ELECTRIC VEHICLES TECHNOLOGY

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INTRODUCTION

A new electrical energy transportation world appears right around the corner. Pure electrical, hybrids, plug-in hybrids and extended-range electric cars are appearing on the world highways. Their modes of operation differ in the acceleration, cruising and deceleration phases. They also differ according to whether the chemical battery is in a charged or depleted state.

The USA sells 17 million cars a year, and there are about 180 million cars on the road. In 2018, only a few hundred thousand EV cars were sold. In the short run, EVs will have little impact on ICE servicing businesses; in the long run, those businesses will decline dramatically into a sunset.

Figure 1. “Gigafactory” Panasonic/Tesla cell manufacturing facility.

There are roughly 1.3 billion automobiles being driven on the roads across our planet. Out of those 1.3 billion automobiles, at the end of 2016, approximately 2 million of them were electric. For every 650 conventional combustion engine automobiles on the road, there is only 1 electric car. Ten million electric cars in use will quintuple the number that were on the road at the end of 2016. After growing fivefold to 10 million cars, the market share of the electric vehicles will still be less than one percent. This will create a shift in the use of mineral resources such as Li, graphite and Cobalt for batteries, and Cu for wiring.

The main components in these designs include an internal combustion engine, an electrical generator, an electric motor, a fuel tank and a chemical battery.

Electrical hybrids vehicles such as Toyota's Prius are a common sight. The major automakers are proposing a next generation of hybrids that can be plugged in to extend their electric range and vastly improve their fuel economy.

Figure 2. Lithium-ion battery pack of the Volt car. Source: GM.

The first type of plug-in hybrid, labeled “Plug-in Hybrid,” is basically a conventional hybrid vehicle with a larger battery pack. Companies such as Tesla, BMW, Toyota and Ford are developing hybrids of this type.

For heavy acceleration and high speed, hybrid vehicles rely on power from both an internal combustion engine and an electric motor. But a larger battery pack in plug-in hybrids allows them to rely much more on electricity than conventional hybrids do.

“Extended-Range Electric” vehicles represent a radical departure from conventional hybrids. Whereas in conventional hybrids, the wheels are turned by an electric motor, an internal combustion engine, or both; the wheels in these newer designs will be turned only by a large electric motor. For short trips, the motor will run on battery power alone. For longer trips, an internal combustion engine-powered generator kicks in to supply electricity.

Instead of gasoline powered hybrids there exists a need to develop a diesel-electric vehicle much like existing train locomotives and diesel-electric submarines.

Learning from the aerospace industry, the reciprocating internal combustion engine should be replaced by rotating turbo machinery that would more efficiently couple to the rotating electrical motors and generators used in the different versions of electrical vehicles. This would allow heavier loads and longer cruising ranges.

USAGE TRENDS AND JUSTIFICATION

In 1960, passenger cars achieved about 14 miles to the gallon, traveled 587 billion miles all for 180 million people. They used 41.1 billion gallons of gasoline. In 2010, passenger cars got about 23 mpg, traveled 2025 billion miles to service 309 million people. They used 86.8 billion gallons of gasoline. This is more than three times the number of cars registered and a little more than twice the use of fuel. The USA went on a car buying spree, added a lot of people to its population but forgot to raise the mileage (mpg) far enough to cover the increase in travel miles.

For Electric Vehicles (EVs) to go as far as the 2010 cars, it would cost 73 billion dollars in electricity. The USA drivers spent $348 billion on gasoline in 2010 and $448 billion on gasoline in 2011, and $337 billion was spent on gasoline in 2015. It appears that the savings on gasoline would pay for a full replacement of cars with EVs, especially since it is expected go up in price again. It would pay for the USA public to shift to EVs, which is better than eventually paying $6-10 for a gallon of gasoline. With falling production and increasing cost for oil production, it is best to remain out of the demand end of the situation.

Before the gasoline prices reach $6-10 per gallon there will be several generations and improvement in electric car cost and performance as well improvements in the power distribution such as grid level storage. The utilities would need to increase the number of power plants by an estimated 40 percent. In the long run, unlike Internal Combustion Engines(ECEs) the power for EVs can be easily locally generated in a distributed system of solar and wind installations.

The diesel-electric locomotive and automobile internal combustion engines had large advantages over coal fired steam locomotives, so coal faded as a transport fuel without a large price rise. The EVs large potential advantages over gasoline engines, especially since we are at the peak production time and gasoline will only become more expensive over time.

ALL-ELECTRICAL, AE VEHICLES

The Tesla Motors Roadster is a sports car, but reaches a 200 miles cruising range, 125 mph top speed, 130 mpg equivalent.

The sticker price for the base model was $109,000 and the fully loaded special version was initially $155,000. The four-wheel-drive version, with a 310-mile driving range and a premium interior, has a price out the door of $51,000; with $9,000 of federal and state tax credits, resulting in a net cost of $42,000 in 2019.

The Roadster uses 6,831 little Li-Ion batteries arranged in 12 modules. They can be recharged in 3-4 hrs from a 240V/70A power line.

The Roadster electric motor sits directly between the rear wheels, as the axle. It weighs about 115 lbs including its cooling system and reaches about 280 HP.

CONVENTIONAL HYBRID VEHICLES

At low speed, an electric motor using the charge in a battery provides enough power to rotate the wheels without help from an internal combustion engine.

After about a mile distance, the battery is depleted enough that the internal combustion engine kicks in to drive the wheels and to power a generator that charges the battery.

