NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Hydrogen Fueling Infrastructure – Status and Needs

International Hydrogen Fuel-Cell Technology and Vehicle Development Forum

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Outline

- Hydrogen and infrastructure in the US today
- Fueling infrastructure needed
- Fueling infrastructure costs
- Cost reduction opportunities
- Necessary scale of potential incentives

Hydrogen Use in the United States

- Hydrogen is used as a commodity for refining and chemical processing

Production & Delivery of Hydrogen

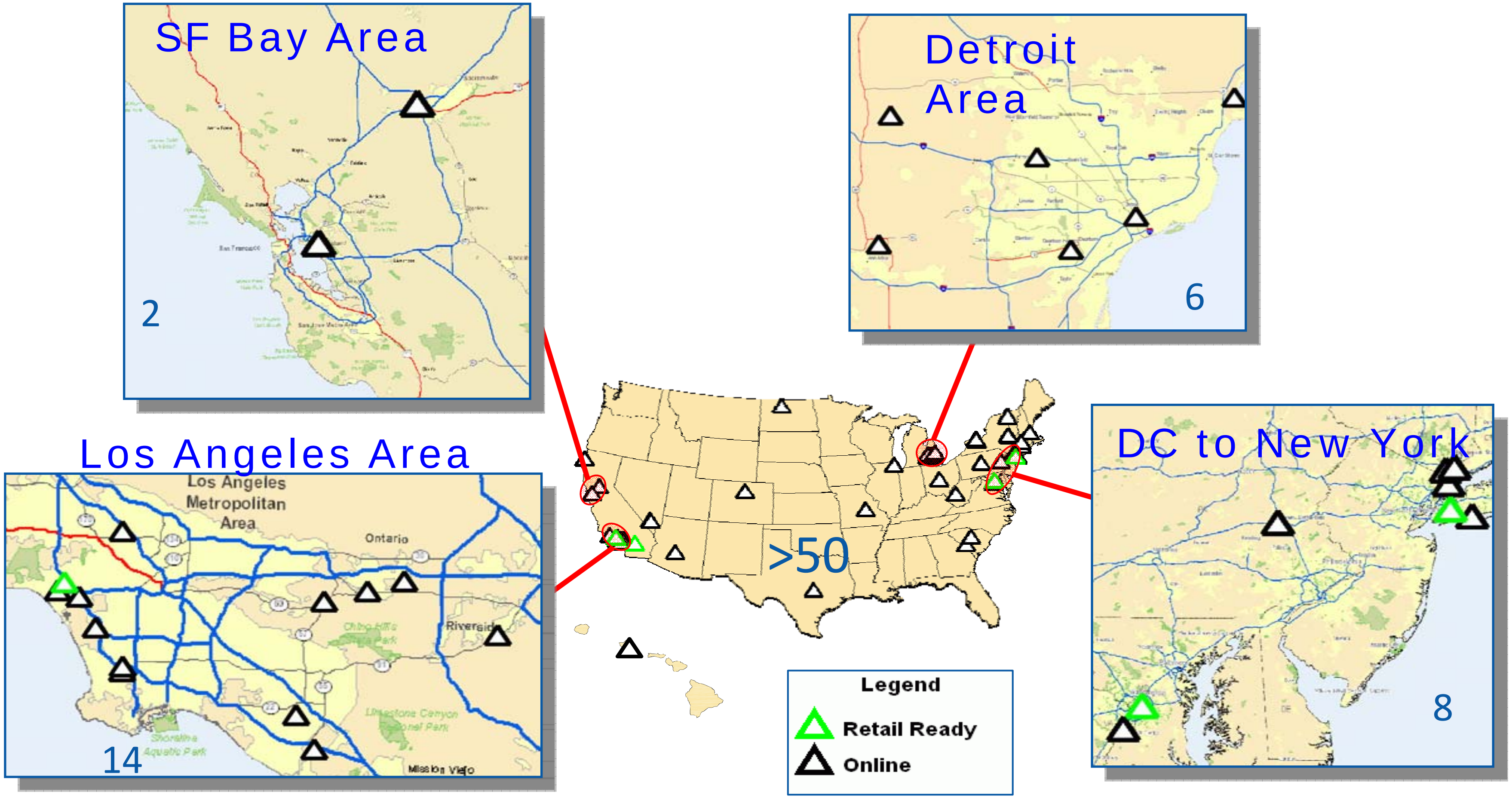
In the U.S., there are currently:

