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Hydrogen Vehicle Implementation Plan

Presented at

CEC-ARB Workshop on Developing a State Plan to Increase the Use of Alternative Transportation Fuels

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1. Methodology
2. Barriers
3. Assumptions
4. Projections
5. Summary

Agenda

1. **Methodology**
2. **Barriers**
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Hydrogen consumption, associated benefits, and cost of implementation were estimated using inputs from a variety of sources

- Stakeholder Interviews
  - Joan Ogden, UC Davis: Hydrogen pricing (2007)
  - Honda: Hydrogen vehicle development (2007)
- Stakeholder Publications
  - *GM Fuel Cell Vehicles Moving Forward* (Christine Sloan, 2007)
- Data Sources
  - *California Hydrogen Highway Network Blueprint Plan* (CA EPA, 2005)
  - *H2A Model Results*, (U.S. DOE)
  - *Integrated Energy Policy Report* (CEC, 2005)
  - *Low Carbon Fuel Standard for California* (A. Farrell, D. Sperling, 2007)
  - *ZEV Technology Review* (California EPA/ARB, 2007)

Analysis focuses on the deployment of hydrogen fuel cell vehicles due to the significant investment in, and benefits of, fuel cell vehicles

- Considered by many manufacturers to be the "ultimate solution to reducing both criteria pollutant and climate change emissions"[1]
- Numerous performance advantages over hydrogen ICEs
  - Improved efficiency
  - Zero-emissions
  - Electric vehicle platform
- The federal government has committed over a billion dollars to date to develop hydrogen FCVs
- The majority of auto manufacturers are also investing heavily in FCV development indicating a commitment to FCVs being the car of the future
- Most importantly, the ability to successfully deploy hydrogen FCVs is the key to achieving significant hydrogen market share in California and the U.S.

[1] California EPA/ARB, *ZEV Technology Review*, April 2007.

Predicted FCV production milestones drive penetration projections from which follow emissions benefits, petroleum reduction and cost estimates

- Outline barriers to implementation
- Project vehicle penetrations for two scenarios based on various estimates for production milestones and California FCV sales
  - Business-as-Usual Growth
  - Aggressive Growth
- Verify feasibility using HEV sales growth as a measure for FCV growth potential
- Determine potential gasoline reductions as compared to competitive vehicles: present gasoline, Pavley-compliant gasoline, and PHEV 20/40
- Illustrate the relative ability of FCVs to reduce GHG emissions
- Estimate infrastructure costs and incremental vehicle costs
- Outline actions necessary to overcome barriers to implementation

[1] California EPA/ARB, *ZEV Technology Review*, April 2007.

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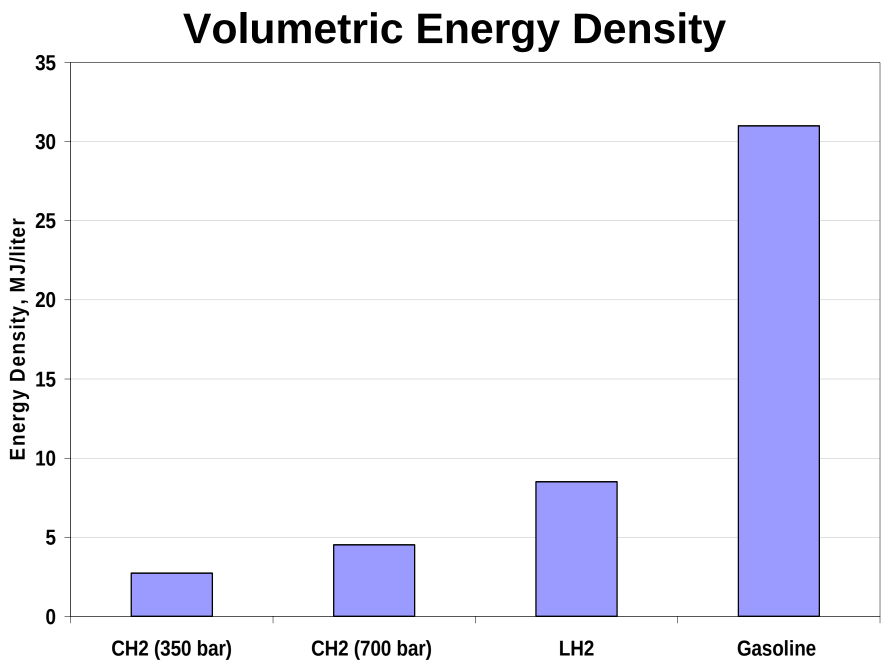
As stated in the *ZEV Review*, "the cost, weight, and volume of hydrogen storage remain major barriers to commercialization"

- The volumetric energy density of H2 makes it difficult to store the required energy on-board the vehicle
- Commercial vehicles require fuel storage to provide a 300-mile range
- In the near term, OEMs intend to use compressed H2 storage, as opposed to liquid storage for complexity and energy reasons



- Research is on-going into alternative storage techniques that may improve gravimetric and/or volumetric energy density
  - Options include metal/chemical hydrides and activated carbon structures
  - Too early to make accurate predictions about performance and cost

Despite substantial progress in automotive fuel cell development, significant challenges remain before commercialization is achieved

