EV Application Shakeout – Part 1

By John Benson

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1. Introduction

When two or more technologies compete, society wins. Everyone assumes that the best technologies will emerge, but it's rarely that simple. In many cases, the most cost-effective and market-appropriate technologies will claim the largest segments of a given market, whereas other technologies will occupy smaller niches, and others may not survive. Also, technologies may merge and create hybrid solutions in order to effectively address complex markets or market segments.

I currently believe all of the above is the case for the overall electric vehicle (EV) market. Here we will look at a market that includes ALL significant electric vehicle segments in this two-part series, including the following:

- Road-going vehicles - Part 2
- Off-road vehicles (construction and agricultural) – Part 1
- On-track vehicles – Part 1
- Flying vehicles – Part 2
- Marine vehicles – Part 1

In this series we will address storage technology for electric vehicles, and how I believe that competing technologies will shake out in the next decade or two. Our overall goal is to greatly reduce greenhouse gas (GHG) emissions from the mobility sector.

In Part 2 we will also update recent developments by Tesla, and how these might support the development of a reasonable market for short range flying EVs as well as expand the dominance of their primary market (road-going EVs). We will also look at one of their developing competitors in an on-road market segment.

2. Simple and Hybrid Technologies

When readers see the title of section they might think of internal combustion / battery hybrids (like the Prius). That is <u>not</u> what we will discuss herein. The subjects of this section are different. But first we need to talk about a 900 pound EV Gorilla.

Simpler is better, and the smallest and shortest-range EV applications have been dominated by the simplest of all technologies – battery electric vehicles (BEVs). Also, this is where the largest market segment is – as measured both by the number of EVs that are (and will be) sold every year and the yearly market financial yield. As this technology continues to improve, I see no contender for this segment's dominance anytime soon.

However in the intro we saw that there are other market segments, and some of these are not well served by BEVs (although some sub-segments will use this architecture). The sub-segments of each segment that are not currently well-served by BEVs are described below:

- Road-going vehicles: very long range transports like transcontinental big rigs
- Off-road vehicles (construction and agricultural): any job site or agricultural facility that is not near the grid
- On-track vehicles: applications that require a longer range than can be economically be provided by batteries alone
- Flying vehicles: Most long routes including most interstate, trans-continental and ocean-crossing flights
- Marine vehicles: Most routes except ferries and other ships with very short voyages

Hybrid systems will have different architectures, depending on the specifics of a given application. These could be:

- A medium-sized battery plus a medium-output electric generator using very low-GHG fuel (green hydrogen, blue hydrogen or ammonia manufactured from green or blue hydrogen)[1] integrated into each vehicle
- Battery electric vehicles plus separate self-contained recharging systems using a separate battery, a very low GHG fueled generator, a renewable generator (mainly photovoltaic arrays), or a combination of these

In the following sections and in part 2 we will cover each of the above bulleted segments and sub-segments.

3. Off-Road Vehicles

Construction vehicles (excavators, bulldozers and the like) and agricultural vehicles (tractors, harvesters and the like) may or may not be near an electric grid connection, and it may not be economically viable to extend a connection to the grid. Most of these vehicles are likely to evolve to battery-electric vehicle (BEV) technology. The question is: how do the owners/users recharge the batteries? There are two instances where a separate self-contained system may be the best fit, or the only game in town:

Economics: The question is, what is the least expensive way to recharge these EVs? The agricultural applications are likely be near a grid connection, but power companies charge for their power. Farms and ranches may have many large buildings and open space. Photovoltaic (PV) arrays plus batteries could provide most or all of the energy that an agricultural facility might need, including for recharging their BEVs. Also, with the declining price of PV + battery technology, it may be less expensive than grid power today, and certainly will be in the future. Also, given that many rural power systems tend to have low availability, A PV + battery system may be more reliable.

A reasonable addition to PV plus batteries for agricultural facilities might be biogas-fueled generation using locally produced biogas (from anaerobic fermentation of biomass) and an internal-combustion gen-set for the best economics. Of course this would probably make it a microgrid.

