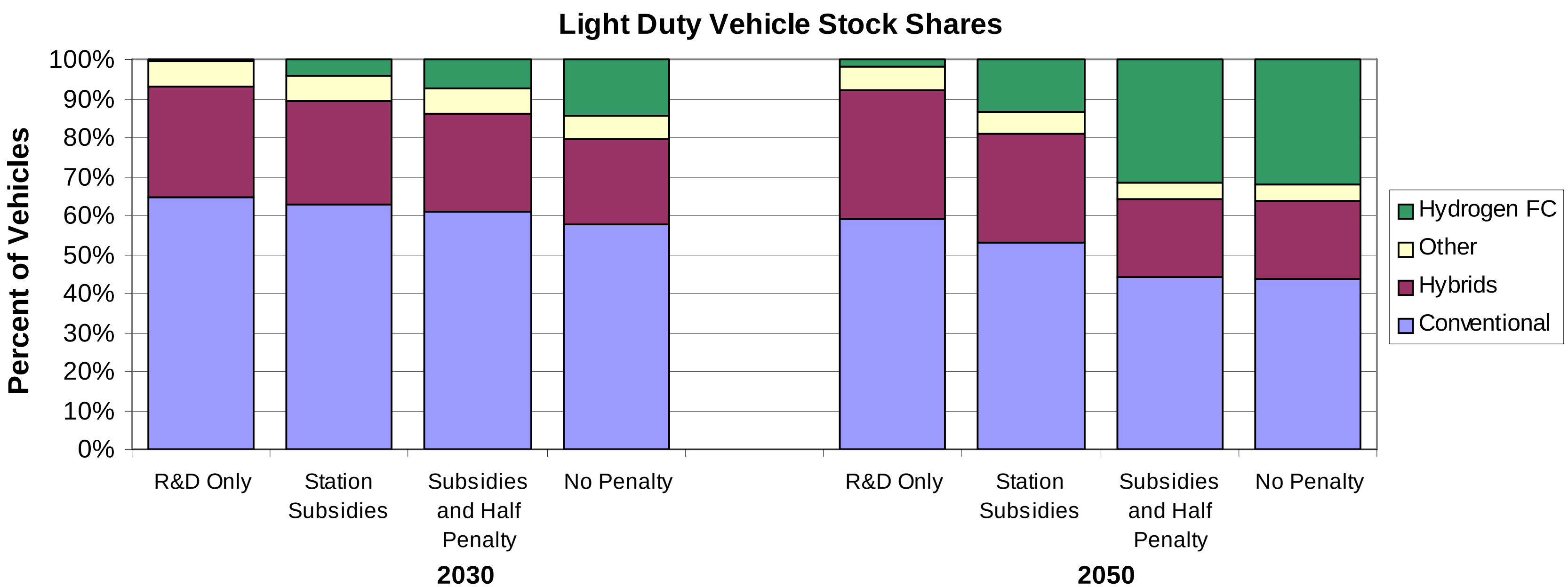
(note – all results are preliminary)

Cases to Examine Fuel Availability

- Four cases were constructed to illustrate the importance of hydrogen availability to consumers
  - Equivalent “cost” to consumers as much as $7000 if there are very limited stations
  - Penalty becomes insignificant once 15-20% of stations carry fuel
- All cases include successful fuel cell R&D by DOE
  - Vehicle prices roughly $1500 more expensive and 2.5 to 2.9 times as efficient as conventional vehicles
- Cases include:
  - R&D Only
  - Station subsidies to increase number of stations in large city markets to 10% of total
  - Station subsidies and half the consumer fuel availability penalty value
  - No penalty for lack of fuel availability

