Impact of Renewables on Hydrogen Transition Analysis

Project ID #
ANP2

DOE Merit Review
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Timeline

- Start date: May 2006
- End date: Aug 2006
- 0% Complete (new project)

Budget

- Total project funding (FY06)
  - DOE share = $100k
  - No cost share

Barriers

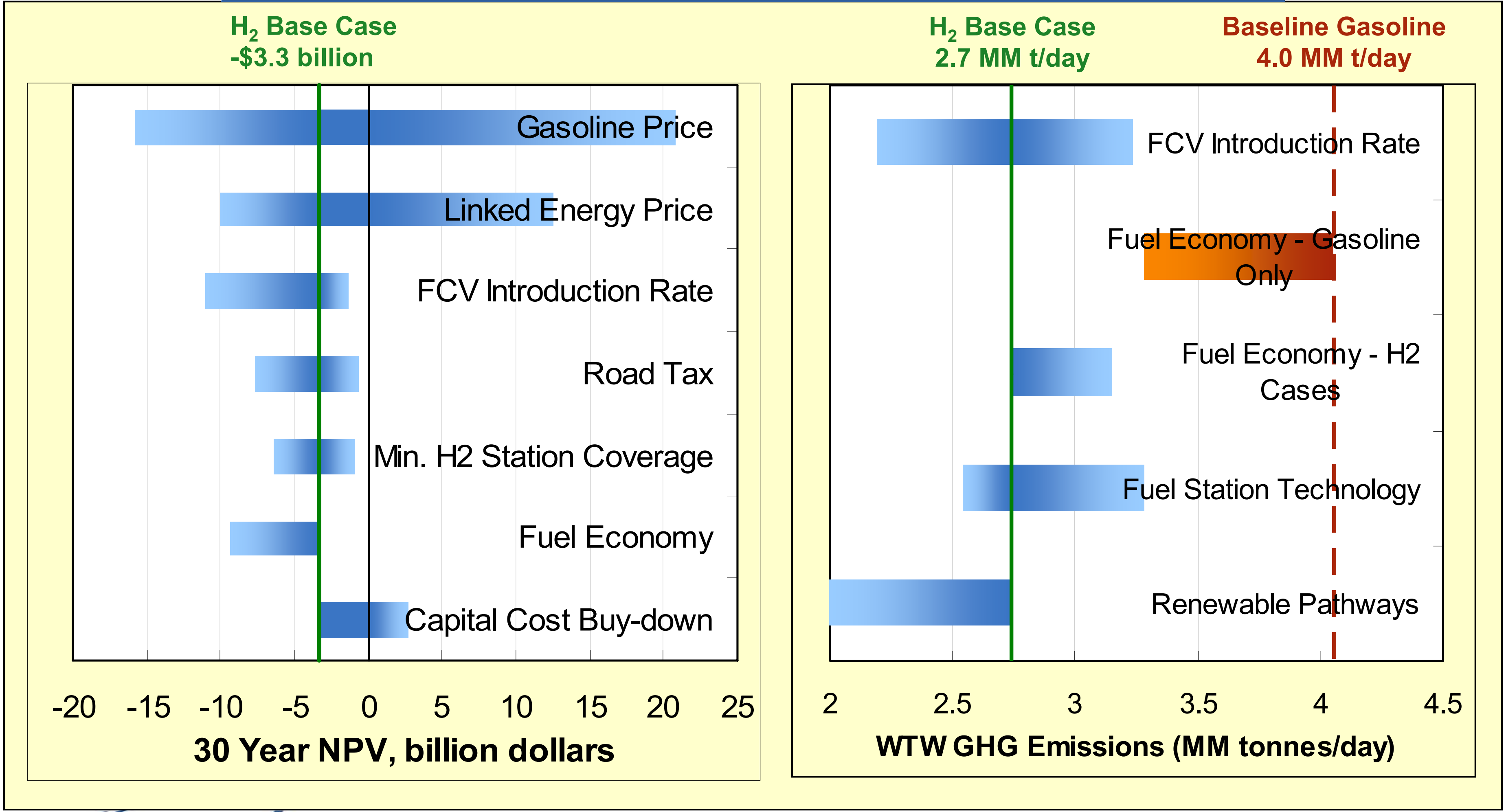
- Production - AD. Market and Delivery
- Delivery - A. Lack of H_2/ Carrier and Infrastructure Options Analysis
- Storage - V. Life Cycle and Efficiency Analysis

Partners

- Collaboration: H2A, UC Davis Hydrogen Pathways program
- Feedback: National Labs, Energy Companies, Automakers, Hydrogen technology developers

TIAX has previously developed a Transition Model to assess the impacts of building a H_2 fuel infrastructure for light duty vehicles.

