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*Comment Received From: Gregory Cane, President, CA H2 Car Owners Assn*
*Submitted On: 6/21/2024*
*Docket Number: 24-ALT-01*

## Is there a Place for Light-Duty Fuel Cell Electric Vehicles in Californiaâ€™s Green Energy Future?

*Additional submitted attachment is included below.*

# - Cons and Pros -

# Is there a Place for Light-Duty Fuel Cell Electric Vehicles in California's Green Energy Future?

**California Hydrogen Car Owners Association, June 21, 2024**

## Summary

During the June 7, 2024, meeting of the Advisory Committee for the California Energy Commission (CEC) Clean Transportation program (CTP) 2024-2025 Investment Plan, a number of perceived shortcomings of light-duty fuel cell vehicles (LD-FCEVs) were voiced by those in opposition to continued funding support of these ZEVs. It is the purpose of this submittal, where possible, to fairly look at the disadvantages (cons) and advantages (pros) of the deployment of hydrogen cars in California's green energy future.

*"LD-BEVs (Light-duty Battery Electric Vehicles – ed.) have currently captured market share and do offer a number of advantages. However, contrary to what some LD-BEV proponents would say, LD-BEVs cannot carry the whole passenger car market forward. The case for having LD-FCEVs play a sizeable role in the passenger car mix is not only scientifically and technically sound but is also enshrined in State Assembly Bills and Executive Orders. To make a simple metaphor, we have both square holes and round holes. We must promote and maintain a mix of both square pegs and round pegs, to properly fill the gaps that face us."* [A]

To further explore the metaphor, LD-FCEVs are a round peg for a round hole, perhaps most especially in the case of the many, many future ZEV drivers that live in apartments. One, single, hydrogen refueling station in an area of apartments could serve thousands of future hydrogen car drivers. One of our members said it best:

> *"As someone who has lived in apartments most of my life, the other clean-energy personal transportation alternative is battery electric vehicle but these are very inconvenient for my use case, as it is millions of other Californians who don't have access to chargers - this is clearly evident in the data where millions of Californians choose not to buy battery electric cars, despite so many incentives and a nearly fully functional recharging network. Therefore, in order for California to achieve the green transportation goals, we need the solution provided by hydrogen cars but this will not happen unless a reliable and extensive hydrogen refueling network is built*." [B]

Those who have opposed more HRS for light-duty FCEVs have argued that the slow growth of HRS (and hydrogen cars in the State) is a reason for arguing against faster growth. We take a different view, that: The tepid growth of HRS has so frustrated hydrogen car drivers in this emerging alternative to fossil fuels that our numbers cannot grow. An underfed child cannot thrive. Neither can hydrogen cars fulfill their place in California's green energy future without a robust commitment from industry and government to build more refueling stations.

As noted, the paper clearly admits the downsides of these vehicles. At the end of the paper, we list what, we view as the significant strengths that these cars have in the requisite all-of-the above approach to meeting our climate goals.

Those who oppose hydrogen for light duty FCEVs conveniently and consistently ignore the advantages of hydrogen as a transportation fuel of the future. These advantages are:

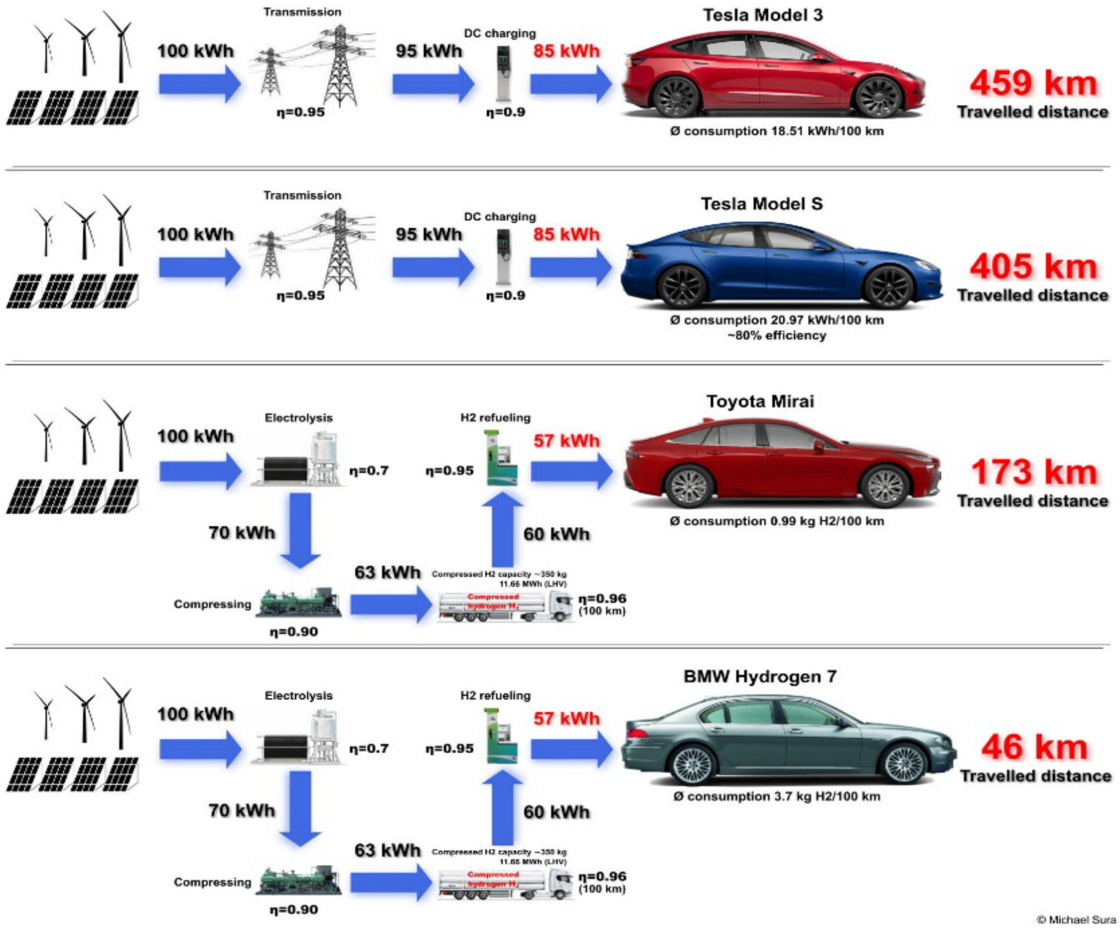
- Fast refueling
- Hydrogen cars and trucks have a symbiotic relationship
- No automaker has walked away from this technology
- Drivers universally love these cars (but hate the refueling)
- Better for Diversity, Equity and Inclusion concerns
- H2 production can occur during periods of excess grid energy from P2P

There is a place for FCEVs and BEVs in our green energy future and to deny this is not in our best interest.[C D E F] LD BEVs and LD FCEVs may not yet know it, but they are on the same side.

Abbreviations

| | |
|---|---|
| BESS: | Battery Electric Storage System |
| BEV: | Battery Electric Vehicle |
| CARB: | California Air Resources Board |
| CEC: | California Energy Commission |
| CHBC: | California Hydrogen Business Council |
| CHC: | California Hydrogen Coalition |
| CTP: | Clean Transportation Program |
| DEI: | Diversity, Equity and Inclusion |
| FCEV: | Fuel Cell Electric Vehicle |
| FEF: | FirstElement Fuel |
| HD: | Heavy-duty |
| HRS: | Hydrogen Refueling Station |
| H2FCP: | Hydrogen Fuel Cell Partnership |
| LD: | Light-duty |
| LD-FCEV: | Light-Duty Fuel Cell Electric Vehicle |
| MD: | Medium-duty |
| P2P: | Power to Power (alternately, power to gas to power) |
| SMR: | Steam Methane Reformation |
| ZEV: | Zero Emission Vehicle |

# LD-FCEVs are Not as Efficient as BEVs




# Efficiency in the Bigger Picture

This is addressed in Section 2 (*Common misconception about the well-to-wheel efficiency of BEV and FCEV*) of Ogitsu paper. (See Appendix 2)

# Hydrogen is Not Green

As described at the June 7, 2024, meeting of the Committee, “*current hydrogen production methods mean that heavy-duty fuel cell vehicles running on fossil SMR hydrogen are only marginally better than existing diesel heavy duty vehicles from a climate perspective*”[G]

**EER for hydrogen in passenger vehicles is 2.5, while the EER for heavy duty trucks and buses is 5.0. The EER is a factor that adjusts the carbon intensity (CI) of an alternative fuel, such as hydrogen, to account for the different engineering and system efficiencies of different vehicles and powertrains. The CI of an alternative fuel is calculated by dividing its CI value by its EER, which results in an EER-adjusted CI value.**