During gradual acceleration at low speeds, the electric motor provides enough power on its own. For very fast acceleration or once speed reaches about 35 mph, the internal combustion engine kicks in to provide added power.

At higher speeds power to the drive train comes primarily from the internal combustion engine.

During deceleration and braking, the internal combustion engine turns off and the wheels spin the motor using regeneration to recharge the battery.

Charged Battery State

At low speeds, the electric motor provides enough power for electric only operation.

While standard hybrids only store enough charge for a mile or two of all-electric driving, a larger battery allows the car to continue in the all-electric mode for 10-40 miles, depending on the size of the battery.

During gradual acceleration at low speeds, the electric motor provides enough power on its own. For very fast acceleration or once speed reaches about 35 mph, the internal combustion engine kicks in to provide added power.

At high speeds, power can come from the internal combustion engine and the electric motor at the same time.

During deceleration and braking, the internal combustion engine turns off and the wheels spin the motor to recharge the battery.

Depleted Battery State

At low speeds the electric motor provides enough power for electric-only operation.

After a mile or so the battery is depleted enough that the internal combustion engine kicks in to drive the wheels and power a generator that charges a battery/

During gradual acceleration at low speeds the electric motor provides enough power on its own. For very fast acceleration or once speeds reach 35 mph, the internal combustion engine kicks in to provide added power.

At higher speeds power to the drive train comes primarily from the internal combustion engine.

During deceleration and braking, the internal combustion engine turns off and the wheels spin the motor to recharge the battery.

RANGE EXTENDED ELECTRIC VEHICLES, SERIAL HYBRID VEHICLES

Charged Battery State

The car starts in the all-electric mode using the battery without using the internal combustion engine.

While standard hybrids only store enough charge for a mile or two of all-electric driving, a larger battery allows the vehicle to continue in the all-electric mode for 10-40 miles, depending on the size of the battery.

The electric motor provides enough power for heavy acceleration.

At high speeds, the electric motor continues to draw down the charge in the battery.

During deceleration and braking, the internal combustion engine turns off and the wheels spin the motor to recharge the battery.

Depleted Battery State

When the battery in an extended range vehicle is largely depleted, it can still provide enough power for short distances without the help of an internal combustion engine.

Once the battery has discharged to a minimum level, it is recharged by an onboard generator powered by an internal combustion engine. In addition, the electrical generator provides power to drive the wheels. Sometimes the battery provides additional power, preventing the generator from running at inefficient speeds.

As power demand increases, the internal combustion engine and generator continue to provide electrical power. For heavy acceleration, the generator may be pushed beyond its optimal operational range.

The internal combustion engine and electrical generator supply the electrical energy needed by the electrical motor.

During deceleration and braking, the internal combustion engine turns off and the wheels spin the motor to recharge the battery.

CHEVROLET VOLT

The Chevrolet Volt is an electric vehicle that runs on batteries charged from an ordinary power outlet for trips shorter than 40 miles.

For longer journeys, an onboard gasoline or ethanol-powered generator will recharge the battery.

Two battery companies, LG Chem and A123 Systems, based in Watertown, Massachusetts, have been in the running to supply the key component of a battery pack or the individual battery cells for the Volt. Hundreds of such cells must be wired together and paired with control electronics to create the vehicle's 16kW-hour battery pack.

Initially, cells from LG Chem will be assembled into battery packs by a subsidiary of LG Chem: Compact Power, based in Troy, Michigan. Once a new manufacturing plant is built, General Motor (GM) itself will assemble cells into battery packs

General Motor's decision is part of a strategic shift by the company toward the electrification of its automobiles, which will range from cars that rely on electric motors and batteries for brief bursts of power to those that run on electricity alone.

The company also plans to increase its in-house battery development by building a 31,000-square-foot battery lab and hiring hundreds of battery engineers. The lack of qualified and experienced battery engineers in the USA has been one of the big challenges facing battery startups such as A123 Systems. Most advanced battery production takes place in Asia, and this could hold back a switch from conventional vehicles to electric ones in the USA.

TESLA CARS TECHNOLOGY

Figure 3. Aerodynamics are enhanced without need for a radiator cooling grid at the front. A lower flexible vent opening provides air flow for liquid radiator cooling. The four-wheel-drive version, with a 310-mile driving range and a premium interior, has a price out the door of $51,000; with $9,000 of federal and state tax credits, resulting in a net cost of $42,000 in 2019.

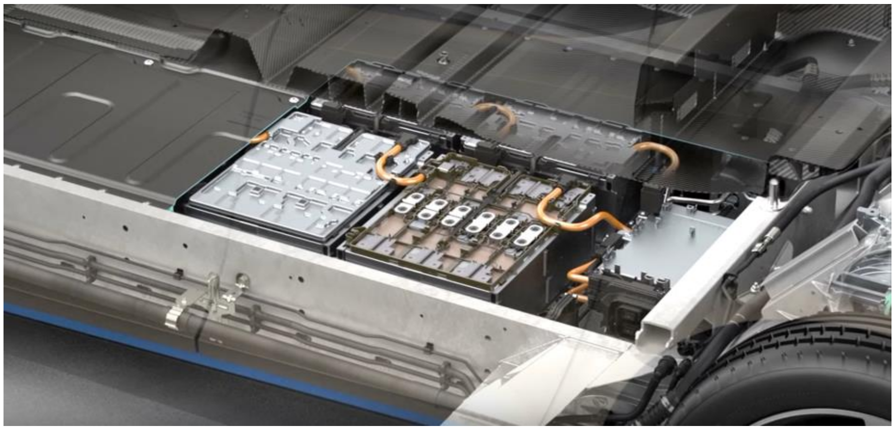


Figure 4. BMW uses prismatic cells in customized battery packs.

