Hydrogen as an Energy Carrier: Outlook for 2010, 2030 and 2050

Joan Ogden
Institute of Transportation Studies
University of California, Davis

Presented at
The Pew Center/NCEP 10-50 Workshop
Washington, DC
March 25, 2004

Why Consider Hydrogen as a Future Energy Carrier?

- Zero or near-zero emissions at point of use
- Low to zero well-to-wheels emissions of both air pollutants and greenhouse gases
- H_2 can be made from widely available primary resources (fossil, renewable, nuclear)
- H_2 is widely used today in chemical industries (~2% of world energy use ->H_2 production ; strong technical base exists for H_2 production, storage and delivery).
- Rapid progress in H_2 and fuel cell technologies
- H_2 might enable new products and services, transforming the way we produce and use energy.

H_2 is one of the only long-term options for fuels sector that allows radical reductions in GHG emissions, air pollutant emissions and oil use.

Barriers to a Hydrogen Economy

- current lack of a widespread H_2 infrastructure
- current high cost of H_2 end-use technologies
- Technical maturity: need to develop emerging tech and adapt current H_2 technologies for a H_2 energy economy (e.g. fuel cells, H_2 storage for vehicles, small scale H_2 production systems, long term, low-cost "zero carbon" H_2 supply: fossil H_2 production with CO_2 sequestration, renewable H_2, nuclear H_2).
- "Chicken & Egg Problem" for vehicles. (More generally, problem of matching H_2 supply and demand during transition.)
- lack of policies reflecting the external costs of energy

Key RD&D Areas for H_2

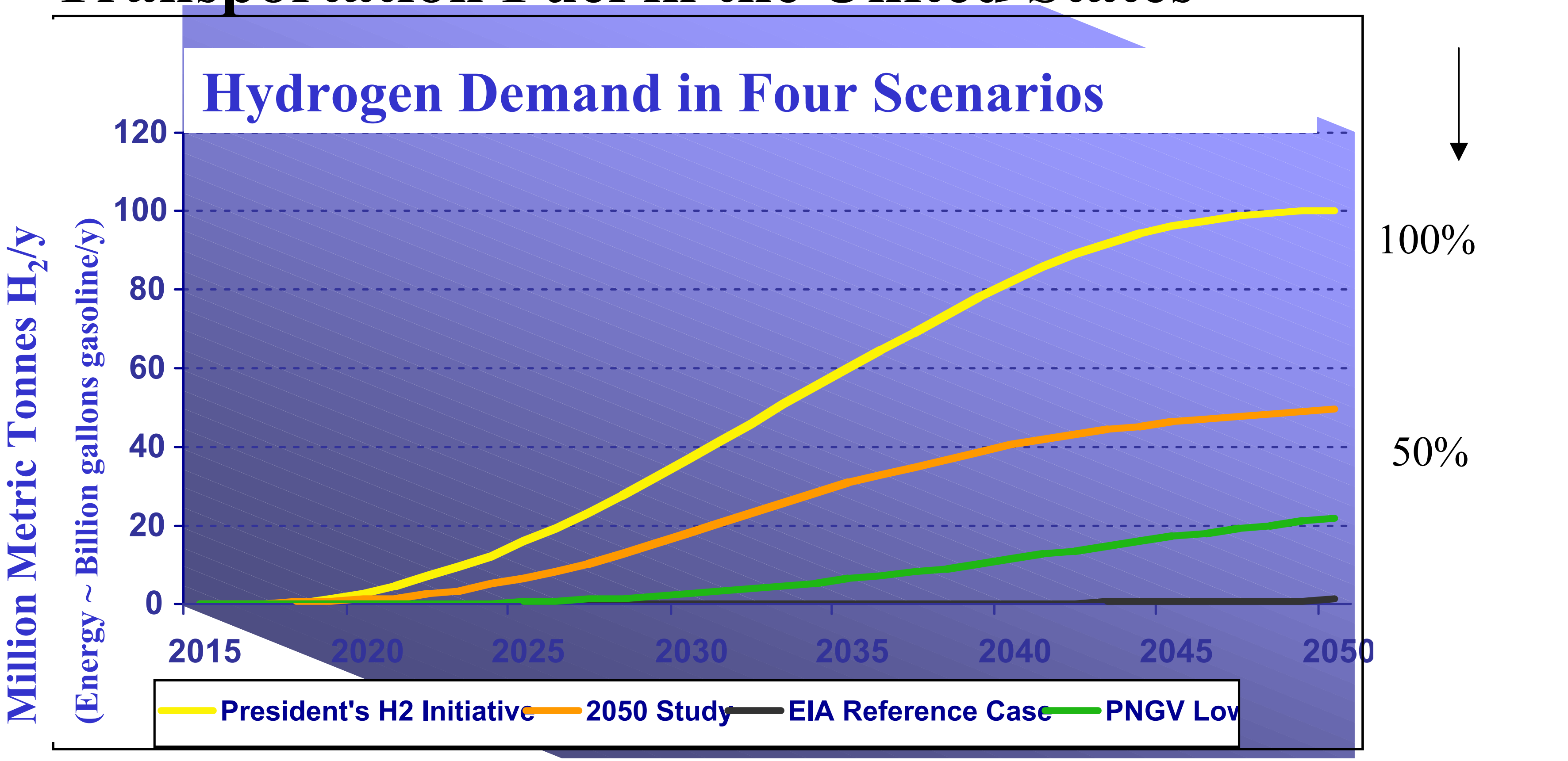
- H_2 Production: In the near term, H_2 could be made from natural gas with reduced well to wheels GHG emissions.To fully realize H_2's benefits, need vigorous support for RD&D to develop near-zero GHG emission H_2 production technologies.
- H_2 Storage and Delivery: Support for R&D on hydrogen storage could have a large payoff. Development of a novel hydrogen storage medium that required neither high pressure nor low temperature would not only facilitate use of hydrogen in vehicles, but could reduce hydrogen infrastructure costs and complexity as well.
- H_2 End-Use: RD&D on H_2 vehicle and fuel cell technologies is key. For H_2 vehicles to compete in automotive markets, they must offer comparable or better performance at a similar cost to competing vehicles. Incentives or other policy measures would likely be needed to make up any difference in costs, until mass production brought H_2 vehicles to a competitive level. Public/private partnerships among stakeholders needed.
- H_2 Strategies: Analysis is needed to better understand the societal costs of energy and role of H_2 in the future energy system.

