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SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS

An Institute of Transportation Studies Program

NextSTEPS White Paper: The Hydrogen Transition

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NextSTEPS Webinar
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Talk Outline: H2 White Paper Highlights

- **Intro: A Comeback for H2? What are drivers?**
- **Tech status for FCVs and H2 supply**
- **Near and long term transition issues**
  - Managing Risk in Early FCV Rollout
  - Getting to “Green H2”
  - H2 Transition Costs in Perspective
- **Current status of the Global Hydrogen FCV Rollout**
  - FCV Commercialization
  - H2 Infrastructure
  - Rise of Public/Private Partnerships
- **Hydrogen Policy**
  - Public funding trends
  - Policy Review
- **Conclusions and Recommendations**

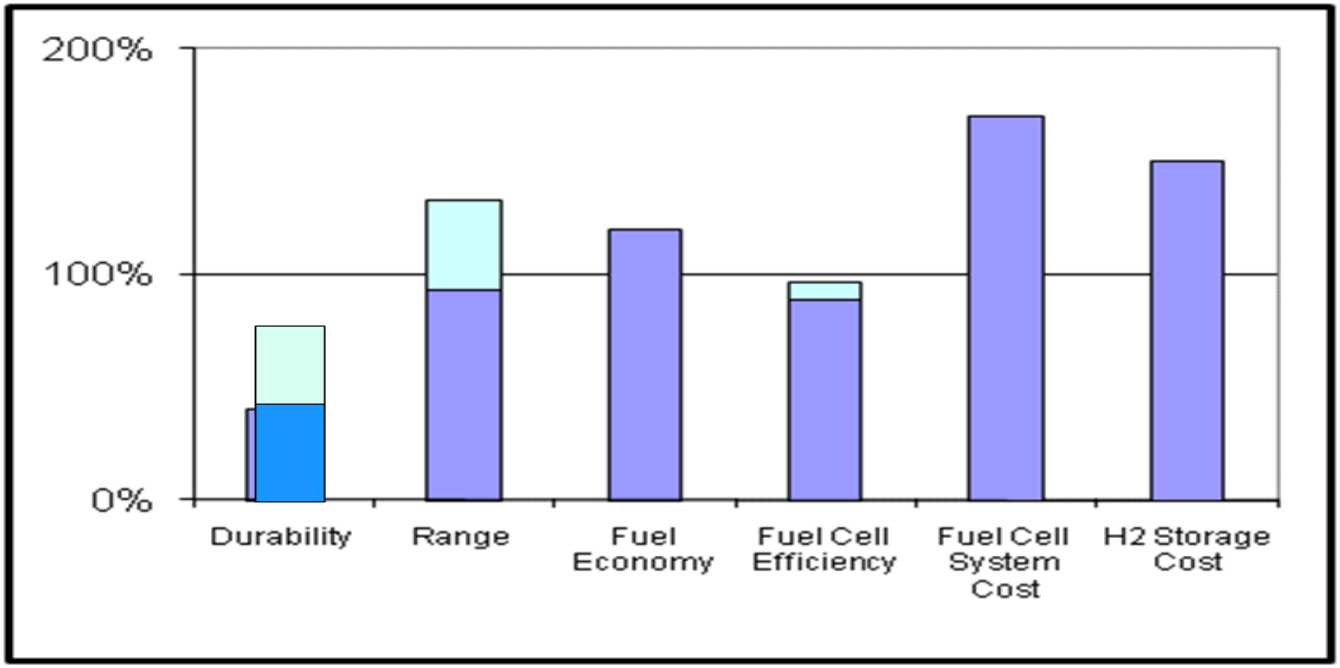
Comeback for Hydrogen?

- Enthusiasm for H2 FCVs in early 2000s. Lots of R&D, investment by stakeholders.
- By late 2000s it appeared that battery PEVs might be quicker route to zero emissions. H2 seen by some as too difficult, decades away, if ever.
- Early 2010s. New factors emerging, re-accelerating H2 FCV Rollout.
- Next 2-3 years will see concerted efforts to introduce 100s of H2 stations capable of supporting 10,000s of FCVs in selected regions worldwide, backed by $100s millions in public funds, $billions in private investment.
- If these efforts succeed, H2 FCVs might be just a few years behind PEVs in commercialization process, not decades.

New (& some Old) Factors Accelerating H2 FCV Rollout

- Automakers continued commitment to FCVs as zero emission vehicles "without compromise": good performance, larger size, fast refuel, 300+ mile range. (synergy w/ PEV technologies)
- H2 infrastructure planning more sophisticated, workable, network thinking. Plans w/ stakeholder buy-in. Automakers partner with energy suppliers.
- Rise of Regional and National public private partnerships
- Public Funding, policy support generally trending upwards (mixed in US).
- Good prospects for low cost, plentiful H2. Shale gas boom.
- Success of H2 FCs in stationary, CHP and forklift markets
- H2 FCV recognized as key tech for low-C energy future
- Interest in H2 as energy storage for intermittent renewable energy
- Transition costs appear manageable. Long term benefits >> costs
- At least 3 regions where expertise, stakeholders, funding are at the right scale for successful rollout.

Progress in FC Technologies

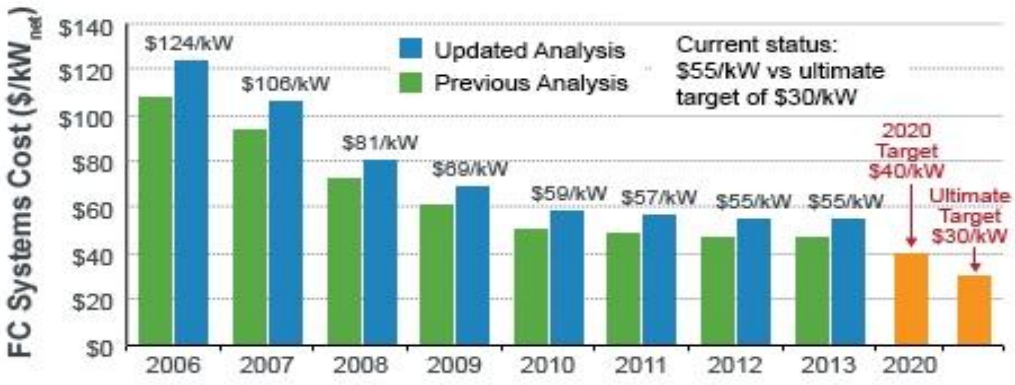


At 100% technology meets goal for FCV commercialization

Source: Ogden J.M. and L. Anderson, Sustainable Transportation Energy Pathways, Institute of Transportation Studies. University of California, Davis, Regents of the University of California, **August 2011.**