- Improvements are required in:
  - MEA* power density
  - Catalyst loading/cost
  - Operating lifetime
  - Wider temperature range
- Time to meet these requirements varies between developer estimates, generally between 2010-2020
- *ZEV Review* Panel remains cautiously optimistic that commercialization can be achieved in 5-10 years

	FreedomCAR Goals	Present Status[2]	Forecasted Status[2] (2015)
Lifetime (years)	15	2-3	10-13
Peak Efficiency (%)	60	50-60	60
Gravimetric Power Density[3] (W/kg)	325	300-500	700-1100
Volumetric Power Density[3] (W/l)	220	N/A	N/A
Cost[4] ($/kW)	$40 (2010) $30 (2015)	$75-$600	$30-$75

1. Consist of fuel cell stack, the fuel cell stack auxiliary sub-systems (e.g. sub-sytems for air supply, fuel supply, thermal management, and any other necessary functions, such as water management), the hydrogen storage system, the high-voltage energy s

2. Assessment of EPA/ARB ZEV Review Panel

3. Excluding hydrogen storage

4. Direct material/labor and production facility costs. Indirect costs, marketing and profit not included. Design level assuming 250,000 units per

- R&D costs are unknown, but will likely continue at present rate or increase
  - Hydrogen Fuel Initiative: $1.2 billion from 2003-2008
  - Likely a 50/50 cost-share with industry, actual industry investment unknown

* Membrane electrolyte assembly

Despite significant domestic hydrogen production, the development of additional production and a distribution infrastructure is required

- Hydrogen is presently produced in significant quantities for use, primarily, by the oil industry for hydrotreating in the refining process
  - Annual domestic production is ~9 billion kg annually
- The lack of a fueling infrastructure is a major barrier to implementation
  - Classic "chicken-and-egg" problem that requires proactive action
  - California has begun demonstrating such action by developing a plan for the California Hydrogen Highway
- Numerous additional efforts are underway to determine optimum development of a larger hydrogen infrastructure
  - Unclear how government and industry will interact to build infrastructure
- Hydrogen can be produced on-site (likely SMR or electrolysis) or a central plants (likely SMR or gasification) and distributed by truck or pipeline

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Penetration projections were based on estimates of commercialization milestones for two growth scenarios: business-as-usual and aggressive

- Business-as-Usual Growth (BAU)
  - Based on the commercialization milestones specified in the *ZEV Technology Review* and 2020 estimates for CA sales in the *Low Carbon Fuel Standard*
  - *ZEV Review* predicts total FCV production at 10,000 vehicles/year in 2020
    - 10% assumed sold into the California market
- Aggressive Growth (AGG)
  - Based on the California sales estimates specified in the *Low Carbon Fuel Standard* documentation
  - Predicts 2020 California FCV sales to be 235,000 vehicles per year

		Scenario Years*	
Vehicle Technology Status	**Vehicles/year (Global)**	**BAU**	**AGG**
Demonstration	100	2008	2008
Pre-Commercial	1,000	2009	2009
Low-Volume Commercial	10,000	2020	2012
Mass-Commercialization	100,000	2025	2015
Million Vehicles	1,000,000	2055	2045
		10% of production FCVs sold into	100% of FCVs sold into California

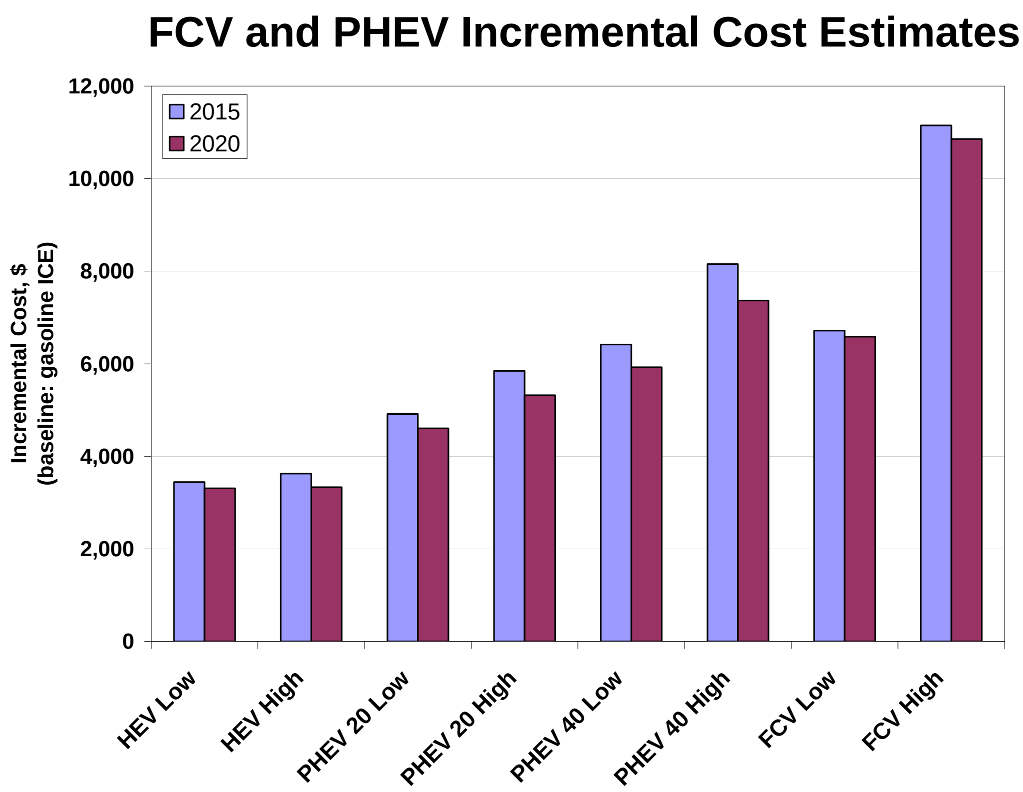
Further development of FCV components can reduce incremental vehicle costs, but up-front costs will not be directly competitive with ICE vehicles

