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Review of

2050 Greenhouse Gas Emissions Analysis:

Staff Modeling in Support of the Zero Emission Vehicle Regulation

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This document contains a review of the CARB 2050 Greenhouse Gas Emissions Analysis conducted by ARB staff in support of the Zero Emission Vehicle Regulation.

Overview Comments

- **Overall, the report is well-done and the analytic approach is sound**. CARB staff is to be commended for developing a high quality model that captures many of the key issues around the role of ZEVs in GHG reductions in California.
    - Up to date data sources were used for California's current and future energy use.
    - The methodology was explained well.
    - Using the VISION-CA stock turnover model is a good method for modeling the evolution of the fleet.
    - The sensitivity studies were very useful.
    - The biofuels discussion was well done.
- In modeling a scenario this complex, the results for GHG reductions necessarily depend on many input assumptions. While the text and graphs provided a good deal of information**, I felt that the reader might need more detail to fully understand the two scenarios, and to assess the results. Adding an appendix providing more detailed information on the modeling assumptions would add transparency and enhance the report's credibility.** This information could be conveyed by tables or even by spreadsheet printouts, similar to what was done for the UC Davis 80 in 50 study [Yang et al. 2009]. In particular, I thought **several assumptions needed more explanation or rationale**.

- The fuel economy assumptions in Figure 3 seem a bit aggressive. Are these for small cars only? What would the combined light duty fleet numbers look like, including both cars and light trucks? The MIT fuel economy numbers are higher those used in other reports: (NRC 2008 H2 Transition study, HyTrans, USDOE's Multipath study (Plotkin and Singh 2009)). That's OK, but the report needs to provide more info on the vehicle assumptions leading to these values (or refer to this discussion in Figure 3). Also need to clarify the average LDV fleet fuel economy (only cars are shown).

- For PHEVs, need a little more explanation of how you estimate the gasoline and electrical energy use (or refer to the accompanying CARB technical report).

- How was the mix for hydrogen production in 2050 selected (Fig. 6)? The choices seem unlikely to me because solar central electrolysis and high-temperature water splitting are probably going to be a lot more expensive than other low-carbon options like biomass gasification and fossil w/CCS. In recent studies by the NRC and UCD, we found that the lowest cost, low carbon H2 mix is a combination of biomass gasification, fossil w/CCS and onsite SMR.

- **In general, the report did a good job assessing the relevant literature on vehicle characteristics** and transitions (the accompanying technical report does this, as well).
  - In a few places, **more use of references would help support key assertions**
  - R**eviewing a few more recent studies might be informative: DOE's Multipath study (Plotkin and Singh 2009), recent UCD studies of future grid and EVs (McCarthy 2009, McCarthy and Yang 2009) and other studies of fuel economy for advanced vehicles by ANL (Elgowainy et al. 2009, ORNL.**
  - Also, references should be given in standard citation format (e.g. give the names of the authors) with weblinks where possible. This will make it easier for the reader to find the references.

- **It would help to specifically define concepts** such as fuel economy (is this on-road fuel economy, EPA combined urban and highway drive cycle?)
  - You might consider showing graphs for the whole LDV sector as well as separate graphs for cars and trucks. I wasn't sure what fraction of the LDV fleet were cars vs. trucks for the two scenarios.

- **It was somewhat hard to follow the scenario descriptions in the text. I recommend including a summary table giving the characteristics of Scenarios 1 and 2, and some key results. This will make it easier for the reader to understand the important features of each scenario at a glance**.

- **From Figures 9 and 10, the main difference between Scenario 1 and Scenario 2 appears to be how fast PHEVs are displaced by ZEVs.** The early market introduction dynamics for ZEVs (before 2025) determine how fast this can happen. It would help to show Scenario 2 on Figure 13, so we can see what an 80% success case looks like.

