Hydrogen, Thermal Runaway, Buses and the Inevitability of Mathematics

The author as a young man attended what was arguably the best high school in the state and was in the leading Physics class. The teacher would obviously have thought that he was one of the 'best' and acted accordingly.[i] At the time, the HP-35 calculator had just been released and many of the students had one. It had more computing power than the Apollo space craft that had taken man to the moon.

NASA was about to release the new Space Shuttle and the 'elite' teacher posed the question of what was the probability of a Shuttle launch failure. The numbers were:

- Each Shuttle had 10,000 parts;
- Parts had a reliability factor of 99.999% in any one year;
- There were 1 to 4 launches per year planned.

The answer was about 14 years and was calculated on the length of time it took to reach a 50:50 percent chance of failure or putting it another way was when would there be a 50:50% success rate. About on time in 1986, the first shuttle fell out of the sky and 17 years later the second followed, but for a different reason. The result of simple mathematics a senior high school student could work out (with a reasonably advanced scientific calculator). The calculation was a combination of the number of launches; the 99.999% probability of success (which meant there was a 0.001% chance of any one part failing in any year) and the number of parts (10,000). It was the 10,000 parts that killed the shuttle. It only took one (in the first instance an O-Ring and in the second some tiles) to kill it.[ii] The 49% probability was reached at 7 years, so 2 x 7 years was near certainty, crashing in 13-14 years was likely.

In the case of cars/trucks and buses it is the number of vehicles on the road and the concept of having no control over other drivers that make some things inevitable. The author witnessed a 4WD drive straight into the side of a bus of school children at high speed. One occupant of the 4WD died. The other was severely injured but there were no major injuries on the bus. The thing that amazed the author was the fact that all the children on the bus just sat there like 'stunned mullets' none moved. The bus driver was in shock; the kids just sat there. The author after 3-5 minutes attending to the people in the 4WD; got the bus driver to open the door and then he got on. He then instructed those children who could move (everyone but one) to get off and stand or sit on the footpath. (There was the danger that the 4WD would catch fire and set off the bus).[iii] **Note:** The flashpoint of diesel is 65^{o}C.

The ***Hindenburg*** is another example of mathematics and probability. Everybody knows that H_2 and air (oxygen) will explode if there is a spark. Everybody also knew that an airship would lose electrons as it goes through the air and rubs against it (that is inevitable). Thus, on any voyage the ship will build up a positive charge on its skin. The designers went to huge lengths to minimize H_2 gas leakage. They went to reasonable lengths to prevent a spark and minimize static electricity putting the airship in danger (by using hemp ropes which didn't carry a charge in normal circumstances etc.)

The Hindenburg crashed and burned (burnt first) because of two inevitable factors at the same time.

1. There was a Hydrogen leak; and,
2. It was raining gently (gentle rain is potentially worse than heavy rain).

The Hindenburg had a gas leak (this can be seen from old picture/movies) as it approached the mooring pilon. It dropped the pull-down ropes (to pull it down to the ground) and the ropes hit the ground. No spark eventuated because the ropes were dry and non-conductive (as had been the case on other trips) but then the light rain started to wet the ropes. It took 4 minutes and 16 seconds before the ropes were wet enough to be able to carry current (in the water); the craft 'earthed to ground' the spark went up the ropes and ignited the leaking hydrogen and the rest is history …

The Airship Industry Died with it…

Inevitable mathematics in inevitable circumstances.

People think Hydrogen is safe in cars. The Hydrogen cylinder is at 350 bar (11,000 psi). As one engineer said, "The shut off valve takes 0.01 seconds to shut off. In that time 1 x liter of liquid H_2 can escape. It turns into 250 liters of H_2 gas; that automatically mixes with oxygen in the air. EVs have electric motors and inevitably are full of sparks. The result is inevitable – it's just a matter of time.

While talking about Hydrogen something people should know is how incredibly inefficient Hydrogen production is. To split water i.e. separate oxygen from hydrogen takes a lot of energy and most of it is wasted. Oxygen is terribly reactive. A glowing match can be brought back into flame by putting it into pure oxygen. Oxygen is so reactive that it will lift the atoms of iron out of steel one atom at a time.