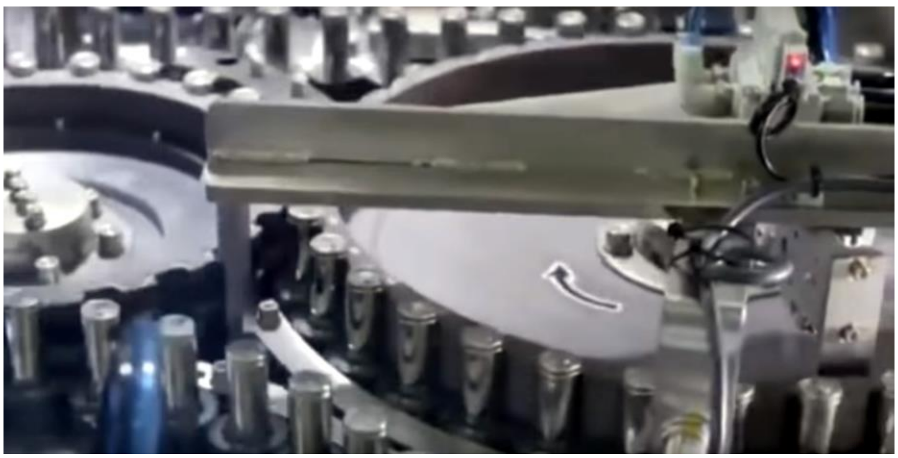
Figure 5, Types of Li ion batteries used by different car manufacturers. Li is the 25th element in abundance on earth. Aluminum, Nickel, Cobalt, and Manganese are also used. Electronics such as phones and laptops use Lithium Cobalt Oxide LCO chemistry batteries with a specific energy but a short lifespan as a 2 year life expectancy compared with 4 years for car batteries.

Table 1. Evolution of battery technology.

	2009-2012	2016-2018	2018-20??
Cobalt	11 kg/vehicle	7 kg/vehicle	4.5 kg/vehicle
Cathode	graphite	Graphite +5-15 % Si oxide	-
Anode	Graphite 54 kg/battery	graphite	graphite
Battery type	Panasonic 18650	Panasonic 18650	Panasonic 21700

Table 2. Comparison of graphite and silicon oxide anodes.

	graphite	Si oxide
Expansion charge/discharge	7-10 %	300-400 %
Energy capacity	1/10 of silicon oxide	10 times of graphite



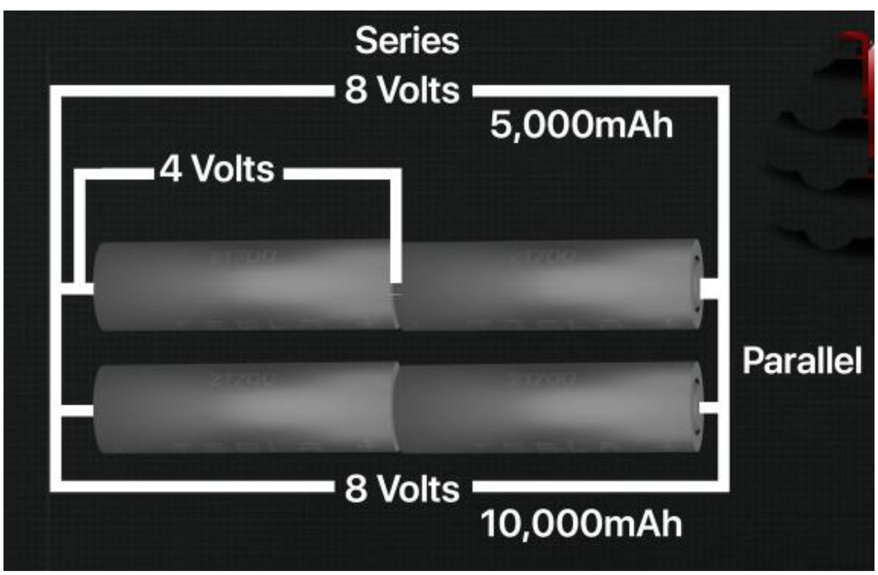
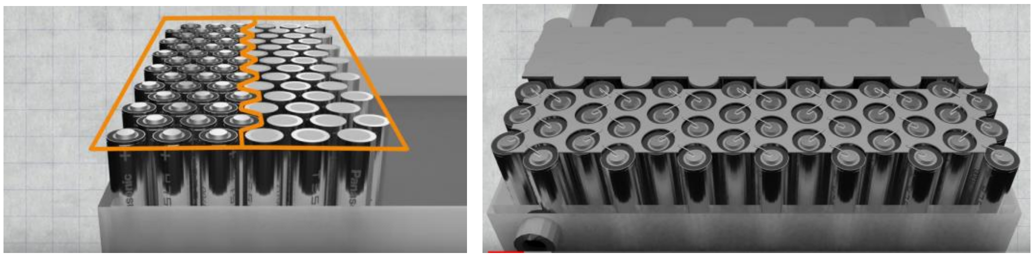


Figure 6. Tesla Cylindrical 2170 cells for battery pack is composed of 4416 lithium-ion battery cells in 16 modules wired in series for higher voltage or in parallel for higher capacity hence larger cruising range configurations.



