

THIRD PARTY ASSESSMENT OF POLICIES, PLANS AND IMPLEMENTATION OF THE MANUFACTURE OF ELECTRIC VEHICLES IN PAKISTAN

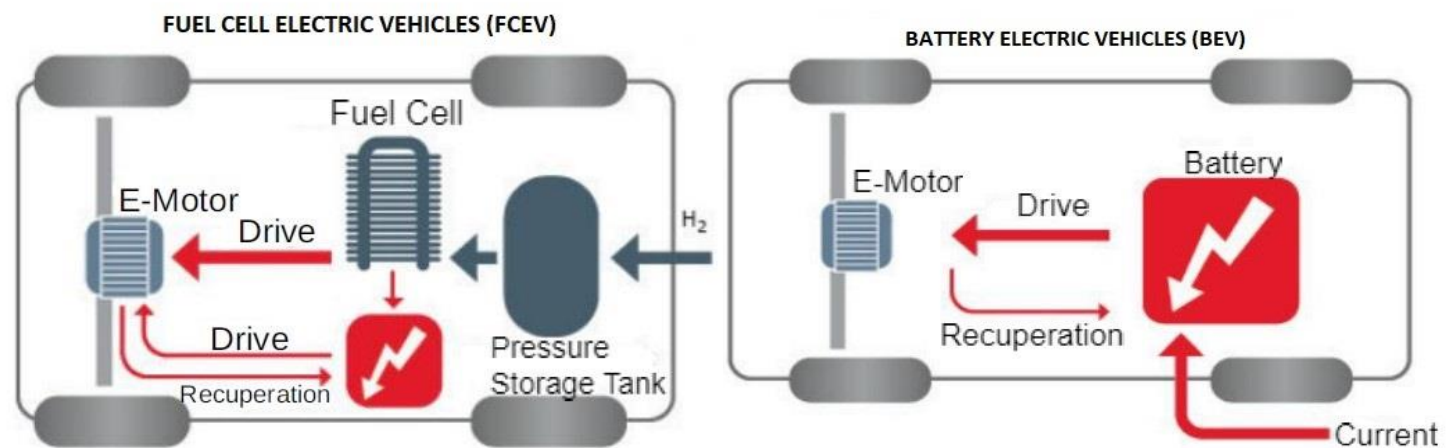


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PREFACE

The developed countries have a tradition of sponsoring Review and Assessment of Programmes at the national level, particularly related to the emerging technologies. Institutions have been established to conduct technology assessment, that are answerable to the national parliaments.

The Academies of Engineering in a number of countries have been frequently tasked to carry out comprehensive reviews of the status of technology use in variety of fields.

The Pakistan Academy of Engineering, a learned society, decided to fill up the gap of independent assessment and reviews of policies, plans and implementation framed by the government in respect of technology based projects. The present exercise **“Third Party Assessment of Policies, Plans and Implementation of the Manufacturing of Electric Vehicles in Pakistan”** is a valuable example.

Global trends indicate that rigorous efforts are being made to introduce electromobility, primarily to combat climate damage. It is heartening to note that the Ministry of Climate Change, Government of Pakistan, brought out the National Electric Vehicle Policy in 2019. The Engineering Development Board, Ministry of Industries and Production, Government of Pakistan, issued the Auto Industry Development and Export Policy (AIDEP 2021-26), which includes promotion of new technologies, particularly related to Electric Vehicles.

The Pakistan Academy of Engineering understands the environment under which the emerging technology has to be harnessed. It has tapped into the deep resources of knowledge about what is new. A comprehensive review of available EV Technologies has been conducted. The objective is to examine whether the public policy takes into account the risks involved in such ventures and whether the dose of incentives is enough to attract investments by the private sector. Since technology is constantly evolving, disruptions have become very common. The entire systems can become outdated in a short span of time.

The Pakistan Academy of Engineering is mandated to provide complimentary services to the premier engineering organization Pakistan Engineering Council. This study has been prepared with the financial support of the PEC.

The study has been designed to promote advisory role of the PEC for the Government.



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2. Executive Summary

Electric Vehicles are gaining momentum worldwide due to climatic change and net zero commitments, dependence of ICE based vehicles on gasoline with rising cost of gasoline, and electric vehicles having benefits of lower operating costs and low emissions.

Pakistan is faced with critical issues of high fuel import costs, surplus electrical power generation capacity, increasing vehicle market size, environment pollution and rising inflation. Looking at the potential benefits of what electric vehicles have to offer in the context of Pakistan's issues, the initiative of the Ministry of Climate Change, Government of Pakistan to bring out the National Electric Vehicle Policy (2019), and the issuance of electric vehicle related Auto Industry Development and Export Policy (AIDEP 2021-26) by the Engineering Development Board, Ministry of Industries and Production, Government of Pakistan, are certainly steps in the right direction. NEVP (2019) has laid the foundation for electric mobility promotion in Pakistan. With proper policy support and implementation, it will help in achieving following major goals;

- Reduce fuel imports and thus, improve Pakistan's energy security
- Reduce energy intensity of road transport by leveraging higher efficiency of EVs over conventional vehicles; and
- Reduce carbon footprint and vehicular emissions

It is true that global expansion in electric vehicle market is primarily driven by policy support by the leading governments, technology improvements (for both EV types i.e. BEV and FCEV), declining battery costs and renewed focus on renewable energy (e.g. Solar/Wind energy) to produce hydrogen at cheaper rates. In short, the global trends show that initially Battery Electric Vehicle (BEV) is the choice, but later on they will be converted to FCEV's due to their benefits of outreach, zero emission, and thermodynamic efficiency.

NEVP (2019) has defined the penetration targets for medium term (five years), long term Targets (2030), Ultimate Targets (2040) for various categories of vehicles. Medium term target (five years) for EV penetration for Cars (including vans, Jeeps, small trucks) is 100000, for 2 wheelers (motor bikes) and 3 wheelers (rickshaws) is 500,000, and 1000 for buses and heavy trucks. With the target penetration of first five years, the expectation is that Pakistan will conservatively get around PKR 110 billion yearly through savings and earnings.

Auto Industry Development and Export Policy, (AIDEP 2021-26) EV policy has provided decent subsidies for electric vehicles and other non-tariff incentives for EV's approved for Islamabad Capital Territory and recommended for consideration of other relevant authorities include exemption from registration fees (for EV's only), annual renewal fee to be fully exempted for all kinds of EVs, NHA/Ministry of Communications to consider 50% exemption on toll tax, bulk insurance at concessional rate for commercial fleets, special incentivized power tariff on charging stations for EV's.

The report also highlights the evaluation criteria for electromobility viz. Political Targets, Technological Advantages, Storage Capacity, Outreach, Efficiency, Infrastructure, Fuel provision, Emission free mobility, Critical Raw Materials, Life Cycle Cost, Value Realistic (cost) and Customer Use.

The road transport sector in Pakistan has been growing steadily. The total number of registered vehicles stood at 31 million in 2021. Two-wheelers or motorbikes hold dominant share which represents 76% (i.e. 23,849,010 vehicles) of the total registered vehicles. The three wheelers have also shown a steady progress over the years and represents 959,049 registered vehicles. Therefore, motorbikes or two-wheelers and 3 wheelers /rickshaws constitute the major EV market.

It is important to note that electric vehicle upfront purchase costs are still very high compared to the ICE based counterpart vehicle. Therefore, the rate of electric vehicle penetration in Pakistan will not be easy and straightforward. Critical factors that will influence the battery electric vehicle adoption in the country over the next decade or so will include policy support, vehicle purchase cost, operating cost, outreach, battery cost and its charging infrastructure readiness. Hydrogen and its infrastructure readiness, technological advancements in FCEV and its components, and localization of supply chain for electric vehicle manufacturing in Pakistan coupled with export market development, will determine the growth of FCEV market.

There are some gaps and deficits in the policies and plans, which are as follows:

Import of all types of SUV's should be stopped completely. It results in a major outflow of foreign exchange.

Import of CBU electric vehicles even for test marketing should not be allowed in the case of 4 wheelers. This applies to cars, jeeps, station wagons, SUVs. Electric vehicle technology is evolving and currently the purchase cost of these vehicles is very high and will result in significant outflow of foreign exchange from Pakistan.

Import of DC Charging stations/level 3 chargers & above should be restricted for general use. EV ramp-up in Pakistan is based on market size and two-wheelers (motor cycles) and three-wheelers (rickshaws) dominate the market size. For two wheelers and three wheelers, there is no need for level 3 or above chargers / charging stations due to smaller size EV batteries.

Initially, only handful of level-3 DC chargers import can be allowed for a very specific, very high utilization case of 'Fixed route' buses after carefully reviewing all the relevant details of use.

Very strict import and monitoring mechanism of 150KWh EV batteries for LCV's should be in place to avoid the import and use of these batteries in any other vehicle category.

Companies that are approved to import CBU of electric vehicles by EDB after verification of their manufacturing facilities should be monitored/evaluated quarterly (if monthly monitoring /evaluation is not possible) for their readiness to manufacture electric vehicles in Pakistan.

Custom duty on import of localized parts of Heavy Commercial Vehicles (Trucks, Buses, Prime Movers) needs to be clearly defined in AIDEP 2021-26. Import of localized and non-localized parts should not be at the same level of 1% custom duty. Otherwise, there is no incentive to manufacture these parts locally.

Strict control and very limited import of level-3 DC chargers (higher than 50KW capacity) can be allowed only for very special situations of commercial applications.

The report provides recommendations on policy measures, incentives and interventions. The key takeaways from the report are as follows:

- The smaller battery size results in lower battery charging times coupled with lower infrastructure costs. Therefore, battery electric vehicles offer advantages in "shorter range

/outreach” due to smaller size battery, better re-charging time, low operating cost and low infrastructure costs in smaller size vehicles.

- Electric vehicle manufacturing in Pakistan should be focused initially only on 2 wheelers and 3 wheelers market segment in line with penetration targets set in NEVP (2019). This alone will provide a huge benefit to Pakistan. As stated in National Electric Vehicle Policy (2019), in case of 2 wheelers and 3 wheelers (with 5 years’ cumulative target of 500,000 electric vehicles) it will result in an estimated yearly income and savings from EV of Rs. 63.47 with Five Year Penetration Target.
- By keeping the commercial AC charging rates low (i.e. equal to residential electricity rates), especially in the case of 2 wheeler motor bikes and 3 wheeler rickshaws (by virtue of their smaller battery sizes), the end user will see a bigger benefit in using BEVs and will result in rapid ramp-up of EVs in Pakistan.
- DC charger stations costs are very high. ABB - a European manufacturer, has installed a few 50 KW chargers in Pakistan with an equipment cost of PKR 4.9 million [10]. This implies that there is a significant cost involved in installing fast chargers along the major motor ways and highways after every 15-30 km (as per AIDEP 2021-26). The length of highways in Pakistan (as of 2018) is 12131 km and projected to be around 15201 km by 2025 [28]. By using total length of Highways of 12131 Km [28], using ABB Fast charger installed cost of Rs.4.9 million [10] and applying the AIDEP (2021-26) policy decision of fast charger installation at every 15-30 km of motor ways/highways, this cost can be in the range of at least Rs.1.981 billion to Rs.3.962 billion (not including any price increases in fast chargers due to high inflation). Currently, the assumption is that these fast chargers will be imported so this will result in significant outflow of foreign exchange from Pakistan.
- The current challenge for battery-electric vehicles is long-haul logistic operation and transport of very heavy goods (which implies high energy consumption per kilometer) and will require the use of high capacity DC chargers due to bigger battery sizes in electric trucks, so the recommendation is to remove the “Heavy trucks/ Heavy vehicles” from penetration targets for next five years (and make appropriate changes in AIDEP 2021-26 EV related policy) with the expectation that the reduction in prices of electric trucks, batteries and positive technological changes down the road will result in better solution for Pakistan’s transportation needs. Otherwise, this will result in significant outflow of foreign exchange from Pakistan due to the imports of expensive heavy electric vehicles and its associated infrastructure components.
- Infrastructure of BEV and FCEV should be developed by keeping the costs and their benefits in mind. There is a possibility of redundancy of technology due to the disruption of emerging technology.
- Long term energy independence in the form of renewable energies available in Pakistan by keeping an eye on the latest proven technological advancements should be the focus. Projects which have the potential to produce ‘Green Hydrogen’ at cheaper rates for downstream usage have to be expedited and given priority. These projects should also be given incentives, so that Fuel cell electric vehicles infrastructure development can be expedited. This will eventually cater to the needs of ‘long range’ bigger size electric vehicles with the help of renewable energies.
- Costs of solar panels and solar systems should be reduced by removing the sales taxes and/or by providing other subsidies (if possible). This will be a big incentive for rapid adoption of electric vehicles in Pakistan and will help in infrastructure development of electric vehicles.
- Imports have to be minimized and local manufacturing of EV’s and its components should be the goal, starting with 2 wheelers and 3 wheeler electric vehicles.

- Pakistani companies should invest in the local manufacturing of export quality components (e.g. Electric vehicle batteries, Fuel cells /systems. Electric motors, various types of valves for thermal management, hydrogen fuel tanks etc. and equipment's (e.g. Battery chargers, Electrolysers etc.) related to Electric Vehicles and make technical collaboration, and export agreements with foreign companies to manufacture for them locally, and for local use in Pakistan.
- Establishment of National Center for electric vehicles should address the needs of entire Pakistan and have its branches in all the big cities of Pakistan, especially where the high rates of 2 wheeler motor bikes/ 3 wheeler commercial utilization are expected. Secondly, the Center should have collaboration with Pakistani engineering universities in respect of the latest technological advancements in materials, solid state batteries, Additive Manufacturing, Thermal Management System, and Fuel Cell development.

3. Introduction

Thermodynamically, the electrical systems are more efficient than mechanical systems. Internal combustion engines (ICE) are more deficient because of the energy in the exhaust. Our objective is to decarbonize the transport system, reduce the cost of transportation, and improve mobility.

This is in line with the prime goal of reduction in greenhouse gas emissions, as part of global climate policy. In the transport sector electric drives provide a significant solution. Renewable sources of energy may service the electric vehicles. Furthermore, electric drives provide local freedom from emissions and noise in road traffic.

Globally vehicle industry is moving towards electric vehicles (EV) but its pace of progress is hindered by very high initial price of electric vehicles and lack of infrastructure to support it. Our objective is to reduce the price of electric vehicles.

It is important to note that electric vehicle offers key benefits i.e., zero emission levels, low electric vehicle operating cost compared to internal combustion engines (ICE), and removal of the dependency from fossil fuels. Therefore, in the near future we expect to see the transition from ICE based vehicles to electric vehicles.

The vehicles will be on the road if supplied with spares, therefore, the development and manufacturing of key components and their spares is the key for sustaining the electric mobility. Combustion engine is not dead. The huge investment in the manufacturing facilities cannot be written off easily in the near future.

A gradual conversion of ICE based vehicle assembly plants to electric vehicle assembly Plants or completely new electric vehicle assembly Plants will be the foreseeable scenarios. This has to be done by carefully evaluating the Pakistani vehicle market size, rising fuel costs, upcoming technological changes in electrical vehicle technologies, cost of associated components, trend of vehicle purchase cost and operating cost, infrastructure readiness, and rising inflation.

4. Global Trends

The history of electric vehicles goes back to 1914 when 'Detroit Electric Brand' was made by Anderson Electric Car Company, Detroit, Michigan, USA. Before the World War I, many women chose electric cars because they started instantly without hand cranking and had no difficult-to-shift transmission.



Fig. No.1 'Detroit Electric Brand' Image courtesy of 'thehenryford.org – Digital Collections'

In Pakistan, under the guidance and patronage of Prof. Dr-Ing. Jameel Ahmad Khan (Ex-Vice Chancellor, N.E.D. University of Engineering and Technology), the first solar powered electric car was made in the late 1980's. Similarly, other universities / colleges in Pakistan also worked on solar power electric vehicle later on and Dr. Nasim Khan, Ex-Vice Chancellor NUST (EME college) was also instrumental in making solar powered car in 2003 at EME College (NUST). The global trends indicate two streams of development. Battery Electric Vehicle viz. (BEV) and Fuel Cell Electric Vehicles (FCEV).

4.1 Battery Electric Vehicles (BEV)

In terms of the overall EV market size, the leader is currently China, followed by Europe and then the United States. In the 2020 business year, Chinese consumers bought 1 million electric vehicles, Europeans 720,000, and Americans 250,000.

Of these markets, Europe showed the strongest year-on-year growth in 2020, with a 112% rise from the 2019 numbers. The prevailing view is that this growth was mainly due to the doubling of the subsidies offered to the buyers of electric vehicles. For example, in 2020, the German government doubled the federal share of its environmental subsidy from €3,000 to €6,000 per vehicle, which, when combined with the manufacturer's share, resulted in a total subsidy of €9,000 on vehicles priced at €40,000 or below. This subsidy was only available until the end of 2020. In June 2020, the French government also launched a limited-time €7,000 subsidy, representing a €1,000 increase over existing subsidies, that was offered to the individuals purchasing or leasing electric vehicles priced at €40,000 or below. [1]

China

Chinese Automotive manufacturers are heavily focused on BEV (Battery Electric Vehicles) and have successfully done it.



Fig.No.2 Shanghai city bus depot rooftop PV system [2]

Shanghai is the first city in China to generate power for the city's electric buses using a rooftop PV system on the bus depot, exploring a new model of direct recharging zero emission vehicles.

The installed rooftop PV system can recharge 6 of the 70 electric buses at the same time and provide electricity for other purposes at the bus depot.

In order to run electric buses on renewable energy and achieve 100% emission free transport, Shanghai has set up the very first solar power project for bus depot in China. The 195 kW rooftop PV system is providing enough energy to recharge 6 buses at the same time, and the expected annual power generation is up to 20 MWh. The system also provides energy for other purposes at the facility and even feeds electricity back to the grid. Covering nearly 2,000 m², the solar panels have also improved the heat insulation of the roof.

This project derives the following benefits:

- *Economic* Distributed PV generates 20 MWh of green power per year, which according to the reported electricity tariff in Shanghai will save the bus company CNY 170,000 annually.
- *Environment* Using solar power to generate energy will reduce 6 tons of oxynitride and 160 carbon dioxide emissions.
- *Health* Using solar energy to power electric buses reduces vehicle emissions, urban haze, and air pollution, bringing many benefits to human health. [2]

Germany

Germany saw a 10 percent decrease in new car registrations in 2021 compared to the previous year, but a large rise in the share of electric and hybrid cars, Federal Motor Transport Authority (KBA) said in its annual statistics release.

Pure electric cars showed an increase of 83 percent, reaching a share of 14 percent in all new registrations. Hybrid cars (including plug-in hybrids) reached a share of 29 percent (+43% compared to 2020).

The share of petrol and diesel passenger cars dropped by 29 and 36 percent respectively. Some 25 percent of all new registrations were in the SUV segment.

In Germany purchases of purely electric cars are supported with up to 9,000 euros and buyers of plug-in hybrid cars receive up to 6,750 euros in support. The government spent over three billion euros on supporting e-car sales in 2021.

Japan

In Japan only 14,604 electric vehicles were sold in 2020. Not only is this a far cry from the 1 million sold in China, the 720,000 sold in Europe, and the 250,000 sold in the United States, Japan's BEV sales are orders of magnitude lower when seen on a per-capita basis as well.

Japan's level of publicly available charging infrastructure is also at par with that of Europe. The low numbers are probably caused by the scarcity of EVs suitable for the Japanese market, the tendency of Japanese dwellings not to enable domestic charging points to be installed, and the national tendency to be cautious about car purchases.

Another issue is the fact that Japanese manufacturers have not played an active role in the BEV market. While Mitsubishi was the first manufacturer to mass-produce an EV in 2006 with its i-MiEV in the ultralight category, and in 2010, Nissan released the Leaf. Neither model was as successful as hoped, and the i-MiEV was taken off the market in March. Meanwhile, Nissan only sold its 55,000th Leaf (globally) last year.

As mentioned above, the global electric vehicle market is still only a small part of the auto market as a whole, and the demand generation is reliant on the government subsidies. [1]

USA

According to the car registration data from Experian (via *Automotive News*), some **378,466** electric vehicles were registered from January to October 2021, which is **94% more** than in 2020 at this point. That's about **2.9%** of the total market, compared to 1.7% a year ago.

Most registered all-electric models reveals the continued domination of [Tesla](#), which has two models - [Model Y](#) (134,504 (up 182%; 35.5% of all BEVs) and [Model 3](#) (112,314 (up 39%; 29.7% of all BEVs) and 117,534 non-Tesla.[3]



Fig.No.3 Tesla Model Y – Image courtesy TESLA

India

Currently, Tata Motors is the leader in the Indian electric car market with Tigor EV And Nexon EV. Moreover, the brand has confirmed that it will launch a few more electric vehicles in the near future. A list of five upcoming Electric cars that will debut in India in the coming years.

Tata Sierra EV

Earlier showcased in concept form at Auto Expo 2020, Tata Sierra EV Following the EV-specific architecture, the new Sigma will be based on the platform. The upcoming Sierra EV will likely be available in two versions – a front-wheel-drive and an all-wheel-drive. Dimensionally, the Sierra EV measures 4,150 mm, which is slightly smaller than the Skoda Kushak and Hyundai Creta. When launched, the Tata Sierra EV is expected to cost around Indian Rs 14 lakh (ex-showroom). Tata technical specifications and features details are yet to be revealed.

Tata Nexon EV Long Range

The company is working to expand the Nexon EV range in India in the coming months. The Tata Nexon compact SUV will come equipped with a bigger battery and several new features, such as adjustable regenerative braking system, an air purifier, ventilated front seats, new alloy wheels, ESP, cruise control, rear disc brake and more. According to reports, the all-electric Nexon will use a 40 kWh unit instead of the 30.2 kWh battery currently used. We expect the Nexon Long range to cost around Indian Rs 14.54 lakh (ex-showroom).

Tata Punch EV

Tata Motors is planning to add an electric powertrain to its Punch SUV and when launched, it could be the most affordable electric SUV in Tata's lineup. Likely to be launched this year, the mini-SUV will use a 30.2kWh lithium-ion battery and an electric mill, which will be powered by Ziptron EV powertrain technology. The engine and battery together will generate 100 PS of power and 200 Nm of torque. The Tata Punch EV will offer a range of 300 km on a single charge.

Tata Altroz EV

The Tata Altroz EV showcased at the Auto Expo 2020 was in the near-production stage. According to media reports, the Altroz EV will make its India debut in 2022 as Tata Motors is aggressively working on EV expansion across the country. When launched, the Altroz EV is likely

to offer an official range of 250-300km per charge. With a DC fast charger, it can take around 1 hour for the battery to charge from 0-80%, while it can take up to 8 hours for the battery to charge with a regular wall charger.

Tata Curve EV

Tata Motors recently digitally unveiled its coupe-style SUV, the Curvv EV in India. The brand has confirmed that the SUV will be primarily launched in the EV form and a later ICE variant will follow. Built on the 'Generation 2' architecture, the Curve SUV will offer a massive range of 500 km per charge. The Tata Curvv EV price in India is expected to be around Indian Rs.20 lakhs (ex-showroom) upon launch. [29]

4.2 Fuel Cell Electric Vehicle (FCEV)

Since FCEV's use hydrogen as a fuel, therefore, it is important to understand the characteristics of Hydrogen in relation to the other fuels especially in the context of energy, emissions, and storage. The tables shown below provide the understanding of key characteristics of Hydrogen with other fuels:

Comparison of Key Properties of Hydrogen And Other Fuels

Fuel Type	Energy per unit mass (MJ/kg)	Energy per unit volume (MJ/m ³)	Specific carbon emission (kg C/kg fuel)
Liquid hydrogen	141.90	10.10	0.00
Gaseous hydrogen	141.90	0.013	0.00
Fuel oil	45.50	38.65	0.84
Gasoline	47.40	34.85	0.86
Jet fuel	46.50	35.30	—
LPG	48.80	24.40	—
LNG	50.00	23.00	—
Methanol	22.30	18.10	0.50
Ethanol	29.90	23.60	0.50
Bio diesel	37.00	33.00	0.50
Natural gas	50.00	0.04	0.46
Charcoal	30.00	—	0.50

Table No.1 Comparison of Key properties of Hydrogen [9]

Energy Content of Energy Carriers

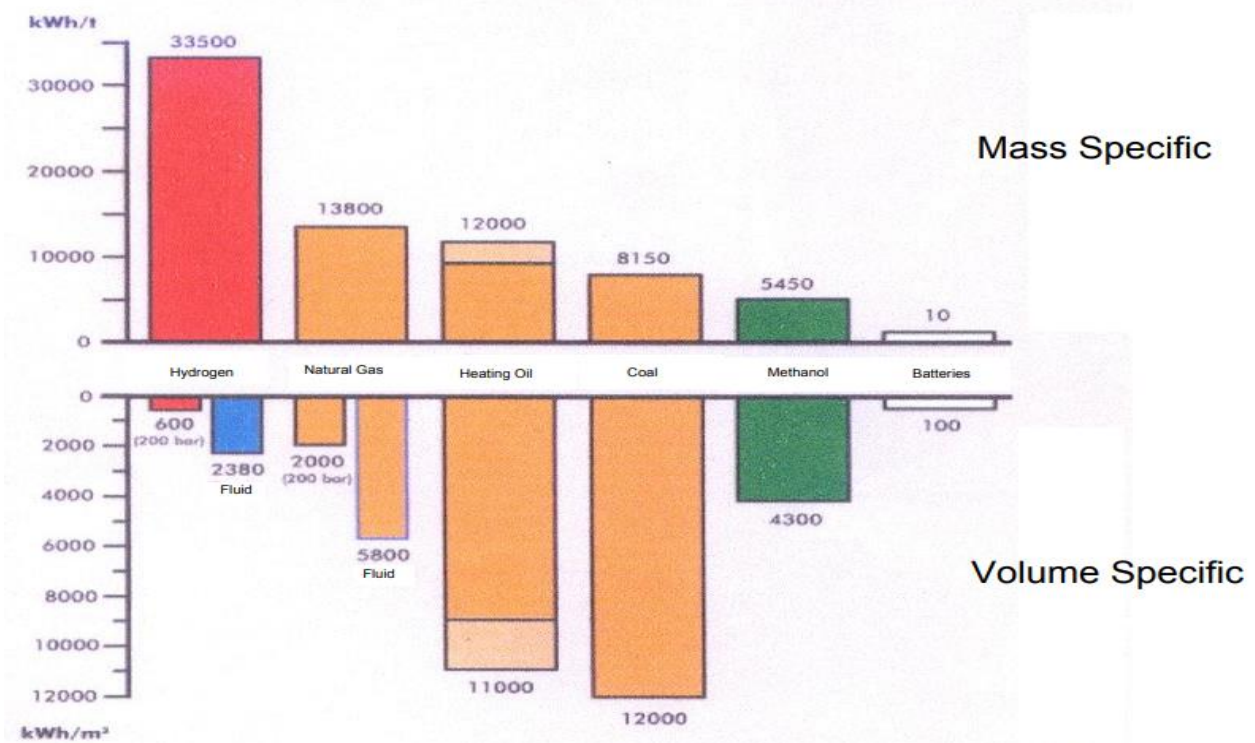


Fig.No.4 Energy Content of Energy Carriers [9]

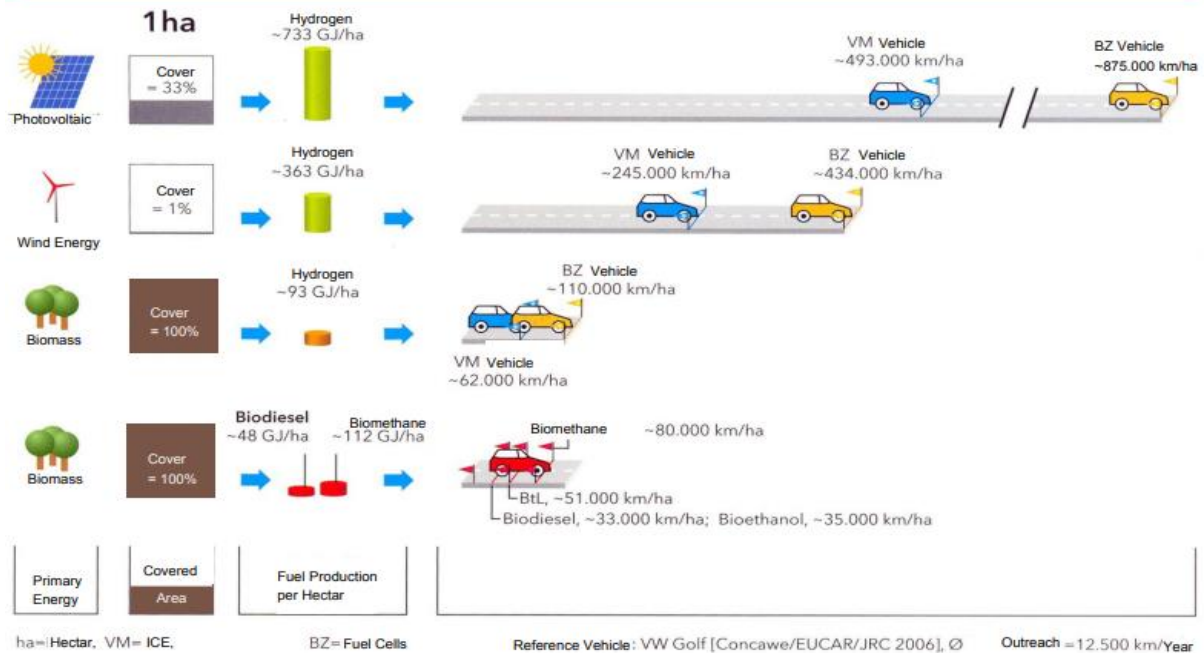
POLLUTANTS PRODUCED BY THREE ENERGY SYSTEMS

Pollutant	Fossil fuel system (kg/GJ)	Coal/synthetic fossil system (kg/GJ)	Solar-hydrogen system (kg/GJ)
CO ₂	72.40	100.00	0
CO	0.80	0.65	0
SO ₂	0.38	0.50	0
NO _x	0.34	0.32	0.10
HC	0.20	0.12	0
PM ^a	0.09	0.14	0

^a Particulate matter.

