Summary Comparison of Alternative Vehicles

Alternative vehicles for the 21st century should be compared in terms of:

- Vehicle cost
- Total life cycle cost (LCC) or total cost of ownership (TCO)
- Fuel infrastructure cost
- Greenhouse gas (GHG) emissions
- Local air emissions
- Oil consumption
- Commercial Readiness

This document will show that the hydrogen-powered fuel cell electric vehicle (FCEV) is superior in all seven criteria compared to other options such as battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs) and biofuel PHEVs.

Vehicle Cost. Kromer and Heywood at MIT[1] have estimated that by 2030 a mass-produced SUV sized FCEV with 350 miles range will cost $3,600 more than a conventional car, while a BEV with only 200 miles range will cost $10,200 more, and a PHEV with 40 miles all-electric range will cost approximately $5,000 more. The highly respected McKinsey & Company issued a report[2] in 2010 showing that, by 2030, the FCEV would cost less to own and operate than either a BEV or a PHEV; this result is particularly credible, since 10 major automobile companies[3] shared their proprietary cost data with the McKinsey analysts in a "clean room". Note in figure 1 that the TCO includes the cost of the hydrogen infrastructure (small purple bar at top of each main bar--even though this cost would be

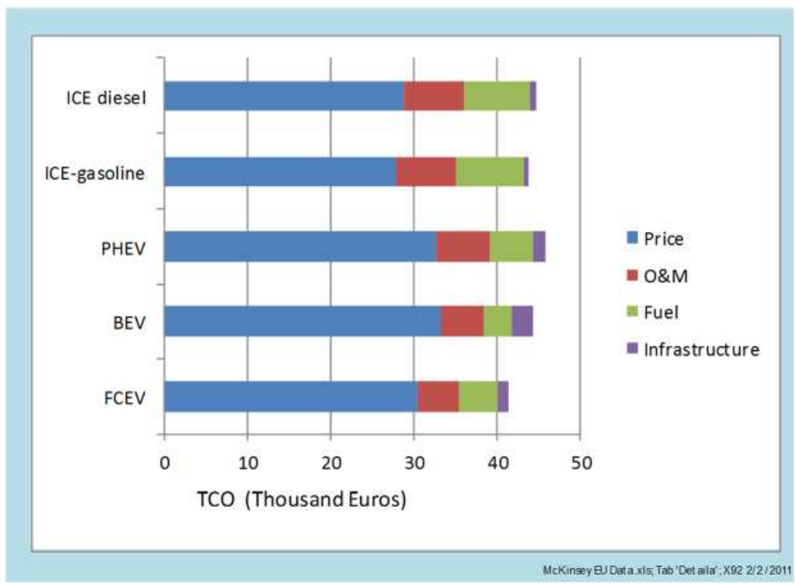

Figure 1. McKinsey estimate of vehicle total cost of ownership (TCO) in 2050 for SUV-sized vehicles

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[1] http://web.mit.edu/sloan-auto-lab/research/beforeh2/files/kromer_electric_powertrains.pdf

[2] For a summary of the McKinsey report, see: http://www.cleancaroptions.com/McKinsey_EU_Report_key_points.pdf
The full Mckinsey report "A Portfolio of power-trains for Europe: a fact-based analysis- the Role of battery electric vehicles, plug-in hybrid electric vehicles and fuel cell electric vehicles" can be downloaded from http://www.now-gmbh.de/die-now/publikationen/studie-entkarbonisierung-individualverkehrs.html

[3] BNW, Daimler AG, Ford, GM LLC, Honda R&D, Hyundai Motor Corp., Kia Motor Corp., Nissan, Renault, Toyota Motor Corp., Volkswagen.

buried in the price of hydrogen in the real world); this shows that hydrogen infrastructure is a very small portion of total costs.

