Scientific Review of the California Air Resources Board's Proposal to Implement the Low Carbon Fuel Standard

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About the author

Dr. Linsey C. Marr is an Associate Professor of Civil and Environmental Engineering at Virginia Tech. She received a B.S. in Engineering Sciences from Harvard and M.S. and Ph.D. in Civil and Environmental Engineering from the University of California at Berkeley. Her expertise lies in the measurement and estimation of motor vehicle emissions and air quality modeling. She has published 24 papers in the peer-reviewed literature and has served as a reviewer for numerous scientific journals, the National Science Foundation, Environmental Protection Agency, and other organizations.

Overview

This review of the Low Carbon Fuel Standard (LCFS) focuses on the proposed rule's greenhouse gas modeling and environmental and multimedia impacts, especially motor vehicle emissions, while also offering comments on other scientific and implementation aspects of the regulation. The review of technical details is limited to my areas of expertise and does not address certain aspects of the calculation of carbon intensities, such as extraction and processing of fuels, and land use change or economic impacts beyond a superficial level.

As specified in the request for this review, the rule is held to a standard in which professional judgment is given substantial weight when available scientific data are not as extensive as desired to provide absolute scientific rigor. Section I.A contains general comments about greenhouse gas modeling, and Section I.B contains specific comments that refer to certain pages of the LCFS report about this issue. In parallel structure, Sections IV.A and IV.B contain general and specific comments, respectively, about environmental and multimedia impacts. Sections II, III, and V contain brief statements about my lack of qualifications to review the scientific substance of the land use change modeling, economic impacts, and credit trading aspects of the proposed rule, respectively. The last section lists typographical errors noticed during review of the document.

With respect to greenhouse gas modeling and environmental and multimedia impacts, the proposed rule appears to be based upon sound scientific knowledge, methods, and practices. From the perspective of an expert in motor vehicle emissions and air quality modeling, the California Air Resources Board (CARB) staff has taken considerable care in developing carbon intensities. For example, the GREET model used to develop carbon intensities was customized with California-specific parameters to improve the accuracy of the calculations of greenhouse gas emissions. Some minor issues require additional analysis that should improve the scientific quality of the report. These are outlined in the sections below.

I. Greenhouse gas modeling

A. General comments on greenhouse gas modeling

1. The rule is based on establishing carbon intensities for various transportation fuels and their substitutes. In purely scientific terms, it would be more sensible to measure lifecycle greenhouse gas emissions in grams of carbon dioxide equivalent (g CO2e) per distance traveled in kilometers rather than per energy content of the fuel in megajoules (MJ) because the distance traveled is the more useful metric ultimately. Obviously, political and practical barriers hinder the more direct approach, so the LCFS establishes carbon intensities for each "fuel" and applies energy economy ratios to account for differences in the distance that can be traveled using various propulsion technologies.

2. The largest uncertainties in the estimation of carbon intensities are associated with the indirect effects. Relatively speaking, the magnitude of direct effects are much more certain. In keep to this reviewer's expertise, the comments presented here focus on

direct effects, but readers should be aware that the uncertainties in this arena are smaller compared to those associated with land use change.

3. It is surprising that the fuel pathway for biodiesel is still under development and has not yet been completed. This is one non-petroleum fuel that is already widely used. I am not familiar with California's biodiesel consumption rate, but in other parts of the country, substantial portions of the bus and equipment fleets are operated on biodiesel. According to the Department of Energy (http://www.afdc.energy.gov/afdc/progs/ind_state.php/CA/BD), there are dozens of biodiesel refueling stations in California, at least as many as there are hydrogen (http://www.afdc.energy.gov/afdc/progs/ind_state.php/CA/HY), for which the fuel pathway has been completed. Biodiesel is a fuel currently in use whose carbon intensity should be included in this report.