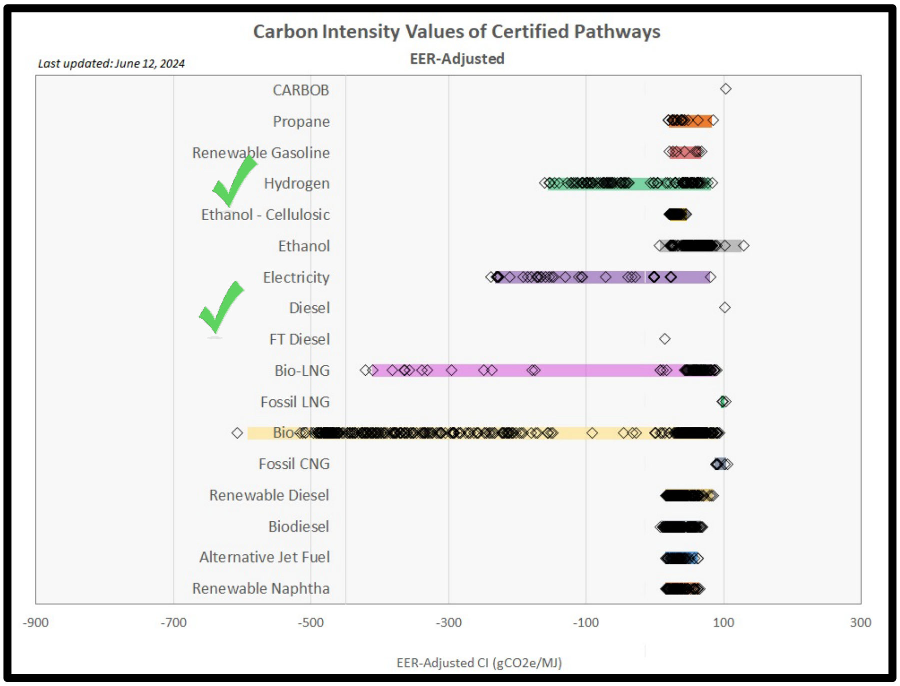
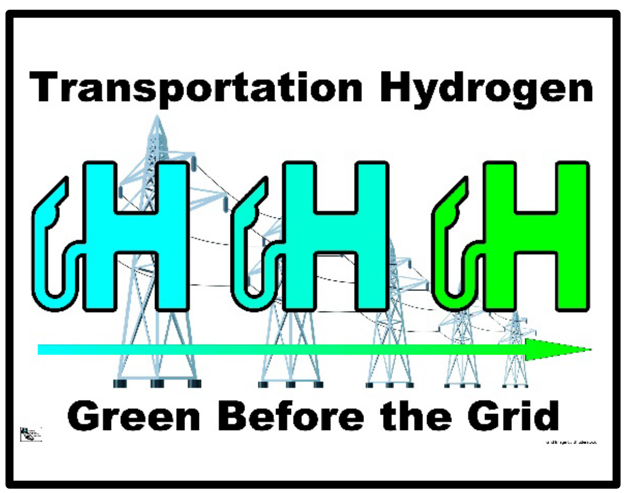



Fig. 1 – From CARB website, *LCFS Pathway Certified Carbon Intensities*[H]

When EER is taken into account, the most carbon intensive hydrogen production processes are slightly less than the carbon impact of diesel (See check marks in Figure 1).

## Hydrogen “Greenness” – Now and in the Future

Our point here is not to quibble about small differences. As reflected in Figure 2, the range of EER-adjusted carbon impacts for hydrogen is significant. From a +75 (Steam Methane Reformation from fossil natural gas without carbon capture) to an amazing -160 (swine manure).

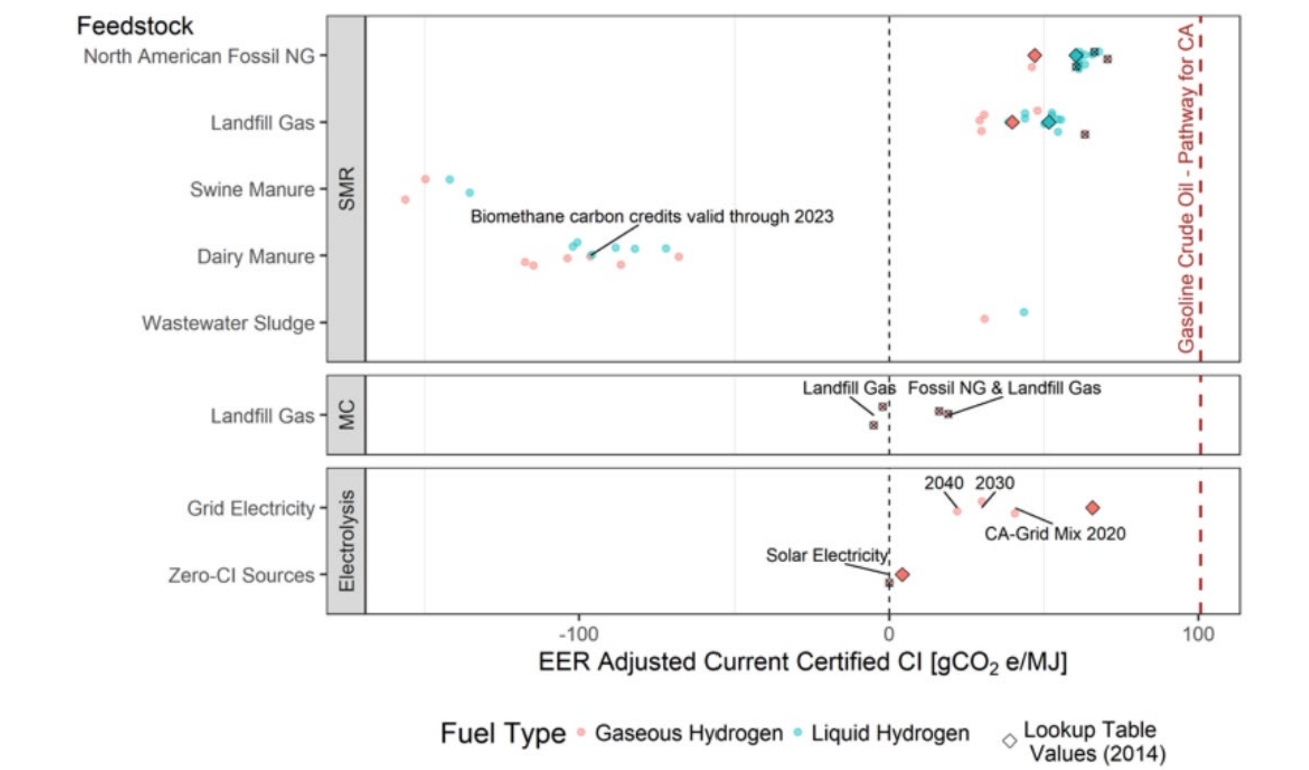



It is well to look at other approaches to the question of the “greenness” of hydrogen. Dr. Petropoulos, in his review “*CO2 Intensity of FCEVs and BEVs: SMR Hydrogen and Grid Power*” (Appendix 1) reflects in Table 3 that considering the current power mix of the California grid, SMR from fossil fuels with <u>no carbon capture or directed biogas</u>, FCEVs have more $CO_2$

per mile emitted than BEVs. This provides a conservative, but instructive worst-case scenario. As reflected in the next paragraph, the good news is that currently hydrogen production has a lower CI than grid electricity.

This other approach takes a look at the CI quarterly summary for transportation fuels from CARB[I]. As of the end of 2023, column BC, rows 112 and 114, electricity from the grid has a CI of 45 gCO2e/MJ while hydrogen is 37 gCO2e/MJ. By this analysis, transportation hydrogen has a lower CI than grid electricity.

In this real world need for a rapid transition to a green economy, we must remember that we should not let perfection become the enemy of the good. From the perspective of those that will not accept a fossil fuel (natural gas) as a source for hydrogen, we are not there yet, i.e. not as green as we should be. Rest assured, you are “preaching to our (Association) choir” because, as stated in our

