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RECENT DEVELOPMENTS IN ELECTRIC VEHICLES

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ABSTRACT
Electric vehicles continue to develop at a rapid pace in recent years. Due to innovations in industrial and motor technology, electric vehicles can both travel longer and reach higher speed. In recent years, as environmental sensibility has increased, and fossil fuels have been exhausted in the world, electric vehicles have become a serious alternative to gasoline diesel vehicles since they provide solutions for gasoline-diesel vehicles. Due to the decisive stance of states that have advanced industry, electric vehicles will soon become a necessity rather than a good alternative. From the reasons we talked about, electric vehicles have become a matter of serious investment and development, which is at the focal point of various community.
The main focal point of the developments in electric vehicles is to go to longer distances with lower energy and store more energy in both light and small batteries. The production stages are also one of the current problems. The lack of hardware in serial production of electric vehicles is being tried to be solved using different technologies. In this study recent developments are discussed to broaden horizon for future works.

Keywords: *Electric Vehicle, Batteries, Battery Management, Rex Engine, Electric Motor*

INTRODUCTION

The world is struggling to find clean power sources to run millions of different vehicles that are the main contributors to the release of toxic emissions from internal combustion engines. These toxic emissions adversely affect climate change and the health of air pollutants. Fuel cell devices are slowly replacing internal combustion engines in the transport industry. This article discusses some of the key challenges of PEMFC technology. High costs, low durability and hydrogen storage problems are among the biggest hurdles to be investigated in this research. The latest developments and design features in electric car technology were investigated in literature and compared the characteristics and technologies of the three types of electric cars available on the market [1].

Due to the high demand for fossil fuel by the transport sector, there is continual diminution of fossil based resources of energy such as crude oil. The worlds total energy consumption is highly dominated by the transport industry which accounts for nearly 55% of the world energy consumption and 30.9% of carbon dioxide gas emissions according to recent research studies [2]. It was also anticipated that if no proper action is collectively taken the situation will get worse and the negative impacts on the environment and world economies will further increase. Figures. 1 and 2 from Das et al. [3] explain the levels of energy consumption by 2 sectors over the past few years. From Figures. 1 and 2 it is also possible to predict the likely events in the future if the situation is not carefully addressed.

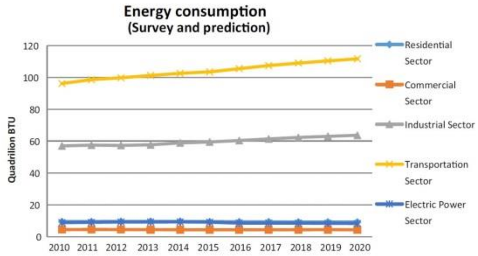

Figure 1. Consumption of energy in different sectors [4].

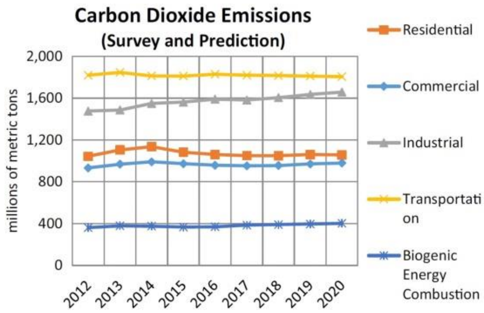

Figure 2. Emission statistic of carbon dioxide statistics in different sectors [5].

It is estimated that electric vehicles cost nearly 2cents per mile while conventional petrol powered cars cost around 12 cents per mile indicating an extra 10 cent per mile needed in running a petrol powered vehicle. Recent studies have revealed that electric cars can operate within 4–8 miles per kWh energy with zero emission of greenhouse gases (GHG). The US Department of Energy also reported that internal combustion engines (ICE) vehicles normally use 15% of the total fuel energy to run the car while 75% of the energy is usefully utilized in electric vehicles [6,7]. Most electric vehicles are quite expensive due to the cost of their source of energy that accounts for almost one third of the entire cost of the car. A number of energy storage mediums in electric cars are currently being considered with the express purpose of reducing the cost relating to energy storage and utilisation.

Electric cars are classified under three main categories. These include battery electric vehicles (BEVs), Fuel cell electric vehicles (FCHEVs) and hybrid electric vehicles (HEVs). Extensive research work has been carried out to analyse energy consumption and compare fuel types including alternative fuel cell systems which are shown to yield positive results [8]. This in effect will reduce the demand for oil consumption in the transport industry [9]. Vehicle emission problems can be solved using two approaches. The first method is to change the fuel type used which can be addressed by either enhancing the quality of conventional fuel or by using alternative fuel systems. The second alternative has to do with the engine technology which involves the reduction of in–use vehicles emissions and the new vehicles emissions standards. In parallel with these developments; the transport sector can have a positive effect on a viable eco-driving strategy and reduction of excess fuel consumption [10-12]. A representative tool was developed by Achour et al. [13] for a local authority to help them identify the air quality issues caused by traffic emissions. Most of the outcomes of these investigations were applied in developed countries as the transport sector is going through some challenges. The concept of a fuel cell was developed by Sir William Groove in England in 1800s but the actual utilization of the concept only occurred in the 1950s when Nasa conducted extensive research work in the agency search for methods for generating power for space vehicles.