4. The development of energy economy ratios is straightforward with the current fleet, in which nearly all light-duty vehicles are gasoline powered, but a light-duty fleet with greater diesel presence, as was present in the past and is likely to be in the future, would require a modification to the approach. Eventually, propulsion technologies and vehicles will be produced without consideration of whether they are "replacing" gasoline- or diesel-fueled engines. How will energy economy ratios for such vehicles be calculated, i.e. to which fuel's carbon intensity baseline will they be compared? For example, hydrogen producers whose product is used to fuel light-duty vehicles could argue that the hydrogen is replacing diesel fuel because there are some light-duty diesel-powered vehicles currently in existence, at least in other parts of the country if not California.

5. Energy economy ratios certainly must be included to adjust for the different efficiencies of propulsion technologies in converting a certain amount of energy into linear motion. It would be instructive to report how variable the EER is across vehicle sizes. For example, what is the EER for a compact electric car versus a compact gasoline-powered car, and what is the EER for a large electric SUV versus a large gasoline-powered SUV? If the difference is large, multiple EERs may be needed for different vehicle classes.

6. The EER for plug-in hybrid electric vehicles (PHEVs) will require much more careful calculation once they are commercially available for testing. The value will depend very much on whether the vehicle is operating purely on electric power over its first ~30 miles or on its hybrid gasoline engine after this point. CARB will need to be able to make informed assumptions about the everyday use characteristics of PHEVs in order to determine an appropriate EER. How will updated EERs be handled?

7. Finally, with regard to EERs, a discussion of the importance of idling by heavy-duty trucks is warranted because EERs are not valid during idling. Does idling comprise a sufficiently small fraction of total diesel consumption that it can be neglected? Are idle reduction programs in place in California? What are the carbon intensities for "shore" electric power replacing diesel consumption in this case?

B. Specific comments on greenhouse gas modeling

8. (p. ES-15) Table ES-5 indicates that two pathways for electricity generation have been completed for average and marginal electricity used in the state. Given the growth in renewables, are sources of electricity expected to change enough over the next 10 years that the carbon intensity for either pathway will be different in 2020?

9. (p. ES-19) Table ES-7 lists the energy economy ratio for electricity substituting for diesel as 3.0, but everywhere else in the report, this value is given as 2.7.

10. (p. ES-36) Both the Pavley regulation and the LCFS will achieve GHG reductions from vehicles. Further clarification is needed as to the interaction between the two rules, i.e. how to avoid double-counting emissions reductions.

11. (p. IV-1) "In general, a land use change occurs when farmland devoted to food and feed production is diverted into biofuel crop production causing supplies of the displaced food and feed crops to be reduced." Is it also the case that land formerly dedicated to non-agricultural use might be converted to biofuel crop production directly?

12. (p. IV-10) Figure IV-1 would be more accurate if it showed each component of the direct effects summing to the direct effects. In its current form, the figure suggests that total direct effects are added to its components, effectively double-counting these.

13. (p. IV-16) Regarding the discussion of indirect effects resulting from intermediate market mechanisms, e.g. vehicle production, these are usually minor compared to direct emissions associated with vehicle operation. MacLean and Lave (2003, *Environmental Science and Technology*) showed that the majority of energy and GHG emissions are associated with use of the vehicle rather than production of it, so it is correct to focus on emissions from driving.

14. (p. C-57) "Due to lack of available data for Venezuelan crude, extraction and processing emissions were assumed to be similar to heavy oil recovery and processing in GREET. The GHG emissions associated with heavy oil recovery were based on the GREET calculations for oil sands assuming that the fuel source was bitumen." Insufficient information is provided to justify this assumption. Is Venezuelan crude recovery known to be closer to heavy oil recovery than primary recovery? What recovery method is assumed for other countries? If it is the same 98% recovery efficiency assumed for Alaskan crude, why are the Alaskan and Other Imported carbon intensities different in Table C12-6? Do they have different heating values?

15. (p. C-59) "These emissions are then included in the statewide overall fuel mix using the 40% cogeneration, 60% OTSG weighting described above." The 40%/60%

weighting described on the previous page is described as being based on the steam-oil-ratio and not whether cogeneration is used. Clarification is needed.