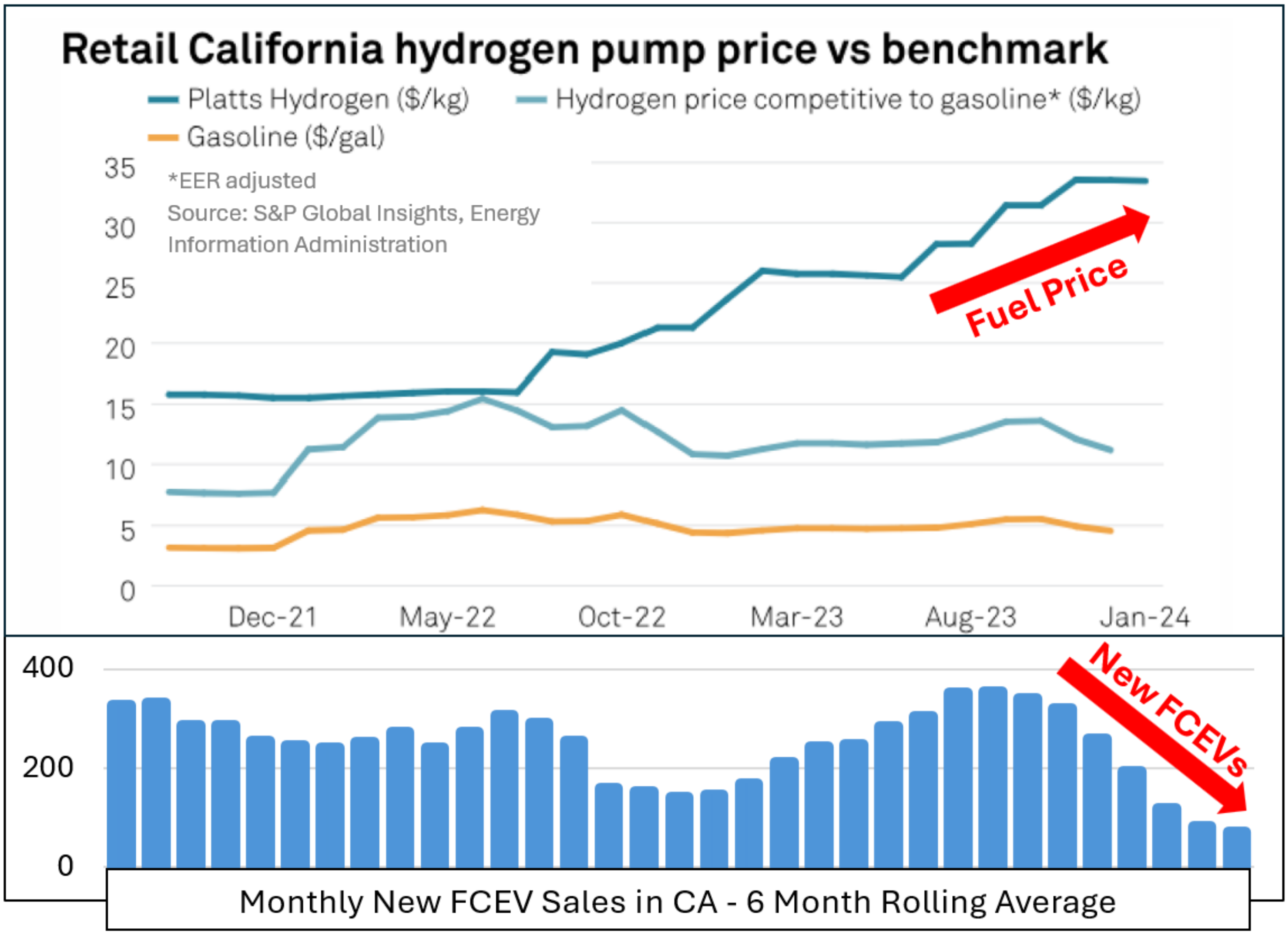



*CI Scores of Main Hydrogen Production Pathways as Used in Transportation Applications. Source: Compiled by UC ITS from California Air Resources Board June 2022 data. Notes: MC is methane cracking; NG is natural gas. Carbon intensity values are from: ww2.arb.ca.gov/es/resources/documents/lcfs-pathway-certified-carbon-intensities.*

Fig. 2 - Hydrogen Can Have a Much Lower Carbon Intensity than Fossil Fuels But This is Largely Depends on How it is Produced and Distributed[J]

“Green Before the Grid” campaign, it is essential that transportation hydrogen rapidly continue the transition to an ever-lower, fossil fuel free, CI. This can happen. In the opinion of Dr. Timothy Lipman, Co-Director of the Transportation Sustainability Research Center (TSRC) at UC Berkeley, we can get to 100% “green” if we can eliminate the economic and policy barriers that are delaying that desired outcome.[K]

## Hydrogen Fuel Prices Are Inexplicably High :



Source: https://h2fcp.org

Figure 3

The sales record for LD FCEVs is a poor indicator of the demand for hydrogen. As reflected in Figure 3, the price of hydrogen at the pump in California has more than doubled in the last two years while the sales of these new cars have plummeted.[L]

It is patently unfair that Medium and Heavy Duty FCEVs pay less than half the price that LD drivers see at the pump per kilo of hydrogen. LD hydrogen price must be brought in line with the price offered to MD/HD and transit agencies, and it should be competitive with gasoline.

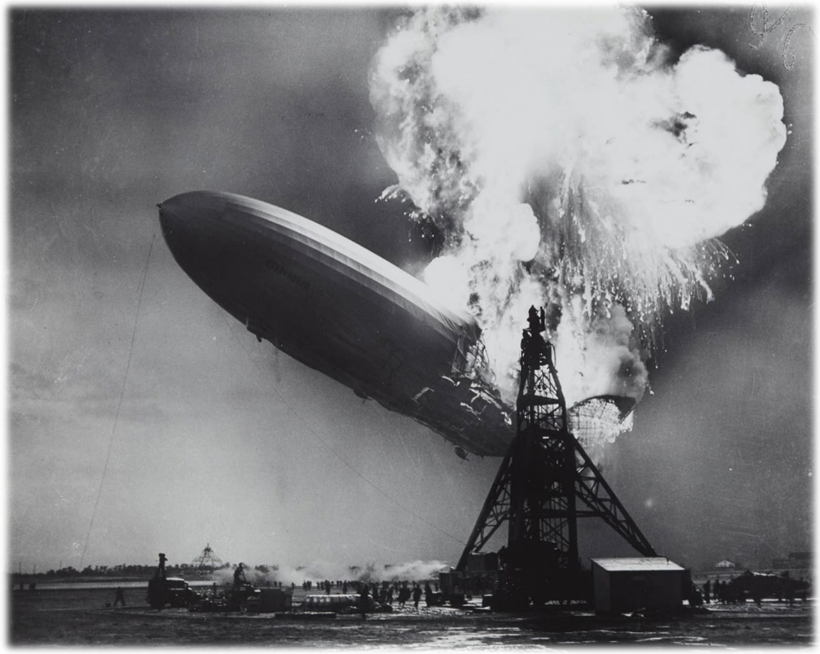
## Hydrogen Fuel Price – Anticipated Trend

We have spoken to several industry representatives who have told us that with more hydrogen production, competition in the market for hydrogen fuel stations, and with some additional help from Low Carbon Fuel Standard (LCFS) modifications expected in the Fall of 2024, the price of hydrogen at the station for LD drivers should come down.

# Hydrogen is Dangerous

We have a vanity plate on our FCEV. I had initially thought that, as a joke, I'd ask for the lettering, "**H-BURG**". As so often happens, my wife talked me out of another of my crazy notions.

- G. Cane



# Reflecting on the Safety of Hydrogen

From Hydrogen Fuel Cell Partnership:

> *FCEVs are as safe as any vehicle on the road. HFCP vehicle manufacturer members subject fuel cell electric vehicle models to extensive safety testing prior to releasing them on public roads. Current testing employs both destructive and non-destructive evaluations and occurs at the component, system, and vehicle level.*
>
> *The on-board hydrogen storage tanks are extremely strong, carbon-fiber wrapped tanks. Similar to CNG tanks, hydrogen tanks are put through a battery of extreme tests, including bonfire, pressure cycling, impact, burst and penetration tests. The cylinders must meet strict manufacturer guidelines and are being tested to an international standard, the GTR 13. This will ultimately be the US DOT's hydrogen fuel cell vehicle safety standard.*
>
> *Hydrogen is colorless, odorless and non-toxic. Other fuels either have odor (gasoline) or are odorized (natural gas) and leaks are detected by smell. Hydrogen is not odorized due in part to its small molecular weight and buoyancy, and because an odorant would contaminate hydrogen purity and affect vehicle performance. Leaks are detected by sensors.*
>
> *HFCP does extensive training with fire fighters and other first responders in the communities where FCEVs and FCEBs are and will be deployed. The combination of vehicle design, safety systems and knowledgeable responders make FCEVs as safe as other vehicles on the road.*[M]

While hydrogen skeptics routinely cite the Hindenburg explosion of 1937, the hydrogen tanks and their hardware would likely survive even if the rest of the car were destroyed in a crash. No injuries or deaths specific to the hydrogen components have been recorded in the relatively small number of FCEVs sold to date.[N]

# Hydrogen Leakage is Bad for the Environment

Headline:

"*Hydrogen 11 times worse than CO2 for climate, says new report*" [O]

# Hydrogen Leakage, a More Careful Review

"… *my take is that this* (fugitive hydrogen) *is definitely not a "nothingburger" (so shouldn't be dismissed or responded to glibly) but also no reason to not encourage H2 where it can make a significant climate impact, especially displacing diesel."* [P]

From a 2023 Cambridge University Study:

"*Therefore, in this global scenario the increase in equivalent CO2 emissions, based on 1% and 10% H2 leakage rates, offsets approximately 0.4% and 4% of the total equivalent CO2 emission reductions respectively. Whilst the benefits from equivalent CO2 emission reductions significantly outweigh the disbenefits arising from H2 leakage, they clearly demonstrate the climate importance of controlling H2 leakage within a hydrogen economy*." [Q]

## Plugging in is Easy

As noted in the discussion block to the right, charging can be very easy.

