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EXECUTIVE SUMMARY

NextSTEPS White Paper: THE HYDROGEN TRANSITION

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INTRODUCTION

Hydrogen fuel cell vehicle (FCV) technologies experienced a surge of interest in the early 2000s due to their potential to provide significant reductions in greenhouse gas and criteria air pollution, good performance, fast refill, long range and ability to use a fuel (hydrogen) derived from diverse domestic energy resources. However, public interest waned by the late 2000s as fuel cell vehicles did not materialize in the showrooms and plug-in electric vehicles began entering the commercial market. The perception of some stakeholders was that hydrogen was too difficult, and would not appear for several decades, if at all. However, in the past few years important factors have emerged that are re-accelerating the commercialization of hydrogen and fuel cell technologies.

The next two to three years will see concerted efforts to introduce hundreds of hydrogen stations capable of supporting the introduction of tens of thousands of FCVs in selected regions worldwide, backed by several hundred million dollars in public investment and billions of dollars in private investment. If these regional rollouts succeed, hydrogen FCVs might be just a few years behind plug-in vehicles in the commercialization process and might ultimately capture a larger share of the light-duty vehicle market.

DRIVING FACTORS FOR HYDROGEN AND FUEL CELLS

Perhaps the largest reason for the hydrogen renaissance is several major automakers' continuing commitment to hydrogen FCVs as a necessary complement to plug-in electric vehicles and a critical component of automakers' long-term strategy to provide vehicles that contribute to energy and climate policy goals. In many respects, hydrogen FCVs could offer features that are similar to today's gasoline cars and are more challenging to achieve in battery-powered vehicles, including good performance, large vehicle size, refueling time of 3-5 minutes and a range of 300-400 miles. In other words, hydrogen FCVs could enable zero tailpipe emissions and significantly lower life-cycle emissions without compromising consumer expectations.

Hydrogen and fuel cell vehicle technologies are making rapid progress toward technical and cost goals. In 2013, automakers announced new alliances to commercialize FCV technology. Automakers have developed and leased demonstration hydrogen FCVs to real-world customers for the last five years and have stated their intention to introduce these vehicles in commercial volumes of 1,000s or more in the 2014 to 2018 timeframe.

Hydrogen fueling infrastructure has also been a major challenge—the so-called 'chicken or egg' dilemma where automakers have been reluctant to market cars without infrastructure and station provider/operators have been reluctant to build stations without cars. Recently, regional public-private partnerships around the world have developed smart, comprehensive strategies for coordinating early hydrogen infrastructure development with FCV rollouts in North America, Europe and Asia. Through these partnerships, key stakeholders are coming together and a few regions (notably California, Japan and Germany) have committed significant funds to support the next crucial steps forward on infrastructure build-out.

Worldwide, public funding for RD&D and policies supporting hydrogen is trending upwards (with the notable exception of the United States where federal support has fallen by about 60% from its peak in 2008, although states have moved to support hydrogen). Global public support now totals about $1 billion per year, leveraging many times that amount in private funds (USDOE 2012).

The near-term prospects for plentiful, low-cost hydrogen are good. The boom in low-cost shale gas has improved the prospects for natural gas-derived hydrogen, especially in the United States, where it is a major force in the resurgence of federal interest in hydrogen energy. And while natural gas-derived hydrogen does produce greenhouse gas emissions, these emissions are less than half those of a conventional gasoline vehicle, due to the greater efficiency of the fuel cell (Nguyen et al. 2013). Furthermore, as discussed below, several methods of producing hydrogen, including from renewable sources, provide the potential for even greater benefits.

Fuel cells are succeeding in stationary power and battery replacement markets, such as forklifts, giving further confidence in the technology. Increasing numbers of fuel cell power plants are being installed for secure and reliable distributed power and central power plant applications around the world. Residential fuel cell combined heat and power systems are thriving in Japan and Europe, with tens of thousands of units installed in Japan and thousands planned in Europe (Walker 2014).

Another important driving factor is deepening concern about climate change and the growing realization that hydrogen FCVs could be a critical technology enabling a low carbon transportation future. Recent studies of low carbon futures suggest that a variety of electric drive vehicles will play a major role in the future light-duty vehicle fleet. In the International Energy Agency's "2 degree scenarios" (corresponding to 80% GHG emissions cuts by 2050), hydrogen FCVs and plug-in electric vehicles account for over half of on-road passenger cars by 2050 with about equal shares.