Table No.2 Pollutants produced by three energy systems [9]

Area Requirement for renewable fuels: Utilisation of land per hector for the Production of Fuels



Source : Wasserstoff aus erneuerbaren Energien, Reinhold Wurster, Ludwig-Bölkow-Systemtechnik GmbH

Fig.No.5 Area Requirement for renewable fuels [9]

Target and Current Status of H₂ Storage Technologies

Storage targets	Gravimetric kWh/kg (kg H ₂ /kg system)	Volumetric kWh/L (kg H ₂ /L system)	Costs \$/kWh (\$/kg H ₂)
2017	1.8 (0.055)	1.3 (0.040)	\$12 (\$400)
Ultimate	205 (0.075)	2.3 (0.070)	\$8 (\$266)

Projected H ₂ storage system performance	Gravimetric (kWh/kg)	Volumetric (kWh/L)	Costs (\$/kWh)
700 bar compressed (Type IV)	1.5	0.8	17
350 bar compressed (Type IV)	1.8	0.6	13
Metal hydride (NaAlH ₄)	0.4	0.4	TBD
Sorbent (MOF-5, 100 bar)	1.1	0.7	16
Chemical hydrogen storage (AB-50 wt. %)	1.7	1.3	16

Table No.3 Target and Current Status of H₂ Storage Technologies [9]

FUEL COST		
FUEL	RATE (As on April, 2022)	COST (Rs/GJ)
❖ CRUDE OIL	USD/bbl 102.84	3,150
❖ CNG	Rs/kg 195.00	3,900
❖ LPG	Rs/kg 132.00	2,674
❖ DIESEL	Rs/litre 144.15	3,774
❖ GASOLINE	Rs/litre 149.86	4,386
❖ HYDROGEN	a1) USD/kg 1.10	1,713
	b1) USD/kg 5.50	8,565
❖ ELECTRICITY	a) Rs/kWh 20.82	5,795
	b) Rs/kWh 24.67	6,866

a1: (Avg. grey hydrogen production cost, as per IEA)
b1: (Avg. green hydrogen production cost, as per IEA)

Table No.4. Fuel Cost Comparison [9]

China

China is expanding its hydrogen fueling infrastructure with several carmakers now working on fuel-cell cars, including Great Wall Motor, which plans to develop hydrogen-powered SUVs.

High production costs have kept hydrogen-powered cars from reaching a commercialized stage in China and elsewhere. The difficulties of storing and transporting the highly explosive gas add to the costs. At current market prices, hydrogen to power a fuel cell car in China costs about 70 yuan per kilogram. The figure needs to come down to less than 40 yuan per kilogram before hydrogen-powered cars can be competitive with traditional gasoline-powered vehicles, according to an estimate by Fu Guanyun, a researcher at the National Development and Reform Commission, China's state planner.

The most mature method for large-scale production of hydrogen without extracting it from fossil fuels is water electrolysis, using electricity to split water molecules into oxygen and hydrogen. The key challenge of electrolytic hydrogen production is cost, including the initial capital expenditure and electricity expenses.

More than 70% of the cost of extracting hydrogen from water is electricity. It takes about 60 kilowatt-hours of electricity to produce 1 kg of hydrogen. Based on the industrial electricity price of 0.65 yuan (\$0.10) per kilowatt-hour, the cost would be as high as 39 yuan per kilogram of hydrogen. One solution would be to use renewable energy -- such as hydroelectric, wind or solar -- in the electrolysis of water. Beijing Jingneng Power is building a 23-billion-yuan green hydrogen plant in Ordos in north China's Inner Mongolia autonomous region to be powered by solar and wind energy. Since 2019, China has had more than 30 green hydrogen projects in the work.

The mainstream view in the industry is that green hydrogen will be economical only when the cost of renewable power falls below 0.2 yuan per kilowatt-hour. The cost of wind and solar electricity now is around 0.3 yuan per kWh. Zeng Tao, chief analyst of power equipment and new energy at investment bank China International Capital, said he expects green hydrogen can cost less than coal-based hydrogen by 2040.

Most of China's hydrogen is transported by truck, which is more expensive and less efficient than pipelines. China mainly uses trailers with a capacity of 300 kg of hydrogen, which is less than half the capacity of trailers commonly used in Western countries.

Transporting hydrogen via pipeline would be efficient but requires high upfront investment. State-owned China Oil & Gas Pipeline Network, or Pipe China, included hydrogen pipeline research in its 14th Five-Year Plan. State-owned China Petroleum and Chemical, or Sinopec, is accelerating infrastructure construction for hydrogen, including pipelines and filling stations.

China has a stronger environment for nurturing the fuel cell vehicle industry, Ma said, as all parties are more willing to sacrifice short-term interests and promote the industry. In addition, China is rich in hydrogen resources and has far more production capacity than Japan, Ma said.

Since 2020, Toyota has stepped up cooperation with China's hydrogen fuel cell industry. In March, Toyota and Chinese hydrogen fuel cell engine-maker Beijing SinoHytec agreed to set up a 50-50 joint venture to produce fuel cells for commercial vehicles in China. In August last year, the Japanese carmaker established United Fuel Cell System R&D with five Chinese companies, including Beijing SinoHytec, to develop hydrogen fuel cells for commercial vehicles.

Toyota may play a role in a segment of China's hydrogen fuel cell vehicle industry that's similar to Tesla's role in battery-powered cars, Ma suggested. As the world leader in electric vehicles, the arrival of Tesla in China's market has encouraged smaller domestic players to innovate and compete, which in turn could promote growth of the entire industry. [4]

Germany

BMW and Audi are developing hydrogen fuel-cell passenger vehicle prototypes alongside their fleets of battery cars as part of preparations to abandon fossil fuels.

BMW is hydrogen's biggest proponent among Germany's carmakers, charting a path to a mass-market model around 2030. The company also has one eye on shifting hydrogen policies in Europe and in China, the world's largest car market. BMW has developed a hydrogen prototype car based on its X5 SUV, in a project already partly funded by the German government. BMW would build a test hydrogen fuel-cell car fleet of close to 100 cars in 2022.

BMW's hydrogen technology was too expensive to be viable for the consumer market today, but said costs would come down as trucking companies invested in the technology to bring fuel-cell vehicles to market at scale.

BMW saw hydrogen fuel-cell cars as "complementary" to its future battery electric model range, providing an alternative for customers who cannot charge at home, want to travel far and refuel swiftly. The motor in the hydrogen X5 is the same as BMW's all-electric iX.



Fig. No.6. BMW iX5 Hydrogen is seen during Munich Auto Show, IAA Mobility 2021 in Munich, Germany, September 8, 2021. REUTERS/Wolfgang Rattay

VW's premium Audi brand had assembled a team of more than 100 mechanics and engineers who were researching hydrogen fuel cells on behalf of the whole Volkswagen group, and had built a few prototype cars.

Hydrogen is viewed as a sure bet by the world's biggest truck makers, such as Daimler AG (unit Daimler Truck), Volvo Trucks and Hyundai, because batteries are too heavy for long-distance commercial vehicles.

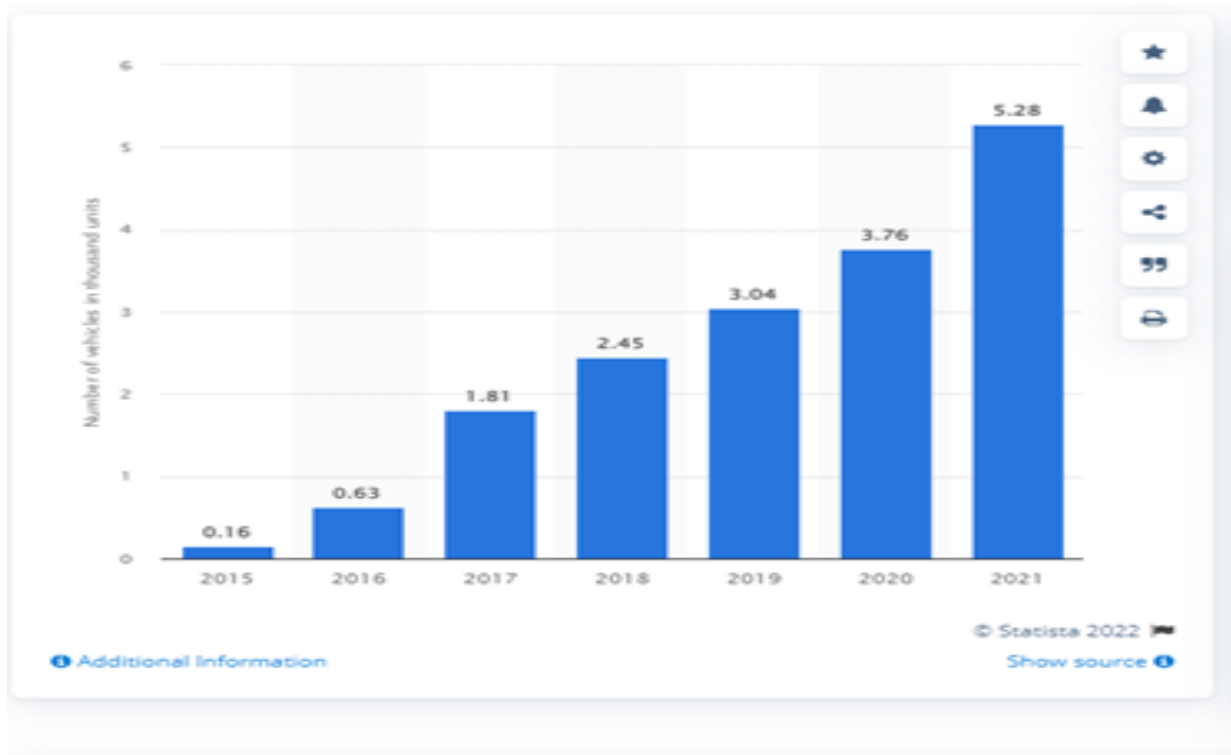
Yet fuel cell technology - where hydrogen passes through a catalyst, producing electricity - is for now too costly for mass-market consumer cars. Cells are complex and contain expensive materials, and although refueling is quicker than battery recharging, infrastructure is more scarce.

Some carmakers view hydrogen technology as an insurance policy as the EU targets an effective ban on fossil-fuel cars from 2035.

The EU wants to build more hydrogen fueling stations for commercial vehicles. Fitch Solutions auto analyst Joshua Cobb said the bloc was only likely to start pushing hydrogen passenger cars in two to three years' time, given it was still figuring out how to pay for its battery-electric car push and how to obtain enough "green" hydrogen from renewable sources. [5]

Japan

Japan is also progressing in FCEV, as shown in the following statistics that as of March 2021 approximately 5280 (i.e., $5.28 \times 1000 = 5280$) units Fuel cell electric vehicles were in use in Japan increasing from less than 200 units in 2015:



Number of hydrogen vehicles in use in Japan 2015-2021

Published by [D. Gorka](#), Dec 10, 2021

Fig. No.7. Number of FCEV in use in Japan from 2015-2021 [6]

Japanese Prime Minister Suga Yoshihide, in an official setting emphasized hydrogen as a “key technology” in the effort of Japan’s goal of reaching net-zero emissions by 2050.

The government plan includes the aim of having “electrified vehicles,” a broad category that encompasses any car propelled by an electric motor, hybrids included, account for all new auto sales by 2035.

Bolstering the ratio of fuel-cell electric vehicles (FCEVs) like the Mirai will require heavy investment in the country’s hydrogen infrastructure.

The government has pledged to increase the current number of fueling stations from 150 to 1,000 while also boosting the domestic supply of hydrogen to as much as 3 million tons by 2030, with the goal of expanding this to 20 million tons by 2050.

Toyota released the Mirai second-generation in December 2020. Toyota redesigned the fuel cell system to have fewer principal components and revamped other aspects of the car, enabling it to cut production costs by two-thirds and boost manufacturing capacity to 30,000 units a year. The new Mirai also has a 30% longer range, traveling up to 850 kilometers on a single tank, boasts a longer and wider chassis, and can carry five adult passengers, one more than its four-seater predecessor. The sticker price of ¥7.1 million still makes it a formidable investment, but for consumers in the market for a luxury sedan, its quietness, power, and stylish design make it an attractive option.



Fig.No.8 Toyota Mirai – image courtesy of Toyota Motor Corporation

Cross-Sector Cooperation Toyota has begun to offer a compact module of its fuel cell system featured in the car to companies that are developing and manufacturing fuel cell products in an attempt to give them a leg up as a means to promote the use of hydrogen across sectors. It designed the module to be easily utilized by a range of manufacturers, including makers of equipment like stationary generators as well as companies in the transportation industry, such as builders of trucks, buses, trains, and ships.

In March 2021, Toyota also announced a partnership in commercial vehicles with subsidiary Hino Motors and Isuzu Motors to accelerate the application of advances in what the company has labeled as CASE technologies, covering fields like autonomous driving and electrified vehicles. In July, Suzuki and Daihatsu declared they were joining the collaboration, expanding the potential application of Toyota's fuel-cell technology from large trucks to small commercial vehicles.

Toyota aims to sell 8 million electrified vehicles in 2030, including 2 million EVs and FCEVs. However, it is also exploring new applications for hydrogen. In May, the company entered a hydrogen engine-equipped Corolla in the Fuji Super TEC 24 Hours Race at the Fuji Speedway in Shizuoka Prefecture. The three-cylinder vehicle was fueled with hydrogen produced from renewable sources at the Fukushima Hydrogen Energy Research Field.

Unlike a fuel cell, which relies on the chemical reaction between hydrogen and oxygen to create electricity, a hydrogen engine burns the element in much the same way as a conventional gasoline motor. A number of hurdles still need to be cleared before Toyota can make a commercial model available, including boosting power output and designing components to withstand the high temperatures of hydrogen combustion. [7]

USA

Hydrogen fuel cell cars (an alternative zero-emission solution for battery-electric cars) is facing issues of price of the car, overall energy efficiency, and lack of refueling infrastructure. The year 2020 was pretty weak for FCEVs as only 937 were sold (down 55%), according to the California Fuel Cell Partnership. In 2021, things got better and achieved a new record level of **3,341 (up 257% year-over-year)**.

The California Fuel Cell Partnership's FCEVs sales data comes from Baum and Associates. "Sales data is based on car sales sold by a dealer to a retail or fleet customer".

The growth rate is high, but it's always easy from a low base. The volume, although at a record high, remains very low. It's now more than 100 times behind battery-electric cars, which are sold at a rate of several hundred thousand per year in the U.S.

Hydrogen Fuel Cell Vehicle Sales In U.S. - 2021

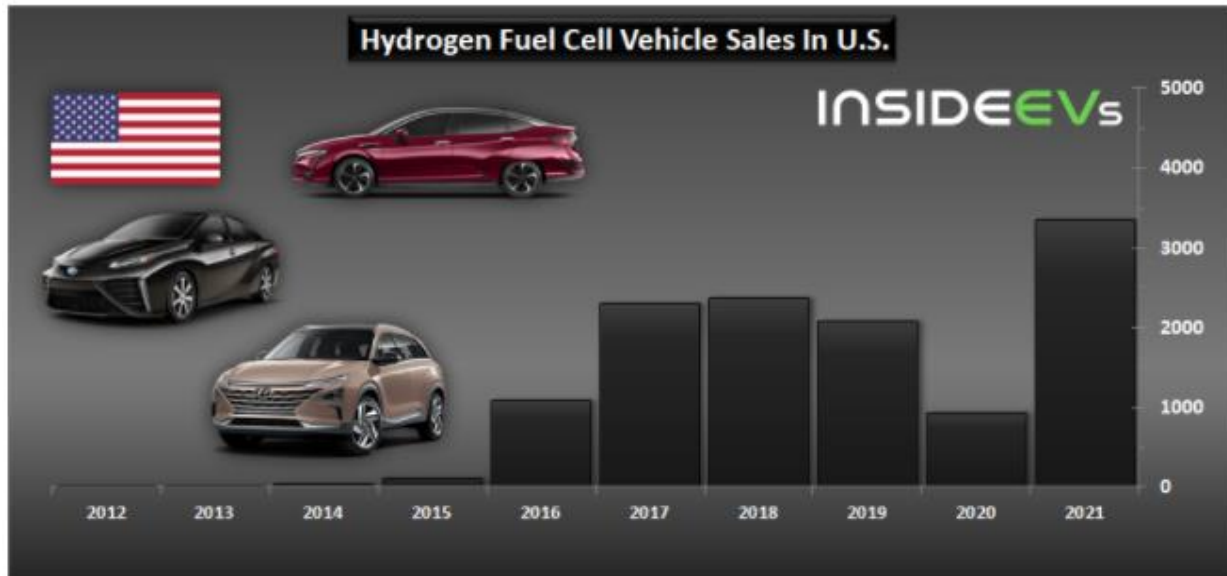


Fig.No.9 Hydrogen Fuel Cell Vehicle Sales in U.S. - 2021

The growth in 2021 is associated mostly with the push from Toyota and also Hyundai. Toyota Mirai specifically noted 2,629 sales in the U.S. which is 427% more than a year ago. It's also nearly 79% of the total FCV segment.

Sales in 2021 (Mirai and NEXO sales as reported by the manufacturers):

Toyota Mirai - **2,629** (up 427% from 499)

Hyundai NEXO - **430** (up 107% from 208)

other models - 282 (up 23% from 230)

Total: about 3,341 (up 257%, from 937)

Cumulatively, hydrogen fuel cell car sales in the U.S. reached 12,272 as of the end of 2021 (37% more than a year ago).

As of January 31, 2022, the number of open retail hydrogen stations in California stood at 48, which is just 5 (or 12%) more than a year ago on January 20, 2021. 12 new stations are under construction.

A quick calculation reveals that there are 256 cars per single station (cumulative sales divided by the number of stations). [8]

Overall view

More than 30 countries have developed hydrogen road maps, and 228 large-scale hydrogen projects were announced across the value chain, according to a report published in February by the Hydrogen Council, a global CEO-led initiative of leading companies. The council projects that hydrogen could meet 18% of total global energy demand and create a \$2.5 trillion market with more than 30 million jobs by 2050.

Japan is leading in hydrogen fuel cell technology, while the United States is at the forefront of laboratory research. Europe is more focused on upstream hydrogen production, and China has the largest hydrogen market, said Wang Cheng, director of the hydrogen fuel cell laboratory at Tsinghua University

"In terms of green hydrogen production technology, China basically stands at the same starting line with the U.S. and European countries," Wang said. [4]

In short, the global trends show that initially Battery Electric Vehicle (BEV) is the choice but later on they will be converted to FCEV's due to its benefits of outreach, zero emission and cleaner fuel technology.

5. Pakistan's EV Projections

5.1 EV Penetration Targets (as per National Electric Vehicle Policy 2019, Ministry of Climate Change, Government of Pakistan)

As discussed in National Electric Vehicle Policy 2019, Ministry of Climate Change, Government of Pakistan, the leading factor in deteriorating the climatic conditions in Pakistan is transport sector and 43% of the airborne emissions in Punjab are from transport sector [25]. In order to solve this critical challenge of deteriorating climatic conditions in Pakistan, National Electric Vehicle Policy 2019 as published by Ministry of Climate Change, Government of Pakistan has set the following EV Penetration Targets:

EV's purchase cost is much higher than the ICE based vehicles, therefore, governments around the world give subsidies, incentives and tax breaks for EV adoption amongst the masses. The expectation is that these subsidies, incentives and tax breaks will pay for itself with the savings in fuel import bill, reduction in emission related expenses, usage of idle electricity and income from charging revenues. For example, with the target penetration of first five years Pakistan will conservatively get around PKR 110 Billion yearly through savings and earnings. [25]

EV Penetration Targets	Medium Term Targets (Five Years) Cumulative	Long Term Targets (2030)	Ultimate Targets (2040)
Cars (including Vans, Jeeps and small Trucks)	100,000	30% of New Sales (Approximately 60,000)	90% of New Sales
Two and Three Wheelers Four Wheelers of UNECE 'L' Category	500,000	50% of New Sales (Approximately 900,000)	90% of New Sales
Buses	1000	50% of New Sales	90% of New Sales
Trucks	1000	30% of New Sales	90% of New Sales

Table No.4: Electric Vehicle Penetration Targets [25]

5.2 EV policy incentives for Electric vehicles (as per Auto Industry Development and Export Policy (AIDEP 2021-26), Engineering Development Board, Ministry of Industries and Production, Government of Pakistan)

The main objectives of the EV policy include the industrial growth in Pakistan by encouraging auto and related industry to adopt alternate manufacturing, mitigate negative aspects of climate change, employment generation through induction of new investments and contribute to the reduction of current account deficit through reduction in overall share of oil import bill by shifting to fuel efficient technologies. In order to achieve these objectives, following are the summarized EV policy incentives for electric vehicles which are provided in Auto Industry Development and Export Policy (AIDEP 2021-26), Engineering Development Board, Ministry of Industries and Production, Government of Pakistan):

Description	Vehicle Type	Customs Duty (CD)	General Sales Tax	Additional Incentives
Completely Knocked Down (CKD) -	Buses & Trucks	1%	1%	0% Sales Tax at import stage 0% Additional Customs Duty No FED 0% Additional Customs Duty No FED 0% Additional Customs Duty No FED 0% sales tax at import stage
EV Specific Parts	4W - Vehicles & SUVs	1%	1%	
	2W Motor Bikes & 3W Auto Rickshaw	1%	1%	
For CKD Localized Parts	Cars, SUVs, LCVs and Vans	25% (local)		
For CKD Non-Localized Parts		10% (Non-local)		
Completely Built Unit (CBU)	Buses & Trucks	1%		0% sales tax at import stage
	Passenger Vehicles & SUVs	(Maximum 100 units per company allowed with max. of 10 units/variant) (For cars/vans/SUV, with 50KWh battery or below and for LCV, with 150KWh or below battery pack only)		No FED 0% VAT and exemption of sales tax at import stage
	2W Motor Bikes & 3W Auto Rickshaw	➤ 10CBU units (for each variant) allowed at 50% of prevailing CD to the extent of 200 units (max)		0% Sales Tax at import stage
		➤ (Maximum 200 units per company allowed and subsequent manufacturing within 2 years of import will be compulsory)		
Duty- and Tax-Free Import of Plant Machinery of EV		0% CD 0% ACD		Income tax exemption for auto part manufacturers for setting up manufacturing facility for EV related equipment
Import of EV Charging Equipment		1%		
Import of all parts (local and non-local) for Heavy vehicles (i.e.; buses, trucks, and prime movers) only		1%		

Table No.5 EV policy incentives for Electric vehicles (as per Auto Industry Development and Export Policy, AIDEP 2021-26) [24]

- Other non-tariff incentives for EV's approved for Islamabad Capital Territory are as follows:
- Registration (for EV's only): Exemption from registration fees.
- Annual Tax: Annual renewal fee to be fully exempted for all kinds of EVs.
- Toll Charges: NHA/Ministry of Communications to consider 50% exemption on Toll Tax.
- Insurance: Bulk insurance at concessional rate for commercial fleets.
- Power Tariff: Special incentivized power tariff on charging stations for EV's. [24]

6. Evaluation Criteria for Electromobility Technologies

Following are the criteria for the evaluation of electromobility technologies, as per criteria defined by VDI/VDE [11]:

- 6.1 Political Targets
- 6.2 Technological Advantages
- 6.3 Storage capacity
- 6.4 Outreach
- 6.5 Efficiency
- 6.6 Infrastructure
- 6.7 Fuel provision
- 6.8 Emission free mobility
- 6.9 Critical raw materials
- 6.10 Life cycle cost
- 6.11 Value Realistic (cost)
- 6.12 Customer Use

6.1 POLITICAL TARGETS

Electromobility promotes renewed use of renewable energies in transportation industry and supports efforts towards sector coupling.

Battery vehicles (BEV) and Fuel Cell Vehicles (FCEV) are locally emission-free. They support the federal government's objectives regarding the reduction of CO₂ emissions when renewable electricity is used.

In future, production of fuel cells and fuel cell systems including the associated components will result in the value creation in Pakistan for (FCEV) Fuel Cell Electric Vehicles.

Similarly, BEV batteries manufacturing in Pakistan will also result in value creation. This will, in the long run has the potential to reduce the EV battery costs which in turn will result in the reduction of vehicle price.

This is in line with Pakistan Government's goal to promote industrialization and support local make in Pakistan initiative.

