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Roadmap for Hydrogen and Fuel Cell Vehicles in California: A Transition Strategy through 2017

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Roadmap for Hydrogen and Fuel Cell Vehicles in California: A Transition Strategy through 2017

A Collaborative Effort by Public and Private Stakeholders

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- California Air Resources Board
- California Energy Commission
- California Fuel Cell Partnership
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- Toyota Motor Co *
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Disclaimer

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Finally, we would like to thank all the workshop participants for their active engagement in the project. Over the course of 15 short months, we held five workshops, and many of the same individuals traveled to UC Davis for all five events. We thank you for your support and contributions in making this a unique dialogue forum on the hydrogen infrastructure challenge such a success.

Executive Summary

Overview and Goals

Global energy challenges, including climate change, energy security and air quality, require that we transform the way we produce and use energy in transportation and other sectors. To reach long-term goals for deep reductions in transportation-related greenhouse gas emissions, more efficient vehicles, lower carbon fuels, and electric drive technologies will play important roles. Hydrogen (H2) and fuel cell vehicles (FCVs) are one of many solutions that will be needed to address these challenges.

Momentum is building at the national level for a comprehensive carbon policy with binding 2050 targets and deep carbon reductions on the order of 80% which will ultimately require a significant market share for zero emission vehicle (ZEV) alternatives. Today, there are only three energy carriers that can achieve an 80%+ reduction in life-cycle greenhouse gas emissions when combined with electric drive technology – advanced biofuels, hydrogen, and electricity. Advanced biofuels will play a significant role, but there will be limits on both physical supply and the use in light-duty vehicles compared to other sectors. If H2 is not part of that fuel mix because of lack of early investment, the only significant option would be electricity used in battery vehicles. Relying on these limited options increases the risk of not achieving our long term climate and transportation energy goals, given current technical and market uncertainties.

Over the past decade, there has been rapid, ongoing progress in the development of fuel cell vehicle technology, and hydrogen refueling systems. This reflects strong support from the public sector and commitment from both the automotive and energy industries. Hydrogen and fuel cell vehicles are ready to take the next step toward commercialization: a regional pre-commercial deployment of thousands of vehicles with a concentrated hydrogen fueling network.

This will require major investments. The automotive and energy industries have the capabilities to make these investments, but their commitment to this alternative is fragile for two reasons. First, political momentum for hydrogen has declined at the time when larger public and private cooperation is needed. Second, introducing hydrogen and fuel cell vehicles will require a distinct coordination between new H2 stations and planned vehicle placements. To proceed industry stakeholders need:

- Confidence in the technical success of the H2-FCV alternative, and consensus on a realistic appraisal of current technical status, costs, and timelines for commercialization.
- Clear evidence of a durable, consistent government commitment to the H2-FCV alternative and accompanying policies, throughout a pre-commercial transition.
- A coordinated plan among the major stakeholders on how industry and government can collaborate to accelerate the rollout of H2 and FCVs.
- A long-term business case for hydrogen and fuel cells in a future economy with increasingly stringent carbon policies.

The California Hydrogen and Fuel Cell Vehicle Roadmap Project was developed to provide a targeted forum for discussing the challenges facing this alternative and to conduct a fresh, independent analysis on the topic of a transition to a hydrogen economy in California. The project had the following primary goals:

- Through a series of coordinated workshops, come to consensus on technical and cost issues, illuminate stakeholder motivations and attempt to align perspectives among the stakeholders to enable constructive action.

- Contribute information that could help industry stakeholder coordination of vehicles and station placements[1].
- Identify public policy mechanisms that could constructively align stakeholder actions for near term action, ideally through policies that change long-term investment decisions.

This document summarizes key insights from the workshop process and UC Davis' analysis, and sets forth a series of recommendations for the major stakeholder groups.

Varying Motivations

It became clear in the workshops that fundamentally different factors are motivating the automotive and energy industries around hydrogen and fuel cell vehicles. An understanding of these differences is important to identify constructive means of coordinating future actions. While all stakeholders agreed that we are likely to see increasingly strict limits on carbon emissions, there is uncertainty about the timing of these measures and what they might mean for the automotive and energy industries. At present, stakeholders are subject to various policies with several of the relevant policies (ZEV and GHG) undergoing revision. This dynamic situation provides an uncertain context for stakeholders' decisions around hydrogen and fuel cells. In the recommendations below (and in Chapter 6), we highlight policy options that might encourage and enable development of hydrogen supply to meet ZEV vehicle timelines.

The **automotive sector's** advanced vehicle strategies have changed and diversified considerably in the past 10 years, with technical progress and an evolving policy landscape. Throughout, California's ZEV Regulation has been a key factor driving the auto companies' development timeline of electric drive vehicles (both battery vehicles and hydrogen fuel cell vehicles). The ZEV Regulation is now approaching a critical new phase when significantly higher volumes of pure ZEVs are required. Moving from hundreds of battery electric and fuel cell vehicles today to 25,000 – 50,000 pure ZEVs by 2017 will require a shift towards commercial-ready vehicles driven by average household consumers.

The **energy companies** have provided strong collaboration with automotive partners over the past 10 years by providing demonstration hydrogen stations and experimenting with new station technology. However, further near-term hydrogen infrastructure investments are being carefully considered, as momentum for hydrogen has lagged, and long-term policy signals have remained unclear for fuel providers (as outlined on the previous page). Although California's new Low Carbon Fuel Standard (LCFS) has emerged with distinct 2020 targets, this is more immediately applicable to biofuels than to electricity or hydrogen, and the federal Renewable Fuel Standard (RFS) is explicitly restricted to biofuels. Truly long-term carbon policies, putting us on a path toward deep emissions cuts by 2050, have not been set into law, and there are various views within the energy firms as to when durable carbon policies will emerge, and what they might mean for transportation. This makes it difficult to develop a viable business case.

Although all stakeholders acknowledged that energy security and climate change goals will drive stricter future carbon reduction policies, corporate investment decisions are driven primarily by existing near-term policy and market signals. This is to be expected in the private sector where financial returns to shareholders are required, and truly long-term policy signals have not yet been developed. This implies that even when binding 2050 carbon policies are established, investments may not be made today for the long-term solutions given discount rate factors and near-term competitive priorities.

[1] UC Davis researchers conducted a rigorous analysis of station network timing, designs and costs with industry input and in coordination with the CaFCP Action Plan process. These results give a strong analytic foundation for future station rollout strategies and plans

Identifying Factors that Determine Investment Decisions for the Next 10 Years

The evaluation of a business plan for hydrogen, with large capital investments, includes numerous factors, including policy signals, market competition, shifts in consumer demand, technology readiness, corporate investment funding, and facility siting factors such as permitting, ownership, financing, taxes, etc. This project studied a number of these factors, but concluded that the primary motivation for the energy industry's hydrogen investments will be carbon regulations and the auto industry's momentum around ZEVs.

As the Los Angeles basin is a near term rollout region for hydrogen vehicles, UC Davis researchers formulated a 10 year hydrogen infrastructure growth scenario for the LA Basin, including an analysis of network convenience, station cost analysis, and an infrastructure cash-flow analysis. This was supported with detailed feedback from the industry stakeholders on critical cost assumptions. The analysis concluded that for an infrastructure of 42 hydrogen stations in the LA Basin that supports 25,000 FCVs by 2017, a $200 million total investment would be required ($170 million to build the stations and $30 million to operate them). If this were amortized over 10 years, an average hydrogen fuel retail price of $10/kg could recoup the costs.

Although $200 million spent over 10 years is a relatively modest investment, especially if shared among multiple energy and government stakeholders, the workshop discussions revealed that the cost was not the only or even the main issue. A larger factor in infrastructure investment decisions is a current lack of certainty in both large FCV vehicle volumes and long-term deep carbon reduction policies. Many stakeholders believe clearer signals are emerging as the fuel cell technology has advanced to the point where commercial vehicles, at volume production, will be available soon. In addition the ZEV Regulation is expected to become even more stringent, providing assurance of ZEV volumes. Until these market and policy factors become clearer, decisions are based on risk assessments and the probabilities of different outcomes. of Currently, a national level commitment to hydrogen and fuel cell vehicle technologies is uncertain. This is evident by the U.S. DOE's May 7, 2009 budget request, which virtually eliminated funding for R&D on hydrogen storage, production and delivery and for fuel cell vehicle demonstrations. Although Congress restored the funding, the initial cuts increase the risk to the industry's hydrogen and fuel cell investments.

2009 is an especially important year to begin strategic hydrogen infrastructure investments. As mentioned above, the State of California has a new hydrogen infrastructure investment fund of $40 million under AB 118. But more importantly, automakers are poised to deploy a modest volume of vehicles into the California marketplace and need the infrastructure to be successful. The ZEV Regulation is being revised early next year which may bring a more rapid introduction schedule for ZEVs, and a revised Clean Fuels Outlet regulation will be developed alongside the ZEV Regulation (this regulation, coordinated by CARB, was originally developed for methanol fueling infrastructure in the 1990s). Automotive FCV investments need to be supported now through timely early infrastructure deployment, to ensure production vehicle programs are launched soon enough to prepare for sales in 2015. Given the uncertainty of the U.S. DOE's support for hydrogen vehicles, state initiatives take on additional importance.

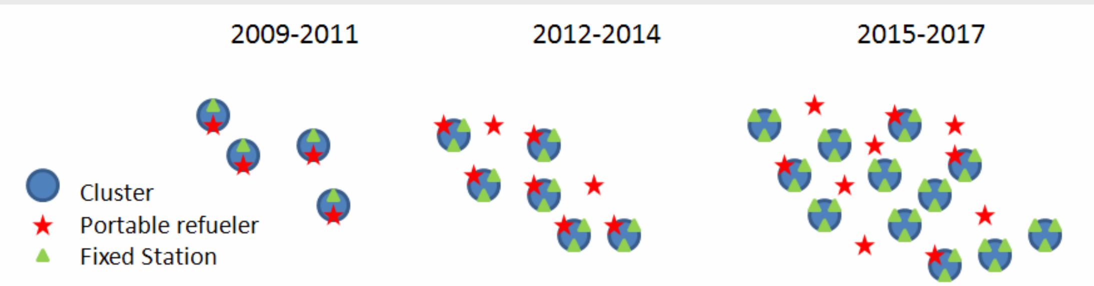
UC Davis Transition Analysis: A Roadmap for Introducing H2 and FCVs in Southern California 2009-2017

UC Davis researchers analyzed a 10 year hydrogen infrastructure growth scenario for the LA Basin, including an analysis of network convenience, station cost analysis, and an infrastructure cash-flow analysis. The analysis concluded that for an infrastructure of 42 (55) hydrogen stations in the LA Basin that supports 25,000 (40,000) FCVs by 2017, a $200 million ($260 million) total investment would be required. If this were amortized over 10 years, an average hydrogen fuel retail price of $10/kg could recoup the costs. Beyond this timeframe, new large hydrogen stations could produce hydrogen at an estimated $5-6/kg.

An additional factor considered was the California renewable hydrogen production requirement, SB 1505 *. When this was factored in, the station costs increased (for renewable bio-methane and/or green electricity) requiring an amortized fuel retail price increase of $0.4 -1.4/kg (for 33% bio-methane in onsite steam reformers), or $5-20/kg (for electrolysis with green electricity).

Table 1 below outlines a scenario for how a station network could be built out in the LA Basin between today and 2017. It is based on the concept of a concentrated, regional approach to early station placement, to provide early market experience for fuel cell vehicle customers. These "clusters" would expand over time and eventually have connector stations to provide long-distance travel. All of the recommendations in this report build on this concept.

This project worked in parallel to the California Fuel Cell Partnership's (CaFCP) Action Plan that defined vehicle and station needs through 2014. UC Davis worked closely with the CaFCP to help inform their Action Plan development, and in turn they participated in this Roadmap process. As a result some important similarities exist between the Action Plan and this project (refer to the box at the end of this section). However, this project provides a longer-term perspective through the next decade on station requirements, an investment cash-flow analysis, quantitative metrics for station network layout, as well as policy recommendations.



	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
Station Mix	4 Portable refuelers 4 SMRs (100 kg/d)	8 Portable Refuelers 12 SMRS (250 kg/d)	10 Portable refuelers 12 SMRs (250 kg/d) 20 SMRs (1000 kg/d)

Table 1: Transition Pathway for Building an Early H2 Infrastructure in Southern California

*. SB 1505 requires, among other things, that 33% of H2 delivered for vehicles come from renewable resources. This requirement applies to all stations publicly funded, and all privately funded stations after the total state-wide dedicated vehicle fleet exceeds 20,000 vehicles (approximately 10 - 15,000 kg/day).

Toward a Shared Consensus

This project provides a unique perspective, at a critically important time for hydrogen and fuel cell vehicles. Through the workshop process the stakeholders came to consensus on the current status of FCV and hydrogen station technologies, and the likely timeline for their future development. The workshop participants defined key “metrics” for each technology, which enabled the group to examine progress toward commercialization, including:

- vehicle component costs (for fuel cells and hydrogen storage),
- fuel cell durability,
- vehicle range and
- hydrogen station capacity and costs.

Defining and agreeing upon progress metrics and timelines increased awareness and confidence among stakeholder groups. Having this common understanding is essential to build consensus on the challenges and actions required. Once this confidence had been strengthened, it opened the way for a discussion of infrastructure business models and honest assessments of why infrastructure growth is not keeping pace with vehicle deployments. The group’s findings on “metrics” and “timelines” are summarized in Chapters 2 - 4.

The group identified market barriers affecting the investment plans and tried to outline a means to remove the barriers, either with new public policy (incentives or regulation) or cooperation amongst private sector firms. This process in itself was an achievement: at the beginning of the project there was lack of agreement on even basic technology status and timelines, whereas near the end there was a much stronger common understanding of technology status, policy landscape and awareness of differing viewpoints and motivations among the stakeholders.