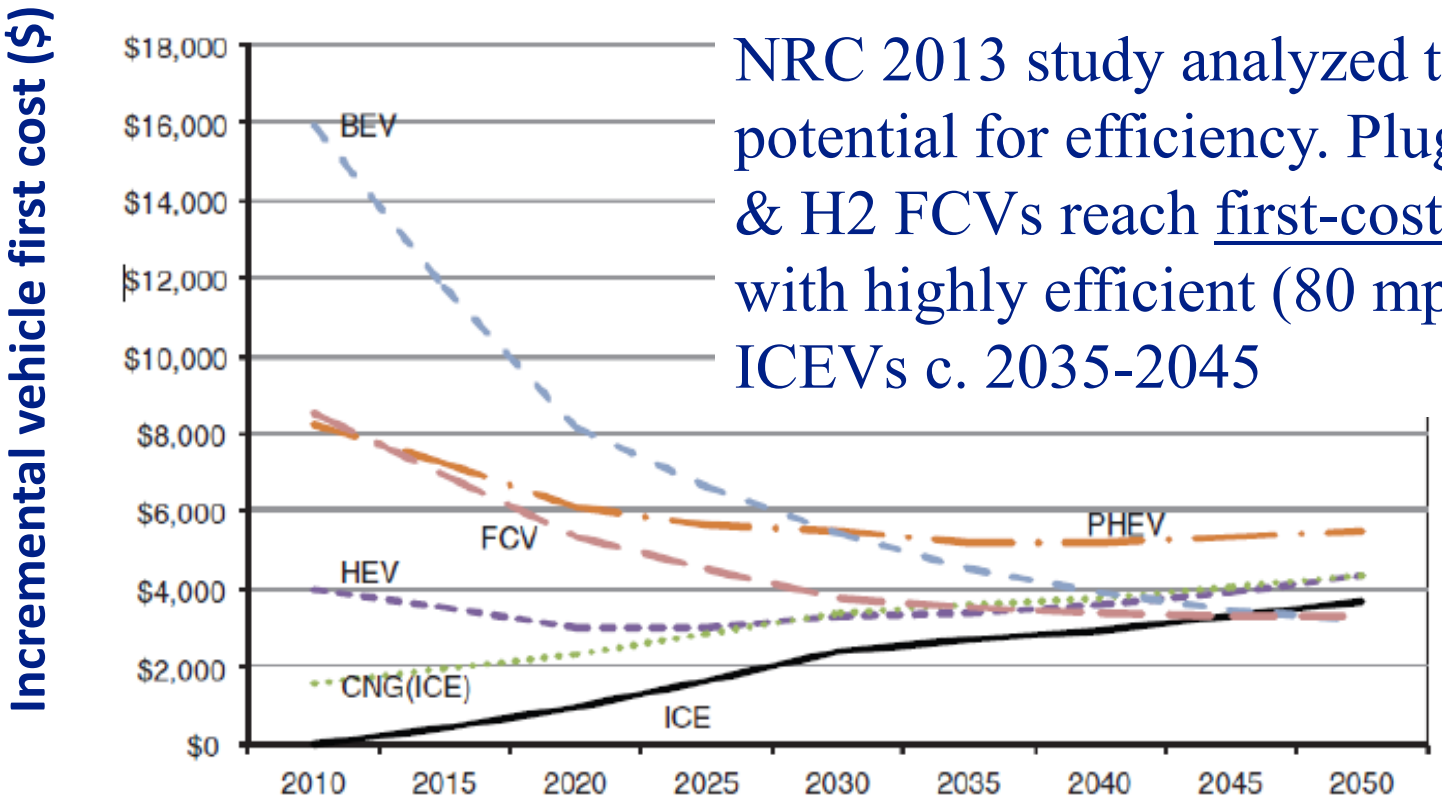
Projected Transportation Fuel Cell System Cost

-projected to high-volume (500,000 units per year)-



Source: US Department of Energy, http://energy.gov/eere/fuelcells/accomplishments-and-progress, 2014.

NRC: Scale Economies of Mass Production, Learning, R&D Bring Long-Term Cost of FCVs ~ Gasoline ICEV



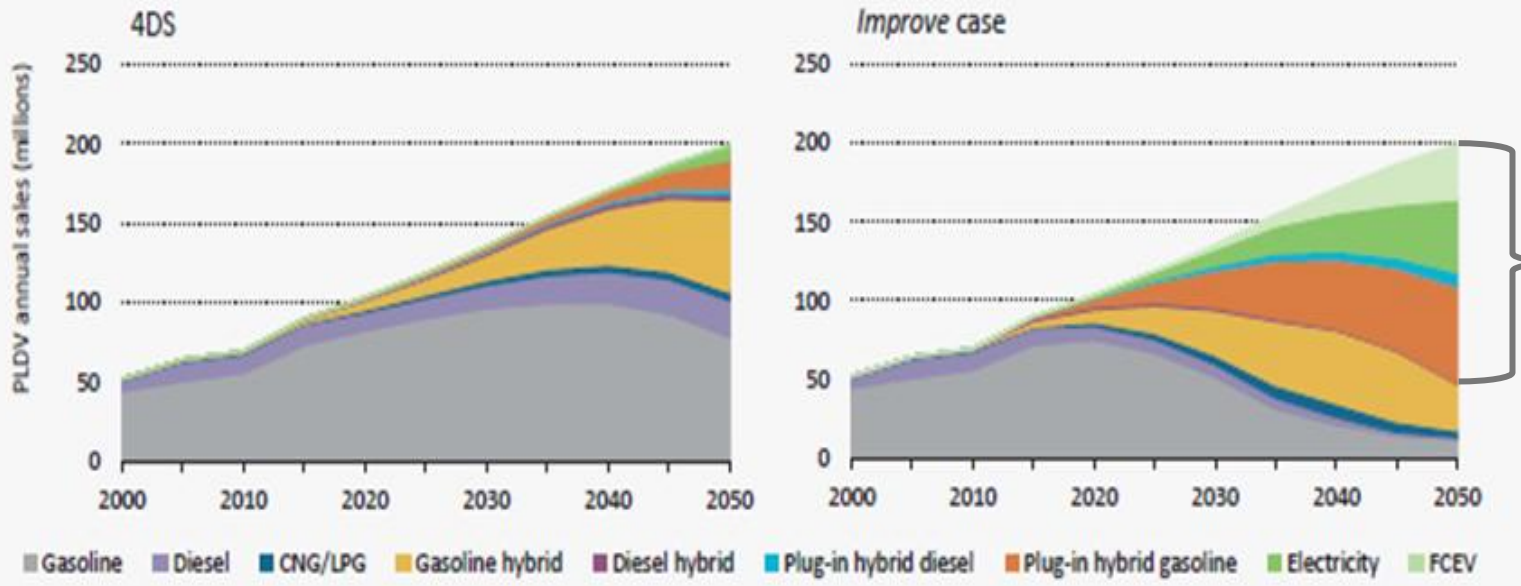
NRC 2013 study analyzed technical potential for efficiency. Plug-in EVs & H2 FCVs reach first-cost parity with highly efficient (80 mpg+) ICEVs c. 2035-2045

FIGURE 2.8 Car incremental cost versus 2010 baseline ($26,341 retail price)—Midrange case.

National Research Council. *Transitions to Alternative Vehicles and Fuels* . Washington, DC: The National Academies Press, 2013. http://www.nap.edu/catalog.php?record_id=18264

Studies => H2 Long Term Potential: Key Tech for 2 Degree Scenario

Figure 13.18 Global portfolio of technologies for passenger LDVs



FCV + PEV

Key point *In the Improve case, electric, PHEV and FCEVs together account for nearly three-quarters of new vehicle sales in 2050.*

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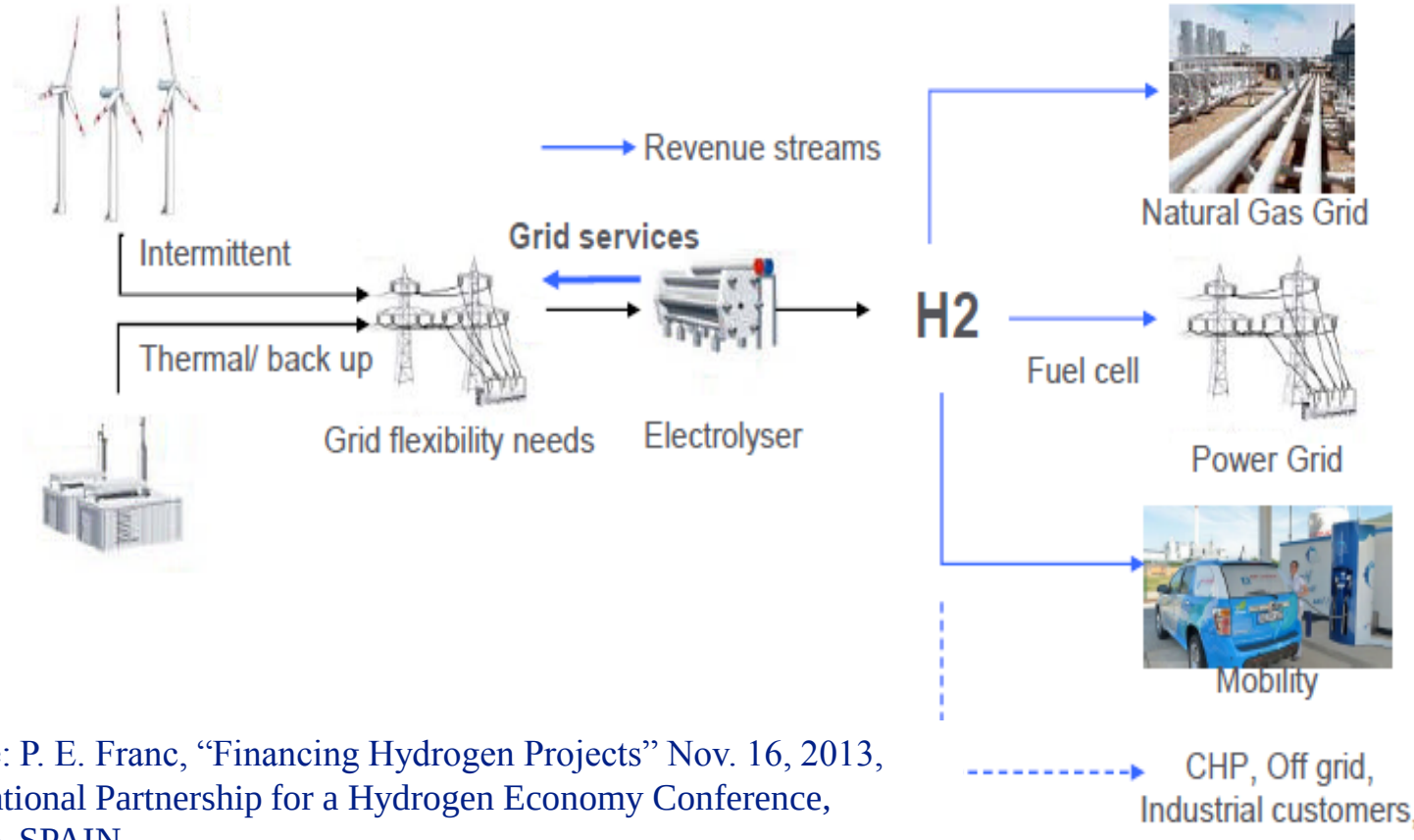
Source: International Energy Agency Energy Technology Perspectives 2012