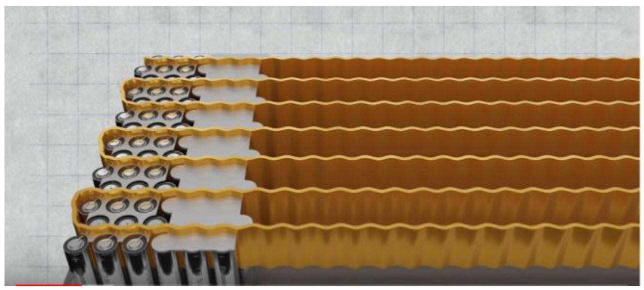


Figure 7. Battery pack bricks connected by a busbar in parallel. A cooling manifold asa ribbed interface that is a good heat conductor and good electrical insulator surrounds the cells and is cooled by a liquid water and glycol flow to a radiator.

Figure 8. Tesla electrical battery “Supercharger” station.

The Tesla car design is revolutionary. A Tesla car comes with two keys that look like credit cards. The car is connected to the Tesla app on iPhone through the 4G network and Bluetooth. The car can be controlled from the iPhone app. If it is hot or cold outside, the air conditioning or heater can be turned on from my phone. The owner can see where the car is at any time. When he approaches the car with his phone is in his pocket, the car door opens. When he sits down, he does not have to push a start button; he just pushes the control lever to D (drive) or R (reverse) and start driving. With the absence of an Internal

Combustion Engine (ICE), the electric motor drive makes no noise when the car is driven. When the control lever is positioned at the P (park) position, the owner can get out of the car that automatically locks itself out [2].

All buttons and other controls are virtually placed on a giant tablet. One can control the stiffness of the steering wheel, turn the regenerative braking on and off, or set the rate of acceleration. The Model 3 comes with a dozen video games that the owner can play when the car is parked or waiting for a Supercharger to fill it up. The games are controlled by the real controls of the car. A driving video game uses Tesla's real steering wheel and brake to drive a virtual car.

The Model 3 has an iPad-looking tablet and minimalistic design, which sits right in the middle of the front console. The software interface of the tablet seemed Apple-like designed by humans for use by other humans.

In contrast to a traditional car, the Model 3 improves about every month with software updates. After an update, the Model 3 owners discovered that their rear seats can be heated. The hardware was already there; the software update activated it. Tesla constantly releases new features, from arcade games to upgrades to the security system, through software updates [2].

COMPARISON WITH INTERNAL COMBUSTION ENGINES

The traditional ICE car has numerous moving parts that are interconnected by belts and gears and need to be constantly oiled and cooled. Air must be continuously mixed with gasoline to achieve combustion. The ICE engine is large, heavy, and cycles several times each second. The electric engine is simpler, lighter and smaller, with a modest number of moving parts that are easy to design replace and maintain and can be mounted directly on the axle removing a lot of complexity in car design. The engine is the most complex and important part of the ICE car. However, it is one of the least complex parts of the EV and the least important one [2].

An ICE engine needs to be revved up to 1,500–6,000 revolutions per minute (rpm) to get optimum torque, then shifting gears results in the desired speed. The electric engine instantly gets to maximum torque; by increasing or decreasing the rpm value. The desired speed is achieved without any gears. Adding gears between the engine and the wheels adds complexity and loses power as friction. ICE cars are 30 percent efficient while EVs are claimed to be 80 percent efficient. That number should be adjusted to the electricity production and battery storage efficiencies of around 30 percent resulting into a comparable efficiency of $0.8 \times 0.3 = 0.24$ or 24 percent.

The fuel system of the ICE is a steel tank with an inlet and cap and an outlet that flows to a filter, fuel pump, and regulating valve or carburetor. To recharge, one pulls into a local fuel station. In modern vehicles, none of these parts go bad, even the fuel filter unless you get a really bad tank of gas.

In an EV, a lithium battery that is attached to a complex and expensive DC to AC inverter. Although the lithium battery has been a massive improvement over the old lead-acid type, it still suffers from capacity and recharge time. It requires periodic replacement. The DC to AC inverter is a complex device, but is likely a lifetime component.

The Achilles heel of the EV is not its electric motor, it is its energy storage system. Until this improves, stops catching fire as the charge/discharge of EV batteries is subject to the heat generation according to Ohm's law, and the adequate infrastructure is developed, EVs will not totally replace ICEs. EVs are currently they are powered primarily by electricity produced by the combustion of coal and natural gas.

COMPARISON OF TWO-WHEELS AND FOUR-WHEELS DRIVES, REGENERATIVE BRAKING

With an ICE engine driving a four-wheel car, we need to transmit the power from the engine at the front of the car, to the back of the car through an oiled metal axle to the back wheels, losing energy and adding weight hence reducing the gas mileage. The EV solution to four-wheel drive is adding an electric motor on the rear axle doubling the power of the car. The second electric motor adds some weight and cost, but it does not increase the complexity of the design. The second engine increases the efficiency and range of the vehicle because the EV actually generates electricity when you brake, through regenerative braking.

Instead of pushing on the brake when you want to slow down losing energy as frictional heat, one lets off the acceleration pedal. The car continues to roll by momentum and turns the electric engine, which instead of consuming electricity, generates electricity, recharges the battery, and also slows down the car. Because two electric motors produce more electricity than one, the second engine increases the EV’s range.