- *~9 million metric tons* ***of H_2 produced annually from natural gas***
- ***> 1,200 miles*** ***of H_2 pipelines (primarily in Texas, Louisiana, Illinois, & Indiana)***

- About 60 fueling stations supply more than 1,500 kg/day hydrogen to >200 fuel cell vehicles and >20 fuel cell buses
- Hydrogen cost at the stations
  - Liquid: $5.70-$8.00/kg at 100 kg/day
  - Gas: $17-$18/kg at 10-20 kg/day

Existing Stations in the US

- Most of the >50 stations are not retail-ready
- Some of the stations produce hydrogen via reforming or electrolysis but many distribute hydrogen generated in central facilities



US Department of Energy Demonstration Projects

Demonstrations are essential for validating the performance of technologies in integrated systems, under real-world conditions.

DOE Vehicle/Infrastructure Demonstration

Four teams in 50/50 cost-shared projects with DOE




- **144 fuel cell vehicles and 23 fueling stations demonstrated**
- **>2.5 million miles traveled, >150,000 kg H_2 produced or dispensed***
- **Analysis by NREL shows:**
  - **Efficiency:** 53 – 59% **(>2x higher than gasoline engines)**
  - **Range:** ~196 – 254 miles
  - **Fuel Cell System Durability:** ~ 2,500 hrs **(~75,000 miles)**

**includes hydrogen not used in the Program's demonstration vehicles*

Demonstrations of Specialty Vehicles: *NREL is collecting operating data from federal deployments and Recovery Act projects—to be aggregated, analyzed, and reported industry-wide.*

→ **Will include data such as:** reliability & availability; time between refueling; operation hours & durability; efficiency; H_2 production; refueling rate; costs (installation, operation, and lifecycle); and others.

→ 40 forklifts at a Defense Logistics Agency site have already completed more than 10,000 refuelings.

Other Demonstrations: *DOE is also evaluating real-world bus fleet data (DOD and DOT collaboration) and demonstrating stationary fuel cells — e.g., tri-generation (combined heat, hydrogen & power with biogas).*

Infrastructure Needs

A proposed buildout scenario for Los Angeles:

Years	Number of stations	Number of clusters served	Average travel time	Diversion time
2009-2011	8-16	4	3.9 min	5.6 min
2012-2014	16-30	6	2.9 min	4.5 min
2015-2017	36-42	12	2.6 min	3.6 min

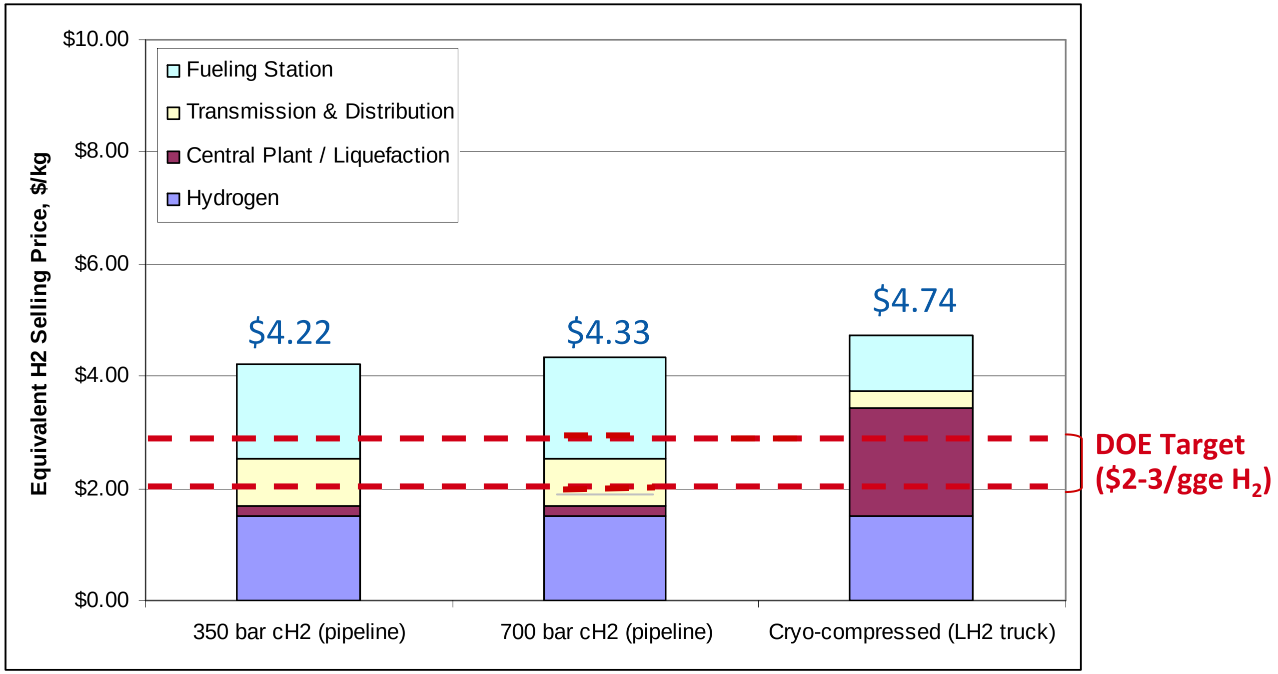
Allowing for reasonable travel times (providing stations are in market clusters) requires stations with small capacity that do not have economies-of-scale