Studies => H2 Long Term Potential: Flexible Storage for Renewables

Versatility of Hydrogen is a key advantage for energy storage



Source: P. E. Franc, "Financing Hydrogen Projects" Nov. 16, 2013, International Partnership for a Hydrogen Economy Conference, Seville, SPAIN

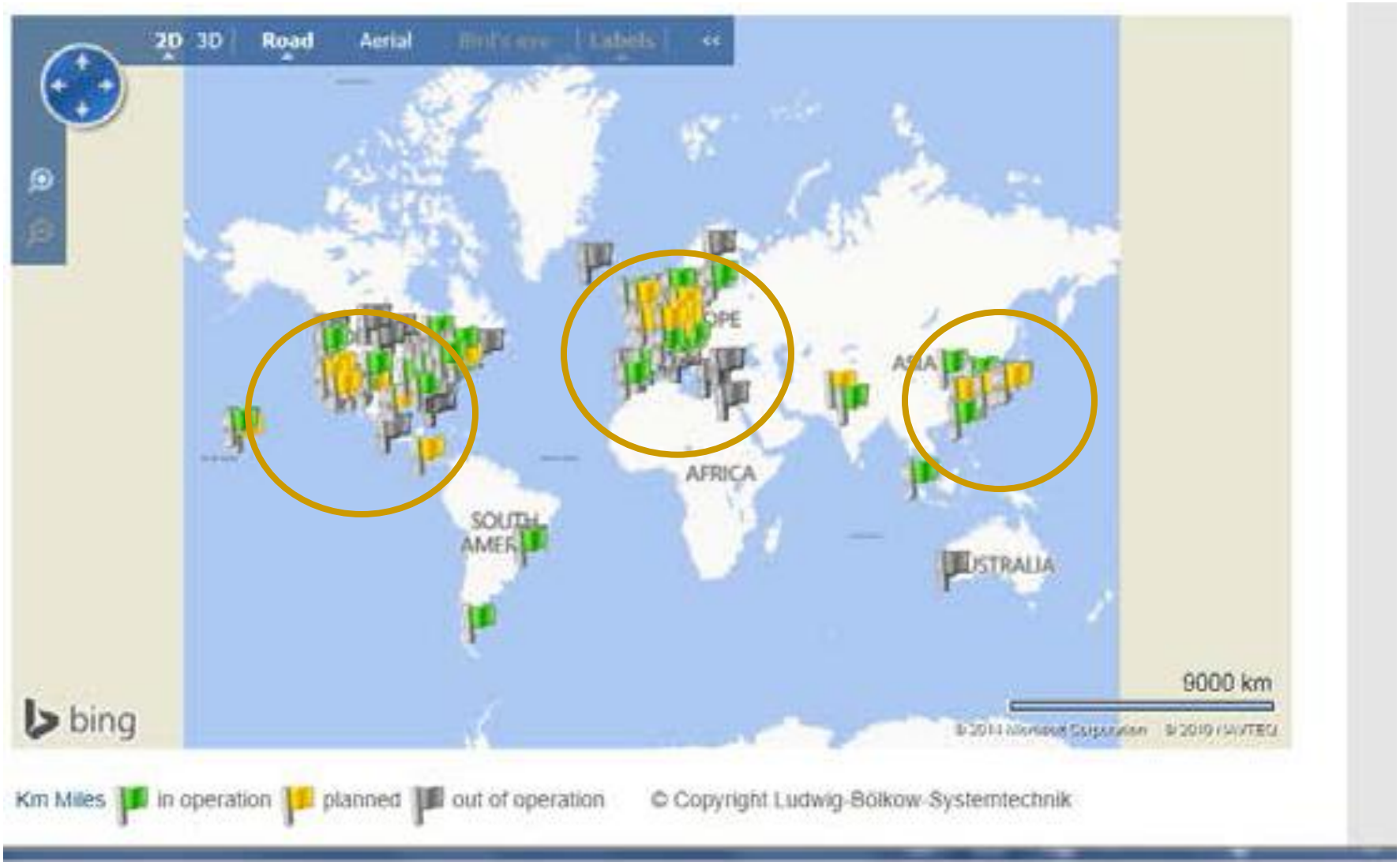
2013: Automakers Form Alliances to Develop FCVs

Announced	Partners	Source
Jan. 24, 2013	Toyota, BMW	http://www.autoweek.com/article/20130124/carnews/130129913
Jan. 28, 2013	Nissan, Daimler, Ford	http://www.inautonews.com/ford-nissan-and-daimler-form-partnership-to-develop-fuel-cells#.U2KbvvLn-ZQ
July 2, 2013	Honda, GM	http://www.fleetsandfuels.com/fuels/hydrogen/2013/07/gm-and-honda-team-on-fcvs/
March 7, 2013	Volkswagen, Ballard Power Systems	http://www.ballard.com/about-ballard/newsroom/news-releases/news03061302.aspx

FCV Market Intro. Dates Announced by Automakers

Company	Previous demos	Commercialisation dates			
		Before 2015	2015-2016	2017-2018	2019-2021
BMW	7 generations of H_2 ICE saloons				
Daimler	>100 B-Class vehicles				
Honda	>100 FCX clarity (C-Class FC car)				
Hyundai	Now deploying a fleet of ix35 SUV's				
Nissan	30 X-Trail SUV in US/Japan				
Toyota	~100 SUV vehicles US/Japan/Germany				