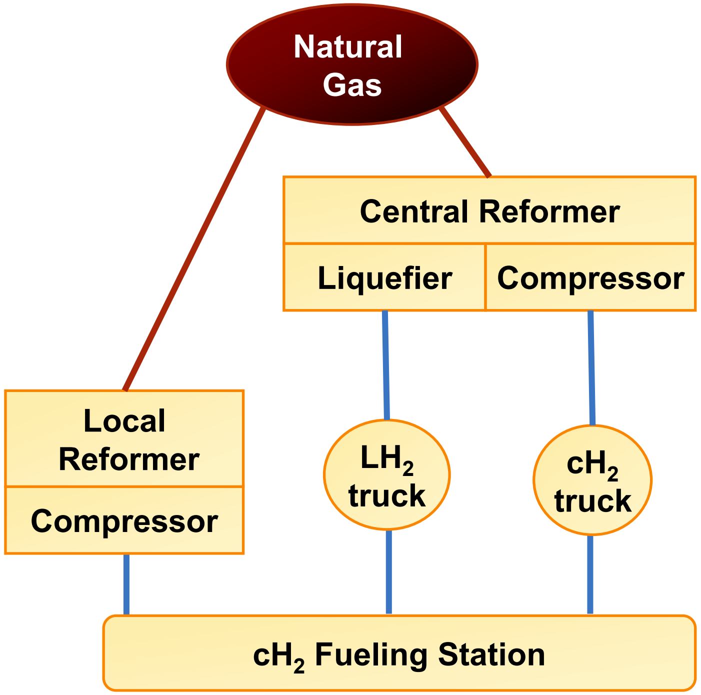
Previous Results: NPV and GHG Emissions Sensitivity Analysis



The previous work focused on near-term hydrogen production and delivery technologies to provide a basis to estimate transition costs.

- We previously analyzed a transition based on hydrogen produced exclusively from natural gas
- Other fuel and feedstock choices will be part of the transition, but costs are unlikely to be less than the existing natural gas options
- In the long-term, other pathways (e.g. pipeline transport, renewable-based production) could be more attractive, but were excluded from the original transition analysis

H_2 Pathways Used in Previous Transition Analysis



Natural Gas

Central Reformer

Liquefier

Compressor

Local Reformer

Compressor

LH_2 truck

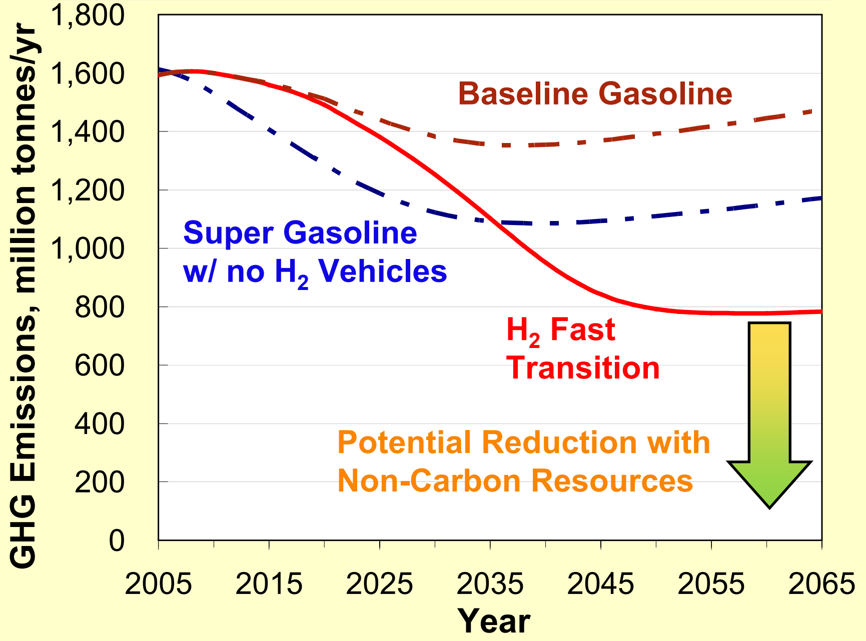
cH_2 truck

cH_2 Fueling Station

* cH_2 = compressed gaseous hydrogen; LH_2 = liquid hydrogen

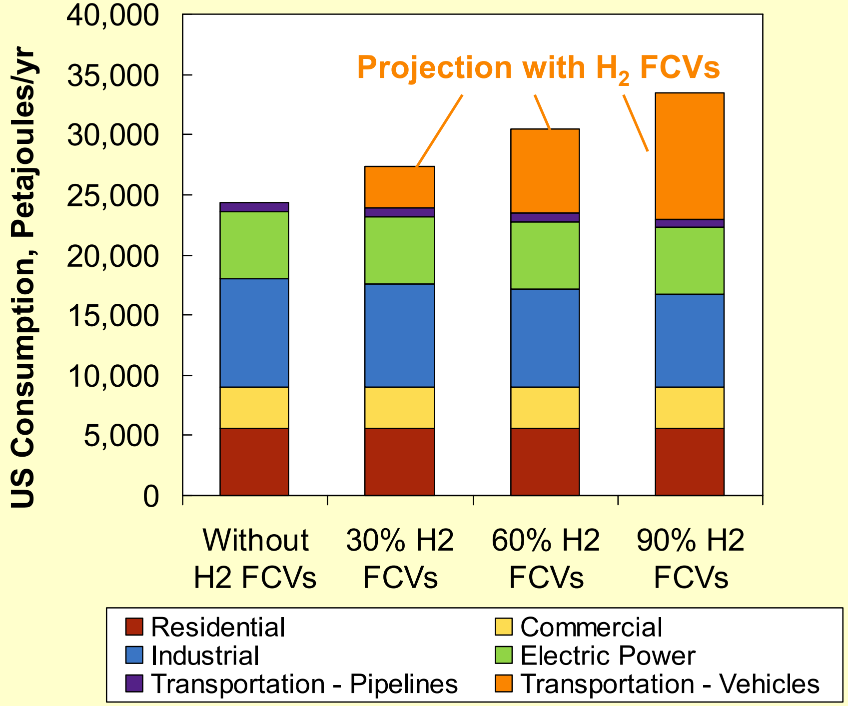
It is widely recognized that national benefits would be greatly enhanced if the sources of hydrogen were non-fossil.