- Compressed hydrogen storage can meet intermediate DOE weight targets but is unlikely to meet long-term weight goals or any DOE cost goals
  - In the absence of major breakthroughs significant cost reductions are not anticipated for hydrogen storage below the present costs

Tank Type Pres. Rating	Cost ($/kWh) Present	DOE Goal
CH2 Tanks (350 Bar)	10-12	4 (2010) 2 (2015)
CH2 Tanks (700 Bar)	13-15	4 (2010) 2 (2015)

  - Minimum cost for a 5 kg tank (assumes 60 mi/kg and 300 mi range) is assumed to be $1,650 (assumed gasoline tank cost: $100)
- Development of hydrogen fuel cells and achievement of the minimum cost predicted by the *ZEV Review* panel (pg. 8) can potentially reduce the power plant incremental cost to $1,210
- Additional incremental costs are associated with the use of an electric drivetrain (costs based on known cost of HEV drivetrain)

Calculation of incremental costs indicate that FCVs will have significant incremental costs at high volumes* but may be similar to PHEVs



- Analysis was performed to indicate that despite the high cost of hydrogen storage, it is cost-effective to store energy in a hydrogen tank as opposed to expensive batteries

* High production volumes: >100,000 units/year

Infrastructure costs are based on California Hydrogen Highway assumptions and the future construction of large on-site SMR stations

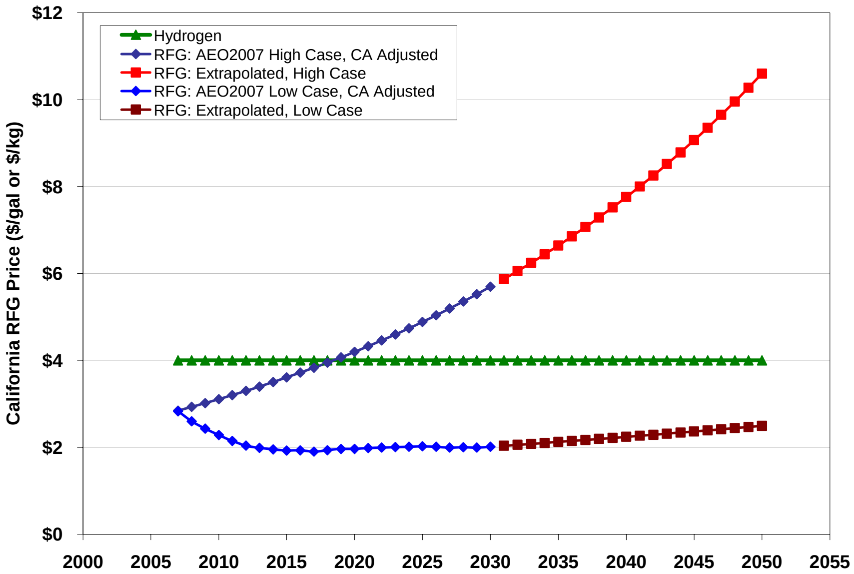
- California Hydrogen Highway predicts total costs of $159 million to develop the infrastructure necessary to serve 20,000 FCVs in major metropolitan areas
  - This costs will be split between vehicle incentives and demonstrations ($18 million) and infrastructure development ($65 million) which will be cost-shared with industry
  - Cost are spread over the time required to achieve vehicle implementation for each phase

Infrastructure Technology Status	Vehicle Population	Total Stations	Phase Cost	BAU	AGG
California HH Phase 1	2,000	100	83,000,000	2016	2009
California HH Phase 2	10,000	250	76,000,000	2022	2011
California HH Phase 3	20,000	250 (high util.)	0	2024	2012

- Future infrastructure estimates are based on the H2A cost for 1,500 kg/day on-site SMR stations
  - Capital cost per station: $3.23 million
  - Vehicles served: 2,250

Fuel costs were not considered in the overall cost of FCV implementation due to the price uncertainty for gasoline and H2 in the transitional period

Hydrogen and Gasoline Price Projections



- AEO2007 high and low estimates are significantly different
- Hydrogen prices are estimated as $2-4/kg in a developed market, but it is unclear what they will be during the transition period, or out to 2050
- Nevertheless, hydrogen may prove to be more cost-effective than gasoline if fossil-fuel prices increase in the future, especially given efficiency benefits