Long-Term Visions of H_2 Supply and Challenges

- **H_2 from renewables** (wind or solar electrolysis, biomass gasification), the issue is primarily cost rather than technical feasibility or resources.
- **Nuclear H_2** issues are cost (electrolytic H_2), technical feasibility (water splitting systems powered by nuclear heat). Same waste and proliferation issues as nuclear power.
- **Fossil H_2 with CO_2 capture and sequestration** offers nearly zero emissions, relatively low cost, assuming suitable CO_2 disposal sites are available nearby, and hydrogen is produced at large scale. Much remains unknown about the potential environmental impacts and

  feasibility of CO_2 sequestration.

Range of Estimated Demands for H_2 Transportation Fuel in the United States



Uncertainties (in technology, policy, market pull of new products) make it hard to project future H_2 demands

Scenario for Introduction of H_2: Context

	2010-2030	2030-2050	>2050
Policy: General	In many countries: Policies to reduce GHG enacted Stringent air pollutant regulations Broad support, RD&D for clean energy technologies National security concerns encourage use of diverse, secure primary supplies	Broad Int'l agreements on GHG reductions, carbon taxes or cap and trade; Developing country regulations on GHG, pollution	Regulations on GHG, air pollutants in place worldwide;
H_2-specific	Vigorous RD&D programs on H_2, FC technologies in US, EU, Japan H_2 codes/standards by 2010 Local/Regional H_2 demo projects; Public/private partnerships for cooperation among stakeholders	National policies to encourage development of H2 infrastructure	
Technical	H2, FC meet technical and cost goals. H2 vehicles enter light duty markets in 2015-2020. Enabling technologies for zero-emission H2 production (wind power, gasification, and CO_2 sequestration) appear in elec. sector.	Further advances in zero emission H2 production technologies, and in H2 storage; H2, FC used in new ways in energy system	low-cost, zero-carbon H2 production, storage and delivery technology available