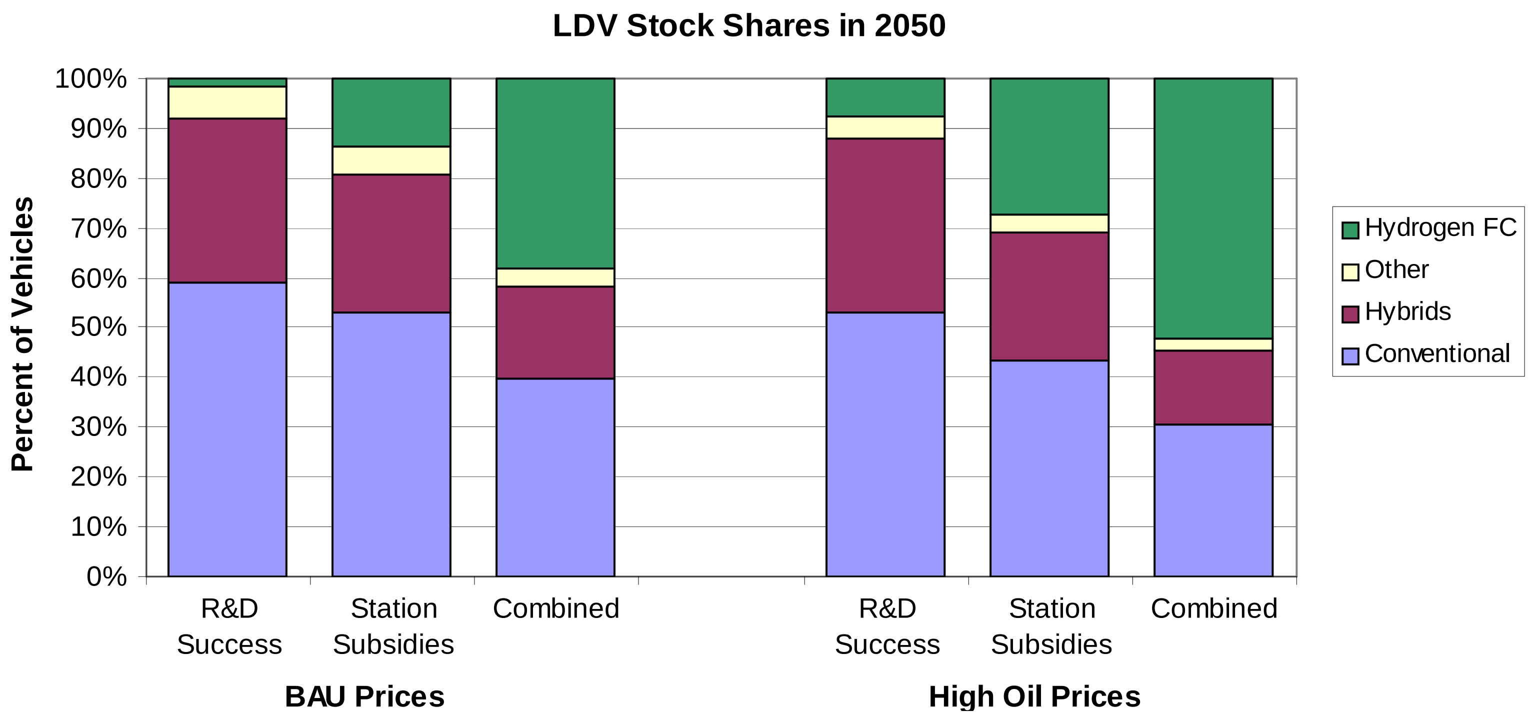
Vehicle Shares

- R&D alone stimulates only a small share for fuel cell vehicles under our base case.
  - Lack of infrastructure hinders consumer interest in FC vehicles
- Increasing fuel availability significantly increases consumer preference for FC vehicles.



Effect of High Oil Prices

- When gasoline prices are roughly 50% higher (prices of $3.20 to $3.60 per gallon), fuel cell vehicle shares increase
- A Combined case was created that includes vehicle and station subsidies along with the half fuel availability penalty assumption



Integration and Energy System Impacts: A Carbon Policy Example

(note – all results are preliminary)