Because the EV engines sit on top of the drive axle, the design is like a skateboard with a battery lying flat around the axle. The absence of a transmission means there is nothing bulging down the center of the car and thus there is more space inside the cabin. In addition there is empty volume up front, which can be used for storage in the so-called “frunk.” A safety benefit is that the frunk acts as a giant bumper absorbing the shock in a front-end collision. The battery pack lowers the Tesla’s center of gravity, improving the driving experience and making the car less likely to flip over.

Electric motors produce greater initial torque then ICEs, resulting in higher initial acceleration. The Model 3 Tesla accelerates from 0 to 60 mph in 4.4 seconds. A performance version costing $7,000 extra reduces that time to 3.2 seconds, on a par with a super sports car like a Corvette.

Electric motors have few moving parts, with less servicing than their ICE counterparts. Due to regenerative braking, the brake pads should last longer than on ICE cars.

ELECTRIC VEHICLES TECHNOLOGY BREAKTHROUGH

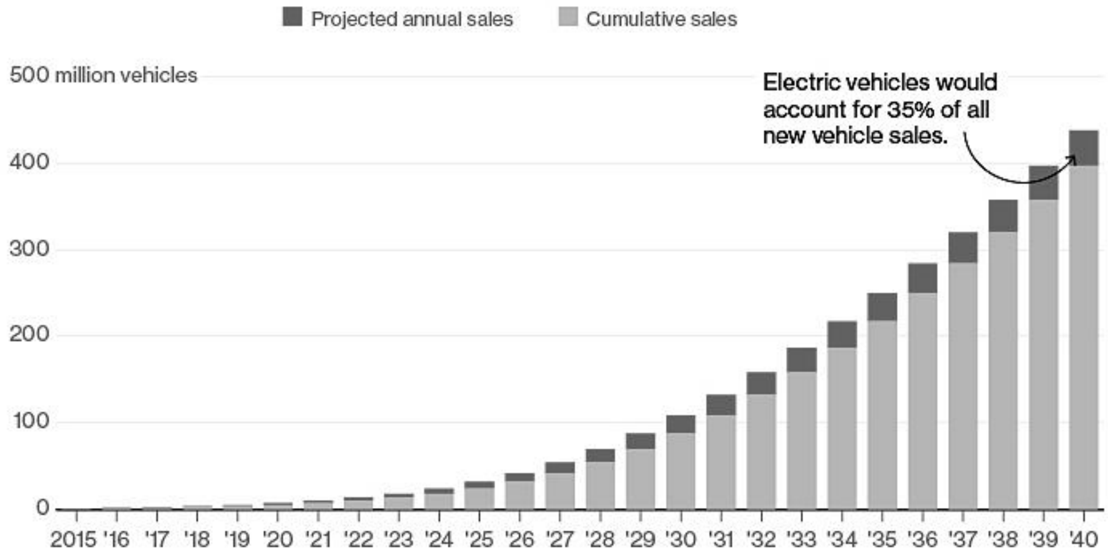


Figure 9. Electric Vehicles (RVs) future sales projection. Source: Bloomberg.

The 2020s may be the decade of the electric car. Battery prices fell 35 percent in 2015 and are on a trajectory to make unsubsidized electric vehicles as affordable as their gasoline counterparts in the 2016-2022 period. By 2040, long-range electric cars will cost less than $22,000 in present day's dollars. Thirty-five percent of new cars worldwide will have an electrical connection plug [1].

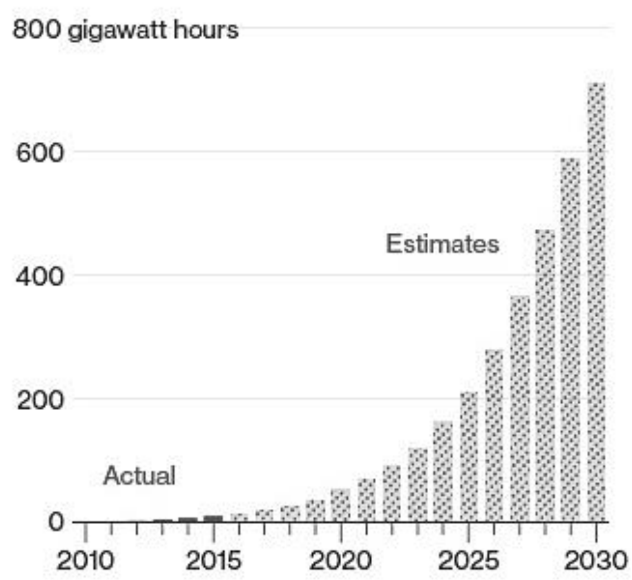


Figure 10. Electric cars yearly demand of energy from renewable and conventional sources. Source: Bloomberg business.

Plug-in cars make up just one-tenth of 1 percent of the global car market today. They are a rarity on the streets of most countries and still cost significantly more than similar gasoline burners. OPEC maintains that electric vehicles (EVs) will make up just 1 percent of cars in 2040 [1].

However, Tesla, General Motors, and Nissan plan to start selling long-range electric cars in the $30,000 range. Other carmakers and technology companies are investing billions on dozens of new models. By 2020, some of these will cost less and perform better than their gasoline counterparts. The aim would be to match the success of Tesla's Model S, which outsells its competitors in the large luxury class in the USA. The question then is how much oil demand these cars will displace, and when will the reduced demand be enough to tip the scales and cause a next oil crisis [1].