6.2 TECHNOLOGICAL ADVANTAGES

To view the differences between Electric Vehicles (i.e. BEV- Battery Electric Vehicle/All electric and FCEV- Fuel Cell electric vehicle) and Gasoline (i.e. ICE-internal combustion engine) vehicles, are shown below:

Gasoline Vehicle

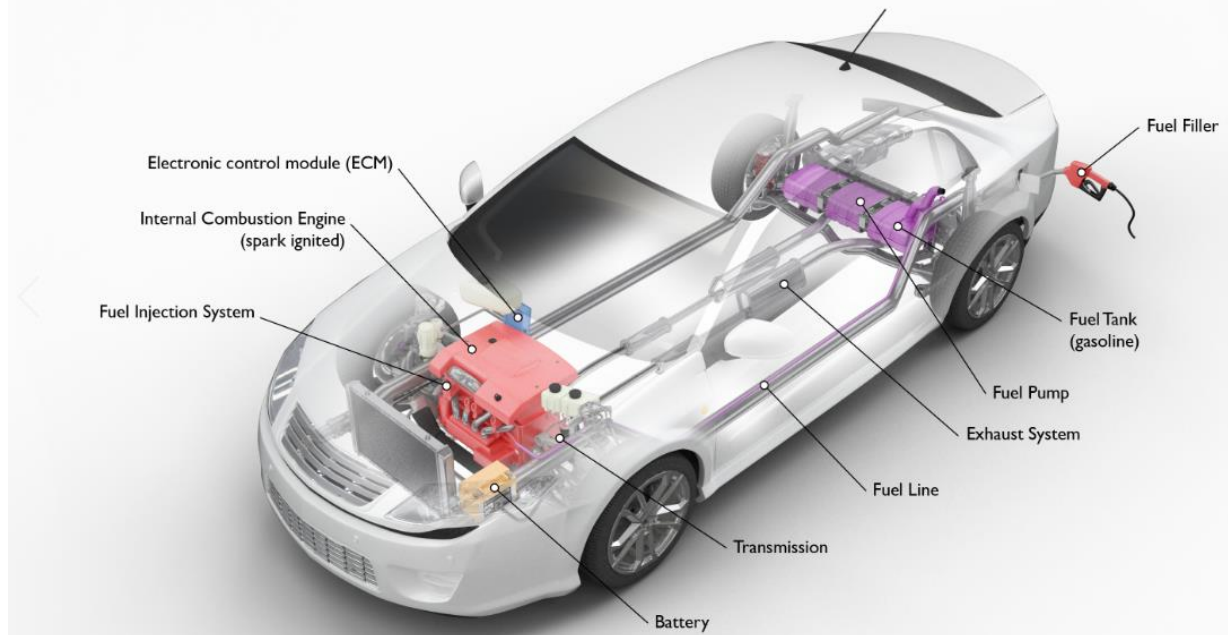


Fig.No.10 ICE-Vehicle, Image courtesy of afdc.energy.gov

All-Electric Vehicle

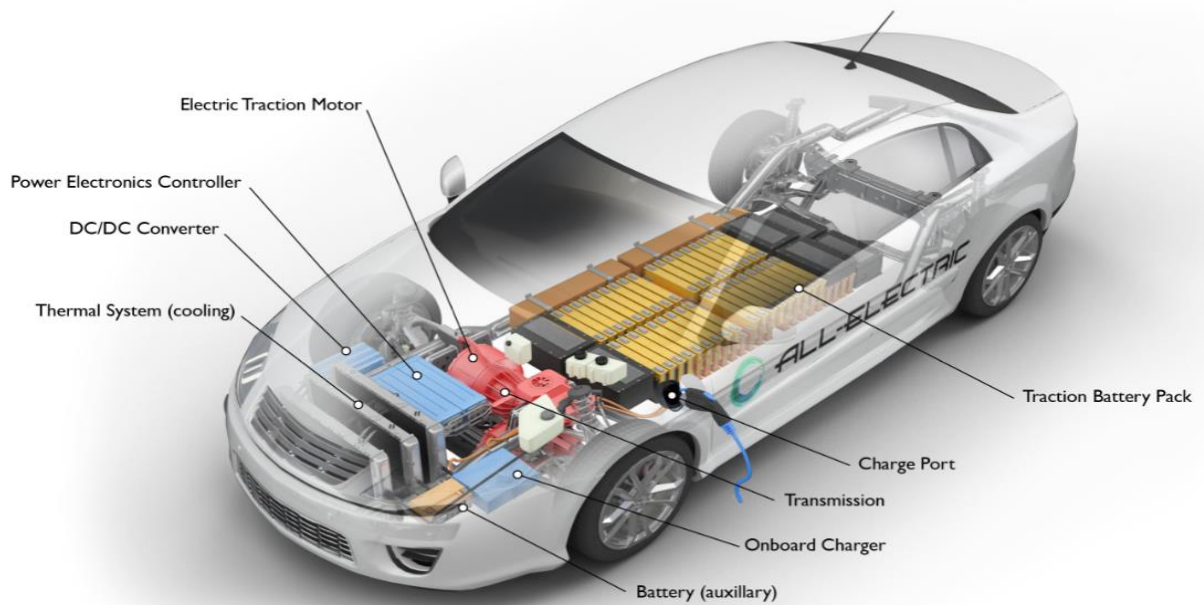


Fig.No.11 BEV, Image courtesy of afdc.energy.gov

Hydrogen Fuel Cell Electric Vehicle

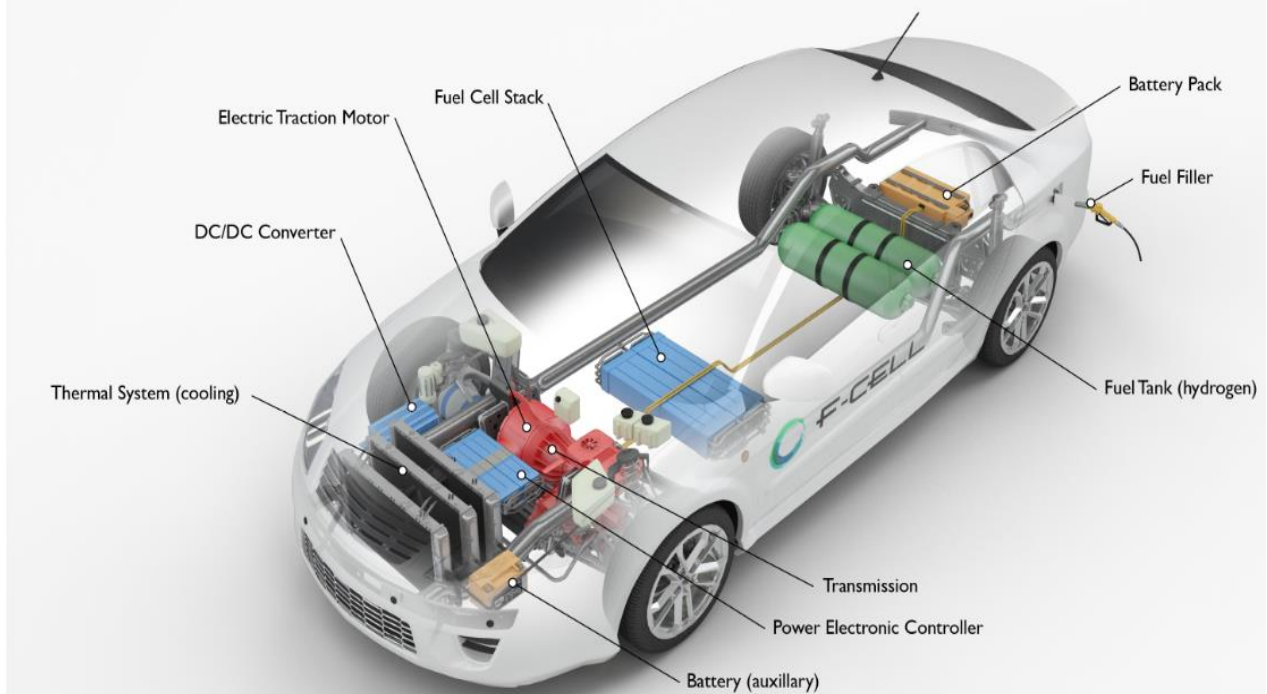


Fig.No.12 FCEV, Image courtesy of afdc.energy.gov

Basic structure view of BEV and FCEV is shown here to understand the technological advantages of Electric vehicle.

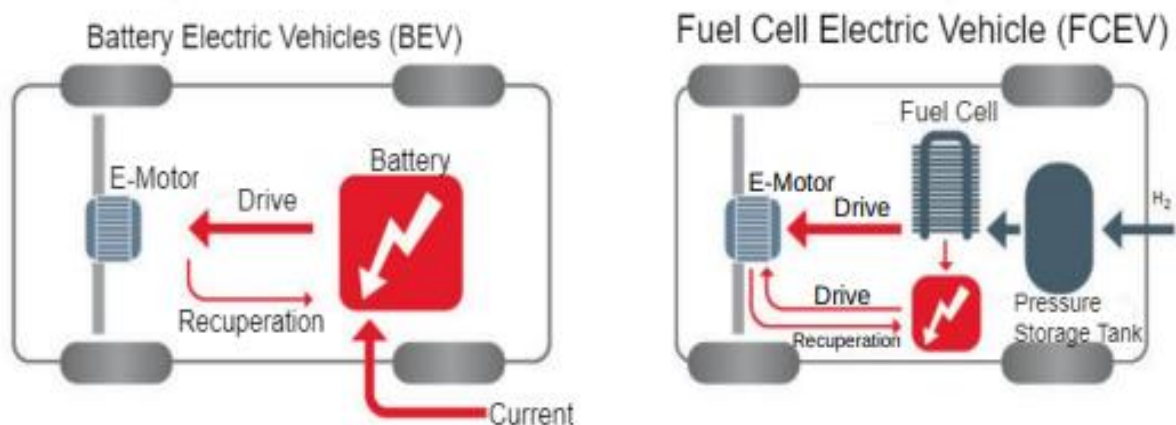


Fig.No.13 Principle of BEV (left) and FCEV (right) (Source: Forschungszentrum Julich)

Today BEVs have advantages in the short-distance area, while FCEVs are particularly recommended for payloads and long-distance travel.

In conventional (ICE) vehicles, the passenger area is heated by using waste heat from the engine. In FCEVs, the waste heat from fuel cells is generally sufficient. In contrast, in BEVs heating is only possible via the battery (through effective thermal management system). This can significantly reduce the range at low ambient temperatures.

Battery electric technology and Fuel Cell technology are complementary technologies and enable substitution from conventional combustion engines without sacrificing comfort. This can be done in medium to long term contribution to reducing the economic costs of mobility compared to the status quo. [11]

6.2.1 Key components of Electric Vehicles

Following are the key components of Electric Vehicles:

6.2.1.1. Electric Vehicle Battery

Following are different types of electric vehicle batteries which are discussed here:

- Solid State Battery
- Lithium-Ion (Li-On)
- Nickel-Metal Hybrid (NiMH)
- Lead Acid (SLA)
- Ultracapacitor

Solid-state Battery

Solid-state battery is a recent development in EV battery industry showing promising results over Li-ion-battery. A lithium-ion battery is composed of cathode, anode, separator and electrolyte. It uses liquid electrolyte solution.

On the other hand, a solid-state battery uses solid electrolyte, not liquid. It is to increase capacity of EV batteries.

A solid-state battery has higher energy density than a Li-ion battery. It doesn't have a risk of explosion or fire, so there is no need to have components for safety, thus saving more space. [12]

Conventional Li-ion cells use a liquid-based electrolyte – commonly a lithium salt suspended in an organic solvent – while solid-state cells swap that out for a wafer-thin solid electrolyte (usually made from either ceramic, polymer or glass). Solid-state cells are lighter and more compact than their liquid-based counterparts, meaning pack weight can be reduced, or energy capacity increased. They should be more resistant to lithium dendrite formation, which will improve power discharge performance and raise potential charging speeds, along with extending the service life of the battery pack. In addition, once mass-manufacturing is achieved, they should be easier and quicker to make than conventional Li-ion cells thanks to the removal of solvents and having fewer production steps. [13]

Lithium-Ion Battery (Li-On)



Fig.No.14 Lithium-Ion Battery [14]

Li-On battery is most widely applied in the battery electric vehicle. The main difference is a matter of scale. Its physical capacity and size on electric cars is much greater – this is often referred to as a traction battery pack. It has very high power to weight ratio, high energy efficiency and performance at high temperatures is also good. This battery type has a greater energy ratio per weight – a parameter that is very important for electric car batteries. The smaller the battery weight (same kWh capacity) means the car can travel further with a single charge.

This battery also has a low “self-discharge” level, so the battery is better than any other battery in maintaining its ability to hold its full charge.

In addition, most parts of Li-on batteries can be recycled, making it the right choice for those interested in environmentally conscious electric cars.

Li-on battery Types:

- Lithium Iron Phosphate(LiFePO_4) — LFP
- Lithium Nickel Cobalt Aluminum Oxide (LiNiCoAlO_2) — NCA
- Lithium Nickel Manganese Cobalt Oxide (LiNiMnCoO_2) — NMC
- Lithium Titanate (Li_2TiO_3) — LTO
- Lithium Manganese Oxide (LiMn_2O_4) — LMO
- Lithium Cobalt Oxide(LiCoO_2) — LCO

Hybrid Nickel-Metal (NiMH) Batteries



Fig.No.15 Lithium-Ion Battery [14]

NiMH batteries are more widely used by hybrid-electric vehicles (HEV), but are also used successfully in some BEV cars.

Lead-Acid (SLA) Batteries

SLA (lead-acid) batteries are the oldest rechargeable batteries. Compared to lithium and NiMH batteries, lead-acid batteries do lose capacity and are much heavier, but the price is relatively cheap and safe.

Ultra-capacitor Batteries



Fig.No.16 Lithium-Ion Battery [14]

The ultra-capacitor battery is not like the general definition of a battery. In contrast to other electro-chemical batteries, this type of electric vehicle battery actually stores polarized liquid between the electrode and the electrolyte. Like SLA batteries, ultra-capacitor batteries are very suitable as secondary storage devices in electric vehicles. The comparison of last four types of electric car batteries can be seen as follows:

Understanding Electric Car Batteries				
	Lithium Ion	Nickel-Metal	Lead-Acid	Ultracapacitors
Easy Access / Inexpensive	✓	✗	✓	✗
Energy Efficient	✓	✓	✓	✓
Temp. Performance	✓	✗	✗	✓
Weight	✓	✓	✓	✓
Life Cycle	✓	✗	✓	✗

Table No.6: Comparison of last four types of electric car batteries [14]

Difference between Lithium-ion battery compared to Solid State Battery

The below figure illustrates the difference between Lithium-ion battery and Solid-state battery.

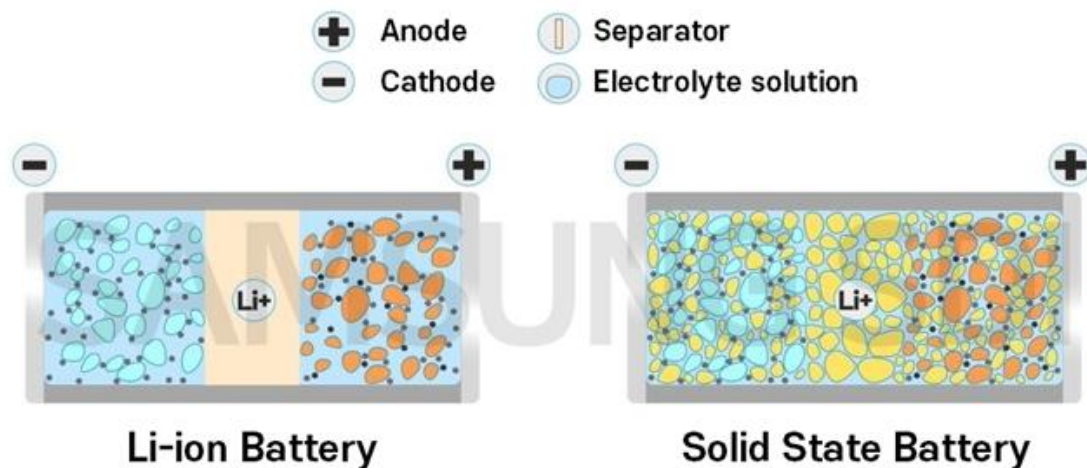


Fig.No.17 [Structure of Li-ion battery(left) and solid-state battery(right)]
 Courtesy SAMSUNG SDI

Looking at the image above, the commercially used Li-ion battery has a separator that keeps cathode and anode apart, with liquid electrolyte solution. On the other hand, the solid-state battery uses solid electrolyte (not liquid electrolyte solution) and the solid electrolyte plays a role of a separator as well.

The current Li-ion battery has a risk of battery damage such as swelling caused by temperature change or leakage caused by external force since it uses liquid electrolyte solution. However, a solid-state battery with solid electrolyte shows improved stability with a solid structure, and increased safety since it maintains the form even if the electrolyte is damaged.

A solid-state battery can increase energy density per unit area since only a small number of batteries are needed. For that reason, a solid-state battery is perfect to make an EV battery system of module and pack, which needs high capacity.

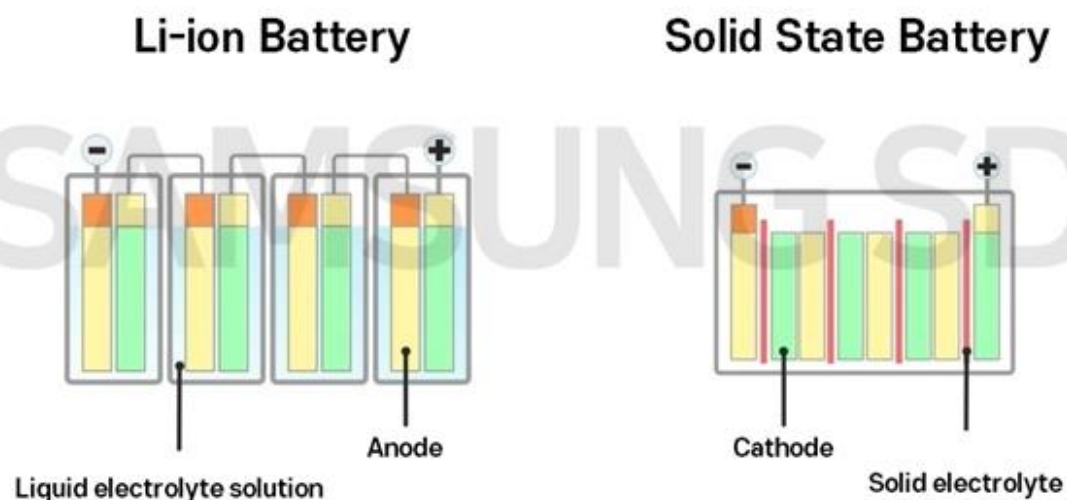


Fig. No.18 [A downsized solid-state battery(right) with the same capacity as the Li-ion battery(left)] –
 Courtesy SAMSUNG SDI

Market trend of a solid-state battery

Samsung SDI is currently working on developing the solid-state battery. In March, the Samsung Advanced Institute of Technology showed the research result of a solid-state battery that can be charged/discharged over 1,000 times with 800km of mileage on a single charge. The study about the technology that increases life cycle and safety, and reduces the size of a solid-state battery in half was published in the 'Nature Energy', a global scientific journal. [13]

Sakuú has been developing its first generation SSB battery technology alongside its flagship additive manufacturing platform. These first-generation batteries comprise 30 sub-cells, utilize lithium-metal and a proprietary printed ceramic separator. The battery has been designed to use current industry standard cathode materials and can support even higher voltage cathodes in the future that could yield up to 25% more energy. This makes the new battery perfectly suited for consumer, aerospace, mobility, and many other applications given its advantages in safety and energy density.

“Over the last year, we have improved our battery energy capacity by a factor of 100 and our volumetric energy efficiency over 12 times and are planning to begin volume production of the batteries in early 2022 to meet the needs of our strategic partners,” said Robert Bagheri CEO and Founder, Sakuú Corp. [15]

6.2.1.2. Electric Motor

There are various types of motors used in EVs.

Overview of Motor Types

EVs use traction motors that are capable of delivering torque to the wheels. Electric motors can be roughly divided into two types: DC and AC motors. Both types can be used in EV applications. DC motors are robust and allow simple control. They can be made as brushed and brushless DC motors. Brushed DC motors are a mature technology that provides low cost, high torque at low speed, and easy speed control. These features are very important for traction motors. However, brushed DC motors are not widely used in EVs because of their disadvantages, which include large size, low efficiency, and requirement for frequent maintenance due to the brush and collector structure. Brushless DC motors have a much higher efficiency. These motors use an electronic commutator/inverter instead of the brushes.

Compared to DC motors, the advantages of AC motors are high efficiency, less maintenance, higher reliability, and regenerative capability that enables braking energy to be returned to the batteries.

What Features Should an EV Motor Have?

An EV's motor and electronics efficiency directly influences the battery weight, because the lost power needs to be compensated. Every 1% lower efficiency requires 1% more power from the battery (meaning more batteries). The EV's performance directly depends on the electrical motor specifications. The performance of the motor is determined by the torque-speed and power-speed characteristic of the traction motor.

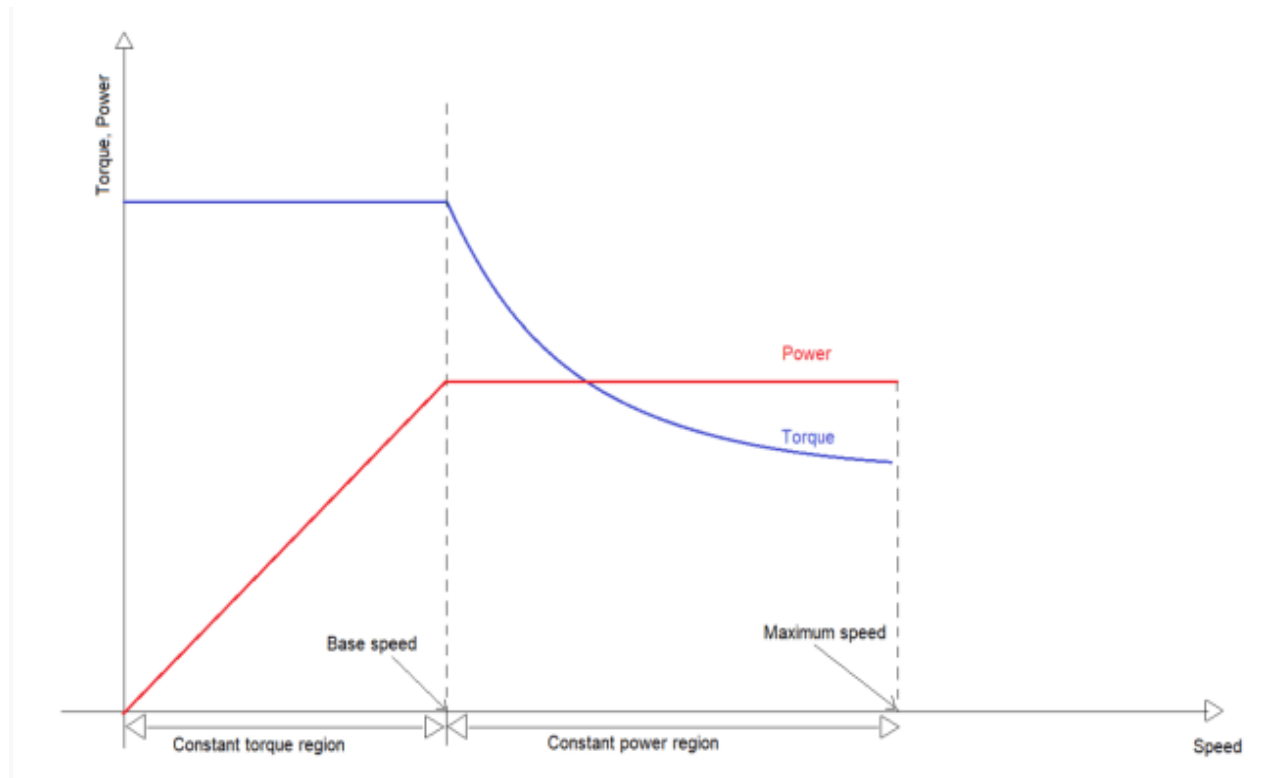


Fig. No.19 Torque/power – speed traction motor characteristics. [16]

The grade ability and maximum speed are important parameters in these curves. The desired motor grade ability requires high torque at low speed, enabling proper starting and acceleration. The EV motor needs to have high power at high speed and a wide speed range in the constant power region as shown in Figure 1. The constant torque operating region is important at low speed to provide a good start and up-hill drive. The constant power region determines the maximum EV speed on flat surfaces.

When the base speed is achieved, the motor reaches its rated power limit and the motor torque decreases proportionally to the square of speed. The constant power region starts beyond base speed in the range from base speed up to maximum motor speed. This range is different in different motor types and it is an important parameter when selecting the proper EV motor type. Also, the motor operation range can be adjusted by using the corresponding control drives.

Selecting the proper output characteristic of an EV motor is a challenge because it is necessary to find the balance between acceleration performance and wide speed range in the constant power region. When increasing the constant power region, the power requirement for acceleration performance is decreased. The torque requirement is increased which influences the motor size and its final price.

These are the features we desire in an EV motor:

- High efficiency
- High instant power
- Fast torque response
- High power density
- Low cost
- High acceleration
- Robustness

We will now look at how these features stack up in the following motor types:

1. DC motors
2. Permanent Magnet Brushless DC motors (PM BLDCs)
3. Induction motors
4. Permanent Magnet Motors
5. Switched Reluctance Motors (SRM)

DC Motor

The biggest advantages of DC motors in EVs are robust construction and simple control. DC motors have appropriate torque-speed characteristics providing high torque at low speed. Their main disadvantages are size, low efficiency, low reliability and high maintenance, and limited speed because of the friction between brushes and collectors. There are two DC motor types: brushless and brushed DC motors. The latter are increasingly suppressed because of the advances in power electronics.

Permanent Magnet Brushless DC Motor (PM BLDC)

PM BLDC motors use permanent magnets instead of the rotor windings. Since they do not include rotor losses their efficiency is higher than inductive motors. PM BLDC motors have a short constant power operation region because of their permanent magnet field weakened by a stator field. Since EVs require a wider constant power region, this can be extended by using conduction angle control where the speed range may reach three to four times the base speed.

The permanent magnets also limit the motor torque to be high. The magnets are significantly influenced by the high temperature which reduces the remnant flux density and thus the motor torque capacity. The mechanical forces and magnet prices are the biggest disadvantages of this type of motor. The increased centrifugal forces caused by higher motor rotation speed can cause safety issues due to the possible breaking of the magnets.

Induction Motor (IM)

This motor type is very common in EVs because of its simple construction, high reliability, robustness, simple maintenance, and low cost and operation at different environmental conditions. IMs can be naturally de-excited if the inverter faults, an important safety advantage for EVs. The field-oriented vector control of IMs is industrially standardized.

The disadvantages of IMs are slightly lower efficiency (compared to PM motors), higher power losses (increased because of the cage losses), and a relatively low power factor. The weakening of the flux can be used to extend the speed range in the constant power operation region. This

region can be extended by using dual inverters as well. Rotor losses can be also reduced by careful motor design.

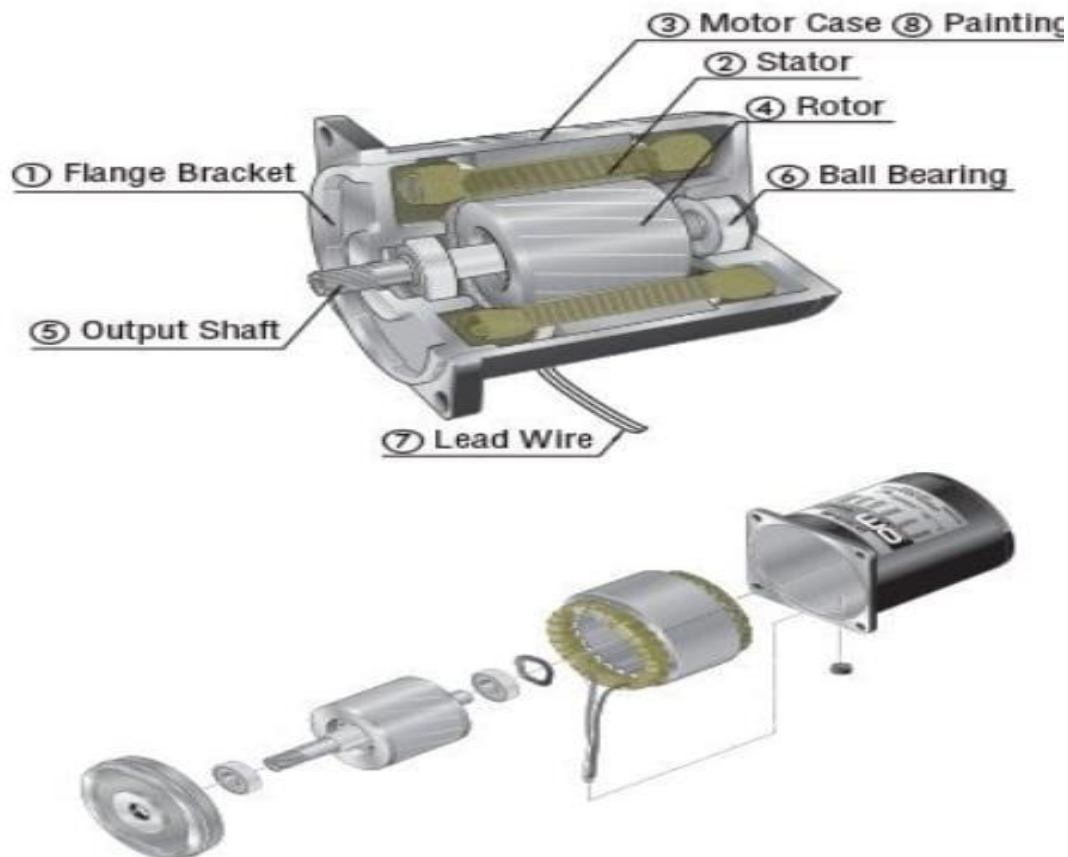


Fig.No.20 Construction of an induction motor. (Image courtesy of Orientalmotor.)

