Introduction

The aim of this document is to provide an external evaluation for CARB recommendations pertaining to forthcoming ZEV regulations. The following documents have been reviewed:

- White Paper: Summary of Staff's Preliminary Assessment of the Need for Revisions to the Zero Emission Vehicle Regulation
- ATTACHMENT A - Status of ZEV Technology Commercialization (Technical Support Document)
- ATTACHMENT B - 2050 Greenhouse Gas Emissions Analysis: Staff Modeling in Support of the Zero Emission Vehicle Regulation

The documents are very well structured and provide an exhaustive list of pertinent references.

Proposed Scenarios

The approach used in the report is to estimate the changes in the vehicle parc needed in order to reach an 80% reduction in GHG emissions from 1990 levels by 2050. Therefore, the analysis is based on projected ZEV sales trajectories between 2010 and 2050, univocally determined by the 80% reduction in GHG emissions.

The scenarios presented in the white paper need to be carefully evaluated with respect to market dynamics, technologies improvements/barriers, required infrastructure, etc. – in order to assess the feasibility of the projections. A risk analysis based on various scenarios is recommended. The background presented in the white paper does not seem to consider any alternative paths should some of the assumptions/projects made not materialize.

It is clear that the analysis presented in the white paper shows what is *needed* to meet the 80% reduction of GHG emissions, but a complete analysis should include sensitivity analysis based on less aggressive ZEV sales projection sales, and also considering what may happen if other energy sectors do not meet their share of GHG reductions. We are especially concerned about the ability of the electric power sector to achieve "zero-carbon" electricity.

Two scenarios are featured in the report:

- Scenario 1 achieves a 66% GHG reduction, and represents a case where all major assumptions are aggressive compared to the business-as-usual case.
- Scenario 2 achieves the full 80% GHG goal by pushing two key assumptions even further: ZEV sales projections, and the amount of biofuels used.

Both scenarios include all advanced vehicle technologies: FCVs, BEVs, and PHEVs, each with aggressive market growth assumptions. In the report it is clearly stated that Scenario 1 achieved a 66% (80% for Scenario 2) reduction in GHG emissions by 2050 using aggressive but *plausible* assumptions and the analysis relied on external studies of how rapid advanced vehicle sales rates could become.

In the report it is stated that 80% might be too aggressive, thus a "less optimistic" scenario (66%) is presented. However, these assumptions risk becoming unrealistic if too aggressive, thus compromising the credibility/feasibility of future mandates and regulations.

EVs, FCVs, PHEVs sales

In the near-term, it is likely that conventional vehicles will continue to make efficiency gains and make up most of new vehicle sales. Therefore, it is essential that all technical advances be directed toward decreasing fuel consumption rather than compensating for increased performance and weight. In addition to conventional ICE vehicles, HEV technology has been shown to be an effective pathway to cost-effective reduction in fuel use. Within the next several years, automakers will likely produce smaller, lighter, and more efficient conventional ICE vehicles as a low-cost approach to GHG reductions, while continuing to hybridize their vehicle portfolios. A key driver in the development of advanced technology vehicles will continue to be cost to the consumer. Unless policy directions change in a dramatic fashion in the next 5-10 years, it is difficult to imagine that the aggressive penetration of PHEVs and BEVs will take place without some equally aggressive tax incentive.

Early markets take time and are very slow to grow initially; for example, it took 10 years for hybrids to reach only 4% of the new vehicle market in California. BEVs, and FCVs present significantly greater uncertainty than HEVs in consumer expectations, creating equally large market uncertainties. Among the proposed technologies, PHEVs have gained most interest over the past decade for several reasons, including potential environmental benefits, reduced use of imported petroleum and ease of recharging. Bust, most important, today PHEVs represent the most cost-effective solution to replacing the use of petroleum based fuels with electricity.

According to the report, PHEVs will play an important role in the electrification of transportation only in the short-medium term, drastically reducing new vehicles sales within few years (no new vehicles sales after 2040), thus being considered a transient product. However, PHEVs are collectively considered to be one of the highest-potential emerging consumer product categories of the next few years.

In the report, one of the main barriers to a higher penetration of PHEVs is the expectation that bio-fuels will experience limited availabilit; at the same time, fuel cell vehicles are presented as the ultimate solution; however, no attention seems to have been paid to the availability/generation of hydrogen from renewable sources.