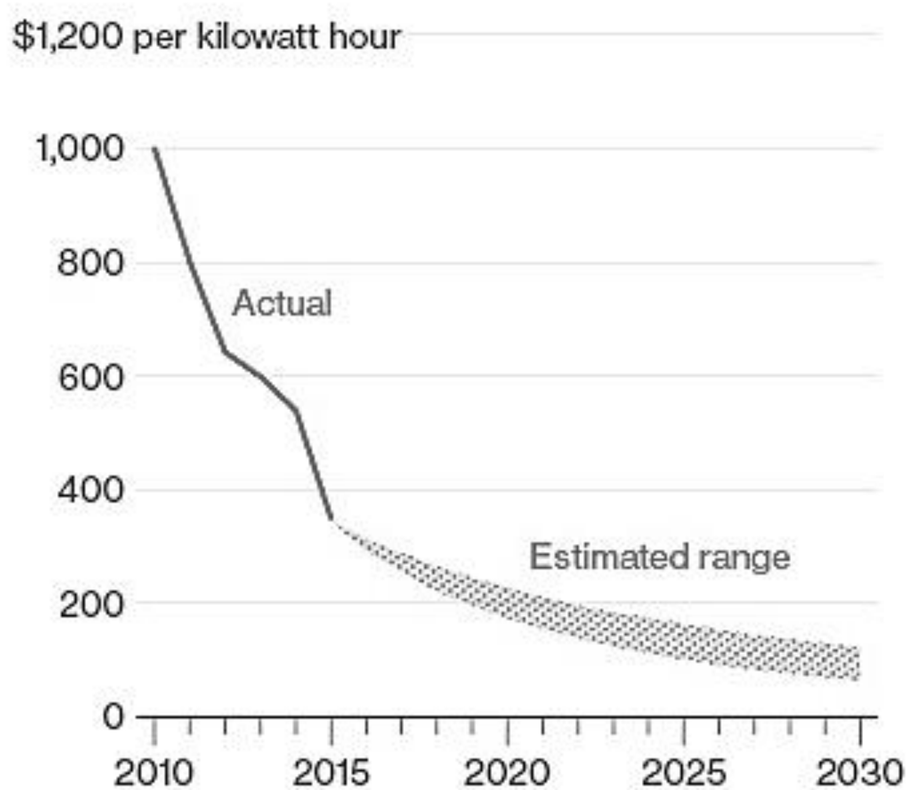


Figure 11. Price of Li-ion battery packs for electric vehicles use. Source: Bloomberg.

In 2015 EV sales grew by about 60 percent worldwide. That is about the annual growth rate that Tesla forecasts for sales through 2020, and it is the same growth rate that helped the Ford Model T cruise past the horse and buggy technology in the 1910s. For comparison, solar panels are following a similar curve at around 50 percent growth each year, while LED light-bulb sales are soaring by about 140 percent each year [1].

At a continued 60 percent growth, electric vehicles could displace oil demand of 2 million barrels a day as early as 2023. That would create a glut of oil equivalent to what triggered the 2014 oil crisis [1]. Compound annual growth rates as high as 60 percent cannot hold up for long, so it is a very aggressive forecast. Crossing the oil-crash benchmark of 2 million barrels is forecast a few years later in 2028 [1].

Batteries account for a third of the cost of building an electric car. For EVs to achieve widespread adoption, one of four options must happen [1]:

1. Federal and State Governments must offer incentives to lower the costs,
2. Manufacturers must accept extremely low profit margins,
3. Customers must be willing to pay more to drive electric vehicles,
4. The cost of batteries must come down.

The first three options are happening now in the early-adopter days of electric vehicles, but they cannot be sustained. Fortunately, the cost of batteries is headed in the right direction.

FUEL CELL HYDROGEN VEHICLES

Fuel cell vehicles use hydrogen as an energy storage medium to generate the electric current used by the electric motor. As electrical vehicle they pose their own challenges in the production, transport and the safe storage of hydrogen as an energy carrier.