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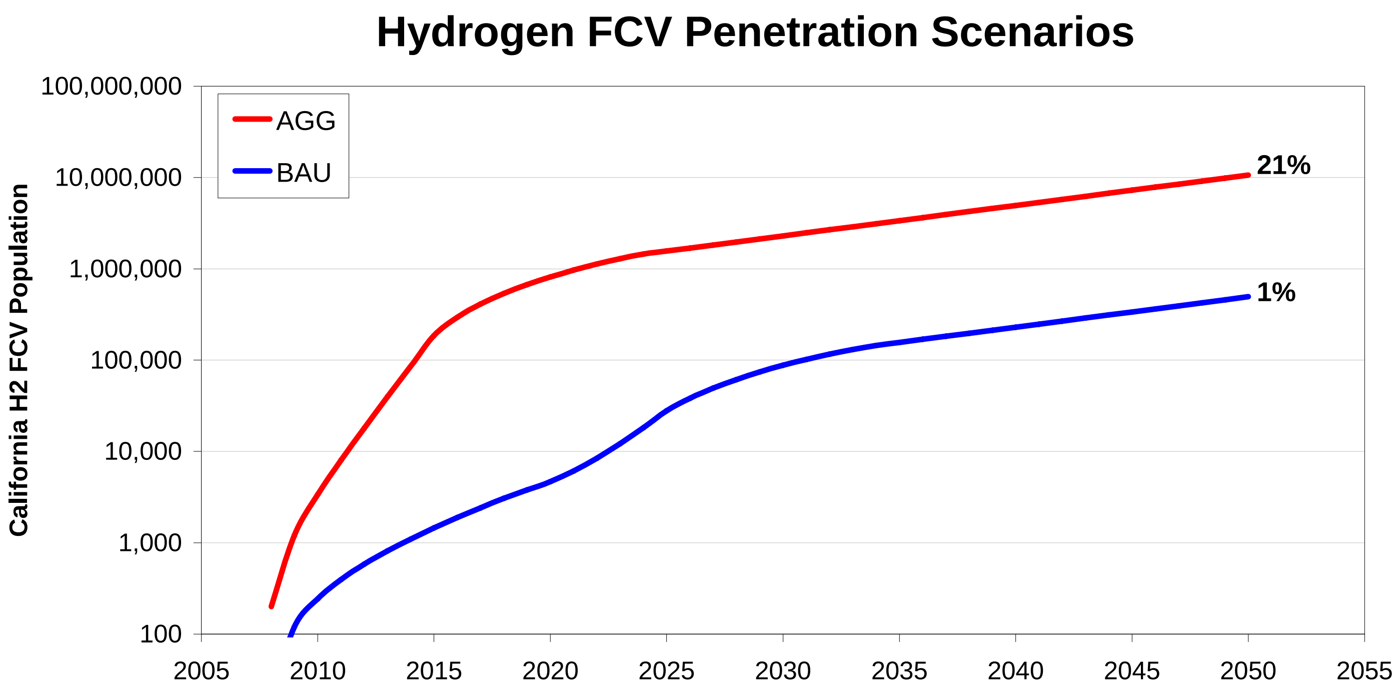
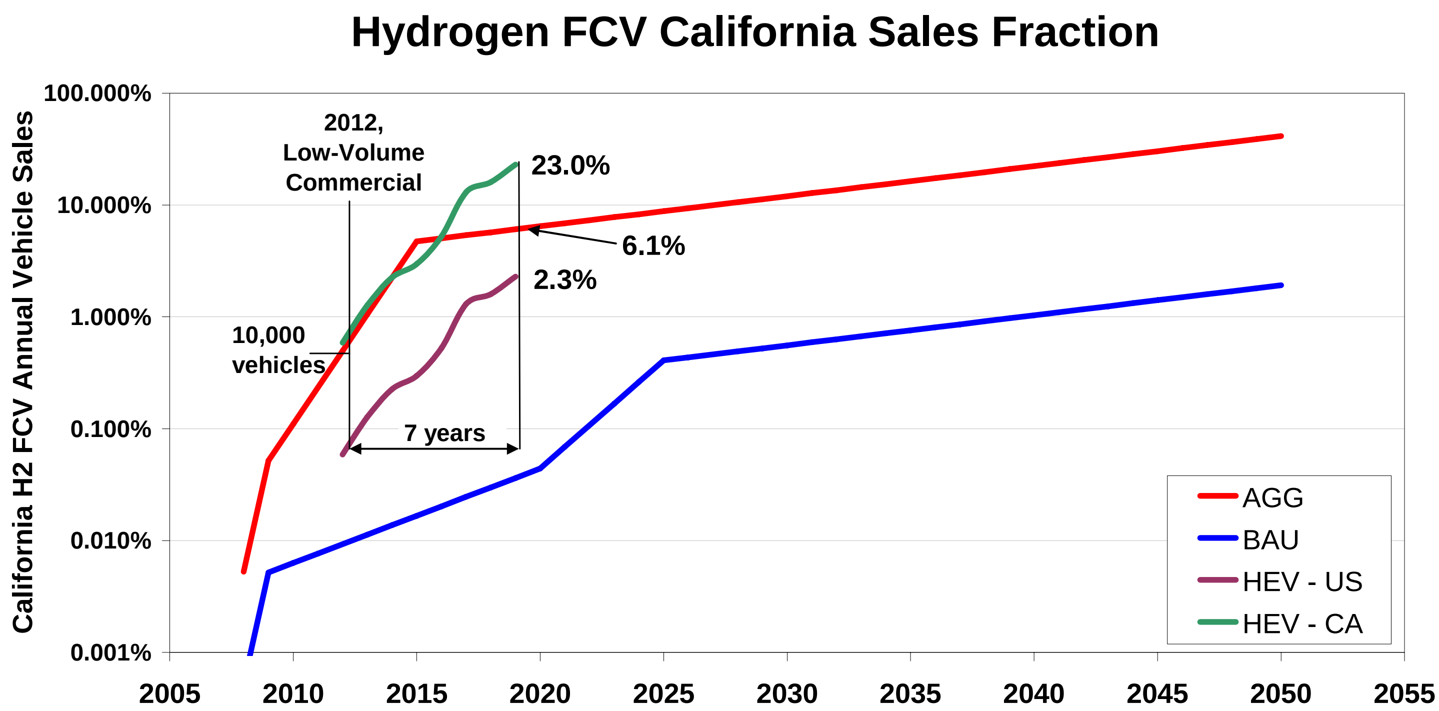
Given the penetration assumptions, the two scenarios lead to vastly different market penetrations by 2050



