

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

Joan Ogden

Institute of Transportation Studies

University of California, Davis

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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
- H₂ can be made from widely available primary resources (fossil, renewable, nuclear)
- H₂ is widely used today in chemical industries (~2% of world energy use ->H₂ production ; strong technical base exists for H₂ production, storage and delivery).
- Rapid progress in H₂ and fuel cell technologies
- H₂ might enable new products and services, transforming the way we produce and use energy.

H₂ 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 H₂ infrastructure
- current high cost of H₂ end-use technologies
- Technical maturity: need to develop emerging tech and adapt current H₂ technologies for a H₂ energy economy (e.g. fuel cells, H₂ storage for vehicles, small scale H₂ production systems, long term, low-cost “zero carbon” H₂ supply: fossil H₂ production with CO₂ sequestration, renewable H₂, nuclear H₂).
- “Chicken & Egg Problem” for vehicles. (More generally, problem of matching H₂ supply and demand during transition.)
- lack of policies reflecting the external costs of energy

Key RD&D Areas for H₂

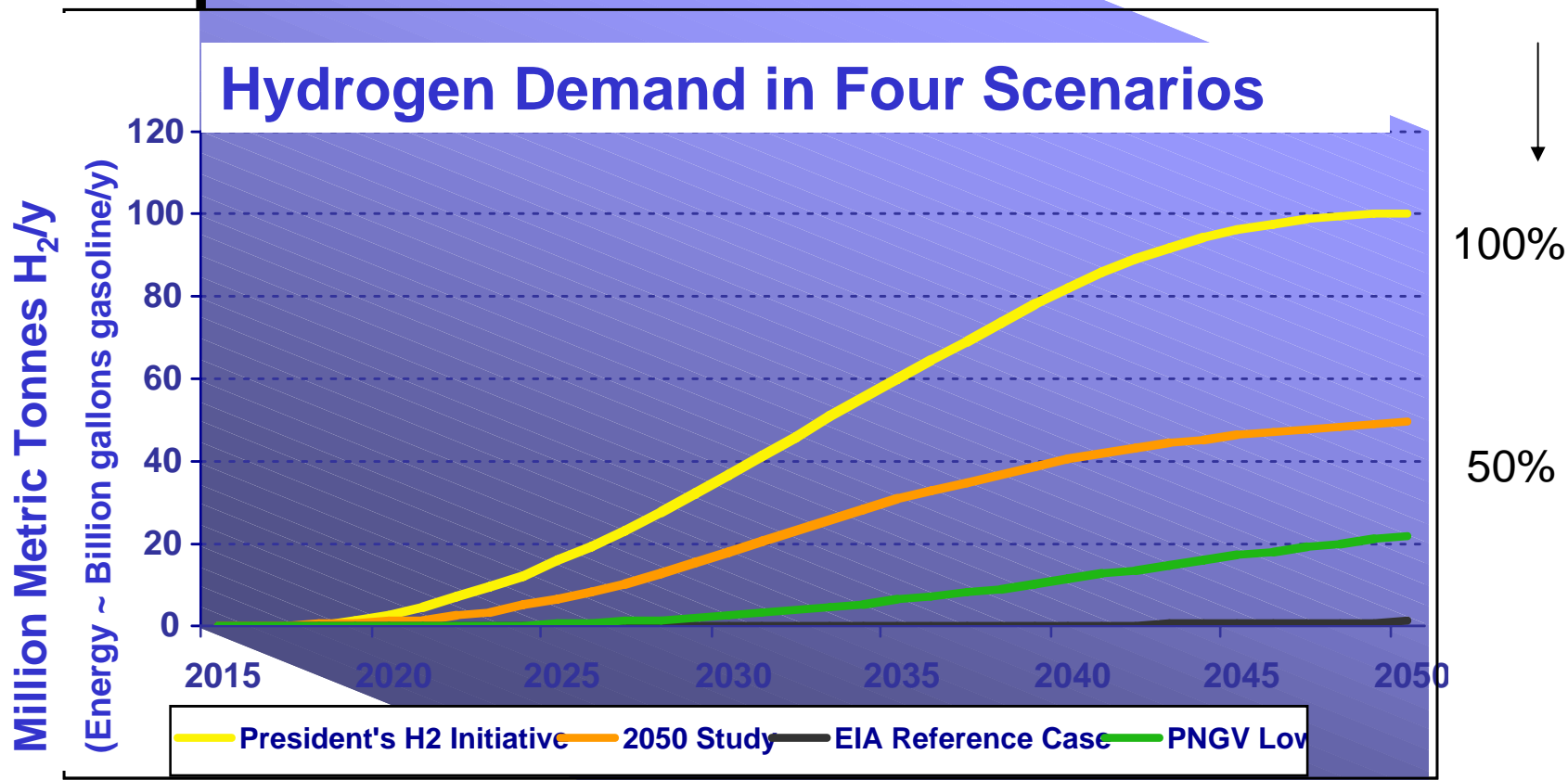
- H₂ Production: In the near term, H₂ could be made from natural gas with reduced well to wheels GHG emissions. To fully realize H₂'s benefits, need vigorous support for RD&D to develop near-zero GHG emission H₂ production technologies.
- H₂ Storage and Delivery: Support for R&D on hydrogen storage could 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.
- H₂ End-Use: RD&D on H₂ vehicle and fuel cell technologies is key. For H₂ 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 H₂ vehicles to a competitive level. Public/private partnerships among stakeholders needed.
- H₂ Strategies: Analysis is needed to better understand the societal costs of energy and role of H₂ in the future energy system.