- **I'd like to see more information on what factors contribute to the reduction in GHG emissions. How much is efficiency (use of more efficient ICEVs, HEVs and PHEVs, and ZEVs)? How much is lower carbon fuels? How much is use of the ZEV technologies? This could be shown as a series of curves similar to those in the NRC 2008 report. (This showed the impact of various levels of advanced vehicle use.) The Yang et al. CA 80in50 paper also broke down the GHG savings in terms of efficiency and fuels, and by transport subsector.**

- **Also, at the end of the results section, I'd suggest highlighting what is different between Scenario 1 and Scenario 2.** The discussion should focus on why Scenario 2 succeeds in reaching the 80% GHG emissions reduction goal, while Scenario 1 does not.

- **Validity of the results and the main conclusions.**

    - The results seem reasonable, although I would like to see the assumptions in an appendix to allow for better transparency.

    - In the Conclusions section, the report revisits 2 key questions.

        (1) What are the cumulative ZEVs necessary by 2050 to help the LDV sector achieve an 80% GHG reduction, and

        (2) What annual ZEV sales are necessary between 2015 and 2025 to initiate these fleet volumes?

    - I'm not sure that <u>cumulative ZEVs</u> by 2050 is the right metric. Instead don't we want to know what % of the on-road fleet are ZEVs in 2050, as this will help determine the GHG emissions?

    - The annual ZEV sales between 2015 and 2025 required to get on a "very fast" (scen 2) or "fast" (scen 1) trajectory are listed on p. 26. Are you recommending that scenario 2 is required to meet the 80% reduction goal? (25,000/y is needed by 2020 and 435,000 by 2025?) If so, this tracks fairly well with the most aggressive DOE and NRC (2008) cases for FCV commercialization, assuming strong policy support. You might mention this. Also you might cross check with the CARB ZEV report. Is scen 2 consistent with their take on how many ZEVs could be produced?

Additional Detailed Comments by Section

1. Introduction and Results Summary

p. 3 I suggest you define terms to make clear what is meant by “ZEVs “(e.g. “pure “ ZEVS = BEVs and FCVs) and by “advanced vehicles” = BEVs + FCVs + PHEVs. Maybe call these “electric drive” vehicles instead of “advanced”.

p. 5 Compare scenario market penetration assumptions with those in other studies, especially Yang et al. 80 in 50 paper, NRC H2 FCV and PHEV studies, HyTrans.

In *Results Summary* section, I had a number of suggestions to improve the flow, and make the results clearer. These are shown in track changes mode in the attached file.

p.6 I’m not sure you can realistically shift ZEV sales 5 years earlier (this would mean 1000s to 10,000s of FCVs or BEVs starting in 2010).

p. 7 In several places, you refer to figures from other reports or from later sections of this report. Either reproduce them or summarize their content within the intro to make this section self contained. Some readers may focus on only the intro and not read the details later.

Literature Review

Redo the format on references (both in footnotes and in the Appendix, to make them easier to find and access. Put in standard format and add weblinks where possible.

2. Scenario Development

Good initial discussion in this section (p.10). I like your description of the usefulness of scenarios.

p. 11 *Efficiency and VMT reductions.* Need to be more specific about how you use existing studies such as MIT on the Road in 2035, as a basis for your assumptions. Also make it clear whether Figure 3 shows the actual on-road fuel economy, EPA fuel economy or fuel economy estimated over some other drive cycle.

In Figure 3, make clear whether this is for cars only or for LDVs (cars and light trucks).

The results in Figure 3 are more aggressive than DOE EIA modeling or NRC 2008 H2 study. (In the NRC 2008 study, on-road fuel economy for a gasoline ICEV vehicle in 2050 was about 40 mpg, HEV about 60 mpg, FCV about 80 mpg.).

p. 12. I'd like to see a little more information on how the PHEV gasoline and electricity use are estimated. This is actually pretty important for your GHG calcs. Kromer and Heywood (2007) or the 2009 NRC PHEV study (Appendix C) have good discussions of these topics.

Figure 4 is very good.

