

#### SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS

An Institute of Transportation Studies Program

## H2 FCV Rollout Strategies: Technical/economic analysis

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# Two NRC 2013 scenarios: consumer focus show major role in US for PEV and FCVs

**PEV Success** 

#### **FCEV Success**



#### NRC 2013 Transition Long Term Benefits Outweigh Costs

# Subsidies \$40B, 2015-2030 but longer term societal benefits are far greater



FIGURE 5.24 Present value cost and benefits of a transition to hydrogen fuel cell vehicles using midrange technology assumptions, fuel cell vehicle subsidies and additional incentives, and a low-GHG infrastructure for the production of hydrogen.

## CALIFORNIA CASE STUDY: from Initial Rollout to "Green" H2 c. 2050 INTRODUCING H2 FCVS IN LA BASIN

- How many stations are needed? Where should they be located?
- Use projected FCV numbers based on California Fuel Cell Partnership surveys (34,000 FCVs in LA area c. 2017)
- Vehicles and stations placed together in 4 to 12 "clusters" identified by stakeholders as early market sites.
- Some connector stations are added to facilitate travel throughout the Los Angeles (LA) Basin.

Joan Ogden and Michael Nicholas, "Analysis of a "Cluster" Strategy for Introducing Hydrogen Vehicles in Southern California", *Energy Policy*, 39 (2011) 1923–1938.

### 16 Station Example Add 8 Connector Stations => lower diversion time



### Example Build-out Case: CLUSTER STRATEGY => FUELING CONVENIENCE W/ SPARSE EARLY NETWORK (~1-2% GASOLINE STATIONS)



	636 FCVs	3442 FCVs	25,000 FCVs
# Stations	8	20	42
# clusters	4 (2 sta/cluster)	6 (3 sta/cluster)	12 (3 sta/cluster)
# connect.sta	0	2	6
Ave travel time	3.9 minutes	2.9 minutes	2.6 minutes
Diversion time	5.6 minutes	4.5 minutes	3.6 minutes

## Infrastructure Economic Analysis

- Consider different infrastructure build-out scenarios in LA area over next decade (#FCVs, #stations, sta. size & type)
- Estimate station capital and operating costs
- Analyze economics from several perspectives
  - Network
  - Single station owner
- Find Cash flow and Break-even year (when can the station produce H2 competitively?)
- Estimate subsidies that might be needed to support early infrastructure

## Network Scenario vs. year (78 sta., 34K FCVs)

#New Sta	2011	2012	2013	2014	2015	2016	2017
Mobile							
Refueler	4	0	0	0	0	0	0
Compressed Gas Truck Delivery							
170 kg/d	0	0	4	0	0	0	0
250 kg/d	0	0	0	10	0	0	0
500 kg/d	0	0	0	0	20	20	20
Total sta.							
capacity							
(kg/y)	400	400	1080	3580	11580	21580	31580
# FCVs in							
fleet	197	240	347	1161	12106	23213	34320
H2							
demand							
(kg/d)	137	168	250	800	8500	16000	24000

#### NETWORK Cash Flow: Delivered compressed H2 @\$6/kg, H2 sell price \$10/kg. 78 Sta. in 2017 Network Capital invest.=\$113 million



#### CASH FLOW: SINGLE 500 KG/D STATION. Base Case. Support needed until cash flow >0, ~\$400-700K



#### REGIONAL (So.Cal.) H2 INFRASTRUCTURE INVESTMENT (\$M/Y) & DELIVERED H2 COST \$/KG): (Ogden, Nicholas, 2013)



## **Early Rollout Economic Results**

- Early strategy using gas truck delivery yields H2 costs of <\$10/kg. Levelized H2 cost decreases at larger sta.size.</li>
   Cap. investment for 58-78 sta. serving ~34,000 cars is \$113-160 million (\$3000-5000/car).
- If (H2 selling price) (truck delivered H2 cost) 
   \$4/kg, the network breaks even in <8 years.</p>
- 500 kg/d station costing \$1.5 million has cash flow>0 within a few years (assuming rapid demand ramp-up). Support to compensate for early negative cash flow ~\$400-700K
- Subsidy: Capital+O&M for 18 small stations (100-250 kg/d)
   & support for 60 500 kg/d stations until cash flow>0 costs
   \$50-\$70 million
- Longer term, introduce onsite stations and lower C pathways. Costs for H2 fall to \$5-8/kg.
- Good Economics depend on rapid growth of FCV market

#### Transition To Green H2 (80% Carbon cut by 2050): Capital investment\* for H2 Infrastructure in CA



Yang and Ogden. Renewable and Low Carbon Hydrogen for California – Modeling The Long Term Evolution of Fuel Infrastructure Using a Quasi-Spatial TIMES Model. *International Journal of Hydrogen Energy*. 38 (11) p 4250-4265. 2013.