A methane (gas) molecule burnt in a combined cycle gas fired power station where the electricity is then used to run an ITEZZE car reduces emissions by 80-90% compared to a petrol fueled car. The CH_4 molecule produces 1 x CO_2 molecule and 2 x H_2O (water) molecules and delivers a massive amount of energy (3 x Oxygen atoms) **more** than a H_2 molecule which only links to 1 x Oxygen atom.

H_2 is an incredibly inefficient mechanism for delivering energy when using the five-step ammonia process to transition it from the solar farm to eventual use. Only about 50% of the energy generated eventually arrives at the wheels compared to 90% for electric vehicles running on ITEZZE. It means that twice as much solar generation and processing infrastructure needs to be built to deliver an equal amount of energy when using hydrogen compared to ITEZZE using Grid wires and battery systems.

Note: ITEZZE makes solar work by putting the power into swap batteries in the day when the car is working and the sun shines; then putting the batteries into vehicles as they go home in the afternoon.

The cost of producing and transporting Hydrogen for cars probably uses more CO_2 than running the same car on electricity from methane gas power stations with ITEZZE. The **full cycle cost** of Hydrogen is not just the solar farm and the engine use. It includes the emissions produced building the vast amounts of infrastructure needed to produce and deliver it. The Hydrogen process[iv] has 5-7 steps, each requires infrastructure that to build, emits CO_2. People talk of producing hydrogen using solar electricity to split water to produce hydrogen; then converting the H_2 into ammonia (NH_3 which costs more energy); then transporting it in trucks etc. using more energy (power lines are much more efficient); then converting the ammonia back into H_2 (using more energy); then compressing it, then eventually using it. In ITEZZE, the electricity (from solar, wind, wave, LNG or other) travels via a Grid wire to the battery (transition losses 10%); then the battery runs the electric motors on the vehicle.

Thermal Runaway and Buses

The other potential issue in EVs is ***Thermal Runaway (TR)***. The difference is that the outcome is not inevitable but incidents may be inevitable given the number of buses that need to be deployed. The difference is the swap battery model bus can safely handle thermal runaway. So, they are not saying it won't ever happen but if it does happen, how **it can be safely managed** without hurting people.

An excerpt from the ITEZZE Website about Thermal Runaway (TR) says,

*"Thermal runaway is where a battery may short and catch fire. **Incinerating passengers is not an option**. Lithium Batteries in EVs can spontaneuosly ignite[v] and battery fires are hard to extinguish.[vi] The method to deal with thermal runaway in the EU is to pick up the car with a crane and drop it into a container of water (and let it burn for upto 3 days). Thermal runaway affects many different battery types not just Lithium. Telstra telephone exchanges have been known to burn down when their lead acid backup batteries ignited. ITEZZE uses the **Triple Battery System** and deals with thermal runaway in city bus fleets by making the **Resident Battery** a PIG so it has wheels and can be ejected and both **the PIG** and **Regeneration Battery** are also able to be ejected."*

The concept is simple – if it catches fire, throw it out before anything else does and line the internal walls of each 'battery hold' with Titanium to prevent it setting anything on fire in the 40-60 seconds it takes to get rid of it. Ejection of batteries if they are on fire is not a new concept. Aviation has had ejector seats on fighter aircraft for many years. The difference is that in this situation because ITEZZE use smaller batteries in their vehicles and because they can swap them at intervals. They can design both the ***Resident*** 40 kWh and 130 kWh 'PIG' swap battery to move on wheels and be easy to eject. The ***Regeneration*** battery is even smaller (8-10 kWh) and is installed in an ejectable cradle making it possible to eject the cradle and battery in it. The other key feature of the system is that the batteries are each stored in separate battery holds; thus, there is very little possibility of one igniting another.

The key feature of ITEZZE which makes this system work is that the bus/truck has three (3) batteries. Thus, if the vehicle has one that catches fire, it pulls over to the roadside. Ejects that battery, then drives away under the power of one of the other batteries. Thus, it is disposing of the danger before it endangers the passengers and then putting space between itself and the burning battery. It also has the power to run and power the equipment that pushes the burning battery from the vehicle.