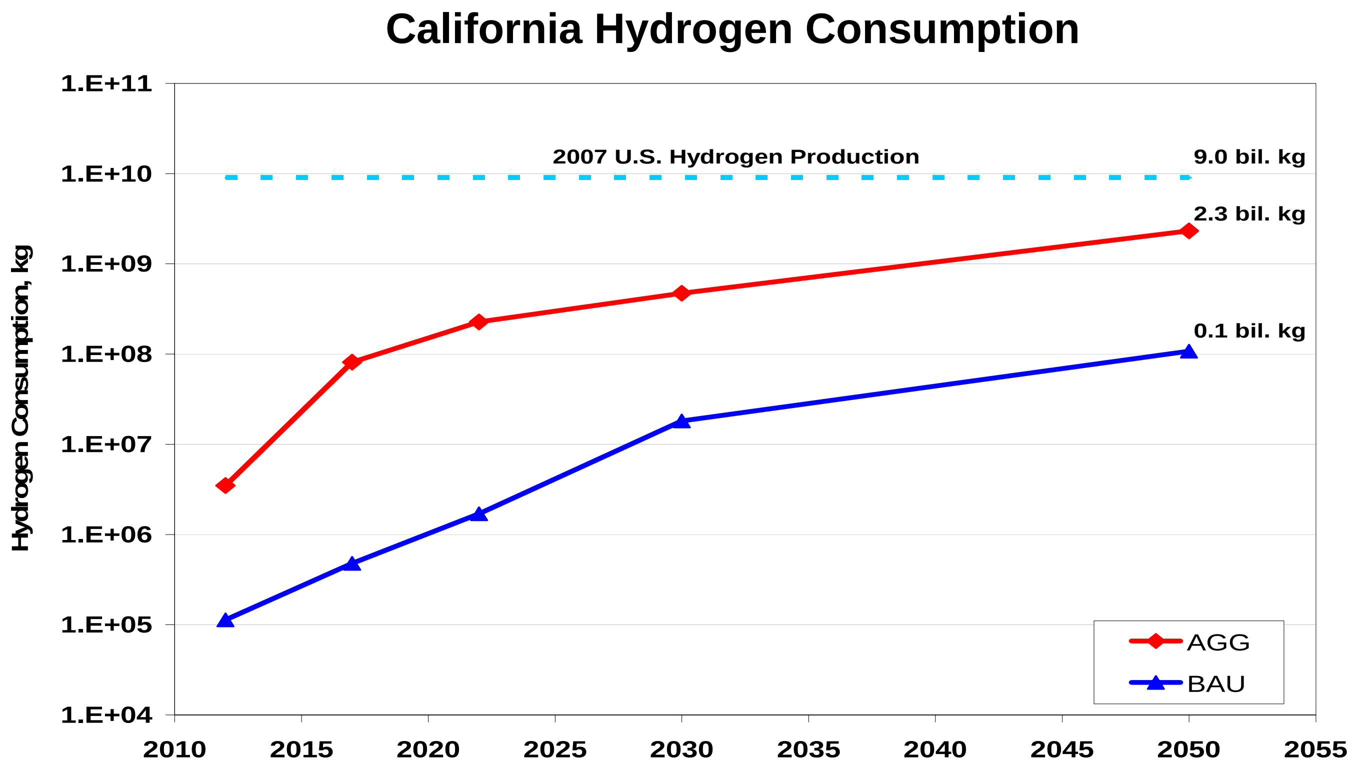
- Business-as-usual growth (BAU) will not be sufficient to achieve a significant fraction of the California fuel market by the AB 1007 milestone years of 2020 and 2030

Aggressive scenario sales growth can be achieved with production increases similar to HEVs, but with concentrated deployment in California



