International Energy Workshop

June 24-26, 2003, IIASA, Austria

Hydrogen Economy: Opportunities and Challenges

Phillip Tseng*, John Lee**, Paul Friley**

Phillip.Tseng@HQ.DOE.GOV

* U.S. Department of Energy

** U.S. Brookhaven National Laboratory

Background

- This study is part of an ongoing analysis of the benefits of hydrogen technologies and assumes that life cycle cost of fuel cell vehicles will be made competitive. Our initial analysis showed that the market penetration of fuel cell technologies would plateau between 2030 and 2040. This study explores the impediments to further market penetration of fuel cell technologies and the role of bioproducts in a hydrogen economy.
- Subsequent analysis dispelled the perception that in a hydrogen economy, technologies such as biomass will not have a role in the energy mix.

Agenda

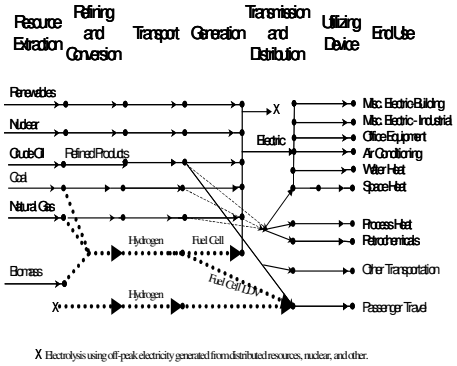
- Objectives of this study
- Analytical approach and Reference Case assumptions
- Hydrogen scenario
- Impacts of the hydrogen economy on the petroleum-based energy system
- Implications on opportunities and challenges

Objectives of This Study

- To simulate the transformation from a petroleum based energy system to a hydrogen economy and understand the economics of energy markets (with the assumption that hydrogen technologies are cost effective)
- To provide quantitative analysis on the impact of policies and changing market conditions on the energy system (focusing only on vehicle technologies)
- To identify opportunities and challenges during this transition

Analytical Approach

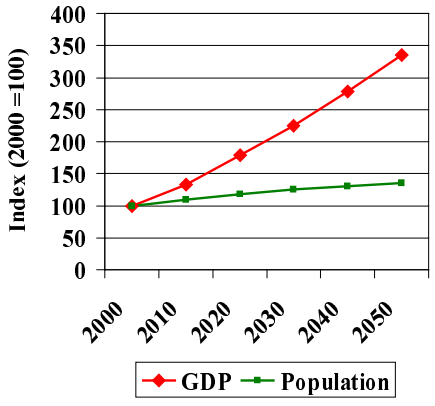
Figure 1: Modeling Hydrogen Economy in MARKAL Reference Energy System



X Electrolysis using off-peak electricity generated from distributed resources, nuclear, and other.

- We use the U.S. MARKAL model to establish a Reference case covering periods from 2000 to 2050.
- We introduce hydrogen technologies to the U.S. economy in 2015

Reference Case Assumptions:
GDP and Population

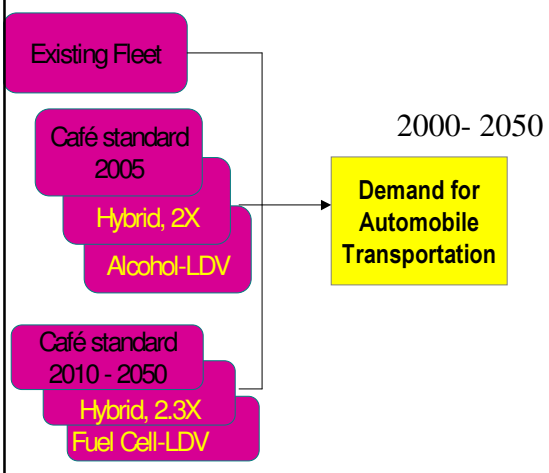


- Reference Case is based on AEO2002 & CBO's long-term economic projections
- GDP is projected to increase at a rate of 3.0% per year from 2000 to 2020, and to an average annual rate of 2.1%per year from 2020 to 2050

Reference Case Assumptions:
Fossil Fuel Prices

2000$	2000	2010	2020	2030	2040	2050
World Oil Price ($/bbl)	28.69	25.06	27.40	28.37	30.44	32.12
N G Wellhead Price ($/MMBtu)	3.87	3.13	3.37	3.96	4.38	4.82
Coal Minemouth Price ($/s ton)	17.01	14.11	13.41	11.95	11.77	12.18

Reference Case Assumptions:
Vehicle Technologies



- Technology assumptions are based on historical trends for conventional technologies.
- For hybrid vehicles, it is based on current technology and technical potential identified as reachable by the research community

Reference Case Assumptions:
Vehicle Technologies: Hybrid Vehicles

Costs of Vehicles Cars and Efficiencies*

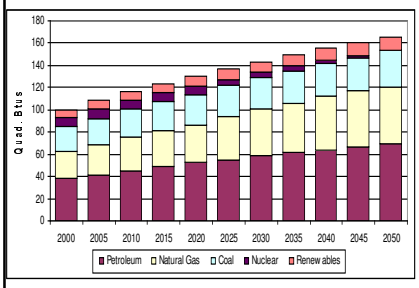
	2015	2020	2030	2050
Capital Cost	1.03	1.01	1.01	1.01
O&M Cost	1.10	1.05	0.90	0.90
Efficiency	1.50	1.50	1.50	1.50

*In multipliers of 2000 vintage of gasoline cars (efficiency = 28.6 miles per gallon, capital cost = $18,000 per vehicle).