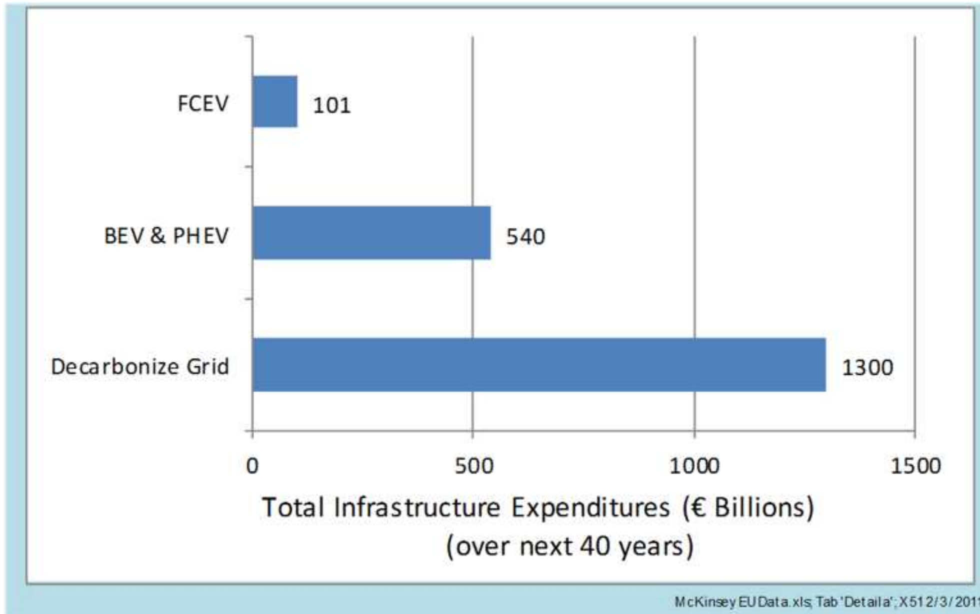

Figure 2. McKinsey estimated costs of installing hydrogen infrastructure for FCEVs and electrical charging infrastructure for BEVs and PHEVs for all of the EU over the next 40 years

<u>Fuel infrastructure cost</u>. The McKinsey report (Figure 2) also estimated that installing an electrical charging network for BEVs and PHEVs in the entire EU would cost 540 Billion Euros, while the cost for installing an EU-wide hydrogen infrastructure would be five times less at "only" 101 Billion Euros over the next 40 years.

The McKinsey report concluded that BEVs would be best suited for small vehicles that traveled short distances; but they determined that 50% of all cars in the EU that generate 75% of vehicle GHGs are larger than average and travel more than average distances. They concluded that FCEVs have already demonstrated the ability to power large vehicles with long driving distances, and therefore hydrogen-powered FCEVs must be part of the vehicle mix to achieve the EU goal of cutting GHGs by 80% below 1990 levels by 2050.

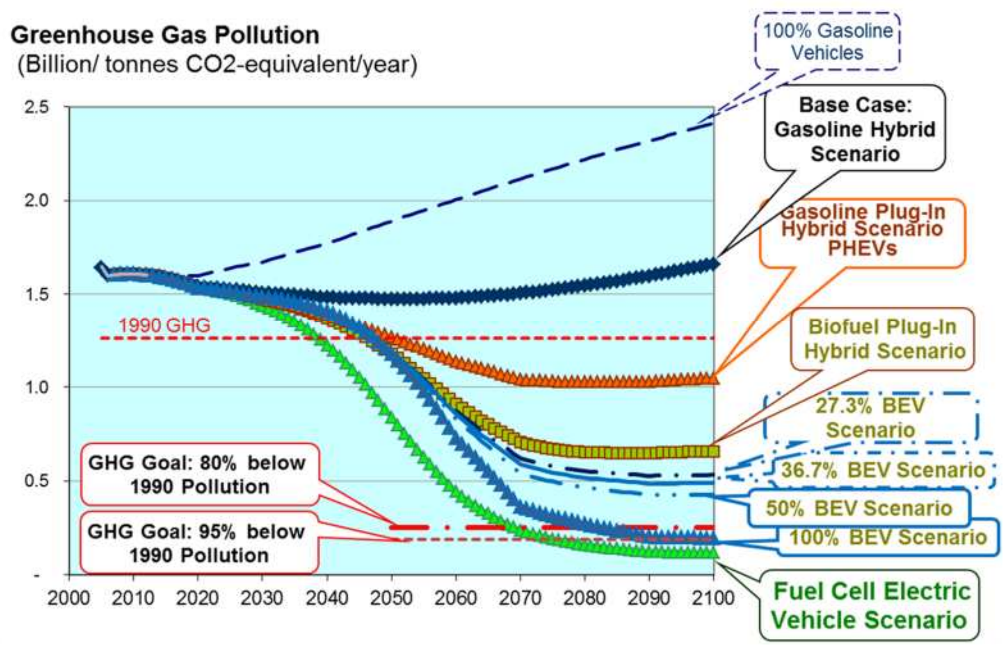

Figure 3 NHA model estimates of greenhouse gas emissions for various alternative vehicle scenarios