Carbon Policy Scenario

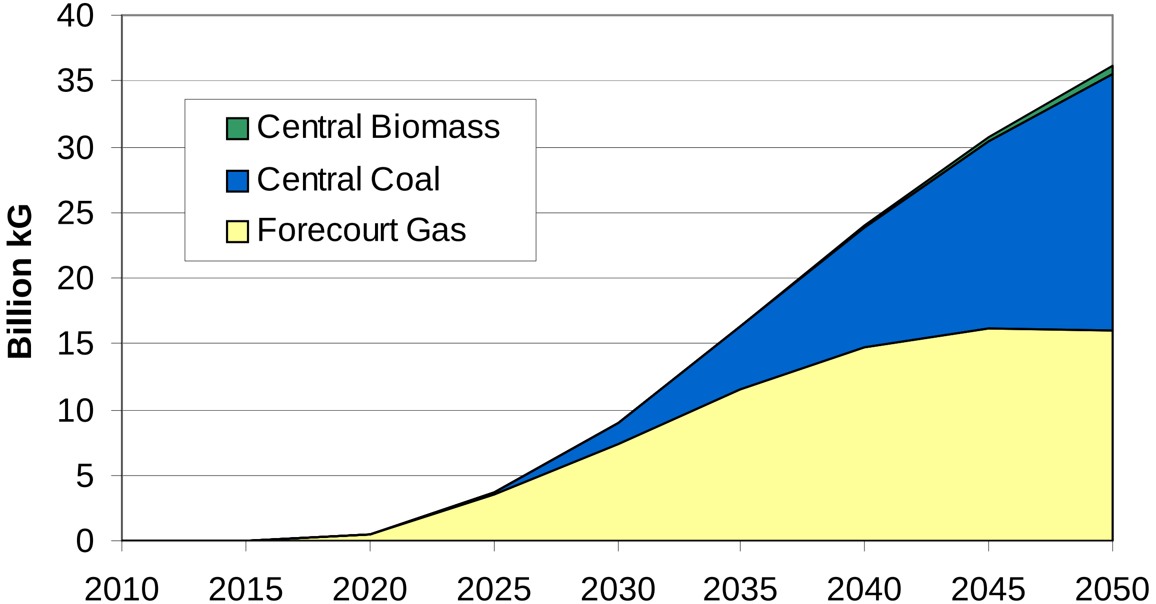
- Carbon allowance price starting in 2010 and ramping up to \$25 per ton of CO2 by 2025.
  - Without hydrogen and with combined hydrogen case
- Carbon value affects entire energy system with implications for hydrogen fuel cell vehicles
  - Higher gasoline prices
  - Higher production costs for hydrogen production: coal, natural gas, biomass (due to competition with other sectors), and electricity
  - Higher value of electricity sold to the grid

Impact of Hydrogen on Energy System

- The benefits of moving to a hydrogen transport system depend not only on the substitution within the transportation sector, but economy wide impacts such as
  - Oil and other fuel imports
  - Gasoline prices
  - Natural gas, coal, and biomass prices
  - Carbon emissions
- In turn, these may affect fuel cell vehicle market share and hydrogen production technology choice