The group did reach consensus on a few important themes.

- First, the H2-FCV remains one of the few options for the LDV sector to achieve California’s 2050 GHG goals.
- Second, in high volumes, FCVs hold the promise of costs only slightly higher than advanced ICEs, whereas BEVs are expected to be noticeably larger.
- Third, in a mature market, H2 stations are expected to provide a similar convenient, short refueling experience that drivers know with gasoline, and will allow easy long-distance travel.

However, market entry barriers are high for H2-FCVs and it is not clear whether enough stakeholder coordination will occur to get over these hurdles. Making H2-FCVs successful will require more stakeholder coordination than any other alternative. There are higher investment risks for energy firms compared to other alternatives, the placement of FCVs in specific communities is heavily reliant on expected infrastructure, and public policy is not providing a robust, comprehensive, portfolio approach to long-term transportation solutions.

It is the conclusion of the participants in this Roadmap that the H2-FCV alternative could be an important part of the future. However, there was clear acknowledgement that existing public policies need to change in order to incentivize long-term energy infrastructure investments.

The final step in this exercise of stakeholder cooperation is to jointly outline a roadmap, or collection of discrete actions required to advance the pre-commercial deployment of H2 and FCVs through the next decade. These recommendations are given below.

Roadmap Recommendations

It is clear that for H2-FCVs to advance to the next level of deployment, a coordinated clustering of stations and vehicles is required to focus resources and effort. This will require close cooperation among all major stakeholders.

The following specific recommendations outline actions each group of stakeholders could take to advance the H2-FCV alternative in California. The recommendations are further organized into two "tiers" to reflect a high priority (Tier 1) and medium priority (Tier 2). High priority items are time sensitive and provide a larger impact on enabling hydrogen for FCVs.

TIER 1 – High Priority

<u>Policymakers - Regulatory Development</u>

1.1 Create "Early Mover" Infrastructure Incentives

Financial incentives for stations are helpful, but are not sufficient to incentivize energy firms to invest during the pre-commercial transition period. An early mover incentive is needed. For example, CARB's Clean Fuels Outlet infrastructure regulation could be enforced with modifications to address this. CARB will be considering revisions to this regulation concurrently with the ZEV Regulation in 2010 to ensure infrastructure is in place for ZEV vehicles. A second incentive tool would be modifications to the Low Carbon Fuel Standard (LCFS) such as a multiplier for ultra-low carbon alternatives including hydrogen and electricity. This decision would have to be carefully judged based on long-term (post 2020) carbon reduction goals.

1.2 Ensure Modified ZEV Regulation Provides a Robust Signal

CARB's ZEV Regulation is being revised with a completion date of late 2010. The initial goal of the revision is to consider revised volume requirements in Phase 4 (2015-2017) to set a path towards California's 2050 GHG goals. However, the policy should also consider new post-2017 requirements and broadly outline the need for multiple technologies to achieve the 2050 GHG goals.

<u>Automotive Firms</u>

1.3 Provide Vehicle Volume Commitments

The California ZEV Regulation is a driving factor for FCV volumes – at least 25,000 FCVs are anticipated by 2017 in California (depending on ZEV credit structure and automotive firm compliance). However, if infrastructure is sufficient, higher volumes could occur by 2017, or shortly after, as vehicle OEMs would prefer to amortize investments quickly[2]. However, automotive firms need to provide specific fuel cell vehicle commitments for the four communities, in the interim years, to provide certainty to energy firms' investments. This can be accomplished privately with energy firms rather than with public announcements.

<u>Energy Firms</u>

1.4 Build a Refueling Network Focusing Initially on Four Hydrogen Communities

Early Infrastructure investments need to focus on four hydrogen communities in the LA Basin - Santa Monica, Irvine, Torrance, and Newport Beach, as identified by the CaFCP. These "clusters" of stations and vehicles are necessary to concentrate the infrastructure and early vehicle deployments. Of the 25 hydrogen stations in California today, there are approximately 6 stations in the LA Basin that are open access and useable by multiple automotive firms. It is recommended that this be expanded (at a

[2] FCVs can be cost competitive with other advanced vehicle alternatives at high mass-production volumes. Several studies (Kromer and Heywood 2007) suggest that ultimately, mass produced FCVs could be less expensive than battery EVs.

minimum) by an additional 8-16 stations by 2011, 20-30 stations by 2014, and 40-55 stations by 2017[3]. Refer to the research summary box above.

Policymakers – Strategic Visioning

1.5 Enhance Engagement with the U.S. Department of Energy on Technology Deployment

California's State agencies and industry partners need to reach out to the U.S. DOE and enhance their role as a strategic partner in the LA Basin infrastructure deployment. Although the U.S. DOE has been engaged on multiple levels on H2 R&D and demonstrations, state policymakers need to bring this to higher level, through increased focus on technology deployment in addition to R&D. This connection could be formed as part of proposals for AB 118. Outreach efforts to Congressional level to support the U.S. DOE budget priorities should continue. This effort can be done by firms independently, or collectively, and it's clear this communication has already begun. CARB and CEC are engaged at high levels with DOE on hydrogen and fuel cell issues.

1.6 Complete Evaluation Criteria for use of State Funds for Hydrogen Infrastructure

Evaluation criteria need to be completed by CEC and CARB, to leverage the recently committed H2 infrastructure funding from CEC. (In April 2009, a 2-year investment plan under AB 118 was approved for 2008-2009 and 2009-2010.) The plan should identify whether the AB 118 funds are restricted to fueling station equipment (vs. fuel production, etc). Vehicle and station placements should follow the "cluster" approach outlined in this and other reports, with close coordination between the energy and automotive firms. (The CaFCP Action Plan provides an additional build-out scenario for stations throughout California.)

TIER 2 – Medium Priority

Policymakers - Regulatory Development

2.1 Ensure California's Renewable Hydrogen Requirement SB 1505 accommodates bio-methane

SB 1505 requires that 33% of hydrogen come from renewable sources once a certain state-wide capacity is achieved. Renewable hydrogen requirements could be met in a number of ways, but only electrolysis is covered in the current law. This is one of the most expensive renewable hydrogen routes. To ensure compliance with SB 1505 occurs in a cost-effective manor, the policy should be clarified to ensure bio-methane resources can be used as a compliance mechanism.

Policymakers - Outreach

2.2 Encourage Regional Leadership in Early Hydrogen Communities

Local government needs to become actively engaged with the industry partners to ensure a smooth deployment of stations and vehicles. Local incentives should be developed to encourage retail fuel station owners to participate with energy firms[4]. Local leadership can help with station permitting and siting requirements, provide local vision for network design, and dedicate regional staff to spearhead these activities.

2.3 Clarify Overlapping State Policies

There are a number of policies that provide incentives or requirements for hydrogen and fuel cell vehicles. A communication tool is needed to help the private sector understand which policies are important and in some cases competing. For example, a firm that

[3] Although a network plan should be defined in terms of installed fuel capacity (allowing industry flexibility to define # of stations). The minimum # of stations outlined here ensures a regional coverage of hydrogen capacity for network connectivity.

[4] Property taxes and/or fuel sales taxes could be reduced with revenue offset from AB 118 funding.

accepts AB 118 funds as a cost share will be obligated to comply with SB 1505. Additionally, stations funded with AB 118 cannot be used as part of their LCFS compliance. It may be important to consider modifying these rules to ensure incentives reinforce each other instead of oppose one another.

Energy Firms

2.4 Continue to Develop Stations with Improved Capacity and Footprint
Hydrogen station technology has advanced to the point where a station capacity of 250 kg/day is possible in an urban hydrogen fueling station. Station development and innovation needs to continue to ensure stations as large as 400-1000 kg/day will be in place by 2017.

2.5 Decision Point for Vehicle Fuel Pressure
Identify a timeframe (~2012) and a collaborative process to reach industry consensus (energy firms and automotive firms) on vehicle hydrogen storage pressure and station technology to support this. Either 350 or 700 bar gaseous storage pressure is sufficient for FCV commercialization, but infrastructure investments need to be focused with common equipment and standards.

2.6 Industrial Gas Companies Participation
The value proposition and stakeholder role of the industrial gas companies (IGCs) will be different than the major energy firms. Some amount of "shared risk" from the IGCs will be needed, and their engagement is required as part of this coordinated investment.

Expanded Collaboration

2.7 Public Private Partnerships (PPP)
It may be appropriate to create a new PPP with industry firms and local/regional government entities. A PPP could help to oversee the public investments while directly coordinating with the private industry on infrastructure planning. Currently, CARB's CaH2Net program and the CaFCP are the lead organizations in California, and added value of a PPP needs to be shown. As discussed in Workshop 4, a clear charter would be required of what this organization would be tasked with before progressing with the idea.

2.8 Consider Holding an Executive Summit
Determine specific stakeholder commitments that would justify an Executive Summit. Such an event would involve senior industry executives and government officials to announce a joint effort on H2-FCVs.

The California Fuel Cell Partnership (CaFCP) Action Plan – March 1, 2009
(Source: CaFCP 2009)

The Action Plan includes the following general themes:

- Station rollout recommendations between 2009 and 2014 in (4) hydrogen communities
- Three geographic programs in California: LA Basin for light-duty vehicles, Bay Area for transit buses, and Sacramento for advanced H2 station testing and standards development
- Predicted vehicle volumes of 50,000 by 2017, as a result of auto partner survey information, though station planning is only defined to 2014
- Recommended state cost-share of 70% on average in early years, $180M commitment through 2014 of combined public-private funding (includes infrastructure in LA Basin, Bay Area, and Sacramento)
- Develop and implement the codes, standards, regulations and permitting processes that will enable the retail sale of hydrogen as fuel, streamlined permitting for stations and enable the use of best-available technology for stations

Table of Contents

1. Introduction

To reach long-term goals for deep reductions in transportation-related greenhouse gas emissions, more efficient vehicles, lower carbon fuels, and electric drive technologies will play important roles. Hydrogen (H2) and fuel cell vehicles (FCVs) are one of many solutions that will be needed to address these challenges. While it is not possible to predict which ZEV technologies will be the market winners, prudent policy suggests we must pursue all promising options (Yang 2009, National Academies 2008). Hydrogen fuel cell vehicles, with their potential to provide the range, high efficiency, rapid refueling, and performance consumers expect while achieving zero tailpipe emissions and dramatically reduced greenhouse gas emissions, are one of these options. (Fuel cells are also unique among ZEVs in their ability to provide motive power for a wide variety of applications including heavy-duty vehicles, ships, and locomotives.)

Because of the long time scales inherent in deploying radically new automotive technologies, early market sales of ZEVs will need to begin before 2020 and achieve significant market share by 2030, to have a major impact on greenhouse gas emissions by mid-century. To ensure the market for FCVs can begin in 2020, pre-commercial deployments are needed over the next 10 years.

Over the past decade, there has been rapid, ongoing progress in the development of fuel cell vehicle technology, and hydrogen refueling systems. Hydrogen and fuel cell vehicles are ready to take the next step toward commercialization: a regional pre-commercial deployment of tens of thousands of vehicles with a concentrated hydrogen fueling network.

As outlined in the Executive Summary, the California Hydrogen and Fuel Cell Vehicle Roadmap Project was developed to provide a targeted forum for discussing the challenges facing this alternative and to conduct a fresh, independent analysis on the topic of a transition to a hydrogen economy in California. The project had the following primary goals:

The work was organized into two components. First, ITS-Davis organized and convened five *multi-stakeholder workshops* to both review technology status, and discuss challenges and solutions for expanding the H2 and FCV markets. Key discussion topics included performance and commercialization metrics, development timing and stakeholder coordination, and policy alternatives that could provide incentives for a hydrogen infrastructure expansion.

Secondly, with expert input from stakeholders, ITS-Davis led several *research projects* that provided independent, long-term insight on the questions of infrastructure growth and vehicle market development in Southern California. The research project areas included 1) a regional station rollout analysis, and 2) a roadmap to low-carbon hydrogen supply. These research projects informed the discussion about hydrogen rollout strategies, and the development of a roadmap report. Separate technical reports on these research projects will be produced as part of the overall project. An expanded description of the deliverables can be found in the box below.

This report is the culmination of the project and represents substantial collaboration between workshop participants and the ITS-Davis researchers. The workshop process was successful, resulting in valuable insights and content for the research, as well as providing a more common understanding between all stakeholders.

The primary goal of this report is to capture insights from the workshops, and to present a realistic Roadmap for a large, coordinated early deployment of FCVs and hydrogen infrastructure in the LA Basin over the next 10 years. While we did not come to a full consensus on all necessary actions, key recommendations are outlined and should be carefully considered to advance the alternative. Interim results from this project provided valuable information for the CaFCP's Action Plan that was developed concurrently.

The following sidebar provides a summary of the deliverables from the project.

H2-FCV Roadmap Study Objectives and Deliverables

The Roadmap Study deliverables are broken down into two categories, defined below. These deliverables are described in later sections of this report. (*Note: WS = Workshop*)

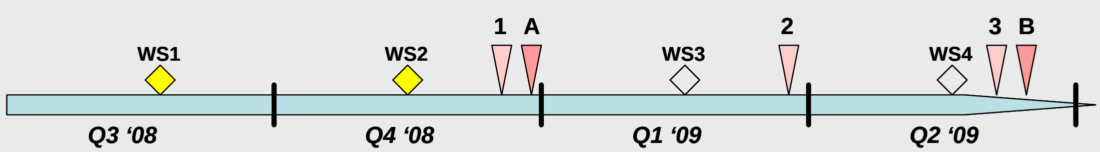
Stakeholder Coordination Topics - driven by workshop discussions

1. **Progress Metrics & Timelines**
   Metrics *are defined as easily measured technical, market or cost indicators and can be used to indicate historical progress or future goals. They should be easily understood by all stakeholder groups.*
   Timelines *indicate the rate of progress toward technical goals and commercialization.*
2. **Infrastructure Business Models**
   A review of existing and potential market factors that affect private investment in hydrogen infrastructure. A key aspect is a review of policy alternatives that could change market factors, creating incentives or market push mechanisms.
3. **2017 LA Roadmap**
   (This report) A culmination of policy and market factors, along with strong stakeholder coordination, that result in a defined vehicle placement and station rollout in a select few communities in the LA Basin for market experimentation.