Fuel cells are often categorized according to the type of the electrolyte being used [14]. The proton exchange membrane fuel cell is the common type of fuel cells in use today. It is often made of a solid polymer as its electrolyte and a porous carbon electrodes containing platinum as its catalyst. The catalyst could also be an alloy. Hydrogen is supplied from an external source, kept in a tank or a reformer is used as its continuous fuel source. The membrane is made in such a way as to be only permeable to protons but not to electrons. There are instances where electrons could pass through the membrane leading to irreversibility and ohmic potential loss. The usual setup is for the electrons to pass through an external circuit. The cathode side on the other hand is designed as the region where the protons and electrons combine with oxygen to produce water which is expelled as the cell only waste product. The oxygen is often supplied to the fuel cell from the air or in a purified form. PEM fuel cells are often preferred for transportation applications and other stationary applications. This is simply because they have low operating temperatures, high power density, fast start-up, system robustness, flexibility of fuel type (with reformer) and reduced sealing, corrosion, shielding or leakage concerns [15]. Most buses and cars today are being designed to use PEM Fuel cells.

	FC Vehicle	Production Plan								Status
			04	06	08	10	12	14	16	
Honda		02 (02',12) ▼						♦	★	• 02.12: Lease sale (USA, Japan) • 05.12: 20 cars running ✓ 2012: Production (goal)
Toyota		2002 (02',12) Lease sale ▼				♦				• 02.12: Lease sale (USA, Japan) • 05.12: 30 cars running ✓ 2010: Production (goal)
GMC		'03	▼		♦					• 05.12: 20 cars running ✓ 2012: Production (goal) ✓ 2020: multimillion Production (goal) ✓
DCX		04				♦		★		• 05.12: 100 cars running ✓ 2012: Sales to public (goal) ✓ 2015: 50,000Production (goal)
Ford			▼							05, 12: 30 cars running (USA, Canada)

Figure 3. Several fuel cell vehicle developments (Figure 3 test driving; Figure 3 small production, Figure 3 mass production) [16]

Most car makers were known to be active in the development of fuel cell vehicles including Honda, Toyota and Ford -as listed in Figure 3 had plans a decade ago to build highly efficient fuel cell cars [17].

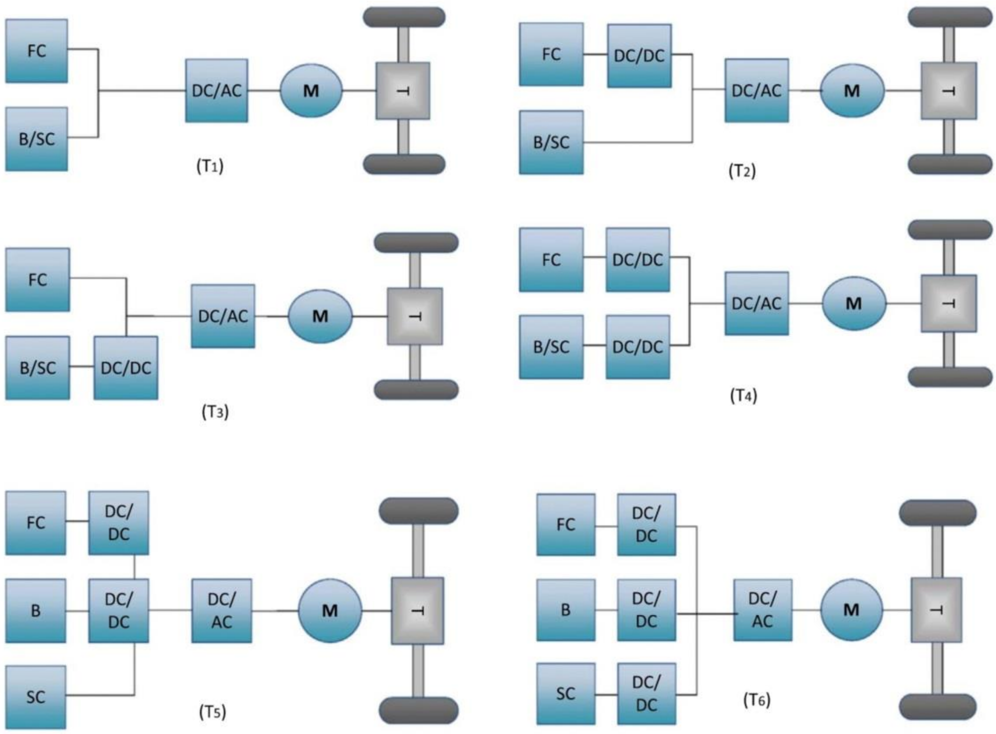

Figure 4. Topologies of FCHEV (T1) floating DC bus, (T2) Controlled FC with floating battery/ultra-capacitor, (T3) Floating FC with controlled battery/ultra-capacitor (T4) Controlled DC bus with Controlled FC, battery/ultra-capacitor, (T5) Controlled FC with controlled battery and floating ultra-capacitor, (T6) Controlled FC with controlled battery and ultra-capacitor [18].

Hybrid vehicles have two stages in their power conversion: the first is the DC-DC conversion and DC-AC conversion. Low voltage DC power from the sources is transformed into high voltage DC in the first stage and then the high voltage DC is transformed into AC by inversion. Figure 4 shows the topographical classification of the multiple stage power conversion [19].