Permanent Magnet Synchronous Motor (PMSM)

PMSMs, similar to BLDCs, have permanent magnets in the rotor. Unlike BLDC motors that have a trapezoidal back electromotive force (EMF) waveform, PMSMs have a sinusoidal back EMF. They have a simple construction, high efficiency, and high power density, thus they are suitable to be used as traction motors (common in hybrid vehicles, EVs, and buses). PMSM motors have a higher efficiency compared to IMs. The drawbacks of this type are high costs, eddy current loss in PMs at high speed, and a reliability risk because of the possible breaking of the magnets. There are two varieties of PMSM motors: surface-mounted permanent magnet (SPM) and interior permanent magnet (IPM) synchronous motor drives. IPM motors have better performance than SPMs, but the downside is their complex design.

Switched Reluctance Motor (SRM)

The benefit of SRMs is their high torque component, enabling their use in many applications such as wind energy, generator starter systems in gas turbine engines, and high-performance aerospace applications. Moreover, their advantages in EVs include their robustness, simple control, high efficiency, wide constant power operation region, fault tolerance, and effective torque-speed characteristics. Since they do not contain brushes, collectors, or magnets, the maintenance of SRMs is very simple and effective and their price is very competitive.

The absence of magnets eliminates the problem with mechanical forces, enabling the motor to operate at a high speed. Since the motor's windings are not used, there are no copper losses in the rotor ensuring the rotor temperature is lower than other motor types. Since the phases are not connected, SRM motors can continue their operation even when one of the phases disconnects. SRM rotors have a lower inertia than other motor types. The drawbacks of this motor type are increased vibration and acoustic noise. In addition, the salient-pole rotor and stator construction cause high torque ripple. The high rotor inductance ratio allows sensor-less control to perform. Proper motor design enables the wide constant power operation region, which in turn allows operation at high speeds. SRMs have a suitable torque/power speed characteristic for EV applications.

Comparison and Evaluation

Dorrell et al. [16.1] evaluated IPM, IM, and SRM motors and compared them at a rotating speed of 1500 rpm and 6000 rpm and their maximum power. Parameters under consideration included torque, iron loss, copper loss, efficiency, and current density.

For the case of 1500 rpm, the torques of IPM and IM are higher than SRM. IM has higher copper losses. It is shown that IPM has the highest efficiency (91.3%).

At 6000 rpm, SRM provides the highest torque value. The IPM has again the highest efficiency and it is higher at higher speed (SRM 96.1%, IM 95.2%, SRM 88.2%).

Mounir et al. [16.2] analyzed DC, IM, PM, and SRM types by comparing their power density, efficiency, controllability, reliability, and price in EV applications.

Characteristics		Motor type		
	DC	IM	PM	SRM
Power density	Low	Medium	Very high	Medium
Efficiency	Low	Medium	Very high	Medium
Controllability	Very high	Very high	High	Medium
Reliability	Medium	Very high	High	Very high
Technological maturity	Very high	Very high	High	High
Cost	Low	Very low	High	Low

Table No.7 Comparing the relevant features of different motor types [16]

It is noticeable that the IM motor type has all the characteristics suitable for EVs. In this application, safety is one of the most important considerations and the SRM and IM types provide driving safety. However, the rated speed of IM is relatively low. PM has a higher power factor and efficiency in low-speed region.

The SRM type does not use brush collectors and magnets and thus has fewer maintenance requirements. This type also has lower power losses than other types. This is because of the short winding ends and their total length. The rotor does not contain conductors enabling low rotor temperature and easy cooling, which is one of the main advantages of SRM type motors. SRM operates at high speeds in a wide constant power region and allows the extremely high-speed operation. Besides this, the motor is lightweight, competitive and has high efficiency. If all characteristics are considered, SRM is the most suitable motor type for EVs.

Even with their relatively high power density and efficiency, BLDC motors are not commonly used in EV applications, mostly because of their limited constant power range.

Motor Types Used by Popular EVs

The Tesla Model S and Model X use conventional IMs. The Model 3 uses an SRM with internal permanent magnets in the stator, called an internal permanent magnet switched reluctance motor (IPM-SRM). Dual-motor versions were also introduced by Tesla—the Model 3 uses an IM in the front and an IPM-SRM in the back. It is the opposite case for the Model S and Model X.

The GM Chevrolet Bolt uses a PMSM where the magnets are placed inside the rotor. This motor type is also used by the Toyota Prius, Nissan Leaf, and BMW i3. Every manufacturer utilizes their approaches and technologies to make their propulsion as efficient as possible and produces many varieties of the same motor type. [16]

6.2.1.3. Battery Management System

To prevent battery failure and mitigate potential hazardous situations, there is a need for a supervising system that ensures that batteries function properly in the final application. This supervising system is referred to as a Battery Management System (BMS).

6.2.1.3.1 Functions of Battery Management System in EV

The primary function of a BMS is to fulfill safety requirements. Objectives related to the more efficient usage of battery cells and prolongation of their lifetime are also being increasingly integrated into the design of BMS. It should be designed with a minimal set of requirements such as:

- It must measure individual cell voltages.
- The BMS must measure temperatures at different points as close as possible to the battery.
- It must measure currents flowing through it.
- The BMS should communicate information to control units and undertake action to ensure the battery will be operated within safety limits.
- The BMS should balance battery cells passively or actively.
- And, the BMS should provide thermal management support

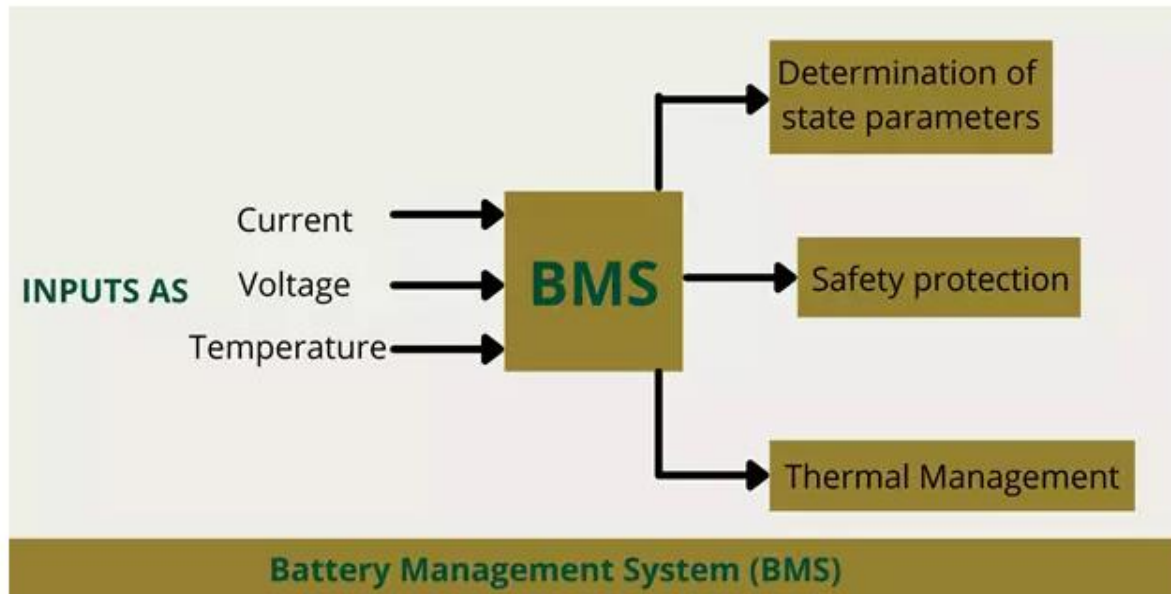


Fig.No.21 Battery Management System [17]

6.2.1.3.2 Battery State Parameters

For the management of the batteries during electric vehicle operation, to achieve the best performance and prolong battery life, it is necessary to monitor various states inside the battery depending on the battery management system (BMS) in real-time.

These states include state of health (SoH), state-of-charge (SoC), state-of-function (SoF), charge acceptance (CA), etc.

State of Charge (SoC)

All vehicles have a fuel indicator, in the same way, EVs also have a battery state of charge (SoC) indicator. BMS helps in indicating and showing the driver the actual state of charge in the battery. The SoC of a cell is a percentage value that expresses the remaining charge Q of a battery.

State of Health Definition (SoH)

With advancing battery degradation, the internal resistance of the battery increases while the capacity of the cell fades. This leads to drastic changes in cell behavior and might make a cell unsuitable to be used for its primary application, such as in an EV. Therefore, it is necessary to track the cell degradation, using the parameter state of health (SoH).

The battery SoH characterized by the slow-changing parameters, such as capacity fading and resistance increasing, varies with cycles and hence it needs to be monitored in a long timescale.

State of function definition (SoF)

In simple words, SoF can be defined as a parameter that describes how a battery's performance meets the application's demands during use. The SoF can either be a percentage value, a concrete value in, for example, kW, or even a binary value representing whether the battery is or is not able to fulfill the demand of the application. A more generalized definition of SoF can be as the fraction of the ΔP (difference of available power to demanded power) to the ΔP_{max} (difference

of maximum power battery pack can supply to demanded power), that is, it is a percentage value that describes how much the current battery state (SoC, SoH, temperature, etc.) differs from the optimal battery state.

Charge acceptance (CA)

It indicates the maximum charging current the battery can accept at present conditions (SoC, SoH, temperature) and for a given charging voltage and is therefore highly relevant for regenerative braking. However, both SoC and SoH cannot be directly measured by the sensors, they are only monitored and reflected based on the measured parameters such as voltage, current, temperature, and internal resistance. A variety of methods have been developed for both SoC and SoH estimation. Considering the practical applications, the methods can be roughly categorized into online and offline ones.

The online methods can be used for the real-time state estimation of the battery. However, the offline methods are not suitable during battery operations due to strict experimental schemes or high computational costs.

6.2.1.3.3 Classification of Soc, SoH Estimation Methods

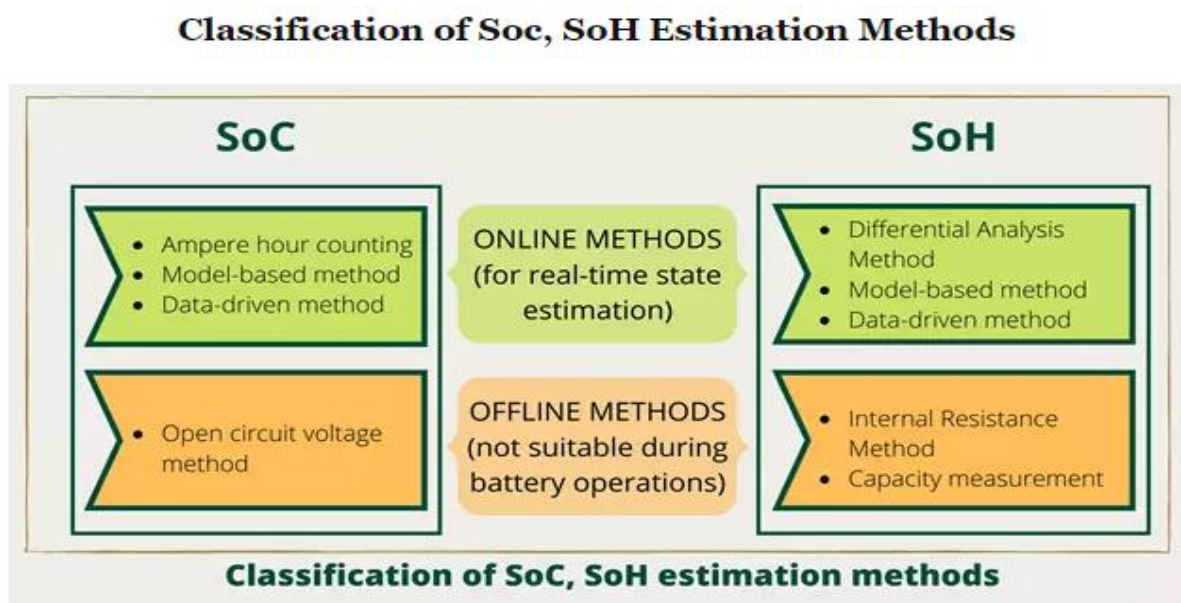


Fig.No.22 Classification of SoC, SoH estimation methods [17]

Beyond the basic functionality of a BMS for hybrid electric vehicles (HEVs)/ battery electric vehicles (BEVs) of measuring cell voltages, cell temperatures, and the current flowing through the battery pack, automotive BMS must provide methods for charge equalization of imbalances between the individual cells of a multi-cell battery system to increase both the cell lifetime and the usable energy in each discharge cycle.

6.2.1.3.4 Battery Cell Balancing

The imbalances between the cells are exacerbated by continual charge/discharge cycles if they are not corrected, which results in drifting apart of the cells. Cells with less total capacity than the best performing cells in the system could become overcharged, which causes those cells to degrade prematurely.

This degradation leads to a capacity fade and consequently accelerates the original problem. Additionally, this overcharging can become a safety hazard as it might cause active components in the battery to react with each other and cause a thermal runaway.

6.2.1.3.5 Causes of Imbalance in Battery Cells

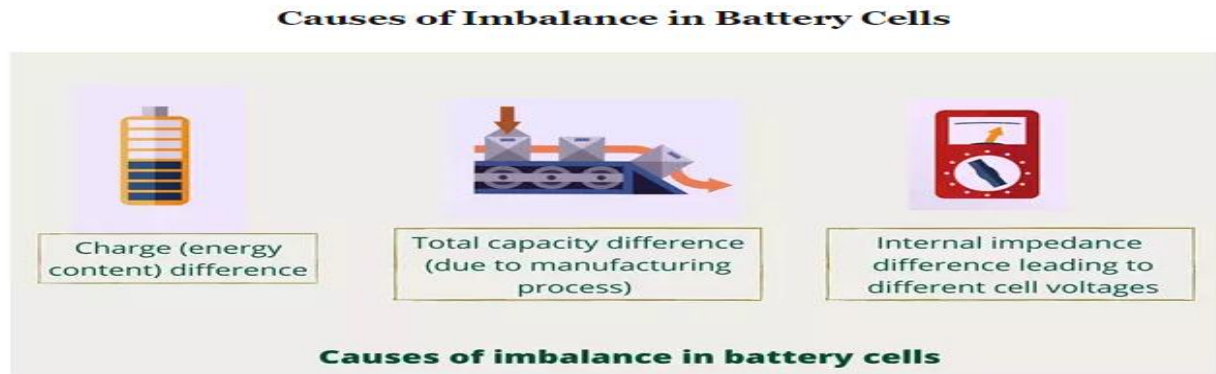


Fig.No.23 Causes of Imbalance in Battery cells [17]

6.2.1.3.6 Classification Systems for Balancing Methods

There are different classification systems for balancing methods.

- **Static Methods**

Methods that are either carried out before the pack is in operation or are not controllable by the BMS once the pack is in operation.

- **Dynamic methods**

Balancing methods that are controllable by the BMS, further divided into active and passive methods. The active cell balancing technique uses inductive charge shuttling or capacitive charge shuttling to transfer the charge between the cells. This technique is proven to be an efficient approach as it transfers energy to where the energy is needed instead of wasting it.

However, this demands additional components to be added to the system which in turn translates to increased cost. The passive cell balancing technique uses the idea of discharging the cells through a bypass route that is mostly dissipative in nature.

It is simpler and easier to implement than active balancing techniques as the bypass can either be external or be integrated — keeping the system more cost-effective either way. However, since all the excess energy is dissipated as heat, battery run time is adversely impacted and is less likely to be used during discharge.

Adopting precise cell balancing achieves a larger capacity for the intended application because the state of charge (SoC) that can be accomplished is higher. [17]

6.2.1.4. Thermal Management System

Thermal management entails regulating heat flows inside the vehicle. After all, components must be operated in their respective optimal temperature range while also generating pleasant temperatures for passengers in the vehicle interior. Thermal management systems in electric vehicles are generally more complex than in conventional vehicles featuring combustion engines.

The eAxle (for example), must be cooled at all times while the battery needs to be cooled or heated depending on the respective situation. Furthermore, no waste heat is available from a combustion engine to heat the vehicle interior requiring the use of energy-efficient measures here, e.g. by using a heat pump.

The refrigerant circuit and the cooling circuit must be optimally coordinated to transport heat inside the vehicle and to provide the requisite temperatures. Interconnection of these two circuits changes depending on the heating or cooling requirements. This gives rise to various operating modes. Coolant is circulated by a pump in the cooling circuit. The coolant transports heat from where it is produced to wherever it is required inside the vehicle.

The high specific thermal capacity enables coolant to absorb a lot of heat in a very small space, which is necessary for effectively cooling the eAxle or battery, as an example. Coolant can also be used to distribute heat very flexibly within the vehicle. When coolant absorbs heat, its temperature rises and needs to be cooled in a heat exchanger.

A refrigerant circulates in the refrigerant circuit which can be both liquid and gaseous. By means of evaporation (transition from liquid to gaseous) of the refrigerant, a refrigerating capacity is generated which facilitates cooling even below the ambient temperature. This well-known principle for air conditioning the vehicle interior in the summer is also used to cool the battery at very high outdoor temperatures. The heat released during condensation (transition from gaseous to liquid) can also be used to heat the vehicle interior in winter. The refrigerant circuit is powered by an electric air conditioning compressor which compresses the refrigerant to the requisite pressure, enabling evaporation and condensation at the chosen temperature levels.

Winter driving

At cold outdoor temperatures, both the vehicle interior and the battery require heating in order to guarantee full drive power at all times. The interior is heated via the heat pump with the refrigerant circuit. The battery is heated using an electric flow heater with additional support provided by waste heat from the eAxle. Using a heat pump improves the efficiency of the interior heating, which also has a positive effect on the vehicle's range. By utilizing waste heat from the eAxle to heat the battery, efficiency is improved and full battery performance is guaranteed.

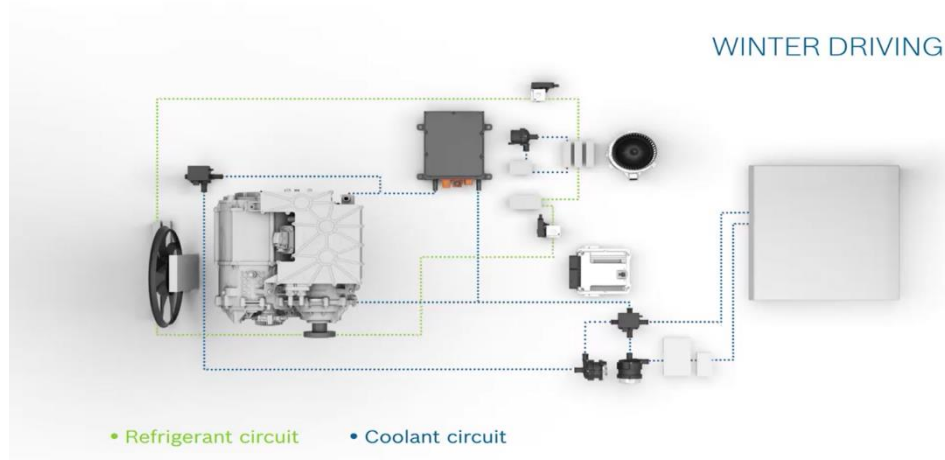


Fig.No.24 Winter Driving Circuit [19]

Fall and spring driving

At moderate outdoor temperatures, the battery and eAxle can be cooled together by a cooling circuit, whereby the waste heat is dissipated into the environment via the cooling module. This reduces energy consumption for thermal management to a minimum which has a positive effect on efficiency and range. At the same time, the battery and the eAxle can be set at optimal temperature levels for optimal operation of the powertrain.

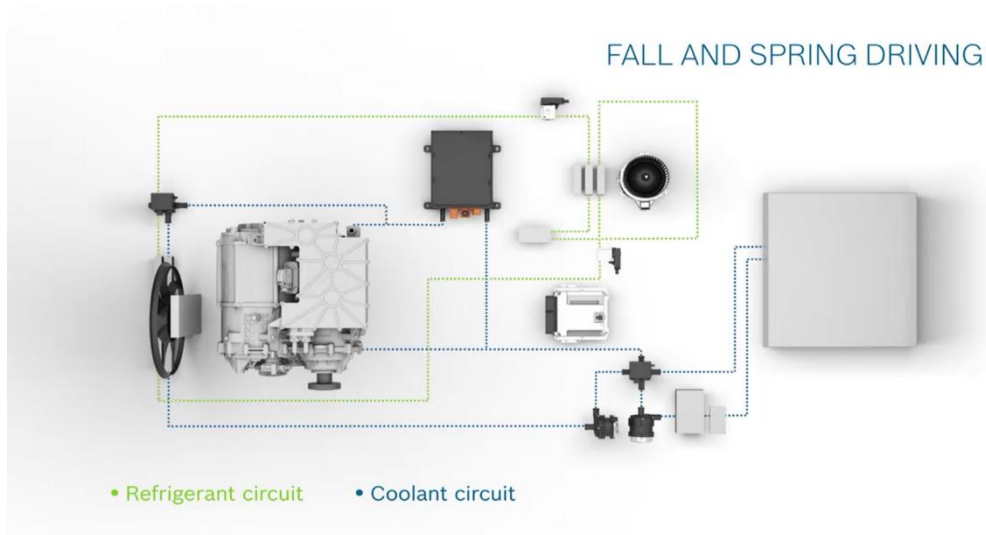


Fig.No.25 Fall and Spring Driving Circuit [19]

Summer driving

At high outdoor temperatures, the battery needs cooling via the chiller (heat exchanger between the cooling and refrigerant circuit) and the refrigerant circuit in order to guarantee the permissible maximum battery temperature, thereby ensuring a long battery service life. The refrigerant circuit is also responsible for air conditioning the vehicle interior. Separate from the battery, the eAxle is cooled via the cooling module which makes unlimited and energy-efficient cooling of the eAxle possible.

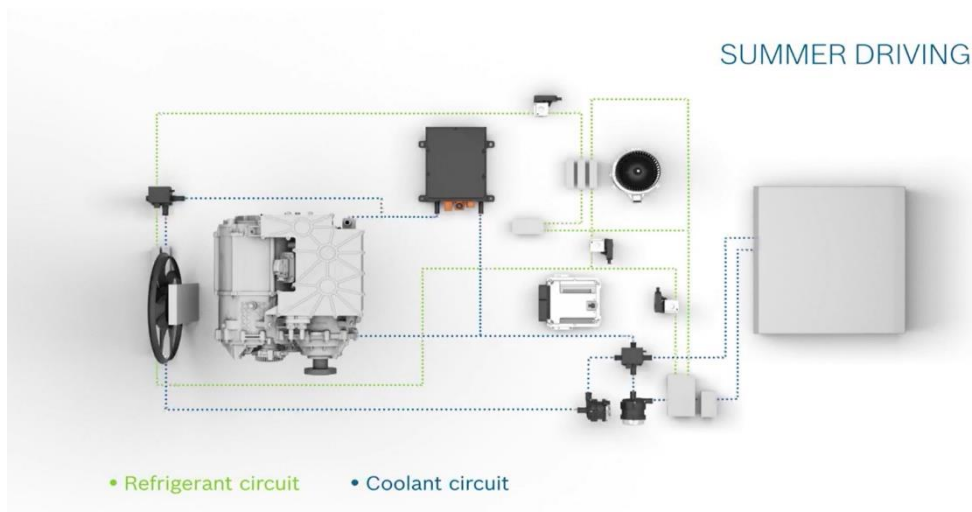


Fig.No.26 Summer Driving Circuit [19]

Normal charging

At home or at work, a limited charging capacity with alternating current is usually available for charging the battery. The charger – responsible for converting alternating current into direct current – and the battery are both cooled via a cooling circuit and the cooling module. This makes it possible to minimize charge losses which also has a positive effect on the charge time.

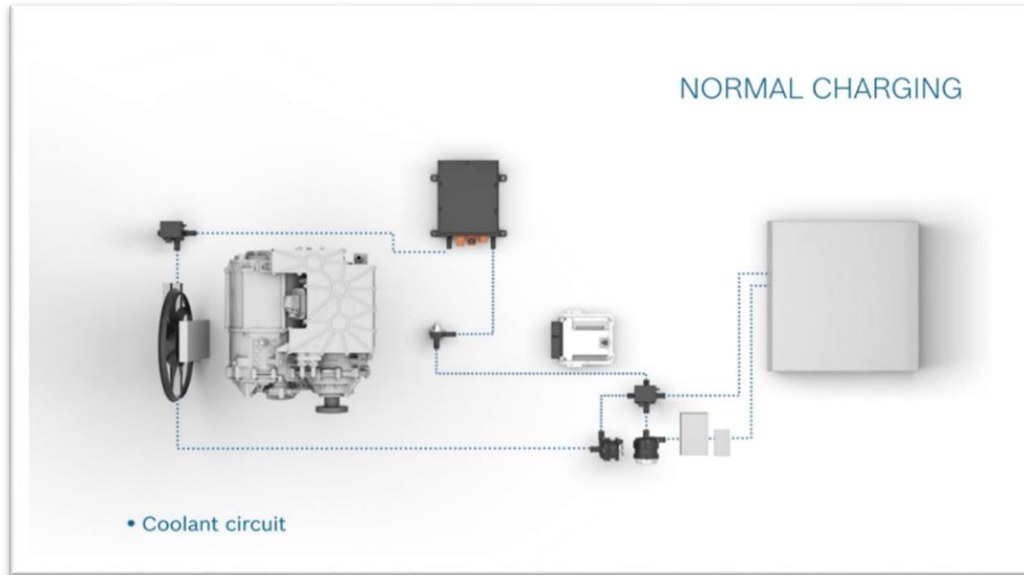


Fig.No.27 Normal Charging Circuit [19]

Fast charging

Fast charging at high outdoor temperatures causes the temperature inside the battery to rise very fast. To prevent the permissible maximum temperature from being exceeded and enable the swift dissipation of heat, the battery is cooled via the chiller (heat exchanger between the cooling and refrigerant circuit) and the refrigerant circuit. This ensures fast charging at all times. [19]

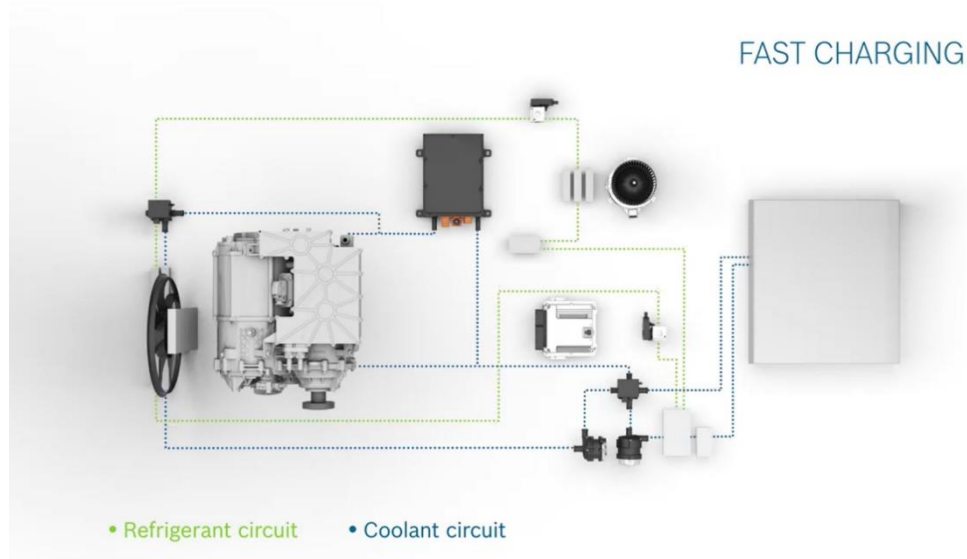


Fig.No.28 Normal Charging Circuit [19]

6.2.1.5 Fuel Cell and Fuel Cell system in FCEV

The following diagram illustrates the operating principle of a typical FCEV.