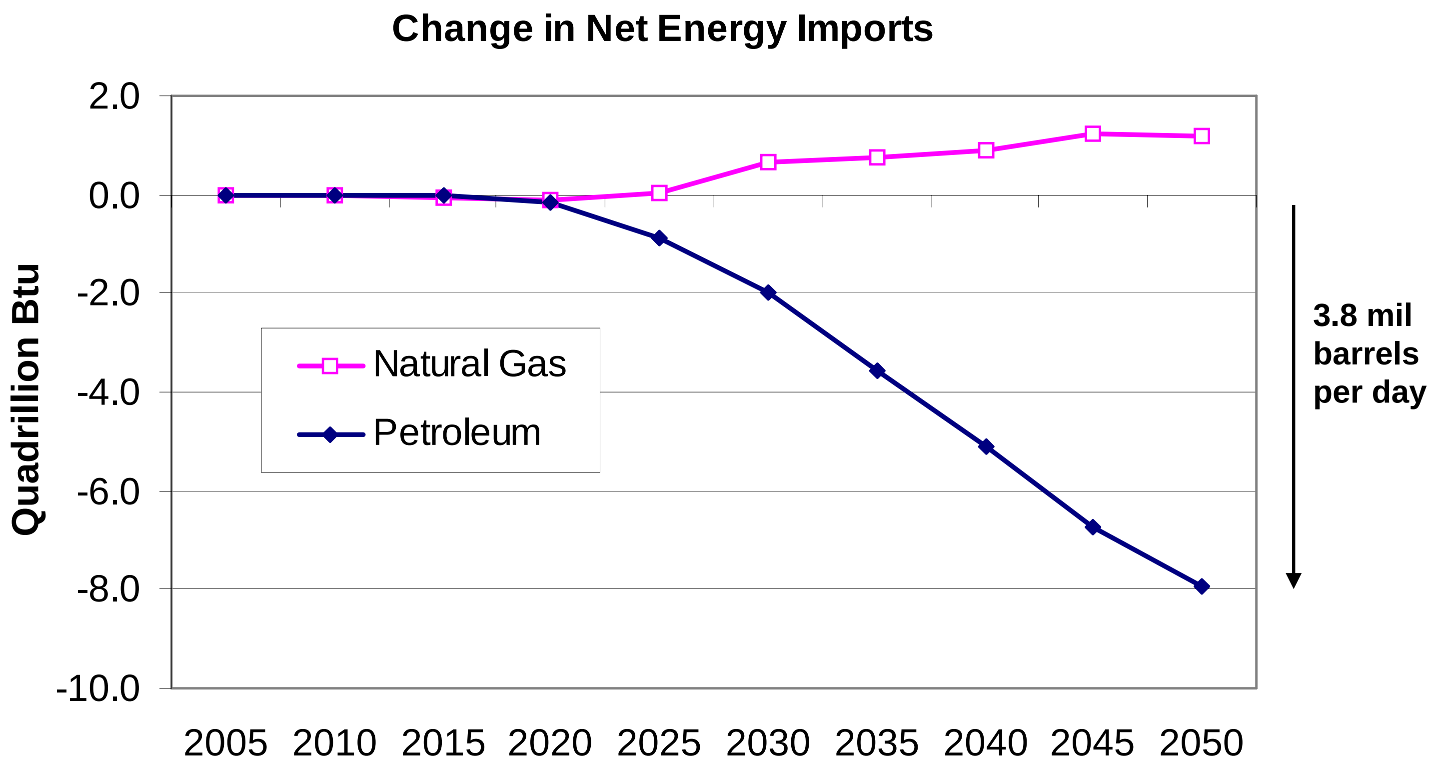
Hydrogen Production

- Initially hydrogen is produced locally at fueling stations using natural gas reforming.
- As demand increases, there is a shift to central production.
- In this case with a $25 per ton CO_2 penalty, central production is primarily sequestered coal with some biomass use as well.