- Capital cost of hybrid vehicles range 1 to 3% higher than conventional vehicles
- O&M cost of hybrid vehicles is projected to drop below conventional vehicles in the long run
- Hybrid vehicle efficiencies are assumed to be 50% higher than conventional vehicles.

Reference Case Energy Mixes

Primary Energy Consumption, 2000-2050



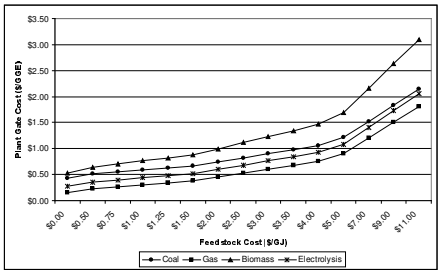
- Total primary energy use is projected to increase at a rate of 1.3% per year from 2000 (99 quads) to 2020 (130 quads), and at an average annual rate of 0.8% between 2020 and 2050 (166 quads).
- Oil's share of total energy consumption is projected to increase from 39% in 2000 to 42% in 2050, driven by petroleum use in the transportation sector

Hydrogen Economy Scenario

- We model hydrogen production from coal, natural gas, biomass, and electrolysis.
- We assume most hydrogen plants will be situated within 100 miles of demand centers to minimize costs of transporting hydrogen
- Existing rail lines and natural gas pipelines may be used to transport coal or natural gas to hydrogen plants

Hydrogen Economy Scenario:
Assumed Cost of Hydrogen Production by Technology & Feedstock

Hydrogen Plant Gate Cost by Feedstock Cost



- Cost goals at gate of .75 $ per gallon of gasoline equivalent at reference feedstock costs ($/GJ) : biomass = 1, gas = 4, coal = 2., electricity = 1 cent per kWh.
- Cost goals of hydrogen transport & storage at .65 $ per GGE for 50 – 100 miles delivery, .4 $ per GGE for less than 25 miles.
- The significance of transport cost creates niche markets for biomass-produced hydrogen

Hydrogen Economy Scenario:
Assumed Cost and Efficiency of Hydrogen Fuel Cell Vehicles

Costs of Hydrogen Fuel Cell Cars and Efficiencies*

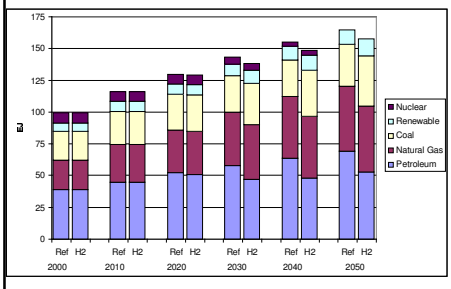
	2015	2020	2030	2050
Capital Cost	1.15	1.15	1.15	1.10
O&M Cost	1.10	1.05	0.90	0.90
Efficiency	2.20	2.50	2.90	2.90

*In multipliers of 2000 vintage of gasoline cars (efficiency = 28.6 miles per gallon, capital cost = $18,000 per vehicle).

- Capital cost of hydrogen fuel cell vehicles range 10% - 15% higher than conventional vehicles
- O&M cost of hydrogen fuel cell vehicles is projected to drop below conventional vehicles after 2020
- Hydrogen fuel cell vehicle efficiency increases from 2.2X to 2.9X (57 mpg to 83 mpg) between 2015- 2050.

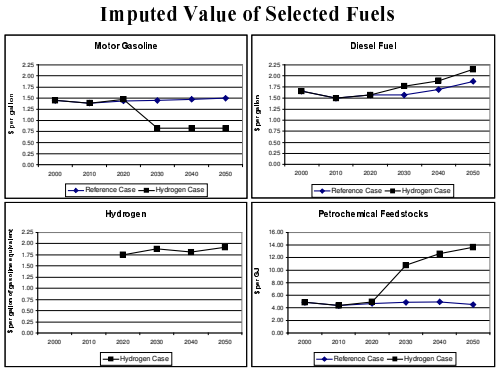
Impacts of the Hydrogen Economy on US Primary Energy Consumption

Primary Energy Consumption by Fuel



- Total primary energy consumption is reduced by 5 quads in 2030 and 7.5 quads in 2050 due to improved system efficiency
- Oil consumptions (mostly from imports) is reduced by 11 quads in 2030 and 17 quads in 2050, as hydrogen replaces gasoline
- Coal and biomass consumption increase as feedstock inputs to produce hydrogen