Figure 5. Is the right hand axis gCO2e per MJ of electricity? If so, you might give these numbers in terms of gCO2e/kWh. This will allow a ready comparison with other studies. If I read the right, the gCO2e/MJ decrease from about 120 gCOe/MJ to 30 gCO2e/kWh (432 gCO2e/kWh to 108 gCO2e/kWh). These are very pretty carbon electricity values. They seem lower than Ryan McCarthy's estimates for the CA grid, which are more like 600 gCO2/kWh (figure below is from McCarthy and Yang new Journal of Power Sources paper). Check these?

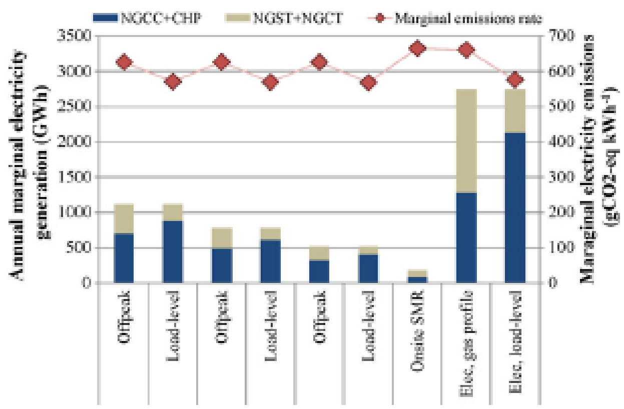

Fig. 4. Marginal electricity generation and direct GHG emissions rates by vehicle and fuel pathway.

R. McCarthy, C. Yang / Journal of Power Sources 195 (2010) 2099–2109

Figure 6. I am curious about the assumed sources for H2 production over time. How did you choose the mix in 2050? Solar central and high T electrolysis will be much more costly than other low-C options like biomass gasification and fossil w/CCS. In several studies, UCD researchers found that the lowest cost options in CA included onsite SMR, central biomass gasification and central coal w/CCS (each about 1/3). If we did see electrolysis, I'd expect to see off-peak wind perhaps. (This is described in the NRC 2008 H2 transition report.) Also cross-check with 80in50 CA study assumptions for H2.

Nice discussion of biomass issues on p.15.

Figure 8. Please explain assumptions behind this figure more completely.

In particular, why are assumed fractions of biomass resource allocated among various uses different from left most set of bars in Fig 8 (IEA) and middle set of bars (NRC)?

- IEA 15% for CA, 20% for Tranpsort, 30% for LDVs
- NRC 15% for CA, 50% fpr transport, 50% for LDVs

In Figures 9 and 10 show BEVs and FCVs separately. You discuss them separately in the text, so this would be helpful.

In discussion on p. 17-18, add some words about scenario 2. Say what's different about scen 1 and scen 2, and how they relate to earlier studies including NRC 2008 (H2 trans) and 2007 CARB ZEV report.

This is a perfect place to add a summary table about Scenario 1 and Scenario 2 to help guide the reader.

3. Results

Sidebar on p. 20, Should note that there are costs for EV infrastructure: home charging and in longer term T&D upgrades, smart grid, and new generation.

p.21. discuss whether it's realistic to get ZEVs out 5 years earlier than scen 1. What kinds of ZEVs? Are automakers planning this.

Figure 13. Show scenario 2 market penetration curve as well. Want to see what 80% success looks like compared to other cases.

Figure 17. Indicate which cases correspond to scenario 1 and scenario 2 (is this the same as "success"?)

4. Conclusions

p. 26 Are Scenario 2 ZEV market penetration levels required to meet 80% reduction goal?

Are there other ways to get there?

Benchmark with NRC H2 transitions, HyTrans, 2007 CARB ZEV Panel and other studies.

p. 27. Discuss assumptions about H2 supply mix, too, which contained major assumptions about the viability of electrolysis and Hi-T electrolysis. Other studies (NRC) suggest that the success of H2 doesn't require these rather exotic tech to work out.

References should be given in standard citation format (e.g. give the names of the authors) with weblinks where possible. This will make it easier for the reader to find the references.