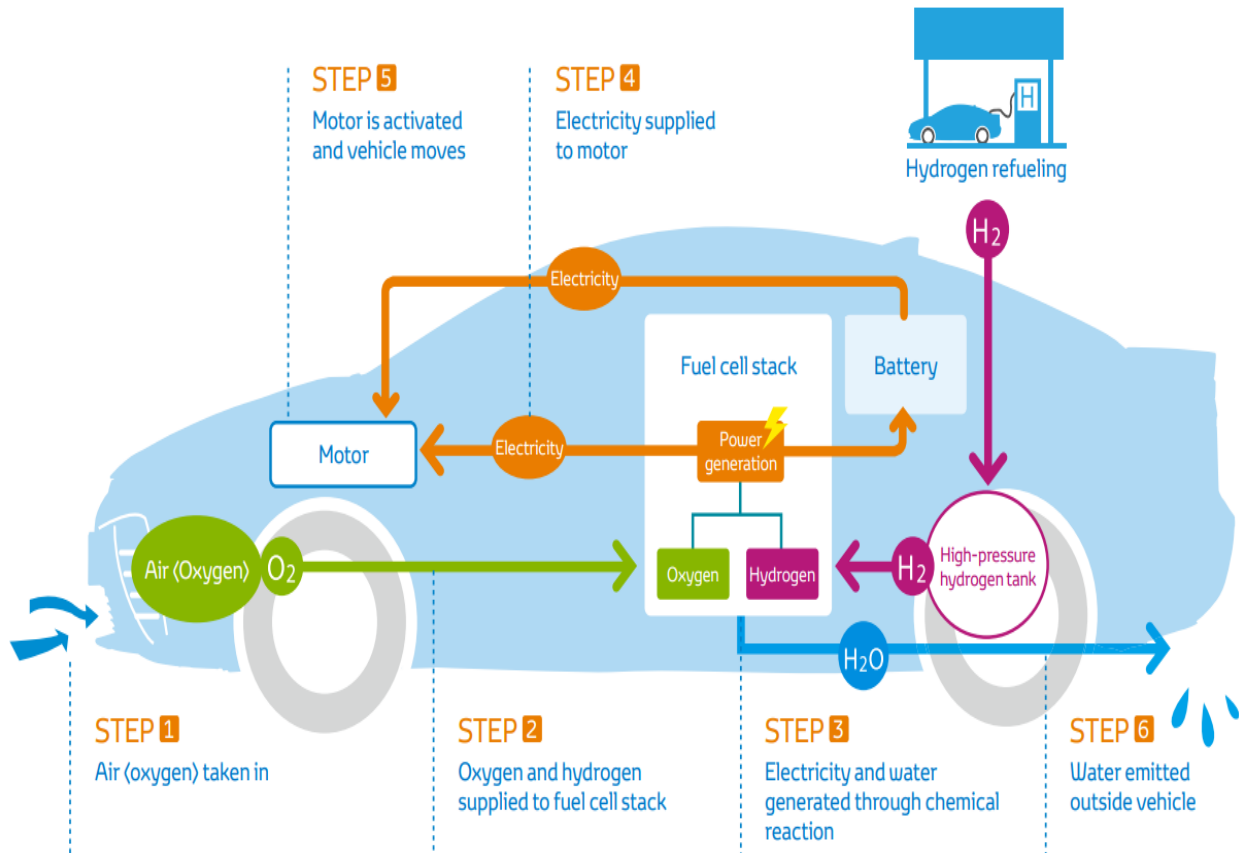


Fig.No.29 Typical of FCEV - Courtesy of www.toyota-europe.com

Polymer electrolyte membrane (PEM) fuel cells, also called proton exchange membrane fuel cells, use a proton-conducting polymer membrane as the electrolyte. Hydrogen is typically used as the fuel. These cells operate at relatively low temperatures and can quickly vary their output to meet shifting power demands. PEM fuel cells are the best candidates for powering automobiles. They can also be used for stationary power production. However, due to their low operating temperature, they cannot directly use hydrocarbon fuels, such as natural gas, liquefied natural gas, or ethanol. These fuels must be converted to hydrogen in a fuel reformer to be able to be used by a PEM fuel cell.

In a PEM fuel cell, an electrolyte membrane is sandwiched between a positive electrode (cathode) and a negative electrode (anode). Hydrogen is introduced to the anode, and oxygen (from air) is introduced to the cathode. The hydrogen molecules break apart into protons and electrons due to an electrochemical reaction in the fuel cell catalyst. Protons then travel through the membrane to the cathode.

The electrons are forced to travel through an external circuit to perform work (providing power to the electric car) then recombine with the protons on the cathode side where the protons, electrons, and oxygen molecules combine to form water. [18]

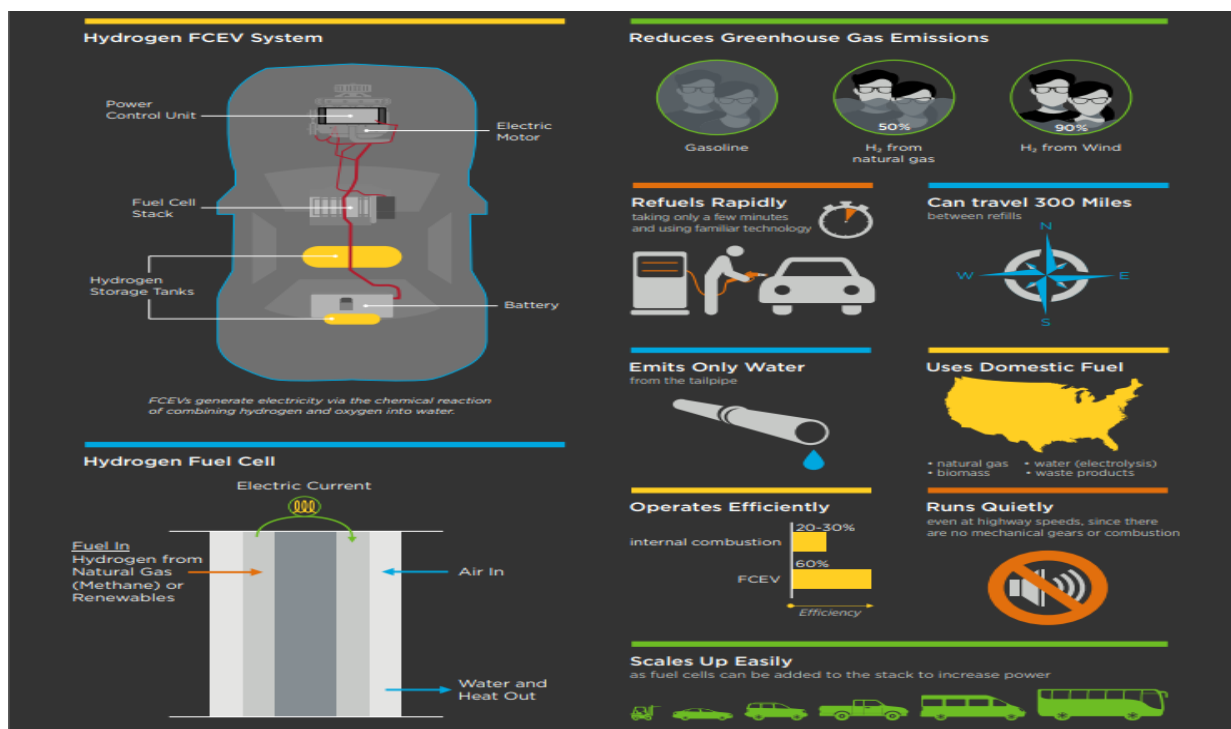


Fig.No.30 Hydrogen FCEV system [18]

6.2.1.6 New catalyst for producing Hydrogen for Fuel Cell:

A new sustainable and practical method for producing hydrogen from water has been discovered by a team of researchers at the RIKEN Center for Sustainable Resource Science (CSRS) in Japan led by Ryuhei Nakamura. Unlike current methods, the new method does not require rare metals that are expensive or in short supply. Instead, hydrogen for fuel cells and agricultural fertilizers can now be produced using cobalt and manganese, two fairly common metals. The study was published in *Nature Catalysis*.

If hydrogen can be extracted from water using renewable electricity, the energy grid can be made clean, renewable, and sustainable. Additionally, hydrogen is the key ingredient needed to produce ammonia, which is used in virtually all synthetic fertilizers. But instead of cleanly extracting hydrogen from water, currently, ammonia plants use fossil fuels to produce the hydrogen they need.

"This is primarily due to a lack of good catalysts," says Nakamura. "In addition to being able to withstand the harsh acidic environment, the catalyst must be very active. If not, the amount of electricity needed for the reaction to produce a given amount of hydrogen soars, and with it, so does the cost."

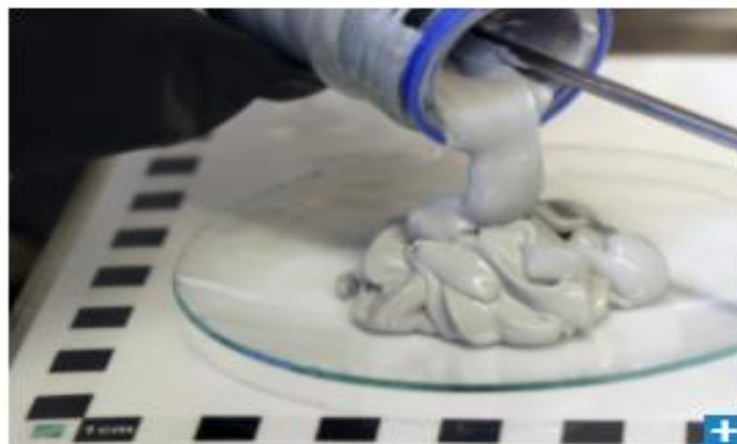
In their search for a better catalyst, the researchers looked at mixed cobalt and manganese oxides. Cobalt oxides can be active for the required reaction, but corrode very quickly in the acidic environment. Manganese oxides are more stable, but are not nearly active enough. By combining them, the researchers hoped to take advantage of their complementary properties. Eventually, the team overcame these issues by trial and error, and discovered an active and stable catalyst by inserting manganese into the spinel lattice of Co_3O_4 , producing the mixed cobalt manganese oxide Co_2MnO_4 .

Testing showed that Co_2MnO_4 performed very well. Activation levels were close to those for state-of-the-art iridium oxides. Additionally, the new catalyst lasted over two months at a current density of 200 milli-amperes per square centimeter, which could make it effective for practical use. Compared with other non-rare metal catalysts, which typically last only days or weeks at much lower current densities, the new electrocatalyst could be a game changer.

The next step in lab will be to find ways to extend the lifetime of the new catalyst and increase its activity levels even more. "There is always room for improvement," says Nakamura, "and we continue to strive for a non-rare metal catalyst that matches the performance of current iridium and platinum catalysts." [22]

6.2.1.7 Hydrogen-powered drives for e-scooters

Hydrogen vehicles are equipped with a reinforced tank that is fueled at a pressure of 700 bar. This tank feeds a fuel cell, which converts the hydrogen into electricity. This in turn drives an electric motor to propel the vehicle. In the case of passenger cars, this technology is well advanced, with several hundred hydrogen-powered automobiles already in operation on German roads. At the same time, the network of hydrogen stations in Germany is projected to grow from 100 to 400 over the next three years. Yet, hydrogen is not currently an option for small vehicles such as electric scooters and motorcycles, since the pressure surge during refilling would be too great.



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POWERPASTE

Fig.No.31 POWERPASTE, Courtesy - Fraunhofer IFAM Dresden

Researchers from the Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM in Dresden have now come up with a hydrogen-based fuel that is ideal for small vehicles called POWERPASTE, which is based on solid magnesium hydride. "POWERPASTE stores hydrogen in a chemical form at room temperature and atmospheric pressure to be then released on demand," explains Dr. Marcus Vogt, research associate at Fraunhofer IFAM. And given that POWERPASTE only begins to decompose at temperatures of around 250 °C, it remains safe even when an e-scooter stands in the baking sun for hours. Moreover, refueling is extremely simple. Instead of heading to the filling station, riders merely have to replace an empty cartridge with a new one and then refill a tank with mains water. This can be done either at home or underway.

The starting material of POWERPASTE is magnesium, one of the most abundant elements and, therefore, an easily available raw material. Magnesium powder is combined with hydrogen to form

magnesium hydride in a process conducted at 350 °C and five to six times atmospheric pressure. An ester and a metal salt are then added in order to form the finished product. Onboard the vehicle, the POWERPASTE is released from a cartridge by means of a plunger. When water is added from an onboard tank, the ensuing reaction generates hydrogen gas in a quantity dynamically adjusted to the actual requirements of the fuel cell. In fact, only half of the hydrogen originates from the POWERPASTE; the rest comes from the added water. "POWERPASTE thus has a huge energy storage density," says Vogt. "It is substantially higher than that of a 700 bar high-pressure tank. And compared to batteries, it has ten times the energy storage density." This means that POWERPASTE offers a range comparable to – or even greater than – gasoline. And it also provides a higher range than compressed hydrogen at a pressure of 700 bar.

Suitable for e-scooters – and other applications as well

With its huge energy storage density, POWERPASTE is also an interesting option for cars, delivery vehicles and range extenders in battery-powered electric vehicles. Similarly, it could also significantly extend the flight time of large drones, which would thereby be able to fly for several hours rather than a mere 20 minutes. This would be especially useful for survey work, such as the inspection of forestry or power lines. In another kind of application, campers might also use POWERPASTE in a fuel cell to generate electricity to power a coffeemaker or toaster.

POWERPASTE helps overcome lack of infrastructure

In addition to providing a high operating range, POWERPASTE has another point in its favor. Unlike gaseous hydrogen, it does not require a costly infrastructure. This makes it ideal for areas lacking such an infrastructure. In places where there are no hydrogen stations, regular filling stations could therefore sell POWERPASTE in cartridges or canisters instead. The paste is fluid and pump able. It can, therefore, be supplied by a standard filling line (using relatively inexpensive equipment).

Initially, filling stations could supply smaller quantities of POWERPASTE – from a metal drum, for example – and then expand in line with demand. This would require capital expenditure of several tens of thousands of euros. By way of comparison, a filling station to pump hydrogen at high pressure currently costs between one and two million euros for each fuel pump. POWERPASTE is also cheap to transport, since no costly high-pressure tanks are involved nor the use of extremely cold liquid hydrogen. [20]

PowerPaste has been patented in the US and at the European Patent office, and Fraunhofer IFAM is currently building a pilot PowerPaste production plant at its Project Center for Energy Storage and Systems ZESS in Brunswick, northern Germany. Due to open at the end of 2021, the plant aims to produce up to four tons of PowerPaste a year. [21]

6.3 STORAGE CAPACITY

Storage at Filling Stations

Due to the possibility of on-site storage of large quantities of hydrogen at the filling station, peaks in demand with full utilization of the filling station are possible.

The filling station concepts for FCEV go from a storage of hydrogen at pressures of 900 bar up to 1000 bar; for the vehicles themselves a storage pressure of approx. 700 bar is provided. It

should be taken into account that at refueling a smaller part of the gas (gas rise in the tank pipe) after the tank is completed is drained. This loss depends on the type of dispenser and is typically 7 g to 10 g, i.e. around 0.3 kWh (0.07 %).

H₂ storage on board the vehicles take place in usually gaseous (CH₂), in passenger cars at a pressure of 700 bar, with trains, trucks, buses and forklifts mainly at 350 bar. There seems to be an alternative for ships, planes, trains or even trucks Hydrogen storage in liquid form (LH₂) is possible, which would improve the range (Fig.No.27) [11].

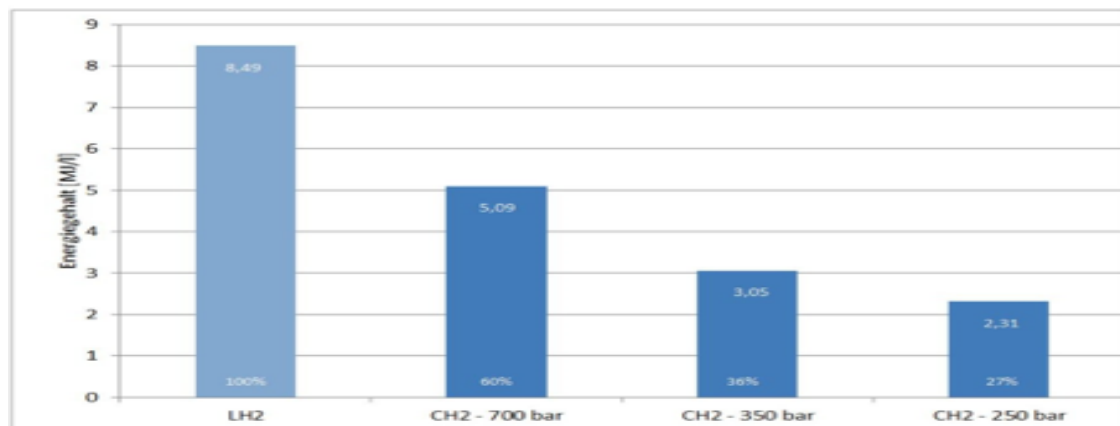


Fig.No.32. Energy content (MJ/l) of liquid and gaseous hydrogen at different pressures (source: ZBT GmbH)

In contrast to FCEVs, a significantly longer charging time can be assumed for BEVs. This is dependent on the available charging infrastructure, the battery capacity installed in the vehicle and the charging converter in the vehicle for AC charging or DC fast charging. Depending on the charging power, full charging takes between 20 minutes (DC quick charging up to 80% battery capacity) and several hours.

By using hydrogen produced on a large scale and expanding existing filling station facilities, the hydrogen infrastructure can be quickly adapted. In the medium to long term, as with the charging infrastructure for BEV to assume a gradual expansion of the generation and transport systems.

Long term storage

Hydrogen storage in Salt caverns for storing large amounts (e.g. 10 TWh) is a solution. For the battery vehicles, it includes the large scale requirements of charging stations and the network expansion requirements in distribution networks.

6.4 OUTREACH

According to the current state of development, FCEVs have a greater range than BEVs with a larger payload and enable heating in winter without a significant reduction in range.

FCEVs are characterized by the fact that power and energy storage are decoupled. FCEV are comparable to conventional (ICE) vehicles in terms of range. With normal 700 bar H₂ tanks, distances of 800 km are possible. The fuel consumption of electric vehicles will increase analogous to the internal combustion engine usually per 100 km driving distance specified.

Increase in the range, i.e. capacity, can be done simply by enlarging the tank reach with a small weight gain. This means that it must be taken into account when using the vehicles.

In BEV, the performance of the battery correlates with the battery capacity. With increasing range, i.e., As the battery capacity increases, so does the performance and the weight of the battery.

FCEV and BEV have proven their technical suitability for everyday use many times over. The driving behavior is comparable to that of conventional automatic vehicles. All ZEVs have no cold start capability problem. For FCEV, the manufacturers assume that an outside temperature of at least -20°C poses no problem. For Toyota vehicles and Hyundai are even mentioned as -28 °C.

In terms of cooling in FCEV and BEV, the drive of the air conditioning unit is electric. FCEVs obtain the energy for the drive of the refrigeration system via the fuel cell from the hydrogen tank. A restriction in driving options (if noticeable) is comparable to that of today's vehicles with internal combustion engines. BEV, on the other hand, obtain the energy for driving the refrigeration system from the battery, therefore, the range is also affected here.

In conventional (ICE) vehicles, the passenger cell is heated by using waste heat from the engine. In FCEVs, the waste heat from fuel cells is generally sufficient. In contrast to this with BEVs, heating is only possible via the battery. This can significantly reduce the range at low ambient temperatures.

Today, BEVs have advantages in the short-distance area, while FCEVs are particularly recommended for payloads and long-distance travel.

6.5 EFFICIENCY

Battery vehicles currently use the primary energy used at least twice as efficiently as Fuel cell vehicles. The storage effect of hydrogen and the possibly significantly lower curtailment of electricity sources from renewable energies is not taken into account.

The conversion of hydrogen in the fuel cell into electrical energy is associated with losses in efficiency. FCEV, therefore, have a significantly lower efficiency compared to BEV. However, in comparison with ICE vehicle, FCEV vehicle is much more efficient (as shown below):

A comparison (see Figure 33) of the typical efficiencies over a normalized test cycle (NEDC) between a conventional gasoline engine vehicle and a FC vehicle shows that for the same amount of equivalent consumed fuel energy, the FC vehicle will deliver significantly more energy both at the level of the fuel converter and to the wheels.

Furthermore, the efficiency of the fuel cell stack remains quite constant over a large operating power range while the efficiency of an internal combustion engine (ICE) is only at its best in a very narrow range of power.

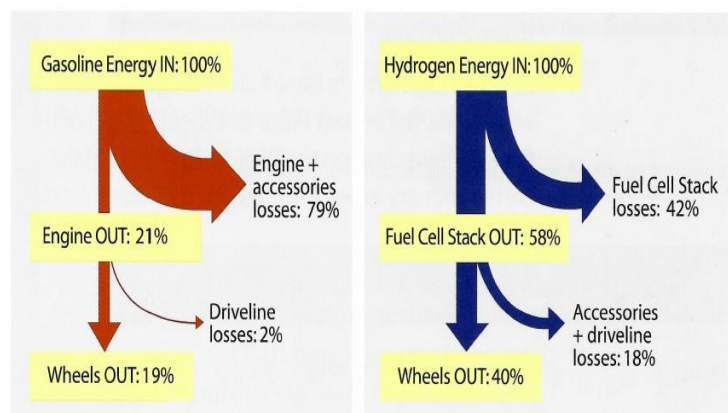


Figure 33: Typical efficiency of a conventional 1.6 l gasoline car (left) and a Fuel Cell car (right) over a NEDC test cycle

Fig.No.33 Typical Efficiency of a conventional 1.6 l gasoline car (left) and a Fuel cell car (right) over a NEDC test cycle [23]

With regard to the charging losses in BEVs, it is true that they are among other things are from the onboard chargers or the DC fast charging stations as well as the battery temperature dependent.

According to Siemens, a DC fast charging station from an efficiency of > 94% at a rated power of 417 V/120 A can be assumed. ABB also states an efficiency of 94% rated output power. This information does not take into account the charging losses depending on the current charging capacity and the battery temperature. In the case of onboard chargers, there can also be an efficiency factor of approx. 94% at nominal power can be assumed.

In addition, DC fast charging stations also have the stand-by losses into account. The charging losses are estimated at an average of 20% of the energy input. Figure 34 shows the dependency of the efficiency from the charging power of an onboard charger a rated power of 22 kW. To that extent for DC fast charging stations, a similar course can be assumed (must be subject to further experience). With very high charging power, the battery may need to be cooled.

For an efficiency comparison of FCEV and BEV the schematic shown in Fig.No.35 describes the process flows used. Shown here is the complete process chain from the electrical energy provided (here from renewable sources) to end-use vehicles for typical BEV and FCEV vehicles. When evaluating the efficiency chain to take into account that additional influencing variables such as energy storage, sector coupling, etc. are not considered here. These can improve the efficiency of the FCEV system.

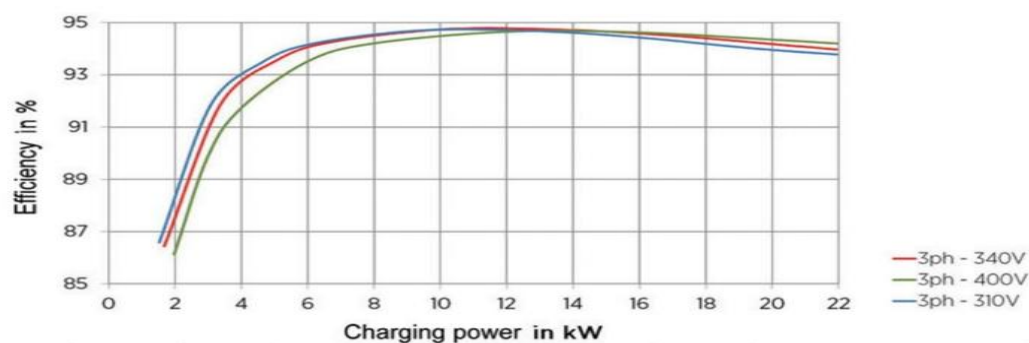


Figure 34. Efficiency depending on the charging power (source: BRUSA Elektronik AG)

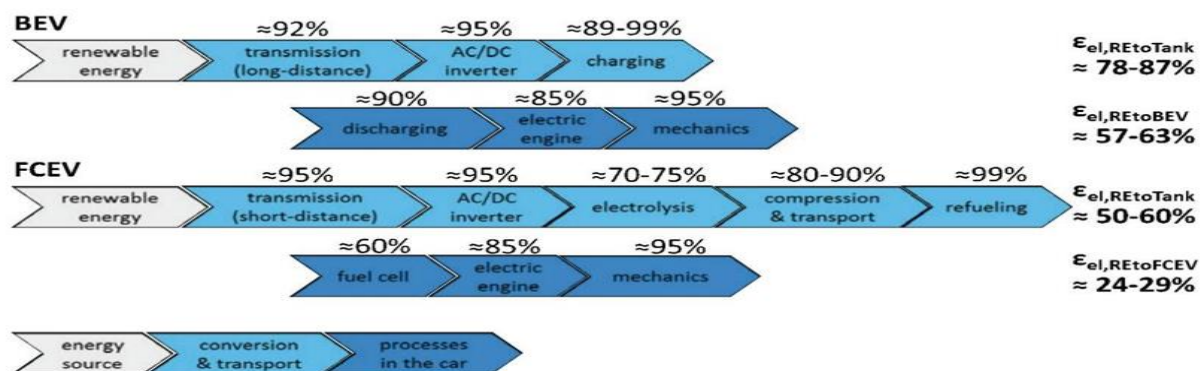


Figure 35. Electrical efficiency chain (source: University of Hanover)

The values assumed in the illustration are based on [11]. In favor of batteries are the higher efficiency and the simpler structure of the systems. Electrical power is charged directly into the batteries via charging stations and called up for driving when required. For overall efficiency of the vehicle (excluding of power generation and upstream grids), the only dominated losses in the battery are from charging and discharging as well as by the losses of the power converter used

in each case. The above Network losses (transmission) can be reduced by using locally generated renewable electricity (PV or wind).

Fig.No.35 shows typical values for the losses in electricity transport, energy conversion and of drive technology is taken into account. More precisely and vehicle-specific consumptions are more individual, which depend very much on the type and the selected driving cycle. [11]

6.6 INFRASTRUCTURE

In the case of FCEV, by using hydrogen produced on a large scale and expanding existing filling station facilities, the hydrogen infrastructure can be quickly adapted. In the medium to long term, (as with the charging infrastructure for BEV) a gradual expansion of the generation and transport systems has to be assumed.

Due to the on-site storage of large quantities of hydrogen at the filling station, peaks in demand with full utilization of the filling station are no problem.

With low market penetration, infrastructure investments for BEVs are lower. With a high level of market penetration, lower costs for the H2 infrastructure can be assumed (depending on the assumptions).

H2 is usually transported by truck. In the future (if there is greater demand), it will make sense to use existing natural gas pipelines by converting them for exclusive H2 transport.

The provision of liquid hydrogen (LH2) leads to technically simpler filling stations, since the complex gas compression, pre-cooling and quality analyzes can be omitted. The amount of H2 transported in a trailer can be increased to 4 t (a factor of 3 to 3.5 compared to compressed gas transport).

The comparison of H2 filling stations and charging stations shows that the tank capacity with almost 3 MWH2 clearly is higher than that of fast charging stations with approx. 350 kWel. In a certain period of time, significantly more FCEVs can be supplied per fuel pump than BEVs per charging point. For comparison here, BEVs require a large number of charging stations in order to charge a comparable number of vehicles at the same time during this period. This also applies to the use of DC fast charging stations. Therefore, a correspondingly larger number of parking spaces with charging facilities should be provided in order to achieve the same refueling capacity.

The expansion of H2 filling stations can be relatively easy to design, since corresponding refueling systems can be implemented in the environment of conventional filling stations. There is experience from completed projects (see the example of Berlin Heerstraße) [11], who speak in favor of replacing H2 tank facilities expansion of existing filling stations. This would offer the advantage that the location search partially can be omitted and part of the infrastructure available at the filling station also for H2 filling could be used.

The capacity design of hydrogen filling stations is similar in comparison with today's gas stations. Also the space requirement of H2 dispensers does not deviate significantly from that of today's petrol and diesel pumps. Depending on the H2 delivery concept, however, an increased space requirement must be assumed due to the required H2 storage at the filling station location. During the market launch, use H2 delivery done by trucks. In the case of high regional demand, pipeline delivery offers advantages.

A lesson learnt is, the existing hydrogen infrastructure in Germany allows no large-scale deployment of FCEVs yet. Due to the high investment costs and the small fleet sizes, there is a hesitation in expansion. By expanding the filling station network, the market ramp-up and eventual market penetration of FCEV could be supported.

If at a local network station many BEVs can be charged at the same time, uncontrolled loading to local overloads in the low-voltage grid [11].

To supply the charging stations, free capacities of the distribution grids are used. With a further market penetration, greater charging power due to larger battery capacities and faster charging processes will increase the power requirement. Among other things, this would have to cover as much area as possible.