Years	Number of H2 vehicles	Average H2 use rate	Station capacity
2009-2011	636	445 kg/day	27-55 kg/day
2012-2014	3442	2410 kg/day	75-150 kg/day
2015-2017	25,000	17,500 kg/day	410-500 kg/day

Source: Nicholas 2010

Potential Cost of Fueling Stations

- Fueling stations and infrastructure are a large portion of the levelized cost of hydrogen for mature market / technology status



Source: TIAX

Note: These results should be considered in context of their overall performance and on-board costs.

Assumptions

- Assumes economies of scale have been reached for station construction.
- Station size is 1,000 kg/d.
- Produced H2 cost is $1.50/kg (without delivery).
- Market penetration is 30%.

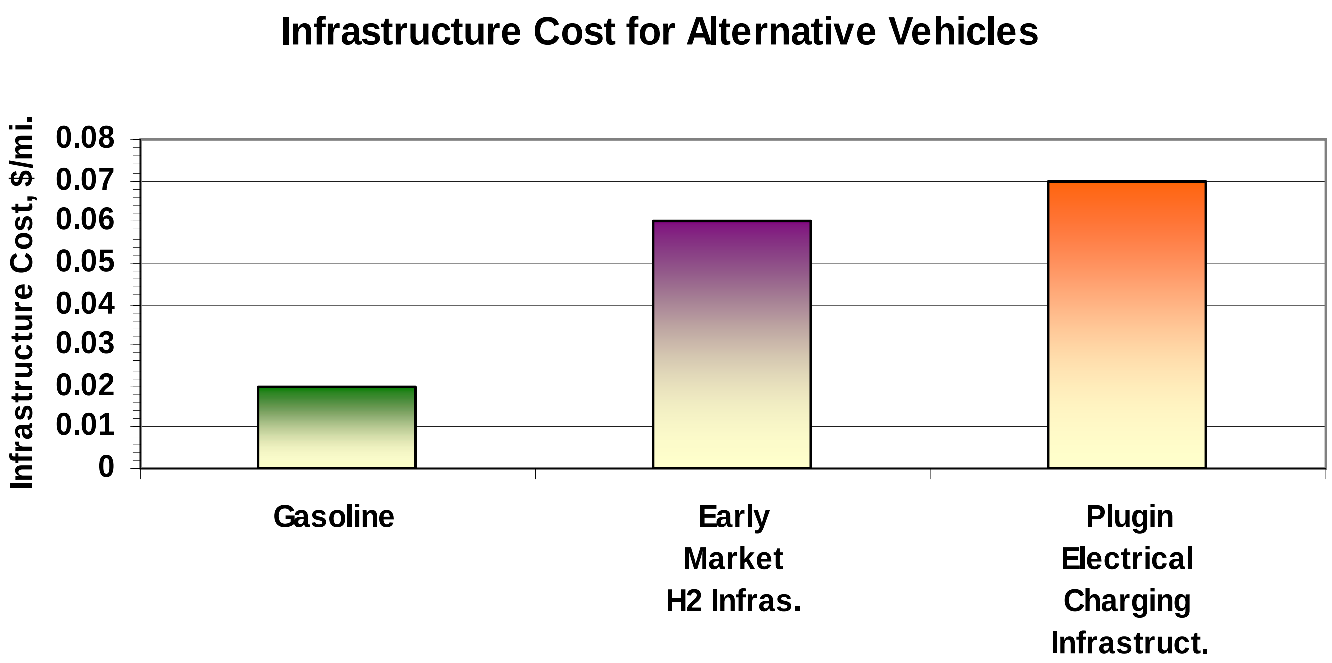
300 and 700 bar Compressed Gas

- Distribution mode is compressed gas pipeline.
- Dispensing temperature is ambient for 350 bar and (-40*C) for 700 bar.
- Hydrogen losses are <1%.

Cryo-compressed

- Distribution mode is via liquid tank truck.
- Tank truck capacity is 4,100 kg.
- Dispensing temperature is (-253*C).
- Hydrogen losses are ~7.5%.
- On-board storage pressure is 270 bar.

Early Market Infrastructure Costs are Prohibitive



Assumptions and Supporting Comments:

- Gasoline infrastructure cost based on Shell information of $0.40/gal for station. ICE vehicle fuel economy of 23 mi/gal used to obtain $/mi.
- Hydrogen infrastructure cost based on station cost of ~$2 million for early market 100 kg/d Hydrogen station from California state funded projects (see slide 9). Early market stations assumed to have delivered hydrogen. FCEV fuel economy of 60 mi/gge used to obtain $/mi.