#### H2 INFRASTRUCTURE COST PERSPECTIVE California

Bringing H2 to cost competitiveness w/gasoline might take 5-7 yr, and \$50-100 million support early stations, assuming rapid FCV adoption.

Once large stations (>400 kg/d) are built and # of cars reaches 10,000s and , H2 could compete w/gasoline (cent/mile);

Business case for station owners 2017+.

Long term green H2 supply could be developed at an investment cost of ~\$2000/car, H2 cost of \$4-6/kg.

#### US

To fully support H2 FCV transition (buy down cost of vehicles and build infrastructure) cost \$10s Billion spent over 10-15 years (only 20% of this would be for infra, 80% for vehicles).

This is much less than the \$1 Trillion cost projected for oil & gas infrastructure in N. America 2007-> 2030.



## UC DAVIS H2/FCV RESEARCH TEAM

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## UC Davis Recent H<sub>2</sub> Publications

- A. Xuping Li, Joan Ogden, and Christopher Yang, "Analysis of the Design and Economics of Molten Carbonate Fuel Cell Tri-generation Systems Providing Heat and Power for Commercial Buildings and H2 for FC Vehicles," Journal of Power Sources (2013), pp. 668-679. DOI information: 10.1016/j.jpowsour.2013.04.068
- B. Tyson Eckerle, Remy Garderet, Ken Gunn ,Catherine Dunwoody, Jackie Birdsall, Bill Elrick, Joan Ogden, Tim Brown, "Incentivizing Hydrogen Infrastructure Investment, Phase 1: An Analysis of Cash Flow Support To Incentivize Early Stage Hydrogen Station Investment," Report to the California Fuel Cell Partnership, June 18, 2012.
- C. Christopher Yang and Joan Ogden, "Renewable and Low Carbon Hydrogen for California Modeling The Long Term Evolution of Fuel Infrastructure Using a Quasi-Spatial TIMES Model," International Journal of Hydrogen Energy, volume 38, issue 11, year 2013, pp. 4250 4265
- D. Xuping Li and Joan Ogden, Understanding the Design and Economics of Distributed Tri-generation Systems for Home and Neighborhood Refueling, Part II: Neighborhood Refueling Case Studies, Journal of Power Sources 197 (2012) 186–195
- E. Joan Ogden and Michael Nicholas, "Analysis of a "Cluster" Strategy for Introducing Hydrogen Vehicles in Southern California", *Energy Policy*, 39 (2011) 1923–1938.
- F. Y.L. Sun, M.A. Delucchi and J.M. Ogden, "The Impact of Widespread Deployment of Fuel Cell Vehicles on Platinum Demand and Price," International Journal of Hydrogen Energy, <u>Volume 36, Issue 17</u>, August 2011, Pages 11116-11127.
- G. Y.L. Sun, M.A. Delucchi and J.M. Ogden, "Societal Life-Cycle Buydown Cost of Hydrogen Fuel Cell Vehicles," Transportation Research Record, Journal of the Transportation Research Board, No. 2191, "Energy and Global Climate Change 2010, Transportation Research Board of the National Academies, Washington, DC, 2010, pp. 34-42. <u>http://trb.metapress.com/content/28x4nn471g20j680/</u>

## Transition Study: Use 2010 CAFCP estimates for FCVs in fleet in Southern California

YEAR	<b>#FCVs in fleet</b>
2011	197
2012	240
2013	347
2014	1161
2015-2017	34,320

## **Station Capital Cost Assumptions**

Station costs based on interviews with energy and industrial gas company experts reflecting current and future costs.

- Onsite Reformer 100-1000 kg/d
- Onsite electrolyzer 100-1000 kg/d
- LH2 truck delivery 100-1000 kg/d

Compressed gas truck delivery 100-500 kg/d

For onsite future stations, assume \$0.5-2 million for site prep, permitting, engineering, utility installation, for green-field site before any fuel equipment goes in. H2 equipment costs are added to this.

For 2012-2014, equipment costs = 2 X H2A "current tech"

For 2015-2017, equipment costs = H2A "current tech"

IGC Estimates for low-cost gas truck delivery options

## Compressed gas truck delivery H2 Station Cost Assumptions: 700 bar dispensing.

Time frame	Capital Cost	Annual O&M cost \$/yr		
<u>Phase I (&lt;2013)</u>		\$100 K (fixed O&M) +		
100 kg/d -> 170 kg/d	\$1 million	1 kWh/kgH2 x kg H2/yr x \$/kWh		
250 kg/d (has more	\$1.5 million	(compression elec cost)		
ground storage)	<b>+</b>	+ H2 price \$/kg x kg H2/y		
0		(H2 cost delivered by truck)		
<u>Phase 2 (2014)</u>				
100 -> 170 kg/d	\$0.9 million	Same as above		
250 kg/d	\$1.4 million			
<u>Phase 3 (2015+)</u>				
100 -> 170 kg/d	\$0.5 million	Same as above		
250 kg/d	\$0.9 million			
400 -> 500 kg/d	\$1.5-2 million			