Research Reports - led by UC Davis researchers

A. **Regional Hydrogen Station Rollout Analysis: LA Case Study**
   A technical and cost analysis of hydrogen station placement and network connectivity in the LA Basin. This modeling effort resulted in several quantitative measures of network connectivity, including time between home and fuel stations.

B. **Roadmap to "Green" Hydrogen Supply**
   This analysis has two focus areas. First, a careful assessment of near-term (2010-2020) delivered cost of hydrogen from renewable feedstocks. Second, a long-term assessment of low-carbon hydrogen options.



Unique Value of This Project

This project provided a unique perspective. Through the workshop process the stakeholders came to consensus on the current status of FCV and hydrogen station technologies, and the likely timeline for their future development. The workshop participants defined key "metrics" for each technology, which enabled the group to examine progress toward commercialization. Defining and agreeing upon progress metrics and timelines increased awareness and confidence among stakeholder groups. Having this common understanding is essential to build consensus on the challenges and actions required. Once this confidence had been strengthened, it opened the way for a discussion of infrastructure business models and honest assessments of why infrastructure growth is not keeping pace with vehicle deployments. The intention is to identify market barriers affecting the investment plans and to try to outline a means to remove the barriers, either with new public policy (incentives or regulation) or cooperation amongst private sector firms.

The final step in this exercise of stakeholder cooperation is to jointly outline a roadmap, or collection of discrete actions required to advance the pre-commercial deployment of H2 and FCVs through the next decade. This summarizes the discussions of the five workshops – at the beginning of the project there was considerable debate and miscommunication, whereas near the end there was a much stronger common understanding of technology status, policy landscape and awareness of differing viewpoints and motivations among the stakeholders.

Roadmap Report Structure

The structure of this report follows the outline in the box above. Chapters 2 and 3 outline the most relevant metrics identified by the three stakeholder groups (policymakers, automotive industry, energy industry), with Chapter 2 focusing on public policy metrics and Chapter 3 focusing on automotive and energy industry metrics.

Characterizing stakeholder progress and development goals is framed in terms of “metrics” (e.g. easily measured technical, market or cost indicators) that describe progress toward commercialization, or a social goal (in the case of public sector metrics). Part of the effort is identifying which metrics are most important for the different key stakeholder groups: energy firms, automakers, and the government. These metrics need to be easy for all stakeholder groups to understand and improve confidence between stakeholder groups.

The next few chapters delve into the timelines, analysis and specific recommendations. Chapter 4 describes the development timelines for station placement and vehicle development and directly relates it to near-term policy goals over the next 10 years. Chapter 5 discusses the station network analysis, providing insights into how many stations are necessary for certain numbers of vehicle, and outlining the concept of co-locating stations and vehicles (clustering) in the pre-commercial phase. Chapters 6 and 7 review the infrastructure business models and relates it to public policy, both existing and potential. Chapter 8 provides concluding comments and potential follow-on stakeholder discussion sessions.

2. Public sector metrics - Government GHG and energy policies

Metrics – public sector

Long-term, broad, climate goals

- GHG Emissions: By 2020 reduce GHG emissions to 1990 levels (AB 32)
- By 2050 Reduce GHG emissions 80% below 1990 levels (California EO S-03-05)

Sector-specific catalyst policies

- ZEV Volumes: 7500 pure ZEV credits by 2014; 25,000 pure ZEVs by 2017 (CA ZEV Regulation)
- Fuel Carbon Intensity: 10% reduction in carbon intensity of all fuel sold in state by 2020 (CA Low Carbon Fuel Standard)
- Cost Effectiveness of government funding incentives for H2-FCVs in meeting ZEV and GHG goals. (e.g. CaH2Net; US DOE Tech Validation Program, AB 118)

Key messages

- H2-FCVs are one of the few alternatives available that can achieve deep carbon reductions by 2050 (along with BEVs)
- H2-FCVs can help meet goals for GHG reductions. Near term, they offer ~50% reductions in well-to-wheel GHG emissions/mile compared to gasoline vehicles (assuming H2 made from natural gas). In the long term, emissions can be near-zero with renewable electrolysis or CCS.
- To meet 2050 GHG goals, the LDV sector will need to be largely ZEVs by 2050 which, when factoring in fleet market growth timelines, requires markets for ZEVs be established by 2020.

In this chapter, we describe the key metrics used by policymakers to evaluate H2-FCVs with respect to policy goals. We begin with a background discussion of California's existing policies.

California's Existing Policy Context

Energy challenges have increasingly led to comprehensive, and aggressive social policy goals in California. Although California's alternative fuel and vehicle policies began by addressing regional air quality challenges, they have now expanded their focus to reducing greenhouse gas (GHG) emissions and petroleum consumption. The primary California and Federal policies effecting hydrogen and fuel cells are listed in Table 2 below.

Over the past 10 years, the ZEV regulation has driven much of the development in FCVs. Recent analyses have highlighted the importance of ZEV technologies for meeting longer term GHG reduction goals. The state of California is currently reviewing its GHG and ZEV regulations to develop a coordinated policy framework for GHG reductions, recognizing the need for multi-decade lead-times to substantially change the automotive fleet.

The California Air Resources Board (CARB) is working on regulations to meet the goals for the 2020 GHG reductions set forth in California's Global Warming Solutions Act of 2006 (AB 32), a return to 1990 levels by 2020. In addition, the state has long-term climate goals of 80% reduction of GHGs by 2050 (from 1990 levels), which will require revolutionary vehicle technologies and low-carbon fuels (Executive Order S-03-05).

Table 2: California and Federal Policies on alternative transportation fuels and vehicles

California	Scope	H2-FCV Relevance
ZEV Regulation	7500 pure ZEVs by 2014 25,000 pure ZEVs by 2017	++
AB 1493 ("Pavley Bill") – vehicle CO2 standard	-30% GHGe by 2016	0
SB 76 – Funding for CaH2Net program	$6.5M/yr, yr-by-yr	++
AB 118 – Funding for hydrogen infrastructure	$40 M over 2 yrs	++
SB 1505 – Low-carbon H2 production requirements	33% renewable @ 10k veh	++
AB 32 – 2020 comprehensive climate change law	1990 levels by 2020	+
Executive Order – 2050 GHG emission goals	80% below 1990 by 2050	++
LCFS – Low Carbon Fuel Standard	-10% carbon by 2020	+
Clean Fuels Outlet	Provide alternative fuel supply once 20K veh on road	++
Federal		
CAFÉ	35.5 by 2016	0
PHEV, biofuel tax breaks	$0.54/gal EtOH, $7.5k/PHEV	0
U.S. DOE R&D for fuel cell vehicles H2 production, delivery and storage	Reinstated into U.S. DOE budget, Oct 2009	++
U.S. DOE H2-FCV demo program (TechVal2)	Not yet appropriated	++

California's ZEV Regulation has already resulted in significant industry investment in battery electric and hydrogen fuel cell vehicles. CARB strived to make its regulations technology neutral so that automakers will pursue options they believe have the greatest opportunity for mass market appeal. The ZEV policy has indirectly led to the introduction of hybrid electric vehicles (HEVs) in 2000 and subsequently to the development of plug-in hybrid electric vehicles (PHEVs) with lithium-ion batteries, pure battery EVs, and hydrogen fuel cell vehicles. Different automakers have emphasized varying types of ZEVs. The ZEV Regulation and other long-standing policies are now being redefined as part of the comprehensive strategy under AB 32 and Executive Order S-03-05 to combat climate change.

Defining Policy Metrics

In the simplest terms, policy "metrics" should measure how well H2-FCVs can help meet policy goals (see Table 2). Even though this project is focused on the pre-commercial transition period (next 10 years), project stakeholders were unanimous in the view that the public sector metrics should focus on long-term social goals. A major focus was measuring how hydrogen and fuel cells could contribute to long term GHG reduction goals. Both California and the US have stated goals of an 80% reduction in GHG emissions by 2050. California's GHG goals are shown in Figure 1 below.

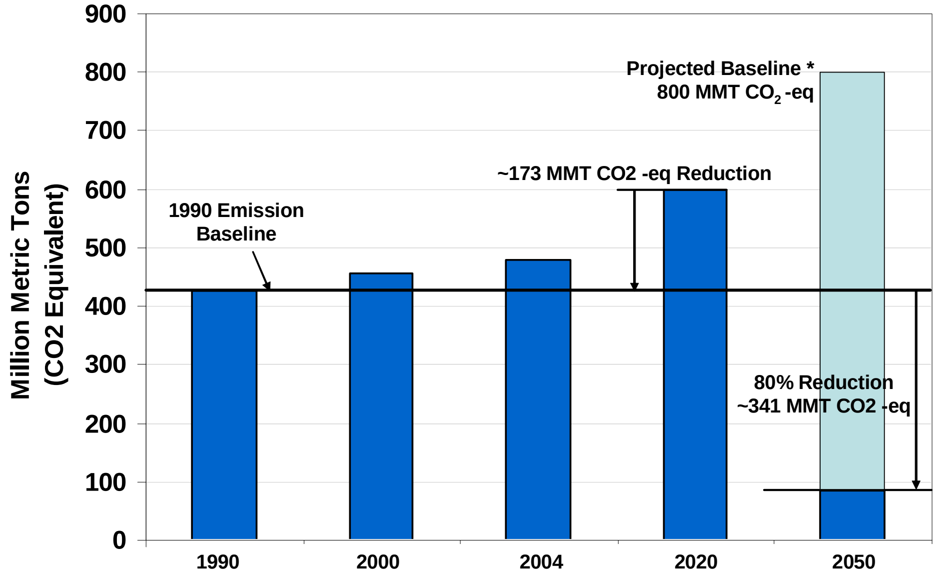


Figure 1: California's 2020 GHG Regulation (AB 32) and 2050 GHG Goal (EO S-03-05)

In defining these metrics, the following specific recommendations emerged from the workshops:

- Focus on long term social goals (CO_2 and petroleum reduction) as metrics,
  - o Specifically show how H2-FCV scenarios will contribute to these goals
- Show projected progress in 2030 towards the 2050 goals,
  - o 2030 is a more tangible milestone in corporate planning
- Show government funding committed relative to the # vehicles and stations placed

Evaluating the role of H2-FCVs

Achieving California's 2050 targets will be extremely challenging and will require multiple vehicle and fuel solutions, along with consumer behavior and market changes. A recent study confirms how challenging these reductions will be (Yang 2009), revealing that no one solution will result in the full 2050 GHG reductions required in California. Other studies (Greene 2007) enhance this conclusion when pointing out the decades-long timeframes required to create new market share of an alternative vehicle (refer to Figure 2 below). Policies will be needed to provide support throughout the lengthy pre-commercial period.

Figure 3 illustrates that hydrogen has the potential to dramatically reduce well-to-wheels GHG emissions compared to gasoline internal combustion engine vehicles, gasoline hybrids and ethanol vehicles. Part of hydrogen's advantage comes from the FCV's higher efficiency: hydrogen FCVs have 2-3 times the "tank to wheels" fuel economy of comparable gasoline ICEVs (Kromer and Heywood 2007). The second factor is the "well to tank" carbon intensity of the fuel itself, which depends on the fuel production and delivery pathway. In the near term, most hydrogen is likely to come from natural gas, via onsite reformation at refueling stations (NRC 2008) giving roughly half the well-to-wheels GHG emissions of an advanced gasoline ICEV. In the longer term, hydrogen enables use of a variety of near-zero carbon pathways including hydrogen from renewables like biomass, wind and solar, and fossil sources with carbon capture and storage (NRC 2008). Along with battery electric vehicles, hydrogen is the only option that could enable use of these resources in transportation. A recent assessment by the National Academies confirms that hydrogen is an important part of a portfolio of options to achieve deep carbon cuts in transportation by 2050.