II. Land use modeling

16. The most contentious component of the rule is likely to be the inclusion of indirect effects of biofuels. Although land use change is not my area of expertise, I concur that such factors must be taken into account because an important recent study showed that land use change associated with the production of corn-based ethanol doubles greenhouse gas emissions over 30 years and increases those from switchgrass-based ethanol by 50% (Searchinger et al., 2008). Ignoring land use change would be likely be counterproductive to the goals of the LCFS. As the staff report notes on p. IV-45, some stakeholders argue for land use change carbon intensities near 0 gCO_2e/MJ, while others propose using values of 100 gCO_2e/MJ or higher. Obviously, large uncertainties still exist in the estimation of these values, so the rule should have some provision for incorporating improved estimates as they become available.

Beyond this general observation, I am not qualified to review the scientific basis of the land use modeling.

III. Economic impacts

I am not qualified to review the economic impacts of the LCFS.

IV. Environmental and multimedia impacts

A. General comments on environmental and multimedia impacts

17. Appendices F2, F4, and F5 carefully consider criteria pollutant emissions associated with fossil fuel refineries projected to the year 2020. Full lifecycle emissions are considered for new ethanol and biodiesel capacity at a detailed level. For instance, emissions are calculated from truck trips for distribution of the feedstock and fuel, and emissions with rail transport of imported fuel are also estimated. For biofuel production facilities, emissions estimates go into a detailed level, even including emissions from backup electrical generators. The assessment of criteria pollutant emissions is based on sound scientific knowledge, methods, and practices, although a few details can be improved, as listed in the section below.

18. The health risk assessment uses an inconsistent approach to pollutant dispersion for carcinogenic versus non-carcinogenic effects and seems unfairly focused on the negative effects associated with biorefinery emissions while overlooking positive effects associated with reductions in emissions from a fleet containing more advanced vehicles. The health risk assessment for emissions associated with biorefineries indicates that they will be associated with approximately 24 premature deaths; 8 hospital admissions; and 367 cases of asthma, acute bronchitis and other lower respiratory symptoms. Because emissions from the facilities themselves are expected to be offset, the main source of net emissions is diesel truck traffic to and from the facilities. It would be fairer to put these numbers in the context of the overall effect off the LCFS, rather than to presents them in isolation. Why does the health impacts

section not include mortality and morbidity avoided due to reductions in tailpipe emissions? As a result of the LCFS-inspired introduction of advanced vehicles, tailpipe emissions from the vehicle fleet will be lower, and the reductions in mortality and morbidity are likely to outweigh the effect presented in the detailed risk assessment about biorefineries.

B. Specific comments on environmental and multimedia impacts

19. (p. VII-18) "Staff estimates a maximum increase of 84 ton/year VOC evaporative emissions from refueling results in switching to scenario 2 volumes of E10 and E85 in 2020, as opposed to not switching from an energy equivalent volume of CaRFG3 fuel (E10). The other scenarios offer somewhat smaller increases. Emission standards for vehicles which use E85 are the same as for vehicles which use gasoline. Therefore, staff does not expect to see a significant difference in the emissions." This statement overlooks evaporative emissions. Increased hot soak, running loss, and diurnal emissions are also expected with a higher volatility fuel such as E85, but the report does not address these. Emissions standards apply to tailpipe emissions only and not evaporative emissions, so an argument based on standards only is incomplete. Knowing the vapor pressure of E85 versus RFG and evaporative losses from gasoline-powered vehicles should enable the calculation of engineering-based estimates of such losses with E85.

20. (p. VII-19) "Emissions of formaldehyde (HCHO) were also greater on E85 than on gasoline, showing a much larger difference, although there was only one pair of test values (DaimlerChrysler)." Larger emissions of formaldehyde could be important for air quality because of its role as an initiation species in photochemistry. Additionally, formaldehyde is an air toxic. This topic merits additional consideration. Recent studies in the literature also conclude that formaldehyde emissions will be higher with E85 (Graham et al., 2008; Yanowitz et al., 2009)

21. (p. VII-19) "This is because staff is currently conducting an extensive test program for biodiesel and renewable diesel and will follow that effort with a rulemaking to establish specifications to ensure there is no increase in NOx." This statement assumes that NOx emissions can be controlled through fuel specifications. Because much of NOx originates from thermal formation and not the fuel itself, the approach may not work; it may not be possible to control NOx emissions through specifications on biodiesel. In this case, the assumption that biodiesel will cause no increase in NOx emissions is unjustified, when studies in the literature suggest that NOx emissions increase with the use of biodiesel versus petroleum-based diesel.