DC fast charging stations installed at motorway service stations, shopping malls and parking lots (and in locations with a high expected simultaneity factor, e.g. in sports facilities, hospitals, mosque areas, etc.) will require network expansion in the low and medium voltage network.

The charging performance of the DC fast charging stations (once available at several locations) will reach 100 kW to 350 kW in the future. This sets medium voltage connections (MV connection) ahead, which in many cases involves significant investment for the line expansion and (if necessary) also necessitate the construction of new substations.

Investment costs for H2 infrastructure lower than for BEV supply

As part of a study by the Institute for Electrochemical Process Engineering at the Research Center Jülich and the Chair for Fuel Cells, RWTH Aachen University [11], an attempt was made to evaluate the effort required to set up an H2 tank and electricity charging infrastructure using a scenario analysis.

Comparison criteria included investments, costs, efficiency and emissions of the respective infrastructures, where between the supply of a few hundred thousand and several million vehicles for electricity or hydrogen was distinguished. In the case of the hydrogen variant, in particular, options for Integration and storage of surplus electricity taken into account in the future by renewable Energies dominated energy systems arise (Fig.No.36).

Scenario assumptions

- The share of renewable energies in the Electricity generation amounts to 80%.
- With regard to hydrogen, the conversion of gas production will take place in the transitional phase from fossil energy to the use of regenerative surplus electricity. In the initial phase, there are higher side for these investments required than for the charging infrastructure.
- For smaller vehicle stocks up to several hundred thousand were charged for the loading the costs of the charging stations and the need for grid expansion in distribution grids are taken into account. Any necessary network expansion in the transmission network and seasonal storage was neglected.
- In the large inventory scenario ZEV (20 million vehicles) includes the H2.

Salt caverns for H2 storage were accepted as a storage option, with the help of which large quantities (several 10 TWh) of renewable energies can be stored particularly cheaply (0.2 to 1 €/kWh).

Scenario Analyses

- For small vehicle stocks (up to a few hundred thousand) are the investments in the infrastructure expansion for both technology paths almost the same.
- With high market penetration (20 million vehicles) are the investments for a charging infrastructure at around €51billion compared to the hydrogen infrastructure at around €40billion (Fig.No.37)

The specific cost per kilometer driven are almost the same for both supply concepts with high market penetration. They lie in average at 4.5 ct/km for electric charging and at 4.6 ct/km for the hydrogen.

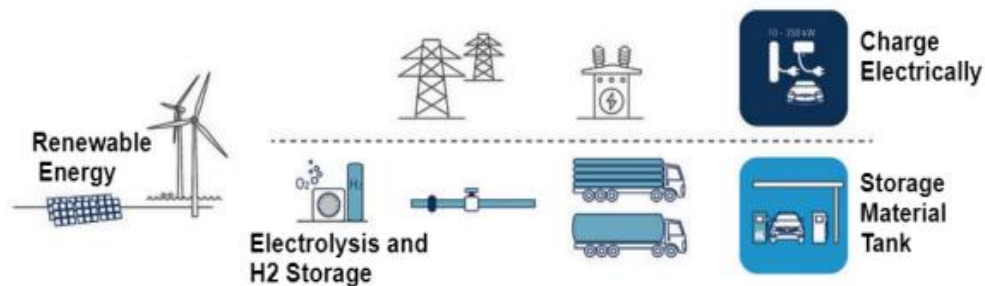


Figure36. Schematic representation of the examined supply infrastructures (source: H2Mobility)

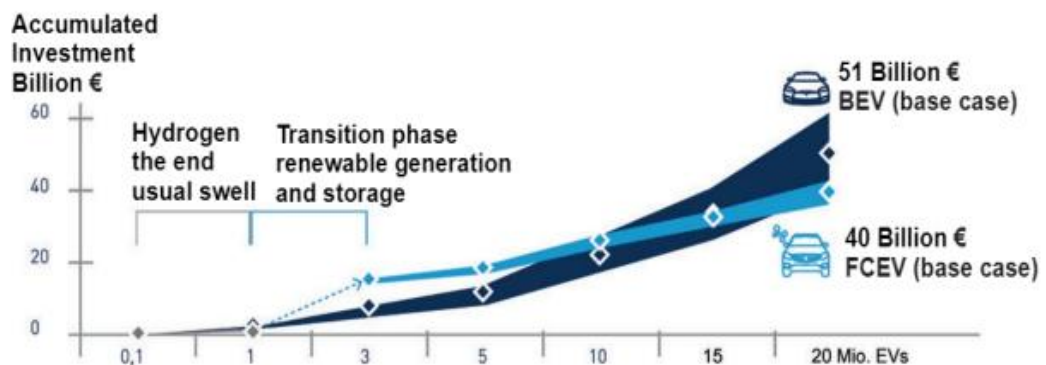


Figure 37. Comparison of cumulative investments for infrastructure development (source: H2Mobility)

Expansion of the H2 network options:

For the gas supply of H2 filling stations, the following options are available:

- The hydrogen is generated locally using electrolyzers installed in the filling station area, post-compressed and then stored in high-pressure accumulators at pressures of up to 1,000 bar.
- The hydrogen is produced in larger factories and transported to the distribution centers (Gas stations) by truck. This is recommended because of the greater energy density of transport in liquid form (truck transport capacity of 4,000 kg H2 liquid). But it is also conceivable delivery in the gaseous state (transport capacity depending on the pressure rating up to 1.000 kg).
- Hydrogen is transported by pipe line.

Conversion Efficiency of 1 kg Hydrogen to Electricity

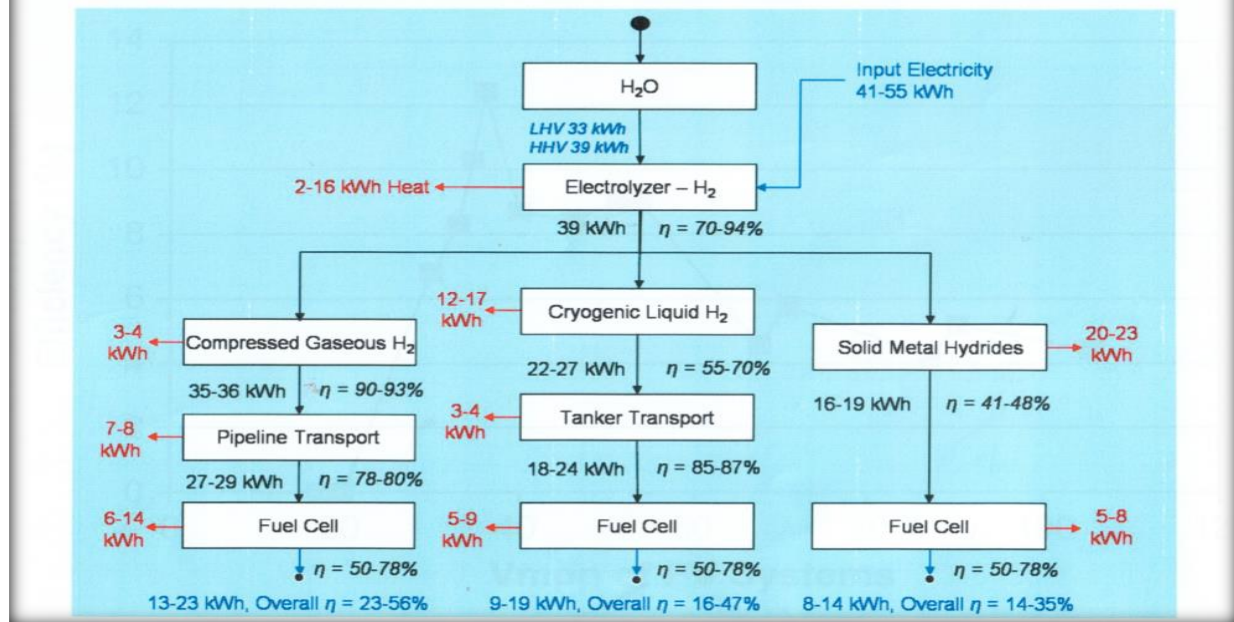


Fig.No.38 Conversion Efficiency of 1kg Hydrogen to Electricity [9]

The above figure shows conversion efficiency of Hydrogen to Electricity via different mechanisms.

Hypotheses on infrastructure development for hydrogen-based mobility

The following hypotheses are not based on studies backed up with reliable data and facts.

1st hypothesis

Compressed hydrogen logistics in the next five years – 350 bar and 500 bar semitrailer. The extremely small fleet of hydrogen-using Mobility systems (cars, trucks, trains) will be coming five years with pre-compacted CGH₂ (compressed gaseous hydrogen) supplied. Hydrogen filling stations have pressure storage tanks of different pressure levels, up to 1,000 bar and complex H₂ compressor and cryogenic precooler. The vehicles, in turn, carry the hydrogen at high pressure, between 350 bar and 700 bar with it. Possibly even higher in the passenger car sector. Pressures realized to ranges > 500 km also to be realized safely under unfavorable conditions.

2nd hypothesis

With increasing fleet strength Compressed hydrogen logistics (CGH₂) is carried out liquefied hydrogen (LH₂) substituted.

Demand is initially replaced by existing ones. Large condenser served. (In addition to the existing locations operated electrolysis plants).

The increasing demand for hydrogen increases the logistics expenses. Typical semi-trailers transport between 300 kg depending on the pressure level up to slightly more than 1,000 kg of gaseous hydrogen per vehicle with a gross weight of around the 40,000 kg (CGH₂). In contrast, can up to 4,000 kg of liquid hydrogen (LH₂) per vehicle.

Another aspect is rather high level of complexity and the energy requirement of a CCH₂ filling station as well as the fact that at high filling frequencies limited by the high-pressure accumulator, which is small for techno-economic reasons works.

In comparison, LH₂ filling stations are clear easier to set up and can ensure short refueling times until the storage tank is exhausted. Evaporation losses occur sufficiently high demand or only to a minor extent. The hydrogen on board of the FCEV can continue to be stored in gaseous form. However, it is also conceivable that liquid hydrogen will also find its way back into the commercial vehicle sector (trucks/trains) with its high utilization and the CCH₂-Cryo compressed Hydrogen Storage (BMW CCH₂) presented by BMW.

3rd Hypothesis

The production of LH₂ requires large central condensers, as there are currently no known cost and energy efficient liquefaction in small plants.

The evolving LH₂ system could show similarities to that of today's refineries, or even such locations preferred to develop. Logistically already developed, however, they need a significantly strengthened one connection to the new raw material "renewable energies".

If LH₂ becomes a readily available product, other users such as aviation or the chemical industry can become buyers.

4th Hypothesis

In the long term, in addition to the electricity grid as a transport and distribution system for renewable energies, the existing gas grid will also be integrated or expanded. Gas network operators are, therefore, investigating ways of transporting 100% hydrogen by volume in existing pipelines.

With increasing sales volume, the new construction of pipelines for gaseous hydrogen transport will be economically viable. [11]

Infrastructure for Battery Electric Vehicle usage

Infrastructure development for BEV usage requires an understanding of 'EV charging modes', 'Levels of charging' and the 'charging plugs and connectors' awareness for appropriate infrastructure development in Pakistan.

EV Charging "Modes"

The mode of an EV charger is defined to decide its charging application and level of communication between the charger and the vehicle. Globally, there are four modes characterized by level of safety features as defined by IEC 61851 Standard

Mode 1 (AC Charging)

Uses a standard domestic socket-outlet and does not use any safety or control feature. Since there is no protection circuitry preventing accidents, it is considered unsafe by most automakers and offers "low" level of safety.

Mode 2 (AC Charging)

It also uses a domestic socket-outlet, but it employs an in-cable protection device and a power level control that protects the user and the vehicle. This mode of charging is well-suited for longer period of charging at home or in office. Since the mode 2 employs a protection mechanism, it is

considered to have an acceptable level of safety features.

Mode 3 (AC Charging)

A dedicated EV supply equipment (EVSE) and a charging cable assembly is employed and uses specific EV socket-outlet and plug with control and protection function installed. This mode is ideally suited for malls, petrol stations, parking areas, etc.

Mode 4 (DC Charging)

A dedicated external EVSE is used with an AC/DC converter providing direct current with power levels starting at 50 kW (mainly for parking spots along highways, motorways or places where the driver is in a hurry to recharge its car battery).

Charging Plugs or Connectors

A charger type typically refers to the output socket and the connector used by a charger. It also includes the communication protocols between the charger and the vehicle which are required for various charging modes. Globally, there is a wide variation between the different types of sockets due to regional needs and discretion of car manufacturers.

Below figure illustrates popular types of charging ports or connector guns being used by electric car manufacturers all over the world. Currently, there are three ports/connectors for AC charging and four for fast DC charging as listed below:



Fig.No.39 Types of Charging Plugs or Connectors (Source: EnelX) [10]

AC Type 1 is common for American vehicles, it is a single-phase plug and can charge at a speed of up to 7.4 kW. It follows the North American SAE J1772 standard.

AC Type 2 is standard for European and Asian vehicles from 2018 onwards, it can operate both at single and triple-phase plug and can charge at a level of up to 43 kW. It follows IEC 62196 standard.

CHAdeMO a Japanese standard - it was the first widespread technical standard for DC fast charging developed by a Japanese consortium. Nissan and Mitsubishi use this connector and allows for high charging capacities as well as bidirectional charging.

Combined Charging System (CCS) 1 commonly referred as **Combo 1**, which is preferred by US car manufacturers, and **CCS 2 or Combo 2** is commonly used in Europe (BMW, GM, VW, and other carmakers) for DC fast charger.

GB/T Standard for Chinese electric car manufacturers for both AC and DC charging.

Supercharger Standard connector for Tesla for both AC and DC charging.

Lack of harmonization among EVs and charging technology standards is one of pain points towards scaling up of EV charging infrastructure. [10]

Charging connector or plug - suitable for Pakistan's market

Pakistan has to adopt a formal standard for EV charging system. Worldwide, Combined Charging System 2 or (CCS 2) which is commonly used in the Europe - seems to be winning the charging industry. In addition to Europe, many other nations, including Greenland, Australia, Brazil, South America, South Africa and Saudi Arabia have officially adopted CCS 2 standard. Due to its universal characteristics, it can handle DC fast charging, single phase AC and three phase AC. It is very likely that many other countries would continue to adopt CCS 2 as their national standard. CCS 2 operates at 220 Volts and 50 hertz, which is identical to Pakistan mains electricity and as the name indicates it integrates both DC and AC plugs into single charging port.

CCS 2 has a dual use capability for both AC and DC charging using the same charging port. Due to this unique and simple architecture, today more car manufacturers supply EVs with CCS 2 for all regions than any other charging standard. For this very reason, type 2 for AC and CCS 2 for DC could be well suited to Pakistan's market. If CCS 2 standard is adopted, it may provide much needed clarity for OEMs, consumers and charging equipment suppliers and help boost seamless uptake of EVs in the country. [10]

EV Levels of Charging

PARAMETER	SLOW	MEDIUM	FAST
LEVEL	Level 1	Level 2	Level 3
AC OR DC	AC	AC	DC
POWER RANGE	<3.3 KW	3.3-22 KW	50-350 kW
MODE	Mode 1 and Mode 2	Mode 3	Mode 4
TYPE	Domestic sockets	IEC Type 1 IEC Type 2	CCS Combo 1 (US) & 2 (EU), CHAdeMO (Japan) GB/T DC (China) and Tesla connector
UTILITY	Residential	Residential/Work/Commercial	Transport Corridors - Motorways
VEHICLES	2W, 3W, Cars	2W, 3W, Cars	Cars and Buses

Table No.8 Levels of Charging [10]

EV Charging Behaviors

Many factors influence the EV market penetration, such as overall automotive market, policy incentives, purchase subsidies, buying capacity of consumers and emission targets. Considering many dynamic variables of electric mobility, it is quite a challenge to ascertain the EV penetration and the corresponding need for charging infrastructure.

It is plausible to assume that those early adopters who are currently buying EVs, they could charge their vehicles at home overnight. But as the EV go mainstream and purchase cost continues to go down, a greater number of lower- and middle-income consumers would likely shift towards EVs; this would create the additional need for public charging stations, as home charging may not be an option for them.

For adoption of EVs in Pakistan at the early stage, access to home charging would be the most important factor in encouraging consumers to purchase EVs. Evidence from market leaders indicate that the bulk of the charging takes place at home using Level 1 slow chargers overnight at rated power less than 3.3KW. Workspaces is the second most suitable option for recharging where a vehicle is typically parked five hours. Charging at workspace takes place at Level 2 AC charging within a power range of 3.3 and 22 KW. At the early stage, most charge points at workspace could be installed at 7–11 kW.

Battery Swapping

The time required for charging an EV can be a bottleneck as it takes much longer time and battery swapping has the potential to address this challenge because it takes only a few minutes to swap a battery. This eliminates the need to wait for long hours. A decade ago, battery swapping was recommended as a way of overcoming the challenge around long charging time. Tesla tested it in 2013, demonstrating its ability to swap a Model S battery in 90 seconds, but somehow the idea has not been so successful.

Battery swap is a capital-intensive business, as one has to have additional stacks of batteries. Battery constitutes a significant proportion of a total vehicle's costs. This means that OEMs have to provide surplus batteries for swapping to work. Tesla experimented this model but figured out that it is a lot cheaper to build a network of superchargers than battery swap stations.

However, in China this idea is gaining a lot of traction and the government is keen on experimenting the battery swap mechanism. Chinese automaker NIO has already completed 500,000 battery swaps. The major challenge with the battery swap is standardization battery itself for a wide range of vehicles and massive repository of additional battery packs.

It would be too early to anticipate as to how the battery swapping would unfold in Pakistan. However, there could be an economic case for battery swap technology for some business models, such as e- rickshaws, as the size of batteries is generally relatively smaller in these variants. Hence, we believe that battery swapping could be a potential solution for three-wheel rickshaws as it would minimize the downtime for commercial deliveries. Yet standardization of batteries would still be major challenge. [10]

6.7 FUEL PROVISION

Hydrogen allows fast refueling with globally standardized tank systems. At 3 to 5 minutes, full hydrogen refueling of FCEVs is comparable to today's vehicle refueling. Even when using fast charging stations, recharging BEVs takes around 20 minutes if charging is limited to 80% of the battery capacity (SOC).

The mechanical interface between vehicle and gas pump and the refueling process are at standardized hydrogen refueling worldwide. In contrast, there are different connector systems and charging capacities for charging BEVs. Furthermore, the adaptation of the network infrastructure is one essential requirement for the installation of DC fast charging stations.

6.8 EMISSION FREE MOBILITY

Using electrolyzers to generate hydrogen enables emission-free energy supply, provided they are operated with electricity from renewable energies. However, an economically competitive use requires low electricity prices. Hydrogen production primarily via steam reforming, coal gasification and oxidation results in an average of approx. 10kg CO₂ per kg H₂ to 15kg CO₂ per kg H₂, especially in the reformation, again integrated into the material cycle and reused. [11]

Emissions for both supply options are low comparison to the use of fossil fuels (Fig.No.40). The hydrogen infrastructure with inherent seasonal storage can integrate higher proportions of surplus renewable energies and is, therefore, at an advantage when it comes to reducing CO₂.

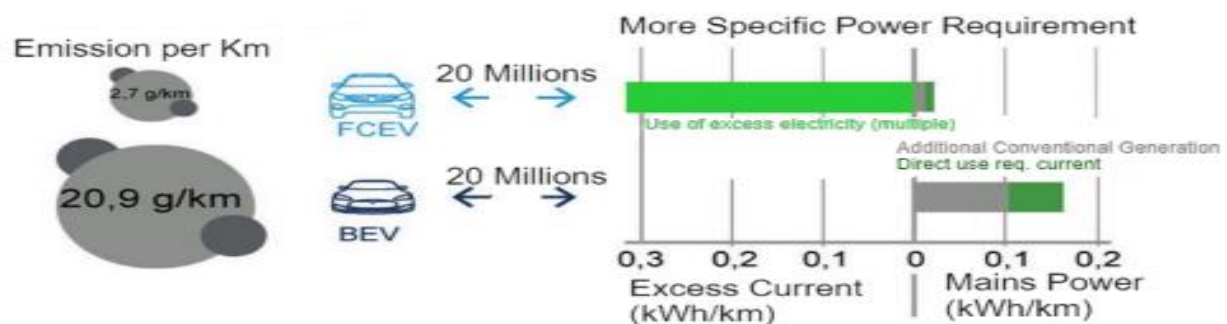


Fig 40. Comparison of CO₂ emission and electricity requirements per kilometer (source: H₂Mobility)

6.9 CRITICAL RAW MATERIALS

Raw materials are required for any technology market penetration and sustainment. These come either from primary sources such as ore mining or, usually with a time lag, (also) from secondary sources such as recycling. Critical raw materials apply to the battery are lithium, nickel, cobalt. In the case of fuel cells, platinum is critical material.

To avoid raw material shortages or price increases, capacity of all mentioned critical raw materials have to be increased (in particular special for lithium and cobalt). This is best done in the form of an increased recycling rate (especially for lithium).

On the other hand, absolute shortages are unlikely due to the fact that new raw material deposits are usually sighted and developed beforehand or raw material substitutions are made be initiated. There are already initial successful developments to use these critical raw materials much more efficiently or even to completely substitute them.

Synchronous motors are mostly used in electric motors utilize neodymium iron boron magnets which ~ 30% mass of rare earth metals such as neodymium, Dysprosium and terbium exist, which have a comparatively high coercivity and heat resistance [11]. The People's Republic of China supplies rare earth metals and main suppliers represent a monopoly share of over 90% [11], which in turn is already increasing temporary shortages and serious price fluctuations. This is supported by an extremely low recycling rate of just 10% [11].

On the other hand, there are already successfully implemented developments of new magnets with a complete substitution of dysprosium and terbium and a reduction in neodymium with less critical rare earth metals such as lanthanum and cerium up to 50% [11]. Furthermore, a complete substitution of rare earth metals in asynchronous motors and electrically excited synchronous motors has already been proposed and electric cars successfully demonstrated it [11].

6.10 LIFE CYCLE COST

The higher costs of using BEV and FCEV are currently from the higher upfront purchase price of the vehicle. Secondly, the mass production of battery systems is more advanced than that of fuel cells. Therefore, correspondingly the cost reduction is currently much more pronounced in battery vehicle systems than with the fuel cell systems. In case of BEV, the smaller the size of the vehicle / battery size, the lower will be the operating cost as shown in the table below.

Comparison of annual costs of FCEV, BEV and ICE

	Purchase (in €)	Depreciation (ten years) (in €)	Energy Costs (in €/kWh, for ICE €/litre)	Consumption (in kWh/ 100 km, for ICE litres/100 km)	Energy Costs (10,000 km) in €	Annual Costs (per year in €)
Toyota Mirai	78600	7860	0.285 (H2)	25308 (H2)	722	8582
Toyota Mirai (price reduced)	71999	7200	0.285 (H2)	25308 (H2)	722	7922
Tesla S 75	71999	7200	0.296 (el.)	18500 (el.)	548	7748
BMW 740i [b]	78863	7886	2.011 €/litre [a]	9.26 (lit/100km)	1856	9742

Table No. 9 Comparison of annual costs of FCEV and BEV (source: Fraunhofer ISE)

Comparison of annual costs of FCEV and BEV (Source: Fraunhofer ISE)

	Purchase (in €)	Depreciation (ten years) (in €)	Energy Costs (in €/kWh)	Consumption (in kWh/ 100 km)	Energy Costs (10,000 km) in €	Annual Costs (per year in €)
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Tesla S 75	71999	7200	0.296 (el.)	18500 (el.)	548	7748
Nissan Leaf	31950	3195	0.296 (el.)	14600 (el.)	432	3627

Table No.10 Comparison of annual costs of FCEV, BEV and ICE

a) Source: https://www.globalpetrolprices.com/Germany/gasoline_prices/

b) Source: <https://www.ccarprice.com/de/bmw-740i-2022-price-in-germany-6758>

Note: Maintenance costs are not considered due to not enough data available for EV's.

From the above listed tables it is obvious that despite the high upfront purchase of Electric Vehicles, the annual operating costs are significantly lower when ICE vehicle is compared against the BEV and FCEV.

6.11 Value Realistic (cost)

In order to arrive at “Value Realistic”, various operating cost comparisons were made based on the key figures listed below:

VEHICLE NAME	Motor (in KW)	Tank Volume / Battery	Wt. in Kg	Range (in km - EPA)	Fuel Consumption (KWh/100km)
Toyota Mirai	113	H2: 165 KWhH2 Batt: 1.6 KWhel	1850	502	33.33 KWhH2
Tesla Model S75	235	Batt: 75 KWhel	2108	401	21.12KWh
Nissan Leaf 30	80	Batt: 30 KWhel	1573	172	16.77KWel

Table No.11. Comparison of typical key figures of representative FCEV and BEV [11] (Source: University of Hannover)

Assumptions and data used for following comparisons:

- Used a residential rate of Rs. 25 /KWh
- Since commercial charging in Pakistan is under development stage, therefore, the percentage difference between residential and commercial charging rates for various chargers used in Germany were used (to estimate the commercial charging rate in Pakistan).
- In the case of FCEV, commercial hydrogen rate of 3.5 euro /kg is used (as the commercial hydrogen production from the upcoming green hydrogen “Oracle Power Project” in Pakistan will be less than 1.75 euro/kg [30]).
- Battery charging time for TESLA: (source:<https://ev-database.org/car/1071/Tesla-Model-S-75>)
- Cost per Kg H2 for refueling (Euro/Kg) = 9.5 (source: (<https://h2.live/en/> , H2 MOBILITY, Germany))
- 2021 Germany - avg. cost in Euro/kwh - DC >= 50 kW commercial charger = 0.4845 (source:<https://www.statista.com/statistics/1167538/electricity-prices-charging-stations-electric-cars-by-provider-germany/>)
- 2021 Germany - avg. cost in Euro/kwh - AC = 22 KW commercial charger = 0.4118 (source:<https://www.statista.com/statistics/1167538/electricity-prices-charging-stations-electric-cars-by-provider-germany/>)

- 2021 Germany - avg. cost in Euro/kwh - Home charging = 0.3193
(source: https://ec.europa.eu/eurostat/statisticsexplained/index.php?title=Electricity_price_statistics)
- Germany - gasoline cost (in Euro /litre) = 2.011
(source: https://www.globalpetrolprices.com/Germany/gasoline_prices/)
- 1 Euro = Rs.198.17 (Mar. 2022)

1. Operating Cost Comparison of BEV vs FCEV vs ICE in Germany

VEHICLE NAME	Toyota Mirai (FCEV)	Tesla Model S75 with 1-phase 32A (7.4 kW)	Tesla Model S75 with 3-phase 32A (22 kW) (commercial charger)	Tesla Model S75 with DC 75KW commercial charger	BMW 740i (ICE)
Annual Distance travelled (km)	15000	15000	15000	15000	15000
Fuel Economy (FCEV: in 1kgH ₂ /100km, BEV: in KWh/100km, ICE: km/litres)	1kgH ₂ /100km	21.12	21.12	21.12	10.8
(in KWh/100km)	33.33	21.12	21.12	21.12	
Fuel needed per year (Kg of H ₂ - FCEV) (KWh - BEV) (litres - ICE)	150	3168	3168	3168	1389
Fuel Cost (FCEV- Euro/kg, BEV-Euro/KWh, ICE- Euro/litre)	9.5	0.3193	0.4118	0.4845	2.011
Annual Cost of Refueling (Euro)	1425.00	1011.54	1304.58	1534.90	2793.06
Cost in Euro/100km	9.5	6.74	8.70	10.23	18.62
Refueling time /Charging time	3-5 min. (Avg. est.)	11.75 hrs (Avg. est.)	5.25 hrs (Avg. est.)	58 min. (Avg. est.)	3-5 min. (Avg. est.)

Table No.12. Operating Cost Comparison of BEV vs FCEV vs ICE in Germany

2. Operating Cost Comparison of BEV vs FCEV vs ICE in Pakistan

Pakistan's first green hydrogen plant (by 'Oracle Power') will be built in Sindh with a capacity to produce approximately 150,000 kg fuel per day from a 400MW capacity plant using energy from wind and solar farms. 'Oracle Power' said 'Power China' had completed the study, and the presented results stating that decreasing costs of wind and solar power in Pakistan could help the project deliver green hydrogen for less than USD 2 (EUR 1.75) per kg. This makes the perfect case for the "high penetration electric vehicle (~20 million vehicles or more) and 'high outreach / range', by looking at the following scenario as per 'assumptions and data' described above.