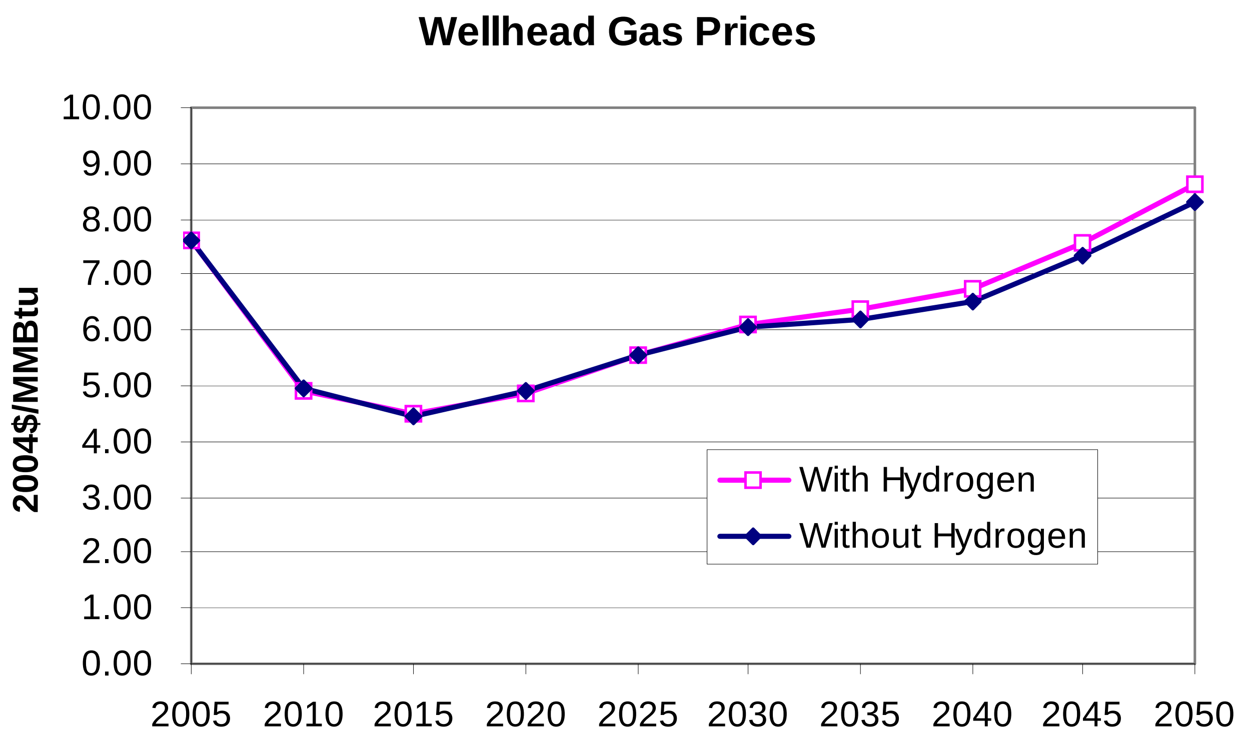
Net Imports

- Hydrogen use decreases dependency on foreign oil imports, but may slightly increase natural gas imports.



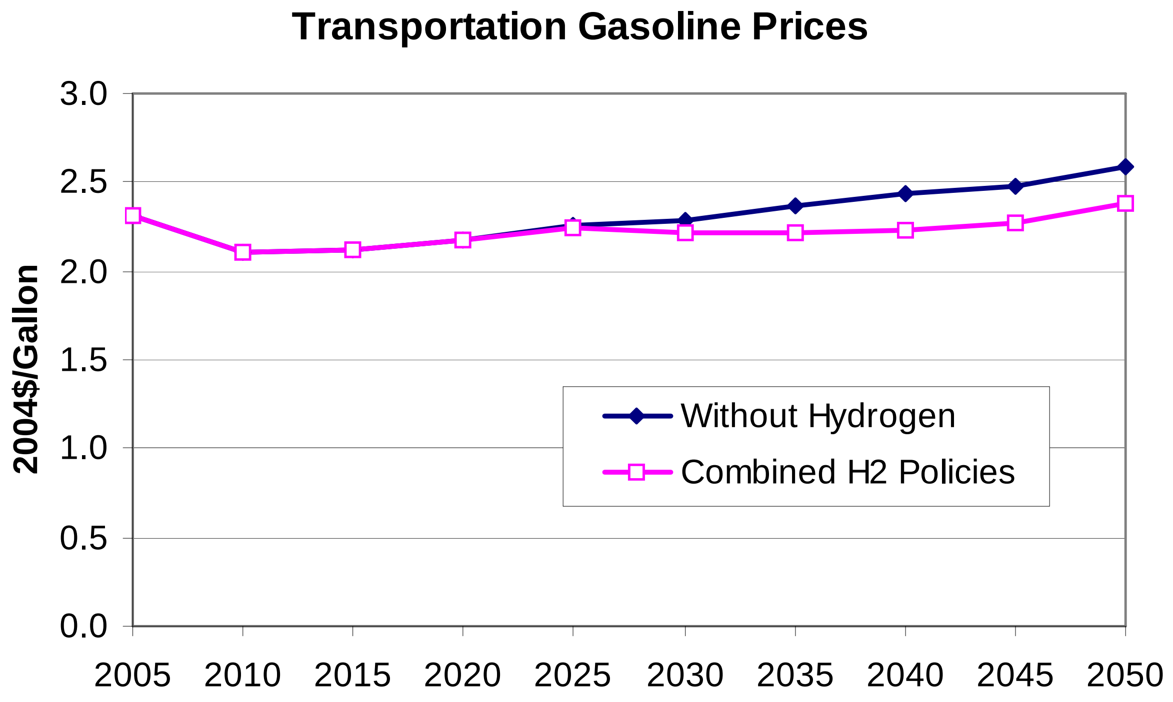
Natural Gas Prices

- Gas prices increase slightly due to greater demand.