Thus ITEZZE, as well as producing a cheaper vehicle has a much safer mechanism for dealing with the inevitability of TR. (**Note**: even though ejection technology is in place ITEZZE still endeavour to use batteries that don't catch fire. Just as insurance companies prepare for events 'just in case').

Risks for bus companies

Buses operate for up to 19 hours/day. In addition to psychological impairment to drivers, there are three (3) groups of 'Risk' that bus companies need to consider:

1. The batteries on the bus ignite spontaneously;[vii]
2. The bus has an accident and its batteries then ignite from damage;
3. The bus collides with a car/truck/SUV vehicle that runs on diesel which itself has a Lithium based battery. The SUV's Lithium starter battery ignites; burns through its fuel lines; diesel with a Flashpoint of 65°C then escapes, runs under the bus and ignites the bus batteries.[viii]

Lessons for Bus Companies

There are consequences in buses where intrinsic variability is built into the operating procedures. In the school bus incident, the bus driver was not expecting or trained for having a crash with a bus full of school children. He was in shock and stupor after it happened. It may have been he was afraid to look behind himself to see what happened to the children. There were no set protocols for how to act. It took persistent loud knocking and calling out to get him to look out and open the door.

Metropolitan Fire Brigades normally **take 6-8 minutes** to respond to an incident.[ix]

Industry participants should review video of the Maroochydore Golf Club Team bus incident. The bus caught fire while taking 28 golfers to a match in Gympie. The fire in the engine bay which (given that use of Lithium-Ion batteries as starter batteries in commercial vehicles is now common) may have been caused by the engine starter battery. The fire engulfed the bus in 3-4 minutes. Fires can move fast in cars/buses etc. due to the high levels of petroleum-based plastics (1-3 minutes is normal) **See:**

Brisbane Channel 7 – Maroochydore Golf Team -Bus Fire

https://www.youtube.com/watch?v=IR1UoaF4YOc&ab_channel=7NEWSAustralia

In this case the driver acted promptly and evacuated the bus. But it shows what could happen if the bus is full of school children, any lack of reaction would have resulted in them being dead. Buses are not a game. Operating protocols need to be trained into drivers. There have to be systems installed

into buses to maintain the lives of passengers. Building fixed non-removable batteries into the floors and roofs of buses is **a guarantee of fatalities**. If the battery **isn't able to be ejected** in 60-80 seconds there is **no guarantee** of passengers not dying. Passengers especially school children that are used to being ordered about (and who without instruction just sit there) aren't able to get off a bus in time. **They just sit there and die.** Drivers have to have protocols and built-in mechanisms to protect them.

Lithium batteries go into TR when heated to 160-180^{o}C. Diesel on fire underearth a bus will set them off in 1-2 minutes. Evacuation and/or ejection of batteries needs to happen within this time. Drivers have a button that just needs to be activated and pressed so they eject. So, lift the cover; press the button (like on aircraft). Protocols are needed to eject batteries automatically when the evacuation alarm sounds. Anything else is murder by incompetence and bus manufacturers if they build them, may be charged with industrial manslaughter or jailed or whatever (as happens in some countries). In Western democracies they can be guaranteed of being sued or made bankrupt. **Note:** Councils, bus makers and operators who think their Public Liability insurance can fill any lack of cover by Third Party insurers as claims exceed risk limits should understand that under the terms of their policy, if they weren't advised and a company didn't disclose known risks, they're automatically uninsured.

Legal Outcomes

There are three groups of people lining up to litigate against bus manufacturers and operators:

1. Passengers and family members
2. Purchasers, Councils/owners etc.
3. Drivers – because of PTSD, personal injury, poor workplace health and safety protocols.

All have legitimate grounds for litigation. The members of families of children killed have obvious reasons. What about the councils that brought the buses? If they ordered 900 buses and the fire happened soon after the 890th was delivered; **are they going to want a refund** on **all 890** of them; or are they going to want them **all** rectified or retro-fitted plus compensation for losses/inconvenience.