- Electrical infrastructure costs of $1,000 - $2,000/kW for plugs for PHEVs were used for the analysis based on information from the NAS PHEV study and information from VTP.
- The chargers for PHEVS were assumed to last 10 years. The life of a hydrogen station is assumed to be 15 years.

Infrastructure Workshop

An infrastructure workshop was jointly organized by IPHE, CAFCP, NREL and DOE - to explore market implementation needs for H_2 infrastructure development in the near-term and to develop creative and practical solutions.

Objectives – to determine:

Business cases and technology approaches for refueling station development.

The number and size of stations needed by 2018-2020.

Business factors that will motivate, hinder, or prevent investments in H_2 stations.

Possible financing scenarios.

Policies, regulations, or other actions needed for a sustainable business case for H_2 stations.

Opportunities for international programs to leverage their efforts, including potential areas for further research and development.

KEY OUTCOMES

- Develop low-cost, 100 kg/day ***starter station*** model.
- ***Policies:*** including tax incentives, subsidies, gas/carbon tax, low-cost financing, and regulations.
- ***Information and education campaigns:*** for legislators and public.
- ***Risk Reducing Strategies:*** PPPs, insurance pool, cost-share, OEM commitments.
- ***Innovative ways to boost H_2 demand:*** target fleets and other FC applications, leverage natural gas industry, increase competition.
- ***Novel Business Models:*** seek new methods of financing, leverage existing H_2 industry.