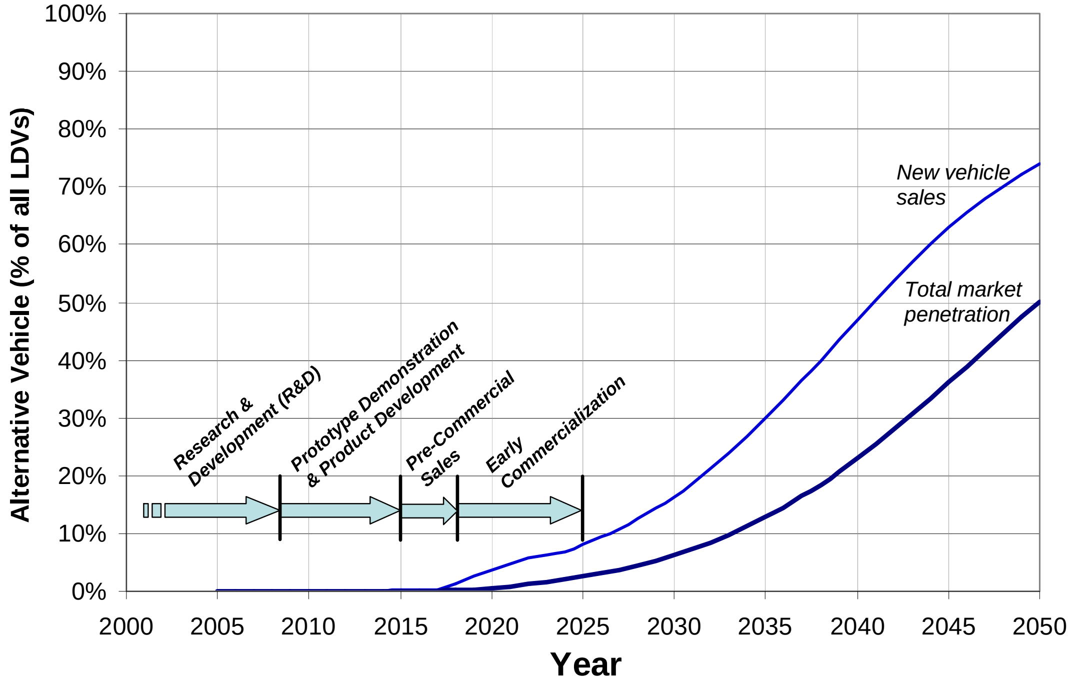


Figure 2: Hypothetical alternative vehicle market growth curve, and development phases prior to commercialization *(Reference: Cunningham et al. 2008)*

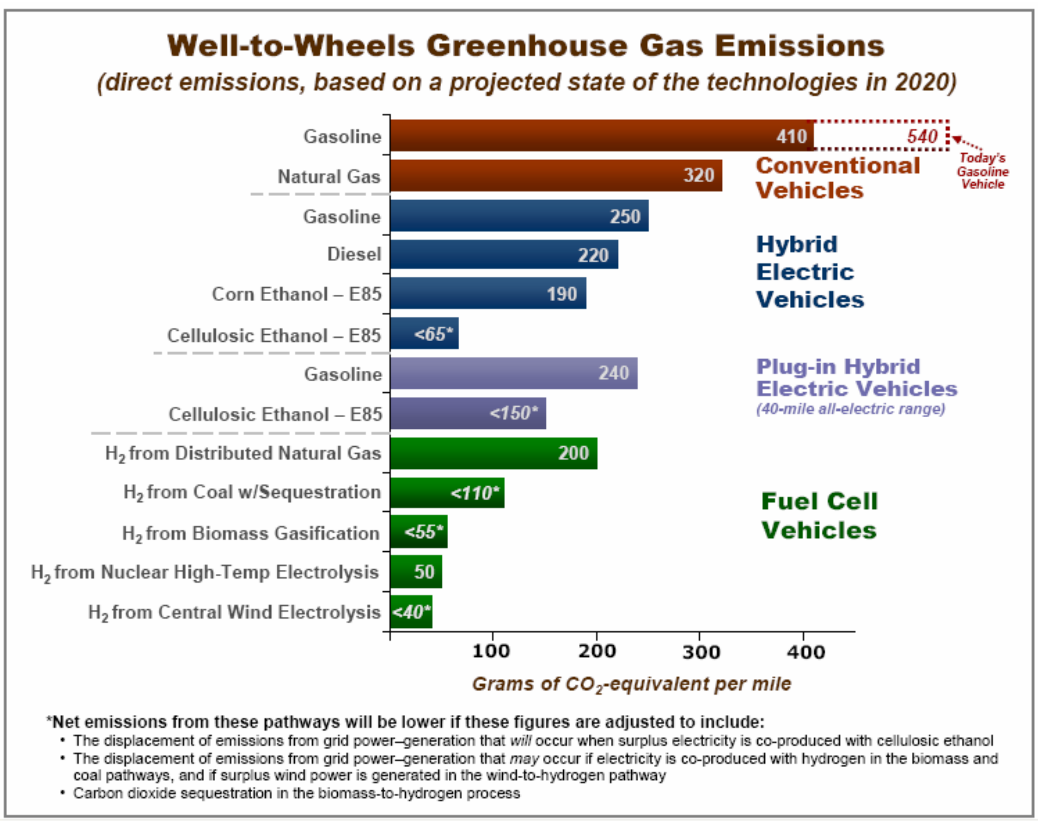


Figure 3: Well to wheel performance of FCVs relative to other alternatives *(Reference: U.S. DOE 2009)*

Starting from Today

The next two years (2009-2010) are an especially important time to ensure correct policy signals are put in place and private investment momentum is maintained for hydrogen and FCVs. In 2009 and 2010 revisions and detailed implementation plans for several key sector-specific policies will be developed, including the ZEV Regulation, the Low Carbon Fuel Standard, the Clean Fuels Outlet, AB 118, the Pavley vehicle GHG regulations, and federal program support for hydrogen.

These policies will directly influence early commercialization of H2 and FCVs over the next 10 years, a stage necessary to set the path to 2050 (Figure 2 shows how critical it is to launch alternative vehicle markets by 2020 given the long timeframes involved in vehicle fleet growth). This is also an important year with unprecedented conditions for the automotive industry. Although the industry is going through financial and market challenges, with revised product plans that include more fuel efficient vehicles, it is a difficult time for the automotive firms to be planning large, risky production plans for an advanced vehicle such as the FCV.

3. Private sector metrics – State of FCV and H2 technology and commercialization

Metrics - Automotive sector

- On-road durability (5000 hrs)
- Vehicle range (300 miles)
- Vehicle purchase cost (primarily), operating cost (secondarily)

Metrics - Energy sector

- Delivered fuel cost comparable to other fuels on cents/mile basis ($5/kg)
- Vehicles served per station (function of station fuel dispensing capacity, # pumps)
- Carbon emissions per kg-H2 (well to tank)

Primary recommendations (Executive Summary)

2.4 Continue to develop stations with improved capacity and footprint
2.5 Decision point for vehicle fuel pressure (and corresponding station pressure)

As summarized in the recent U.S. DOE report to Congress (U.S. DOE 2009) and the 2008 National Academies of Sciences study on the hydrogen transition (NAS 2008), fuel cells and hydrogen have demonstrated tremendous progress through improved performance, durability, and reduced costs. Advances have also occurred in hydrogen fuel production which, when used in a fuel cell vehicle can reduce greenhouse gas emissions between 40-90% compared to today's cars and can be made from a diverse variety of domestic resources, including natural gas, coal with sequestration, biomass, geothermal, wind and solar.

Automotive metrics

The following automotive metrics were the recommended by workshop participants as the most effective in evaluating FCV progress and commercialization potential:

- Durability (fuel cell system)
- Fuel economy
- Vehicle range, and
- Vehicle cost at varying production volumes. (This is important as it will show when FCVs will reach commercial prices given a sales growth projection)

Figure 4 shows how range and fuel economy performance today already meet the 2015 U.S. DOE targets, though durability remains a challenge. Fuel cell vehicles operating with 350 bar fuel storage are approaching the 300 mile range. FCVs at 700 bar far exceed that. The metric that needs improvement by 2015 is on-road durability. Large gains have occurred here in recent years, but more is needed. At the EVS-24 conference in May 2009, Daimler reported 3000 hours and 150,000 km of operations for its F-Cell fuel cell vehicle (Mohrdieck 2009).

	Today	2010	2015	Units
• In-use durability:	2000	2000	5000	hrs
• Vehicle range:	280-400 *	250	300	miles / fill
• Fuel economy:	72	60	60	kg-H2/mi
• Fuel cell system cost:	73	45	30	$/kW (no tank)

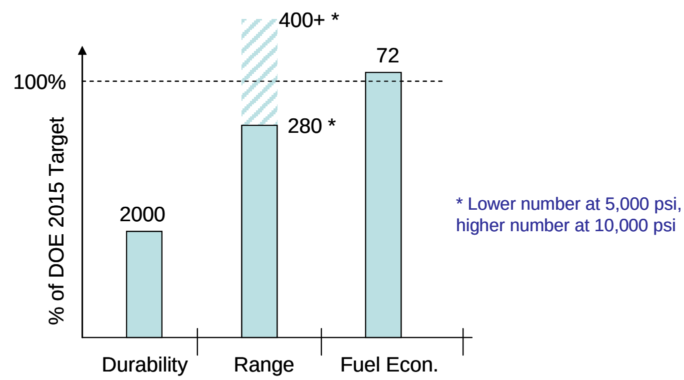


Figure 4: Automotive metrics and current progress

Potentially the most important metric is the fuel cell system and FCV cost. Drawing from a recent MIT study (Kromer and Heywood 2007) and the recent NAS hydrogen study (NAS 2008), costs of FCVs at high volumes are expected to be within a few thousand dollars of advanced ICE vehicles, while pure battery vehicles will cost perhaps $6000-10,000 more. These costs assume mass production at 100,000s of vehicles per year.

Table 3: Incremental vehicle cost compared to an advanced ICE in year 2030
(at high volume manufacturing, 500,000 units)
Reference: Kromer and Heywood 2007

Vehicle type	Incremental vehicle cost ($)
Advanced ICE	--
HEV	+ 1,900
FCV	+ 3,600
PHEV-30	+ 4,300
BEV	+ 10,200

More specifically, the NRC study showed a steady decline in FCV costs as volume production ramped up to 1-2 million vehicles. Figure 5 below shows this cost reduction trajectory. An additional data point and comment is overlaid onto the original NAS figure to emphasize FCV cost reductions at the specific vehicle volumes in the ZEV Regulation.

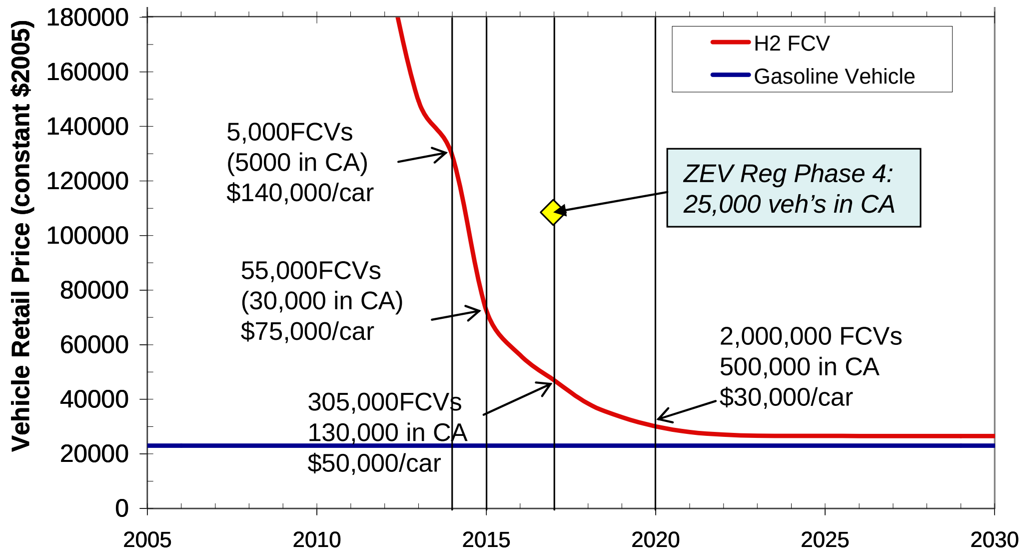


Figure 5: Automotive fuel cell vehicle costs (NAS 2008)

Overall, the automotive stakeholders remain confident FCVs can be commercialized and they have development plans to do so. Most of them see FCVs as the most promising long-term alternative, regardless of whether they are investing in PHEVs or BEVs or not.

Energy sector metrics

In the workshops, we also discussed which metrics were most important for the energy firms. The following metrics were the recommended priorities

- Vehicles served per station (function of capacity and # pumps)
  - As station technology improves, larger station sizes will become viable
  - As vehicle efficiency improves, station capacity can serve more vehicles
- Station availability (down time and physical access)
- Fuel cost (function of all upstream stages including production)
- Physical space requirements of station (can H2 equipment fit into a typical retail site)
- CO_2 footprint per kg-H2, and
- Number of energy firms engaged in the hydrogen alternative

An underlying factor in the metrics above is station size and on-site hydrogen production technology. It was noted that current technology is limited to approximately 250 kg per day (kg/d) in a typical urban fuel station location. Stations as large as 1,000 kg/d will be required in 2020 for early commercialization volumes. Recent analysis by the U.S. DOE suggests that 10-15% of existing urban gasoline stations would be appropriate for a modification to use hydrogen alongside gasoline (Gronich 2007) A key area of research and demonstration, therefore, is to investigate new ways to package on-site equipment for a smaller "footprint" – this will include building alternatives, but also novel new on-site hydrogen storage systems.

In relation to the CO2e carbon footprint, GHG lifecycle emissions associated with hydrogen production was also discussed in Workshop 3, drawing from the U.S. DOE and MIT studies (The U.S. DOE results are shown in Figure 3). Most hydrogen is made today from natural gas which yields a 50% reduction in well to wheels GHG emissions compared to a gasoline car and about 10-40% compared to a gasoline hybrid (NRC 2004). Hydrogen can be made from renewables such as biomass, wind or solar or from fossil fuels with carbon capture and sequestration. These pathways provide reductions of up to 90% over a comparable gasoline ICEV.

U.S. DOE Cost Targets:	**2010**	**2015**	**Units**
• H2 total cost, delivered: [1]	3.00	2.50	$ / gge

Technical station metrics - *LDV stations only*

• Station size (existing): 25 - 50 kg/day

• 100 kg/day stations now being built, 250 kg/day technically feasible; 1,000 to 1,500 kg/day is a goal

Infrastructure Network Metrics - *Existing, LDV stations only*

• Total stations:	16 (27)	So.CA (entire state)
• # Open access: [2]	5 (30%)	So.CA stations
• Network fuel supply:[3,4]	**kg/day**, LA Region only	

2008:	Supply = 165;	Demand = 100
2010:	Supply = 165;	Demand = 270

1. *Corresponds to a station size of 1,500 kg/day*
2. *Multiple OEM use (with agreement), good physical access*
3. *Data based on CaFCP 2007 Deep Dive Survey (used with permission)*
4. *Optimum supply = 1 kg/veh/day = 0.7 kg dispensed + 0.3 kg excess*

Figure 6: Energy sector metrics and current progress

The infrastructure network metrics table reveals the challenges on the fuel supply side. Only a third of the H2 stations in Southern California have sufficient access to consider it “an open” station. Ensuring that each new station provides more access is critical. The data also reveals that although sufficient supply capacity exists today, by 2010 capacity will be outpaced by demand.