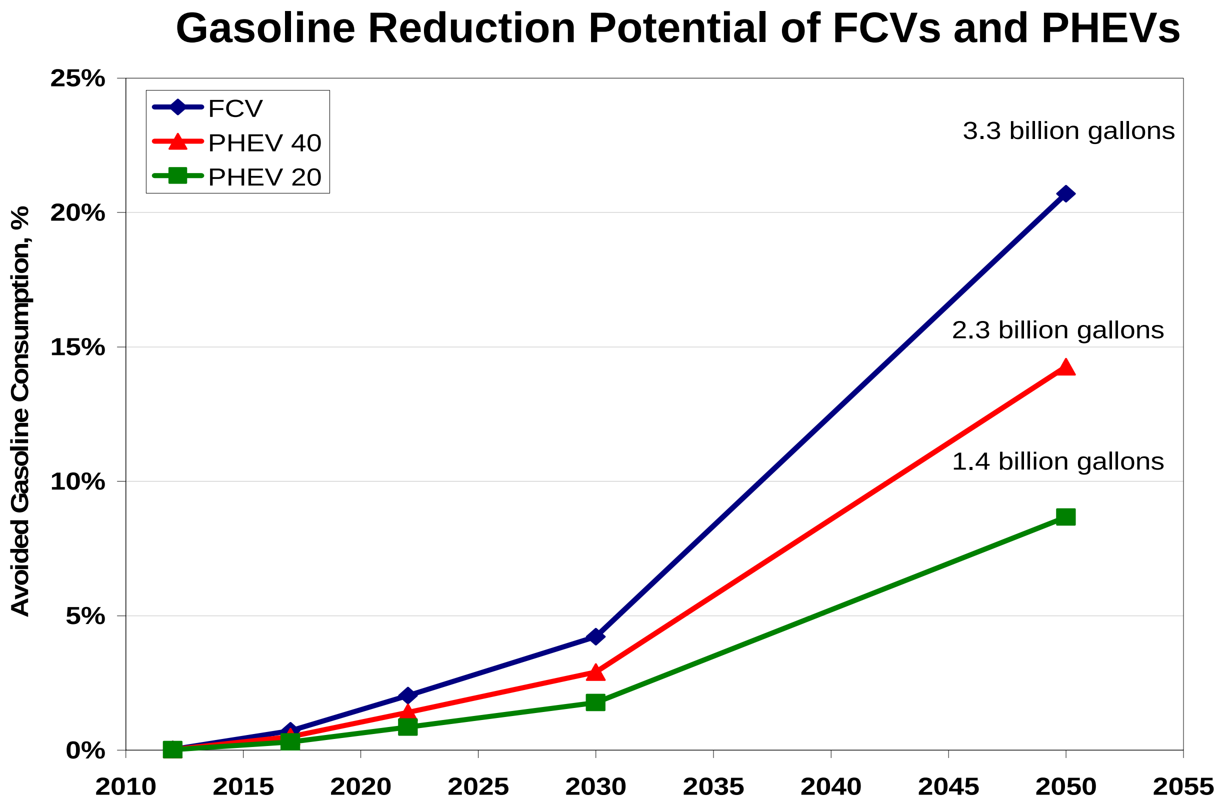
- Preferential deployment of FCVs in California will allow for a market share of 6.1% seven years from commercialization, while increasing production capacity at a rate that has yielded a 2.3% HEV nationwide market share

While significant, the overall hydrogen production required for the aggressive case in 2050 is only 25% of U.S. production in 2007