VEHICLE NAME	Toyota Mirai (FCEV)	Tesla Model S75 with 1-phase 32A (7.4 kW)	Tesla Model S75 with 3-phase 32A (22 kW) (commercial charger)	Tesla Model S75 with DC 75KW commercial charger	Toyota Corolla-Automatic (in PK) (ICE)
Annual Distance travelled (km)	15000	15000	15000	15000	15000
Fuel Economy (FCEV: in 1kgH ₂ /100km, BEV: in KWh/100km, ICE: km/litres)	1kgH ₂ /100km	21.12	21.12	21.12	11
(in KWh/100km)	33.33	21.12	21.12	21.12	
Fuel needed per year (Kg of H ₂ - FCEV) (KWh - BEV) (litres - ICE)	150	3168	3168	3168	1364
Fuel Cost (FCEV-Euro/kg, BEV-Euro/KWh, ICE- Euro/litre)	3.5	25	32	38	0.76
Annual Cost of Refueling (Euro)	525.00	400	515	606	1034.58
Cost in Euro/100km	3.5	2.66	3.44	4.04	6.90
Refueling time /Charging time	3-5 min. (Avg. est.)	11.75 hrs (Avg est.)	5.25 hrs (Avg. est.)	58 min. (Avg.est)	3-5 min. (Avg. est.)
Annual Cost of Refueling (PKR)	104039	79200	102144	120178	205023
Cost in Rs/100km	694	528	681	801	1367

Table No.13. Operating Cost Comparison of BEV vs FCEV vs ICE in Pakistan

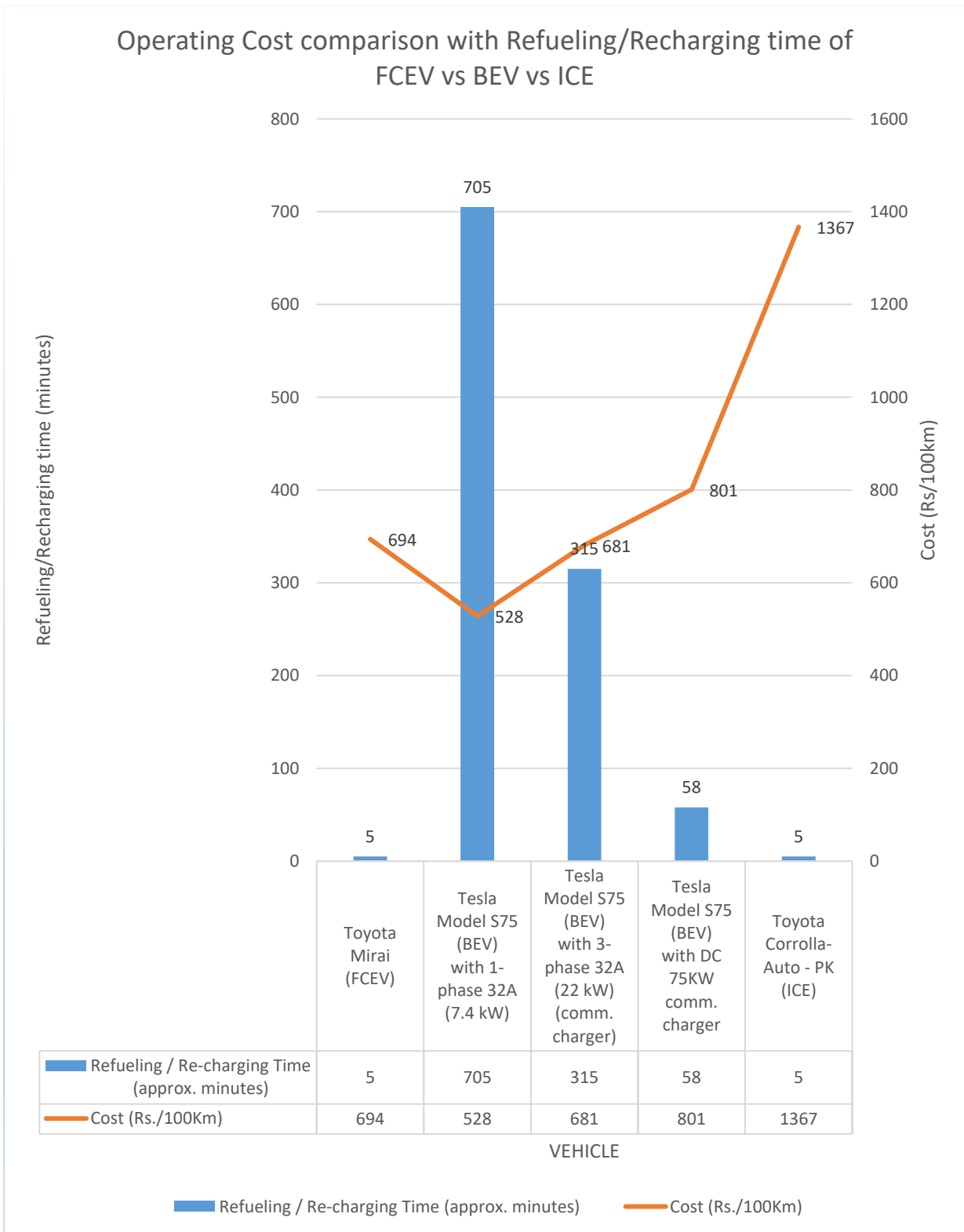


Fig.No.41. Operating Cost Comparison with refueling/recharging time of FCEV vs BEV vs ICE

3. Operating cost comparison based on AC vs DC charging of small BEV using different electricity rates in Pakistan

	NISSAN LEAF 30	with Home charging (~3 KW)	NISSAN LEAF 30	with (7KW charging)	NISSAN LEAF 30	with DC 50KW commercial charger
Annual Distance travelled (km)	15000		15000		15000	
Fuel Economy	16.77		16.77		16.77	
(in Kwh/100km)	16.67		16.67		16.67	
Fuel needed per year	2500.5	KWh	2500.5	KWh	2500.5	KWh
Fuel Cost	25	PKR/kWh	25	PKR/kWh	38	PKR/kWh
Refueling time/Charging time	~10 hrs (Avg est.)		~4.5 hrs (Avg est.)		~30 min (80% charged)- (Avg. est.)	
Annual Cost of Refueling (Rs.)	62513		62513		94856	
Cost in Rs/100km	417		417		632	

Table No.14. Operating Cost Comparison based on AC vs DC charging in Pakistan

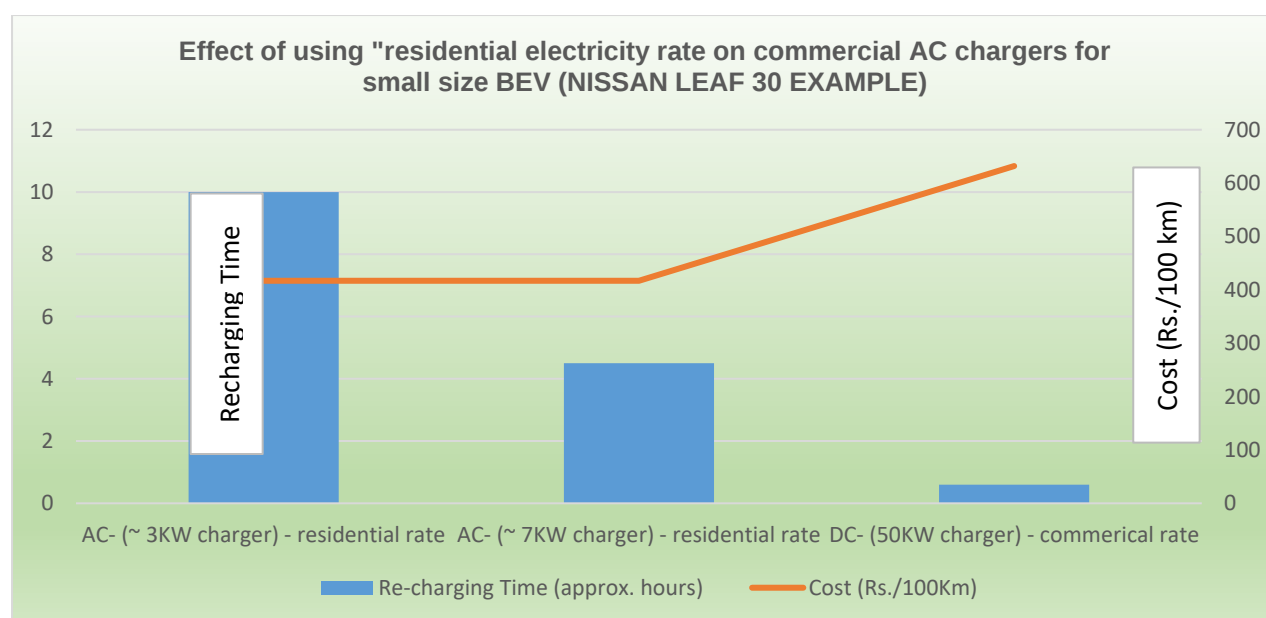


Fig.No.42. Effect of using residential electricity rate on commercial AC chargers for small size BEV

Conclusions

- The scenario no.1 clearly highlights the fact that by considering 'higher outreach/range' and 'comparing refueling time of ICE vehicle' and 'recharging times of BEV' with an FCEV in terms of 'Cost/100 km', FCEV vehicle is a better choice.
- The scenario no.2 further strengthens scenario (a) outcome of FCEV as a better choice and highlights the fact that if the hydrogen availability at the hydrogen pumping stations is within the assumed commercial availability rates, then an FCEV will be the vehicle of choice for a majority of four wheel vehicles on Pakistan's roads and will result in significant fuel savings of (approx.) 49.2% (if not more) when compared with ICE vehicle.
- The focus on sustainable green hydrogen production and its availability at hydrogen stations (similar to current petrol pumps in Pakistan) at a commercially viable rates holds the key to this success.
- The smaller battery size results in lower battery charging times coupled with lower infrastructure costs. Therefore, battery electric vehicles offer advantages in "shorter range /outreach" due to smaller size battery, better re-charging time, low operating cost and low infrastructure costs in smaller size vehicles.
- The scenario no.3 shows that by keeping the commercial AC charging rates low (i.e. equal to residential electricity rates), especially in the case of 2 wheeler motor bikes, 3 wheeler rickshaws and the smaller size 4 wheel cars (by virtue of their smaller battery sizes), the end user will see a bigger benefit in using BEVs and will result in rapid ramp-up of EVs in Pakistan.

6.12. Customer Use

Conversion to electromobility to support the market ramp-up is advisable for vehicle fleets in the private and public sectors. Battery electric vehicles in 2 wheelers and/or 3 wheelers is a good starting point in Pakistan for electric vehicle for fuel savings over an ICE counterpart due to small battery sizes and correspondingly comparatively lower battery charging infrastructure costs. However, the extreme care has to be exercised in the battery charging infrastructure development as the costs of infrastructure development on a large scale will be huge (i.e., with high market penetration (20 million vehicles or more), the investments for a charging infrastructure are at around € 51 billion compared to the hydrogen electric vehicle infrastructure at around € 40 billion. [11]

7. Other Aspects to consider for long term sustainable use of Electric Vehicles in Pakistan.

7.1 Market size in Pakistan

The road transport sector in Pakistan has been growing steadily. The total number of registered vehicles stood at 31 million in 2021^[26]. Two-wheelers or motorbikes hold dominant share which represents 76% (i.e. 23,849,010 vehicles) of the total vehicles. The three wheelers have also shown a steady progress over the years and represents 959,049 registered vehicles. Over a period of 14 years, the total production volume stood at 18,381,414 and sales volume at 18,381,351, respectively. Out of which, the two and three-wheeler motorcycles & rickshaws production and sales were 15,238,267 and 15,239,850, respectively. Therefore, motorbikes or two-wheelers and 3 wheelers /rickshaws have to be an important part of EV implementation.

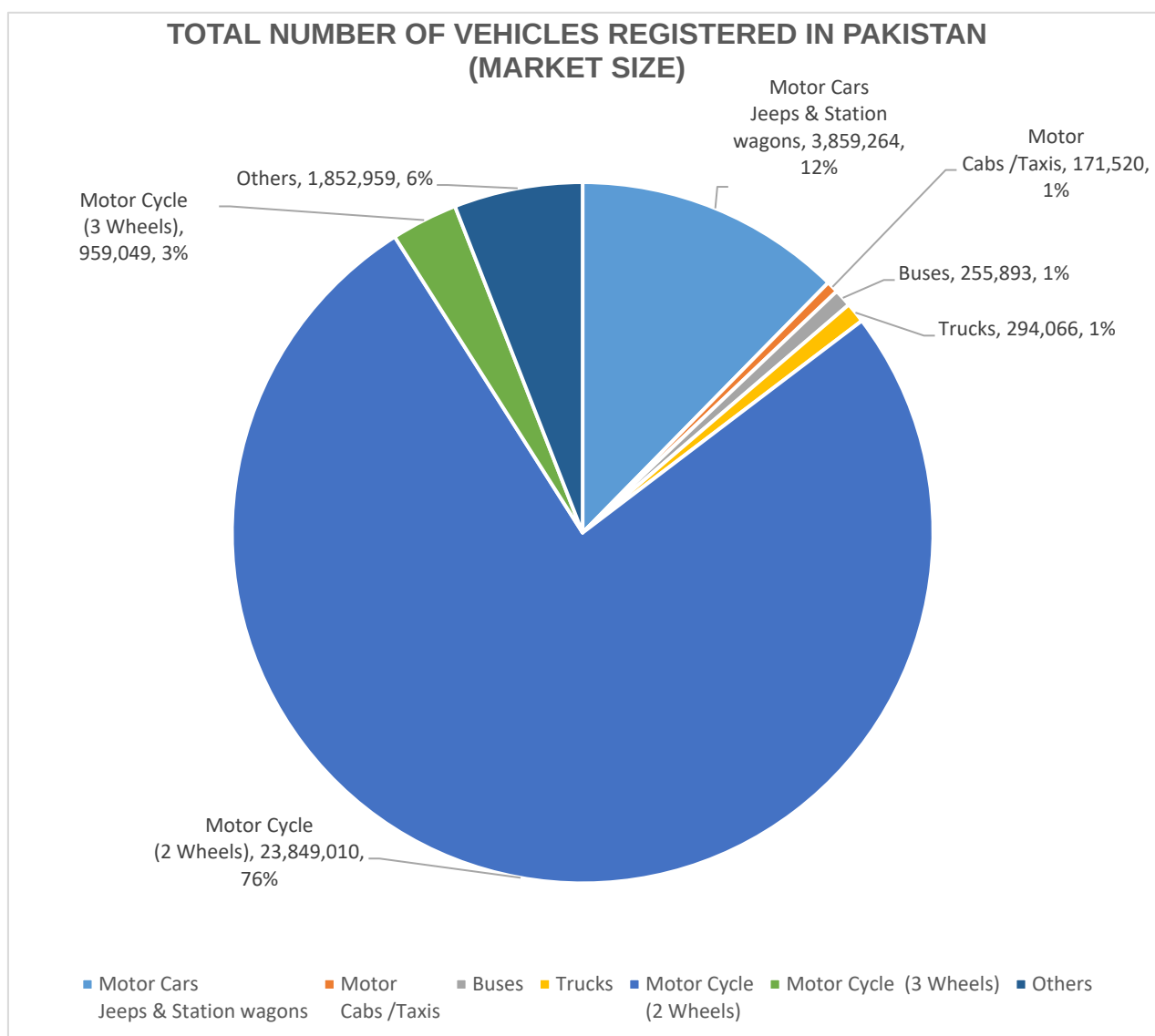


Fig.No.43 Market Size - Total registered vehicles in Pakistan. (2020-21) [26]

TOTAL NUMBER OF MOTOR VEHICLES REGISTERED IN PAKISTAN)

CAL. YEA R	Motor Cars Jeeps & Station wagons	Motor Cabs /Taxis	Buses	Trucks	Motor Cycle (2 Wheels)	Motor Cycle(3 Wheels)	Others	Total
2001	1,198,918	90,062	161,507	155,793	2,283,381	107,555	786,907	4,784,123
2002	1,279,362	90,077	155,555	169,274	2,341,051	120,569	814,239	4,970,127
2003	1,289,854	90,424	165,846	177,478	2,379,260	127,360	834,424	5,064,646
2004	1,298,353	90,460	166,136	179,727	2,609,442	138,153	848,688	5,330,959
2005	1,318,488	91,893	168,713	182,516	2,649,910	101,058	861,851	5,374,429
2006	1,372,191	105,373	175,589	189,950	2,757,842	136,394	896,014	5,633,353
2007	1,440,801	103,397	184,368	199,447	2,895,734	143,215	940,851	5,907,813
2008	1,549,854	104,431	187,367	202,574	3,039,815	156,068	961,646	6,201,755
2009	1,657,860	106,463	195,163	210,944	3,215,583	167,910	1,005,441	6,559,364
2010	1,726,347	122,882	198,790	216,119	4,305,121	201,827	1,081,916	7,853,002
2011	1,881,560	124,651	202,476	225,075	5,781,953	266,390	1,178,890	9,660,995
2012	2,094,289	143,859	215,374	240,888	7,500,182	323,189	1,270,788	11,788,569
2013	2,281,083	145,234	220,347	247,197	9,169,582	380,579	1,340,963	13,784,931
2014	2,437,735	145,424	224,403	253,574	11,006,421	466,185	1,406,819	15,940,561
2015	2,715,322	167,678	229,290	261,845	13,081,400	559,114	1,487,460	18,502,109
2016	2,932,619	170,759	235,521	269,302	15,223,925	670,507	1,555,279	21,057,912
2017	3,195,405	170,890	242,076	277,930	17,507,747	761,420	1,642,682	23,798,150
2018	3,494,007	171,117	249,047	284,683	19,783,957	841,445	1,724,426	26,548,682
2019	3,703,649	171,179	253,996	288,652	22,001,277	919,020	1,799,789	29,137,562
2020 P	3,833,616	171,462	255,409	293,460	23,407,865	951,425	1,844,302	30,757,539
2021 P	3,859,264	171,520	255,893	294,066	23,849,010	959,049	1,852,959	31,241,761

P: Provisional [26]

Table No.15 TOTAL NUMBER OF MOTOR VEHICLES REGISTERED IN PAKISTAN [26]

ANNUAL VEHICLE PRODUCTION AND SALES IN PAKISTAN [27]

YEAR	TOTAL Production	TOTAL Sales
2007-2008	888080	890484
2008-2009	658750	657374
2009-2010	951108	955211
2010-2011	1066823	1054612
2011-2012	1055496	1061780
2012-2013	1009184	1008578
2013-2014	944559	945758
2014-2015	1000514	998166
2015-2016	1620299	1616875
2016-2017	1910501	1907475
2017-2018	2271332	2271112
2018-2019	2080688	2079773
2019-2020	1516459	1518341
2020-2021	1407621	1415812
Grand Total	18381414	18381351

Table No.16 ANNUAL VEHICLE PRODUCTION AND SALES IN PAKISTAN [27]

Annual 2-wheeler & 3-wheeler Production and Sales in Pakistan [27]

YEAR	2-wheeler& 3 wheeler Production	2-wheeler& 3 wheeler Sales
2007-2008	641031	643317
2008-2009	493592	493895
2009-2010	736861	737768
2010-2011	838665	835455
2011-2012	828576	829893
2012-2013	819556	820217
2013-2014	771507	772046
2014-2015	765195	766733
2015-2016	1362096	1358643
2016-2017	1632965	1630735
2017-2018	1928757	1931340
2018-2019	1782605	1781959
2019-2020	1370417	1370005
2020-2021	1266444	1267844
Grand Total	15238267	15239850

Table No.17 Annual 2-wheeler & 3-wheeler Production and Sales in Pakistan [27]

7.2 Pricing

High upfront purchase cost of electric vehicle is hindering its rapid adoption in the market. A large portion of the battery electric vehicle cost is due to its Li-ion rechargeable battery. If the battery cost is taken out of the total upfront electric vehicle purchase cost, then this may result in a comparable electric vehicle purchase cost to its ICE counterpart vehicle (especially in small size vehicles e.g., 2-wheeler motor bikes and 3-wheeler rickshaws).

Secondly, the electric vehicle battery cost can be addressed by asking the end-user to pay a reasonable monthly rental cost of battery (with no interest) divided in suitable time period (say three years). This will help the electric vehicle owners in the long run when they start seeing the benefits from day one. The near future expectation is that cost of electric vehicle battery will be coming down due to the technological advancements and promotion of localize manufacturing (in Pakistan) of electric vehicle batteries.

7.3 EV Operating Cost

As described earlier that Battery electric vehicle certainly offers the advantage in terms of fuel consumption to its counterpart internal combustion engine vehicles but infrastructure development costs are huge for electric vehicles so a balanced approach is needed for a gradual ramp-up of EV's in Pakistan. 2 wheeler motorcycles and 3 wheelers /rickshaws due to its market size and low operating cost (compared to its ICE counterpart) as well as low infrastructure cost and small battery size presents an opportunity for a gradual ramp-up of EV's in Pakistan.

Vehicle Type	Average Vehicle Consumption			
	Average Annual Distance	Electricity	Petrol	Diesel
	km	km/kWh	km/liter	km/liter
2 W Motorbikes	14,600	40	40	—
3 W - rickshaw	45,000	20	20	—
4W Sedan, SUVs LDV	12,000	6	11	17
Buses	75,000	1.3	3	4
Trucks	75,000	1	2.5	3.2

Table No.18 Assumption for average annual distance travelled & fuel consumption by vehicle type [10]

Using the above-mentioned assumptions by utilizing Petrol rate = Rs. 150.35 / liter and Electricity rate = Rs. 25 / KWh, following operating cost comparisons were made:

2-Wheeler Motor Cycle Operating Cost Comparison

	2W- Motor bike - Electric	2W- Motor bike (ICE)
Annual distance travelled	14600	14600
Fuel consumption rate (For BEV - in Km/ KWh, For ICE in Km/ liter)	40	40
Fuel Cost (For BEV - in Rs./KWh, For ICE - in Rs./liter)	25	150
Annual Fuel required (For BEV -in KWh, For ICE - in liters)	365	365
Annual Cost of refueling (Rs.)	9125	54878

Table No.19 Two Wheeler Motor Cycle Operating Cost Comparison



Fig.No.44 Sunra electric Bike - Image Courtesy of Sunra Electric bike

3-Wheeler Rickshaw Operating Cost Comparison

	3W- Rickshaw - Electric	3W-Rickshaw (ICE)
Annual distance travelled	45000	45000
Fuel consumption rate (For BEV - in Km/ KWh, For ICE in Km/ liter)	20	20
Fuel Cost (For BEV - in Rs./KWh, For ICE - in Rs./liter)	25	150
Annual Fuel required (For BEV -in KWh, For ICE - in liters)	2250	2250
Annual Cost of refueling (Rs.)	56250	338288

Table No.20 Three-Wheeler Rickshaw Operating Cost Comparison



Fig.No.45 Sazgar eVe electric Rickshaw - Image Courtesy of Sazgar Engineering Works, Pakistan.

In the case of 2 wheelers and 3 wheelers (as obvious from above comparisons) electric vehicle operating cost is much lower compared to their ICE counterpart for short range travel with the

added advantage of recharging via AC chargers in a reasonable time because of smaller battery sizes.

7.4 Resilient supply of spare parts to sustain reliability

It is a must to have the continuous supply of spare parts as per export oriented quality standards. This has to start right away by identifying the critical spare parts of electric vehicle and then manufacture them locally in Pakistan via tariff-based system as per Auto policy. For example, Battery and Electric motors and its associated parts are critical components of Electric vehicle. These parts should be given priority for local development and manufacturing. Inconsistent and sub-standard supply of parts will result in failure to gain the consumer confidence in electric vehicles so appropriate export-oriented standards as per Auto policy need to be maintained. This will help Pakistan in many ways:

1. Continuous supply of quality components/assemblies locally when needed as well as for exports.
2. Opportunity for Auto-parts suppliers /sub-suppliers to transition from only ICE based parts or addition to their current product line.
3. Head start in understanding the manufacturing process of electric vehicle components development via technical assistance agreement with foreign component/systems suppliers and development of supply chain of raw materials/inputs for vehicle components.
4. More employment opportunities in Pakistan to eliminate unemployment.
5. In-shaa-Allah, if done in right way then it will lower the purchase cost of electric vehicle.

7.5 Regional export market development while catering the needs of local market

This has to be enabled via both Government and Private channels by adopting favorable policies and trade agreements. A two-fold approach has to be adopted:

1. Manufacture export oriented electric vehicle parts / assemblies

Electric vehicle motors and its associated parts, controller, charging systems and its associated parts, solid state batteries and its management system, Components of thermal management system (e.g.) Coolant proportional valve, Electric coolant pump, Refrigerant switch valve, Refrigerant expansion valve. In the case of FCEV; Fuel cells, hydrogen fuel tanks etc. are few of the critical export oriented parts and systems which can be exported initially to North America, Australia, European countries, China and Japan where there is a big push towards electric vehicle while other markets are being developed.

2. Export 2 wheeler (motor cycles) / 3 wheelers (rickshaws) electric vehicles

Especially, countries like Afghanistan, Cambodia, Sri Lanka, Turkey, Iran and African countries can be a good market initially for the export of 2 wheeler (motor cycles) / 3 wheelers (rickshaws) electric vehicles.

8. Gaps and Deficits in the Policies and Plans

8.1 Import of all types of SUV's should be stopped completely

SUV's are not fuel efficient vehicles inherently. Secondly, this has resulted in a major outflow of foreign exchange in year 2021, as obvious from the following officially reported data:

Quote:

NOV. 25, 2021: Govt to ban CBU vehicles' import as current account deficit surges to \$1.6 billion a month, says Tarin - Pakistan Today

- Minister of Finance Shaukat Tarin has announced on Thursday that the government has decided to stop the import of CBU (Completely Built Units) vehicles, in addition to other 'frivolous' imports as the current account deficit reaches an alarming \$1.6 billion a month.
- The minister further stated that the government may consider imposing higher duties on vehicles with bigger displacement engines.
- It is pertinent to note that Pakistan has already witnessed record foreign exchange spending on highest-ever arrival of new automobiles in 2020-21 with 10,513 units of new passenger cars, 4x4, vans, pickups, 2-wheelers and buses in FY21 compared to 1,680 units in FY20, 3,716 units in FY19 and 7,424 units in FY18.
- In overall automobile imports of around \$2 billion, the import bill of completely (CKD) and semi-knocked down (SKD) kits for cars, bikes and heavy vehicles stood at record \$1.6bn in FY21 as compared to \$727m in FY20.
- In the first two months of the current financial year (2M-FY22) alone, the import of CKD/SKD kits for local assembly of all vehicles swelled by 214% to \$369m from \$117m in the same period last fiscal year, while import of CBU vehicles posted a growth of 118% to \$103m from \$47m in 2M-FY22. This is because most newcomers despite their assembly plants in the country (which are yet to become in operational state), are heavily relying on imports of CBUs thus burdening the economy.
- Furthermore, the increase in import of CKD/SKD is due to the arrival of new players in the market, however this is something that has to be seriously checked if on one hand we are working towards bringing in new players but with low localization and higher dependency on imports, we will continue to deepen our problems in shape of trade deficits, foreign exchange outflow, higher spendings & zero vehicle or parts exports.
- Earlier, the government, under Auto Policy 2016-21 had allowed assemblers to import 100 units per variant to test the market. But the massive import bill suggests that commercial imports by some specific models have enjoyed an edge. For example, 7,000 units of the MG HS have been delivered to the buyers since November 2020 till date while around 1,000 units are still parked at the port. Additionally, the recent imported batch of Haval H6 & Jolion as well as Proton X70 also exceeds well above 100 units as stipulated in the policy, with local production (assembling) still not in sight.
- Reacting to the development, a leading South Korean assembler said it imported a minimum of five to six units to a maximum of 50 units of different variants ahead of the start of local assembly. Another new entrant said industry pundits claimed the highest-ever localization of parts in cars to up to 65%,

but in reality no investment had been made towards localization of hi-tech parts, engines, transmissions and electronic control units in the last 30 years.

8.2 Import of CBU for test marketing

Import of CBU electric vehicles even for test marketing should not be allowed in the case of 4 wheelers (equivalent to or above 1300 cc ICE engines). This applies to cars, jeeps, station wagons, SUVs. Electric vehicle technology is evolving and currently the purchase cost of these vehicles is very high. If not stopped, then this will result in too much out flow of foreign exchange which Pakistan needs for the gradual ramp-up of Electric vehicles in Pakistan.