Either natural gas (steam reforming) or electricity (electrolysis of water) is needed for this process; how will this increase electricity load and/or demand for natural gas? What will these effects be? What are the benefits of using such “fuels” to generate hydrogen and then electricity? Why not using natural and/or electricity directly to propel vehicles as a fuel for an ICE or as electricity to be stored in batteries? Well-to-wheel analysis (conducted at National Labs, for example) suggests that in both cases, producing hydrogen from natural gas or by electrolysis may not be the most energy efficient use of these energy resources.

The GHG impact of hydrogen-FCV is underestimated, but is mitigated by reference to a renewable fuel standard for hydrogen. If the 'renewable' hydrogen is from biological sources, will the energy efficiency of generating hydrogen be greater than the energy efficiency to for hydrocarbon? If 'renewable' hydrogen comes from 'renewable' electricity via electrolysis, this is a very inefficient use of incremental low-GHG electricity.

The white paper also shows that an increasing amount of PHEV all-electric range (AER) over time was assumed as batteries improve: 10 miles in 2020; 50 miles in 2050. This statement is not

clear. Is this a cost constraint? PHEVs that will be available in late 2010 (according to GM http://gm-volt.com/) will have already 40 miles AER, which is almost the assumption for 2050. Assumptions on PHEVs should be explored in greater depth.

Also, it is well known that PHEV performance depends on exogenous factors, such as electricity generation mix, driving cycles and battery conditions (SOC, life, temperature, etc). However, the report identifies the dependence of performance on driving cycles as negative; this could be misleading. If economic incentives to plug-in instead of buying chemical fuel are appropriately created, confidence in the use of plug-in vehicles should be quite good. If there is a disincentive to plug-in, why would an EV be more desirable? It is reasonable, for example, to posit the growth of multi-car households housing both conventional and BE vehicles. In this case, the same usage uncertainty must apply to EV; with limited range and functionality, drivers will err on the side of caution and use a conventional for trips for which they would have been comfortable with a PHEV. It is difficult to assess PHEVs benefits, but for most US/California driving cycles they represent a very viable solution to drastically reduce emissions, petroleum consumption and cost.

Published reports forecast that more than 500,000 PHEVs will be sold in the U.S. by 2015, following their market introduction in 2010. Market dynamics are fast, but not that fast when it comes to replace the existing vehicle fleet. Thus it is expected that PHEVs will still play an important role in the 2030-2050 transportation arena.

According to "PHEV Value Preposition Study", a DOE funded effort (http://www.sentech.org/phev/pdfs/PHEV_VPS_P1_T4_Int_Report_FINAL_1-09.pdf), PHEVs market penetration is estimated to be 10% (of southern California fleet) by 2030 with annual sales of 5-10% of new vehicles, while the reviewed report estimates a market penetration of about 20% for PHEVs and 10% for BEVs+FCVs by 2030.

Sustainable market, infrastructure and market dynamics

The analysis should look at a sustainable and commercially viable ZEVs market; will ZEVs be able to reach high market penetration (at least 67%) by 2050 and then being sustainable without continuous government/federal incentives?

What is the infrastructure required to achieve such market penetration? What is the investment needed to electrify the transportation sector? Is all this feasible?

- Hydrogen infrastructure – necessary for FCV
- Renewable electricity expansion –
- Smart Grid – the electricity need of millions of electric vehicles will require new power plants and to insure the grid is not overloaded
- Will new power plants be needed? If so, at what cost?

The analysis should also include economic factors and consumer choice, looking at customer expectations, charging/refueling habits, etc. Even with an accurate estimation of new market drivers - such as peak oil and government subsidies, dynamics of consumer demand for EVs and FCVs are not clear, while PHEVs and their associated electrical charging infrastructure, seem to be more promising.

- What effects do increasing energy cost and the economic downturn have on the overall market?
- How will cost constraints affect price of the electric vehicles? And how will this effect the proposed scenarios?
- What is needed to update the infrastructure in preparation for the future availability of electric vehicles?
- Who are the prospective electric buyers? What are their habits, opinions, and concerns regarding electric vehicles?