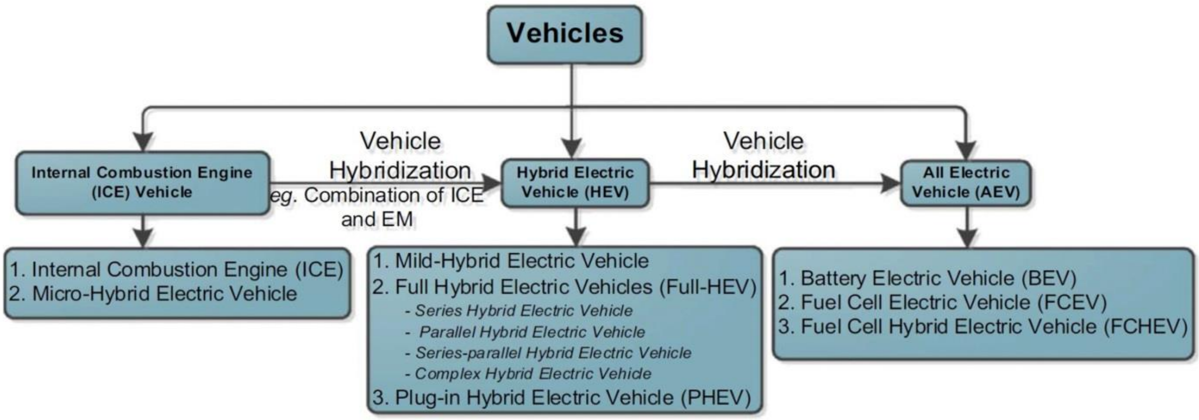

Figure 5. Various classifications of a vehicle [20].

Figure 6. shows the classification of cars while the ratio of the electric motor (EM) power to the total power [21,22].

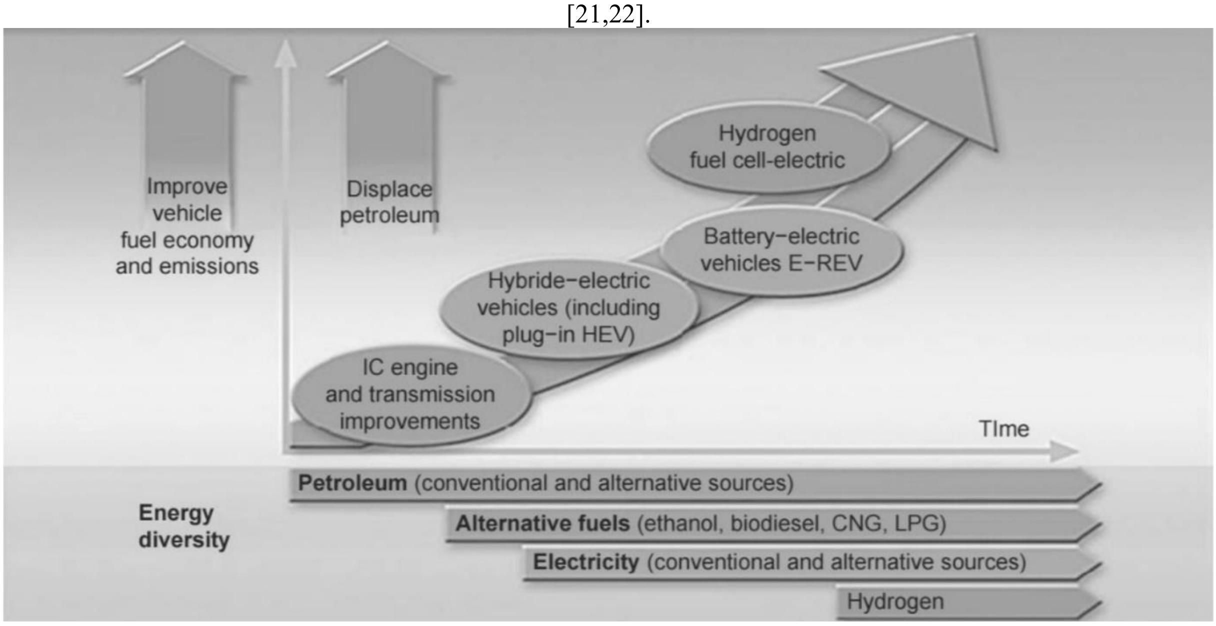

Figure 7. GM's advance propulsion strategy [23].

One strategy that was used by General Motors is the electrification of the automobile, the displacement of gasoline by alternative energy carriers as shown in Figure 5 This will lead to a drastic reduction in fuel consumption, reduced emissions and also increased energy security through geographic diversification of the available energy sources.

Table 1. Summary of the different models of hybrid electric vehicles (HEV'S) [24].

Vehicle model	Type	Energy source	Fuel economy MPGe(city/highway)	Annual fuel cost (per 15,000 miles)
Honda Fit 2014	BEV	Electric	132/105	$500
Nissan Leaf 2015	BEV	Electric	126/101	$550
Ford Focus Electric 2016	BEV	Electric	110/99	$600
Mitsubishi-MiEV 2016	BEV	Electric	126/99	$550
Honda Civic Hybrid 2015	HEV	Gasoline	44/47	$800
BMW Active E 2011	BEV	Electric	107/96	$600

Vehicle model	Type	Energy source	Fuel economy MPGe(city/highway)	Annual fuel cost (per 15,000 miles)
BMW Active Hybrid3 2015	HEV	Gasoline	25/33	$1500
Toyota Camry Hybrid LE 2015	HEV	Gasoline	43/39	$850
Ford Fusion Hybrid FWD 2016	HEV	Gasoline	44/41	$850
Honda Insight 2014	HEV	Gasoline	41/44	$850
Lexus LS 600 h L 2015	HEV	Gasoline	19/23	$2050
Toyota Prius 2015	HEV	Gasoline	51/48	$700
Porsche Panamera S E-hybrid 2016	PHEV	Gasoline - Electric	51(Combined)	$1450
Chevrolet Volt 2015	PHEV	Gasoline - Electric	101/93	$800
Toyota Prius 1.8 2015	PHEV	Gasoline - Electric	95/50	$650
Audi A3 E – TRON 2016	PHEV	Gasoline - Electric	83 (combined)	$950