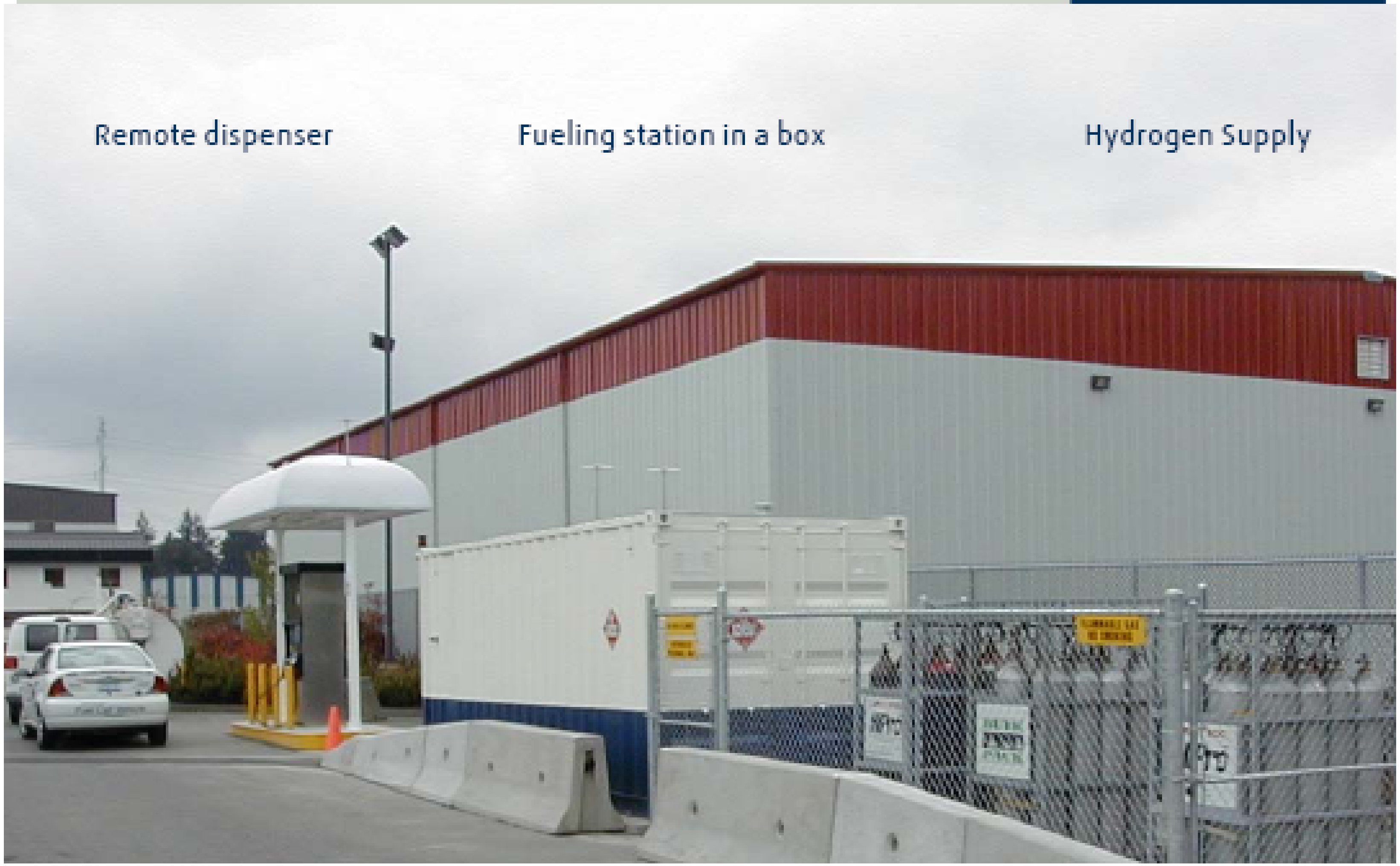
Fuel Retailers' Business Environment

- Traditional fuel retailers have lost market share to non-traditional fuel retailers (e.g.," big box stores"), who often sell fuel below-cost to attract customers.
- Fuel retailers tend make profits from their convenience stores, rather than fuel sales.
- Station owners must achieve 3-5 year ROI to justify investment.
- Consumer demand and price of gasoline are most important factors in determining investment in alternative fuels. Government mandates and regulations affect investment in alternative fuels, but PR value of "going green" has little impact.