Finally, as renewable portfolio standards and carbon policies are being put in place, hydrogen is being widely discussed as a flexible energy carrier for integrating intermittent renewables like solar and wind into the energy system. For example, power grids in Europe and North America are incorporating ever more intermittent renewables (especially wind power), which are not coincident with demand, creating significant amounts of excess generation and driving a growing interest in energy storage. Hydrogen's potential advantage compared to other electricity storage technologies like batteries, compressed air and pumped hydro is its flexibility, enabling concepts like power to gas, seasonal storage as a means of better controlling the grid, and using off-peak power to make hydrogen transport fuel

TRANSITION ISSUES FOR HYDROGEN AND FUEL CELL VEHICLES

Within the last few years the fuel cell industry has clearly moved into a new stage of commercial development. However, hydrogen still faces technical, economic, infrastructure and societal challenges before it can be implemented as a transportation fuel on a large scale. The question now is not whether fuel cell vehicles will be technically ready; they are. The question is how to spur vehicle sales, how to coordinate the rollout of hydrogen infrastructure as vehicles arrive, how to build investor confidence in the market and how to reduce the early financial risks for fuel suppliers and automakers.

Key questions include:

- What is required to initiate a transition to hydrogen and fuel cells?
- What is the latest thinking on launching hydrogen FCVs and designing a viable early infrastructure? How are plans for hydrogen and FCV rollout progressing in North America, Europe and Asia? What would be needed to overcome risk in building early infrastructure?
- How much will it cost to buy down the cost of FCVs and bring hydrogen to scale where it could compete with gasoline? How does this compare to other energy system costs and benefits.
- How do we get to "green hydrogen?" In the long term, to realize the full climate benefits, we will need to make hydrogen from low-carbon pathways such as renewables or fossil with carbon capture and sequestration (CCS)?
- What kinds of policies are currently in place and what more policies are needed? Is there enough funding and investment capital available to launch hydrogen production, distribution and refueling systems? Are current policies moving things in the right direction? What kinds of policies might be needed to catalyze introduction of hydrogen and FCVs and reduce stakeholder risks?

Drawing on experiences from North America, Europe and Asia, UC Davis researchers have examined both near-term and long-term transition issues. These include managing the early introduction of hydrogen vehicles and associated infrastructure, and accomplishing a longer term transition to low carbon sources for hydrogen such as renewables and hydrocarbons with carbon capture and sequestration (CCS).

Our results indicate that it would be technically feasible to build out a hydrogen infrastructure coordinated with vehicle rollouts in a series of lighthouse cities. We find that perhaps 50,000 FCVs in a given region (e.g. Southern California) with 100 stations would be enough to bring hydrogen costs to competitiveness with gasoline on a cost per-mile basis. The station investment cost would be $100-$200 million.

PUBLIC FUNDING FOR HYDROGEN AND FUEL CELLS

It is clear that early and durable public policy will be needed to launch hydrogen infrastructure. Public funding for hydrogen and fuel cells in various countries is shown in Figure ES-1. Japan, Germany, the European Union, South Korea and the United States have programs of at least $100 million per year. The worldwide total exceeds $1 billion per year. Generally, budgets are trending upward with the notable exception of the United States, where the hydrogen budget has fallen over 60% from its high of about $300 million in 2008, although various states including California have programs to support hydrogen FCV rollouts.

Public investment and strong policy spurs additional industry investment. The U.S. Dept. of Energy estimated that its public investment in fuel cells and hydrogen led to 6 to 9 times more in private investment (USDOE Fuel Cell and Hydrogen program annual report 2013).

Our calculations suggest that regional hydrogen infrastructure investments totaling $100-$200 million spent over perhaps 5-7 years in support of 100 stations could launch a cost-competitive regional hydrogen supply. It appears that this is poised to happen in at least three places in the world: California, Germany and Japan.

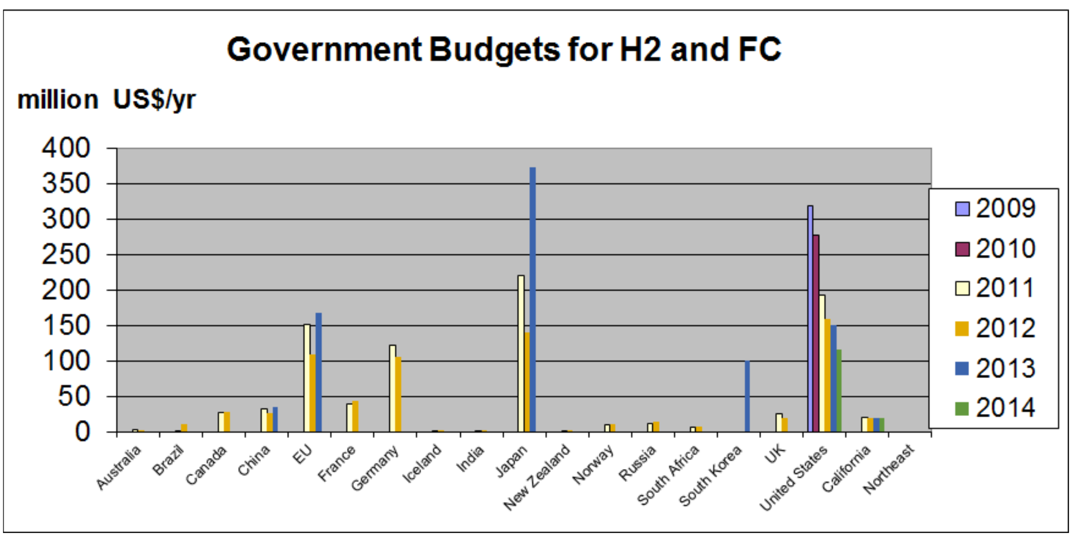

Figure ES-1. Public budgets for hydrogen and fuel cells by country. Source: IPHE Country Updates, November 2013.

