Questions/Comments to LCFS 2023 Amendment

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Disclaimer

Opinions expressed in this document are entirely my own and nothing to do my employer. This study was conducted exclusively during my personal time.

Questions/Comments:

I would like to hear the CARB's responses to the following questions and comments at the hearing on 3/21/2024.

In page SRIA – 16, "3. Fuel Pool Demand, d) Light-Duty Zero Emission Vehicles", it is stated that "*By 2031, staff assumed that BEVs would no longer have a substantial range or **charging-time disadvantage** compared to gasoline-powered LDVs and would therefore achieve 100% of the ICE vehicle VMT*."

1. 5 min charging of 80kWh battery (size of battery used in long range BEVs such as Tesla Model 3/Y) requires 1MW even without considering Joule heating loss and if energy loss is taken into consideration, it will require 10MW electricity supply capacity with 90% energy loss (explained later).
   i. **Question 1-1**: Can CARB elaborate how charging time disadvantage is going to be resolved?
   ii. **Comment 1-1**: 90% loss means that the effective CI will be 10X of the CI of grid electricity, therefore, if the grid cannot achieve 1/10 of current CI by 2031, CO_2 emission from electricity used by BEVs will increase.
   iii. Question 1-2: Majority's adaptation of BEVs will require more than 1000 such DCFCs. 1000 of 10MW DCFC will require 10GW low CI on-demand electricity supply. Could CARB explain how are we going to realize this?
   iv. Comment 1-2: Solar and wind are NOT on-demand power supplies. Nuclear power plant is baseload (constant output). Therefore, significant amount of buffering capacity (temporal storage) is needed for our future low CI power supplies. DCFC must rely on such a buffer.
   v. Question 1-3: Could CARB explain what is the assumed buffering method to address intermittency of solar and wind or inflexibility of nuclear? How much does the solution cost per household?
   vi. Comment 1-3: Please keep in mind, $/kWh of stationary battery is about 100X of underground hydrogen storage.

2. LDV hydrogen fuel cell vehicles have been available from 2014 in California, which have always been capable of 5 min charging for 300+ mile driving range. I assume CARB is aware of this fact.
   i. **Question 2-1:** is CARB LCFS standard ***technology agnostic*** and focusing on decarbonizing transportation sector?
   ii. **Comment 2-1:** assuming the CARB's answer to 2-1 is yes (LCFS is technology agnostic) and considering the CARB's awareness on relevance of charging time and driving range for public acceptance, it is extremely puzzling that CARB assumes overwhelmingly higher rate of public acceptance of BEV over FCEV such as seen in Figures 3, 4, 10.
   iii. **Question 2-2:** could CARB elaborate *why there is no mentioning of LDV-FCEVs* in the section 3 Fuel Pool Demand, d) Light-Duty Zero Emission Vehicle (page 16)?

In the followings, I will provide information relevant to above questions and comments. In my view, these are the critical factors perhaps in the blind spot of CARB staffs.

1. Specification of DCFC necessary to achieve 5 min charging of a long range BEV

Currently, the industry leading long range BEVs can be represented by Tesla Model 3/Y long range models that use 80kWh battery. In order to charge 80kWh of electricity in 5 min, the DCFC must be able to provide at least 80 kWh x 60/5 = 960 kW, which is about 1MW. This does not include energy loss due to Joule heating. In the past, a Tesla expert informed me that current state of art Tesla Supercharger has very impressively low 6% energy loss to achieve one hour charging. In order to achieve 5 min charging, 12 times higher current needs to pass through the circuit. Assuming the resistance of circuit (DCFC and the BEV) is the same, the corresponding Joule heating loss becomes 144 times higher since Joule heating loss goes I^2R (current square multiplied by resistance). 144 x of 6 percent is 864%.

In order to reduce the Joule heating, resistance of the circuit, *R*, must be reduced significantly. I'm not aware of any conductor that offer orders of magnitude lower resistivity than copper. Therefore, I assume reducing *R* by 100x will require 100x larger diameter of cable. Or else, we will need supercoducting material which is affordable and does not consume significant amount of electricity to keep operational.