GHG Emissions. The National Hydrogen Association developed a detailed computer simulation model[4] that estimates the GHG emissions from various alternative vehicles over the 21st century. As shown in Figure 3, The FCEV scenario generates the least GHG emissions, reaching the 80% reduction goal by approximately 2065 with the market penetration rates assumed in the model. BEVs could theoretically reach that reduction level by 2080 if all vehicles (including SUVs, vans and pickup trucks) could be affordably converted to battery-only operation. But if we apply the McKinsey report limit of 50% BEV penetration[5], then BEVs could not achieve the 80% reduction in GHGs. Two other BEV levels are shown in Figure 3: the 27.3% BEV level corresponds to the number of vehicles that are from households with more than two vehicles that could use one BEV and one conventional car. The 36.7% line corresponds to the number of vehicles if one BEV is purchased by all 2-car households, and 2 BEVs are purchased in all households with three or more vehicles. More recently, we have shown that even if BEVs replaced all small cars, all small vans, all small pickup trucks, all small SUVs and 50% of all midsize sedans, then the GHGs would be reduced by less than 10%[6], and if we replaced all other cars with PHEVs, the *maximum GHG reduction* would still be only 28%.

Some PHEV enthusiasts postulate that we need to deploy PHEVs now, since they can enter the marketplace immediately, while FCEVs must wait several years to establish the hydrogen fueling infrastructure. The NHA model accepts this hypothesis, with the FCEV sales lagging PHEV sales by five years. Despite this five-year head-start by PHEVs, the FCEVs will cut GHGs more than PHEVs beginning in the 2022 time period as shown in Figure 4. This is because the hydrogen-powered FCEV immediately reduces GHG by 50% compared to conventional gasoline cars if the hydrogen is made from natural gas, while a PHEV

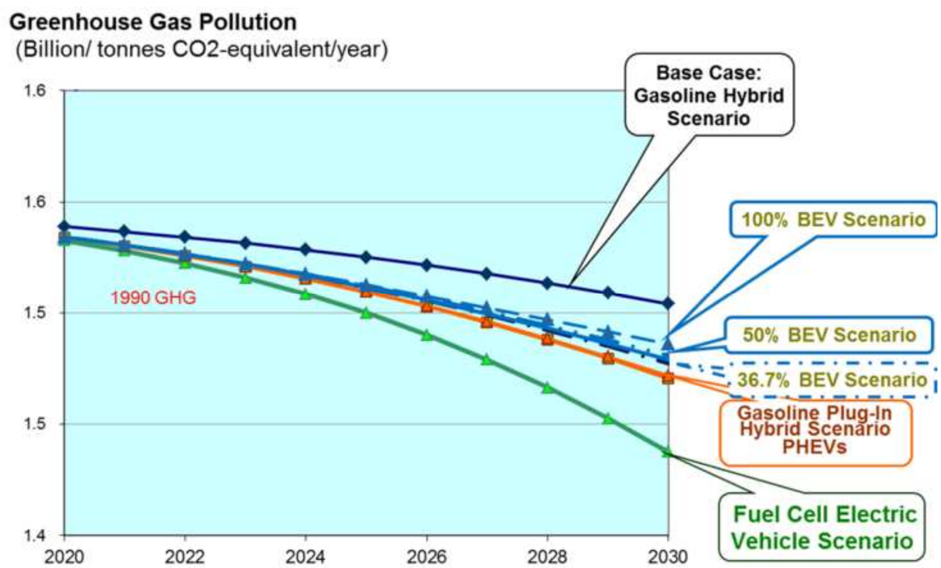

Figure 4. GHG emissions over the near-term (2020 to 2030) for the same scenarios as Figure 3

[4] C.E. Thomas, *Fuel cell and battery electric vehicles compared*, International Journal of Hydrogen Energy, 34 (2009) 6005-6020. [Note: the model in this earlier paper erroneously assumed that all sizes of vehicles including SUVs, vans and pickup trucks would be powered by batteries.] Available at: http://www.cleancaroptions.com/C.E._Thomas_Battery_vs_Fuel_Cell_EVs_Paper_for_Distribution.pdf

[5] We presume that if 50% of all vehicles in the EU are too big or travel too far to be affordably powered by only batteries, then that percentage must be higher in the US with our larger vehicles that travel farther, so the BEV market penetration in the US would be less than 50%.