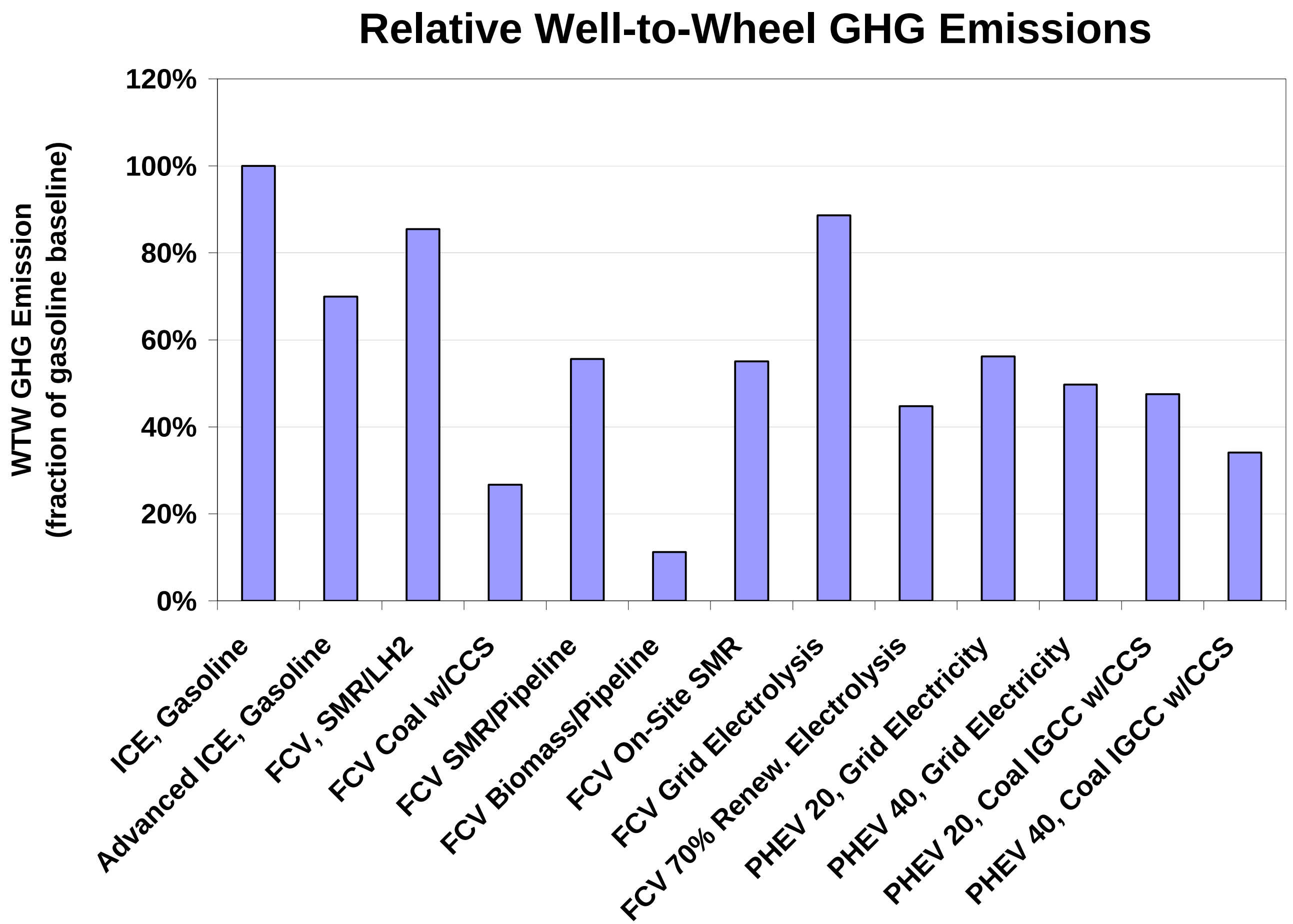
- This illustrates that the development of hydrogen production for transportation purposes should be entirely feasible over such a long period of time

The adoption of FCVs provides significant petroleum reductions and is substantially better than other advanced vehicles such as PHEVs



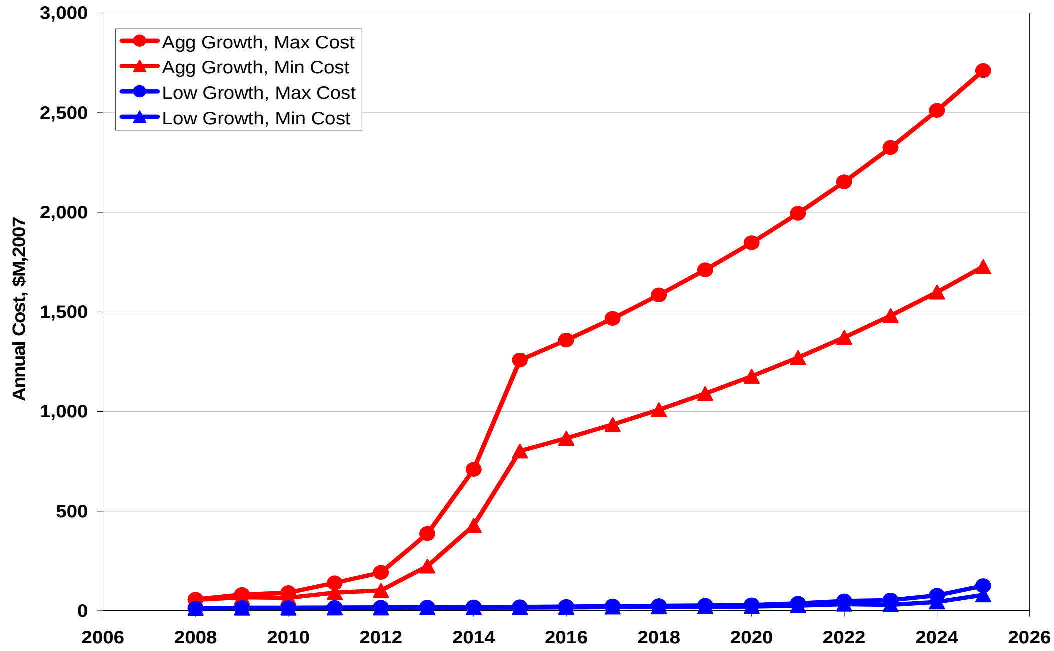
- California gasoline consumption in 2007 is ~16 billion gallons

GHG benefits are difficult to quantify due given the variety of feedstocks, but most options yield improvements over Pavley gasoline vehicles



The total annual cost increases with the vehicle sales of FCVs given that the incremental cost is assumed fixed once mass-production is reached