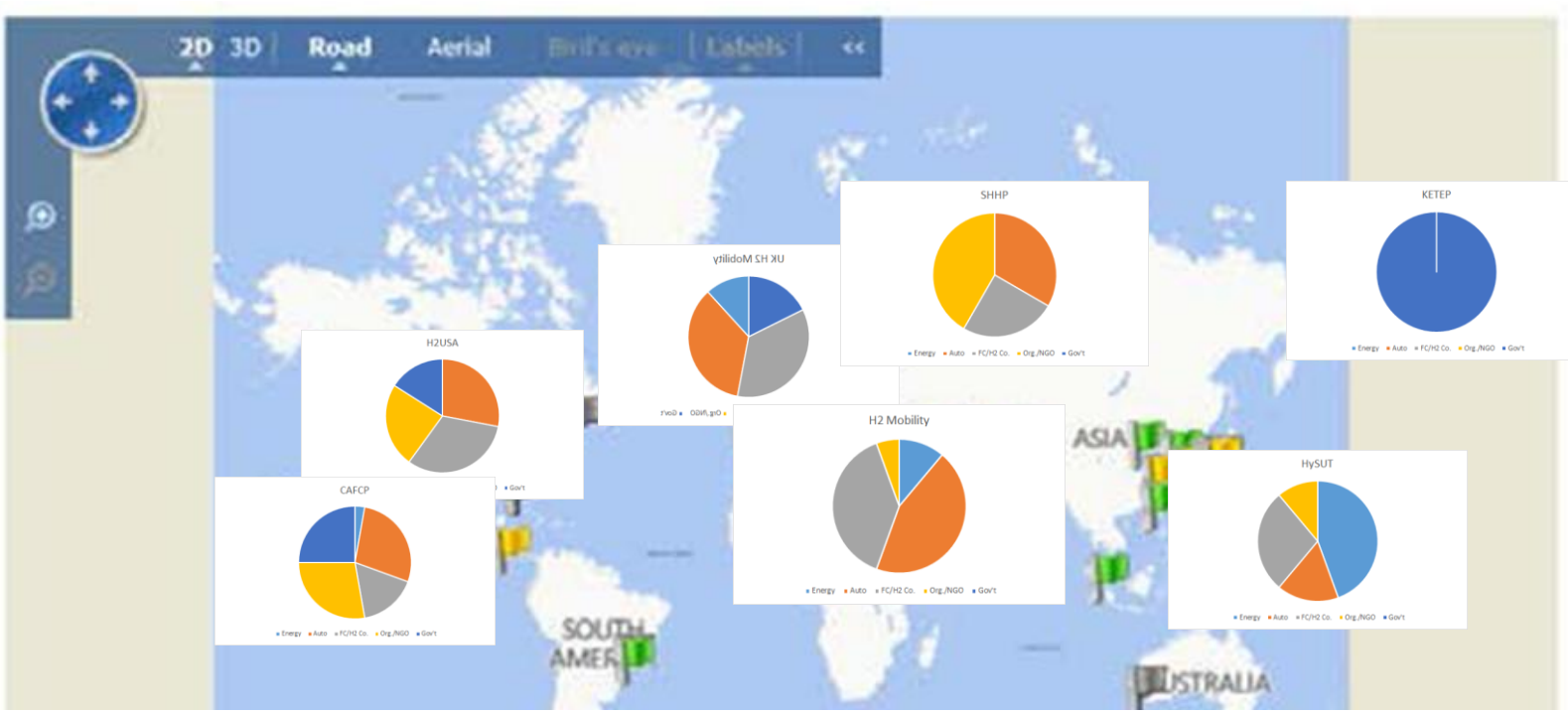
H2 Stations Worldwide: ~220 operational, 100s planned



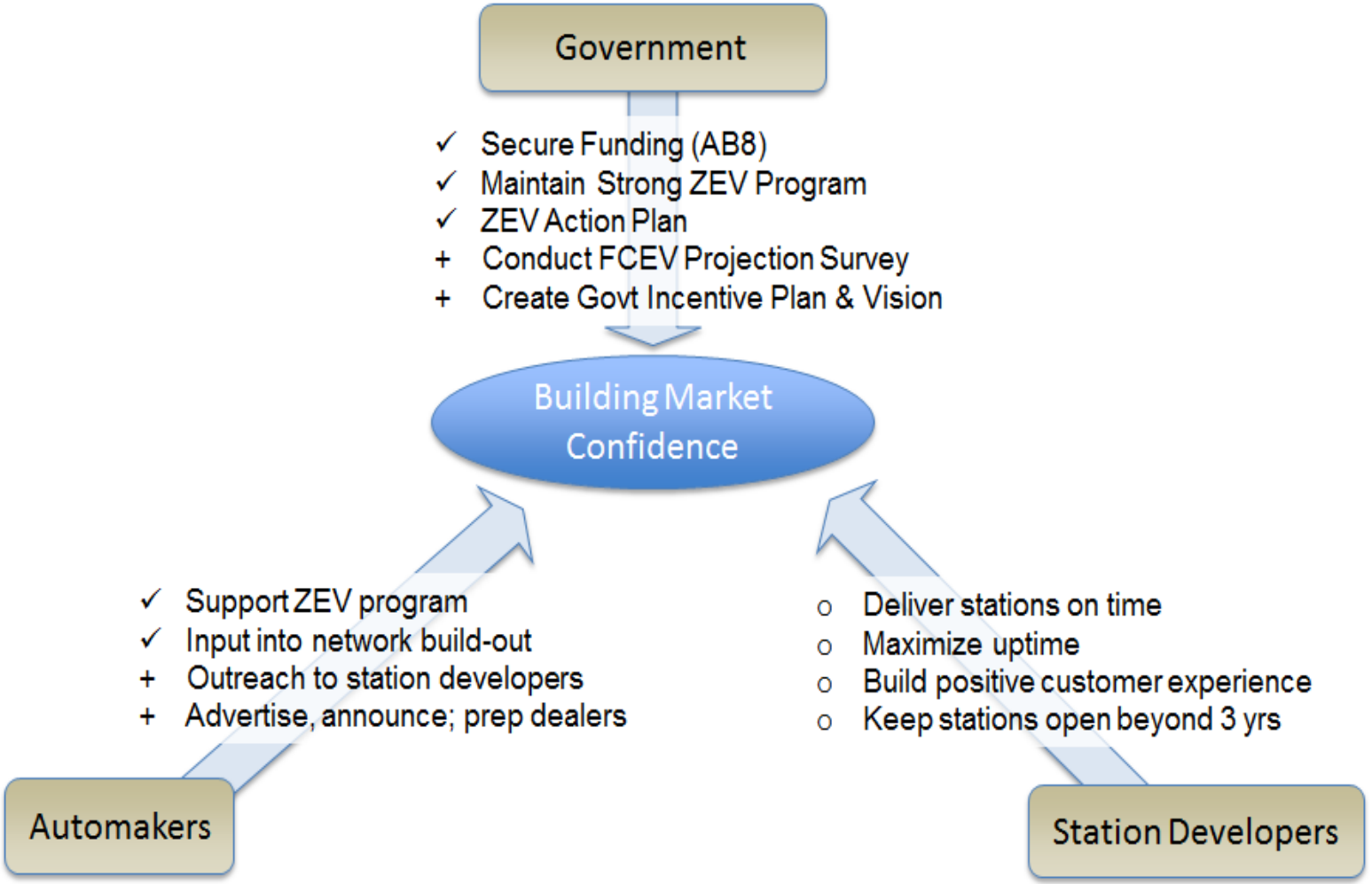
Source: Ludwid Bolkow Systemtechnik, http://www.netinform.net/H2/H2Stations/H2Stations.aspx?Continent=NA&StationID=-1

Rise of Regional public private partnerships

Mix of Partner Organizations varies by region



Early Market Dynamics: Stakeholder Roles



Source: Tyson Eckerle and Remy Garderet, Incentivizing Hydrogen Infrastructure Investment: An analysis of the use of Cash Flow Support To Incentivize Early Stage Hydrogen Station Investment, Energy Independence Now, June 19, 2012. http://cafcp.org/incentivizing-hydrogen-infrastructure-investment

New thinking emerges on H2 infrastructure

- H2 infrastructure planning more sophisticated.
- 1-of-a-kind demos => system thinking/network concepts.
- Realistic Plans w/ stakeholder buy-in.
- More experience building infrastructure

CA is good example of how thinking on H2 Infra. has evolved

CA H2 Highway (2004) Locate stations every 20 miles along the interstates.

Problem: This did not adequately serve H2 vehicles in cities where most people live.

Solution: Focus infrastructure mostly in cities w/ a few stations along the interstates to allow intercity travel.

CA H2 Blueprint Plan (2006) Build Optimized Urban H2 Infrastructure Based On Existing Gasoline System