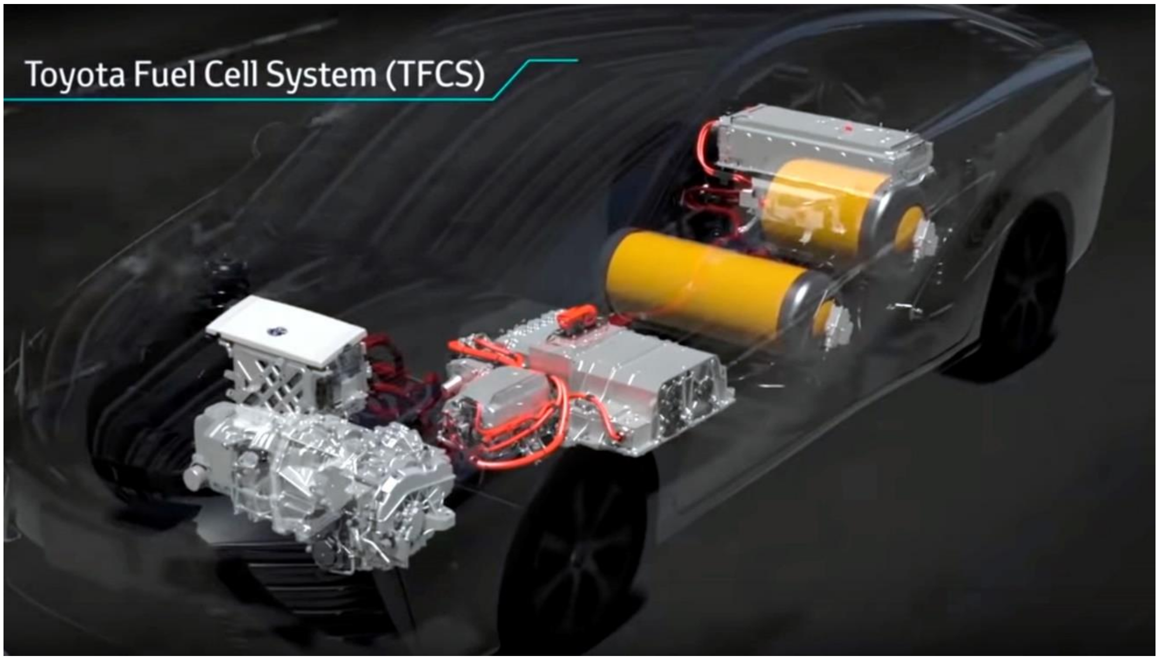


Figure 12. Toyota Fuel Cell System (TFCS) EV uses hydrogen as an energy storage medium.

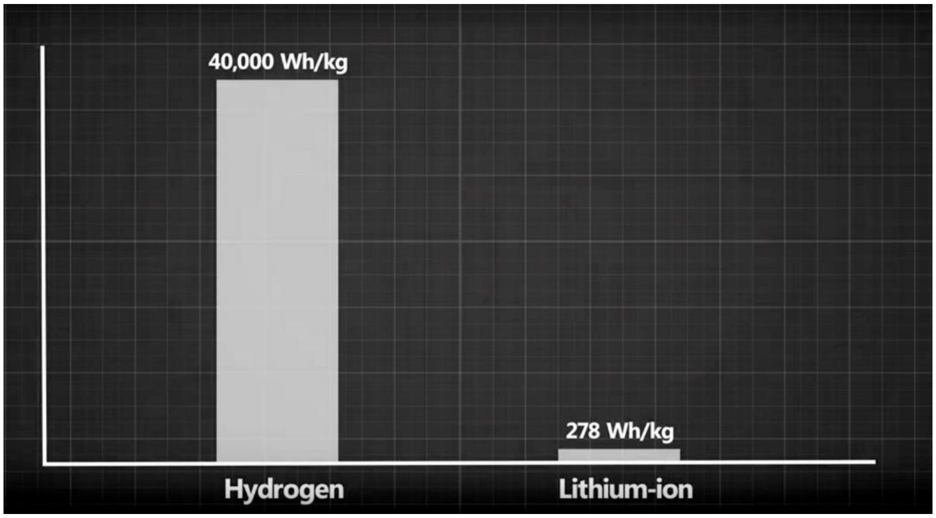


Figure 13. Comparison of specific energy content of hydrogen and lithium-ion batteries as energy storage media. Hydrogen provide a larger energy storage density capability compared with Li-ion technology. Batteries may need replacement after 2-5 years. Car range decreases after a few years of use.

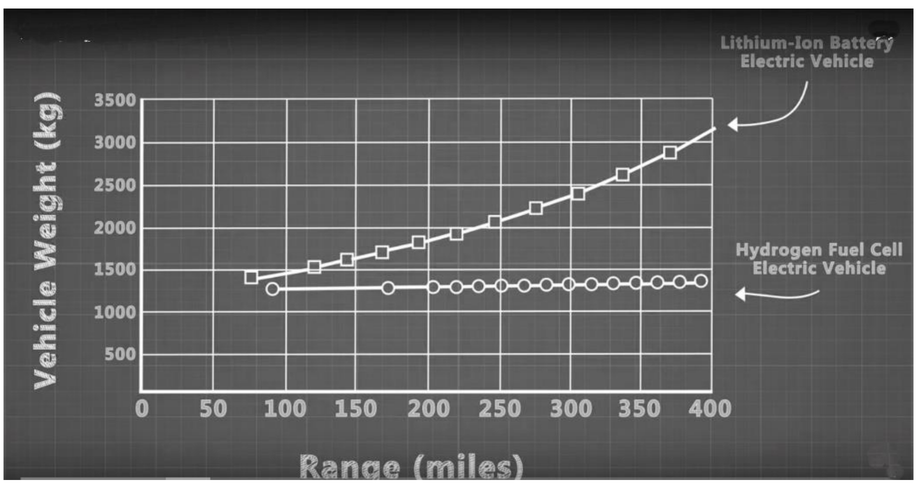


Figure 14. Comparison of vehicle weight using hydrogen fuel cell vs. Li-ion batteries. Li-ion batteries result in heavier vehicle for enhanced range.

A problem with EVs has never been the electric motor, but the storage system of the energy to run those motors. Electric Motor technology is fairly mature, but in EVs they are limited by the amount of energy available in their batteries. Battery technology is also a mature technology and the increases in capacity are linear and relatively predictable.

The fuel cell is the obvious answer and Nissan and Toyota in Japan are pursuing that option. Since almost all commercially available hydrogen is a natural gas product, they can use a Natural Gas (Methane CH_4) fuel cell since the distribution system is already in place and goes right to a lot of USA residences. And NG does not have the storage problems of Hydrogen. Of course, NG is not fully "Carbon Neutral", but neither is Electricity in most of the world.

There is a very significant reduction in emissions switching to Natural Gas and that switch in Electrical Generation has been responsible for the reduction of CO_2 admissions in the USA as well as other pollutants. Hydrogen buses are operating on Hawaii islands and the UPS Company has converted its over the road fleet to NG fuel,

DISCUSSION

By 2040, electric cars will draw 1,900 terawatt-hours of electricity, equivalent to 10 percent of humanity's electricity produced in 2015. Since 2013, the world has been adding more electricity-generating capacity from wind and solar than from coal, natural gas, and oil combined. Electric cars will reduce the cost of battery storage and help store intermittent sun and wind power, possibly on a distributed local basis by individuals and small organizations businesses [1].