22. (p. VII-20) "Clearly the major impact is associated with the additional truck trips." This sentence refers to Table VII-13, which summarizes changes in criteria pollutant emissions stemming from the LCFS and shows that the major increase in emissions is due to additional truck trips, but the net result is still a decrease in criteria pollutant emissions. In terms of magnitude, the major impact comes from ZEVs, not additional truck trips.

23. (p. VII-22) "…it is not practical to expect the air quality model to reasonably predict the impact on ozone air quality." This statement is correct, so it would be impractical to expect the section on environmental and multimedia impacts to predict changes in ozone in a meaningful way.

24. (p. VII-33) While the LCFS does not appear to trigger the multimedia evaluation requirement, the regulation will change the mixture of fuels being used in the state, and the much larger amounts of ethanol and biodiesel being used may have multimedia effects, some of which have been addressed in this chapter. In keeping with the sprit of the regulation, the report appears to address multimedia evaluation requirement properly.

25. (p. F-6) "Using the baseline information presented above, the "Tank-to-Wheel" emissions with the LCFS can be determined. This is done by assuming that there is a 10% reduction in the "tank-to-wheel" carbon intensity factor for each year." On what basis is the assumption of a 10% reduction in the tank-to-wheel carbon intensity factor for each year made? A 10% reduction per year sounds like a lot, especially given that the LCFS calls for a 10% reduction in carbon intensity over a full decade, at least for the full fuel cycle. The values appearing in Table F-1 do not correspond to a 10% reduction per year. This section needs to be clarified, and the 10% reduction per year in "tank-to-wheel" carbon intensity more thoroughly justified.

26. (p. F-35) Why is the Western Biomass Energy plant used as the only basis for projection of future emissions from cellulosic ethanol facilities? Table F5-2 lists two other facilities in Georgia and Louisiana that also cellulosic ethanol, and the Range Fuels Biofuels plant's NO_x and PM_{10} emissions per volume of fuel produced are much higher. Is the gasification catalytic process used by this plant, versus the weak acid hydrolysis process used by the other two plants, not expected to be used in the future?

27. (p. F-42) "The staff has developed five hypothetical compliance scenarios for compliance with the gasoline LCFS. For each of these five scenarios the staff has estimated the amounts of low-carbon intensity corn ethanol, cellulosic ethanol, sugar cane ethanol, and advanced renewable blendstocks that would be needed to meet the required 10 percent reduction in greenhouse gas emissions." The introduction of these five scenarios is confusing because previously, the report discussed four compliance scenarios (Appendix E). How are the two sets of compliance scenarios related? If they are not, they should be aligned with the previously presented compliance scenarios.

28. (p. F-43) "Regulations for vehicles which use E85 are the same as for vehicles which use gasoline." This statement contradicts the values shown in Table F6-4 on the following page, which lists the NMOG standards as 0.089 g/mi for E85 and 0.095 g/mi for gasoline. For the other pollutants, the standards agree.

29. (p. F-45) The review of certification data for FFVs contains statements with contradictory justification, or at least the results are hastily presented without statistical validation. The first point on the page, "Certification values in grams/mile for non-methane organic gases (NMOG) on E85 are mostly greater than on gasoline, more so at 50,000 miles than at useful life," claims that NMOG certification values are mostly greater on E85 (0.049 g/mi) than on gasoline (0.044 g/mi), differing by 11%. The third point on the page, "Certification values in grams/mile for oxides of nitrogen (NOx) on E85 are about the same as on gasoline, both at 50,000 miles and useful life," states that NOx certification values are about the same on E85 (0.03 g/mi) and gasoline (0.04 g/mi), but the difference between these two values is larger, 29%, than for NMOGs (11%). Because the formaldehyde comparison is based on a single pair of values, the fourth point, "Certification values in grams/mile for formaldehyde on E85 are greater than on gasoline, both at 50,000 miles and useful life (note however there was only one pair of values for each)," relies on a weak basis.