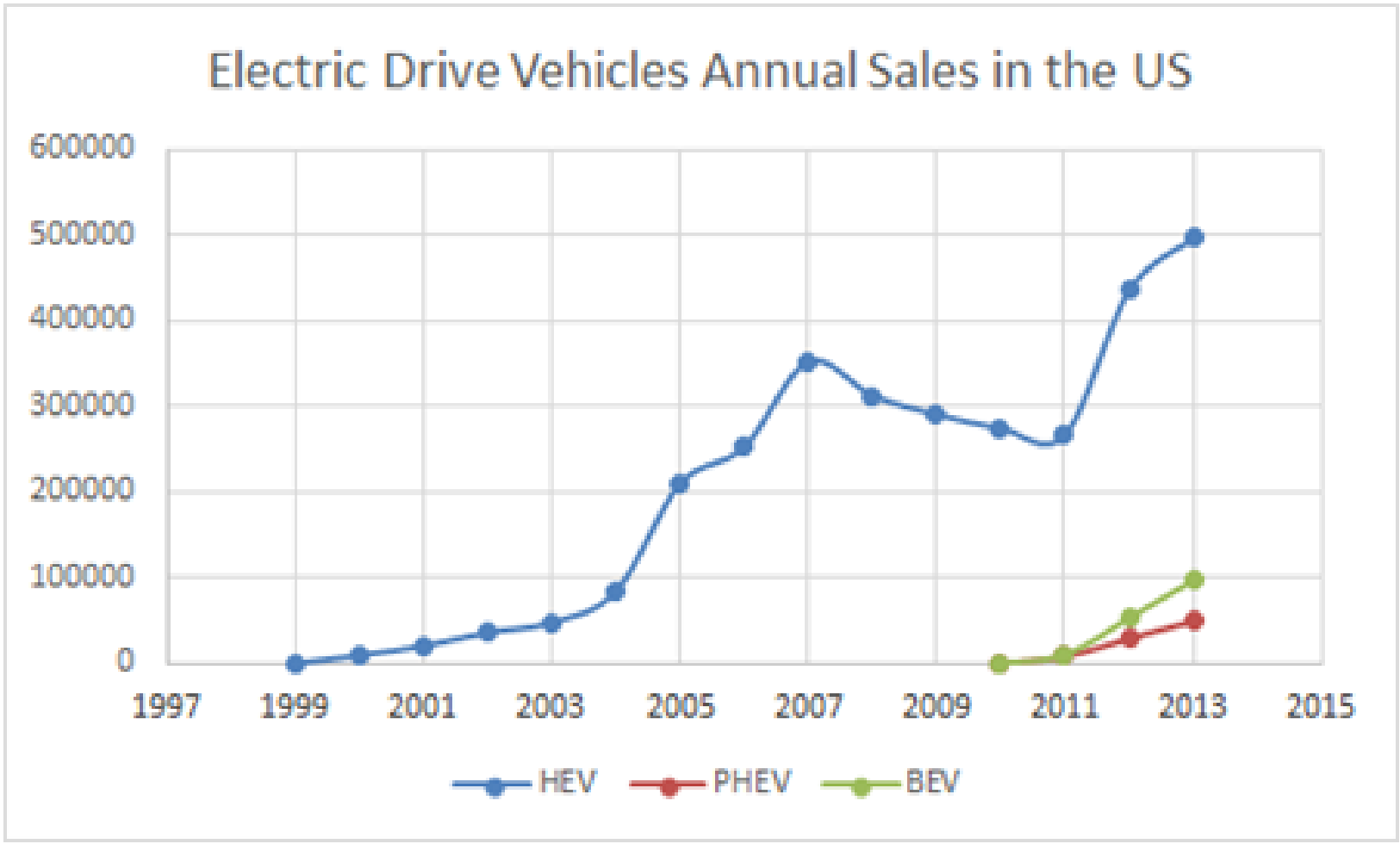
Problem: For good access need H2 at 10-30% of gas stations. In LA this is ~400 stations just to get started.

Solution: Regional "Cluster" Strategy" (current paradigm)

FCVs, H2 stations placed together in "clusters" ID'd by stakeholders as early market sites. "Connector" stations added to facilitate regional travel

How many stations needed? Where should they be located?

Might FCVs follow similar path to HEVs and PEVs?

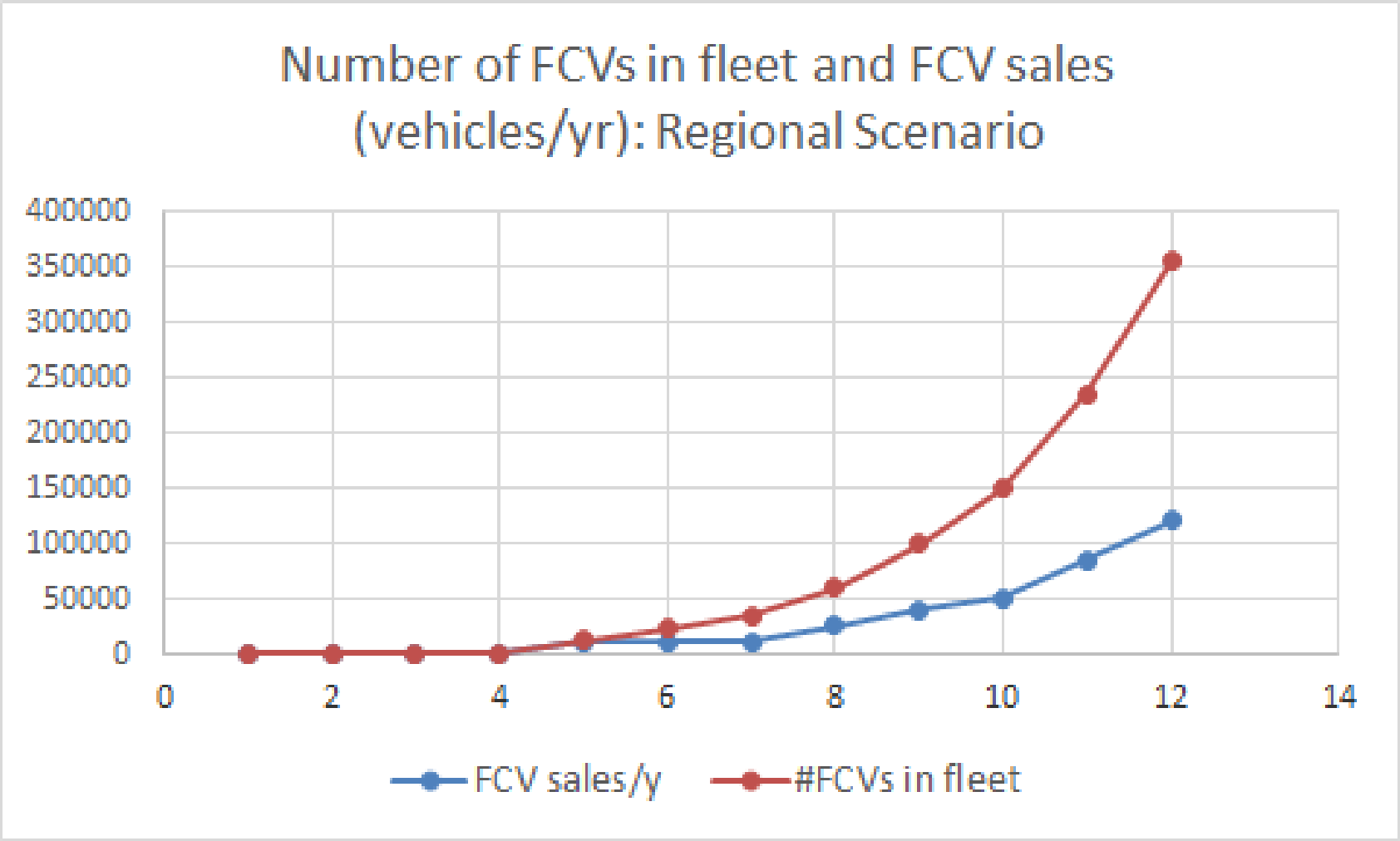


HEVs cum. US sales ~1 million in 2007 (8 years after market intro.), 2 million c. 2010 (11 years). Comparable to US goals (if FCVs ~ 50% of 3.3 million ZEV goal in 2025– 11 years after FCV intro).