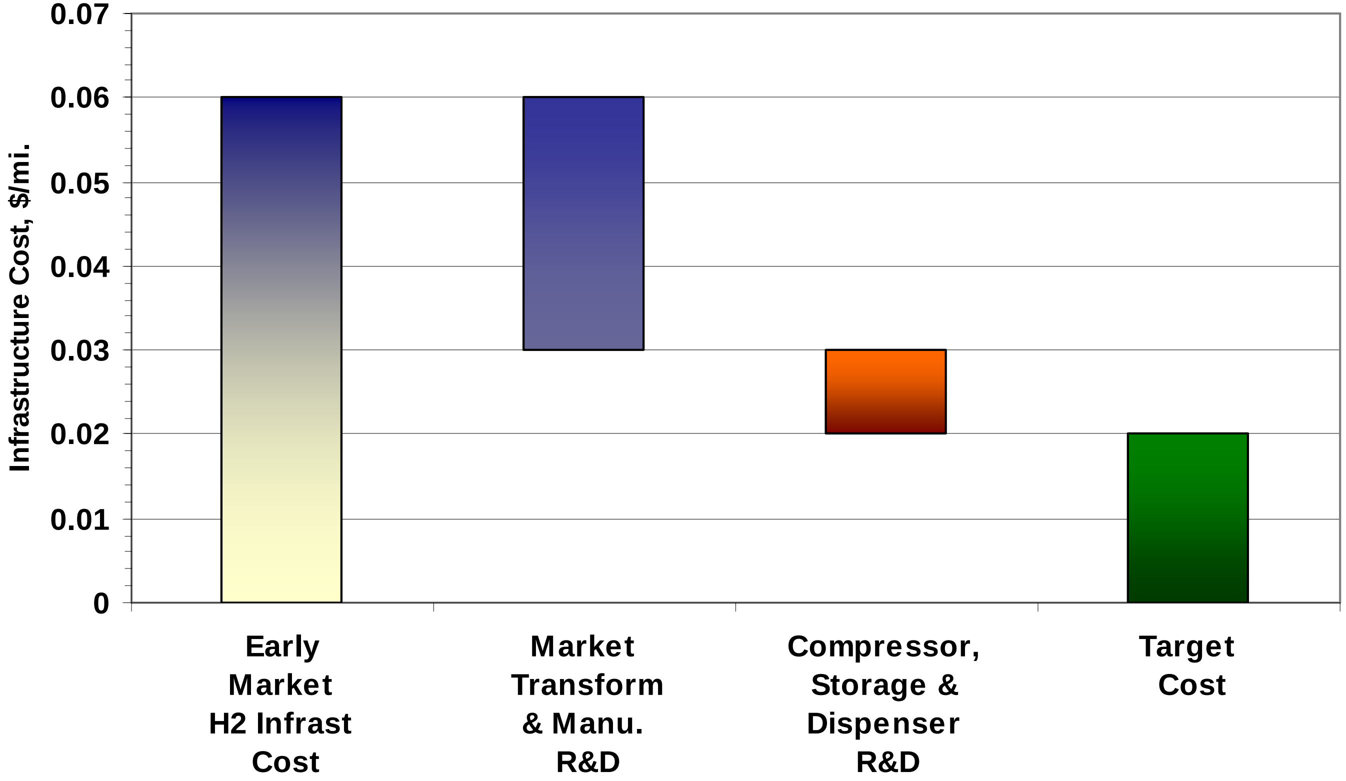
Starter Station Concept

Fueling Station in a Box (2006)
20 kg/day @ 350 bar
(BOC/Linde and PowerTech - Victoria , Vancouver BC)