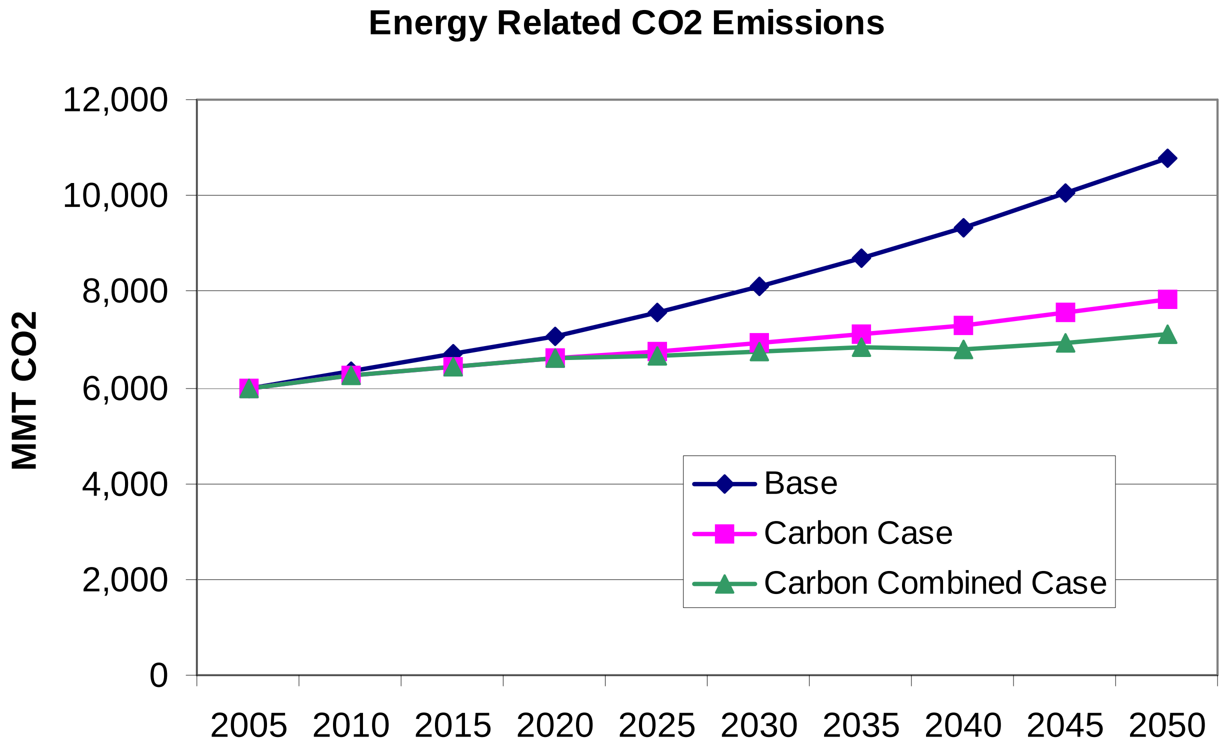
Gasoline Prices

- Reduced demand for gasoline prices leads to slightly lower prices, which reduces fuel cell vehicle attractiveness.



Emissions

- The use of hydrogen further reduces carbon emissions when when a $25 carbon penalty is in place.