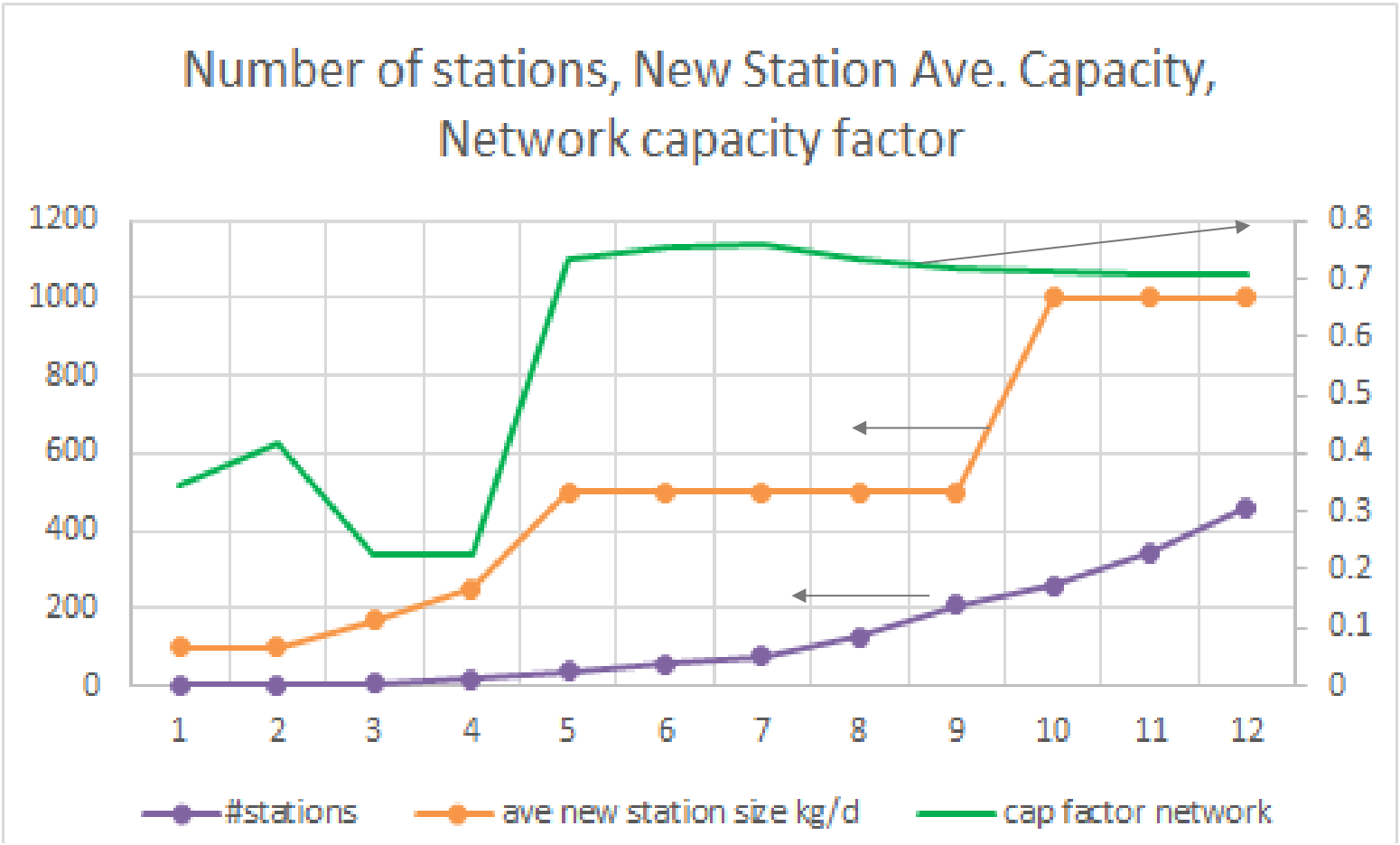
H2 Network Scenario (78 sta., 34K FCVs in yr 7)

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
# FCVs in fleet	197	240	347	1161	12106	23213	34320
H2 demand (kg/d)	137	168	250	800	8500	16000	24000
Total sta. capacity (kg H2/d)	400	400	1080	3580	11580	21580	31580
Number of new stations/y by size, type							
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
Tot.# sta.	**4**	**4**	**8**	**18**	**38**	**58**	**78**