THE LINDE GROUP



Reducing Infrastructure Cost Requires Improved Technology and Manufacturing



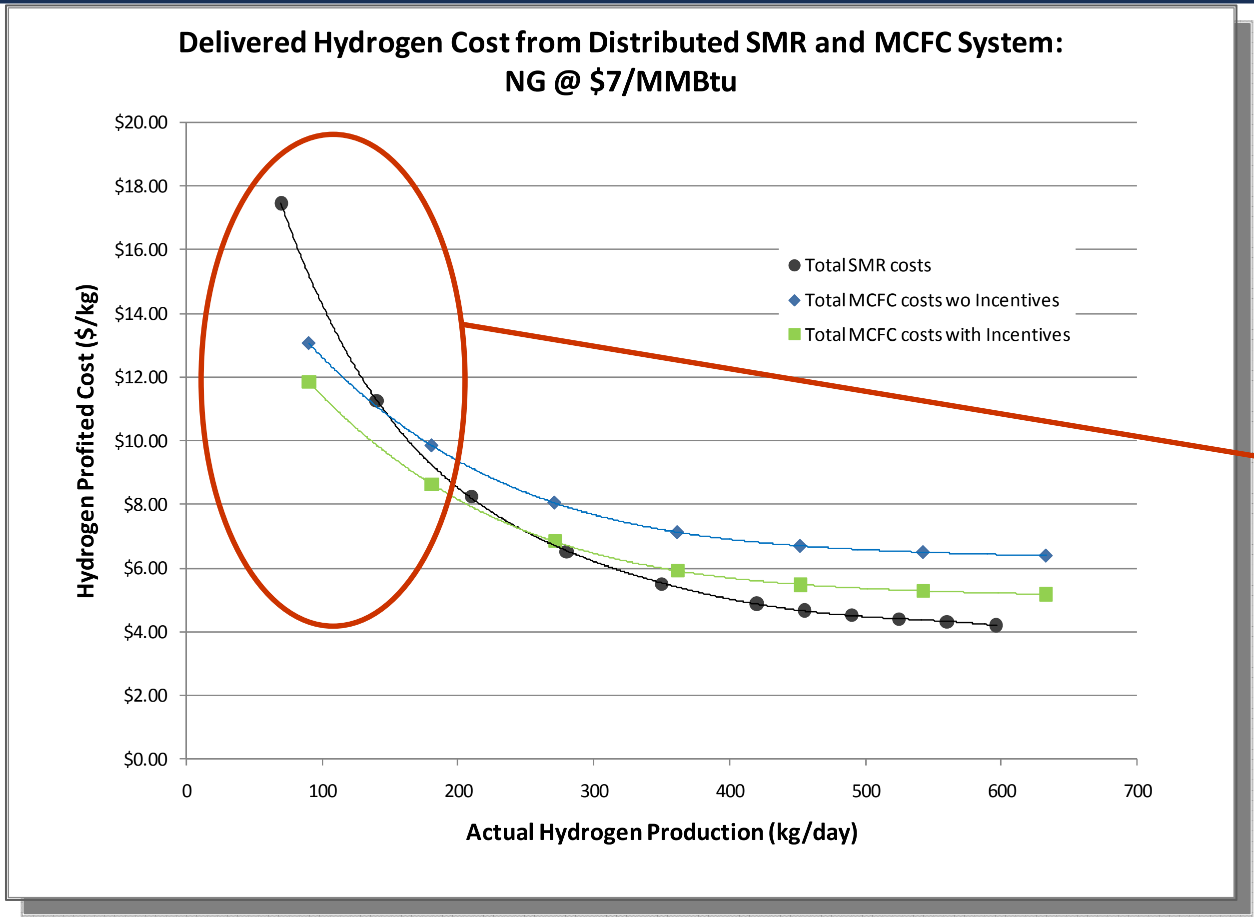
Notes and Assumptions:

- Early Market and Manufacturing R&D could reduce infrastructure cost by ~50% based on information from Shell (May 2010). Shell indicated building stations of same design could reduce station cost by 50% based on information from the EU H2 Mobility project.
- Tech Validation could initiate station buildout by funding demonstration stations with the planned California ZEV rollout.
- Continued R&D in storage, dispensing and compression for the station will enable infrastructure costs to be reduced.
- Target infrastructure cost of $0.02/mi. is based on the current gasoline infrastructure cost of $0.40/gal..
- Hydrogen infrastructure cost based on station cost of ~$2 million for early market 100 kg/d Hydrogen station from California state funded projects.

Early market stations assumed to have delivered hydrogen. FCV fuel economy of 60 mi/gal used to obtain $/mi.

CHHP may reduce Hydrogen Cost at Smaller Scales

Hydrogen production costs for a stand-alone steam methane reforming (SMR) station and high-temperature combined heat, hydrogen, & power (CHHP) application were compared. Even though costs are dependent on natural gas costs, CHHP applications may be more cost-effective at lower production capacities.