[6] See this 6/23/2011 report for details of the maximum possible BEV market penetration in the US and the max GHG reduction of 5%: http://www.cleancaroptions.com/Distribution_of_US_Car_Fleet_by_Car_Class.pdf

generates almost as much GHGs as a gasoline car with today's electricity generation mix which is mostly coal in the US. Therefore the PHEV only begins reducing GHGs when the electrical grid becomes "greener," which the model[7] assumes will occur slowly over the century, reaching near-zero GHGs by the 2070 time period when all coal-based power plants are either shut down or augmented with carbon capture and storage (CCS) technology.

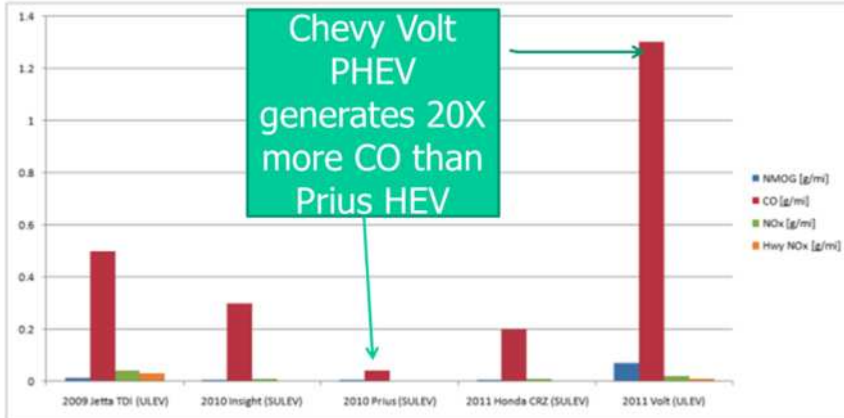

Figure 5 Estimated local air pollution from HEVs like the Toyota Prius and PHEVs like the Chevy Volt, estimated by the California Air Resources Board

While some people believe that PHEVs are low emission vehicles, the California Air Resources Board[8] has determined that a PHEV-40 like the Chevy Volt will actually generate 20 times more carbon monoxide emissions than the non-plug-in Toyota Prius HEV as shown in Figure 5. The PHEV will also generate more NOx and NMOGs.

<u>Oil Consumption</u>. The popular assumption is that PHEVs and BEVs will cut oil consumption more than FCEVs. But, as shown in Figure 6, this would only be true if all vehicles (SUVs, vans, pickup trucks) could be affordably powered by batteries. As shown in Figure 6, if BEV sales are limited to the 27% to 50% range, then the FCEV will cut oil consumption much more than PHEVs or BEVs. Also, with maximum possible BEV market penetration in the US as mentioned above, oil consumption would only be reduced by less than 26%[9], and if we also assume that all other US cars are PHEVs (100% BEVs and PHEVs), oil consumption could at best be reduced by 67%, while FCEVs would eliminate nearly all oil use in transportation.

As with GHGs, the advantage of FCEVs for reducing oil consumption becomes apparent by the 2022 time period as shown in Figure 7. PHEVs still consume some gasoline, while FCEVs eliminate all gasoline use. BEVs do not use any gasoline, but they cannot displace as many gasoline cars as FCEVs and PHEVs.

<u>Commercial Readiness</u>. The Department of Energy's National Renewable Energy Laboratory has documented[10] the on-road performance of 155 FCEVs over the last several years, driven by ordinary U.S.

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[7] For details of the assumptions used in the model, see: http://www.cleancaroptions.com/Alternative_Vehicle_Simulation_Paper_by_C._E._Thomas__for_distribution_.pdf

[8] Available at: http://green.autoblog.com/2010/10/23/carb-rules-the-chevy-volt-is-a-ulev-emits-more-than-prius-or-j/

[9] See 6/23/2011 report at: http://www.cleancaroptions.com/Distribution_of_US_Car_Fleet_by_Car_Class.pdf

[10] Click on "monitoring" link at http://www.cleancaroptions.com/html/ev_fueling_time.html for report by Keith Wipke, Sam Sprik, Jennifer Kurtz, & Todd Ramsden, "2011 Composite Data Products: National FCEV Learning Demonstration," NREL report presented to the Fuel Cell and Hydrogen Energy Association Conference, Washington, D.C., March 29, 2011.

citizens in their daily routines. These FCEVs have operated for 131,000 hours under NREL monitoring, logging over 3 million miles of travel. These FCEVs have been fueled with high pressure hydrogen 28,000 times without major incident, with an average fueling time of 4.4 minutes. No such data exist for BEVs or PHEVs since the major automobile companies have just started producing those vehicles in 2011. Questions remain about the actual range and refueling times of BEVs and PHEVs in real-world driving conditions, including the impact of car heaters and air conditioners, as well as the impact of ambient temperature extremes, and the cost of the vehicles and the cost of the electrical infrastructure as described above and the ability of batteries to affordably power a majority of American cars, SUVs, vans and pickup trucks, which will be essential to make large reductions in GHGs and oil consumption.