Scenario for Introduction of H2: Timeline

	2010-2030	2030-2050	>2050
Markets **Industrial** **Vehicles** **Buildings/ Sta. Power**	Oil Refining; Chemical; Aerospace/military; Niche EVs; Battery replacement Heavy vehicles Lt.duty small fleets -> Large fleets -> General Fuel Cell Heat / Power, (H_2 co-production?)	 H_2 FCVs capture significant fraction of light duty vehicle market H_2 distrib. to buildings/ commercial /industry	General use of H_2 in energy sector
Production/ Primary Supply	Excess industrial H_2 capacity; Fossil H_2 (Steam reforming natural gas; Partial oxidation of oil; coal gasification); electrolysis; CO_2 seq. demos; Renewable H_2 demos;	Fossil with CO_2 sequestration; electrolysis powered by zero emission electricity (wind); Biomass gasification Adv. renewable and Adv. nuclear demos	Fossil with CO_2 sequestration; electrolysis w/ zero emission electricity; Biomass gasification, adv. renewable or nuclear
Delivery Infrastruct.	Truck; Mobile refuelers -> onsite SMR or electrolysis -> central production w/ pipelines	regional H_2 refuel networks, pipelines in some cities; interaction with electricity system begins; developing country applications	National networks for H_2 energy; H_2 integrated with rest of energy system (electricity)
Where Will H_2 Be Used?	Local and Regional H_2 demo projects -> small networks in a few cities	City wide or regional networks; island H_2 systems	National networks in many countries

A No-Regrets Action Agenda:

Hydrogen-specific actions over the next decade

- **Strong support of RD&D on H_2 technologies**: esp. fuel cells, zero emission H_2 production, and H_2 storage.
- **Public/private partnerships** for demonstration of H_2 technologies.
- **Federal and state governments play a role as early adopters of H_2 technologies**.
- **Establishment of codes and standards** for safe H_2 operation in energy applications.
- **Analysis** to better understand the societal costs of energy and role of H**2** in the future energy system.

A No-Regrets Action Agenda:

General actions over the next 10-20 years

- **Development of a consistent national energy policy to address societal problems of climate change, air pollution and national security.** Action on near-term technologies that could help address these problems now (such as energy efficiency and hybrid vehicles). Simultaneous development of longer-term technologies (including H2) that will be needed for deep cuts in carbon emissions
- **RD&D on efficient vehicle technologies** with applications in a wide range of advanced vehicles (including H2 vehicles). These include electric drive train components being developed for hybrid vehicles,

  and advanced lightweight materials for vehicles.
- **RD&D on clean energy technologies with applications in both electricity and H2 production**. These include wind, solar, gasification technologies, CO_2 sequestration, and biomass energy.