The council itself is a target for Litigation given they should have foreseen the consequences of CTP underwriting insurance caps and the risk of thermal runaway in built-in battery buses. The obvious potential result of a bus fire and litigation would be compounded by the fact that Council Technical Officers should have recommended the use of ejectable batteries, given the ever-present risk of thermal runaway fires. They would also recommend electric buses (as the City of Montpellier did) over buses running on **Hydrogen** due to the obvious risk of hydrogen induced explosion.

The New Paradigm

Because ***all*** the batteries need to be removable in order to deal with battery fire ITEZZE has changed the paradigm for supplying batteries in EVs. Instead of the carmaker supplying the batteries with the new vehicle; **the vehicle is supplied 'bare' without batteries**. Thus, the carmaker sells the EV just as a vehicle (no batteries). The batteries can be supplied later from the car dealer or the customer can source their own (or rent them). This removes battery risk entirely from the carmaker and reduces the purchase price of the EV significantly (to under the price of equivalent ICE cars).

This allows customers to rent their batteries; so instead of buying a 10 kWh ***Resident*** battery (or 40 kWh for a bus), to stay in their car permanently they can hire one from ITEZZE for US$3/day plus 17½ cents/kWh (1.7 kWh = 1 litre of petrol).[x] They can rent a 23-kWh battery for the car '*Swap Slot*' that can be recharged from their home electricity supply until the ITEZZE swap network is fully functional.

The model for selling electric vehicles (EVs) has changed with the advent of ITEZZE. Carmakers can now sell affordable EVs **safely**, without *'Battery Risk'*. (itezze.com/technical – '*Battery Risk' Button*).

References

[i] EVs are all about science, physics and mathematics synergies; ITEZZE includes Economic ones as well;
[ii] Apollo 13 changed the general public blasé thought that everything was easy in space. The shuttles showed that no matter how good the astronauts were, there was a reason for their title and no matter how good they were, there was a chance every time they took off that they might not come back.
[iii] As the number of Lithium-Ion batteries used in cars, trucks and buses as starter batteries increases the number of fires resulting from accidents also seems to be increasing. Accident damage can cause thermal runaway. Truck fires once were rare; now they appear to happen all the time. Most batteries burn so hot that they can melt the fuel lines in most cars.
[iv] electrek.co
[v] Spontaneous Battery Fires – https://www.businessinsider.com.au/why-tesla-cars-catch-on-fire-2019-4?r=US&IR=T
[vi] Electric car explosive fire – Dad rescued daughter (2) from burning vehicle – Fire burnt for many minutes before Fire fighters arrived https://www.bing.com/search?q=Electric+car+explosive+fire+%E2%80%93+Dad+rescued+daughter+%282%29+from+burning+vehicle&form=PRAUEN&ocid=iehp&httpsmsn=1&msnews=1&refig=35ae41f3121b4250a3d238783fc546e5
[vii] Spontaneous Battery Fires – https://www.businessinsider.com.au/why-tesla-cars-catch-on-fire-2019-4?r=US&IR=T
[viii] **Exploding Lithium battery** – explodes from gas firelighter https://www.bing.com/images/search?view=detailV2&ccid=W3TsLmlW&id=EEA79EC82967F934C7331B189239D3A61A1057E7&thid=OIP.W3TsLmlWlCOu4RcV3cDVsQHaEK&mediaurl=https%3a%2f%2fi.ytimg.com%2fvi%2f0nrsoMsEMNU%2fmaxresdefault.jpg&exph=720&expw=1280&q=Lithium+Ion+Battery+Explosion&simid=608041337809886538&FORM=IRPRST&ck=0D26BF34C7EF87338ED9E9FA232C8A95&selectedIndex=0&ajaxhist=0&ajaxserp=0
[ix] Firefighters not prepared to deal with Electric Vehicles blazes - https://www.nbcnews.com/nightly-news/video/firefighters-not-prepared-to-deal-with-electric-vehicle-blazes-new-report-warns-115930693618 See also: vi Electric car explosive fire – Dad rescued daughter (2) from burning vehicle – Fire burnt for many minutes before Fire fighters arrived

[x] Based on Hyundai Ionic which is about the same size as the Hyundai i-30; the Ionic uses 11.7 kWh per 100 km; the i-30 uses 7.1 liters of petrol per 100 km