Previous Results: WTW GHG Emissions vs Vehicle Fuel Economy



Fleet Fuel Economy Scenarios, mpgge (2050)	Hydrogen	Gasoline
Hydrogen Fast Transition	69	31
Baseline Gasoline (no H_2 Vehicles)	NA	31
Super Gasoline w/ no H_2 Vehicles	NA	38

Previous Results: Current and Projected U.S. Natural Gas Consumption

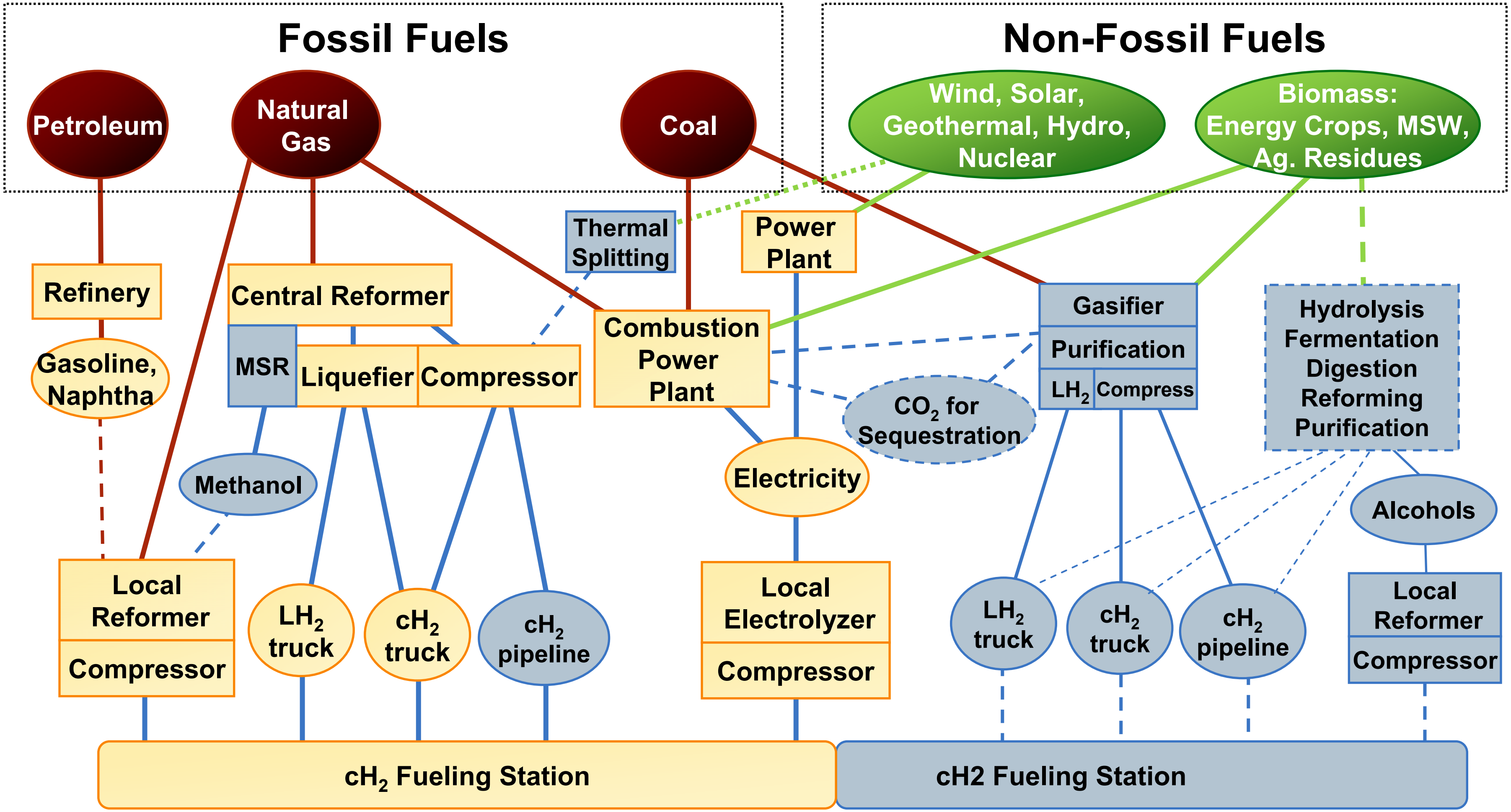


Source for non-vehicle categories: EIA Annual Energy Review 2004, Report No. DOE/EIA-0384(2004), Table 6.5: NG Consumption by Sector, 1949-2004. Numbers represented are for year 2003. Reduced natural gas for refinery operations for displaced gasoline is reflected in industrial sector.

However, important questions remain as to the feasibility of the non-fossil options, especially renewables.

- How much will it cost to generate hydrogen from renewables?
  - Production costs - variable (i.e. feedstock and processing) and fixed capital investment
  - Transportation costs could be significant
- How much can be used? Can hydrogen pipelines cost-effectively transport hydrogen? Where would hydrogen pipelines be located?
  - Resource availability
  - Proximity to hydrogen demand
  - Daily and seasonal variations
  - Competition from other options (e.g. other renewables, coal and nuclear)

This new project will expand the previous analysis by exploring the role of renewables in the hydrogen transition.