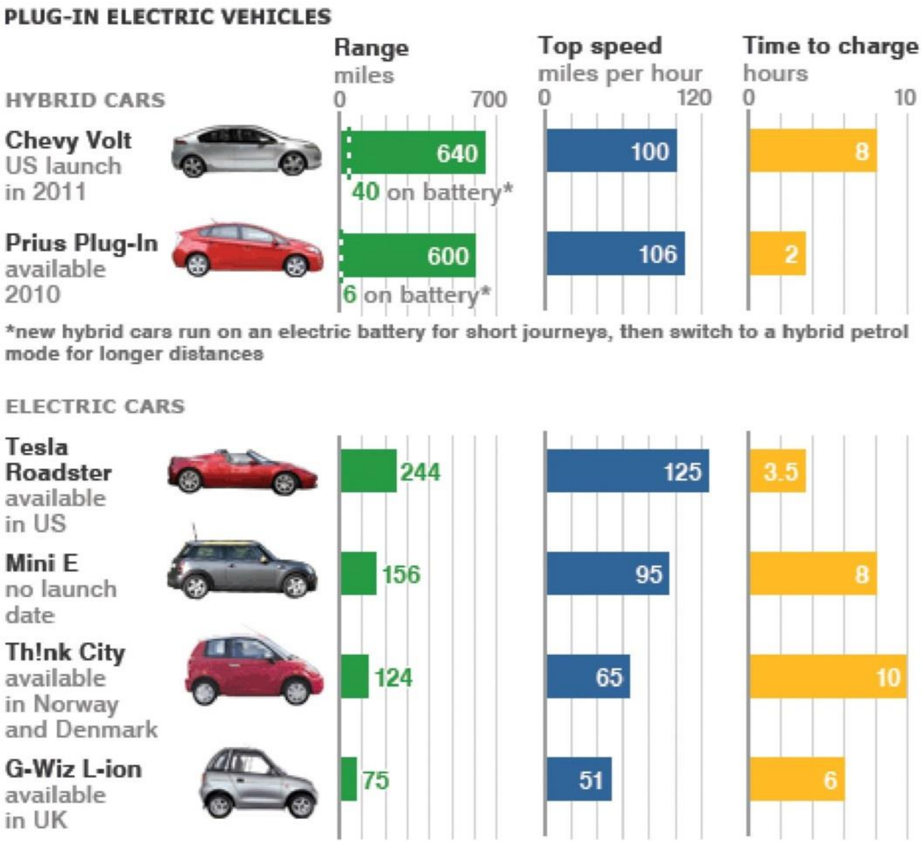

Figure 8. Performance of some electric vehicles as of 2009 [25].

In road transport systems, the differential, vehicle curved slides play an important role in preventing slippage. In practice, mechanical differentials are used, but they are increasing in volume as they increase in weight. Moreover, it is not suitable for electric vehicles, especially those using separate drives for two rear wheels. The electronic differential constitutes the latest technological developments in electric vehicle design to provide passengers with better stability and control. A modeling and simulation of a digital differential using a new wavelet transform controller for two brushless DC motors for two right and left rear wheel versions is focused in literature [26]. For air quality and keeping traffic jam, neighborhood EVs (NEVs) are the best known solution for personal transportation [27]. Implementation has been carried out for NEVs with two different wheel drives via induction motors using a digital signal processor, where both the current and speed controllers are standard proportional integral differential (PID) controllers; it was verified that by concentrating all control variables in the same memory, the system robustness was highly improved [28]. A field-programmable gate array (FPGA) based integrated control system for NEV AC motor drives was investigated, and it was shown that exploiting the parallel processing capabilities of an FPGA to execute several control schemes did not compromise overall system performance [29]. Renowned control methods, such as fuzzy logic, have been employed in the speed controller to fine-tune the slip rate of each wheel of the EV, verifying smooth propagation on straight and curved roads [30]. The advantage of fuzzy controllers is that they do not require prior information about the mathematical model of the plant. Electronic differentials have been used to control motors with a speed controller governed by a PID or fuzzy controller [31–38]. Recently, discrete wavelet transform (DWT) has replaced PID controllers with its technological robustness [39–45]. Wavelet transform (WT) has found applications in AC drives, performing much better than standard Pulse Width Modulation (PWM) techniques in experimental verifications [46,47]. WT techniques have also been extended to AC motor applications [48–52], in particular to control electric vehicles (EVs). For steering control of EVs, fuzzy-neural control WT algorithms have been implemented (AC motor drives) [53]. Also WT has been applied successfully for energy management system in plug-in hybrid EVs (HEVs) [54]. Recently, WT was effectively extended to fault diagnostics in multi-level power converters during short-circuit condition-based adaptive neural-fuzzy interface systems [55,56].

Figure 1(a) shows the schematic of an EV with the electronic differential. Here each wheel is controlled by two independent motors. In the case of a right turn, the differential will have to retain left wheel at a higher speed than the right, which keeps the tires from losing traction on turning (right) and vice versa (left) [57]. Figure 9(b) illustrates the EV turn on curved roads [58],

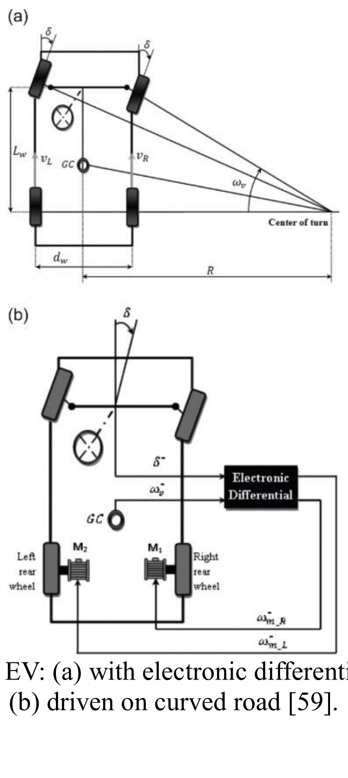

Figure 9. Schematic of an EV: (a) with electronic differential under investigation and (b) driven on curved road [59].