Another important set of observations pertains the electricity sector. The white paper does not discuss how the electric grid will meet its GHG reduction 'fair share'. Even the aggressive EPRI plan yields only 40% reduction in total CO_2. For the grid to achieve its ultimate goal to de-carbonize electricity, it is clear that retirement of coal-fired power plants is a must, and it is the quickest way to achieve significant CO_2 reductions. A growing fleet of EV/PHEV represents a growing load on the electric grid; any increasing load must be met with an equal 'green' capacity if a constant rate of retirement of coal power plants is to be achieved. If not, the total GHG impact of society will continue to increase even as the CO_2/kwh goes down. The use of incremental green electricity to displace existing coal power plants, or even to power EV/PHEV has greater GHG reduction impact. With no plan to get below 150 kg/kWh even without this huge increase in load, how do EV/PHEV help? What is the benefit of EV in this context? One can also suggest that using electricity to make hydrogen just amplifies this effect.

Electricity is the only potential energy source for transportation that addresses the simultaneous need for fuel diversity, energy security, reductions in greenhouse gas emissions, and improvements in air quality that is widely available and produced domestically. Electric utilities must understand the paradigm shift that will occur with an inevitable transition of transportation energy from petroleum to electricity—as well as their new role as a fuel provider for vehicles. The aggressive projections made in the white paper will simply not materialize unless the electric power sector can successfully reduce its CO_2 emissions to an extent that exceeds current projections.

Although electric vehicles can significantly reduce vehicle-produced emissions in highly populated urban centers, increased emissions will be released from electrical power generation sites. With such high penetration of electric vehicles, transportation pollution will just be shifted from the wheel to the well. Hence, it is important to look at the possible energy source scenarios to gain an understanding of the total impact of transportation emissions on global environmental change.

Emission levels are extremely dependent on the marginal generation mix. CO_2 and GHG analysis will be extremely sensitive to this parameter. Future generation mix and smart grid potentialities need to be further analyzed for the following reasons:

- Generation mix determines the average level of emissions coming from the grid to recharge vehicles (and eventually generate hydrogen).
- Smart grid determines when and how vehicles are charged, based on hourly energy dispatch.

Closure

To ensure a successful introduction of ZEVs and subsequent thriving market, several pressing issues need to be addressed:

- Infrastructure: most potential EV owners currently have an accessible charging outlet in their garage or carport. However, most major cities are not yet equipped with the necessary charging stations in work locations or shopping areas to accommodate charging during the day. Even more attention need to be addressed to hydrogen generation/distribution infrastructure for FCVs.
- Policies and Regulations: Similar to the introduction of HEVs, policies that offer financial incentives to potential ZEVs owners to significantly boost market penetration. Favorable ZEVs policies would include tax credits to owners/drivers, incentives for battery/fuel cell manufacturers to produce domestically, and rebates to utilities that fuel ZEVs with electricity/hydrogen at lower rates.
- Collaboration between automotive OEMs and utilities: the concept of grid-connected vehicles has introduced the unconventional need for utilities and auto manufacturers to work together. Both entities have a mutual goal of designing BEVs that exhibit optimal interaction with the grid, ultimately resulting in benefits to all consumers.

Part of this document is based on two recent DoE/Sentech and National Research Council studies, to provide a broader perspectives based on related but independent studies. A summary of these documents is attached.

About the authors

Prof. Giorgio Rizzoni, Fellow of IEEE and SAE, is the Ford Motor Company Chair in Electromechanical Systems at The Ohio State University, a Professor in the departments of Mechanical and Electrical Engineering, and the Director of The Ohio State University Center for Automotive Research, http://car.osu.edu . He has been involved in electric and hybrid vehicle research, education and technology commercialization since 1993.

Dr. Vincenzo Marano is a Research Associate at The Ohio State University Center for Automotive Research. His research interests are in the areas of energy systems and alternative vehicles. Since 2008, Dr. Marano has served as program manager of the SMART@CAR consortium, a collaborative research program with participation of major automotive OEMs and electric power companies (http://car.osu.edu/smartatcar).

DOE/Sentech PHEV Value Proposition Study

Sentech, Inc., Oak Ridge National Laboratory, General Electric Global Research, Electric Power Research Institute, and the Center for Automotive Research at Ohio State University have completed Phase 1 of an in-depth study that investigates the benefits, barriers, opportunities, and challenges of grid-connected plug-in hybrid electric vehicles (PHEVs) in order to establish potential value propositions that will lead to a commercially viable market by 2030. Funding provided by U.S. Department of Energy Vehicle Technologies Program and U.S. Department of Energy Office of Electricity Delivery & Energy Reliability.