Impacts of Hydrogen Economy on the Oil Market



- Gasoline price drops as demand decreases
- Decrease in oil refinery throughput reduce joint product supply (e.g., petrochemicals and diesel) and push up their prices

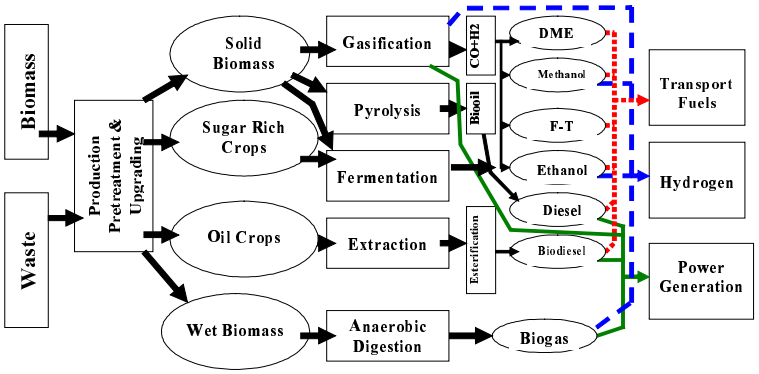
Potential Role for Biomass

Biomass research covers several major areas:

- Gasification of biomass
- Ethanol from biomass
- Biodiesel
- Biochemical products

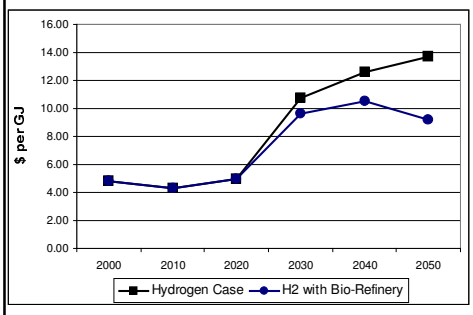
Advanced biomass refinery could optimize production of bio products and convert biogas and ethanol to hydrogen.

Advanced Biomass Refinery:
An Example



Economic Benefits of Bio-refineries in a Hydrogen Economy

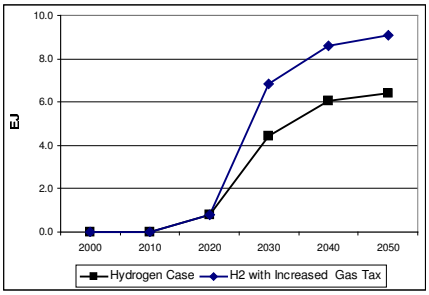
Imputed Value of Petrochemical Feedstocks



- Potential products and bi-products from bio-refineries (e.g., bio-chemicals, diesel) could offset some of the reduced supply of petroleum products
- The new market conditions reduce the cost of hydrogen production due to increased revenue from joint products

Balancing Energy Security and Increased Use of Hydrogen

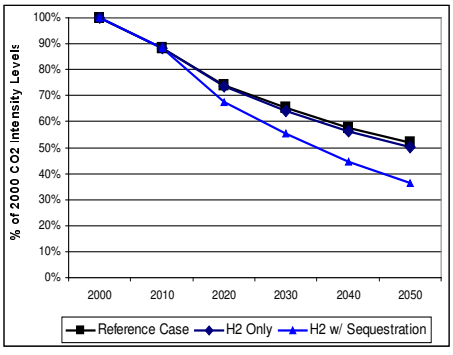
Hydrogen Demand with stable gasoline price



- Reduced gasoline price in a hydrogen economy changes the economics of vehicle choices and could favor gasoline powered vehicles.
- A policy that maintains the price of gasoline at the Reference Case level could encourage increased market penetration of hydrogen technologies.

Environmental Benefits of a Hydrogen Economy

Hydrogen technologies provides cost-effective options in reducing GHG intensities



- Hydrogen production processes allow more efficient pre-combustion CO_2 sequestration
- A much greater reductions in CO_2 intensity in the Hydrogen Scenario with CO_2 sequestration may be attained if R&D on carbon sequestration is successful and policies or market conditions favor such technologies.

Opportunities and Challenges in Building a Hydrogen Economy

Opportunities:

- New markets for a range of products and technologies as the petroleum industry adjusts in a hydrogen economy
- Increased international trade in energy products and technologies during the transition to a hydrogen economy
- More favorable market conditions for biomass and CO_2 sequestration technologies in meeting carbon intensity goals

Opportunities and Challenges in Building a Hydrogen Economy

Challenges:

- Significant cost reductions in the production, transport, storage, and use of hydrogen are required to build a hydrogen economy
- The transition to a hydrogen economy requires the design and implementation of economic incentive schemes and policies to persuade producers and consumers
- Competitive production site selection for feedstock supply and transport of hydrogen to demand centers