Long-Term Visions of H₂ Supply and Challenges

- **H₂ from renewables** (wind or solar electrolysis, biomass gasification), the issue is primarily cost rather than technical feasibility or resources.
- **Nuclear H₂** issues are cost (electrolytic H₂), technical feasibility (water splitting systems powered by nuclear heat). Same waste and proliferation issues as nuclear power.
- **Fossil H₂ with CO₂ capture and sequestration** offers nearly zero emissions, relatively low cost, assuming suitable CO₂ disposal sites are available nearby, and hydrogen is produced at large scale. Much remains unknown about the potential environmental impacts and feasibility of CO₂ sequestration.

Range of Estimated Demands for H₂ Transportation Fuel in the United States

H₂ vehicle
Fraction of LDV
Stock



Uncertainties (in technology, policy, market pull of new products) make it hard to project future H₂ demands

Scenario for Introduction of H₂: Context

| | 2010 -20 30 | 2030 -20 50 | >205 0 |
|--|--|--|--|
| Policy : General H ₂ -specific | 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 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 | Broad Int'l agreements on GHG reductions, carbon taxes or cap and trade; Developing country regulations on GHG pollution National policies to encourage development of H ₂ infrastructure | Regulations on GHG, air pollutants in place worldwide; |
| Technical | H ₂ , FC meet technical and cost goals. H ₂ vehicles enter light duty markets in 2015-2020. Enabling technologies for zero-emission H ₂ production (wind power, gasification, and CO ₂ sequestration) appear in elec. sector. | Further advances in zero emission H ₂ production technologies, and in H ₂ storage; H ₂ , FC used in new ways in energy system | low-cost, zero-carbon H ₂ production, storage and delivery technology available |

Scenario for Introduction of H₂: Timeline

| | 2010 -2030 | 2030 -2050 | >2050 |
|--|--|---|---|
| Markets Industrial | Oil Refining; Chemical; Aerospace/military; Niche EVs; Battery replacement | | General use of H ₂ in energy sector |
| Vehicles | Heavy vehicles Lt. duty small fleets -> Large fleets -> General | H ₂ FCVs capture significant fraction of light duty vehicle market | |
| Buildings/ Sta. Power | Fuel Cell Heat/ Power, (H ₂ co-product ion?) | H ₂ distrib. to buildings/ commercial / industry | |
| 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 H₂ 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 H₂ technologies:**
esp. fuel cells, zero emission H₂ production, and H₂ storage.
- **Public/private partnerships** for demonstration of H₂ technologies.
- **Federal and state governments play a role as early adopters of H₂ technologies.**
- **Establishment of codes and standards** for safe H₂ operation in energy applications.
- **Analysis** to better understand the societal costs of energy and role of H₂ 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, CO₂ sequestration, and biomass energy.

Questions

- Where will H₂ come from? Are there adequate near term and long term resources for H₂ production?
- How Soon Could H₂ Make a Major Difference in Environmental and Energy Supply Problems?
- How much will it cost to implement H₂?

