Electric versus Fuel Cell Vehicles

Electric Vehicles

Batteries are the major technology being proposed for the decarbonisation of transportation, but not the right technology. It has a number of major problems, some of which have no technical fix and others whose fix would be prohibitively expensive.

These problems include:

1. **Grid Reinforcement:** All the EV chargers would require tripling (at least - maybe up to 6x reinforcement) of every single level of the grid from the domestic connection through to the transmission grid, and all transformers and substations in between.
   - And the rush hour (large numbers wanting to use and/or charge their vehicles at the same time) would have to be stopped.
2. **Charging:** 40% of homes (principally poorer ones) don’t have any dedicated parking spaces, and more have insufficient for their vehicles:
   - People will not want to walk substantial distances to find their vehicles;
   - Centralised parking/charging would take enormous public investment, and require the construction of large centralised facilities;
   - Public and commercial charging will always be more expensive than domestic;
   - V2G won’t work when vehicles cannot be left permanently connected;
   - Shared mobility would increase mileage substantially owing to empty journeys;
   - All this would reinforce rather than reduce wealth discrepancies.
3. **Weight and Distance:** It's inappropriate for heavy vehicles (insufficient power density per unit weight and volume) or for more heavily used vehicles (long re-charging times), for both of which hydrogen / fuel cells are better:
   - Energy density of lithium-ion batteries is only 1% of that of petrol or diesel;
   - Re-fuelling hydrogen vehicles will take little longer than petrol or diesel, whereas re-fuelling electric vehicles takes much longer;
   - Fast-charging greatly reduces battery life and places enormous stress on the electricity system supplying the charger, in turn requiring yet more local storage – and refer back to resource insufficiency above.
4. **Efficiency:** there is great emphasis on the efficiency of batteries in vehicles, and none on the inefficiencies of batteries themselves[1]; while this link looks at grid-connected batteries (and therefore apply to charge-point connected batteries), its considerations in fundamental efficiency and its lifetime deterioration remain valid for vehicles.
5. **Resource Sufficiency:** There isn't enough lithium in the earth's crust for all the vehicles of the world[2], even less cobalt and even less rare-earth metals. If the

[1] https://www.storelectric.com/batteries-expensive-and-inadequate-solutions/

[2] There is sufficient recoverable lithium in the world to power only 77% of vehicles by 2080, ignoring any use of lithium for the electricity sector (which uses three time as much energy as transportation, including gas as it will be replaced by both P2G and electrification), portable devices and other uses

40-60 gigafactories currently planned world-wide are built, they would exhaust the lithium deposits in all current and under-development fields in 2-10 years according to figures from The Economist[3]. And that's without considering grid-connected batteries (a roughly equal amount proposed) or portable devices. Or its short asset life and lack of recyclability.

Calculation of Lithium Demand for Transportation

The UK has ~8% of the world's population. We cannot assume that we're the only country seeking a particular energy transition technology, so must assume that what we choose, others will choose too. That applies to the plan to convert our vehicle fleet to battery powered EVs.

- There are 1.42bn vehicles world-wide, of which 1.06bn are cars[4].
  - If the world had the same number per capita as the US, that would be an additional 4.5bn, total 5.5bn. But we'll ignore this.
- Assume that non-car vehicles (lorries, buses, vans etc.) need an average 3x car battery size. So the total fleet is 2.14 car-equivalents.
  - That is, roughly 8.5bn car-equivalents. But we'll ignore this.
- A typical car's battery contains 8kg lithium (and 35kg nickel, 20kg manganese and 14kg cobalt, not to mention rare-earth metals)[5].
- Assuming that the world's vehicle fleet does not grow as less-developed regions develop (which is a false assumption, but errs very heavily on the side of caution), the world's vehicle fleet would require 2.14 x 8 = 17.1bn kg lithium.
- The earth's crust has 9.1×10^9 = 9.9bn kg lithium reserves economically extractable now, and 2.55×10^{10} = 25.5bn kg potentially economic lithium[6].
- Therefore the world's existing fleet would use twice the world's currently extractable lithium, and 67% of potentially extractable lithium.
- However, this makes some very rash assumptions, including:
  - There is no increase in the number of vehicles (likely to at least double and probably triple, see above);

---

https://www.researchgate.net/publication/264854684_Lithium_Resources_and_Production_Critical_Assessment_and_Global_Projections.