**Recently overheard at a Green Car show;**

**BEV Driver: How long does it take to refuel your car?**

**FCEV Driver: About 5 minutes. How about you?**

**BEV Driver: Thirty seconds. I just plug it in.**

## But Plugging in is Not Easy for All

The challenge is that electric vehicle chargers may not be readily available, especially to disadvantaged communities and for those living in multi-family dwellings. As noted by GO-BIZ:

"*Approximately 40% of Californians live in multi-unit dwellings, while nearly half of Californians are renters. FCEVs, paired with a local fueling station, are a solution for increasing access to ZEVs in this critical market segment*." [R]

Hydrogen stations for LD-FCEVs can be good match for these areas.

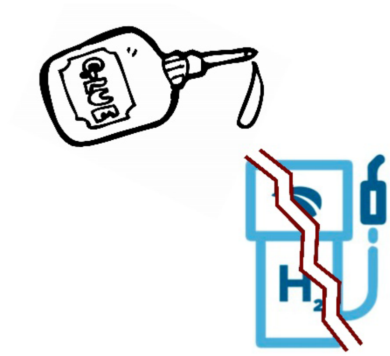
# BEVs are Charging Faster and May be Able to Charge in 5 Minutes in the Future[S]

The Cornell Chronical announced last January that, “A team in Cornell Engineering created a new lithium battery that can charge in under five minutes – faster than any such battery on the market.” [T U]

## Can FCEVs and BEVs Both Achieve 5-minute Refueling/Recharging to 100% Full?

While work toward a battery that can recharge in as little as 5 minutes is enticing, it may not be feasible in the larger picture. Tadasi Ogistu, PhD (Appendix 2) relates that to install DC fast chargers capable of recharging a battery in 5 minutes, the system must be able to provide about 1 megawatt and will have 90% energy loss. To put this into perspective, 1 megawatt can provide power to well over 100 homes. This is not to say that 5-minute charging is impossible, just to provide a cautionary note that there are large obstacles to overcome for such fast chargers to become a reality throughout the State.

# Hydrogen Refueling Stations Have a Poor Reliability Record



“Hydrogen station reliability is a key contributor to market success.” [V]

As reflected in Figure 4, station overall station uptime has not significantly improved in the last 9 months. Station availability to drivers has averaged at about the 50% mark.

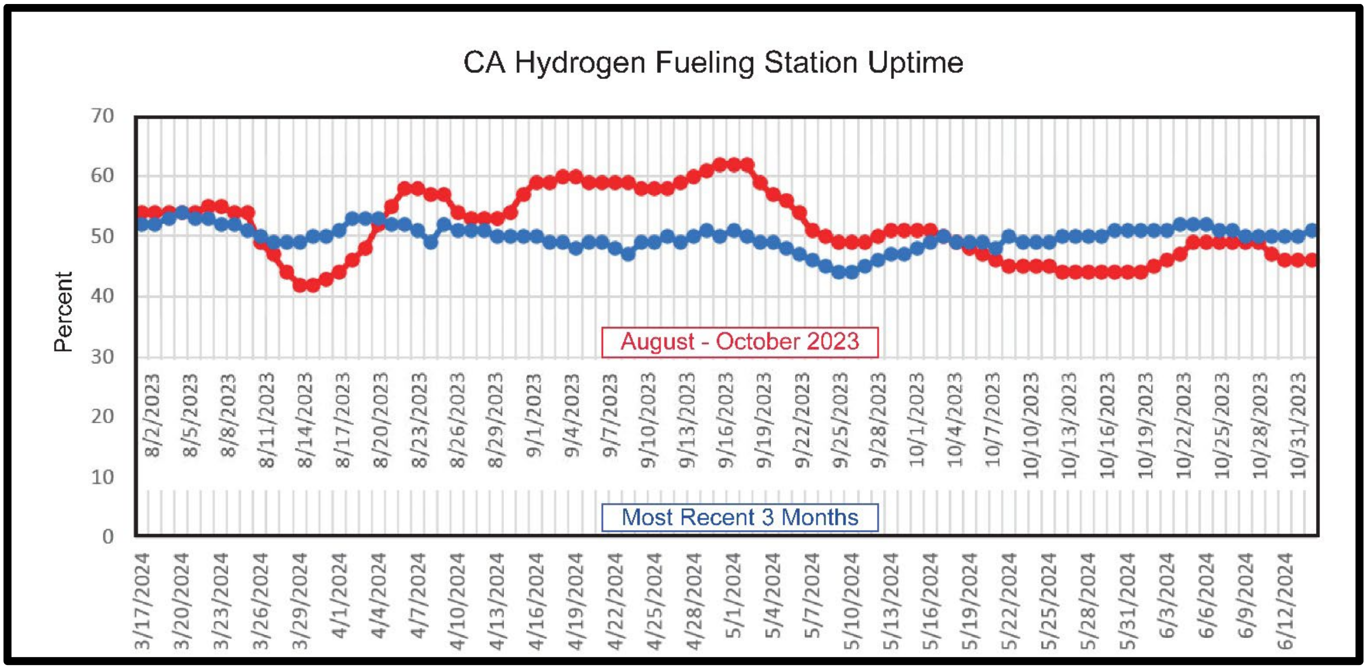



Figure 4: Data derived from H2-CA.com[W]

## Station Reliability is Improving

Last year, the California Energy Commission made available $11M in grants (GFO-23-604)[X],solely, “for projects that will support the advancement of hydrogen fueling station operations and maintenance (O&M) to improve the customer experience.” Two grants were awarded on May 8, 2024, one to Iwatani for $2.5M and one to FirstElement Fuel for $7M. The Scope of Work for each of the recipients includes, as a primary objective, to increase average station uptime to 95%.

In a separate development, FirstElement Fuel has installed “next generation” liquid hydrogen refueling equipment at their new stations. As reflected by heavy blue line in Figure 5, the uptime for new stations is significantly improved.

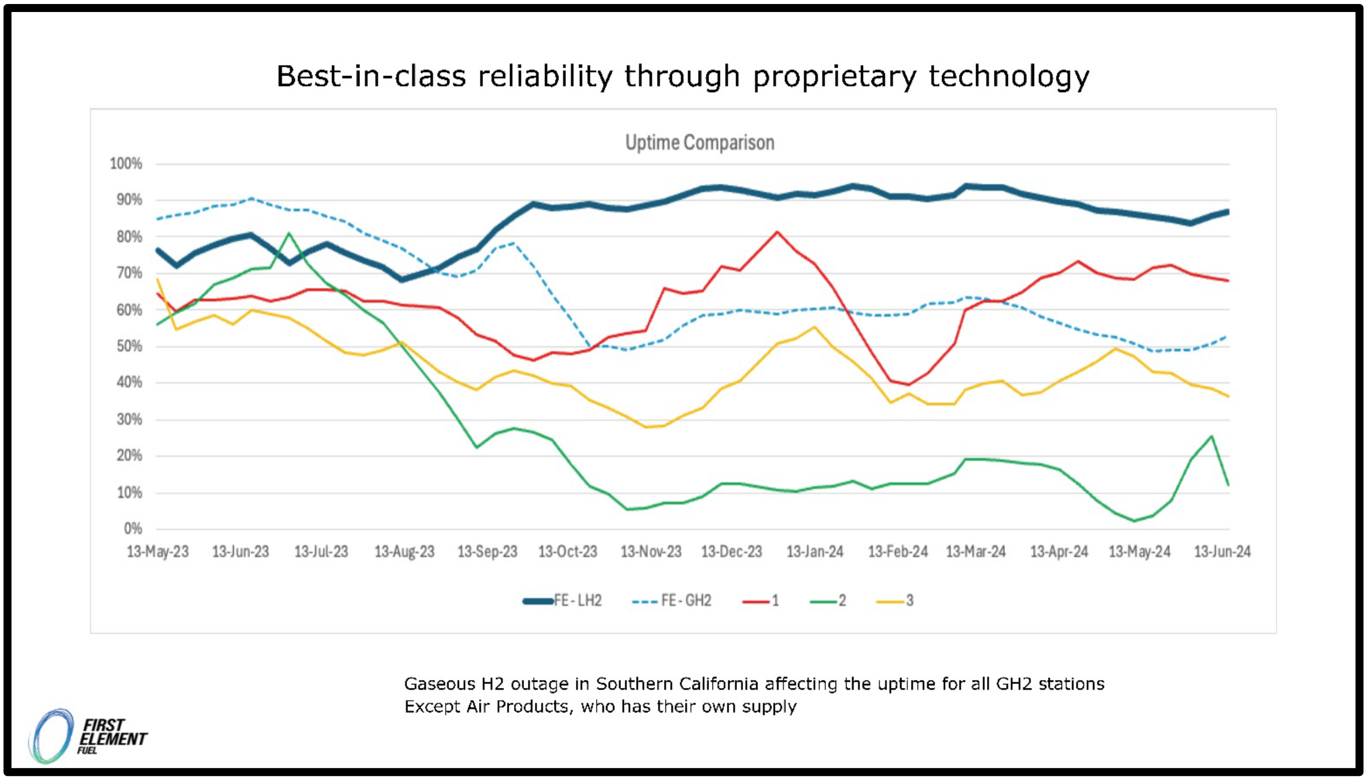

Best-in-class reliability through proprietary technology
Uptime Comparison
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
13-May-23
13-Jun-23
13-Jul-23
13-Aug-23
13-Sep-23
13-Oct-23
13-Nov-23
13-Dec-23
13-Jan-24
13-Feb-24
13-Mar-24
13-Apr-24
13-May-24
13-Jun-24
FE - LH2
FE - GH2
1
2
3
Gaseous H2 outage in Southern California affecting the uptime for all GH2 stations
Except Air Products, who has their own supply
FIRST ELEMENT FUEL