Overall, energy firms believe that building a H2 supply and distribution infrastructure is technically feasible, but not economically attractive and will require a long transition period (10-20 years). This long transition means a profit won’t occur for 10+ years. This lack of a near-term business case may be the single largest reason the energy sector is hesitant about hydrogen. Clearly policy incentives will be needed to reduce this risk and uncertainty.

4. Timelines for technology deployment

Key messages

- It takes ~2 years to complete an H2 station (identifying site, development, and certification). This does not include development of advanced on-site fuel production equipment.
- FCV volumes are expected to be 25,000 between 2015 and 2017, requiring fully certified production vehicles. Vehicle development needs to begin by 2010 to reach the market by 2015.
- Before state incentive funds can be spent, 1-2 years are required for State officials to identify spending priorities, conduct a bidding process, and put contracts or grant awards in place.
- 2009 – 2010 is an important period for State policy development that will set important short-term and long-term signals for industry related to alternative fuels and GHG emissions (ZEV Reg, LCFS, AB 32 Cap/Trade, AB 118 investments, etc)

Along with the metrics, understanding stakeholder timelines are essential for near-term planning. One of the key issues addressed in the workshops was the timing for placing vehicles and infrastructure. We considered timelines for each major stakeholder group separately (automotive, energy government). In consultation with the workshop participants, we developed timelines for each stakeholder group that account for factors such as bringing the technology to maturity, building up manufacturing capability and suppliers, siting, permitting, etc.

Stakeholder Lead-times

To begin low-volume mass production of FCVs by 2015 (e.g. 10,000s of units per year), major research and development (R&D) needs to be completed and a production development program started by 2010. The 4-5 year process of vehicle production development includes engine and vehicle design, component and system performance and durability testing, and test vehicle evaluation. It also includes supplier development and manufacturing preparation. This is outlined in Chapter 7. Depending on the vehicle, this can be upwards of a billion dollar investment. Because of the scale of this commitment, vehicle production volumes are set far in advance. If vehicle changes are expected before the next volume production (2018 in this case), a next generation vehicle may begin development before the previous generation begins production. This is shown in Figure 10.

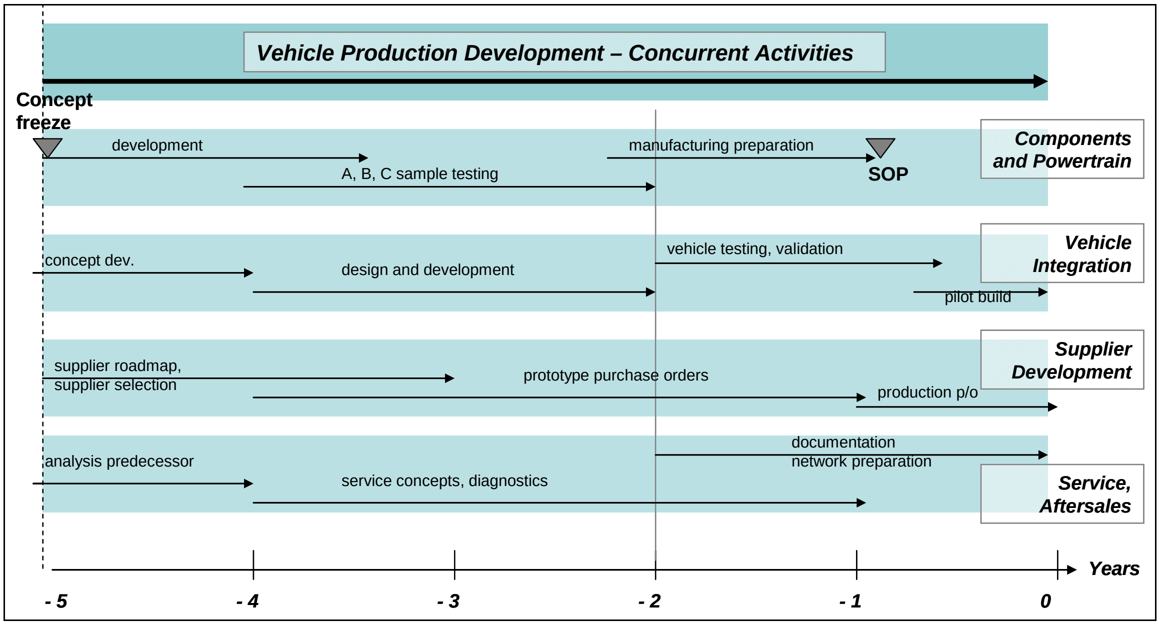


Figure 7: Automotive lead times for production vehicle programs
(Contributions from Automotive Fuel Cell Cooperation (AFCC) and Daimler)

The development and construction of hydrogen stations is also a multi-year process. Although industrial hydrogen production is well established with large-scale, centralized steam methane reformers (SMR), substantial research is on-going to develop small SMR units that are compact and cost effective for on-site production at refueling stations. Individual stations can take up to two years each for siting, facility preparation, site specific final equipment development, construction, and permitting/approval. This later step, permitting/approval, can vary widely by jurisdiction and largely depends on whether local officials are familiar and comfortable with hydrogen as a consumer fuel.

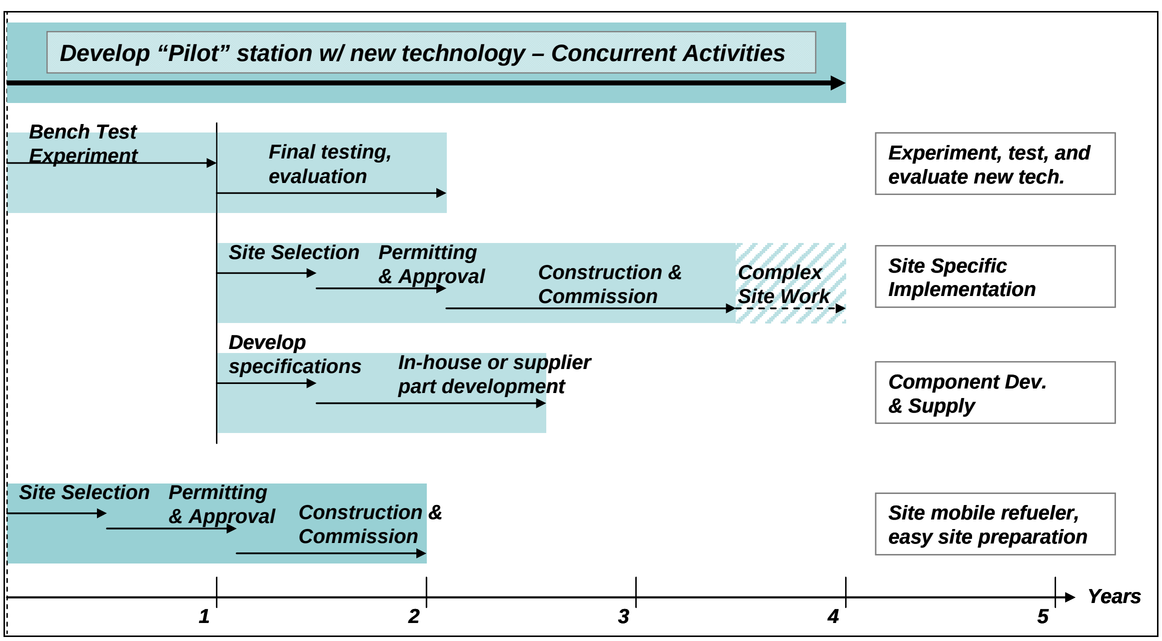


Figure 8: Energy industry lead times for hydrogen stations, both experimental pilot and mobile
(Contributions from Shell Hydrogen and Chevron)

For the government policy development timelines, there are several tasks included in Figure 9. A critical, but commonly underestimated task is the need for on-going outreach and communication at all levels. Outreach could be led by state agency officials and be directed at various audiences, including local elected and appointed officials (leadership and station permitting), the general public (especially in the area of large scale vehicle deployments), legislative officials, and the federal government. There should be a dedicated team for this activity recognizing it's increased importance now that large scale deployments are about to begin. A second key task that will require time for government officials is the development of an investment plan and disbursement of state funds for hydrogen infrastructure. AB 118 currently outlines the State's commitment to $40M over the next two years. Time will be required for the development of the plan, conducting a proposal and bidding process with the private sector, and completion of contracts or grant awards for selected partners.

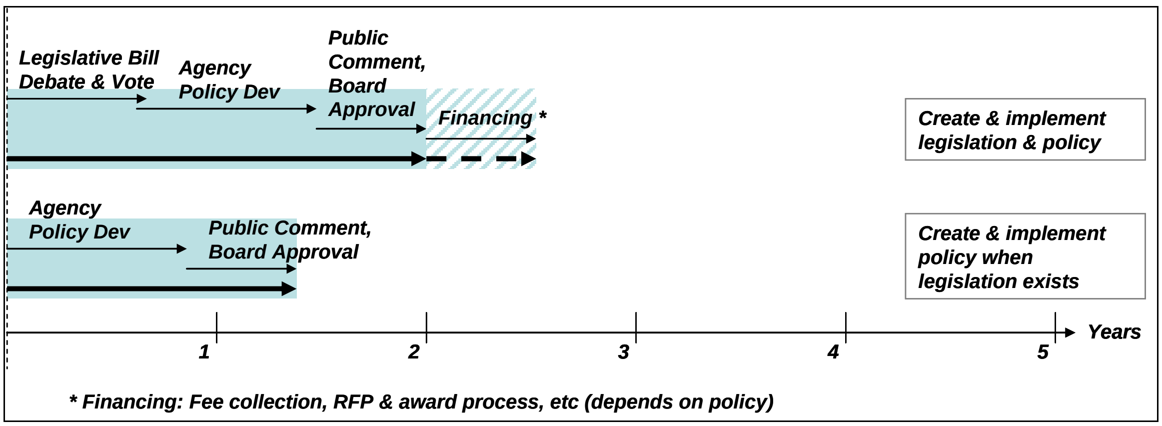


Figure 9: Government lead times for policy development, both with and without existing legislation

Timelines

Figure 10 combines the lead-times for all three stakeholder groups over the next 10 years to effectively launch H2-FCVs in California. By overlaying individual stakeholder timelines in such a way, a plan can be developed with joint stakeholder coordination and decisions. The goal is to provide a planning tool for stakeholder groups to communicate with each other and increase confidence/ consensus around joint milestones.

The figure maps the simplified stakeholder lead-times against the ZEV Regulation Phases between today and 2020. Given that the Phases require increasing H2 and FCV volumes, there is a continuous placement of stations and vehicles over the timeframe. For example, FCVs required for Phase 3 volumes are in the finishing stages of a multi-year development program. And the next generation of FCVs for the higher volumes in 2015 have production development programs that are about to be kicked off today. Because the lead-times to place a station are smaller than developing a vehicle program, the planning can occur a bit closer to the time of fuel demand, but still require pre-planning and coordination. The colors on the station and vehicle bars correspond to the colors of the Phase they apply to.

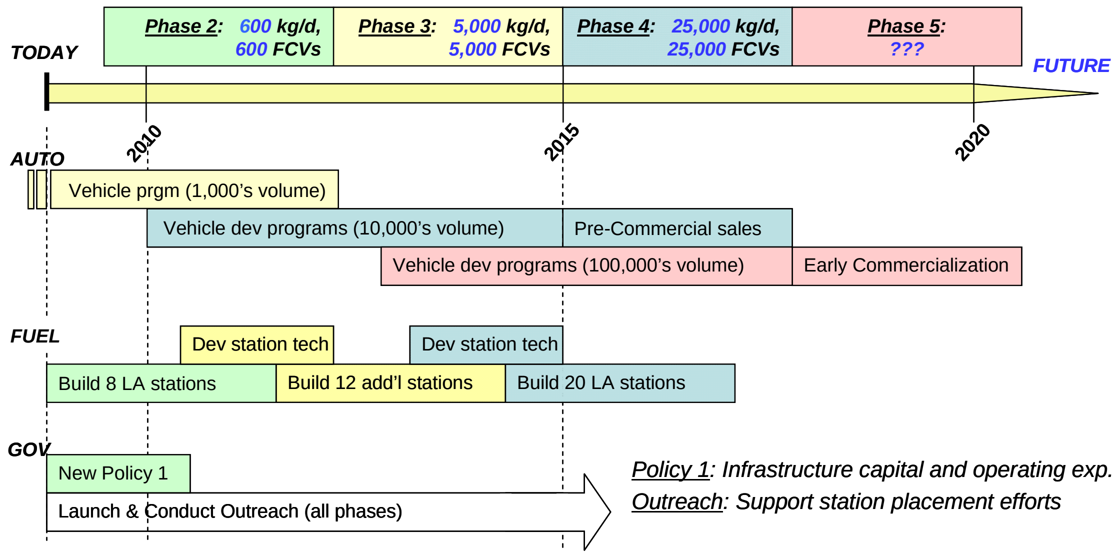


Figure 10: High-level stakeholder timelines mapped against estimated ZEV Regulation vehicle and fuel volume requirements (grouped by phases of Regulation)

Joint Stakeholder Decisions

Timelines can be used to outline resources necessary once decisions have been made. However, they can also illuminate when key upcoming decisions need to be made. Figure 11 outlines several high level decisions that affect multiple stakeholders and are necessary for the State's hydrogen plans to move forward. This includes:

- **2009-2010: Coordinate Vehicle and Station Placements**
  A number of industry stakeholders have chosen the 4 "cluster" areas in the LA Basin, for initial concentrated deployment of vehicles and stations. Detailed plans need to be made for which cluster moves first. Station placement plans need to commence immediately to avoid potential supply capacity shortfalls as new FCV fleets are arriving in 2010. Public-private teams need to be formed around specific station proposals to coordinate expected vehicle usage, station development, and potential local and State incentives.