30. (p. F-46) "ARB staff is continuing to examine California certification data of 2008 and 2009 flexible fuel vehicles to see if there are significant differences in emissions between gasoline and E85." Such a review is critical to assessing the criteria pollutants' emissions impacts related to the LCFS. The review should analyze the data in much greater depth than presented in this report.

31. (p. F-51) The mention of five light-duty vehicle deployment scenarios that are collapsed into three is confusing. Unless the five scenarios correspond to scenarios used elsewhere in the report, these could be presented more clearly as simply three scenarios. Table F8-1 would be more easily interpreted if values were presented in thousands of vehicles rather than millions since the numbers are so small in all but Scenario 4's PHEVs in 2020.

32. (p. F-52) Table F8-2's footnote claims that emission values are rounded to two significant digits, but entries smaller than 10 tons/year show only one significant figure. Table F8-3 showing emissions reductions in tons per day is redundant because the previous table, F8-2, shows the same information in tons per year.

33. (p. F-61) The health risk assessment for diesel emissions associated with truck deliveries to biorefineries uses up-to-date modeling techniques with appropriately conservative assumptions. Please clarify whether this activity is expected to have the greatest negative health impact of all changes in emissions associated with the LCFS. For example, new biorefineries will emit criteria and toxic air contaminants from their stacks. Even though such emissions are expected to be offset, they will have local impacts. Are the risks from these emissions expected to be less than for the diesel trucks servicing the facilities? Why isn't a health risk assessment performed for changes in criteria pollutant and air toxic contaminant emissions from tailpipes? The health risk reduction from such an analysis is likely to far outweigh the case study presented in this section.

34. (p. F-63) "Staff also assumes each truck to be idling at the loading and unloading area located in the center of the facility for five minutes." Five minutes of idling sounds optimistically low in the analysis of diesel truck emissions from biorefineries.

35. (p. F-73) Unlike the health risk assessment for carcinogenic effects, which undertook dispersion modeling around hypothetical biorefineries, the non-cancer health risk assessment assumes emissions to be spread across the air basin. Inconsistent approaches are taken to estimating health risk for cancer versus non-cancer effects. Please explain the reasoning behind the different approaches. Appendix F11 provides little detail on the emissions being considered, so the reader is assuming that like in Appendix F10, they are the emissions associated with increased diesel truck traffic to and from biorefineries.

36. (p. F-76) "Biorefinery emissions were not included in the health impact calculation because increased local emissions from biorefineries are expected be offset by decreased emissions within the air basin." This assumption seems hasty because it is unlikely that local emissions from biorefineries exactly offset decreased emissions within the air basin. Furthermore, local emissions from biorefineries affect mainly the air basins in which they are located, while decreased emissions (from tailpipes I assume) are statewide.

37. (p. F-83) "Thus the proposed LCFS candidate fluid fuel production schemes should not create a water use problem if sited near large coastal WWTP and utilize ocean discharge water. Sites located inland may face difficulty finding water supplies." This is a good recommendation, but on p. VII-9, the document states, "Production facilities would be located in close proximity to local feedstocks." For biofuels, feedstocks, i.e. crops, are likely to be grown in the Central Valley, not near the ocean. A single recommendation for siting of liquid fuels, considering both water quality and consumption and transport of feedstocks, would be useful.

V. Credit trading

I am not qualified to review credit trading included in the LCFS.

Typographical errors

38. (p. ES-1) The word "percent" appears to be missing in, "Each standard is set to achieve an average 10 reduction in the carbon intensity of the statewide mix transportation fuels by 2020."

39. (p. ES-2) The word "the" is missing in, "A regulated party meets its compliance obligation by ensuring that amount of credits it earns (or otherwise acquires from another party) is equal to, or greater than, the deficits it has incurred."

40. (p. II-2) A space is missing in, "vehicle hours traveled; andI…"

41. (p. III-10) There is an extra line break at the end of, "Natural gas liquefaction dates back to the…"

42. (p. IV-11) There is a subject-verb mismatch in, "As an example for biofuel pathway, details of the process of calculating carbon intensity for a corn ethanol pathway is presented below."