Figure 5

# Grid Impacts and ZEVs

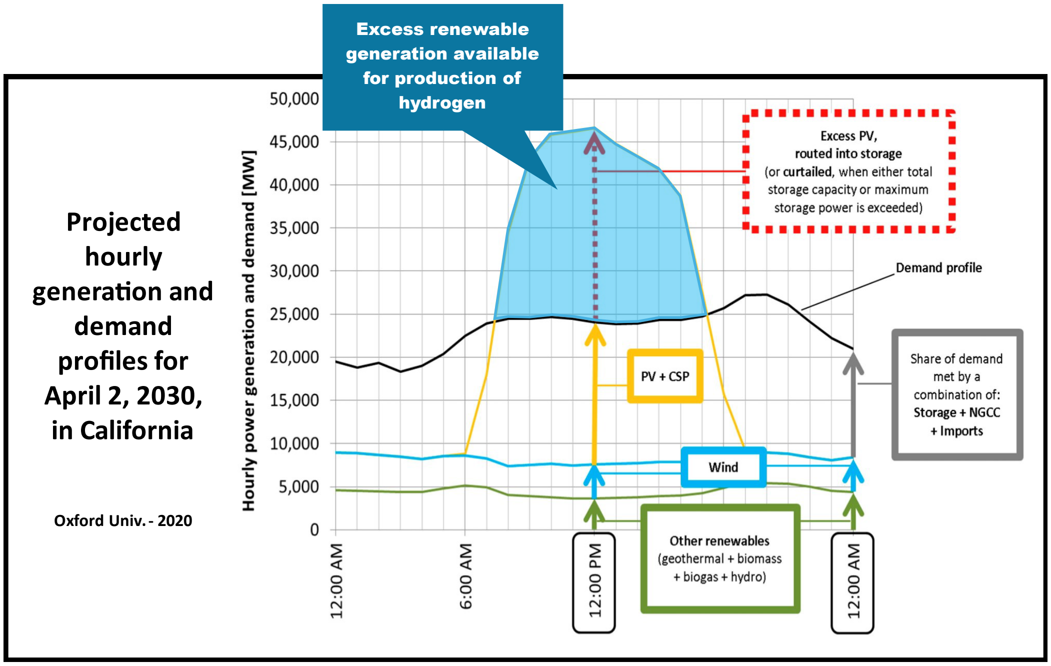



Figure 6 - From Oxford Univ. 2020 [Y] (Excess renewable generation for $H_2$ added)

As reflected in Figure 7, the electrical grid in California is at elevated risk. Using hydrogen cars can reduce the strain on the grid by providing an alternative energy source for mobility, especially in regions with inadequate electricity supply. As electric vehicle adoption increases, the demand for electricity to power them also rises, putting additional strain on the grid, particularly during peak charging times. Diversifying the energy sources used for transportation can alleviate this demand on the grid.

As depicted in Figure 6, "*Hydrogen produced by electrolysis … will play an important role in integrating large amounts of otherwise-curtailed renewable electricity*."[Z]

"*… hydrogen can be used to absorb excess renewable electricity, using the gas (hydrogen – ed.) grid to store this excess. Power to gas is the simple solution when there is a surplus of renewable electricity on the National Grid, in the case of high levels of production from wind turbines or solar panels,*

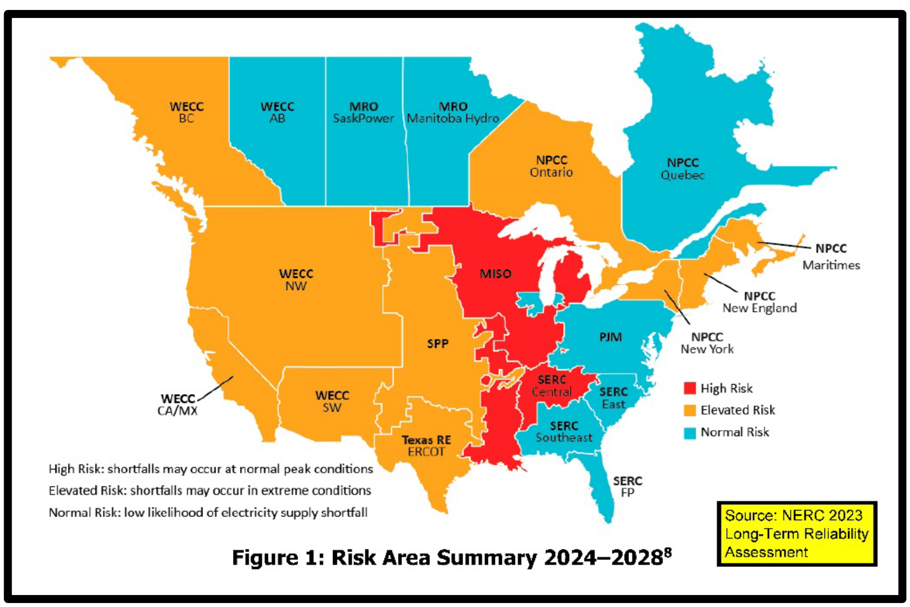


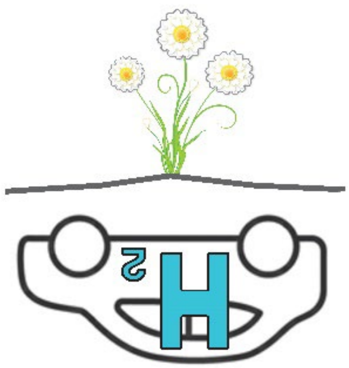

Figure 7 - Grid Risk Area Summary, NERC 2023

*or in the case of lower demand. As Jenifer Baxter points out, the excess electricity can be used to produce hydrogen by electrolysis of water. This ensures that no renewable electricity is wasted by using the existing natural gas grid to store the excess hydrogen produced by electrolysis*."[AA]

As detailed in the Ogistu and Petropoulos analyses (Appendices 2 & 3) hydrogen storage will become a necessity for grid management. It is one of the most viable, least expensive long term storage methods for storing excess renewable energy from the grid. [BB]

*From Colbertaldo, et al (2019),*[CC] *"Furthermore, a preliminary economic analysis shows the potential attractiveness of the hydrogen-based P2P storage system compared to a BESS-based system. It also indicates that the overall capital cost of the proposed P2P storage system is equal to about 60% of the investment cost of the required RES power generation infrastructure. In contrast, an alternative purely electric BESS-based storage system would increase costs massively*."

# Fuel cell cars are dead - Long live the fuel cell truck”[DD]



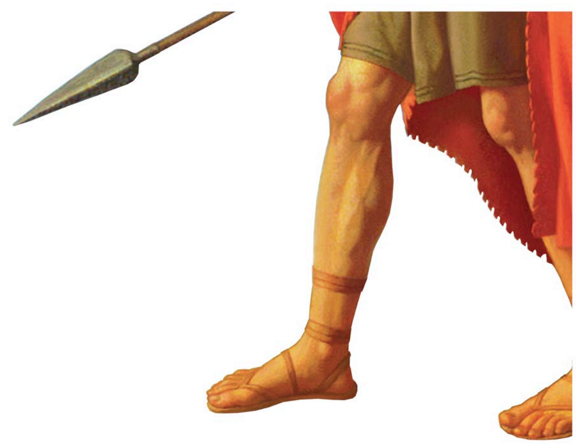
With the:

- Recent decline in the number of hydrogen refueling stations (HRS),
- High cost of fuel, and
- Poor HRS reliability

It is no wonder that drivers are as mad as hell.

*“Lacking that hydrogen fuel, reliably delivered at 10,000 psi, an HFCV is no more than a large, pricey doorstop. If we had to guess, we'd suggest the future for passenger cars is more likely to be electric.”* [EE]

## Is There a Future for Light-duty Fuel Cell Electric Vehicles?

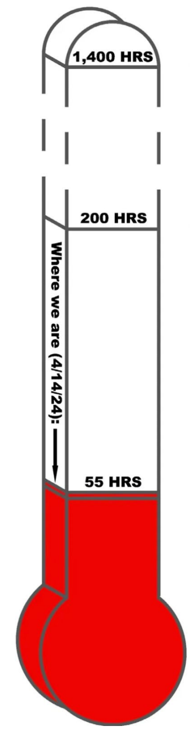


There are many reasons for believing in a positive future for LD-FCEVs:

- Drivers almost universally love these cars.
- They can refuel from empty to full in 5 minutes.
- In a recent discussion with CEC staff, they related that it was their belief that 2024 will be a “transition” year, but 2025 looks brighter for LD-FCEVs.[FF]
- “No automaker has walked away from this technology”.[GG]
- “Yes, we (Toyota) are still committed for the long haul!” [HH]

- Several hydrogen refueling station developers have committed to building additional stations (see below).
- Light-duty FCEVs have a necessary and “symbiotic” relationship with medium-duty and heavy-duty FCEVs (see below).
- “The author concludes that uncertainty about a future hydrogen economy and its market dynamics will not prohibit its domination in future decarbonized power systems.” [II]

## Station Progress Thermometer:




- CHCOA monitors a station progress thermometer. Our first goal as an Association is to work toward the construction of 200 HRS by 2030
- In total, FirstElement Fuel, Air Products, Iwatani, and Chevron have committed to over 80 new HRS. These stations will be for light-duty FCEVs, or mixed use (LD/MD/HD).