[3] https://www.economist.com/news/briefing/21726069-no-need-subsidies-higher-volumes-and-better-chemistry-are-causing-costs-plummet-after (noting that "vehicles" primarily means cars, not vans, buses or lorries) -

Vehicles, 2016	25	GWh	750,000 vehicles
Mid-range: 2040 Bloomberg	15,500	GWh	465,000,000 vehicles
2040 OPEC	5,000	GWh	150,000,000 vehicles
2040 ExxonMobil	3,000	GWh	90,000,000 vehicles

Total lithium, 2016	180,000	tonnes in one year
2040 Bloomberg	111,600,000	tonnes in one year, just for vehicles
2040 OPEC	36,000,000	tonnes in one year, just for vehicles
2040 ExxonMobil	21,600,000	tonnes in one year, just for vehicles

Total available lithium in planet	210,000,000	tonnes
Years' output: 2040 Bloomberg	1.9	years, just for vehicles

[4] https://www.rfidtires.com/how-many-cars-world.html

[5] https://www.nature.com/articles/d41586-021-02222-1

[6] http://large.stanford.edu/courses/2010/ph240/eason2/

- ◊ All batteries last forever and don't need replacing;
- ◊ Any replacements are 100% efficiently recycled (prohibitively expensive, and zero waste is totally unachievable, e.g. vehicles dumped or crashed);
- ◊ 100% of economically extractable lithium is extracted (impossible: cannot extract under, for example, cities or national parks);
- ◊ No lithium is used for anything else, such as (all of which use it currently) –
  - Grid balancing
  - Portable devices
  - Aviation
  - Lightweight alloys;
  - Specialist glases and ceramics;
  - Air conditioning and industrial drying;
  - Lubricants;
  - Medicines and medical devices.
- And this ignores the cobalt and rare-earth metals that are used in EVs (not just in their batteries, but in their motors and other electronics too), which are much scarcer.

Electrifying just British cars "would require production of just under two times the current total annual world cobalt production, nearly the entire world production of neodymium, three quarters the world's lithium production and at least half of the world's copper production" according to leading scientists[7]. And these ignore:

- Vans, buses and lorries;
- Use of batteries in electricity systems, houses, portable and remote devices, or other applications such as aviation, shipping, rail etc.;
- The short life and poor recyclability of batteries; or
- Any of these considerations in any other country – there is sufficient lithium (ignoring the other metals, many of which are scarcer) for just 77% of cars world-wide[8], ignoring all other uses and considerations.

Nobody has ever addressed these issues while worshiping in the pro-battery faith. They just respond with pieties such as "lithium isn't the only type of battery", ignoring the practicalities that led to lithium dominance today. It is thinking like a metaphorical lemming ("we'll go this way because everyone else is") rather than analysing the challenges of the energy transition dispassionately.

Hydrogen / Fuel Cell Vehicles

As for hydrogen, the only reason why electrolysis is so expensive is because the only two technologies being promoted are PEM (expensive, especially as the membrane is a costly consumable item, and limited in scale) and alkali (expensive and noxious). Other electrolysis technologies are not being funded – I know of two such that have real potential for large-scale electrolysis cheaper than steam methane reformation, which is the current principal source of hydrogen for industrial use.

[7] https://www.greencarcongress.com/2019/06/20190624-uk.html
[8] https://www.mdpi.com/2075-163X/2/1/65/pdf

Hydrogen-powered fuel cell vehicles avoid all these issues:

1. There's no resource scarcity;
2. Hydrogen can be distributed through the gas grid;
3. Energy density per kilogram is 175 times that of Li-ion batteries[9];
4. Fuelling would be very similar indeed to current petrol and diesel refuelling, in both time and method;
5. Fuel cell vehicles can carry more range and power, and are more quickly and easily refuelled during the day/journey.

Vehicle to Grid

A response is that this fails to address the requirements of the grid which can be supported by Vehicle to Grid (V2G) storage. However the assumptions and forecasts relating to this require some challenging; for example,

1. All the cars in most developed countries, if turned into EVs that are 100% used for grid-connected storage, would account for only a part of the storage needs – they consume similar amounts of energy to the entire electricity grid, with only a 2-4-hour range, only half of which at most (if the system works flawlessly) would be available to the grid. Therefore it lacks the duration to provide true back-up for renewables.
2. Where they charge from solar power (office, shopping), which is the proffered model, differs from where they would operate as grid-connected batteries, and nobody has proposed a cost-effective model for the financial flows.
3. Most people don't want their vehicles on less than half charge, which halves (or less) the energy/storage available.
4. The bulk of the need for the storage is in the evening, when vehicles' charge is lowest, yielding a grossly disproportionate multiplication of point 3.
5. To roll out cars-with-solar widely, a high proportion of the parking spaces in the country would have to be fitted with chargers - who would bear the cost of that?

The above-listed challenges would need to be answered for V2G storage services to be reliable. And it appears that all these V2G proposals assume 100% efficiency in V2G services, which will not be attainable: a perfectly new battery requiring no cooling yields ~96% efficiency, whereas one approaching the end of its life yields ~75%, so a reasonable assumed average efficiency would be ~85%; then there are converter efficiencies – 90% is reasonable[10], which has to be applied twice – once for charging and once for discharging. The total round-trip efficiency is therefore 0.85 x 0.9 x 0.9 = 0.6885 or 69% round trip, or about the same as large-scale long-duration storage.

Analysing this roughly,

- ♦ Vehicles will be at different states of charge, so assume 50% charged.
- ♦ Travelling capacity will need to remain in the vehicle, so halve that to 25%.
- ♦ Over its life, it loses ~20% of capacity, so average battery capacity is reduced by 10%, cutting the available amount to 22.5%.