Legend:

Near-term hydrogen pathways
Longer-term hydrogen pathways

Objectives

- Evaluate the impact of renewables on hydrogen transition costs and Well-to-Wheel benefits
  - Incorporate renewable hydrogen resources and scenarios into previous hydrogen transition analysis
  - Evaluate impact on hydrogen infrastructure costs, primary energy use, petroleum reduction and GHG emissions over time
- Identify the most promising renewable pathways for hydrogen production
  - Develop likely future scenarios for renewable supply and hydrogen demands
  - Consider constraints on resource availability and hydrogen delivery

Approach Overview

This project will incorporate renewable production scenarios into the previously developed Hydrogen Transition Model.

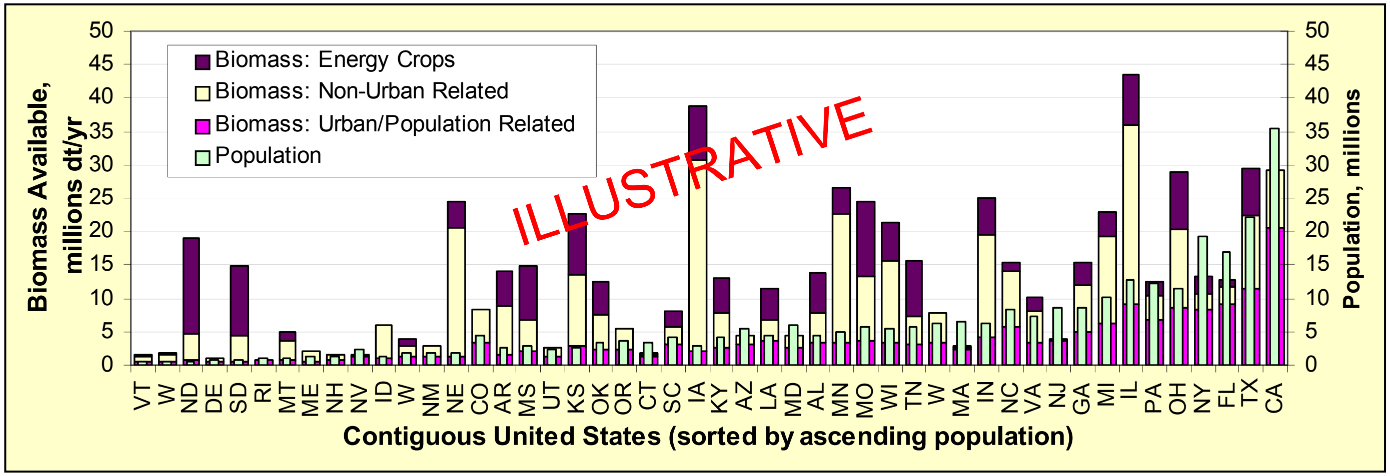
- Estimate demand-based use of renewable hydrogen for various future scenarios, including the amount, geographical location, and delivered cost
  - Leverage previous assessments of renewable potential (NREL, ORNL)
  - Develop a Demand Model to evaluate renewable-based H_2 production/ delivery costs and constraints based on regional supply and demand
  - Incorporate H2A assumptions, scenarios and results
- Update previous Transition Model and analysis to reflect the potential use of renewables taking into account future scenarios from above, including:
  - Electrolysis based production
  - Long-distance hydrogen transmission pipelines
  - Sensitivity analysis taking into account variations in scenario assumptions (e.g. hydrogen demand, equipment capital costs)
- Recommend future analysis needs and development pathways to accelerate the use of renewables for hydrogen production

Approach Renewable Use Potential

First, we will combine previous resource assessments with land use information to determine geographical availability of renewables.

Biomass Type	U.S. Available Quantity at 0-40 $/dt (farm-gate price), million dt/year ADL	ORNL[6]	USDA[7]	Comments
Agricultural Crop Residues[1]	156	151	425	Both analyses used the same source for corn stover and wheat straw. The ADL analysis included rice straw and cotton stalks. USDA assumes increase in agricultural productivity.
Forest Residues	84	45	124	Both analyses used the same source. The ADL analysis used updated data. USDA includes logging residues/culls and also fire hazard thinning.
Primary Mill Residues	2	90	196	Both used the same source. ORNL data included the currently used portion (for fuelwood, fiber, and misc. by-products). ADL excluded currently used portion of primary mill wastes. USDA includes fuelwood and mill wastes.
Other Wastes[2]	161	37	47	ORNL included used and unused fractions of MSW wood, yard trimmings, and C&D wood. The ADL analysis included only unused fractions of organic MSW, C&D wood, and UTR. USDA is urban wood waste.
Biogas[3]	11	NA		USDA wrapped into sludge below.
Sludge[4]	50	NA	75	USDA includes manure, biogass, sludge and others.
Potential Energy Crops[5]	159	188	431	ADL analysis assumed a linear interpolation of the ORNL data. USDA assumes meeting current production of other Ag. Products, putting 50 million acres into energy crop production, plus 56 tons of ethanol.
Total	**623**	**511**	**1300**	

1. Agricultural crop residues includes corn stover, wheat straw, rice straw, and cotton stalks.
2. Other wastes include the organic fraction of municipal solid waste, urban tree residues, and construction and demolition wood.
3. Biogas includes landfill gas, digester gas, and sewage gas.
4. Sludge includes manure and bio-solids.
5. Potential energy crops include switchgrass, hybrid poplar, and willow.
6. Based on a presentation given by Marie Walsh of ORNL (Walsh, 2000). Transportation cost assumed to be $10/dt to convert the ORNL data
7. USDA report 2005 “A billion-ton feedstock supply for a bioenergy and bioproducts industry”