Annual Cost of Hydrogen FCV & Infrastructure Implementation

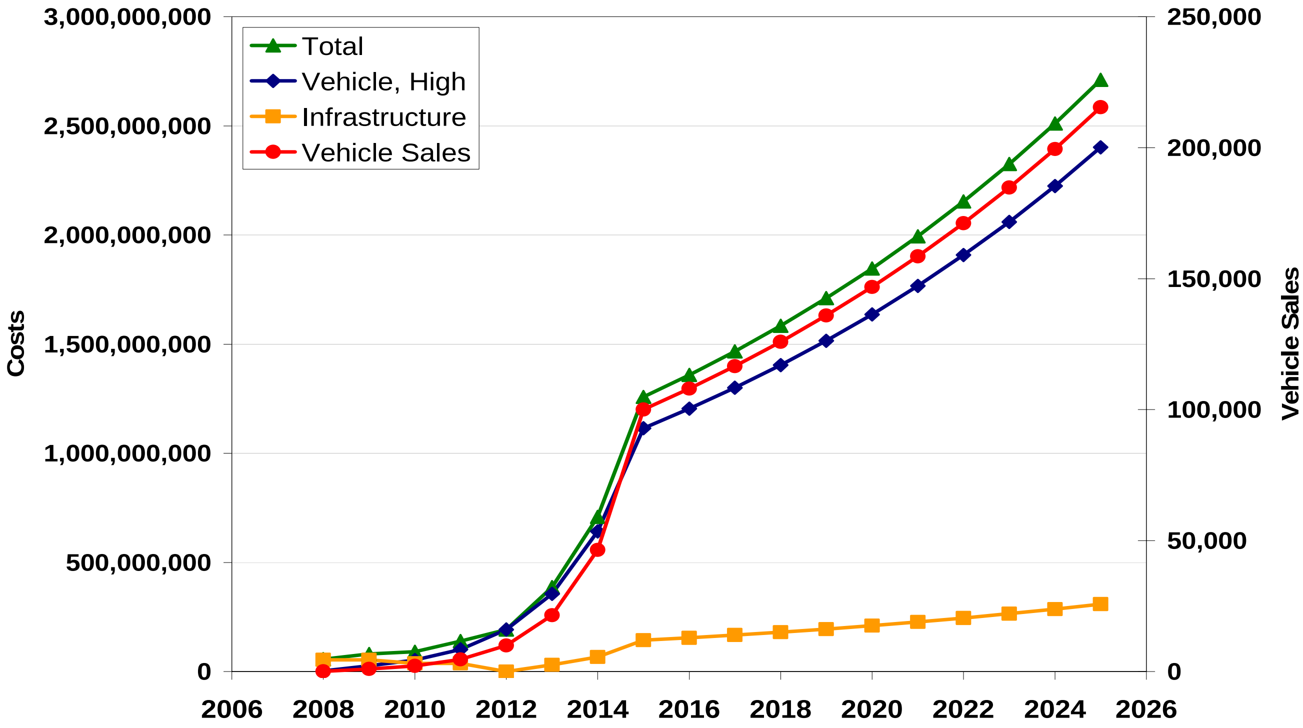


- Note that annual costs are only shown through 2025 due to the increasing level of uncertainty in incremental vehicle costs almost two decades in the future
- Fuel costs may vary between a $10 billion cost or $26 billion in savings*
- Total discounted cost until 2025: $6.8 billion (assumes 10% discount rate)

* For 2050 aggressive case replacing Pavley-compliant vehicles - not shown

Cost-breakdown illustrates the relative effects of infrastructure cost and incremental vehicle cost

Cost Breakdown and Vehicle Sales, Aggressive Scenario



- Infrastructure costs dip during the period when the California Hydrogen Highway is undergoing a period with little construction and increasing utilization

In addition to the social GHG and petroleum benefits, incremental vehicle costs necessitate vehicle attributes attractive to consumers

- Adoption of non-fossil, low-carbon fuels produced from a variety of feedstocks makes the consumer no longer subject to the price volatility of fossil-fuels
  - This also benefits manufacturers by decoupling the viability of future business from volatile fuel markets
- FCVs may also benefit from the possibility of home refueling, similar to the home refueling for natural gas vehicles
  - Beyond home refueling, Honda is developing a home energy station that allows for tri-generation of hydrogen, electricity, and heat
  - Such a technology may favorably affect other facets of energy use and costs in the home
- The ability to remove the ICE allows OEMs to offer new and unique vehicle platforms, such as GM's AUTOnomy skateboard chassis
  - This may allow for vehicles that are more attractive to consumers
- The purchase of a ZEV may also yield more practical benefits such as access to California's HOV lanes

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Many technical barriers impede FCV commercialization, but FCVs promise significant petroleum reduction, GHG benefits, and vehicle advancement

- Technical improvements are required to meet performance and cost standards for:
  - On-board hydrogen storage
  - Automotive fuel cells
  - Hydrogen infrastructure
- In the short term, the most important actions are the continued or increased funding of R&D as well as a sustained effort to develop a H2 infrastructure
- In the long-term there will need to be further reductions in incremental vehicle costs or methods to incent consumers to purchase FCVs
- Aggressive deployment of FCVs will provide GHG benefits determined by the upstream emissions of the feedstock and significant petroleum reductions
  - The monetization of petroleum reduction in the form of tax credits or a similar incentives will be particularly beneficial to hydrogen FCVs
  - Financial incentives for the reduction of GHG will promote the adoption and utilization of more low-carbon sources

Thank you for your attention

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