I must therefore conclude that 5 min charging of 80kWh battery in 2031 at DCFCs that are ubiquitously available for general public is extremely unlikely to take place..

The other possibilities: a significant improvement on the vehicle efficiency, in other words, significant reduction on the required size of battery. Factors of consideration: air drag (major source of loss on highway) and air conditioning (nonnegligible loss in cold winter/hot summer).

Air drag is proportional to (drag coefficient) x (cross sectional area) x velocity^2 . Unfortunately it is extremely unlikely that drag coefficient could be reduced by 100x. Needless to say the cross section of car cannot be reduce by order of magnitude since the driver and passengers need to fit into the car.

Air conditioning: it is said that about 20% of driving range will be reduced by using air conditioning when it is hot (90~100F) or cold (20-30F). In other words, 80% was used to move the BEV. Let's say the vehicle efficiency (moving) gets 100x efficient, we still use 0.2 x 80kWh = 16kWh for air conditioning. Unless battery consumption for air conditioning can be reduce by order(s) of magnetite, total vehicle efficiency cannot be improved that much.

2. Common misconception about the well-to-wheel efficiency of BEV and FCEV

It is often argued that the well-to-wheel efficiency of BEV is much higher than that of FCEV. This argument completely ignores the cost for necessary amount of storage to address intermittency of solar and wind. One can download the supply and demand time profile data in California from caiso.com and simulate how much storage may have been necessary if we are to eliminate fossil power plant by, for example, installing more solar. All what one has to do is integrate demand over one year (or multiple years), then adjust solar supply data in such a way that total demand matches with total supply. Then calculating cumulative loss/gain between supply and demand over the period will give you the ballpark estimate on the necessary storage.

Next is to estimate the cost of storage. This is very simple: look up $/kWh values of available storage solutions and multiply it with the necessary storage capacity. One may also consider the round trip efficiency (RTE). I usually use 0.4 for hydrogen and 0.8 for stationary battery. Then, we may normalize the cost for per-household (about 13M household in California). At last, we need to take the lifetime of such storage solutions to estimate how much all of us need to pay. I used 30 years for hydrogen underground storage and 10 years for stationary battery.

With this, one can estimate the cost/household/year for each storage solutions.

My conclusion was hydrogen underground storage will cost about one hundred dollar per household per year. Stationary battery will naturally cost more than two orders of magnitude higher than hydrogen underground storage, which is not affordable for majority.

Take home message: claimed high well-to-wheel efficiency of BEV (over FCEV) is <u>***economically unattainable***</u> with intermittent power sources such as solar/wind.

I had series of debates on this issue with Mr. Michael Liebreich, who popularize the notion that LDV-FCEV is inefficient compared to BEV therefore governments should not support H2 station deployment. I had pointed him out that the claimed high well-to-wheel efficiency of BEV is economically unattainable due to intermittency of solar and wind.

His response to my comment was overproduction.

I hope CARB staffs understand critical flaw in his argument. Overproduction means system waste either produced electricity or the production capacity *by design*. One cannot claim high well-to-wheel efficiency, while the underlying infrastructure is designed to waste significant portion of produced electricity or the production capacity. Hydrogen solution, while RTE (round trip efficiency) may be much lower, enable us to fill the supply-demand gap created by intermittency of solar and wind and/or inflexibility of nuclear (constant output) in an affordable way for majority.