43. (p. V-27) An extra space appears between the word, "only," in, "does it apply onl y to subsequent ARB rulemakings…"

44. (p. VII-x) "Staff" is capitalized elsewhere but not in this chapter. The 2 in CO2 is only sometimes subscripted.

45. (p. B-19) In Table B-5, "Renewables" should be left justified and not indented. The percentage contribution of each type of renewable in the rightmost column should be italicized or otherwise differentiated from the other values. The column sums to more than 100% because renewables are double-counted.

46. (p. B-47) The word, "that," is missing in, "California has at least one CCS project could be operational before 2020 (approximately 1 MMT in total)..."

47. (p. C-55) The x-axis labels in Figure C12-1 are not legible.

48. (p. C-58) Please define OTSG when it first appears in Table C12-3. The definition appears later on in Table C12-6.

49. (p. C-59) In Table C12-6, the "Average Carbon Intensity" appears to be a weighted average, and the table heading should state as such.

50. (p. D-4) The title of Table 2 suggests that it presents the compliance schedule for gasoline, but the data appear to correspond to diesel. The gasoline values were presented on the previous page in Table 1.

51. (p. F-50) In Table F7-1, BD and RD are not defined. I assume these are biodiesel and renewable diesel.

52. (p. F-52) "Sox" needs to be fixed in Tables F8-2 and F8-3.

53. (p. F-54) The word "bee" appears in, "A large portion of the outdoor forklift market uses gasoline, diesel or propane as a fuel, if these have the potential to bee replaced with hydrogen forklifts then significant emissions reductions can be achieved."

54. (p. F-54) "Populations" is possessive and should have an apostrophe in, "These vehicles have the potential to replace a segment of the populations transportation needs, such as limited distance travel or private property use (e.g. city vehicle, resorts, universities)."

55. (p. F-55) "Affect" should be "effect" in, "Therefore the affect on the SIP is dependent on the specific location and method of hydrogen production."

56. (p. F-55) "Vehicles" is possessive and should have an apostrophe in, "A vehicles size will not make a difference on the SIP since the vehicles themselves produce zero emissions and will at worst affect traffic and at best improve the emissions profile for all transportation in that air district."

57. (p. F-56) "Of" should be "or" in, "However the reduced vehicle noise in an urban environment creates a danger for people with partial of full impairment of vision, the danger is created at street or parking locations where there are no controls."

58. (p. F-57) A run-on sentence appears: "These reserves do not include the reserve base which is estimated at 410,000 tons for the United States, these are lithium supplies which are currently uneconomical sources yet meet the USGS physical requirements for lithium."

59. (p. F-58) "It" should be "they" in, "Currently, Toyota offers a monetary reward for used hybrid vehicle batteries to ensure they are recycled and Honda offers free shipment for hybrid batteries so that it is not disposed of improperly."

60. (p. F-62) A letter is missing in the first word of, "xposure to diesel PM is a health hazard, particularly to children whose lungs are still developing and the elderly who may have other serious health problems."

61. (p. F-62) "Gallon" should be plural in, "According to AB 32 Scoping Plan, there may be 30 biorefinery facilities with an average production capacity of 50 million gallon per year established in the state of California by 2020."

62. (p. F-63) The grammar needs to be corrected in, "As indicated in Figure F10-1, staff assumes an "L" shape truck routes within the facility…"

References

Graham, L.A., Belisle, S.L., Baas, C.L., 2008, Emissions from light duty gasoline vehicles operating on low blend ethanol gasoline and E85, *Atmospheric Environment*, 42, 4498-4516.

Searchinger, T., Heimlich, R., Houghton, R.A., Dong, F., Elobeid, A., Fabiosa, J., Tokgoz, S., Hayes, D., Yu, T., 2008, Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change, *Science*, 319, 1238-1240.

Yanowitz, J., McCormick, R.L., 2009, Effect of E85 on tailpipe emissions from light-duty vehicles, *Journal of the Air and Waste Management Association*, 59, 172-182.