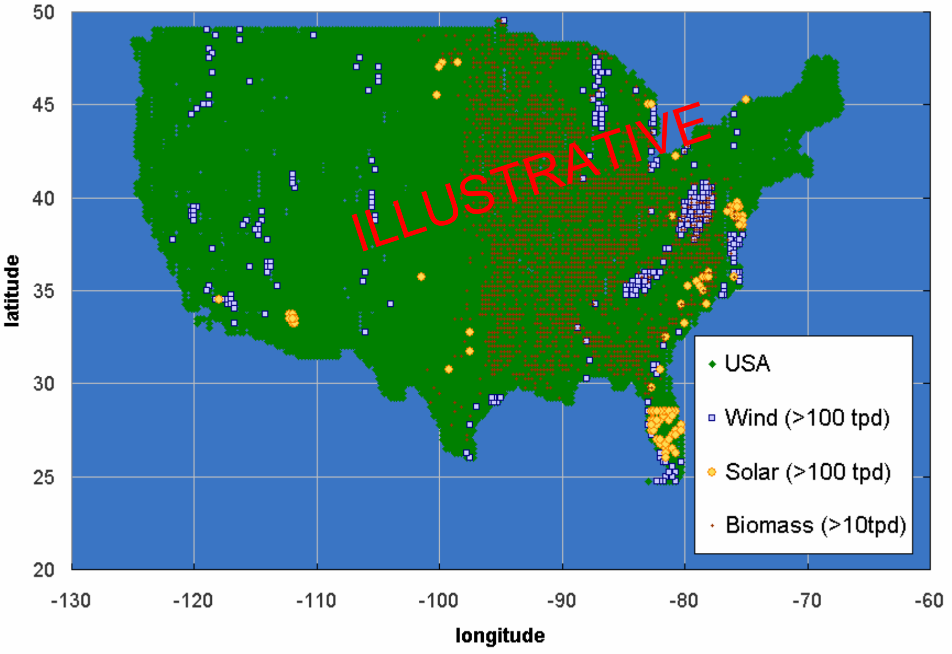


Approach Demand Model Overview

Next, we will develop a Demand Model to evaluate renewable-based H_2 costs and constraints based on regional supply and demand.

- The model will match renewable hydrogen resources with demand so that utilization of renewables can be assessed
  - Determines the appropriate location of central hydrogen production
  - Auctions off hydrogen to the lowest bidder
- The model also calculates the average cost of hydrogen by supply and demand

Demand Model Example: Renewables Utilization



Approach Demand Model Inputs

We will incorporate H2A assumptions, scenarios and results into the Demand Model.

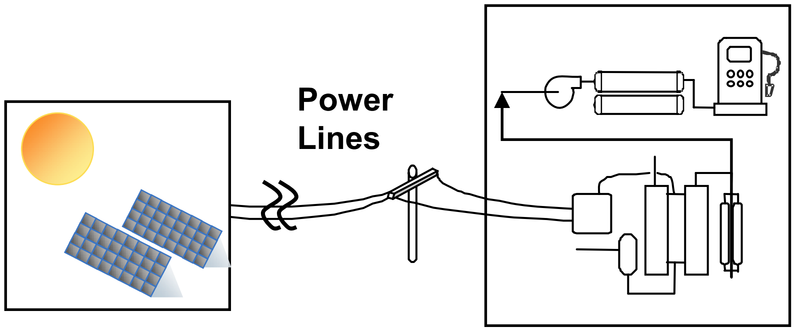
- Hydrogen costs for 20+ H2A runs
  - Central and forecourt production
  - Wind-based electrolysis for various wind classes
  - Solar-based electrolysis based on solar insolation values
  - Biomass conversion (e.g. energy crops, MSW, agricultural residues)
- H2A hydrogen demand scenarios
  - Large and small cities, rural
  - Vehicle market penetration and fuel economy assumptions

H2A Results Example: Central Wind-based Electrolysis, \$/kg H_2

Approach Distributed vs. Central Production

We will investigate both distributed and central hydrogen production options.

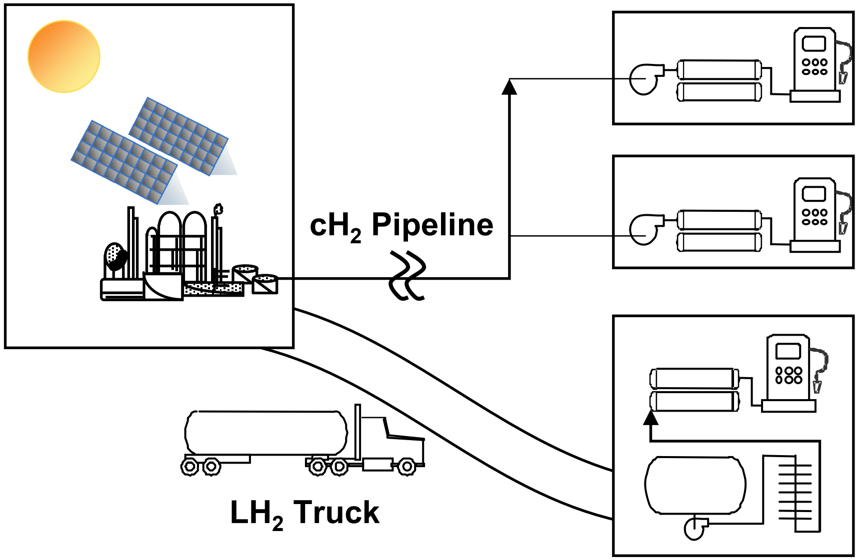
Distributed Hydrogen Production



Example:

- Dedicated solar PV power plants
- Transmit electricity to H_2 fueling stations
- On-site electrolysis

Central Hydrogen Production with Delivery



Example:

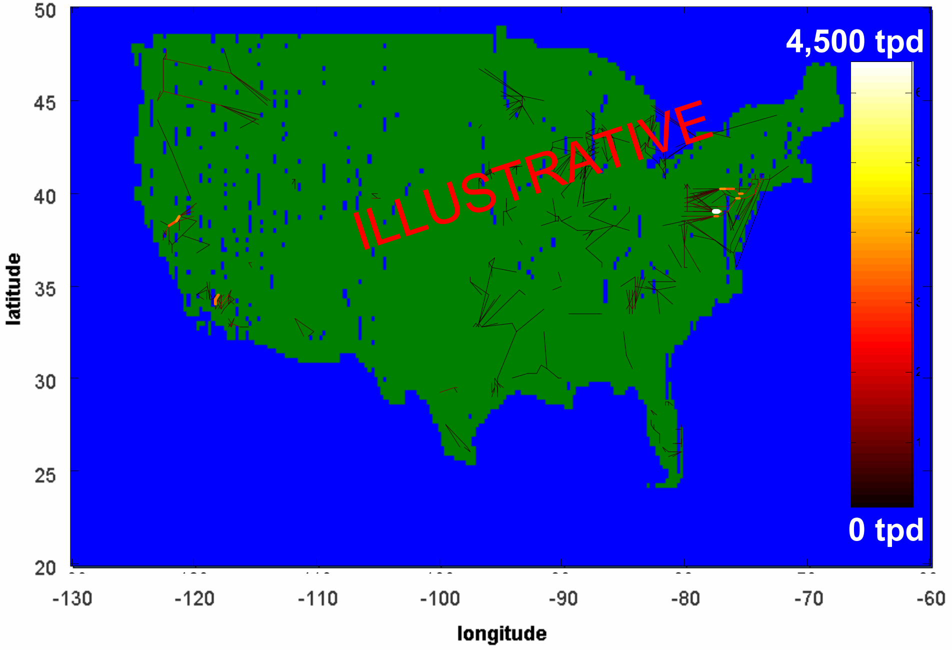
- H_2 generation in central locations at solar PV fields
- Pipeline or LH_2 transmission/ distribution to fueling stations

Approach Demand Model – H_2 Pipelines

For central production, the Demand Model will be used to determine the location and size of long-distance hydrogen pipelines.

- Location and size of H_2 flows will be calculated based on results of H_2 auction
- Model will consolidate information into a scenario for pipeline transmission capacity
  - Pipelines will use Dijkstra’s algorithm (like mapquest.com) to go from source to sink via allowable nodes (cities)
  - Pipelines in close proximity will be consolidated to one, larger pipeline

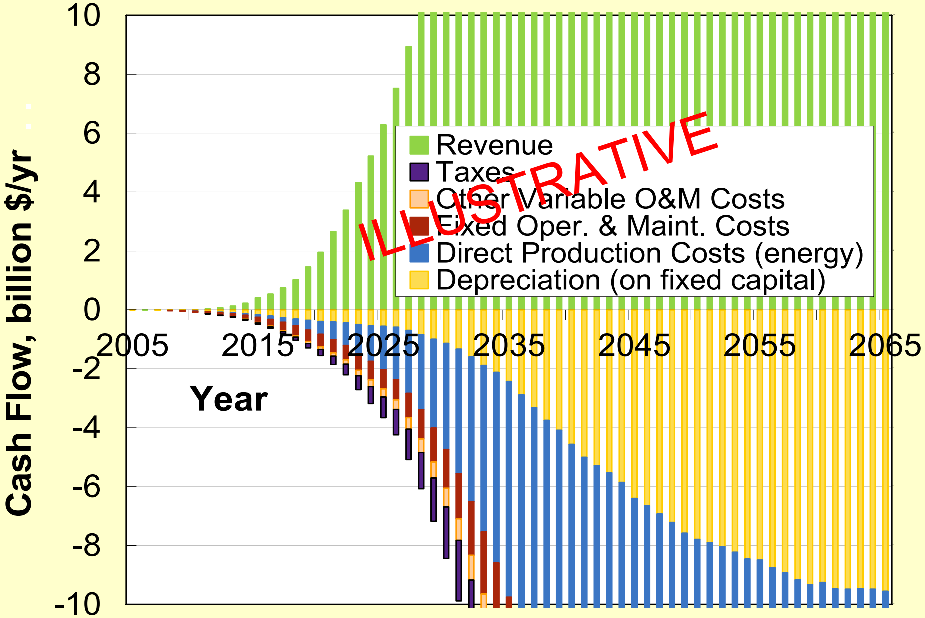
Demand Model Example: Hydrogen Pipelines



Next, we will update the previous Transition Model and analysis to reflect the potential use of renewables.