## LD/MD/HD - A symbiotic relationship:

The University of California – Davis, FirstElement Fuel, Air Products, Toyota and Hyzon have all expressed the need for light-duty, medium-duty and heavy-duty FCEVs to grow concurrently.

"…the number of production Class 8 truck offerings along with other offerings in the LD, medium-duty (MD) and HD segments is expected to grow exponentially in the coming years."[JJ]

# Build it, and They Will Come:

It is undeniable that the lack of reliable hydrogen fueling infrastructure in California is single-handedly thwarting the success of these cars in the U.S.

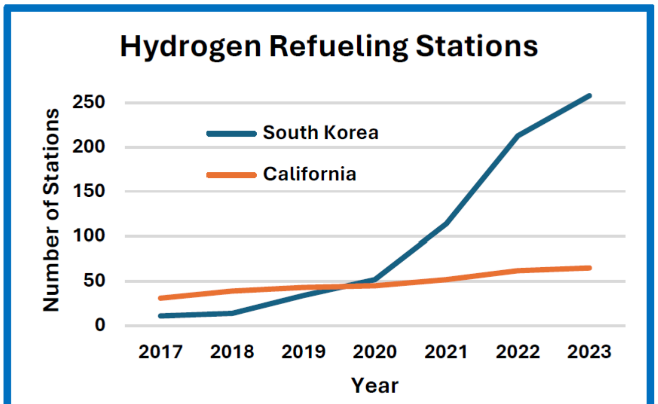
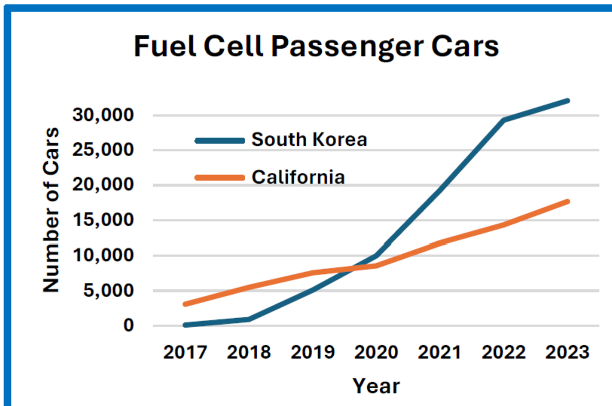


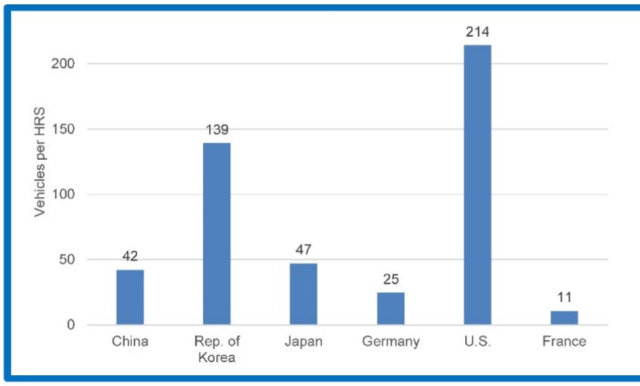

Figure - 8




Sources: CA Energy Commission, CA Air Resources Board, International Energy Agency, H2Stations.org

Hydrogen refueling station (HRS) deployment must precede the adoption of hydrogen fuel cell electric vehicles (FCEVs) by the public. South Korea provides an excellent real-world example of how this can work:

> As reflected in Figure 8, the blue line on the upper left graph shows the very rapid growth of HRS in S. Korea; approx. 250 stations in 6 years. The deployment of HRS infrastructure in California has been more staid (orange line). The result is that there has been a 253% average year-over-year growth of FCEVs in Korea vs. a 35% average year-over-year growth in California (right graph).




**Vehicles (FCEVs) per Hydrogen Refueling Station**

Figure - 9

As reflected on the bar graph (Figure - 9), the U.S. (mainly California) has a 214 Vehicle to HRS ratio; the least desirable in the world (i.e., too many FCEV drivers chasing too few stations). The resulting driver frustration and disillusionment with FCEVs is what the California Hydrogen Car Owners Association hears about on almost a daily basis.

# Endnotes

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[A] Anastassios Petropoulos, PhD, email communication to CHCOA, H2FCP, CHC, FEF and CHBC, June 11, 2024

[B] Gautam Prabhakar, PhD, Submittal to the docket, June 4, 2024

[C] De Wolf, D.; Smeers, Y., Comparison of Battery Electric Vehicles and Fuel Cell Vehicles. World Electr. Veh. J. 2023, 14, 262. https:// doi.org/10.3390/wevj14090262 (Copy here)

[D] Comparative Analysis of Infrastructures…

[E] Robinus, etal. Comparative Analysis of Infrastructures: Hydrogen Fueling and Electric Charging of Vehicles, 2018, pg. 79

[F] De Wolf, et al, Comparison of Battery Electric Vehicles and Fuel Cell Vehicles, Sept 2023, pg. 12

[G] Comment by CTP Committee member at June 7, 2024 meeting

[H] https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities

[I]https://docs.google.com/spreadsheets/d/17OffAioWfwYc6X0pa_8kCFJ_1U7FKbJ8/edit?gid=1082541930#gid=1082541930

[J] https://drive.google.com/file/d/1X3jbf7YIx1AAR0idZkIDbCIyAs6QfQC5/view

[K] Page 2 of May 2024 Issue of Proton Monthly newsletter

[L] Graph and section comments:  Refence docket submittal dtd 6/6/2024 of Anastassios Petropoulos, PhD; https://efiling.energy.ca.gov/Lists/DocketLog.aspx?docketnumber=24-ALT-01

[M] https://h2fcp.org/cars

[N] Car and Driver, April 29, 2024

[O] https://newatlas.com/environment/hydrogen-greenhouse-gas/

[P] T. Lipman, PhD, Email communication to Cane, June 5, 2024

[Q] Warwick, et al, October 2023

[R] GO-Biz, Hydrogen Station Permitting Guidebook, 2022, pg. 2

[S] https://www.fastcompany.com/91016543/scientists-just-invented-an-ev-battery-that-can-fully-charge-in-5-minutes

[T] https://www.cell.com/joule/abstract/S2542-4351(23)00540-8

[U] https://news.cornell.edu/stories/2024/01/fast-charging-lithium-battery-seeks-eliminate-range-anxiety

[V] Kurtz, et al, Hydrogen station prognostics and health monitoring model, January 2024, pg. 1

[W] See https://h2-ca.com/graphs

[X] See https://drive.google.com/file/d/16LvtOQztFdQqsi3jKwvu54aJdOVY5RYM/view

[Y] Raugei, et al, Life-Cycle Carbon Emissions and Energy Return on Investment for 80% Domestic Renewable Electricity with Battery Storage in California (U.S.A.), Aug 2020, pg. 11

[Z] Robinus, etal. Comparative Analysis of Infrastructures: Hydrogen Fueling and Electric Charging of Vehicles, 2018, pg 79

[AA] De Wolf, et al, Comparison of Battery Electric Vehicles and Fuel Cell Vehicles, Sept 2023, pg. 11

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**Appendix 1**

# $CO_2$ Intensity of FCEVs and BEVs: SMR Hydrogen and Grid Power

A.E. Petropoulos

19 June 2024

A comparison of $CO_2$ costs of 'dirty' FCEVs and 'dirty' BEVs is presented. For mileage estimates, we take as representative the Toyota Mirai XLE, 2023 Model Year, and the Tesla Model 3 RWD, 2023 Model Year.

Table 1 has the break down of all the necessary quantities for an FCEV (Fuel Cell Electric Vehicle), assuming the hydrogen comes from Steam Methane Reformation with the Water Gas Shift reaction. Furthermore, any electrical power needed is assumed to come from a coal-fired power plant, and transport of hydrogen is assumed to be done with diesel trucks. The effect of using cleaner power (California's average grid) is examined in Table 3.

Table 2 has the break down of all the necessary quantities for a BEV (Battery Electric Vehicle), assuming the power used to charge the battery also comes from a coal-fired power plant.

Tables 1 and 2 both use EPA figures for mileage, which are generally speaking optimistic compared to real-world driving.