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[1] A large majority of hydrogen used in industrial processes (like making most ammonia) is produced by reforming natural gas, but this produces CO_2 (the main GHG). I have heard this called gray hydrogen. Hydrogen produced by electrolysis (no GHG) with 100% renewable (very low GHG) electricity is commonly called green hydrogen. Hydrogen produced by reforming natural gas with CO_2 capture and sequestration is commonly called blue hydrogen.

Necessity: Large construction sites sometimes are not near grid connections, especially during the initial ground-moving phase. Also, it may be less expensive to rent a temporary self-contained charger station rather than pay the local utility to provide an early connection (plus their energy charges).

I would guess the self-contained charger station might consist of:

- A large trailer with a fold-out PV array and/or electric generator using very low-GHG fuel
- A second large trailer containing battery cabinets, power electronics, the charger connections and possibly a fuel cell / hydrogen energy-extender.

It should be noted that the self-contained charger station could provide power for any other remote facility and replace diesel generators.

4. On-Track Vehicles

My former employer, Siemens, is one of the few companies that has all of the components of a rail-based energy system (including the trains/engines). The following subsections each cover one of these offerings. Although I will mention Siemens offerings I will also mention other companies that have these in the U.S.

4.1. Electrified Commuter Rail

Many commuter rail systems are using electrified tracks (or track segments) for their service. In the U.S., examples of this include the Bay Area Rapid Transit (BART) System, Washington (DC) Metropolitan Area Transit Authority (WMATA), the Metropolitan Atlanta Rapid Transit Authority (MARTA) and Portland (OR) TriMet MAX light rail system, among others. These systems offer medium to high speed and relatively reliable operation. The down-side of this technology is that the cost of deploying new electrified tracks is very expensive. Also, it is rarely cost-effective to repurpose existing (non-electrified) tracks.

4.2. Multiple Units

Diesel Multiple Unit (DMU) trains are used extensively world-wide, just not so much in the U.S. Currently only around ten U.S. transit agencies use DMUs. DMUs are single- to four-car integrated trains. One of the agencies using this design in the U.S. is BART (see prior subsection and the picture below). This unit is made by Stadler, a Swiss Company that has sold at least five DMU fleets in the U.S.

BART uses the above pictured design for a relatively short dedicated rail extension into Eastern Contra Costa County.

Siemens has sold a fleet of DMUs to North County Transit District in San Diego County, California, and also supplied most of the components for the Portland, OR light rail system.

A major problem in using DMUs in the U.S. comes with unique regulations in the U.S. vs. many other parts of the world. *In the United States only FRA-compliant DMU systems are permitted on freight rail corridors. This is due to the Federal Railway Administration setting higher coupling strength requirements than European regulators, effectively prohibiting the use of lighter weight European-style inter-city rail DMUs on U.S. main line railways without timesharing with freight operations or special waivers from the FRA. This has greatly restricted the development of DMUs within the U.S. as no other country requires the much heavier FRA compliant vehicles, and no export market for them exists.*[2]

Siemens makes DMUs as do many other manufacturer's world-wide (see reference 2). Siemens is currently evolving the DMUs to electric multiple units (EMUs), and offering them with either just batteries or batteries plus fuel cells for longer range routes. The main market for these (world-wide) is replacing DMUs with very low greenhouse gas emitting designs. I believe that most other DMU manufacturers are probably following the same path.

Apparently, the only two U.S. companies that made DMUs, the Budd Company and Colorado Railcar, are out of business. Siemens has a major rail vehicle manufacturing plant in Sacramento, so if there is a reasonable opportunity to sell EMU's (and related systems) in the U.S., they might be in a position to take advantage of it.

4.3. Green Hydrogen and Ammonia

When an EMU has a route long enough to require batteries plus fuel cells, the electric traction motors are mostly supplied from the batteries, and the fuel cell generates enough power to overcome the EMU's consumption (plus provide battery recharging power) for most of the average route, including:

- Cruising on level ground
- Going downhill
- Parked at stations

The batteries provide peak power for:

- Acceleration
- Going uphill

And the electric traction motors provide regenerative braking when decelerating or holding speed on a downhill track segment.