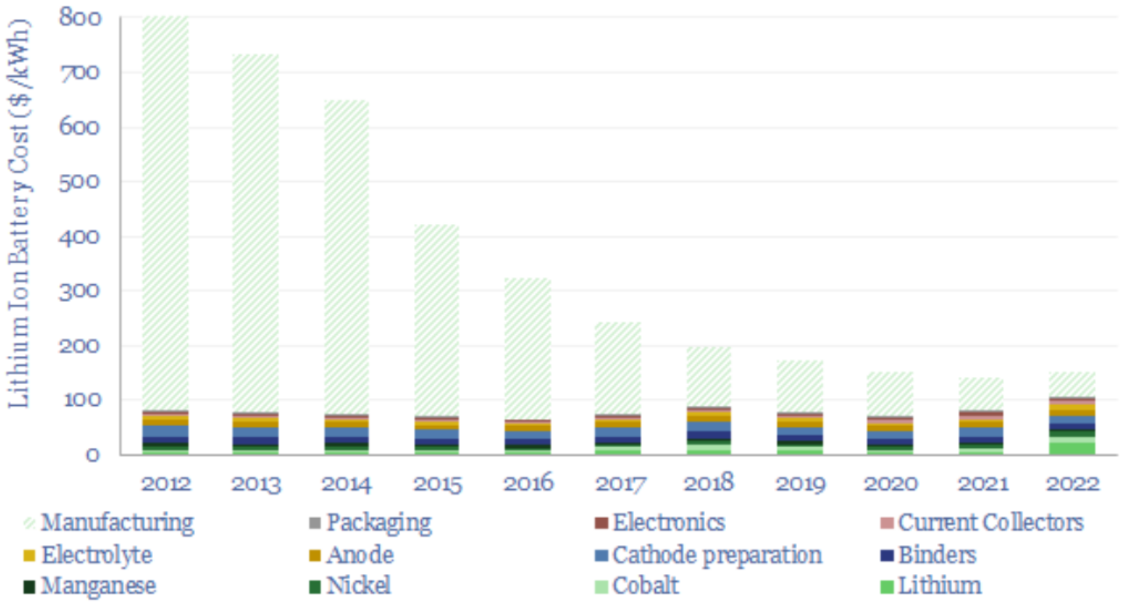
Can innovation bring the cost of battery down to resolve this issue?

Most likely no. The reason is the cost of material necessary for these storage solutions.

Amount of materials necessary for gas (or liquid) storage is proportional to the surface area (R^2), while that for battery is proportional to the volume (R^3). Therefore, for the limit of large storage size, gas storage offers greater economy than stationary battery as witness in about two order of magnitude difference in $/kWh values between hydrogen underground storage and stationary battery.

I also hear some people arguing mass production will reduce the cost of battery. Please remember, it is usually the process cost that could be reduced significantly by mass production. Material cost depends on accessibility and abundance of the chemical species. The material cost could be increased as the consequence of mass production (demand exceeds supply).

For instance, according to https://thundersaidenergy.com/2023/11/18/grid-scale-battery-costs-kw-or-kwh/, recent trend of cost breakdown looks as below. As you can see, manufacturing cost decreased significantly to the point that material cost became dominant. On the other hand, material cost has not come down (as expected). Therefore, I conclude that significant reduction of $/kWh value of stationary battery is very unlikely to take place.



Lithium ion battery costs breakdown between materials and manufacturing

Figure 1: Cost breakdown of battery from https://thundersaidenergy.com/2023/11/18/grid-scale-battery-costs-kw-or-kwh/

At last, I highly encourage the CARB staffs to revisit The Periodic Table and look for the combination of chemical species that could be used to store energy via electrochemical process. What are the abundance of such chemical species?

I hope you do not overlook the first candidate, hydrogen, which is the most abundant chemical species in the universe and is known to produce electricity via electrochemical process with oxygen (fuel cell). One can produce hydrogen out of water (electrolysis). These processes do not produce any harmful chemical species.

Lithium is after hydrogen and helium. Is there any reason to ignore hydrogen?

3. Business sustainability of DCFC and the area coverage of LDV-BEV

It is well known that 90% of charging of BEVs is done at home overnight. In other words, DCFC business market size will be less than 10% of the gas stations. This indicate that number of DCFC stations that is profitable will be about 10% of number of gas stations. Could the area coverage of LDV be kept in a similar level with the current gasoline car and gasoline stations?
We know that the area coverage can be retained with hydrogen fuel cell cars due to the quick fueling time and long driving range that are comparable to gas cars. LDV-FCEV will rely on hydrogen fueling stations so it is very likely that hydrogen fueling station business could simply replace gas stations.