During this initial phase of this study, business scenarios were developed based on economic advantages that either increase the consumer value or reduce the consumer cost of PHEVs to assure a sustainable market that can thrive without the aid of state and Federal incentives or subsidies. The Phase 1 case study presented the project team with the challenge of integrating most aspects of the PHEV industry in order to provide an all-encompassing outlook.

Phase 1, located in southern California, concludes that the combined operating cost savings and societal benefits attainable with PHEVs will support a commercially viable and sustainable PHEV market by 2030 (10% market penetration). Specifically, PHEVs in the studied region benefit from:

- Fuel costs reduced by 55% and 33% compared to conventional vehicles and HEVs, respectively
- 16% less total ownership cost than conventional vehicles; 4% less than HEVs
- Unique attributes (e.g., emergency backup power, mobile power, battery recycling credit)
- Decreasing gasoline consumption by 80% and 70% compared to conventional vehicles and HEVs, respectively
- Emitting 25% less carbon dioxide and total greenhouse gas emissions than conventional vehicles
- Consuming 40% and 10% less total energy than conventional vehicles and HEVs, respectively
- Potentially increasing utilization of domestic renewable resources

Ongoing tasks include:

- Include updated utility, industry and national laboratory data related to consumer preference surveys, T&D system characteristics
- Continued exploration of battery leasing, third party ownership, and buy-back/recycling business models, based on the financial and battery modeling outputs of Phase 1.
- Alternative geographic settings outside southern California to account for the nation's diverse range of generation mixes, climates and other variables.
- A Market Introduction Study to identify action items that are critical to creating and sustaining a market for PHEVs once they are available for purchase. The project team will investigate what policies, incentives, and regulations are likely to be key enablers to accelerate commercialization of PHEVs. Critical pinch points capable of limiting the success of the PHEV market will also be identified.

National Research Council (NRC) Transition to alternative transportation technologies: Plug-in hybrid electric vehicles

The report, written by the National Research Council (NRC) to analyze PHEVs as one of the possible ways for a transition to alternative transportation technologies, provides:

- an analysis of the factors that will affect how rapidly PHEVs could enter the marketplace, including the interface with the electric transmission and distribution system
- a prevision of a maximum practical penetration rate for PHEV consistent with the time frame and factors considered in the 2008 Hydrogen Report
- an estimation of the costs and impacts on petroleum consumption and carbon dioxide (CO2) emissions

Two different market penetration rates were considered in the analysis:

- A maximum practical scenario which assumes manufacturers are able to rapidly increase production and consumers find these vehicles acceptable. This scenario would lead to approximately 240 million PHEVs sold by 2050 in US (about 65% of vehicles fleet). Such rapid penetration would require strong policy intervention because PHEVs will cost significantly more than ICEVs and HEVs.
- A probable scenario without strong market-forcing policies - market penetration is slower than in the maximum practical scenario and would lead to 110 million PHEVs on the road by 2050 (about 30% of vehicles fleet).

Starting from the 2009 EIA reference case for electricity demand (increasing by 26 percent from 2007 to 2030), an alternative set of scenario for U.S. power generation was developed jointly by the Electric Power Research Institute (EPRI) and the Natural Resources Defense Council (NRDC) to explore the relationship between the grid and PHEVs if it becomes necessary to lower CO2 emissions. Nine modeling scenarios were developed spanning high, medium and low emissions of CO2 and low, medium and high penetrations of the fleet by PHEVs. EPRI and NRDC concluded that all nine cases showed significant GHG reduction attributable to PHEV fleet penetration. Key results can be summarized as follows:

- Lithium-ion battery technology has been developing rapidly but cost are still high and the potential for dramatic reduction appears limited.
- PHEV-40s are unlikely to achieve cost-effectiveness before 2040 but PHEV-10s may get there before 2030.
- At the maximum practical rate 40 million PHEVs could be on the road by 2030 (about 12% of vehicles fleet).
- PHEV-10s will emit less carbon dioxide than non-hybrid vehicles, but more than HEVs.

In a previous report "Transitions to Alternative Transportation Technologies--A Focus on Hydrogen (2008) it is stated that the maximum practicable number of HFCVs that could be on the road by 2020 is around 2 million (less than 1%). Subsequently, this number could grow rapidly to as many as 60 million by 2035 (about 18%) and more than 200 million by 2050 (about 55%), but such rapid and widespread deployment will require continued technical success, cost reductions from volume production, and government policies to sustain the introduction of HFCVs into the market during the transition period needed for technical progress.