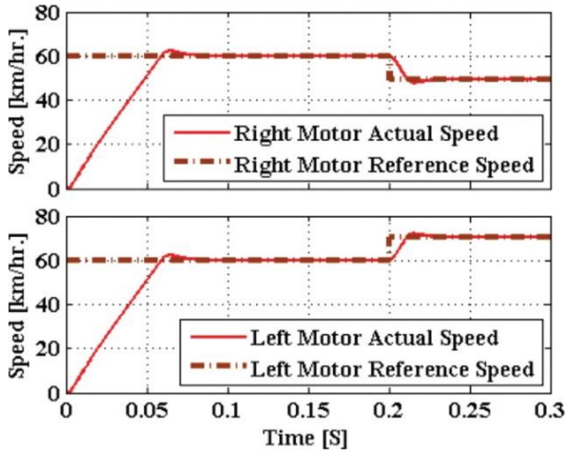

Figure 10. Numerical simulation of Test I output response behavior of BLDC motors by the PID controller, motor 1 (top) and motor 2 (bottom) [60].

The Tesla can travel a distance of 244 miles on lithium – cobalt battery pack and is able to accelerate to 60 mph in 4 s. This explains how its performance is relatively high compared to other electric vehicles as shown in Fig. 10. Table 2 shows prototypes and commercialization of FCHEV vehicles in single fuelling and fuel economy in both city and high way driving conditions [61].

Table 2. Various types of electric cars [62].

Vehicle model	**Type**	**Energysource**	**Fuel EconomyMPGe (City/highway)**	**Range (mile)**
Honda FCX clarity 2014	FCEV	Hydrogen	58/60	231
Honda clarity fuel cell 2017	FCHEV	Hydrogen	–	434
Toyota Mirai 2016	FCEV	Hydrogen	66/66	312
Hyundai ix35 2013	FCEV	Hydrogen	49/51	265
Toyota FCHV-adv	FCHEV	Hydrogen	–	369
Audi sportback A7h-tronQuattro 2014	FCHEV	Hydrogen	39/43	400–500
Honda FCV Concept 2014	FCHEV	Hydrogen	62 (overall)	310.7
Mercedes-Benz F800 2010	FCEV	Hydrogen	–	435
Nissan Terra FCEV SUV 2012	FCEV	Hydrogen	–	373
Roewe 950 Fuel Cell 2014	FCEV	Hydrogen	–	249
Volkswagen GolfHymotion 2014	FCEV	Hydrogen	–	310
Kia Borrego FCEV	FCEV	Hydrogen	–	426

There are various types of batteries with different capacity and characteristics available due to the reliable energy source for long time [63,64]. There are five main types of batteries for vehicular purposes such as lead acid batteries, nickel batteries, Zinc batteries, lithium batteries and metal air batteries. Table 3 shows the types of battery specifications and applications [65-68].

Table 3. Applications and different types of batteries [69].

Energy Storage type	Specific energy (Wh/kg)	Energy density (Wh/L)	Specific power (W/kg)	Life cycle	Energy Efficiency (%)	Production cost ($/kWh)	Application
Lead battery							Conventional automotive starting, lighting and ignition, large power backup, grid energy storage, BEV's, UPS, IC engine start up
Lead acid	35	100	180	1000	>80	60	
Advance lead acid	45	–	250	1500	–	200	
Valve regulated lead acid (VRLA)	50	–	150+	700+	–	150	
Metal foil lead acid	30	–	900	500+	–	–	
Nickle battery							Ni—Cd – Two way radios, emergency medical equipment, professional video cameras and power devices tools, NiMH – Powering portable low powered devices. Ni – Fe – off – grid power system storage.
Nickle - iron	50–60	60	100–150	2000	75	150–200	
Nickle - zinc	75	140	170–260	300	76	100–200	
Nickle – Cadmium (Ni—Cd)	50–80	300	200	2000	75	200–300	
Nickle-metal hydride (Ni-MH)	70–95	180–220	200–300	<3000	70	200–250	
ZEBRA battery							Suitable for automotive applications: cars, buses and transporters where low maintenance is needed.
Sodium - sulfer	150–240	–	150–230	800+	80	250–450	
Sodium-nickle chloride	90–120	160	155	1200+	80	230–345	
Lithium battery					80	110	Light weight and high energy density battery. Can be used for EV's, portable devices like laptop, torch, smartphone, camcorder, digital camera, electronic cigarettee, toys
Lithium – iron Sulphide (FeS)	150	–	300	1000+	–	350	
Lithium – iron Phosphate (LiFePO4)	120	220	2000–4500	42,000	–	150	
Lithium – ion Polymer (LiPo)	130–225	200–250	260–450	>1200	495	150	
Lithium-ion	118–250	200–400	200–430	2000	–	2000	
Lithium-titante (LiTiO/NiMnO$_2$)	80–100	–	4000	18,000			
Metal air battery							Vehicle propulsion, Grid storage
Aluminium – air	220	–	60	–	–	–	
Zin – air	460	1400	80–140	200	60	90–120	
Zin - refillable	460	–	–	–	–	–	
Lithium - air	1800	–	–	–	–	–	

Battery thermal management (BTM), which is a critical issue for the development of pure electric vehicles, typically pure electric passenger cars [70, 71, 72], has received little attention during the last few years because the understanding of lithium-ion battery thermal issues is lacking. EV, which was invented ahead of the first gasoline-powered vehicle, consists of mainly four elements: an energy source (the battery), a power convertor, an electric motor, and a mechanical transmission [73]. A vehicle driven by an electric motor is much more efficient than an engine-driven vehicle, for that the motor has high efficiency over 90% compared to 30% obtained by the engine [74]. Other merits such as a high-torque at low revolution speed, quicker torque response, and recovering kinetic energy into electricity from braking torque are also favourable. Shimada [75] compared the energy efficiency of FCV (fuel cell vehicles), HEV (hybrid electric vehicles), CNG (compressed natural gas), and BEV (battery electric vehicle) based on the input energy per 1km during 10-15 mode driving cycle test [75].