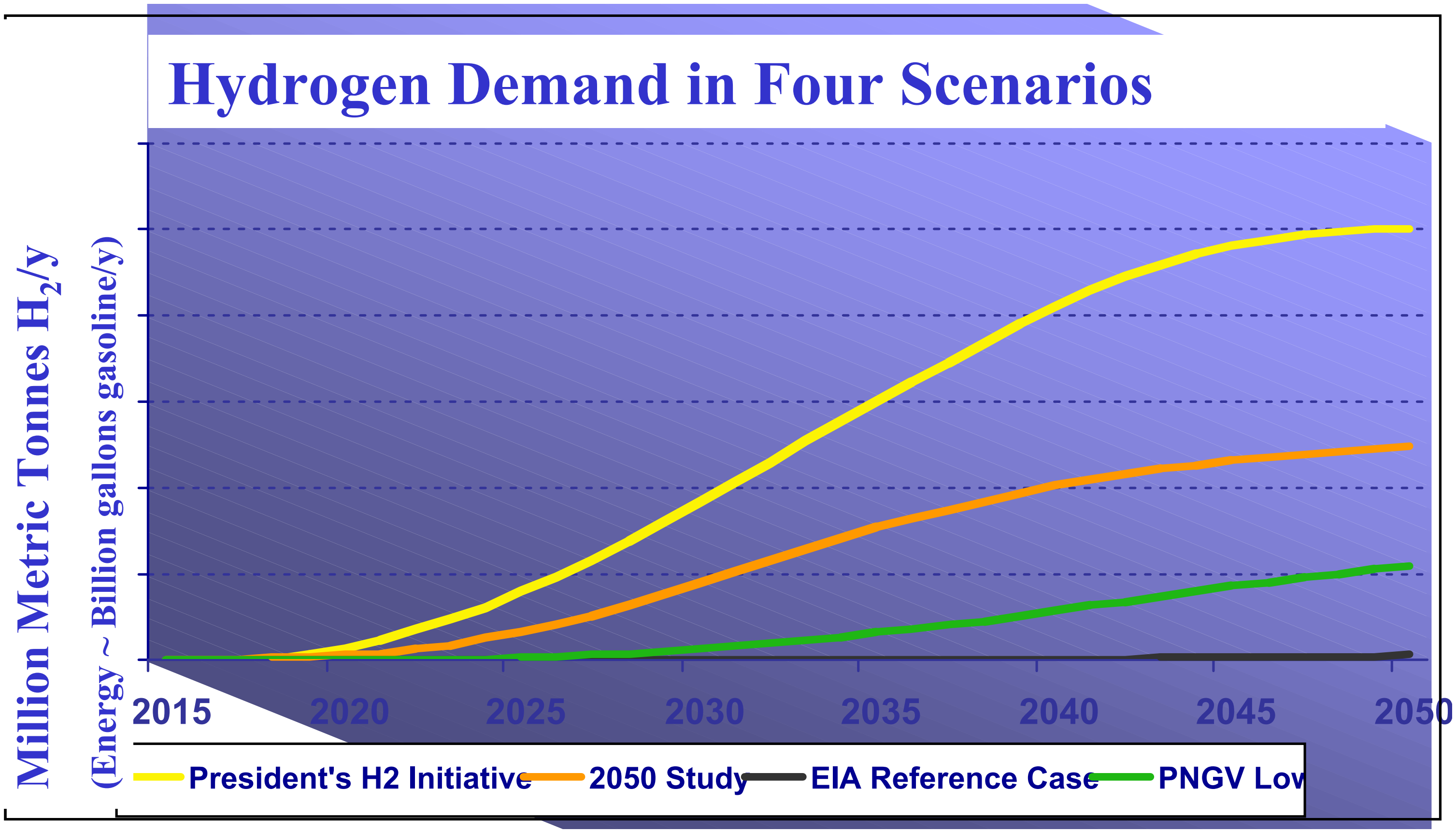
Questions

- Where will H_2 come from? Are there adequate near term and long term resources for H_2 production?
- How Soon Could H_2 Make a Major Difference in Environmental and Energy Supply Problems?
- How much will it cost to implement H_2?

Where will the hydrogen come from?

- Natural gas is widely seen as a transitional source for H_2 production in the United States over the next few decades
  - 10-40% GHG emissions reduction v. adv. ICEVs
  - Small impact on natural gas use, at H_2 use levels <2025
- Long term: To realize the GHG benefits of H_2 technologies, change to H_2 supplies with near-zero GHG emissions. There are ample resources for zero emission H_2 production in the United States, and in many areas of the world.
- Many solutions for H_2 supply, depending on the level of demand, resource availability, geographic factors.

Primary Energy to Meet US H_2 Demand



Percent of current US resource use to provide H_2 for LDVs (assuming one resource for all H_2)