Several major auto companies have declared that they will begin serial production of FCEVs on or before 2015. Hyundai has announced that they will produce 2,000 FCEVs by 2014. Daimler has announced that they will build a $50 million fuel cell manufacturing plant in Burnaby, British Columbia, with a goal of increasing their current fleet of 100 FCEVs to 10,000 FCEVs. This is how McKinsey & Company judged the commercial readiness of FCEVs:

> "Given satisfactory testing in a customer environment - with more than 500 cars [FCEVs] covering over 15 million kilometres and 90,000 refuellings - the focus has now shifted from demonstration to planning commercial deployment so that FCEVs, like all technologies, may benefit from mass production and the economies of scale."

Conclusion: we need a *mixture* of alternative vehicles to meet our environmental and energy security goals: BEVs for small vehicles with short driving distances, FCEVs for larger vehicles and longer driving ranges, and PHEVs to bridge the gap.

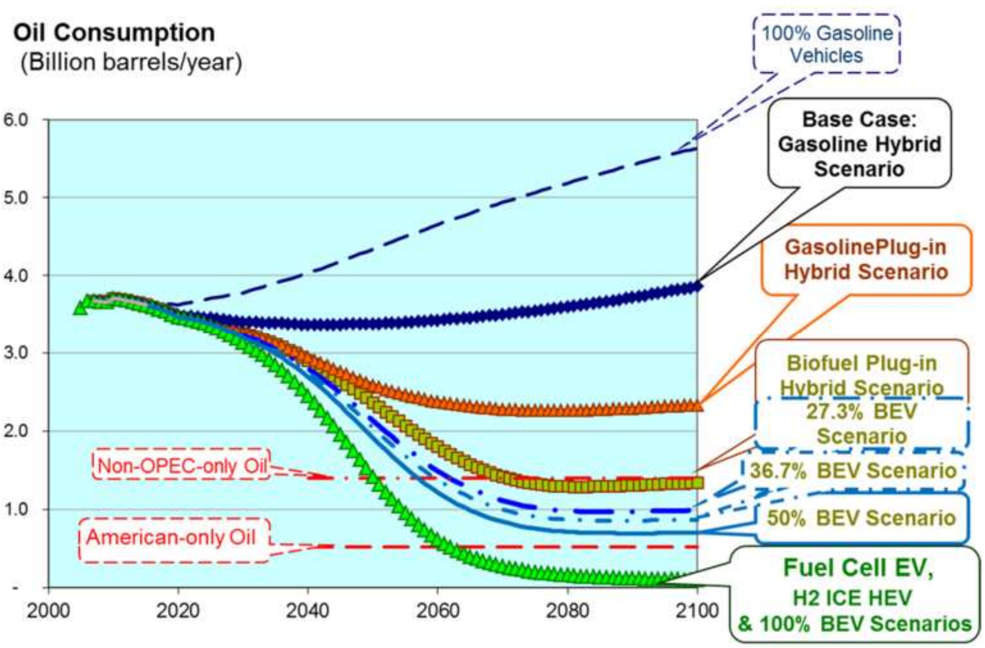

Figure 6. Estimated oil consumption for the alternative vehicle scenarios over the 21st century

The imperatives to cut GHG emissions and cut our addiction to oil are too great to "pick winners and losers" at this point of time, which is what the Obama administration has done by attempting to eliminate all funding for hydrogen and FCEV projects while lavishing billions of dollars on batteries, BEVs and PHEVs and electric charging outlets.