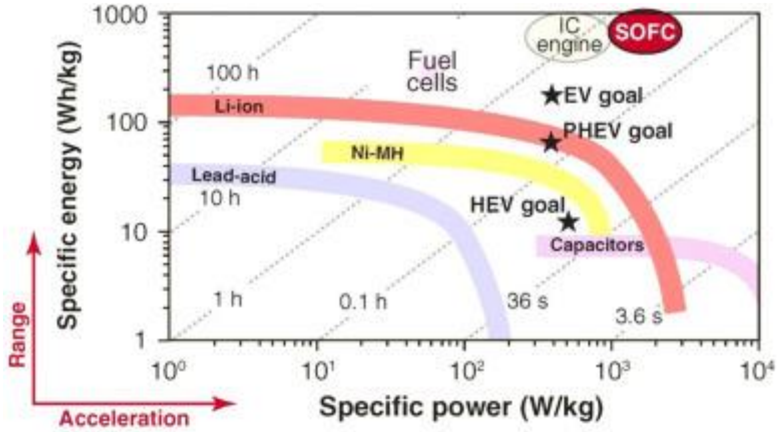

Figure 11. Ragone plot of various electrochemical energy storage and conversion devices [70] including recently reported SOFC [76].

A Ragone plot for various batteries, electrochemical capacitors, and fuel cells (including recently reported solid oxide fuel cell (SOFC) [10]) made for many applications ranging from consumer electronics to vehicles is provided in Figure 11.

From Table 4, lithium-ion batteries seem to be the best among other cell chemistries due to high energy and power density, long life cycles, ambient operating temperature, and high open-circuit cell voltage. Table 5 shows the major components of lithium-ion batteries. Lithium-ion batteries can store more energy per mass compared to NiMH, and achieves high cell voltage of 3.6 V in contrast with 1.23 V obtained by NiMH. More importantly, lithium-ion refers to the family of battery chemistry, which indicates material flexibility and potential in cost reduction through material substitution.

Table 4. Properties of electric vehicle batteries that operate at ambient temperature [77].

Q_{max} (W h/kg)	P_{max} (W/kg)	*t* (min)	*N*	$/kW h	*V* (V)
Lead-acid					
35	150	/	1000	60	2.1
Advanced lead-acid					
45	250	/	1500	200	/
Valve regulated lead-acid					
50	150+	15	700+	150	/
Metal foil lead-acid					
30	900	15	500+	/	/
Nickel-iron					
50	100	/	2000	150-200	1.2
Nickel-zinc					
70	150	/	300	150-200	1.7
Nickel-cadmium					

Q_{max} (W h/kg)	P_{max} (W/kg)	*t* (min)	*N*	$/kW h	*V* (V)
50	200	15	2000	300	1.2
Nickel-metal hydride (NiMH)					
70	200	35	2000+	250	1.23
Lithium-ion					
120-150	120–150	<60	1000+	150	3.6
Aluminium-air					
220	30	/	/	/	1.5
Zinc-air					
200	80-140	/	200	100	1.65

Table 5. The major components of lithium-ion batteries and their properties [78,79].

Abbrev.	**LCO**	**LNO**	**NCA**	**NMC**	**LMO**	**LFP**	**LTO**
Name	Lithium cobalt oxide	Lithium nickel oxide	Lithium nickel cobalt aluminium oxide	Lithium nickel, manganese cobalt oxide	Lithium manganese spinel	Lithium iron phosphate	Lithium titanate
Positive electrode	$LiCoO_2$	$LiNiO_2$	$Li(Ni0,85Co_{0},1Al_{0},05)O_2$	$Li(Ni_{0},33Mn_{0,}33Co_{o}33)O_2$	$LiMn_2O_4$	$LiFePO_4$	LMO, NCA, …
Negative electrode	Graphite	Graphite	Graphite	Graphite	Graphite	Graphite	$Li_4Ti_5O_{12}$
Cell voltage (V)	3.7–3.9	3.6	3.65	3.8–4.0	4.0	3.3	2.3-2.5
Energy density (Wh/kg)	150 mA h/g	150	130	170	120	130	85
Power	+	o	+	o	+	+	++
Safety	–	o	o	o	+	++	++
Lifetime	–	o	+	o	o	+	+++
Cost	--	+	o	o	+	+	o