Regarding the lithium and other finite materials used in the batteries there is not an issue. Through 2030, battery packs will require less than 1 percent of the known reserves of lithium, nickel, manganese, and copper. They require 4 percent of the world's cobalt. After 2030, new battery chemistries such as vanadium will probably shift to other source materials, making packs lighter, smaller, and cheaper [1].

Figure 15. Tesla Li ion battery fire in Germany, 2017, suggests a need for lower risk energy storage options. According to UL Laboratories: "Lithium-ion battery technology is not intrinsically safe. Short circuit, overcharge, over-discharge, crush, and high temperature can lead to thermal runaway, fire, and explosion."

Figure 16. Fire damage at front of Li ion car battery in modules 15 and 16. Rust colored loose individual cells, vertically stacked cells below loosened top covers, orange insulation caps covering high voltage terminals. NTSB report said: “During that operation, modules that had separated from the battery ignited on the tow truck when workers passed a chain over them. When the car was loaded onto a second tow truck, the battery caught fire again and had to be extinguished a second time. Additionally, when the battery was being unloaded at the tow yard, the case ignited once again.” Tesla in fatal accident was traveling 100 mph around a curve in a 30 mph zone. Typical Tesla sedan model rates at 691 HP with top speed of 155 mph, original price $70-95k.

Figure 17. Parked Model S Tesla spontaneous battery fire, Santa Monica Boulevard, Los Angeles, California, June 2018.

Figure 18. “Artisanal Cobalt” at $80,000 per tonne mining for Li ion batteries in Democratic Republic of Congo, DRG.

Autonomous cars and ride-sharing services being developed by Apple, Uber and Lyft, would put more cars on the road that drive more than 20,000 miles a year. The more miles a car drives, the more economic battery packs become. If these new services are successful, they could boost electric-vehicle market share to 50 percent of new cars by 2040 [1].

As Tesla telemetry can accurately locate locations and have complete control over the accelerator, NTSB and state agencies may require all Tesla's to drive below the speed limit or less particularly in urban environments. Individual states may request Tesla for telemetry and send out automatic speeding tickets. Adding sensors of G-forces entering into sharp turns to slow down the vehicle could add to driving safety.

More electric cars are expected to hit the road, with less demand for hydrocarbon fuels. A transition to plug-in hybrids or All-Electrical (AE) vehicles will place a burden on the existing electrical grid. There will be a need to upgrade the electric distribution system to supply electricity to the added load of thousands of plug-in hybrids. The present electrical distribution system in the USA does not have the capacity in most regions with the electric power capacity reserves at a record low levels.

REFERENCES

1. Tom Randall, “Here’s how Electric Cars Will Cause the Next Oil Crisis. A shift is under way that will lead to widespread adoption of EVs in the next decade,” Bloomberg Business, February 25, 2016.

2. Vitaly Katsenelson, “Tesla, Elon Musk and the EV Revolution,” 2019. https://contrarianedge.com/tesla-elon-musk-and-the-ev-revolution/

APPENDIX

ALL OUR PATENTS ARE BELONG TO YOU

by Elon Musk

Yesterday, there was a wall of Tesla patents in the lobby of our Palo Alto headquarters. That is no longer the case. They have been removed, in the spirit of the open source movement, for the advancement of electric vehicle technology.

Tesla Motors was created to accelerate the advent of sustainable transport.

If we clear a path to the creation of compelling electric vehicles, but then lay intellectual property landmines behind us to inhibit others, we are acting in a manner contrary to that goal. Tesla will not initiate patent lawsuits against anyone who, in good faith, wants to use our technology.

When I started out with my first company, Zip2, I thought patents were a good thing and worked hard to obtain them. And maybe they were good long ago, but too often these days they serve merely to stifle progress, entrench the positions of giant corporations and enrich those in the legal profession, rather than the actual inventors. After Zip2, when I realized that receiving a patent really just meant that you bought a lottery ticket to a lawsuit, I avoided them whenever possible.

At Tesla, however, we felt compelled to create patents out of concern that the big car companies would copy our technology and then use their massive manufacturing, sales and marketing power to overwhelm Tesla. We couldn't have been more wrong.

The unfortunate reality is the opposite: electric car programs (or programs for any vehicle that doesn't burn hydrocarbons) at the major manufacturers are small to non-existent, constituting an average of far less than 1% of their total vehicle sales.

At best, the large automakers are producing electric cars with limited range in limited volume. Some produce no zero emission cars at all.

Given that annual new vehicle production is approaching 100 million per year and the global fleet is approximately 2 billion cars, it is impossible for Tesla to build electric cars fast enough to address the carbon crisis. By the same token, it means the market is enormous.

Our true competition is not the small trickle of non-Tesla electric cars being produced, but rather the enormous flood of gasoline cars pouring out of the world's factories every day.

We believe that Tesla, other companies making electric cars, and the world would all benefit from a common, rapidly-evolving technology platform.

Technology leadership is not defined by patents, which history has repeatedly shown to be small protection indeed against a determined competitor, but rather by the ability of a company to attract and motivate the world's most talented engineers. We believe that applying the open source philosophy to our patents will strengthen rather than diminish Tesla's position in this regard.

Elon Musk