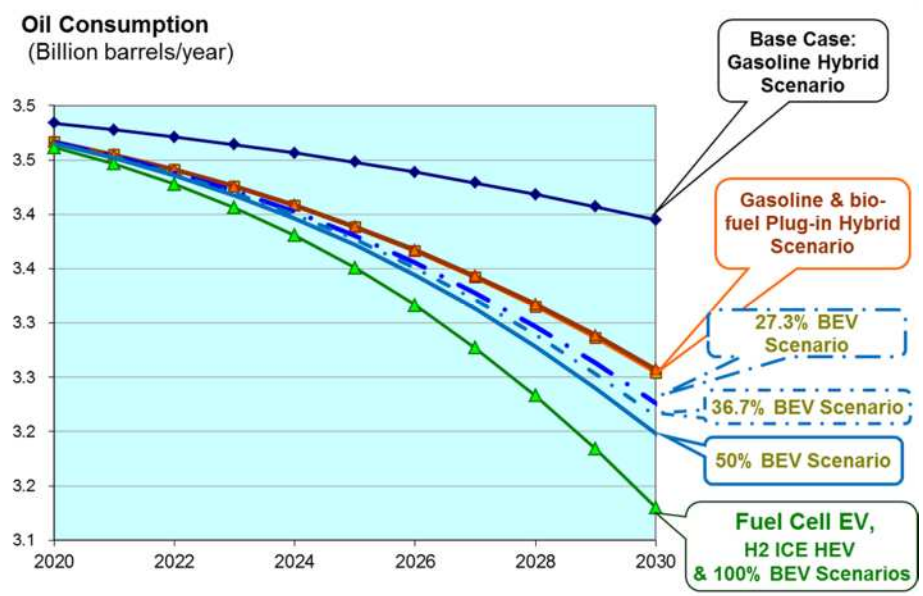

Figure 7. Near-term (2020 to 2030) oil consumption for the various scenarios

The need for a mixture of vehicles is illustrated by the plans of the California Air Resources Board as they seek to implement California's goal of cutting GHGs by 80% by 2050. Figure 8 is a slide presented by CARB's Tom Cackette at the 2011 Hydrogen and Fuel Cell Association's conference[11] in Washington D.C., CARB assumes a portfolio of vehicle options starting with hybrids, then PHEVs, then BEVs, with the majority of vehicles being FCEVs by the 2050 time period.

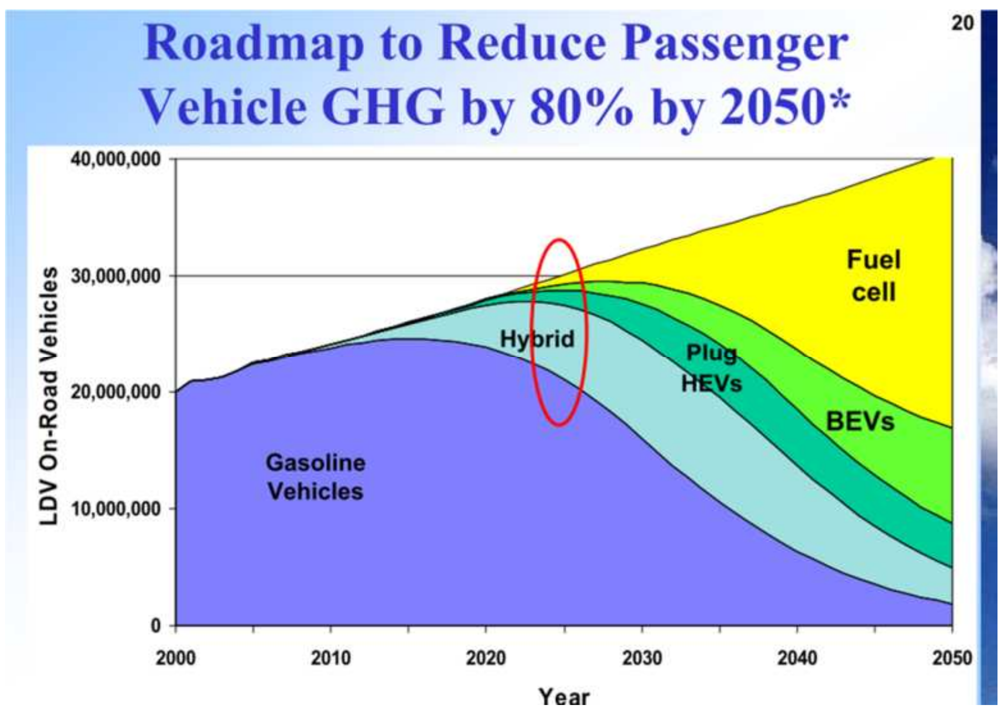

Figure 8. Mixture of alternative vehicles suggested by CARB to achieve an 80% reduction in California GHGs by 2050

[11] Tom Cackette, "California climate change policy and the role of hydrogen," presented at the Fuel Cell and Hydrogen Energy Conference, Washington, D.C., February 1, 2011