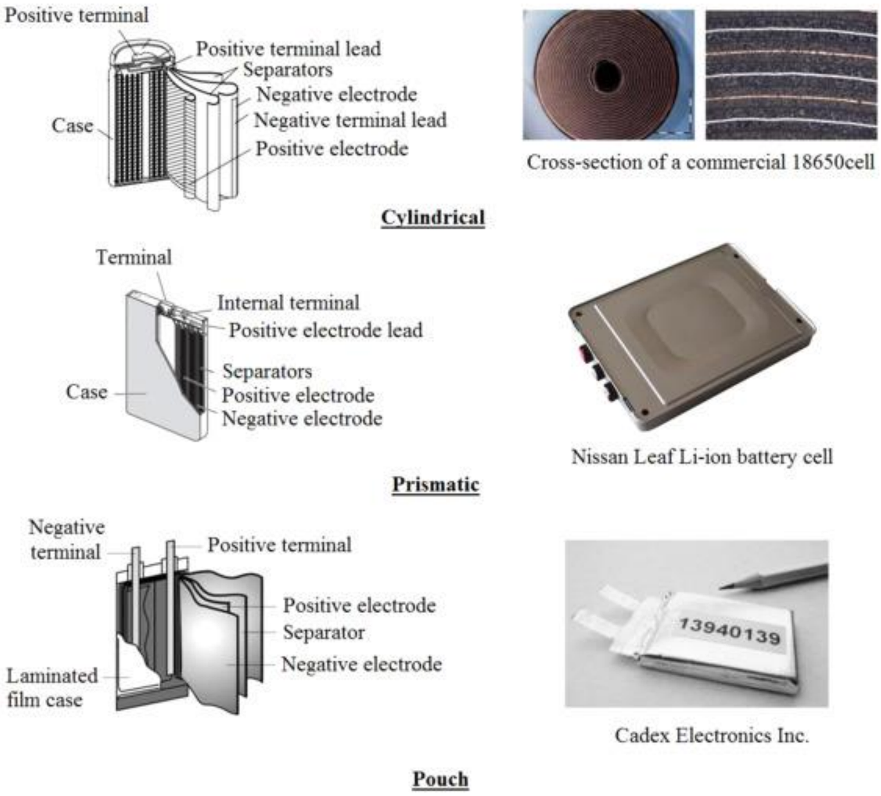

Figure 12. Battery cell configurations [79].

Three configurations of lithium-ion battery cell are shown in Figure 12 Both cylindrical and prismatic lithium-ion batteries at cell-, module-, and pack-level for EVs have been demonstrated by Figure 13

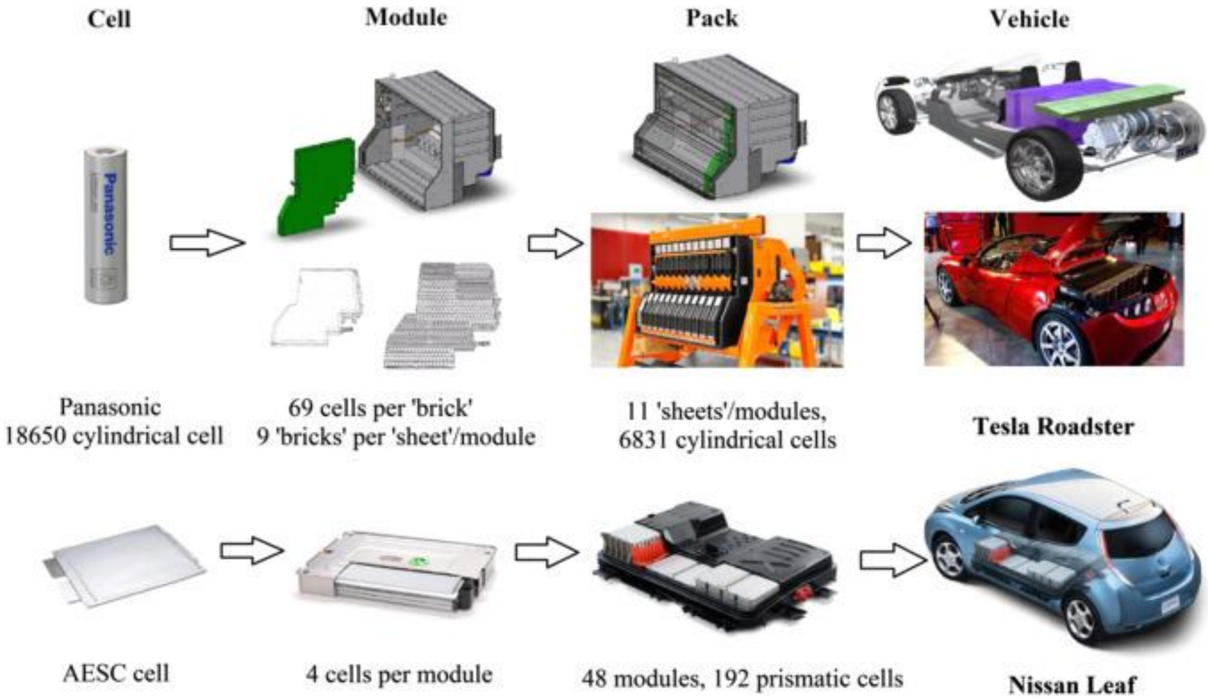

Figure 13. Lithium-ion battery cell-, module-, and pack-level demonstrated by two vehicle examples: Tesla Roadster [80, 81] and Nissan Leaf [82].

THERMAL ANALYSIS OF BATTERIES

Various battery chemistries have different responses to failure, but the most common failure mode of a cell under abusive conditions is the generation of heat and gas [82]. The possible exothermic reactions and thermal stability of lithium-ion batteries have been reviewed in [83,84]. Table 6 summaries the identified reaction of the components used in a lithium-ion battery. It shows that the components are completely stable below 80 °C, but once the temperature reaches to 120–130 °C, the passivation layer (SEI – solid-electrolyte interface) starts dissolving progressively in the electrolyte causing the electrolyte to react with the least protected surface of graphite generating heat.

Table 6. Thermal stability of components used in a lithium-ion battery (values measured with differential scanning calorimetry on electrodes) [84].