Scenario for Regional H2 FCV Rollout Years 1-12

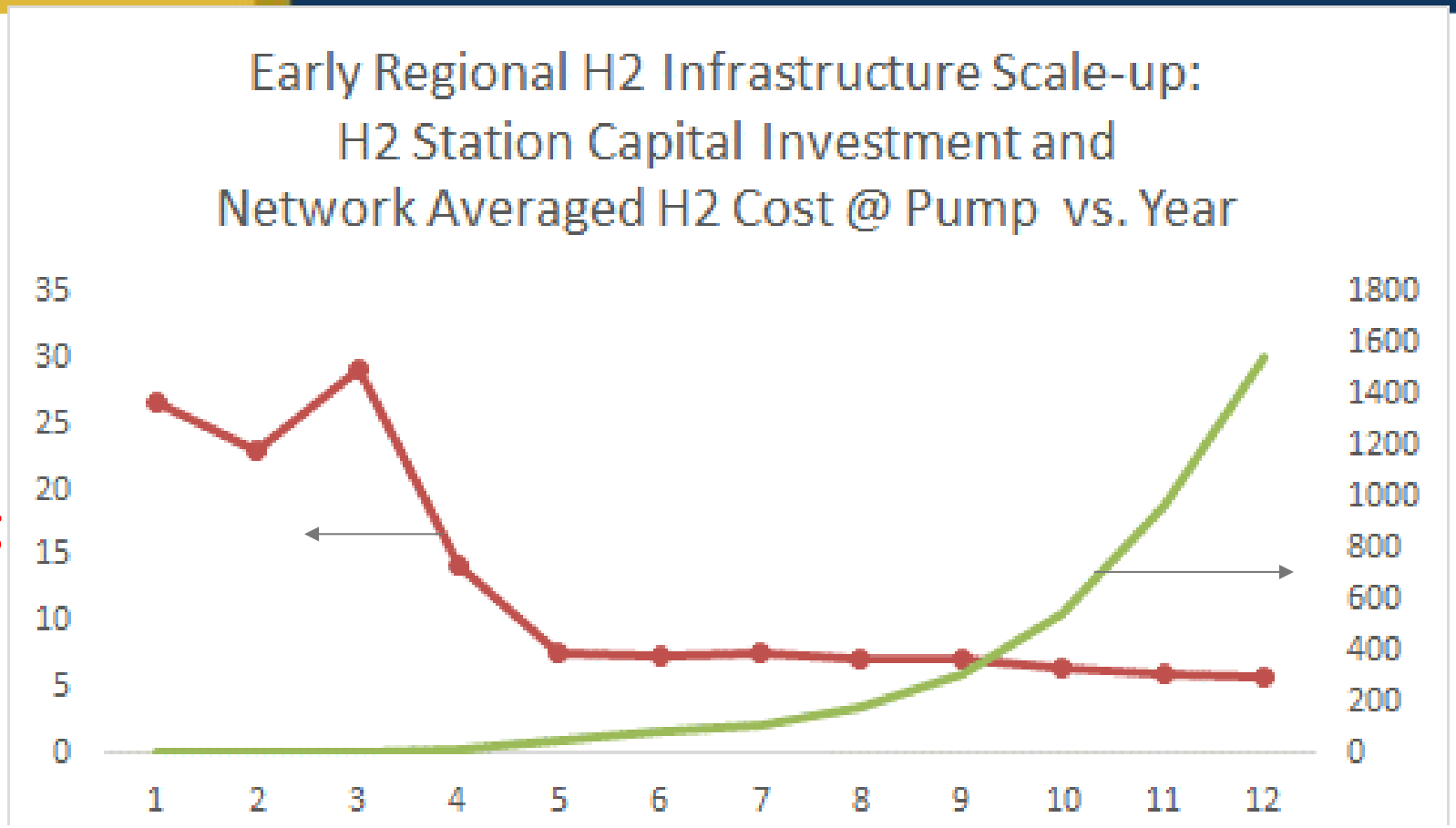


Scenario for regional station rollout to year 12



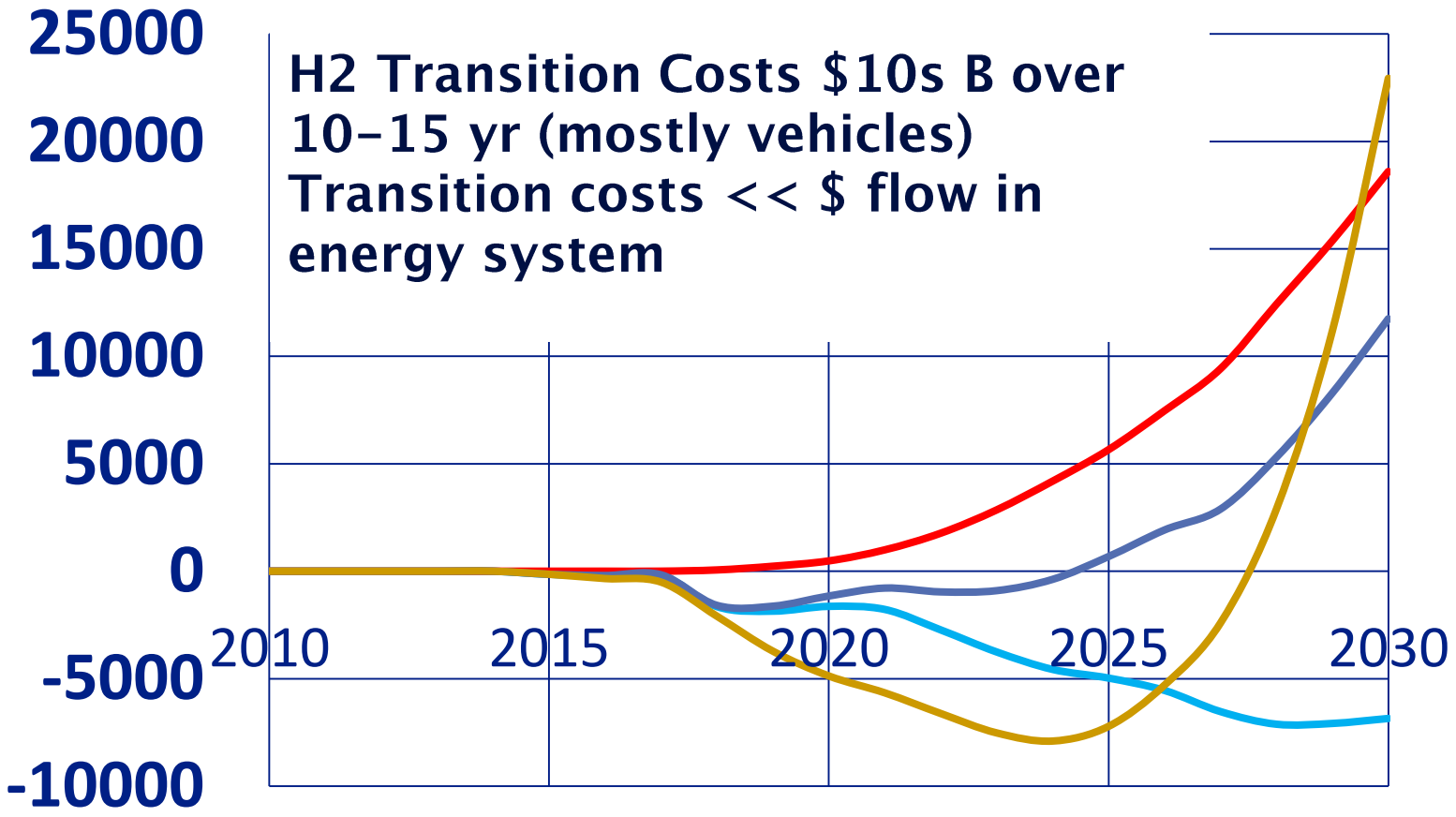
At first, network capacity factor low, as stations are built ahead of vehicle deployment. In first few years stations small, located to provide coverage for early adopters

Investment to launch regional H2 fuel supply



$100-200 million capital investment for ~100 stations (serving 50,000 FCVs) to reach H2 <$7/kg, Assumes FCV market grows rapidly.

Buydown Cost for FCVs in US ($million/y)



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Analysis includes private costs only.
Un-taxed fuel costs.

Long Term Benefits >> Transition Cost (NRC 2013)

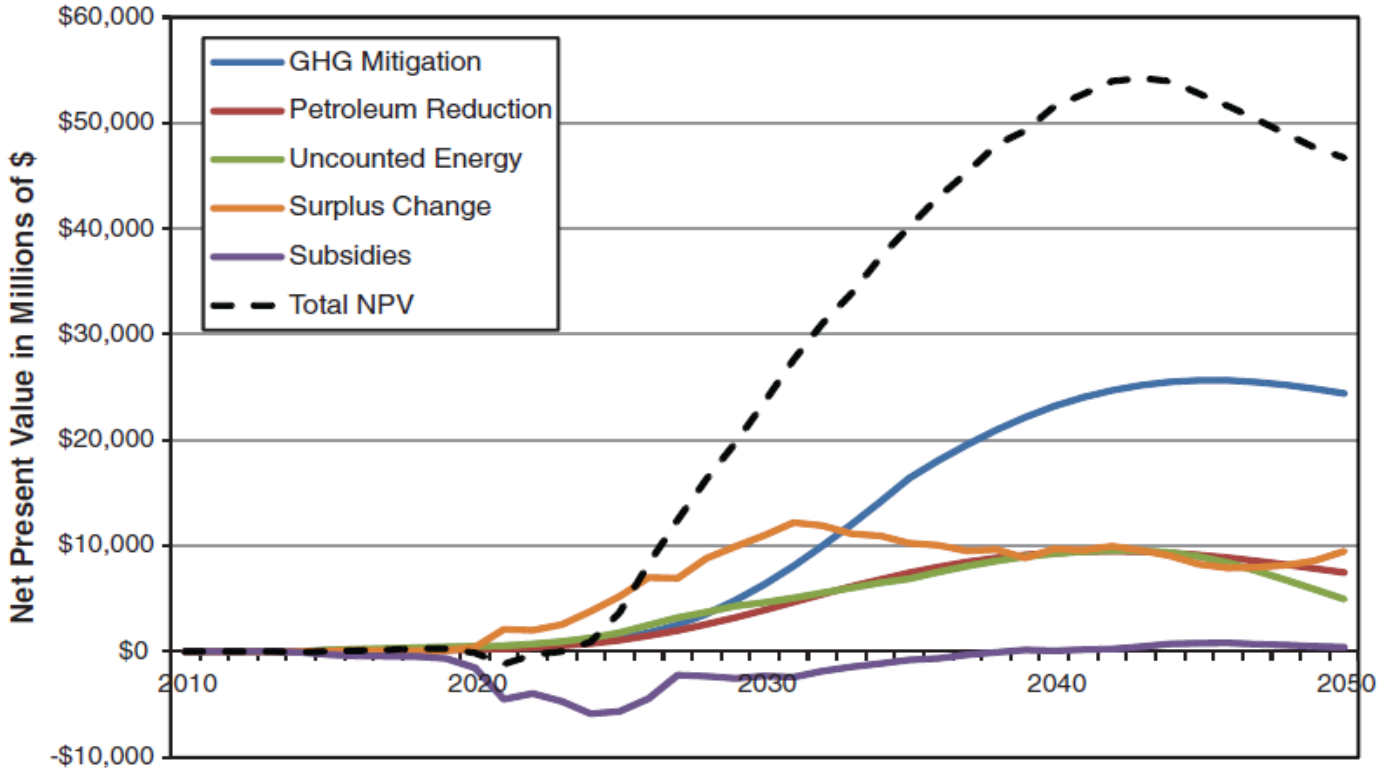
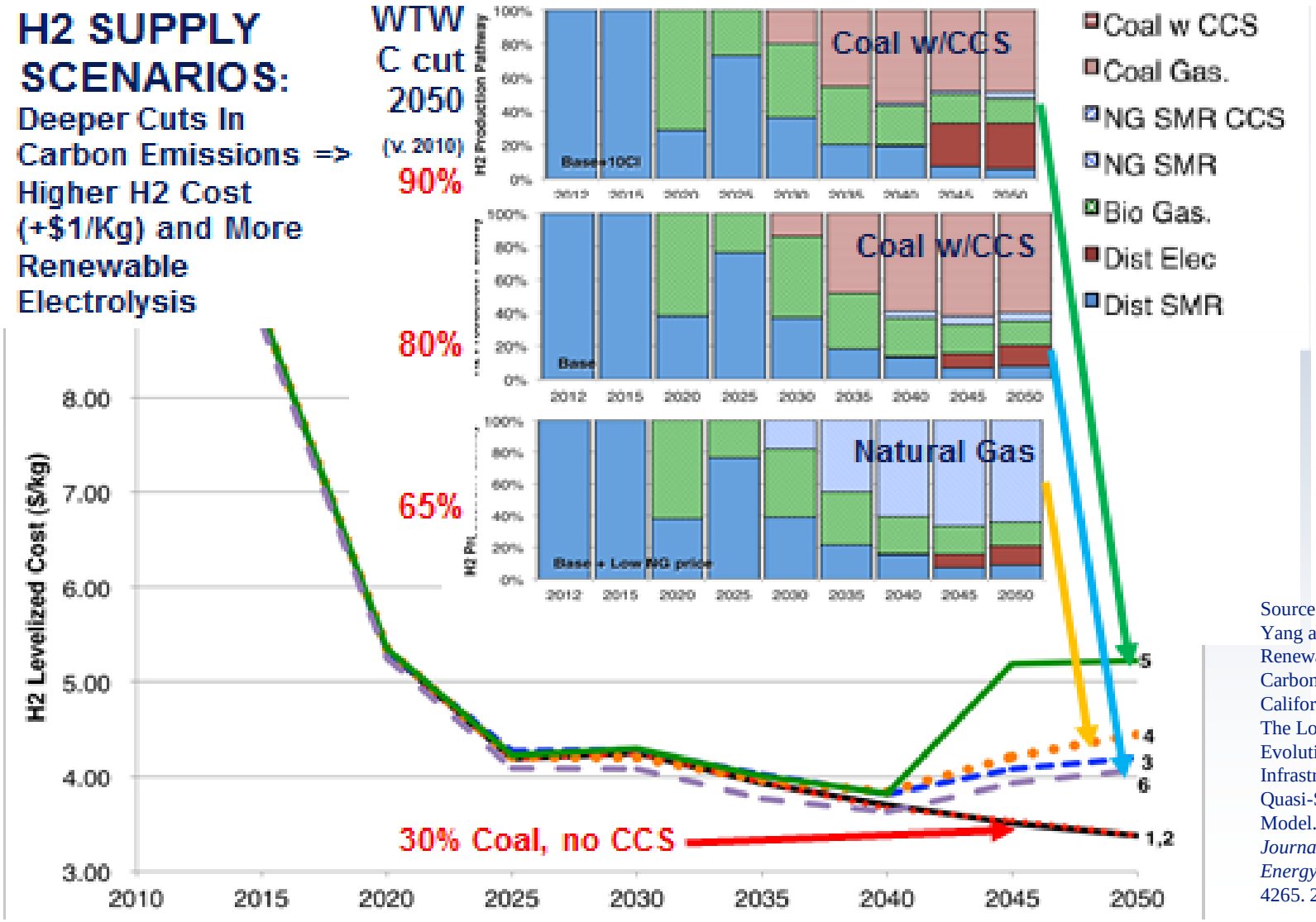