- **2010: Policy Development in California**
  In late 2009 and throughout 2010, CARB will be developing a revised version of the ZEV Regulation and potentially the Clean Fuels Outlet station regulation. The LCFS will also be progressing and may offer additional support to very low carbon fuels. Decisions on these policies are critical for sending robust investment signals to the private sector as they prepare for programs that take several years.

- **2010 – 2011: Planning for ZEV Phase 3 (2012-2014)**
  Throughout the next few years, additional State policies need to be developed, including spending priorities for the AB 118 investment funds. Station planning and construction needs to begin to ensure sufficient station capacity is in place by 2012-2014 when larger FCV deployments occur.

- **2012 – 2013: Consensus on vehicle fuel pressure**
  There will be several gaseous fuel pressure levels in FCVs over the next few years. But fuel and automotive stakeholders have emphasized that by 2013, a consensus is required for the preferred fuel pressure so production vehicle and station designs can be focused on one concept.

- **2014 – 2017: Expanding deployments**
  Continued planning and construction of ever-larger stations is necessary keep pace with rapidly expanding ZEV deployments. A larger use of renewable hydrogen is anticipated as SB 1505 comes into full effect (policy agreement on role of bio-methane is needed).

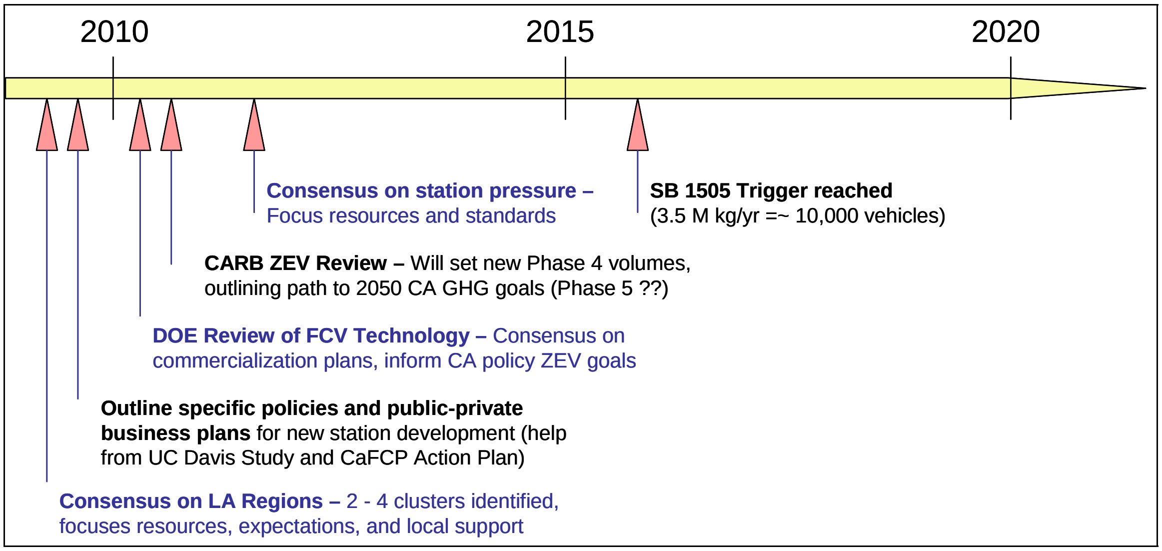


Figure 11: Joint stakeholder decision milestones

5. Infrastructure rollout scenarios in the LA Basin – Creating hydrogen clusters

What's in this section

- Cluster strategy for early H2 station build-out; role of connector stations
- Station placement analysis (travel time analysis) – starting from existing and planned LA stations
- Network build-out criteria (consumer convenience, cost, refueling experience, network growth including new clusters)
- Infrastructure Build-out Costs and investments, including renewable H2

Primary recommendations (Executive Summary)

1.3 Provide vehicle volumes commitments (OEMs)
1.4 Focus and build initial infrastructure by serving four hydrogen communities

There is rapid, ongoing progress in development of both fuel cell vehicle technology, and hydrogen refueling systems. Although hydrogen and fuel cell vehicles are not yet ready for full commercial deployment, they are ready to take the next step toward commercialization. This is widely seen as a "networked demonstration" in a localized region or "lighthouse city," involving hundreds to thousands of vehicles and an early network of tens of refueling stations. Because of California's ZEV regulation, Southern California has been proposed as an ideal site for this early introduction of hydrogen vehicles and is a major focus of interest worldwide (Gronich 2007, Melendez 2007, NAS 2008, Greene et al. 2008). [5]

Developing a successful early hydrogen refueling network in Southern California, even at the relatively small scale envisioned for 2009-2017, requires a coordinated strategy, where vehicles and stations are introduced together. A major question is how many stations to build, what type of stations, and where to locate them. Key concerns include fuel accessibility, customer convenience, quality of refueling experience, network reliability, cost, and technology choice.

In this section, a strategy of "clustering" is explored. Clustering refers to the focused introduction of hydrogen vehicles in defined geographic areas such as smaller cities (e.g. Santa Monica, Irvine) within a larger region (e.g. LA Basin). By focusing initial customers in a few small areas, station infrastructure can be similarly focused, reducing the number of stations necessary to achieve a given level of convenience. We evaluate the potential for clustering to improve customer convenience, reduce refueling network costs, and enhance system reliability.

We analyze a variety of "clustered" scenarios for introducing hydrogen vehicles and refueling infrastructure in Southern California over the next decade, to satisfy the requirements of the California ZEV regulation. For each scenario we estimate:

- Station placement within the Los Angeles Basin
- Convenience of the refueling network (travel time to stations)
- Economics – capital and operating costs of stations; cost of hydrogen for different station scenarios.

We also discuss transitional strategies for the choice of hydrogen supply pathways, as the network expands. A transitional cash flow analysis is carried out by ITS-Davis to illustrate the

[5] Automakers have announced plans to bring several hundred fuel cell vehicles to California in the next three years, and are regulated to produce thousands of zero emission vehicles starting in 2012. However, the energy companies, who have been leaders in hydrogen station demonstrations, do not have the same near-term requirement to build the next round of hydrogen stations.

investments that might be needed over time to bring hydrogen fuel to cost competitiveness with gasoline.

Key Findings

Through a series of interviews with expert stakeholders, we developed scenarios for FCV volumes, hydrogen demand, station placement, and numbers of stations in LA, for 3 time periods:

- 2009-2011: 636 FCVs (using an average of 445 kg H2/d) and 8-16 stations
- 2012-2014: 3442 FCVs (using an average of 2410 kg H2/d) and 16-30 stations
- 2015-2017: 25,000 FCVs (using an average of 17,500 kg H2/d) and 36-42 stations

We assume vehicles and stations are placed in 4 to 12 "clusters" identified by stakeholders as early market sites (Figure 12). Some connector stations are added to facilitate travel throughout the LA Basin.

We used spatial analysis methods to develop two measures of consumer convenience, the ***average travel time*** from home to station, and the ***"diversion time"*** (average time to a station while traveling anywhere in the LA Basin). Our results suggest that clustering is a very effective way to provide good access to fuel, even with a small number of stations.

When vehicles and stations are co-located in clusters, scenarios with as few as 8 to 16 initial stations, located in 4 to 8 clusters, can give average travel times of only 2.5 - 4 minutes from home to station, and "diversion times" of 4.5 - 5.5 minutes for travel throughout the region. (Without clustering, if vehicles had been located in homes throughout the LA Basin, the average travel time to the nearest station would have been much longer, 11-15 minutes.) Adding more stations within a cluster can significantly reduce the average travel time from home to station. Adding connector stations between clusters can significantly reduce the diversion time.

The cost of building an early hydrogen refueling network was estimated over an early transition period (see Figure 13 below). We conducted a literature review and interviews with stakeholders to estimate station costs[6], and technology status. From this we proposed various station combinations over time including both portable (mobile refueler) and fixed (onsite steam reformer, onsite electrolyzer or liquid hydrogen) stations. We use conservative cost estimates to reflect near term costs, but allow for technology improvement and cost reduction by 2017. Station cost and performance numbers were developed in consult with energy industry experts, and through literature review.

We start with a significant number of mobile refuelers and a few fixed stations, and move toward larger, fixed stations over time. For each phase we estimate the cost of building new stations and operating the network. The results are summarized in Figure 12 and Table 4.
As the station network expands to meet a growing hydrogen demand, the average travel time and diversion times decrease. The levelized cost of hydrogen (e.g. the annualized cost of capital

[6] We assume that it costs $2 million for site preparation, upfront permitting, engineering, utility installation, for a green-field refueling station site before any fuel equipment goes in. This would be the same for gasoline or hydrogen. $2 million is the "baseline cost" of a H2 station and H2 refueling equipment costs are added to this.

H2 station costs in (2009-2011) are based on interviews with energy company experts reflecting their costs today. For 2012-2014, we assume equipment costs are twice the H2A "current technology" values. (Rationale: H2A is based on producing 500 stations per year. If we reduce this by a factor of ~50-100 to reflect 2012-2014 production of stations (5-10 stations per year), the equipment cost should be about 2 times the H2A estimate (Weinert 2006). For 2015-2017, we analyze two cost cases:

1) **Low Cost**: assume that the H2A current equipment costs are appropriate (we are building 100 stations/yr in LA and elsewhere, if FCVs are "taking off")
2) **High Cost**: Costs are the same as in 2012-2014

and operation expenses divided by the annual hydrogen production) falls over time as demand increases:

- $77/kg in 2009-2011
- $37/kg in 2012-2014
- $13/kg in 2015-2017 (Figure 4)

By 2015 the cost of hydrogen from the early infrastructure, if untaxed, is approximately competitive with gasoline at $6.5/gallon accounting for the higher fuel economy of the FCV.

We estimated the annual cash flow, assuming that hydrogen could be sold for $10/kg throughout the transition period (2009-2025). Initially, the cash flow is negative (due to initial capital expenditures to build the stations at the beginning of each phase), but eventually, as the station size grows and more fixed stations are employed, the cost of hydrogen declines. By 2024, the initial investment of approximately $200 million ($170 million for station capital and $30 million for operating expenses) is recouped, if hydrogen can be sold at $10/kg throughout the transition period**. It is important to note that the cost of hydrogen will continue to decrease after 2017. For 1000kg/d stations built in 2017 and beyond, the cost of hydrogen is estimated to be $5-6/kg, and could compete with gasoline at $2.5-3.0/gallon.**

We explore the sensitivity of the cost results to station capital cost assumptions, energy prices, and rollout scenario.

There are several options for near-term renewable hydrogen production (via onsite reformation of bio-methane) that could meet California's requirement for 33% renewable sources for hydrogen production at a modest cost premium of $0.1-0.4 per kg of hydrogen.

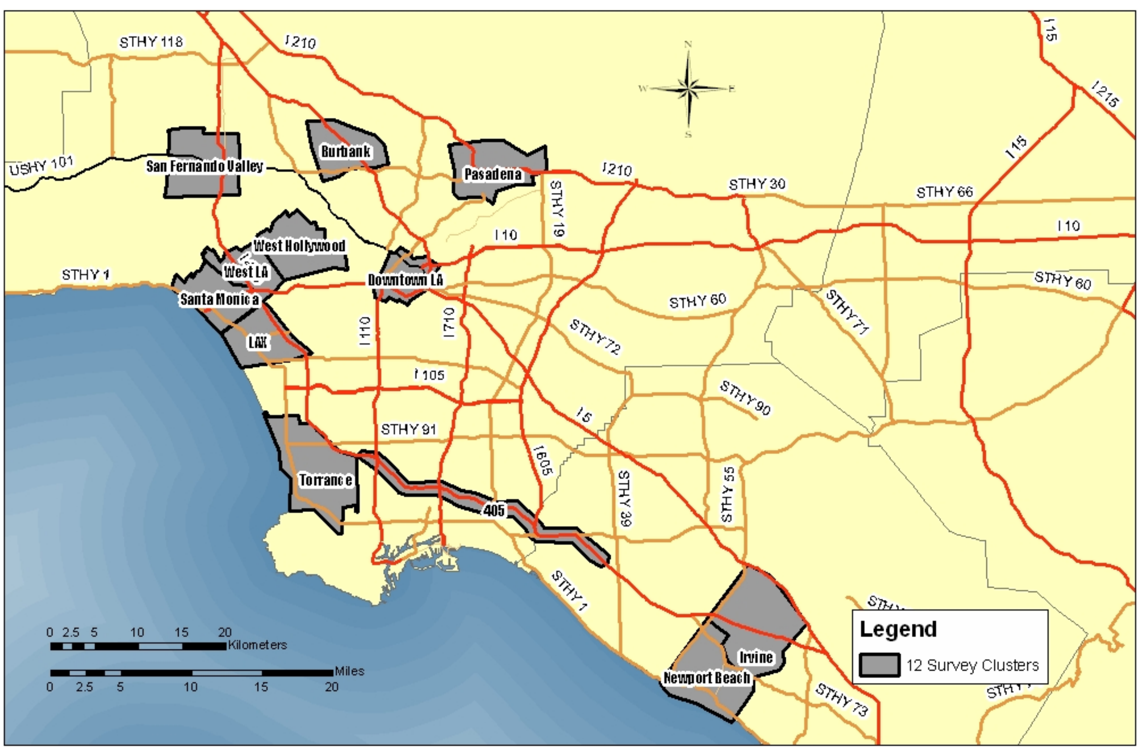
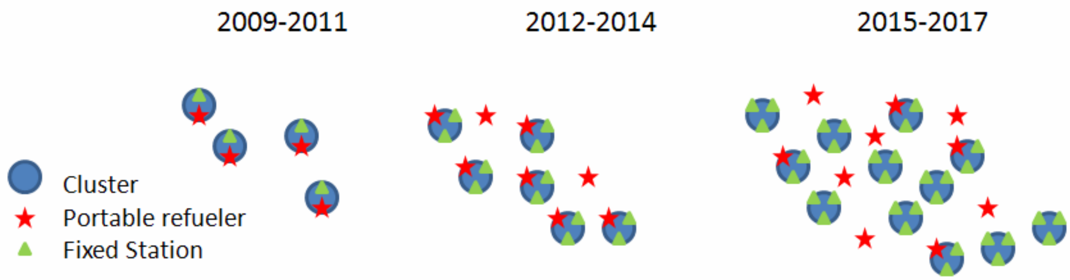