NG	Coal	Wind*	Bio**
68	92	45	33
34	46	22	16
14	18	9	7

* > class 3 wind

** fraction of range + pastureland required for H2 via gasification

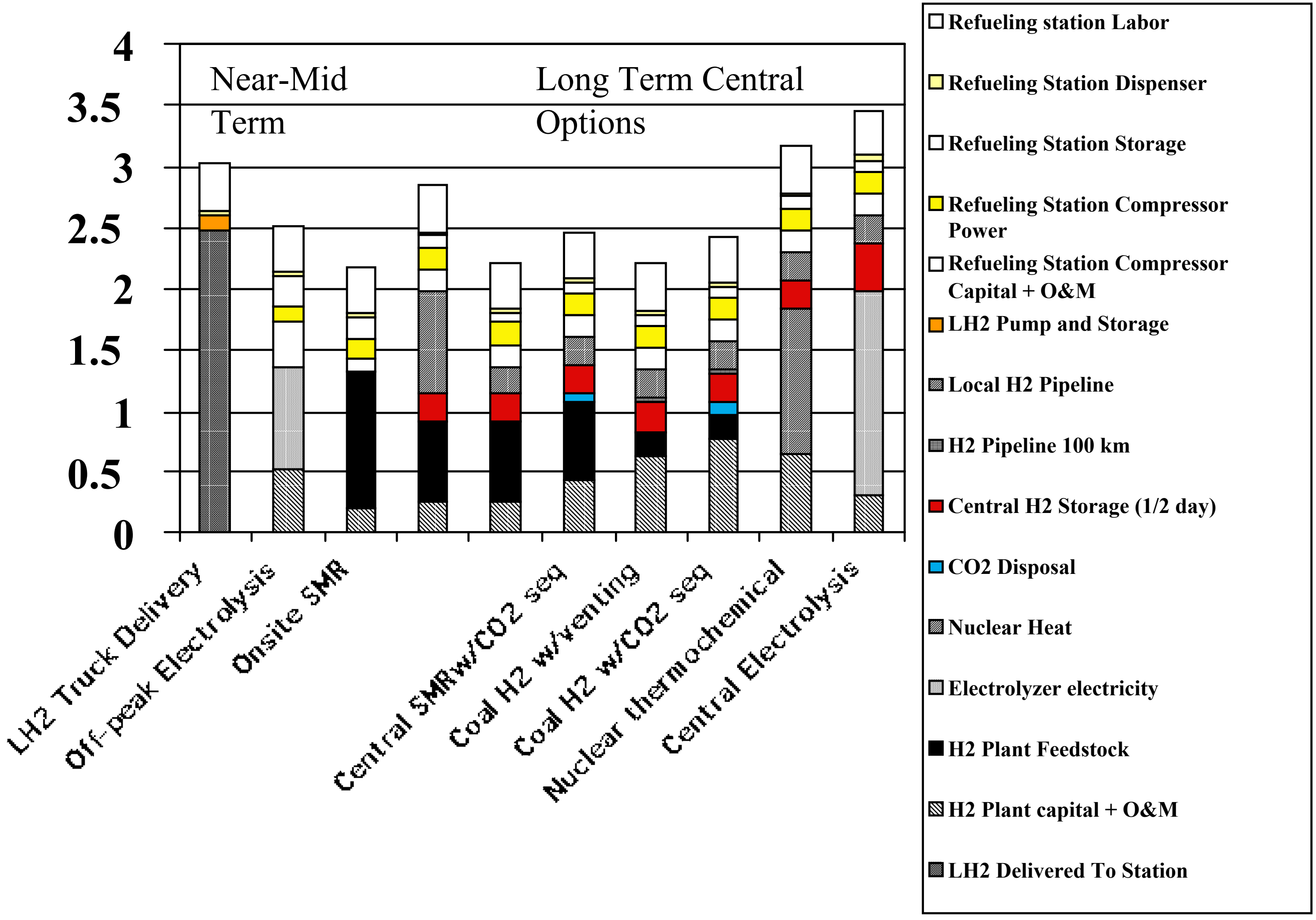
100 million H_2 Light duty vehicles with 2-3 X today's gasoline vehicle fuel economy would require 26-38 million tonnes H_2/y (3.1-4.6 EJ/y)

How Soon Could Hydrogen Make a Major Difference in Environmental and Energy Supply Problems?

- Time scale for changing the energy system is historically several decades.
- H_2 technologies need further development and testing before introduction into mass markets, and time to penetrate markets.
- Most analysts suggest that it will be several decades before hydrogen could make a major difference in reducing emissions and oil use on a global scale. (This is true of all long term options for deep GHG emissions reductions.)
- Beyond 2025, most analysts see <u>potential</u> for large impact of H_2 technologies on reducing emissions.
- Further, there is the potential that H_2 could transform how we produce and use energy (new types of vehicles, mobile electricity generation, energy storage, diversify primary supplies).

Delivered Cost of H_2 ($/kg H2)

$1/gallon gasoline ~ $1/kg



Questions for Discussion

- Are major scientific breakthroughs needed for H_2 to play a major role?
- What is the balance between policies for near-term and long-term technologies?
  - Is hydrogen "in competition" with energy efficiency or biofuels?
  - Comprehensive strategy: Encourage use of clean, efficient internal combustion engine vehicles in the near term, coupled with a longer term strategy of research, development and demonstration of H_2 and fuel cells.