FIGURE 5.24 Present value cost and benefits of a transition to hydrogen fuel cell vehicles using midrange technology assumptions, fuel cell vehicle subsidies and additional incentives, and a low-GHG infrastructure for the production of hydrogen.

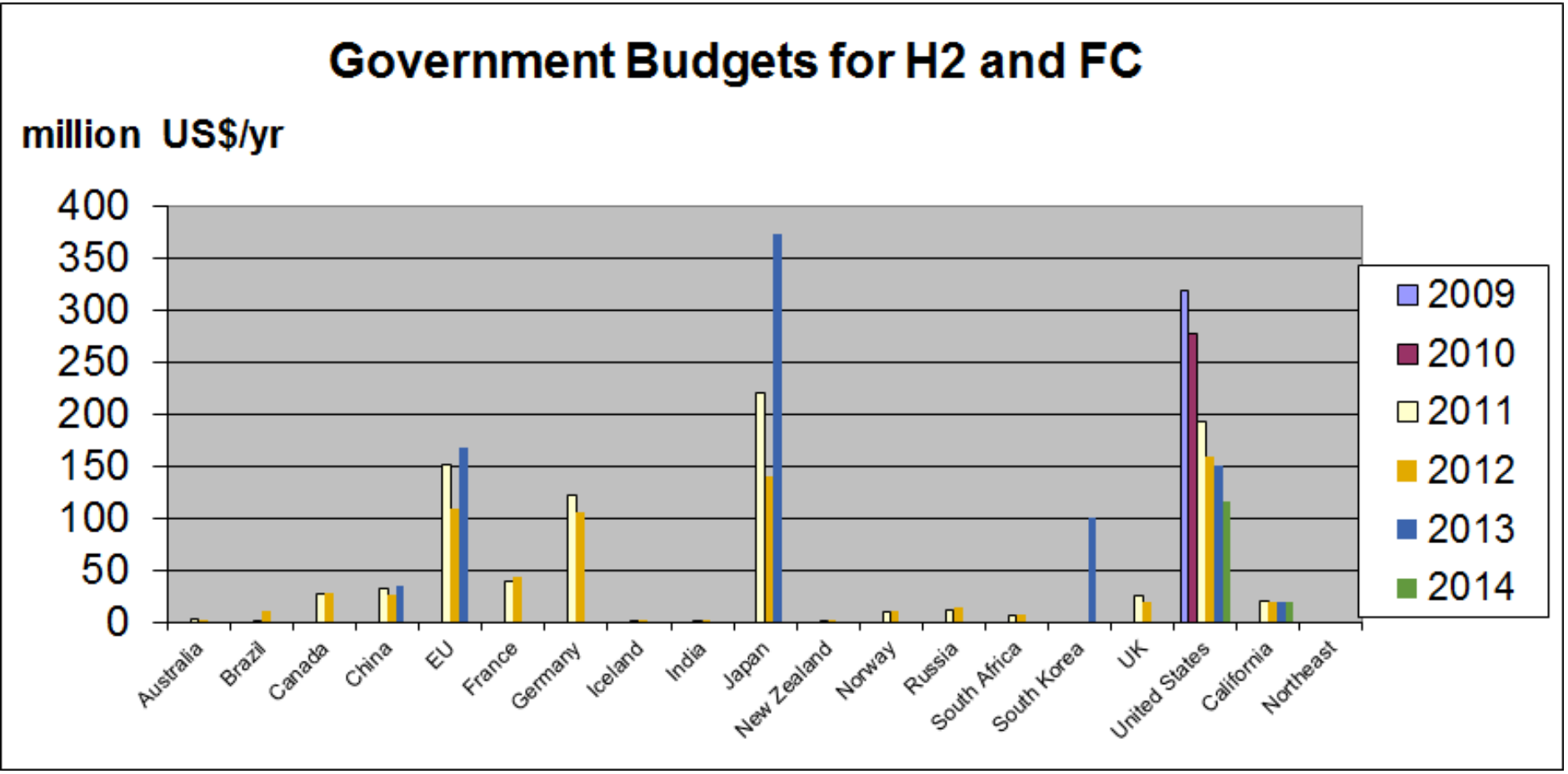
National Research Council. *Transitions to Alternative Vehicles and Fuels* . Washington, DC: The National Academies Press, 2013. http://www.nap.edu/catalog.php?record_id=18264

Long Term Transition: Getting to "Green H2"



Source: 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*. 38 (11) p 4250-4265. 2013.

Trends in public funding for H2 and FC



Global Total Public Funding: ~$1B/y

Upward Trend except US

Leverages 6-9 X in private funding (USDOE)

H2 Policies Worldwide (many similar to PEV policy)

		Canada	USA	California	EU	Denmark	France	Germany	Netherlands	UK	Iceland	Norway	China	Japan	S. Korea
consumer	Vehicle purchase Subsidy		X	X		X		X		X		X	X	X	
	Vehicle purchase tax exemption					X		X		X	X	X			
	Vehicle "Perks" (HOV lanes, free parking, etc.)			X								X			
	H2 fuel subsidy		X	X		X						X			
Auto Co.	Zero emission vehicle reg.			X				X		X		X			
	Fuel economy targets	X	X	X	X								X	X	X
Energy/Fuel Supplier	H2 Infrastructure subsidy		X	X		X		X						X	
	Renewable H2 reg.			X											
	Low Carbon Fuels Reg.			X											X
	Renewable Fuels Reg.		X								X				X
	Subsidy stationary power FCs		X	X				X		X			X	X	X
Other	Public/private partnerships for H2/FCVs	X	X	X	X	X	X	X	X	X		X		X	
	H2/FC R&D	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Nat'l Goals #FCVs		X	X				X		X				X	X
	Renewable Portfolio Standard			X											
	Carbon policy			X	X		X	X	X	X	X	X	X	X	X
	Goal to end fossil fuel use by 2050					X									

Conclusions

- We seem to be tantalizingly close to the beginning of a hydrogen transition. Is it different this time?
- Workable strategies for H2 infrastructure rollout emerging with buy-in from key stakeholders: and public funding to support building early stations, overcoming first mover disadvantage.
- Our estimates => perhaps 50,000 FCVs in a region with 100 stations would be enough to bring H2 fuel costs to competitiveness. The station investment cost would be $100-200 million.
- At least 3 regions where expertise, stakeholders, funding are coming together
- If these regional rollouts are successful, hydrogen FCVs may be just a few years behind battery EVs, not decades.
- It appears that these efforts may jump start the hydrogen economy at last.

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Thank you for your financial and intellectual contributions.

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EXTRAS

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

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

California Air Resources Board 1st Annual Evaluation of FCV and H2 Station Deployment in California