Figure 12: Potential regions, "clusters", for early hydrogen vehicle and station placement *(We used GIS analysis to evaluate scenarios where vehicles are introduced in 2 to 12 of these clusters between 2009 - 2017 to meet the requirements of the ZEV Regulation)*

Table 4: Transition Pathway for Building an Early Hydrogen Infrastructure in Southern California between 2009 and 2017



	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
Station Mix	4 Portable refuelers 4 SMRs (100 kg/d)	8 Portable Refuelers 12 SMRS (250 kg/d)	10 Portable refuelers 12 SMRs (250 kg/d) 20 SMRs (1000 kg/d)
New Equip. Added	4 Portable refuelers 4 SMRs (100 kg/d)	4 Portable Refuelers 12 SMRS (250 kg/d)	2 Portable refuelers 20 SMRs (1000 kg/d)
Capital Cost	$20Million	$52 Million	$98 Million
O&M Cost	3-5$Million/y	11-14 $Million/y	30-40 $Million/y
H2 cost $/kg	77	37	13
Ave travel time	3.9 minutes	2.9 minutes	2.6 minutes
Diversion time	5.6 minutes	4.5 minutes	3.6 minutes

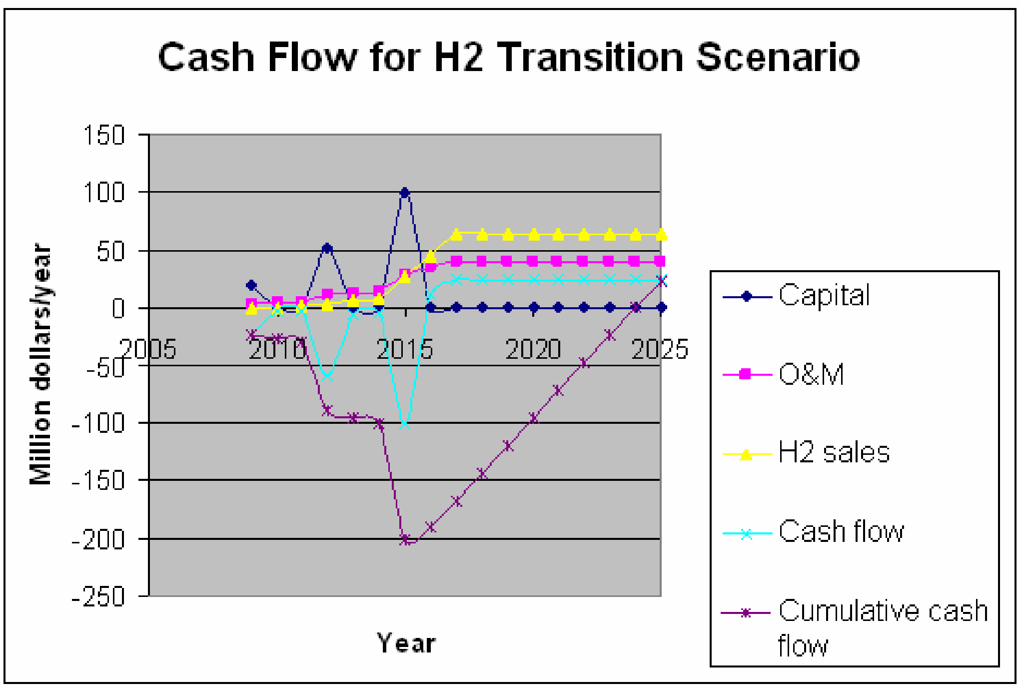


Figure 13: Cash Flow analysis for Transition Pathway in Table 4, assuming hydrogen is sold at $10/kg throughout the transition period (2009-2025)

Sensitivity of Results

Sensitivity studies were carried out using the cost model developed at UC Davis. These identified the key factors impacting the economics of the transition:

- Station type (on-site generation via SMR was most attractive)
- Station utilization
- Station size (there were scale economies in onsite stations that gave lower)
- Capital cost of stations
- Fixed operating costs especially site preparation,
- Operating costs of stations, including land rental, the cost of purchased hydrogen, electricity and (for on-site SMRs) natural gas or bio-methane)
- Selling price of hydrogen

Shell analysts examined the transition in detail and suggested that policy could be effective in addressing important barriers (station capital cost, long time until payback, and the need to reward energy companies who are pioneers or early movers. Their analysis is summarized in the table below.

Table 5: General policy alternatives to address market entry barriers for hydrogen infrastructure *(From the perspective of an energy firm's investment decisions.* ***Source*** *– Shell)*

Phase	Main policies (can span phases)	Benefits	Downsides/ risks	Cost to govt	Effective -ness
1. Reduce capex burden (depth of trough)	Subsidy to build sites	• Right subsidy will encourage network growth	• Expensive to govt	High	Medium
	Site building mandates by current market share	•Effective in getting network up • Equitable – all players share cost	• Uneconomical and unsustainable for oil companies • Risk of players exiting California	Low	High
	Mandate open-access to all existing H_2 sites (e.g. OEM trial stations)	• Reduced capex need for new station build • Earlier emergence of a fuelling network encourages customers sooner	• Potential health and safety risks of opening privately run stations to the general public	Low	High
2. Shorten time to positive cash flow (length of trough)	Subsidy to customer to purchase FCV Subsidy to customer to purchase H_2 fuel	• Supports a strong H_2 economy which can gain independence and materiality quickly	• Expensive to govt	High	Medium
	Strong H_2 benefit in LCFS	• Uses market forces to balance oil companies portfolio of heavier crudes	• May be sub-optimum bias against other future fuel options	Low	Medium
	Mandate then guarantee IGCs contribution of low cost H_2	• Makes retail economics less unattractive • Lowers risk of natural gas price increases	• Less market incentive to develop clean/green H_2	Low	High
	Subsidise then guarantee IGCs contribution of low cost H_2			Medium	
3. Reward Pioneers	License for first movers only in H_2	• Rewards innovation and very strongly encourages first mover	• Competition may be too concentrated • Anti-trust issues?	Low	High
	Future tax benefit (for H_2 or gasoline) for first movers in H_2	• Rewards innovation and encourages first mover	• Tax benefit may not be attractive enough for high risk	Medium	Medium

Three phases are outlined in the table above. Phase 1 represents the period from 2012 to 2014 when large, initial, infrastructure investments are required. Phase 2 represents 2015 to 2020 when vehicle volumes (and fuel sales) are accelerating, payback on initial investments can occur. Policies targeting Phase 3, incentives in the form of long-term market benefits for early energy industry investments, have received little attention, but are important to focus stakeholders on the long-term prize.

Rollout Scenario Analysis Conclusions

"Clustering" is an efficient way to design an early hydrogen refueling network, with very good accessibility for users located within the clusters. Clustered refueling networks in the LA area with as few as 8-16 stations can yield average travel times of less than 4 minutes between home and station, and average diversion times of less than 10 minutes. If a few connector stations are added between clusters, the diversion time is further reduced.

Beginning with a smaller number of stations (8 vs. 16) yields significant savings in capital costs (approximately $50 million over the 2009-2017 timeframe) and results in a lower delivered hydrogen cost, at the expense of slightly higher average travel times and diversion times. Hydrogen costs are lower with fewer stations because of better station utilization and scale economies. The total investment needed is approximately $170 million in capital to build the stations needed through 2017, plus $30 million to operate them.

ITS-Davis estimated the annual cash flow, assuming that hydrogen could be sold for $10/kg throughout the transition period (2009-2025). Initially, the cash flow is negative (due to initial capital expenditures to build the stations at the beginning of each phase), but eventually, as the station size grows and more fixed stations are employed, the cost of hydrogen declines. By 2023, the capital investment of approximately $170 million plus $30 million in operating expenses is recouped, if hydrogen can be sold at $10/kg. (Depending on how hydrogen fuel sales are valued vs. station revenue from a convenience store, car wash, etc., the required hydrogen price to breakeven by 2023 might be several $/kg lower.)

Renewable hydrogen could be produced in the near term via onsite reforming of bio-methane or biomass-derived ethanol. Using these supply pathways, the cost premium to satisfy California's requirement for 33% renewable hydrogen would be modest (less than $1/kg). Electrolysis using green power from the grid would be $5/kg more costly than hydrogen from natural gas; solar PV electrolysis would be perhaps $20/kg more costly.

Even with relatively conservative station cost assumptions, an emerging hydrogen infrastructure could pay for itself within about 15 years if hydrogen is sold at a price competitive with gasoline at $5/gallon (untaxed). Beyond this timeframe (stations built in 2017 and beyond), the cost of hydrogen could compete with gasoline at $2.5-3.0/gallon (untaxed).

Policy measures to address the high capital cost of stations, the long time frame until payback, and to reward early station providers could help improve the business case for hydrogen infrastructure development.

6. Policy mechanisms to incentivize early infrastructure investments

Primary recommendations (Executive Summary)

1.1 Create "early mover" infrastructure incentives
1.2 Ensure modified ZEV Regulation provides a robust signal
1.6 Complete evaluation criteria for use of State funds for hydrogen infrastructure
2.1 Ensure California's renewable hydrogen requirements SB 1505 accommodates bio-methane
2.2 Encourage regional leadership in early hydrogen communities, and
2.3 Clarify overlapping state policies.

Effective public policy for alternative fuels and vehicles (including hydrogen and fuel cells) must address both long-term social goals, and near-term market barriers. It is important to set a long-term vision for societal goals for energy use and GHG emissions (examples include AB 32, and the goal of 80% reductions in GHG by 2050). Strong, durable policies such as performance-based emission standards or a carbon cap and trade system are needed to guide the way toward these goals. In addition, near term, sector-specific policies may be needed to address market entry barriers and incentivize key technologies (examples include the ZEV Regulation, AB 118 State incentives, federal vehicle purchase incentives, and the CA Clean Fuels Outlet).

The long-term societal goals were seen as critically important part of the overall argument for hydrogen (see discussion of policy metrics in Chapter 2). However, this project also focused on specific market entry barriers and current investment motivations of energy firms for hydrogen and fuel cell vehicles.

The two energy firms participating in this project identified the ultimate goal – participation by a significant number of energy and automotive firms in the hydrogen business. This would be the true sign of a robust investment opportunity. The policy challenge will be how to best incentivize energy companies to invest in the near term, given the capital requirements and relatively long timeframe for payback.

The discussion around hydrogen infrastructure policy focused on ideas for incentivizing early mover (pre-commercial) investments by major energy firms. It was clear that funding from the State by itself was not a robust, long-term incentive. Rather, non-financial incentives that change the permanent competitive landscape were preferred. This could take the form of credits towards compliance with other policies and regulations with hydrogen investments, or incentives in the form of streamlined permitting. The following specific policies were discussed in detail, in terms of opportunities to incentivize early infrastructure developers, and are part of the recommendations to policymakers in this Roadmap:

- **Low Carbon Fuel Standard** (fuel performance standard)
  The LCFS, formally approved by the Air Resources Board on April 23, 2009, is a fuel carbon intensity standard. It requires that by 2020, the average carbon intensity of all transportation fuels sold in California be 10% below the levels in 2010. It creates a trading mechanism for regulated firms to more efficiently comply. As currently written, each type of fuel has a carbon intensity default value based on an assumed pathway of lifecycle emissions from fuel production, transport, and end-use (gCO2e/MJ fuel delivered). As such, the carbon intensity values for each fuel vary, but are directly proportional to their assumed embedded carbon.

  Prior to the passage of the LCFS in April, several stakeholders proposed a modification that would have provided an extra incentive for any fuel that was very low carbon. The concept was that in addition to a low carbon intensity value, certain fuels would receive extra credit with the hope of incentivizing their growth in the market. This would primarily apply to electricity and hydrogen, and is motivated by the fact that these fuels have larger market entry barriers than more conventional fuels. Without this, the proponents argued, energy firms could comply with the LCFS by simply overloading the market with slightly improved conventional biofuels, a result that would not set the stage for needed further carbon reductions post 2020.

This concept was discussed at the H2-FCV Roadmap workshops and was the preferred policy recommendation by the energy firms participating. It was argued that modifying the LCFS would be the best way to incentivize hydrogen infrastructure investments because it uses an existing policy tool whose goal is to encourage low carbon fuels for the long-term. Because the LCFS is an existing regulation, providing a mechanism for hydrogen to play a larger role will be an offset of other low carbon fuel investments, not an additional compliance. Additionally, relative to the full compliance requirement (10% reduction in carbon content of all CA fuels), the hydrogen fuel required for 25,000+ vehicles will be relatively minor.

Currently, ARB is reviewing the feasibility of making such modifications to the LCFS. The exact compliance pathway for energy firms under the LCFS can't be known, but several studies have pointed out that the lowest cost compliance may be to sell large quantities of E85 fuel, even if it means subsidizing the ethanol price to ensure sales occur. This would be a sub-optimal result, locking in ethanol infrastructure, when other alternative fuels (including H2) will be required post-2020.