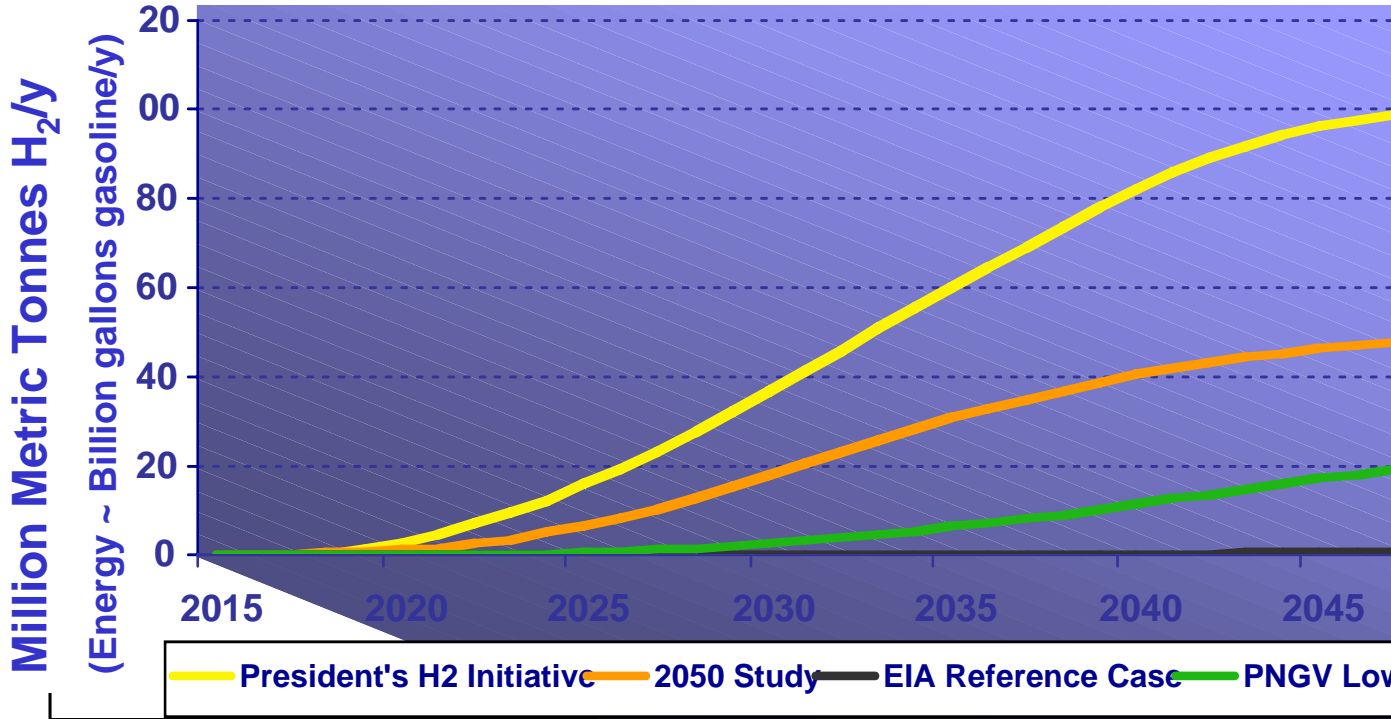
Where will the hydrogen come from?

- Natural gas is widely seen as a transitional source for H₂ 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 H₂ use levels <2025
- Long term: To realize the GHG benefits of H₂ technologies, change to H₂ supplies with near-zero GHG emissions. There are ample resources for zero emission H₂ production in the United States, and in many areas of the world.
- Many solutions for H₂ supply, depending on the level of demand, resource availability, geographic factors.