However, Table 1, for FCEVs, is otherwise consistently pessimistic about (overestimates) the amount of $CO_2$ released per mile driven: 1) The energy needed for compressing and cooling the hydrogen is roughly double book-kept (because the energy savings from having already compressed hydrogen delivered to the hydrogen refuelling station is not readily available in the literature), Rows 7 and 8; 2) The power consumption of the most inefficient type of SMR plant is taken (6.3 MW, Row 2), not the most efficient, and Carbon Capture is not assumed.

In contrast, Table 2, for BEVs, is otherwise optimistic about (underestimates) the various power losses: 1) Charging losses are at the lower end of the range of numbers reported in the literature; 2) Transmission losses (from power plant to charging station) are taken as zero.

## Takeaways

Using EPA values, even with the other numbers biased in favour of BEVs, BEVs still have 12% more carbon dioxide emissions than FCEVs, per mile driven (see Rows 13 and 9 in Tables 1, 2 respectively), assuming 'dirty electricity' and 'dirty H2 production', as outlined in Tables 1 and 2.

In Table 3, changing various parameters to real-world values shows that the percent increase in $CO_2$ emissions of BEVs relative to FCEVs becomes even larger, assuming coal-derived electric power in both cases. Perhaps the fairest comparison, Row 1 in Table 3, where average real-world mileage is assumed instead of EPA mileage, shows that BEV miles produce 33% more $CO_2$ than FCEV miles. In the worst case, Rows 2 and 6 of Table 3, BEVs have a whopping 102% more $CO_2$ emitted than FCEVs per mile driven.

When the actual grid-power mix is used, and real-world mileages and losses are assumed, $CO_2$ emissions are shown in the bottom part of Table 3. In the case of the U.S national grid average, $CO_2$ emissions per mile are quite similar between FCEVs using hydrogen from Steam Methane Reformation and BEVs. In the case of W. Virginia, the state with the most $CO_2$-intensive electric power, BEVs emit 42% more $CO_2$ per mile than FCEVs using hydrogen from Steam Methane Reformation.

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Table 1: $CO_2$ emissions: From Methane to FCEV Miles Driven, via dirty power, hydrogen and dirty truck delivery

| Row | Item | Value | Notes/Source |
|---|---|---|---|
| 1 | $CO_2$ emission from SMR and WGS chemical reactions in H2 production plant, per tonne H2 produced [tonne] | 9.376 | Ref 1, Table 2, Column 1, with unit conversions. No Carbon-Capture is used. |
| 2 | Utility power drawn by production plant [MW] | 6.3 | Ref 1, Table 2, Column 1 verbatim. Conventional Plant. 4.6 MW if HTGR-Integrated plant (Col. 3). |
| 3 | Utility energy drawn by production plant per Tonne H2 produced [MWh] | 0.487 | Ref 1, Table 2, Column 1, with unit conversions. |
| 4 | $CO_2$ emission from coal-fired utility power generation for running the production plant, per Tonne H2 produced [Tonne] | 0.509 | Ref 2: 2.3 lb $CO_2$/kwh for Row 3's 0.487 MWh. |
| 5 | Total $CO_2$ emission from H2 plant operations per tonne H2 produced [tonne] | 9.884 | Sum of rows 1 and 4 |
| 6 | $CO_2$ emission from 200-mile transport by 45-tonne diesel truck from plant to fuelling station per tonne H2 transported [tonne] | 0.224 | Ref 3: 1500 kg H2 per 45-t truck (Slide 3, Titan V, 540 bar); Ref 4: 40 litres Diesel/100km for 45-t truck. Ref 5: 10.19 kg $CO_2$ per gallon diesel burned. |
| 7 | Utility energy for H2 Compression and Cooling to 700 bar at the plant for transport per tonne H2 [MWh] | 2.9 | Ref 6, Air Product's number. There's some double-bookkeeping between Rows 7 and 8, so we are overestimating the total Compression and Cooling energy. Plus Row 6 only needs 540 bar compression, not the 700 book-kept here. |
| 8 | Utility energy for H2 Compression and Cooling to 700 bar for dispensing from the fuelling station per tonne H2 [MWh] | 2.9 | –ditto– |
| 9 | $CO_2$ emission from coal-fired utility power generation for Compression and Cooling energy, per tonne H2 dispensed [tonne] | 6.064 | Ref 2: 2.3 lb $CO_2$/kwh, applied to combined energy of Rows 7 and 8 |
| 10 | Total $CO_2$ emission from coal-fired utility power generation per tonne H2 dispensed to 700-bar FCEV fuel tank [tonne] | 6.574 | Sum of Rows 4,9 |
| 11 | Total $CO_2$ emission per tonne H2 dispensed into 700 bar FCEV fuel tank [tonne] | 16.171 | Sum of Rows 1,10 |
| 12 | EPA Fuel Economy FCEV: Miles driven per kg H2, (2023 Mirai XLE) | 72.04 | EPA numbers: Ref 7, claimed range (402 mi), and Ref 8 useable tank capacity (5.58 kg). Real World is more like 67 mi/kg, see discussion. |
| 13 | $CO_2$ emissions per 100 [EPA] Miles Driven by FCEV using dirty Hydrogen [kg] | 22.45 | Row 11 divided by Row 12 times 100 |

Table 2: $CO_2$ emissions: From coal-fired power to BEV Miles Driven

| Row | Item | Value | Notes/Source |
|---|---|---|---|
| 1 | EPA Range 2023MY Tesla Model 3 RWD [miles] | 272 | Ref. 9 |
| 2 | EPA Battery Capacity 2023MY Tesla Model 3 RWD [kWh] | 60.9 | Ref 10 page 3: Battery capacity 174 [Ah], Battery Voltage 350 V. Ref 11 states that units for battery capacity of Ref 10 are Ah (and that interpretation yields right ballpark numbers). |
| 3 | EPA Fuel Economy BEV: Miles driven per kWh discharged from battery (MY2023 Tesla 3 RWD) | 4.47 | Row 1 divided by Row 2. Real World is more like 3.5 mi/kWh or less (Refs 12, 15, 16, and see discussion). |
| 4 | Charging losses (energy drawn from utility minus resulting energy stored on the battery) [%] | 7 | Ref 13, but that is for a BMW i3 tested in Europe. Ref 14 suggests 10% based on an Argonne Natl Labs study of several EVs. Refs 15, 16 measure real-world charging losses betw. 5 and 40%! See discussion. |
| 5 | Utility power transmission loss (from power plant to vehicle charger) [%] | 0 | Assuming 0 is a freebie that favours EVs. The reality is a 5 % average transmission loss in the US from 2018-2022 (Ref 17). |
| 6 | Energy drawn from power plant per kWh of energy stored in the BEV battery [kWh] | 1.075 | Approx = 100/(100 - (Row4 + Row5)) |
| 7 | $CO_2$ emission from coal-fired utility power plant per kWh electrical energy produced [kg] | 1.045 | Ref 2 (2.3 lbs/kWh). |
| 8 | $CO_2$ emission from coal-fired utility power plant per kWh electrical energy stored in the BEV battery [kg] | 1.124 | Product of Rows 6 and 7 |
| 9 | $CO_2$ emissions per 100 [EPA] Miles Driven by BEV using dirty power to charge [kg] | 25.17 | Row 8 divided by Row 3 times 100 |

Table 3: $CO_2$ emissions under various real-world conditions. Any parameters that are changed wrt values in Tables 1 and 2 are explicitly noted in this table. The $CO_2$ columns are the new values for Rows 13 and 9, respectively

| FCEV Parameter Change | FCEV $CO_2$ [kg/100mi] | BEV $CO_2$ [kg/100mi] | BEV Parameter Change |
|---|---|---|---|
| Real World Mileage, average driving, taken as 67 mi/kg [Row 12]. Ref. 18 | 24.14 | 32.12 | Real World Mileage, average driving, taken as 3.5 mi/kWh [Row 3]. Ref. 12 |
| Real World Mileage, mildly stressful driving, taken as 60 mi/kg [Row 2]. Ref. 19 | 26.95 | 33.76 | Real World Mileage, mildly stressful driving, taken as 3.33 mi/kWh [Row 3]. This is the average over 12+ months reported in Refs 15,16, ranging from 2.97 (Dec.) to 3.94 (June) mi/kWh, for their 2019 Tesla Model 3. Article's grid power consumption converted to power from battery to get these figures |
| Real World Mileage, average driving, 67 mi/kg [Row 12]. HTGR-Integrated SMR plant 4.6 MW [Row 2] | 21.78 | 33.94 | Real World Mileage, average driving, 3.5 mi/kWh [Row 3]. Transmission Losses 5% [Row 5] Ref. 17. |
| | | 36.88 | Real World Mileage, average driving, 3.5 mi/kWh [Row 3]. Transmission Losses 5% [Row 5] Ref. 17. Real World average charging loss 14% [Row 4] Ref. 15 citing Tesla's own reporting to EPA. |
| | | 54.31 | Real World Mileage, average driving, 3.5 mi/kWh [Row 3]. Transmission Losses 5% [Row 5] Ref. 17. Real World worst case charging loss 40% [Row 4] Ref. 15 citing their own tests for the worst case: December, due to cold, and Level-1 at-home charger. |
| *$CO_2$ Assuming Real-World Grid Power Mix, instead of 100% coal-derived electric power, $CO_2$ kg/MWh values from Ref. 20* | | | |
| FCEV case from earlier row, namely: Real World Mileage, average driving, 67 mi/kg [Row 12]. HTGR-Integrated SMR plant 4.6 MW [Row 2]. 21.78 kg/100mi if 100% coal | | BEV case from earlier row, namely: Real World Mileage, average driving, 3.5 mi/kWh [Row 3]. Transmission Losses 5% [Row 5] Ref. 17. Real World average charging loss 14% [Row 4] Ref. 15 citing Tesla's own reporting to EPA. 36.88 kg/100mi if 100% coal | |
| California Grid, 219 kg-$CO_2$/MWh | 16.01 | 7.73 | 45th-ranked state |
| US Grid, 390 kg-$CO_2$/MWh | 17.58 | 13.76 | national average |
| Texas Grid, 406 kg-$CO_2$/MWh | 17.72 | 14.33 | 21st-ranked state |
| Wisconsin Grid, 539 kg-$CO_2$/MWh | 18.94 | 19.01 | 10th-ranked state |
| Missouri Grid, 720 kg-$CO_2$/MWh | 20.61 | 25.41 | 4th-ranked state |
| W. Virginia Grid, 889 kg-$CO_2$/MWh | 22.16 | 31.37 | 1st-ranked state |