However, the next question is: what does the fuel-cell use for fuel? The short answer is Hydrogen, and preferably green hydrogen (see reference 1). However, this results in questions about logistics. Generating the green hydrogen is pretty simple – purchase

[2] Wikipedia Article on "Diesel multiple unit", https://en.wikipedia.org/wiki/Diesel_multiple_unit

renewable power, take delivery of this through the grid, and generate the green hydrogen using electrolysis on the rail-line. For a commuter rail system with 50 to 100 mile route length, a single refueling station should be adequate. Siemens makes an electrolysis system: the SILYZER proton exchange membrane (PEM) system. The SILYZER 200 is a modular 1.25 MW (power input per module) skid-mounted system that can generate 20 kg/hr. of hydrogen per module and probably this will support a fleet of battery + fuel cell EMUs. This system is a high pressure system which operates at about 500 psi. This would need to be further compressed to several thousand psi for bulk storage and refueling an EMU fleet. Below is a SILYZER electrolyzer system.

Per the source here,[3] *The International Energy Agency (IEA) states that 1 kilogram of green hydrogen, containing about 33.3 kWh, comes in at €3.50 to €5* ($4.25 to $6.00), *which is anywhere between €0.10/kWh and 0.15* ($0.12 to $0.18)/kWh.

Grey hydrogen currently costs about $1.80 per kg. Note that the pricing in this and the prior paragraph are from the EU.

In August, Wood Mackenzie predicted the 2020s will be the "decade of hydrogen." The analyst firm estimates that the cost of green hydrogen will fall by as much as 64 percent by 2040, on a level with traditional forms of production from fossil fuel feedstocks.[4]

Commuter rail routes using batteries plus fuel cells as described above will probably store the hydrogen on board EMUs in pressurized gas tanks. Longer routes and larger freight trains can still use green hydrogen, but they may require a different carrier. The best carrier for hydrogen is ammonia, and ammonia made from green hydrogen is commonly called green ammonia. For more details on this, go through the paper described and linked below.

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[3] Marian Willuhn, PV Magazine, "Green hydrogen to reach price parity with grey hydrogen in 2030" July 16, 2020, https://www.pv-magazine.com/2020/07/16/green-hydrogen-to-reach-price-parity-with-grey-hydrogen-in-2030/

[4] Jason Deign, Greentech Media (GTM), "Coalition Aims for 25GW of Green Hydrogen by 2026" Dec 08, 2020, https://www.greentechmedia.com/articles/read/coalition-aims-for-25-gw-of-green-hydrogen-by-2026?utm_medium=email&utm_source=Daily&utm_campaign=GTMDaily

Release the Crackers: This paper investigates why ammonia is probably the best carrier for hydrogen, possibly can be used directly as a fuel, and the latest developments in ammonia technology including crackers.

https://energycentral.com/c/ec/release-crackers

5. Nautical EVs

Many of the developments in the above sections of this post are suitable for use on ships except for one issue – their price. Until recently nautical carriers tended to use the least expensive fuel available, pollution (GHG or otherwise) be damned.

In 2016, the International Marine Organization (IMO) agreed to limit the sulfur content in all marine fuels to 0.5 percent beginning in 2020. The fuel standard for ships previously allowed the use of "bunker oil" that had a maximum sulfur content of 3.5%.

Battery electric ships are, or soon will be price-competitive with diesel in a limited number of applications:

- Where the price of electricity is very low
- Where the price of diesel fuel is high, either due to an escalating GHG tax or cap and trade systems
- For very short routes, such as those in ferry-service

The good news is that, cumulatively, the above niches will start growing the Nautical EV technology-set. Furthermore, most individual technologies used for other EV segments described in other sections will also feed nautical EVs. The synergies provided will drive down pricing for these. Over time more nautical EV sub-segments will find solution technology-sets that make them viable.

The other good news is that ships are physically the largest vehicles, and thus retrofitting them will be relatively easy. Also, incremental retrofits that keeps legacy power plants operating while adding EV power-trains and storage will smooth the transition.