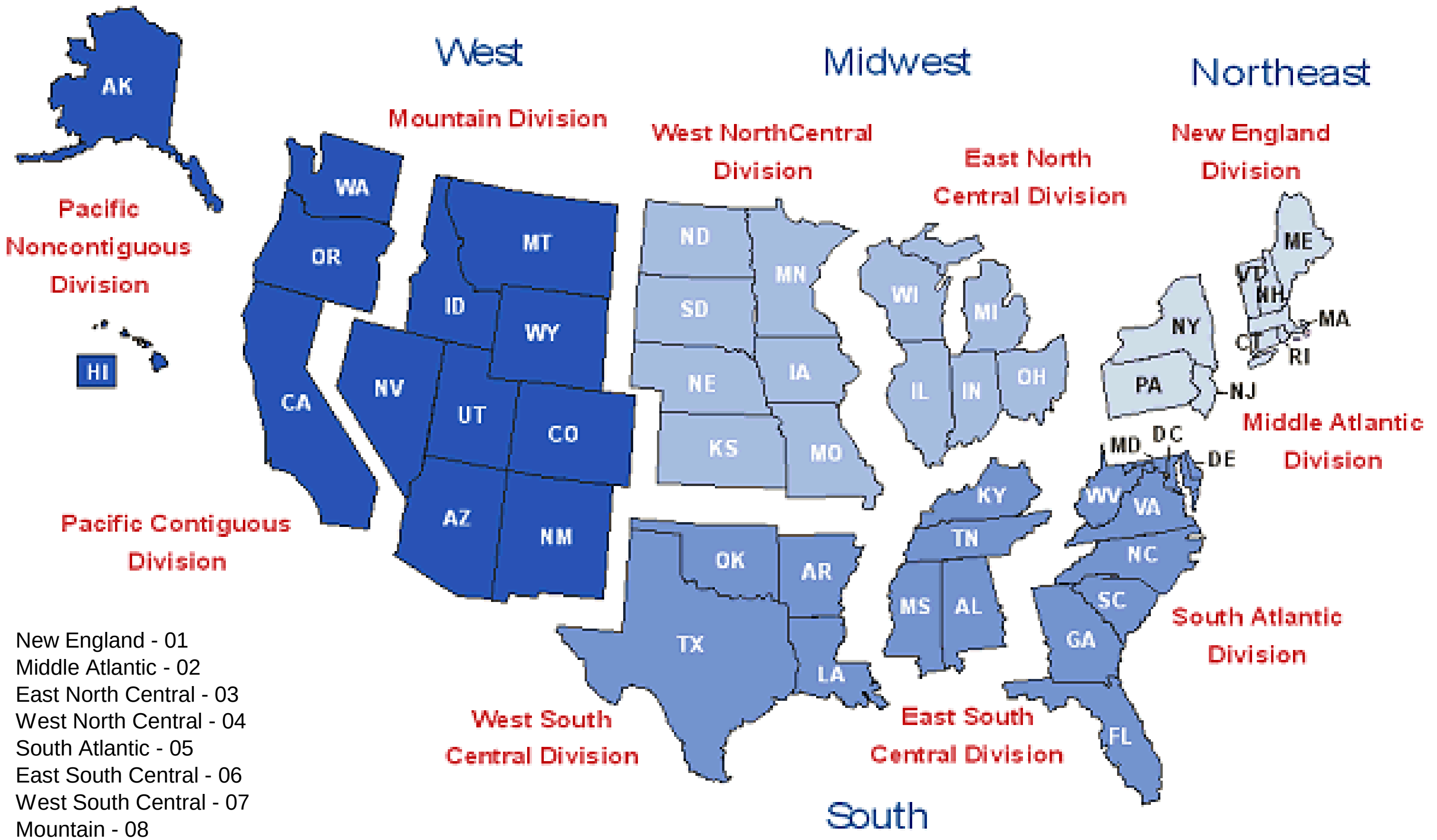


Backup Slides

Hydrogen Production Technologies Currently in the HMM

- Production is defined by three type of facilities
  - Central Production
    - Natural Gas Reforming (with and without sequestration)
    - Coal Gasification (with and without sequestration)
    - Biomass Gasification
    - Electrolysis (grid-based electricity)
  - City-Gate
    - Natural Gas Reforming
  - Forecourt Production
    - Natural Gas Reforming
    - Ethanol Reforming
    - Electrolysis (grid-based electricity)
- Each is represented by capital cost, non-fuel O&M costs, and energy conversion efficiencies.

Hydrogen Market Model Regions



New England - 01
Middle Atlantic - 02
East North Central - 03
West North Central - 04
South Atlantic - 05
East South Central - 06
West South Central - 07
Mountain - 08
Pacific - 09

Transportation Model Modifications

- The NEMS Light Duty Vehicle model represents multiple vehicle types, including hydrogen fuel cell vehicles
  - Consumer vehicle choice represented by multi-attribute logit function taking into account
    - vehicle price,
    - cost of driving (efficiency and fuel price),
    - fuel availability,
    - acceleration, luggage space, and make and model availability
- NEMS-H2 internally projects hydrogen prices that are used in light duty vehicles
- NEMS-H2 LDV module was modified to include market segments with distinct prices and fuel availabilities

Fuel Availability

- Consumers appear to be less willing to buy vehicles if availability of fueling stations is limited.
- NEMS uses a penalty curve based on additional drive time to stations that was developed by David Greene
- The penalty can be expressed in terms of a NPV of costs or an equivalent additional cost to the vehicle price.
  - The function is non-linear, and fuel availability ceases to be important once 15 to 20% of stations offer the fuel.