- Transition Model sums the costs and revenues for individual stakeholders and the total hydrogen infrastructure
- Calculates revenues based on hydrogen demand and price, which vary over time
- Costs include taxes, depreciation on capital, feedstock and other operating costs estimated for each type of infrastructure
- Capital costs take into account production volume economies of scale
- The sum of revenue and costs are presented as the cash flow over time
- NPV is calculated from the sum of discounted cash flows

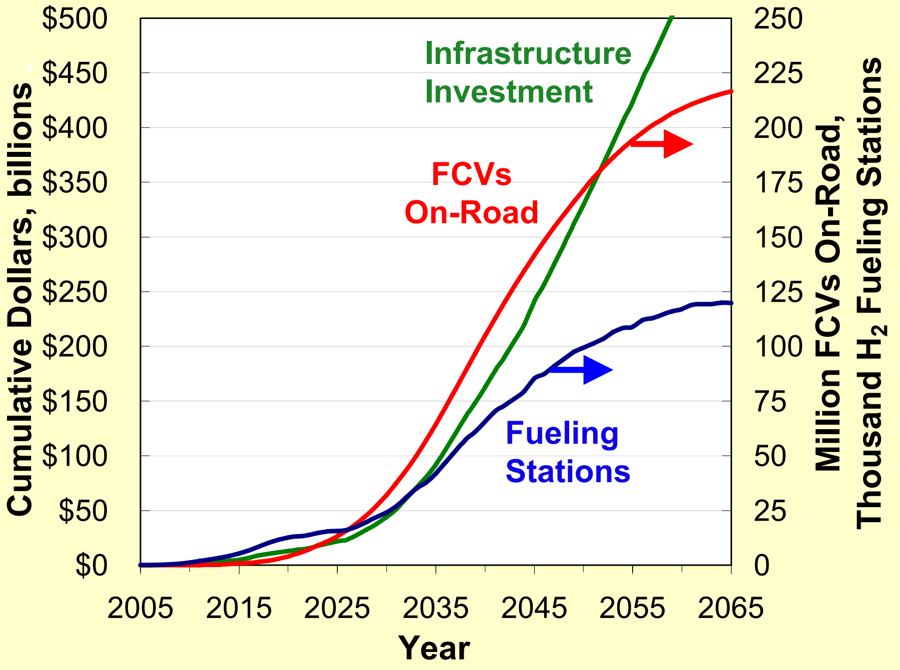
Transition Model Example: Detailed Cash Flow – Base Case, Large SR



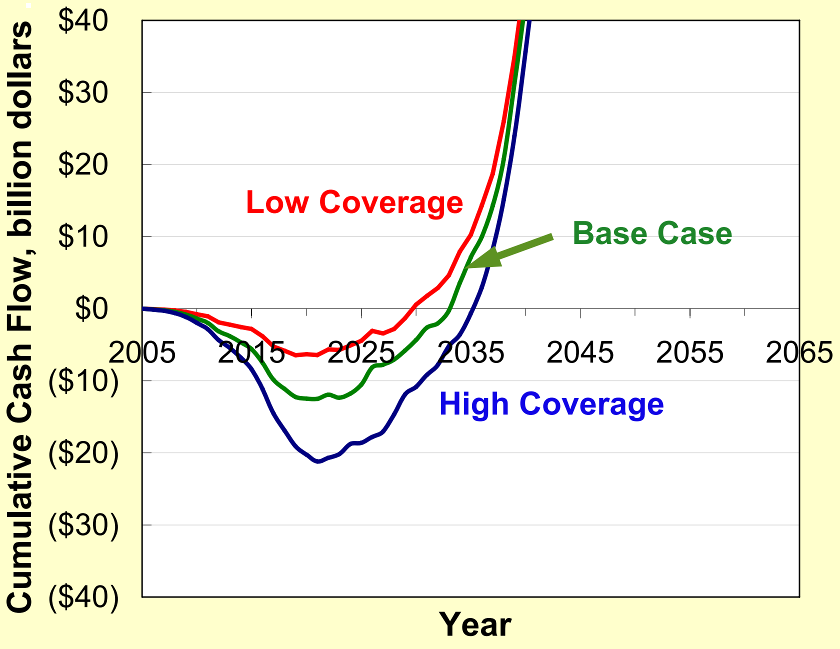
Approach Transition Model – Economics

The Transition Model will be used to calculate economic impacts, such as capital investment, cash flow and NPV on an annual basis.

Previous Results: H_2 Stations & Investment – Base Case



Previous Results: H_2 Cash Flow vs Station Coverage

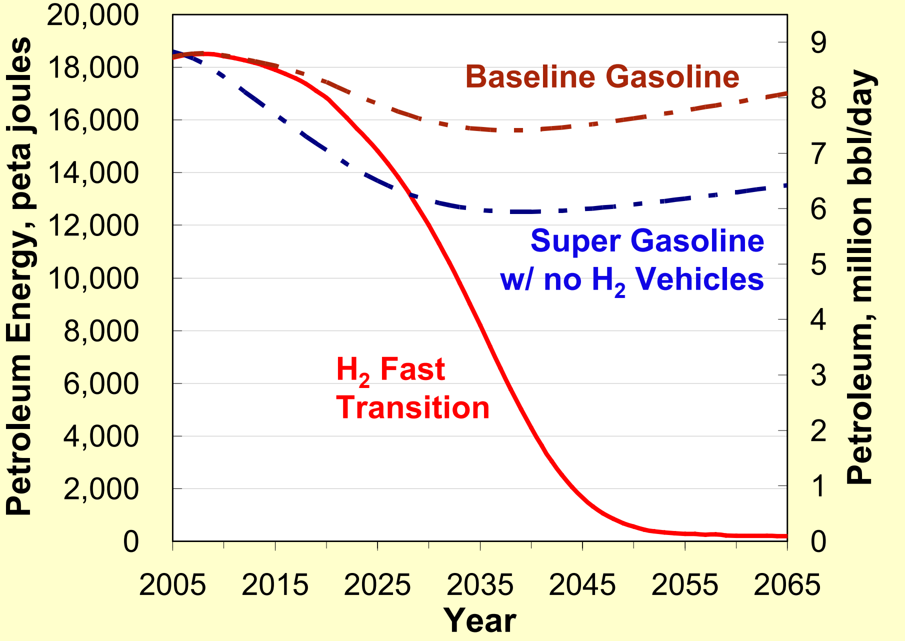


H_2 Station Minimum Coverage Scenarios	2015
Low Coverage Requirement	5%
Base Case	10%
High Coverage Requirement	15%