Appendix 2

*Comment Received From: Tadashi Ogitsu*
*Submitted On: 6/2/2024*
*Docket Number: 24-ALT-01*

## Hydrogen fueling stations for light duty vehicles need to be supported

*Additional submitted attachment is included below.*

# Comments to 24-ALT-01

**Name:** Tadashi Ogitsu
**Affiliation:** Lawrence Livermore National Laboratory
**Title:** Staff scientist, PhD in Materials Science

## 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.

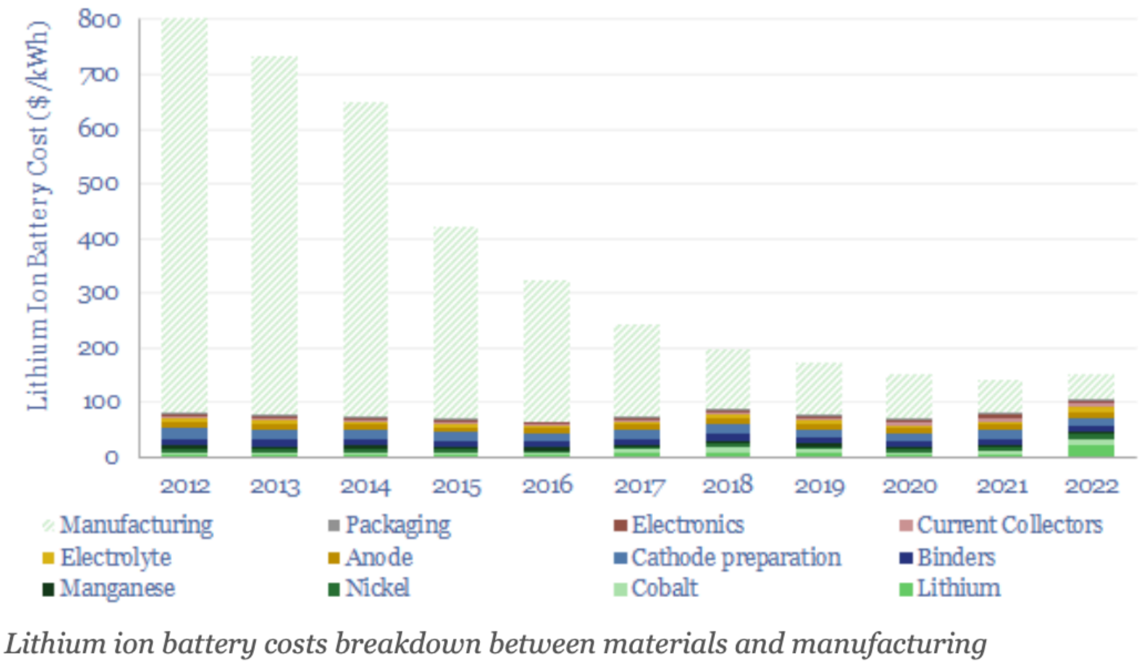


Figure 1: Cost breakdown of battery from https://thundersaidenergy.com/2023/11/18/grid-scale-battery-costs-kw-or-kwh/

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.

# The Challenge BEVs Pose to the Grid

A.E. Petropoulos

19 June 2024

Wide-scale adoption of BEVs (numbers close to 100% are bandied about) will pose unreasonable, and indeed untenable, challenges to the grid. Some of this challenge can be met. To pickup the grid shortfall, and for uses cases that demand a traditional range and fuelling model, hydrogen FCEVs are best suited.

So, to the numbers.

## Cars/Vehicles and Miles

It is really hard to get the actual number of light duty vehicles on the road in the USA or the miles driven by such vehicles. Light Duty vehicles are passenger cars, minivans, SUVs, light trucks (e.g. pickup trucks).
Finally, I came across this link

https://www.bts.gov/content/number-us-aircraft-vehicles-vessels-and-other-conveyances

where the numbers are given for all vehicle types by year through 2021 in Table 1-11. The total vehicle registrations for 2021 of the three vehicle types 1) Light duty vehicle, short wheel base, 2) Motorcycle, and 3) Light duty vehicle, long wheel base is, in total, 267.6M vehicles. This is roughly corroborated by the indirect numbers I could find:

This link https://www.fhwa.dot.gov/policyinformation/statistics/2022/mv1.cfm shows 283M road vehicles (of all types) registered in 2022. Note that this same link shows 100M "Automobiles", but these exclude pickups, SUVs etc, which are lumped wth the trucks (173M in total!), even though they are usually used like a car. Some proponents of BEVs appear to take only this 100M number. Note also that in 2019, there were 109M "Automobile" registrations. The 2022 number was unusually low due to COVID-19.

This link https://afdc.energy.gov/data/10569 shows that 90.71% of all road vehicles in 2021 were "cars, light trucks, motorcycles".

Thus, from these indirect numbers, we get 256.7M vehicles, pretty close to the 267.6M of the aforementioned table.

This link https://www.fhwa.dot.gov/policyinformation/statistics/2022/vm1.cfm shows that light-duty vehicles and motorcycles travelled a total of 2.85 trillion miles in 2022.

## Current Grid Power

This link https://www.eia.gov/totalenergy/data/monthly/pdf/flow/total_energy_2023.pdf very conveniently lists the electircal energy used in 2023 by sector. Converting from the Btus and percentages given, we get the numbers shown in Table 1 (rounding in the Sector percentages causes them to not total exactly 100%).

This link https://www.eia.gov/consumption/residential/data/2020/c&e/pdf/ce2.1.pdf shows 1.305 PWh for residential consumption in 2020, which is of the same order of magnitude as, if slightly less than, the value in the table for 2023.

Table 1: 2023 Electrical Energy Consumption in the USA

| Sector | Percent | PWh |
|---|---|---|
| Industrial | 27 | 1.04 |
| Residential | 38 | 1.47 |
| Commercial | 36 | 1.39 |
| Total | 100 | 3.87 |

## Grid impact of Converting all Light Duty Vehicles to BEVs

An optimistic but perhaps reasonable average kWh-mileage is 3.5 miles/kWh. Smaller vehicles and motorcycles will have better mileage, larger sedans and SUVs will have worse. 3.5 mi/kWh is about average for a Tesla Model 3 (see more details in the $CO_2$ analysis).

Thus, if all these 2.85 trillion miles driven in 2022 were to be driven annually by BEVs, a total of 0.814 PWh (814 billion kWh) would be needed annually.

This annual amount of electrical energy, 0.814 Peta-Watt-hours, is extraordinarily large. This energy must be not only produced, but also transmitted into the deepest depths of the grid. It is 55% of the current residential electrical energy use. It is 28% of the combined residential and commercial electrical energy use, and 21% of the national total electrical energy use.

**Beefing up the Residential and Commercial grids by 28%, all the way to the last substation and the last point of use, is not a tenable proposition. This is compounded by the conversion of energy-intensive appliances, such as stoves, furnaces and water heaters, to electricity. Plus, this percentage doesn't even account for time-of-use and place-of-use intensifications and redundancy requirements.**

**In contrast, hydrogen production, not all of which will be from electrolysis but will also be from other green production methods, impacts only the industrial consumption of electricity. Typically, transmission of this power will be over very short distances from the power generation to the hydrogen production facilities.**

Furthermore, hydrogen is suitable as a long-term energy storage medium for absorbing excess renewable energy, and it would be produced on- or near-site, thereby not stressing the grid. This hydrogen would be used both to power vehicles and to contribute electricity back into the grid when needed.

Lastly, hydrogen-powered transportation is more resilient in the face of electrical outages. If power goes out, hydrogen offers a much more robust option for transport (i.e. can more easily support more vehicles and more miles travelled) than back-up battery power.