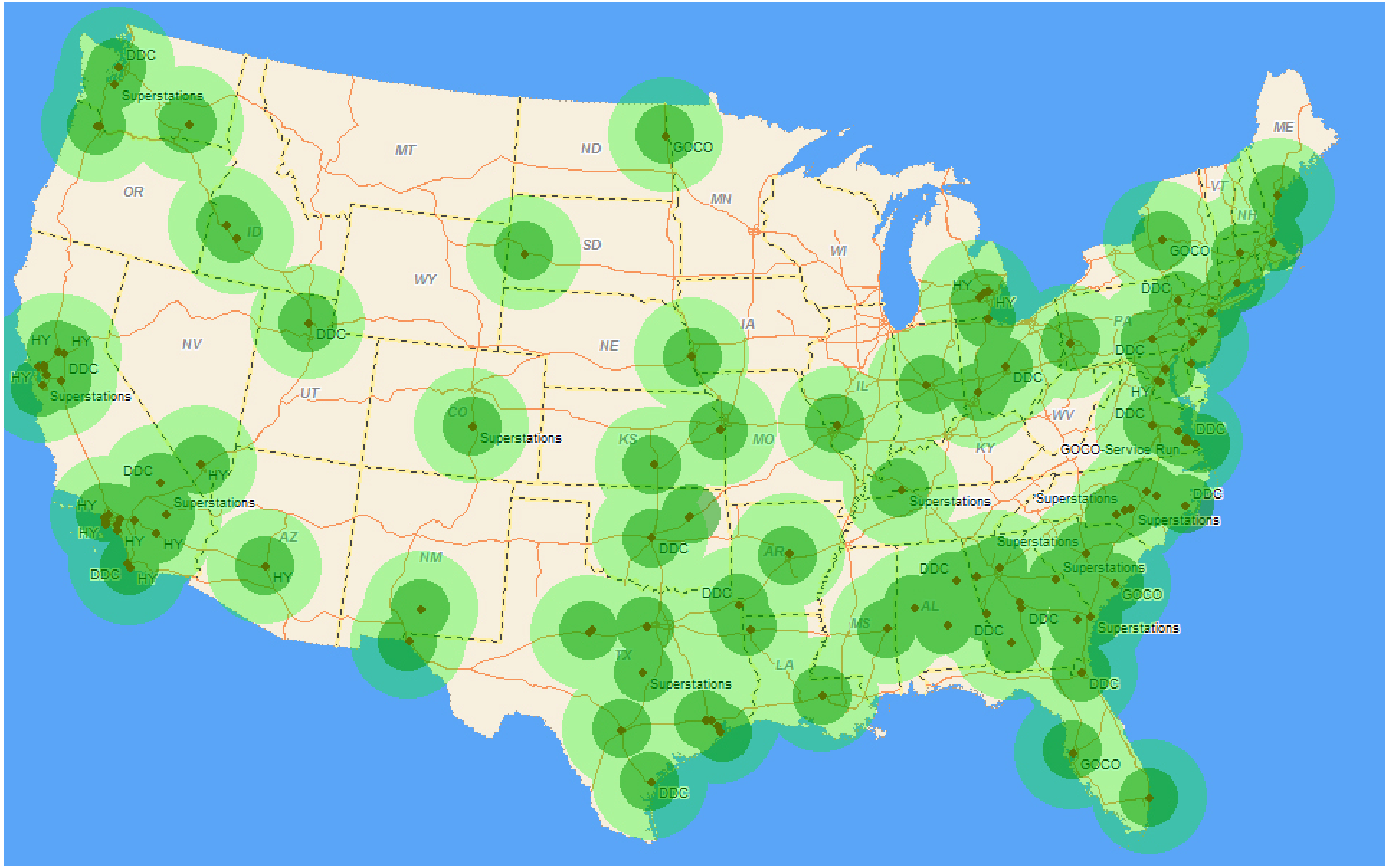


In cases where there is a low demand for hydrogen in early years of fuel cell vehicle deployment, CHHP may have cost advantages over on-site SMR production.

Source: Fuel Cell Power Model

Use of Government Sites to Provide Range

If Defense Logistic Agency major footprints became hydrogen supply sites, a hydrogen infrastructure covering a significant portion of the nation could be developed.



Estimates of Necessary Incentives

Government Subsidies for Infrastructure

NHA Study:

- $3 billion - $7 billion from 2012 to early 2020s (after accounting for revenues from selling hydrogen).

NAS Analysis:

- $10 billion between 2008 and 2023 (hydrogen revenues to fueling station operator not taken into account).

ORNL Analysis:

- $1.5 - $27 billion for the hydrogen infrastructure and $6.5 to $21 billion cumulative between 2012 and 2025 for fuel cell vehicle buy-down incentives, with the largest annual incentive being between $1 billion and $6 billion per year.

Government Subsidies for FCEVs

NAS Analysis:

- $40 billion (cover increased FCV costs over baseline gasoline ICEVs).

ORNL Analysis:

- Government to cost share 50% (Gasoline HEV cost – FCEV cost), OR
- 100% percent tax credit on (Gasoline HEV cost – FCEV cost)
- Cumulative government cost $6.5 billion - $21 billion between 2012 and 2025.

Conclusions

- Large quantities of hydrogen are produced in the US today but there is little infrastructure for vehicle fueling.
- Currently, infrastructure is expensive and cost reductions are necessary
- Multiple opportunities are available to reduce costs including “starter stations;” combined heat, hydrogen, and power; and, use of government sites
- Other opportunities to provide range need to be explored
- Incentives are likely to be necessary