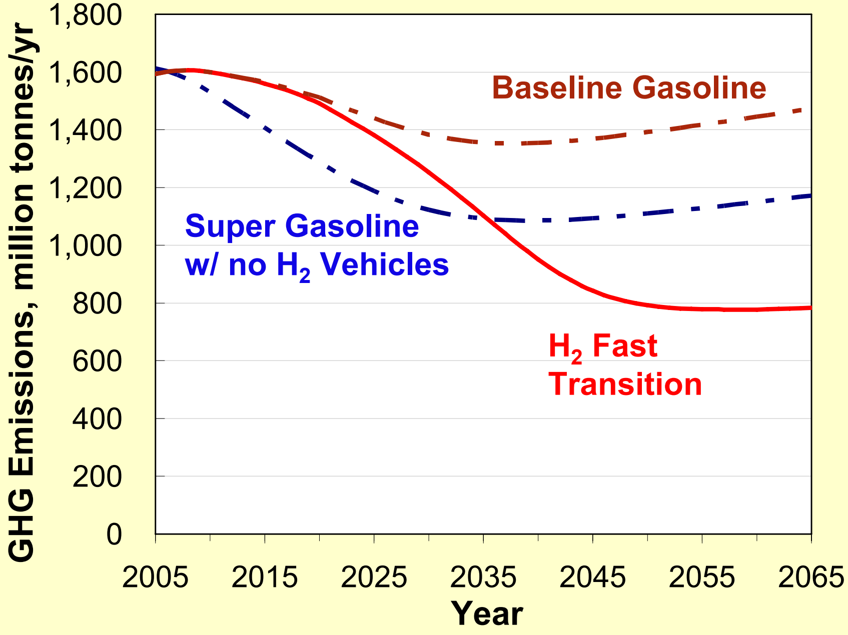
Approach Transition Model – Environmental

The Transition Model will also be used to calculate environmental impacts, such as primary energy use and GHG emissions.

Previous Results: Petroleum Use vs. Vehicle Fuel Economy



Previous Results: GHG Emissions vs. Vehicle Fuel Economy



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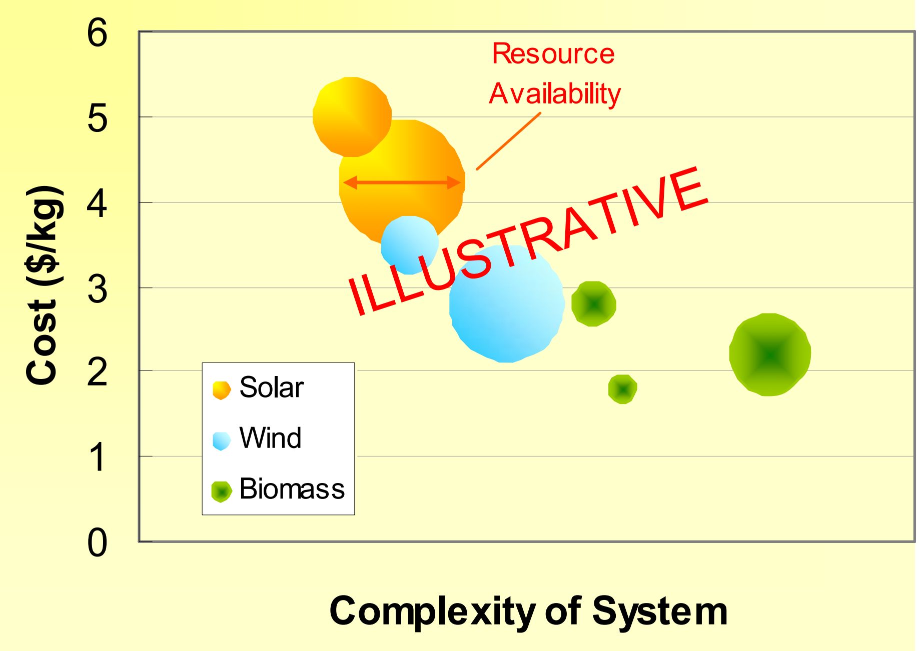
1. Scenarios include a mix of advanced gasoline vehicle technologies including reduced throttle losses as well as mild and full hybridization. Projection for conventional gasoline vehicle fuel economy is improvement from 20 to 28 mpg through 2050.

Approach Recommend Pathways

Finally, we will recommend future analysis needs and development pathways to accelerate the use of renewables for hydrogen production.

- Assess resource limitations
- Develop different spatial scenarios
- Iterate with delivery analysis to identify implementation constraints
- Rank renewable pathways
- Solicit stakeholder input
- Perform sensitivity analysis
- Make recommendations

Renewable Pathway Ranking Example: Hydrogen Cost vs. Complexity



Note: Bubble size corresponds to resource availability. Different bubbles represent central plant and small scale options as well as different biomass categories.