GLOBAL OVERVIEW OF HYDROGEN-RELATED POLICIES

Table ES-1 shows the types of policies in place to support hydrogen and FCVs around the world. These policies target different stakeholders and include direct subsidies for purchasing vehicles and fuel infrastructure, tax exemptions, zero emission vehicle regulations, and low carbon and renewable fuel standards. “Perks” for hydrogen vehicle owners such as HOV lane access, free parking and free fueling exist in a few places.

What kinds of policies might be needed to catalyze a transition to hydrogen? Some analogies can be drawn to other vehicle types. Incentives and driver perks have been important in encouraging the growth of battery electric vehicles and there may be lessons from the PEV experience about what motivates consumers. Because hydrogen infrastructure is a critical part of the pathway in terms of consumer experience, convenience and utility, policies such as public private partnerships, which are aimed at coordinated infrastructure rollouts, are essential.

The move toward zero emission vehicles to improve air quality has been an important driver for hydrogen. In the long term, policies to address carbon emissions and climate change may prove to be the greatest force for adoption of hydrogen. Broad carbon policies like taxes or cap-and-trade systems, by themselves, won’t be enough to cause success of advanced vehicles. It seems almost certain that policies targeted at the transport sector and zero emission vehicles will be needed.

In the IEA’s ETP 2012 report and the 2013 NRC study on light-duty vehicle transitions, consumer choice of hydrogen fuel cell vs. plug-in electric vehicles was a key factor in the mix of light-duty vehicles in 2050. Continued R&D on batteries and fuel cells, hydrogen storage and low-carbon energy production is needed.

Stated national goals for FCV adoption could amount to almost 9 million FCVs on the road globally by 2025-2030 (Japan: 2 million by 2025; Germany 1.8 million by 2030; UK 1.8 million by 2030; Eight U.S. states 3.3 million ZEVs by 2025, including 1.5 million ZEVs in California[1]). In order for these goals to be reached, regional launches need to occur over the next few years and ramp up fairly quickly. As NRC studies have shown, the long-term benefits of hydrogen FCVs are large (NRC 2013, NRC 2009) in terms of fuel cost savings and in terms of reduced costs of climate change, air pollution and oil dependence. By 2050, the total benefits outweigh transition costs by a factor of 10 (NRC 2013).

[1] Note that ZEVs could be either battery electric, plug-in hybrid or fuel cell vehicles.

Table ES-1. Public Policies Related to Hydrogen and Fuel Cell Vehicles

		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			
Automaker	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 AND RECOMMENDATIONS

We seem to be tantalizingly close to the beginning of a hydrogen transition. But energy decision-makers have heard this before. Is it different this time? We believe it may be.

Fuel cell vehicles are technically ready and there appears to be a path to cost competitiveness with incumbent gasoline vehicles.

After a decade of controversy and exploration, workable strategies for hydrogen infrastructure rollout are emerging with buy-in from key stakeholders: the automakers, hydrogen suppliers and regulators, and with public funding to support building early networks of stations.

The stalling point has been that the funding required to launch hydrogen infrastructure is more than the usual amount for R&D projects, though vastly less than for current expenditures on the energy system. The risks involved in getting through the "valley of death"[2] have daunted investors. The long-term rate of return (and societal benefits) are potentially attractive, but the path is not certain. How to get across the valley of death? The first-mover disincentive has made it tougher to get private investment. Not surprisingly, some potential infrastructure investors want to wait until the FCV market is more secure and they could build large, fully utilized stations with confidence.

But the good news is that it might not take that much investment to build up infrastructure to that point where new investments are profitable and less risky for infrastructure providers. Our estimates indicate that perhaps 50,000 FCVs in a region with 100 stations would be enough to make hydrogen cost-competitive with gasoline on a cost per-mile basis. The station investment cost would be $100-$200 million. There appear to be at least three locations where public and public/private partnerships have made commitments on that order (California, Japan, Germany).

If these regional rollouts are successful, hydrogen FCVs may be just a few years behind plug-in electric vehicle, not decades. It appears that these efforts may jumpstart the hydrogen economy at last.

[2] The "Valley of death" refers to the market entry cost barrier facing new technologies that must scale up production in order to compete economically.