- **Clean Fuels Outlet** (station requirement)
  This policy requires that a fueling infrastructure be put in place once a minimum threshold of 20,000 dedicated-fuel alternative vehicles are sold. For example, if 20,000 FCVs are placed in California, a sufficient quantity of fuel must be brought to market to support them. This policy tool is not a preferred approach as it "forces" the energy industry to commit to an alternative fuel, regardless of the business case. However it may be necessary to compliment the ZEV Regulation if the automotive industry is being regulated to provide ZEVs for the market.

  There are several benefits to this policy approach. It creates a certainty on quantify of fuel, providing confidence for the automotive investments. An additional benefit is that it forces all major energy firms to participate, regardless of whether they are interested in hydrogen or not. This reduces the burden on the few energy firms already considering hydrogen. Additionally, the policy could be designed with "early mover" clauses that would reward energy firms who place stations earlier. For instance, firms who place stations before the 20,000 vehicle threshold is reached could be partly alleviated from placing more stations after the threshold. This addresses Recommendation 1.1.

  However, there are several challenges to this policy approach as well. To begin with, as the ZEV Regulation only stipulates "ZEV" volumes, not FCVs specifically, automotive firms would have to make clear their ZEV compliance strategy so FCV quantities would be known. Secondly, the policy would have to be designed such that a "chicken or egg" dilemma isn't created – if energy firms hesitate and don't place stations, automotive firms may not place vehicles in California, and the 20,000 vehicle volume trigger is never reached. Additionally, the use of this policy still requires the State to outline station network priorities for the LA Basin so that appropriate station-to-vehicle ratios are met. Energy firms should have the flexibility to decide specific station designs and locations, but the State needs to outline general regions and fuel coverage of a geographic area.

  The value of this tool will depend on how the vehicle threshold is designed and what kind of "early mover" incentives it creates. This policy will be carefully evaluated in concert with the ZEV Regulation changes due in 2010. The goal of these changes is to establish longer term milestones for the automotive industry, providing a robust policy signal (Recommendation 1.2)

- **AB 118** (infrastructure cost-share incentives)
  Assembly Bill 118 (2008 legislative session) added a vehicle registration fee to California motorists to generate a pool of funds for alternative fuel investments deemed important for addressing California's energy and air quality goals. The program is anticipated to generate ~$200M per year for 7 years, and will have a split oversight by CARB and CEC. The portion of the investment that applies to alternative fuels such as hydrogen and electricity is administered by the CEC. **As mentioned in Recommendation 1.6,** evaluation criteria need to be completed by CEC and CARB, to leverage the recently committed H2 infrastructure funding from CEC. (In April 2009, a 2-year investment plan under AB 118 was approved for 2008-2009 and 2009-2010.) The plan should identify whether the AB 118 funds are restricted to fueling station equipment (vs. fuel production, etc). Vehicle and station placements should follow the "cluster" approach outlined in this and other reports, with close coordination between the energy and automotive firms. (The CaFCP Action Plan provides an additional build-out scenario for stations throughout California.)

  Investment concepts were discussed at the third and fourth workshops of this project. Generally, many stakeholders supported the concept of using the funds for renewable hydrogen production, particularly biomethane-to-hydrogen at a centralized facility. This would be a boost for the industry in meeting the complimentary policy, the SB 1505 renewable hydrogen requirements – and would allow industry to focus private investments and efforts on station development and fuel capacity for the growing FCV fleets (Recommendation 2.1). Additional investment ideas included support for testing stations needed for fuel standards development, transit station investments, and any funding useful to improve local station permitting and siting.

  Details of investment ideas or the joint agency arrangement are not public at this time. There may also be varying investment perspectives between the two agencies that will need to be resolved. But the workshop participants generally agreed that the $40M investment represents an important sign of State commitment to hydrogen and that the funding could, if used effectively, provide a catalyst for private sector investment.

  AB 118 provides an important investment from the State. However, it's critical to identify federal support. Ideally, federal engagement would provide both financial support and guidance for long-term.

Evaluation Criteria for use of State Funds

There are two other policymaker recommendations outlined in the Executive Summary that should be briefly touched upon. Along with a State investment plan for hydrogen infrastructure that also outlines station placement priorities, strategic efforts will be required to foster local leadership in the preferred hydrogen communities (Recommendation 2.2). Finally, a more important priority for policymakers is to simply clarify, for industry stakeholders, the various State policies and how they overlap with each other, in either a complimentary or contradicting way (Recommendation 2.3).

During the workshop process it became clear that there were opportunities for policymakers to enhance the business case for developing an early hydrogen infrastructure. As discussed in Chapter 5, the energy firms see the main impediments to a viable business case as:

- the high capital cost of stations,
- the long time to reach a positive cash flow (10-15 years), and
- the lack of an early mover advantage for those companies that build the first stations.

Ideally, a near-term hydrogen policy should address all these concerns. The preferred policies identified in the workshop discussions were not government subsidies for stations. The most positive response was to policies that gave advantages to early movers, through adjustments of other pre-existing policy obligations (such as the LCFS) or tax policy. Station mandates such as the Clean Fuels Outlet were recognized as effective, but did not generate enthusiasm from the energy industry.

7. Stakeholder partnership concepts

Primary recommendations (Executive Summary)

1.5 Engage the U.S. Department of Energy
2.7 Public Private Partnerships (PPP)

Enhance Engagement with the U.S. Department of Energy on Technology Deployment

California's State agencies and industry partners need to reach out to the U.S. DOE and enhance their role as a strategic partner in the LA Basin infrastructure deployment. Although the U.S. DOE has been engaged on multiple levels on H2 R&D and demonstrations, state policymakers need to bring this to higher level, through increased focus on technology deployment in addition to R&D. This connection could be formed as part of proposals for AB 118. This effort can be done by firms independently, or collectively. CARB and CEC are engaged at high levels with U.S. DOE on hydrogen and fuel cell issues

The U.S. DOE's future commitment to hydrogen and fuel cell vehicles has been uncertain. In May of 2009, Secretary Chu's proposed FY 2010 U.S. DOE budget to Congress recommended a complete elimination of the U.S. DOE hydrogen production, delivery and storage R&D and fuel cell vehicle program, while shifting emphasis toward stationary power applications of fuel cells. Congress has recently re-instated hydrogen and fuel cell vehicle research in the final U.S. DOE budget. But clearly this signaled an uncertain commitment to hydrogen fuel cell vehicles by U.S. DOE's leadership.

Outreach efforts by multiple stakeholders need to be made to senior U.S. DOE officials and at the Congressional level to address the U.S. DOE budget priorities on hydrogen. California's Governor and CARB have already begun to reach out to Dr. Chu on this issue [ref 16, 17], and a number of stakeholders have been in contact with Congressional members on the relevant budget review committees. Additional outreach is necessary and should emphasize the value of hydrogen in addressing the long-term (2050) energy and GHG challenges. It is clear hydrogen will not play a significant role in reducing GHG emissions the next 10-15 years, but it is exactly because of the long-term benefits (and near term market barriers) that the federal government needs to remain supportive (and leading).

Public Private Partnerships (PPP)

The workshop participants briefly discussed the concept of a new public-private-partnership (PPP) to advance the hydrogen infrastructure in California. This concept is very preliminary and it's not yet obvious that such an entity is necessary. One general concept would be to create a PPP that could help oversee the public investments while directly coordinating with the private industry on infrastructure planning.

Currently, these roles are being managed by CARB, CEC, and the CaFCP. CARB's CaH2Net has overseen the State's current cost-share investment in hydrogen infrastructure, managing the proposal, review, and grant award process. Over the past three years, they have fine tuned the process helping to address State contracting barriers. Now that CEC has new cost-share funding (AB 118), they will be playing a role in the proposal and grant award process going forward. The CaFCP, by definition, is a partnership of the State government with private industry to advance the demonstration and technology of fuel cell vehicles. Their active role has been to coordinate multiple public-private committees on such subjects as hydrogen safety, refueling equipment, station construction lessons learned, and to provide valuable outreach information to multiple stakeholders on the technology.

Additional value would need to be defined for a PPP before the concept could be advanced. As discussed in Workshop 4, a clear charter would be required of what this organization would be tasked with before progressing with the idea. In theory, a formal PPP could provide an active coordination role of where infrastructure should be placed and how funds should be used. It could be housed with permanent staff in southern California where the bulk of the infrastructure and FCV deployments are going. It could provide an active outreach and education role for local leadership and permitting officials.

In reality, there would be challenges in setting up a PPP. To begin with, the disbursement of taxpayer funds comes with a number of rules and requires knowledge of the State grant process; a PPP may not be given any added flexibility than the agencies would have. Additionally, creating a legal charter for a PPP could take a long time, especially if it is designed to have spending oversight. A possible compromise role might be to remove the investment disbursement role from the PPP and make it an advising organization to the agencies on investment ideas, but it would remain an active organization in helping local officials and private industry optimize the infrastructure planning and growth. This would be valuable if the State agencies don't have the resources to play an active role in local southern California activities.

8. Conclusions

The California Hydrogen and Fuel Cell Vehicle Roadmap Project provided a targeted forum for discussing the challenges facing the introduction of hydrogen and fuel cell vehicles in California over the next 10 years. Key stakeholders from the private and public sectors contributed fresh insights, augmented by independent analysis from UC Davis researchers.

- Through a series of coordinated workshops, the group came to consensus on technical and cost issues for hydrogen and fuel cell vehicles, and realistic timelines for implementation. The group illuminated stakeholder motivations and discussed actions and policy measures to align perspectives among the stakeholders to enable constructive action.
- Through the workshops and independent research projects, the study contributed information that could help industry stakeholder coordination of vehicles and station placements.
- The project complemented and contributed to ongoing planning by the California Fuel Cell Partnership.
- The group discussed and identified potential public policy mechanisms that could constructively align stakeholder actions for near term action, ideally through policies that change long-term investment decisions.
- The group sought to develop a consensus on next steps for hydrogen and fuel cells in California.

Through this project, a diverse group of key stakeholders came to a much improved understanding and consensus on technology status and timelines, and actions going forward. General consensus emerged on a few important themes. First, the H2-FCV remains one of the few options for the LDV sector to achieve California's 2050 GHG goals. Secondly, in high volumes, FCVs hold the promise of costs only slightly higher than advanced ICEs, whereas BEVs are expected to be noticeably higher. And third, in a mature market, H2 stations are expected to provide a similar convenient, short refueling experience that drivers know with gasoline, and will allow easy long-distance travel.

However, market entry barriers are high for H2-FCVs and it is not clear whether enough stakeholder coordination will occur to get over this hurdle. Making H2-FCVs successful will require more stakeholder coordination than any other alternative. There are higher investment risks for energy firms compared to other alternatives, the placement of FCVs in specific communities is heavily reliant on expected infrastructure, and public policy is not providing a robust, comprehensive, portfolio approach to long-term transportation solutions.

It is the conclusion of the participants in this Roadmap that the H2-FCV alternative could be part of the future. However, there was clear acknowledgement that existing public policies need to change in order to incentivize long-term energy infrastructure investments.

Moving forward, this report outlines 14 key recommendations (see executive summary) that, taken collectively, constitute a new Roadmap for hydrogen and fuel cell vehicles in California. This Roadmap acknowledges that other alternatives will also be required to achieve California's 2050 GHG goals, but strongly states that without H2-FCVs, there is significant risk of missing the target. Addressing these recommendations, outlined by stakeholder groups, will go a long way towards ensuring hydrogen and fuel cell vehicles remain part of the long-term transportation portfolio.

At the fourth and fifth workshops, the project participants discussed several paths of action that could be pursued, based on the learning and recommendations from this project.

1) Use the information derived from this project for individual stakeholder action. This Roadmap document (and UC Davis research) could provide a strong analytic foundation and new ideas for individual stakeholders or companies to approach policymakers.

2) If there was sufficient consensus on the recommendations for coordinated action, an Executive Summit could be held presenting a multi-stakeholder plan for introduction of fuel cell vehicles and hydrogen infrastructure.

At the fifth workshop, detailed action items in support of the highest priority recommendations 1.1 - 1.6 were developed. Individual stakeholders are now moving forward on specific actions. In addition, an Executive Summit has been proposed to elevate the discussion, and commitment (see sidebar below). However, as stated before, such an event is dependent on whether firm commitments exist from each stakeholder to justify the gathering.

Clearly, implementing fuel cell vehicles and hydrogen is a challenging opportunity with potentially huge, long term benefits, but with many uncertainties. The California Hydrogen and Fuel Cell Vehicle Roadmap Project brought together key actors in a focused and honest exploration of the challenges and paths forward.

An Executive Summit

During the fourth workshop of the H2-FCV Roadmap project, it was recommended that a sub-committee be formed to identify specific concepts of what an Executive Summit would encompass and accomplish. Such an event would involve senior industry executives and government officials to announce a joint effort on H2-FCVs. The motivation is to create a renewed public and private stakeholder commitment to hydrogen and to announce specific plans to launch the cluster network concept in the LA Basin. More broadly, a second motivation is to provide a means for engaging the senior executives with the constructive findings of this project and to encourage all stakeholders to keep hydrogen in their long-term portfolio of solutions.

Further consensus around specific commitments is required before an Executive Summit could occur. Senior executives will require specific, tangible actions from each stakeholder, and will also need the actions to be at a high enough level to justify their public involvement. A starting concept would be to have industry stakeholders commit to a specific number of FCVs and stations in the LA Basin, along with the State commitment of funding and incentives. This public commitment could be limited to the vehicles and stations needed to get through 2014, for example, but not necessarily the full investment required through 2017. Is this enough, however? Is it necessary to identify broader commitments such as new partnerships?

9. Appendices

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