8.3 Import of DC Charging stations/level 3 chargers & above should be restricted for general use

EV ramp-up in Pakistan is based on market size and two-wheelers (motor cycles) and three-wheelers (rickshaws) dominate the market size, therefore, they were given the priority. For two wheelers and three wheelers, there is no need for level 3 or above chargers / charging stations due to smaller size EV batteries. Re-charging needs of these batteries can be addressed with level-2 AC chargers and home chargers. This will result in significant reduction in upfront battery charging infrastructure costs.

8.4 Only handful of level 3 DC chargers import can be allowed for 'Fixed route' buses

Initially, the import of handful of DC chargers for a very specific, very high utilization case of 'Fixed route' buses can be allowed after carefully reviewing all the relevant details of use via a very strict approval process for such imports. Again, this is important to keep the battery infrastructure cost very low and to reduce the costs of imports.

8.5 Monitoring mechanism of import of 150KWh EV batteries for LCV's

Very strict import and monitoring mechanism of 150KWh EV batteries should be in place to avoid the import and use of these batteries in any other category vehicles. If this mechanism cannot be put in place, then it will result in significant outflow of foreign exchange unnecessarily. If there is no way to avoid this unnecessary outflow of foreign exchange, then initially the import of 150KWh EV batteries should not be allowed in any category till the results of electric vehicle usage in other categories are available.

8.6 Verification and monitoring of electric vehicle manufacturing facilities by EDB

Companies that are approved to import CBU of electric vehicles by EDB after verification of their manufacturing facilities should be monitored/evaluated quarterly (if monthly monitoring /evaluation is not possible) for their readiness to produce Electric vehicles in Pakistan.

8.7 Custom duty on import of localized parts of Heavy Commercial Vehicles (Trucks, Buses, Prime Movers)

Custom duty on import of localized parts of Heavy Commercial Vehicles (Trucks, Buses, Prime Movers) needs to be clearly defined in AIDEP 2021-26. Import of localized and non-localized parts should not be at the same level of 1% custom duty. Otherwise, there is no incentive to manufacture these parts locally.

8.8 CBU import should be limited per company in the case of Heavy Commercial Vehicles (Trucks, Buses, Prime Movers)

Maximum number of CBU of electric vehicles in this category should be limited to a very small number per company, as they are very expensive and will result in significant amount of outflow of foreign currency from Pakistan. Companies that are approved to import CBU of electric vehicles by EDB after verification of their manufacturing facilities should be monitored/evaluated quarterly (if monthly monitoring /evaluation is not possible) for their readiness to produce electric vehicles in Pakistan.

8.9 Strict control and very limited import of level-3 DC chargers (higher than 50KW capacity) can be allowed only for special situations of commercial applications

In the first few years, import of level-3 DC chargers (higher than 50KW capacity) should be discouraged and can only be allowed in a very limited number (after doing the appropriate due diligence and following strict approval process) only for special situations of commercial applications to avoid an unnecessary outflow of foreign exchange from Pakistan. This very limited import of level-3 DC chargers should be linked with subsequent manufacturing of level-3 DC chargers in Pakistan within 2 years of import.

9. Proposed Solution: Policies, Plans, And Implementation

As we know that electric vehicles implementation in Pakistan will be gradual mainly due to high upfront purchase cost of electric vehicles. It is also a fact that technological advancements are also suggesting a near future possibility of combination of Battery electric vehicles and Fuel cell electric vehicles to co-exist and down the road will be converted possibly to Fuel cell electric vehicles. So, starting the implementation of EV's in Pakistan with 2-wheeler motor bikes and 3-wheeler electric rickshaws is the right focus. We hope, In-shaa-Allah, it will result in right balance of reaping the current and long-term benefits of electric vehicles by keeping the infrastructure costs of battery electric vehicles low and expediting the infrastructure development of hydrogen based Fuel cell electric vehicles. Therefore, following is the proposed solution for implementation for next few years:

9.1 Focused implementation of EV on 2 Wheelers and 3 wheelers

By focusing on 2-wheeler electric motor bike and 3 wheeler electric rickshaw, the total implementation cost of battery vehicle infrastructure will be significantly reduced (as they will not require the DC chargers). As per Table 2 of National Electric Vehicle Policy 2019, 2 wheelers and 3 wheelers (with 5 years' cumulative target of 500,000 electric vehicles) will result in yearly estimated income and savings from EV of Rs.63.5 Billion out of Rs.110 Billion with Five Year Penetration target [25].

9.2 Remove the “Heavy trucks/ Heavy vehicles” from penetration targets for next five years

The current challenge for battery-electric vehicles is long-haul logistic operation and transport of very heavy goods (which implies high energy consumption per kilometer) and will require the use of high capacity DC chargers due to bigger battery sizes in electric trucks, so the recommendation is to remove the “Heavy trucks/ Heavy vehicles” from penetration targets for next five years (and make appropriate changes in AIDEP 2021-26 EV related policy) with the expectation that the reduction in prices of electric trucks, batteries and positive technological changes (long range travel with large pay loads is under evaluation in FCEV and very likely will be the solution for long-haul logistic operation and transport of very heavy goods) down the road will result in better solution for Pakistan's transportation needs. Otherwise, this will result in significant outflow of foreign exchange from Pakistan due to the imports of expensive heavy electric vehicles and its associated infrastructure components.

9.3 Extreme care has to be exercised in the battery charging infrastructure development as the costs of infrastructure development on a large scale will be huge

Since Pakistan has not invested in electric vehicle infrastructure yet, therefore, there is no need to disinvest. This implies that an extreme care has to be exercised in the battery charging infrastructure development as the costs of infrastructure development on a large scale will be huge (i.e., with high market penetration (20 million vehicles or more), the accumulated investments for a charging infrastructure are at around € 51 billion compared to the hydrogen electric vehicle infrastructure at around € 40 billion. [11] The long-term conversion to FCEV should be the focus and this needs to be planned and promoted. Forward thinking tells us that this is a classic case of redundancy of technology in a near future due to disruption of emerging technology.

Secondly, as highlighted in '6.6. infrastructure' section, in a certain period of time, significantly more FCEVs can be supplied per fuel pump than BEVs per charging point. This also applies to the use of DC fast charging stations. Therefore, a correspondingly larger number of parking spaces with charging facilities should be provided in order to achieve the same refueling capacity.

Thirdly, DC charger stations costs are very high. ABB - a European manufacturer, has installed a few 50 KW chargers in Pakistan with an equipment cost of PKR 4.9 million [10]. This implies that there is a significant cost involved in installing fast chargers along the major motor ways and highways after every 15-30 km (as per AIDEP 2021-26). The length of highways in Pakistan (as of 2018) is 12131 km and projected to be around 15201 km by 2025 [28]. By using total length of Highways of 12131 Km [28], using ABB Fast charger installed cost of Rs.4.9 million [10] and applying the AIDEP (2021-26) policy decision of fast charger installation at 15-30 km of motor ways/highways, this cost can be in the range of at least Rs.1.981 billion to Rs.3.962 billion (not including any price increases in fast chargers due to high inflation). Currently, the assumption is that these fast chargers will be imported so this will result in significant outflow of foreign exchange from Pakistan. Also, the fact that higher capital cost of fast chargers will result in higher tariff for charging cost to the end user (if there is no controlled mechanism to keep the tariff low for the charging cost to the end user in order to promote EV ramp-up in Pakistan).

9.4 Commercial AC charging should be provided with residential electricity rates

Off-peak hours AC charging should be encouraged and commercial AC charging should be provided with residential electricity rates to electric vehicle end user.

9.5 Battery manufacturing and manufacturing of other related components of electric vehicle in Pakistan to be expedited

Expedite the battery manufacturing and other related components of electric vehicle in Pakistan starting with smaller batteries for electric motor bikes, electric rickshaws and small electric cars.

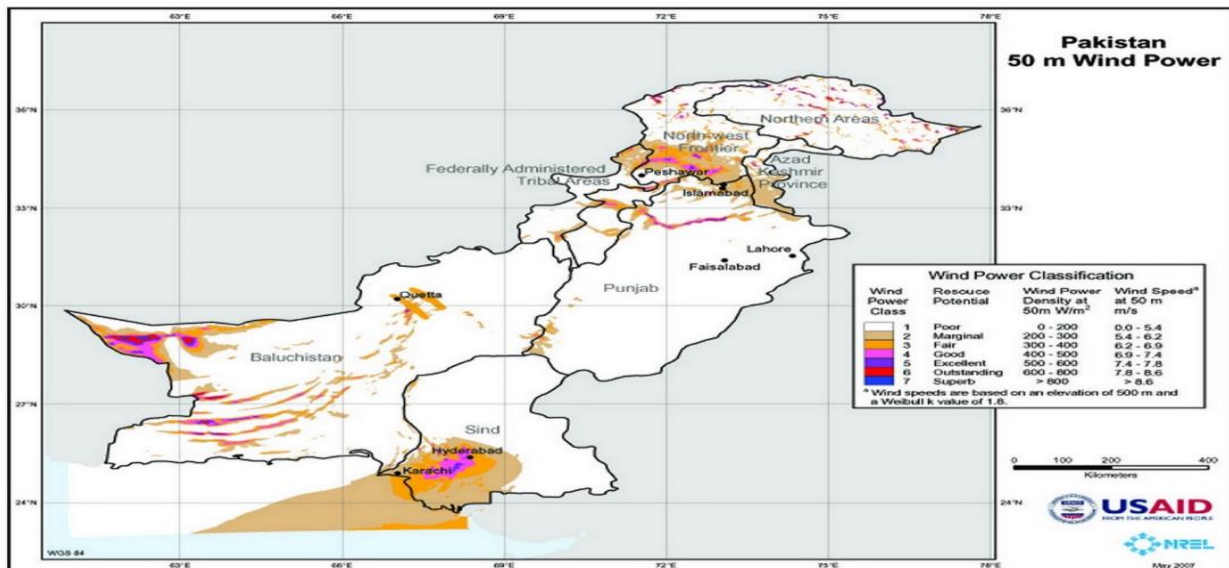
In parallel, secondary focus should be on the larger size batteries manufacturing for electric buses. Other EV component such as electric motors, various types of valves for thermal management, hydrogen tanks, can also be manufactured in Pakistan.

9.6 Provide incentives/subsidies to reduce the Solar panels and solar systems

Costs of solar panels and solar systems should be reduced by removing the sales taxes and/or by providing other subsidies (if possible). This will be a big incentive for rapid adoption of electric vehicles in Pakistan and will help in infrastructure development for BEV (e.g. solar powered roof tops at Petrol stations/bus depots/supermarkets etc. for providing some electricity to charging stations as well as at the same time providing electricity for other purposes). Similarly, in case of FCEV, solar powered hydrogen dispensing stations can potentially be a viable solution. Secondly, it provides the added advantage of cheap electricity availability for the local consumer's daily power needs.

9.7 Projects which have the potential to produce 'Green Hydrogen' at cheaper rates for downstream usage have to be expedited

Projects which have the potential to produce 'Green Hydrogen' at cheaper rates for downstream usage have to be expedited and given priority. These projects should also be given incentives, so that Fuel cell electric vehicles infrastructure development can be expedited. This will eventually cater for the needs of 'long range' bigger size electric vehicles with the help of renewable energies (e.g. ORACLE Power 150,000 kg/day hydrogen generation project via Wind / solar energy with a



less than 1.75 Euro/kg of hydrogen production as per pre-feasibility studies done recently [30]) in Pakistan. Below "Pakistan wind power map" and 'Pakistan Direct Normal Solar Radiation Map" shows where in Pakistan such projects can be initiated and executed.

Fig.No.46 Pakistan Wind Power Potential map - Image courtesy of Alternative Energy Board, Ministry of Energy, Govt. of Pakistan

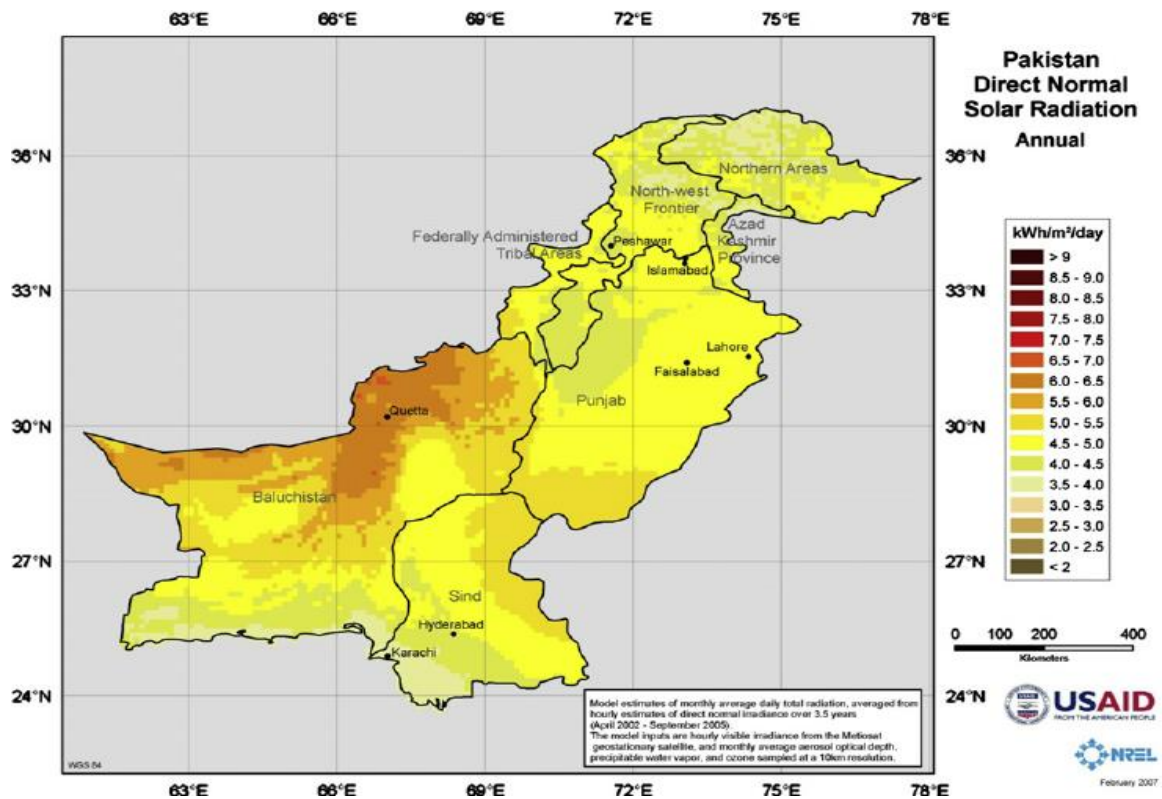


Fig.No.47 Pakistan Direct Normal Solar Radiation Map - Image courtesy USAID/NREL

9.8 Fuel cell system development and manufacturing should be expedited

Fuel cell system development and manufacturing should be expedited by providing appropriate incentives. The idea here is to export the Fuel cells to FCEV ready countries while the infrastructure development for FCEV is in progress in Pakistan. This will result in an added benefit of shortening the learning curve of FCEV development and manufacturing in Pakistan (as Fuel cell system is the backbone of FCEV).

9.9 Give the due focus to both BEV and FCEV where their strength lies

By giving the due focus to both BEV and FCEV where their strength lies (i.e., BEV for short range-smaller size electric vehicles and FCEV for longer range – bigger size electric vehicles), carefully evaluating the constantly evolving electric vehicle technology trend and intelligently focused on the development of their infrastructure based on what works best for Pakistan, In-shaa-Allah Pakistan will be able to reap its full benefits and will become an economically sound country in the near future.

9.10 Interest free/sharia compliant loans can be considered for the ramp-up of EV manufacturing in Pakistan as well as EV infrastructure development

Interest free/sharia compliant loans can be considered for the ramp-up of EV manufacturing in Pakistan and EV infrastructure development after carefully evaluating the business proposals.

9.11 Establishment of National Center for electric Vehicles and its active involvement in all major cities of Pakistan

Establishment of National Center for electric vehicles should address the needs of entire Pakistan and have its branches in all big cities (i.e., higher population density cities) of Pakistan where we have high rate of 2 wheeler motor bikes/ 3 wheeler commercial utilization, as this will help in rapid EV adoption and will result in achieving the EV penetration targets. However, progress of the National Center for Electric Vehicles is unknown which is a cause for a concern. Secondly, it has a collaboration with Pakistani engineering universities where all the latest technological advancements should be researched e.g. latest materials used in Solid State Batteries and its manufacturing processes (e.g. additive manufacturing), Thermal management system advancements, advances in fuel cell system development, hydrogen based technologies development, alternate materials for fuel cell catalyst etc.)

9.12 Substitution of annual production targets of SUV's manufactured in Pakistan

Due to the rising fuel costs in Pakistan / internationally, Pakistan's heavy dependency on fuel imports for ICE based vehicles, and knowing that SUV's are not fuel efficient vehicles, therefore, all the SUV vehicle manufacturers in Pakistan should be asked to substitute their annual SUV production targets with smaller engine size vehicles that they are manufacturing. This will help reduce the out flow of foreign exchange from Pakistan to some extent.

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11. ANNEXURES

Annex I - National Electric Vehicle Policy (NEVP 2019), Ministry of Climate Change, Government of Pakistan.

Annex II - Auto Industry Development and Export Policy (AIDEP 2021-26), Engineering Development Board, Ministry of Industries and Production, Government of Pakistan.

Annex III - Scaling Up Electric Mobility in Pakistan, UNDP via National Energy Efficiency and Conservation Authority (NEECA), Ministry of Energy (MoE), Government of Pakistan.

Annex IV - List of some Electric Traction Motor Manufacturers

Annex V - Sazgar eVe 3 Wheeler Electric Rickshaw Specifications

Annex VI - List of companies currently producing commercially available fuel cell systems for use in residential, commercial, or industrial settings.

Annexure I



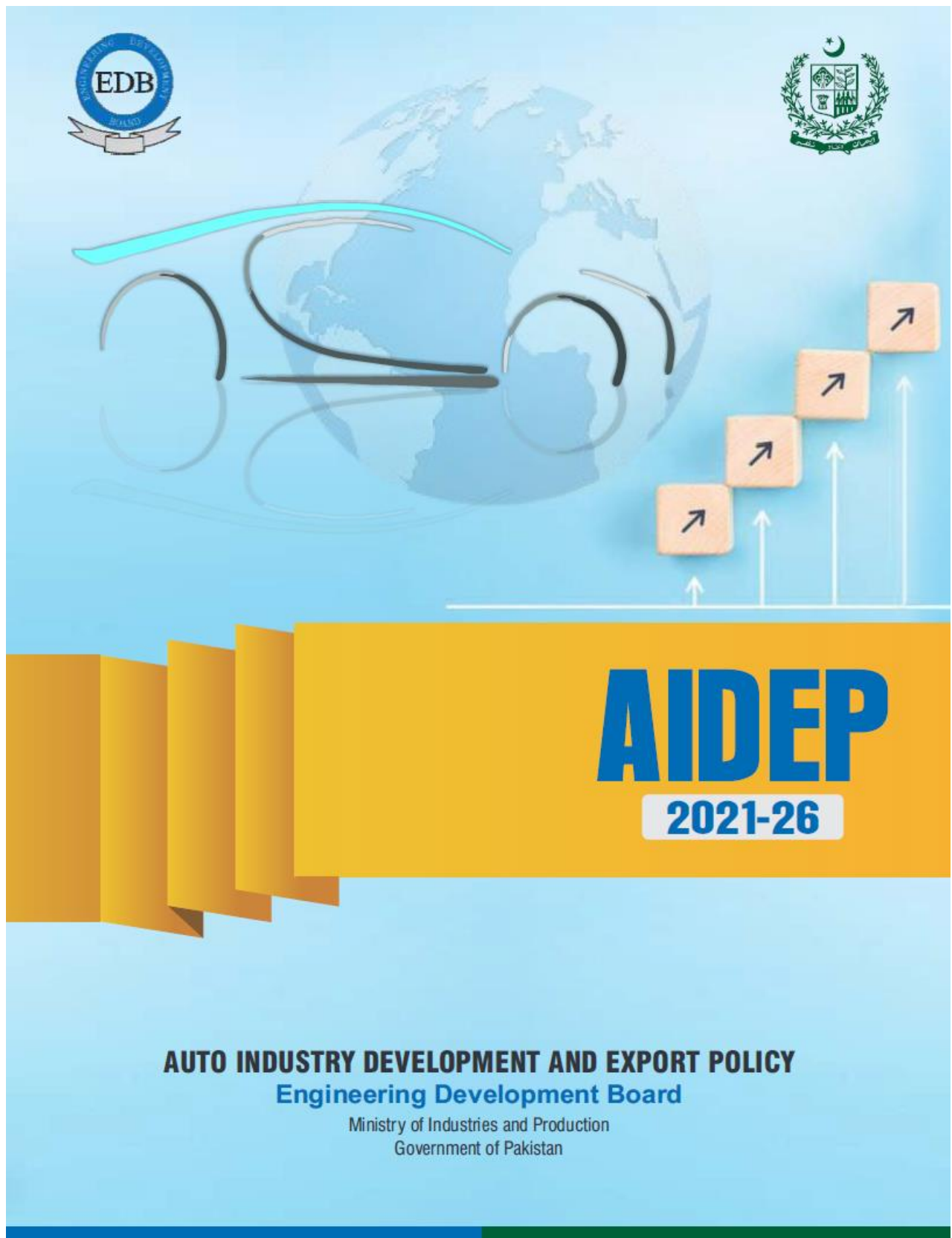
Ministry of Climate Change
Government of Pakistan

NATIONAL ELECTRIC VEHICLE POLICY



GOVERNMENT OF PAKISTAN
MINISTRY OF CLIMATE CHANGE
Islamabad, Pakistan
2019

Annexure II



Annexure III



Scaling Up Electric Mobility in Pakistan



Khalil Raza
National Technical Expert — Electric Mobility, UNDP
October 2021

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Annexure IV

List of Electric Traction Motor Manufacturers

ABB

Address
ABB Ltd
Affolternstrasse 44
8050 Zurich
Switzerland
Phone: +41 43 317 7111
Fax: +41 43 317 4420

Siemens

Address
Werner-von-*Siemens*-Straße 1,
80333 München,
Germany

Ametek (US)

Address
1100 Cassatt Road Berwyn,
PA 19312.
USA
Tel: 610-647-2121.
Email: info.corp@ametek.com

General Electric (US)

Address
General Electric Company
5 Necco Street
Boston, MA 02210
USA

Toshiba

Address
13131 West Little York Road, Houston
TX 77041
USA Phone 800.231.1412

Eaton (Ireland)

Address
EATON HOUSE 30 PEMBROKE
ROAD DUBLIN,
D04Y0C2 Ireland

CG Power and Industrial Solutions (India)

Address
CG Power and Industrial
Solutions Ltd
Mumbai, Maharashtra,
India ·
+91 22 6755 8601

Mitsubishi Electric

Address
Mitsubishi Electric Corporation
Tokyo Building, 2-7-3,
Marunouchi,
Chiyoda-ku,
Tokyo 100-8310,
Japan
Phone: (+81) 3-3218-2111

Voith (Germany)

Address
St.-Pöltener-Str. 43 89522,
Heidenheim an der Brenz,
Baden-Württemberg
Germany
Phone: +49-7321370

Annexure V

Sazgar eVe 3 Wheeler Electric Rickshaw Specifications

Variant 1

Battery: 72V,90Ah, 6.5Kw/h
Charging Time: 4hrs, Approx Range: 100Km/h
Motor: 3Kwh.
Front Suspension: Hydraulic Shock Absorption
Rear Suspension: Leaf Spring Shock Absorber
Gross Weight: 370kgs
Front Brake: Disc Brake
Rear Brake: Disc Brake

Variant 2

Battery: 72V,125Ah, 9Kw/h
Charging Time: 5hrs, Approx Range: 160Km/h
Motor: 3Kwh
Front Suspension: Hydraulic Shock Absorption
Rear Suspension: Leaf Spring Shock Absorber
Gross Weight: 370kgs
Front Brake: Disc Brake
Rear Brake: Disc Brake

Variant 3

Battery: 72V,160Ah, 11.5Kw/h
Charging Time: 5hrs, Approx Range: 210Km/h
Motor: 3Kw/h
Front Suspension: Hydraulic Shock Absorption
Rear Suspension: Leaf Spring Shock Absorber
Gross Weight: 370kgs
Front Brake: Disc Brake
Rear Brake: Disc Brake

Annexure VI

List of companies currently producing commercially available fuel cell systems for use in residential, commercial, or industrial settings.

Nedstack (PEMFC "Varied Applications")

Address

Westervoortsedijk 73, 6827 AV Arnhem, Netherlands

Phone: +31 26 319 7600

Adaptive Energy (SOFC Backup and Auxiliary Power)

Address

5500 South State Road, Ann Arbor, MI 48108

Phone +1-734-302-7632

info@adaptiveenergyllc.com

Ballard (Ballard Fuel Cells "various products")

Address

9000 Glenlyon Parkway

Burnaby, B.C. V5J 5J8

Phone 604-454-0900

Fax: 604-412-4700

Loop Energy Inc. (PEMFC Hydrogen Fuel Cell Modules & Systems)

Address

2880 Production Way

Burnaby, BC V5A 4T6

Canada

Phone: +1 604-222-3400

Toll Free: +1 855-222-1534

Bloom Energy (Bloom Energy Server "BloomBox")

Address

4353 North First Street

San Jose, CA 95134

Phone: (408) 543-1500

SolidPower (BlueGen)

Address

SOLIDpower S.p.A.

Via Trento, 115/117 c/o BIC

38017 Mezzolombardo

Italy

Ceres Power (Solid oxide fuel cell)

Address

Viking House

Foundry Lane

Horsham

West Sussex

RH13 5PX

UK

Doosan Fuel Cell America (PureCell Model 400 and SOFC)

Address

195 Governor's Highway South

Windsor, CT 06074

Phone: (860) 727-2200

Sales: (860) 727-2253

ElringKlinger AG: (PEMFC (NM5 (6-70 kW), NM12 (30-150 kW), Module (100kW, Customized))

Address

Max-Eyth-Straße 2

72581 Dettingen/Erms

Germany

Phone +49 7123 724-0

Fax +49 7123 724-9006

info@elringklinger.com

Horizon: (ECOBOC-MR, Aerostack, Hydromax)

Address

HORIZON SINGAPORE

48 Toh Guan Road East

#05-124 Enterprise Hub

608586 Singapore

Tel: +65 9028 6211

+65 6909 5297

Intelligent Energy (FCM-800)

Address

Intelligent Energy Limited

Charnwood Building

Holywell Park

Ashby Road

Loughborough

Leicestershire LE11 3GB

United Kingdom

Telephone +44 (0)1509 271271

Email sales@intelligent-energy.com

Mitsubishi Heavy Industries: (Solid oxide fuel cell)

Address

Tokyo Branch Office: 2-3, Marunouchi

3-Chome, Chiyoda-Ku, Tokyo 100-8332,

Japan TEL: 81-80-8959-5559 FAX: 81-

3-6275-6484. E-mail:

info_meet@mhi.com

Plug Power Inc. (GenDrive, GenSure, ProGen)

Address

968 Albany Shaker Road

Latham, New York 12110

T:518-782-7700

Powercell (PEMFC S3, S2 and Module)

Address

PowerCell Sweden AB

Ruskvädersgatan 12

SE-418 34 Gothenburg Sweden

+46 (0) 31 720 36 20

sales@powercell.se

Robert Bosch GmbH (PEMFC and SOFC)

Address

Robert Bosch GmbH

Robert-Bosch-Platz 1

70839 Gerlingen-Schillerhöhe

GERMANY

kontakt@bosch.de

+49 711 400 40990

SIQENS GmbH (HT-PEMFC with methanol reformer, SIQENS Ecoport 800)

Address:

Landsberger Str. 318D, 80687

München, Germany

Phone: +49 89 45244630

Toshiba:

Address

Kawasaki

72-34, Horikawa-cho, Saiwai-ku

Kawasaki-shi, Kanagawa 212-8585,

Japan

Zepp.solutions

Address:

Paardenmarkt 1, 2611 PA Delft,

Netherlands

Phone: +31 15 203 0044