Temperature (°C)	Associated reactions	Energy (J/g)	Comment
120–130	Passivation layer	200–350	Passive layer breaks, solubilisation starts below 100 °C
130–140	PE separator melts	-90	Endothermic
160–170	PP separator melts	-190	Endothermic
200	Solvents-$LiPF_6$	300	Slow kinetic
200–230	Positive material decomposition	1000	O2 emission reacts with solvents
240–250	LiC_6+binder	300–500	
240–250	LiC_6+electrolyte	1000–1500	

Table 7**.** lists strengths and weaknesses offered by air, refrigerant, and coolant BTM. Air BTM is suitable for all type of cells, whereas liquid BTM that usually adopts cooling/heating plates within the assembled battery cells prefers prismatic or pouch cell geometry [85]. Table 8 shows suggested operating temperature range for lithium-ion batteries.

Table 7. A comparison among air, refrigerant and coolant BTM [85].

	Advantages	**Disadvantages**
Air cooling/heating	• Suitable for all cell types • Simple • Cheap • Battery heating in winter	• Low heat transfer rate • Ineffective temperature uniformity • High space requirements • Additional weight problems • Potential noise disturbance
Refrigerant cooling	• High heat transfer rate • Allow battery to handle a larger pulse of power • Effective temperature uniformity •	• No battery warming • Electric shortage due to liquid leakage

	Advantages	Disadvantages
	Low space requirements	
Coolant cooling/heating	• High heat transfer rate • Allow battery to handle a larger pulse of power • Effective temperature uniformity • Battery heating in winter	• Expensive (the most costly) • Electric shortage due to liquid leakage • High space requirements • Increased complexity and weight

Table 8. Suggested operating temperature range for lithium-ion batteries [85].

Advised temperature range for optimal performance (°C)	Battery type
<50	Lithium-ion
25–40	Lead-acid, NiMH, and Lithium-ion
0–45 for charge	Lithium-ion
−10–60 for discharge	
20–30	Lithium-ion
15–35	Lithium-ion

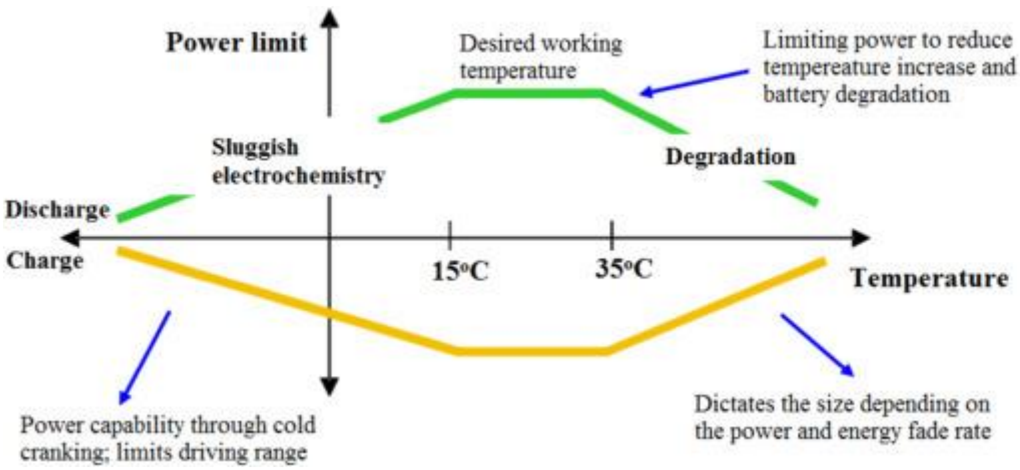

Figure 14. Temperature impact on life, safety and performance of lithium-ion batteries [86].

Temperature effects, heat sources and sinks, EV/HEV batteries, and temperature control should be considered before designing a good battery thermal management (Figure 14). Either low (<15 °C) or high temperature (>50 °C) will progressively reduce the cycle life, and the threat of thermal runaway at a temperature higher than 70 °C leads to cell failure. Pesaran [87] benchmarked the operating temperature for a variety of batteries including lead-acid, NiMH, and lithium-ion. Because electric batteries have sensitive composition, they degenerate when they go out of specifical temperature ranges. They may react differently at particular levels while operating at specific temperature ranges Figure 14.

CONCLUSIONS

This paper reviews recent electrical vehicle technologies, thermal models and battery technologies used for HEVs and EVs. In the near future, EVs will spread far and wide and they will be like walking computers. Therefore, controlling components of EVs will gain an importance. One of the important technologies in EVs is battery management. Also thermal challenges should be considered for efficient vehicles. Thermos-electrochemical structure of electric batteries behave as the heat generation module.

A lot of numerical and experimental measurements have been investigated based on small cells at low charge/discharge rate near environment temperatures. To build thermal model for the entire battery pack predicting the thermal behavior should be built. In this new generation EVs, removing thermal impacts of batteries is provided by thermal management system, which improves temperature uniformity for the battery pack and battery safety. In EVs, heat sinks, heat sources and control of temperature values should be well designed before thermal management strategies. These strategies should be defined in many aspects. In literature it is reported that thermal management strategies especially for lithium-ion batteries need further investigation. These technologies were categorized as air, liquid, PCM, heat pipe, and other combinations and they were reported extensively. In general, air thermal cooling systems are proper for all battery packs especially in NiMH battery technologies for hybrid vehicles. On the other hand liquid thermal cooling solutions have good method compared to air. They has been produced in cooling battery packs in different commercial cars. In literature Phase Change Materials (PCM) were reported in eliminating the need for active cooling and heating during the driving conditions. However these technologies have lower thermal conductivity, therefore they have disadvantages in higher thermal capacities. In thermal cooling systems of EVs, heat pipes can be considered as a newer method and need further investigations. Especially in low power consumption, PCMs and heat pipes can be used for efficient heat sinks.

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