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Hydrogen fueling stations for light duty vehicles need to be supported

Additional submitted attachment is included below.

Comments to 24-ALT-01

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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.

Summary:

Full decarbonization of light duty vehicle (LDV) cannot be done without hydrogen fuel cell vehicle (FCEV), therefore, we must support development of hydrogen refueling stations (HRS) for LDV-FCEV.

The reasons are:

1. Fundamental limitation of fast charging of battery electric vehicle (BEV)
2. Claimed high well-to-wheel efficiency of BEV over FCEV is economically unattainable with intermittent solar and wind
3. If BEV becomes only ZEV option, area coverage will be severely compromised particularly for low income population

One cannot decouple decarbonizing transportation from decarbonizing energy supply infrastructure due to intermittent nature of solar and wind: transportation applications require on-demand power supply, while solar and wind are NOT ON-DEMAND. Affordable storage becomes critical component in filling supply-demand gap to facilitate further introduction of solar and wind. Stationary battery is not affordable for this purpose, while hydrogen underground storage is. The cost difference is dictated by surface to volume ratio.

1. Specification of DCFC (direct current fast charger) necessary to achieve 5 min charging of a long range BEV

First of all, we all must be reminded that charging time and driving range being on parity with gasoline cars have been recognized as acritical criteria for majority acceptance of ZEV. Note that FCEV has been capable of 5 min charging for 400+ mile driving range (2021- Toyota Mirai XLE has 400 mile driving range).

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 other words, 90% energy loss.

Not to mention that such DCFC needs to operate at 12 x higher voltage (V=IR) than the current ones. For example, Tesla supercharger operates at 480V therefore 5760V would be required if the resistance is not reduced.

In order for the Joule heating loss to be significantly lower than 50%, resistance of total circuit (DCFC and BEV) must be less than 1/10 of current value. In order to keep the loss in single digit (<10%), resistance must be less than 1/100.

I strongly recommend CEC to collect below information and share with public:

1. Question to BEV and EV charging industry: how much reduction of resistance of DCFC + BEV is realistically possible, and how they are going to achieve it?
2. Question to the utilities: how are they going to provide on-demand CO2 free electricity to thousands of 1MW class DCFCs in California? FYI: Number of gas stations in California is about 8000.
3. Question to EV charging industry: how are they going to secure on-demand CO2 free electricity to individual DCFCs keep in mind that a single EV charging station will have multiple DCFCs, which means unless the utilities can guarantees on-demand CO2 free electricity supply for all of DCFCs at that station, the EV charging station either needs to slow down the charging speed of individual DCFC when multiple BEVs are plugged simultaneously, or such an EV charging station needs to install sufficient amount of stationary battery to avoid slowing down. How much does the stationary battery cost?

If CEC is to support only BEV for LDV, above must be clarified.

Considering above, I honestly believe that 5 min charging of 80kWh battery at DCFCs that are ubiquitously available for majority is extremely unlikely to take place.

Below I considered about the other factors for the sake of completeness, none of which seem to change my conclusion above.

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.

At the end, I would like to remind the CEC staffs that 5 min charging for 400+ mile driving range has been possible with FCEV from the beginning of hydrogen refueling station (HRS) deployment. While the earlier HRS based on high pressure hydrogen gas lacked capacity (only one pump per station) and reliability, later ones based on liquid hydrogen (LH2) storage steadily improve both capacity (currently 4 simultaneous refueling) and reliability though not entirely satisfactory for general FCEV owners. However, it is my understanding that the next generation hydrogen dispenser, for example, based on high pressure LH2 pump by Mitsubishi Heavy Industry, will address the issues of capacity and reliability. There are a few more companies such as Bosch, Nikkiso and First Element Fuel that are developing the next generation hydrogen dispensers.

See for example, https://www.mhi.com/news/210406.html,
https://www.mhi.com/news/23091101.html

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 ***economically unattainable*** 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 HRS 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 CEC 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. Keep in mind that demand also has seasonal fluctuation: AC use in hot summer and heater use in cold winter.

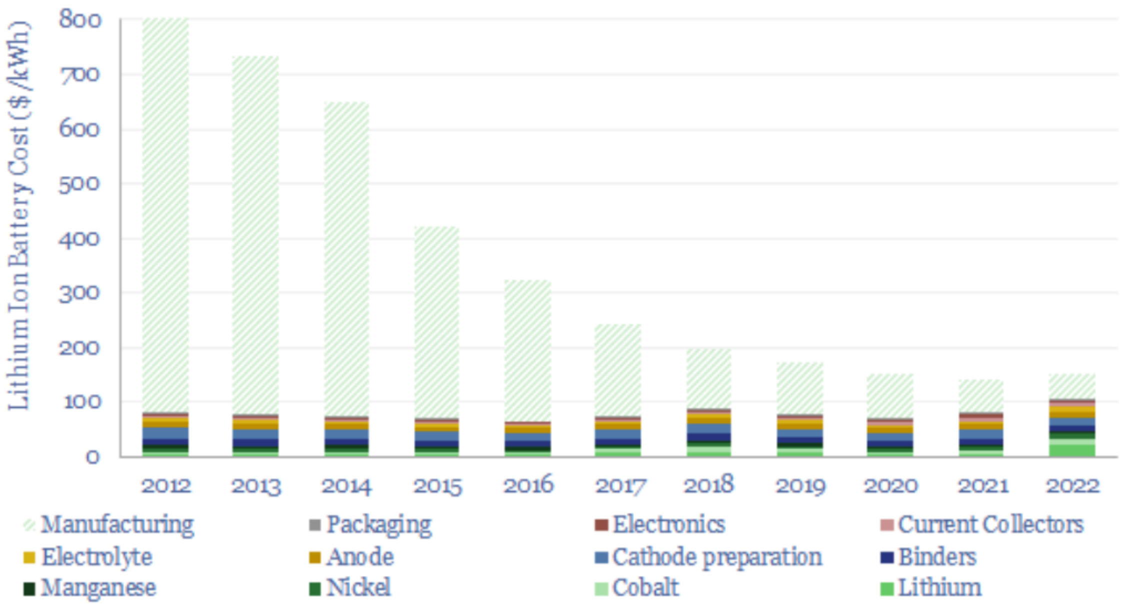
Can innovation bring the cost of battery down to resolve this issue?

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 CEC 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? Please keep in mind that the cost of BEV is dominated by size of battery. In other words, affordable BEV will

have shorter driving range, therefore the area coverage of LDV will be heavily compromised only for low income population if BEV becomes only ZEV option.
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.

4. CO2 emission time profile of California grid and cost of infrastructure

As you may be well aware of, CO2 intensity of California grid peaks in each evening simply because it is solar heavy and sun is down in evening. Keep in mind that more than 90% of BEV charging take place in evening when natural gas power plants provide the most of electricity. Therefore, further introduction of BEV can reduce CO2 emission ONLY IF the utilities install storage, whose size is proportional to the sum of introduced BEVs. Please be reminded that cost of stationary battery storage is 100x of hydrogen underground storage, which is dictated by the fundamental constraint: volume to surface ratio.

5. Closing remark

I sincerely hope that CEC staffs distinguish practical solution that works for majority from partisan politics driven ideological proposition that does not serve people and/or financially motivated business proposition which is nothing to do with the energy transition. I also hope that CEC staffs recognize that goal of ZEV deployment is to assist the energy transition which has to be coordinated with the utilities, not to win the argument against your opponent.