---

[9] https://www.motorbiscuit.com/hydrogen-fuel-cells-vs-batteries/

[10] https://www.electronicdesign.com/power/understand-efficiency-ratings-choosing-ac-dc-supply graph

- We can assume that no more than about ⅓ of such vehicles are left in personal parking spots attached to personal chargers overnight, so the capacity available to the grid is only ~7.5% of total EV battery capacity.
- Applying the 69% round trip efficiency, this drops to 5.2%.
- A typical car battery has 50kWh capacity[11], and there are ~30 million on the road in the UK, so available storage capacity is 7.76GWh.

This looks good until it is compared with the need: after sunset on a windless winter evening the country today consumes ~42GW x 5 hours = 210GWh, forecast by National Grid[12] to double by 2050.

And don't forget that all this consumes battery life.

Therefore the benefits of load shifting (smart charging, i.e. changing the time at which batteries are charged, again only available for the minority of vehicles being charged in private spaces on dedicated chargers) is their greatest benefit to the grid, with V2G (the ability to put charge back into the grid) a secondary benefit confined to smoothing small peaks in demand.

Conclusion

Large-scale long-duration storage is much more cost-effective than using EVs for either load shifting or V2G. The other draw-backs of EVs far outweigh any advantages for the majority of vehicles – the ⅔ which are heavier duty and/or more intensively used, which may account for over 90% of mileage driven.

Therefore EVs are best suited for short-distance light-use applications.

And both money and effort need to be devoted to developing and commercialising non-PEM electrolysis technologies, and rolling out hydrogen fuelling points to filling stations everywhere.

Independent analyses of battery versus hydrogen-fuel-cell EVs are available[13].

---

[11] Example car battery sizes: Tesla Model S 75D is 75kWh; BMW i3 = 42kWh, Nissan Leaf = 40kWh, VW e-Golf = 36kWh, Ford Focus Electric = 33.5kWh

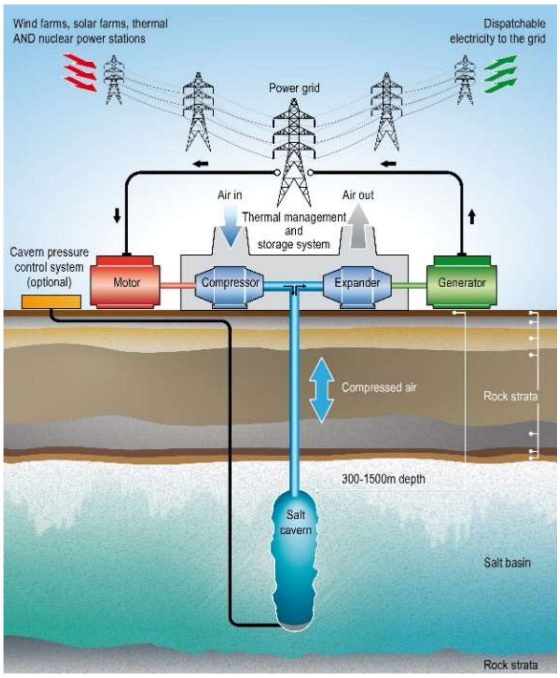
[12] Future Energy Scenarios 2020

[13] E.g. https://www.lexology.com/library/detail.aspx?g=1bf1cbf0-ac2f-4b39-a3de-2df77a9a515e and https://www.motorbiscuit.com/hydrogen-fuel-cells-vs-batteries/

About Storelectric

Storelectric (www.storelectric.com) is developing transmission and distribution grid-scale energy storage to enable renewables to power grids reliably and cost-effectively: the world's most cost-effective and widely implementable large-scale energy storage technology, turning locally generated renewable energy into dispatchable electricity, so…

***enabling renewables to power grids cheaply, efficiently, reliably and resiliently*.**



- ♦ Innovative adiabatic Compressed Air Energy Storage (Green CAES) will have zero / low emissions, operate at 68-70% round trip efficiency, levelised cost significantly below that of gas-fired peaking plants, and use existing, off-the-shelf equipment.
- ♦ Hydrogen CAES technology converts & gives new economic life to gas-fired power stations, reducing emissions and adding storage revenues; hydrogen compatible.

Both technologies will operate at scales of 20MW to multi-GW and durations from 4 hours to multi-day. With the potential to store the entire continent's energy requirements for over a week, global potential is greater still. In the future, Storelectric will further develop both these and hybrid technologies, and other geologies for CAES, all of which will greatly improve storage cost, duration, efficiency and global potential.

About the Author

Mark Howitt is Chief Technical Officer, a founding director of Storelectric. He is also a United Nations expert advisor in energy transition technologies, economics, regulation and politics – invitation here.

A graduate in Physics with Electronics, he has 12 years' management and innovation consultancy experience world-wide. In a rail multinational, Mark transformed processes and developed 3 profitable and successful businesses: in commercialising a non-destructive technology he had innovated, in logistics (innovating services) and in equipment overhaul. In electronics manufacturing, he developed and introduced to the markets 5 product ranges and helped 2 businesses expand into new markets.