Primary Energy to Meet US H₂ Demand

Percent of current US resource use to provide H₂ for LDVs (assuming one resource for all H₂)

Hydrogen Demand in Four Scenarios



Percent of current US resource use to provide H₂ for LDVs (assuming one resource for all H₂)

| Resource | 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

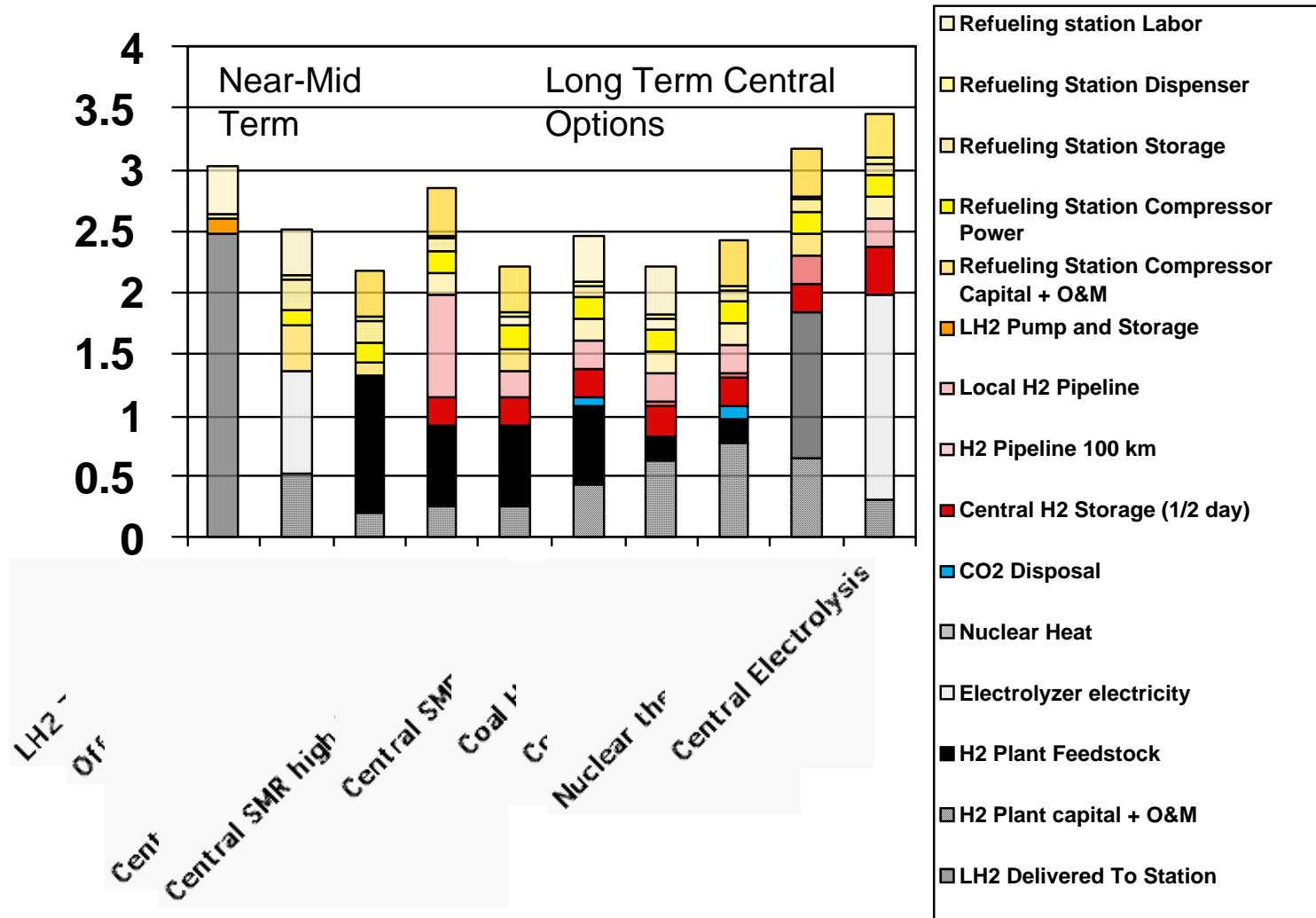
100 million H₂ Light duty vehicles with 2-3 X today's gasoline vehicle fuel economy would require 26-38 million tonnes H₂/y (3.1-4.6 EJ/y)

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.
- H₂ 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 potential for large impact of H₂ technologies on reducing emissions.
- Further, there is the potential that H₂ could transform how we produce and use energy (new types of vehicles, mobile electricity generation, energy storage, diversify primary supplies).

Delivered Cost of H₂ (\$/kg H₂)

\$1/gallon gasoline ~ \$1/kg



Questions for Discussion

- Are major scientific breakthroughs needed for H₂ 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 H₂ and fuel cells.