COMPARISON OF ELECTRIC AND HYDROGEN FUELLED VEHICLES, INCLUDING LITHIUM ION BATTERIES AND HYDROGEN

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(An autonomous Institute of Ministry of New and Renewable Energy, Govt. of India)
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Contents

Foreword

A study on "Comparison of Electric and Hydrogen Fuelled Vehicles, including Lithium Ion Batteries and Hydrogen" was undertaken by National Institute of Solar Energy (NISE). The motivation for undertaking this study was provided by Shri R. K. Singh, Hon'ble Minister of State (Independent Charge) for New and Renewable Energy and Power, Government of India, who was very keen for such a study. For undertaking the study, NISE constituted a Joint Group comprising the experts drawn from industry, academic institution, industry association and NISE. For preparation and finalising the Report of the study, two meetings of the Joint Group were held and each member of the Joint Group provided his contribution for preparation and finalisation of the Report.

Hydrogen and electricity are emerging as potent energy vectors for decarbonisation of the different sectors of the economy. Electric mobility in the form of electric vehicles has made rapid strides in the recent years globally as well as in India. Hydrogen is also called as 'Fuel for Future' and terms like 'Hydrogen Economy' and 'Hydrogen Society' are often used for signifying importance of hydrogen as an energy carrier. However, hydrogen based technologies for transport sector and power generation will have to be brought out from the confines of laboratories to real use for realising dreams of hydrogen society. I am of the view that the findings and recommendations made in the report would help the policy makers in further development and deployment of hydrogen and fuel cell-based technologies along with associated infrastructure in the country.

(Dr. A. K. Tripathi)
Director General

Acknowledgements

The inspiration for preparation of this Report was provided by Shri R. K. Singh, Hon'ble Minister of State (Independent Charge) for New and Renewable Energy, Power and Skill Development, Government of India. National Institute of Solar Energy (NISE) is grateful to the Hon'ble Minister for the encouragement, which made it possible to come out with this report.

NISE constituted a Joint Working Group comprising of the experts from the concerned organisations i.e. Indian Oil Corporation Limited, Society of Indian Automobile Manufacturers, Mahindra & Mahindra, Tata Motors Ltd., Tata Chemicals, Indian Institute of Technology Delhi, and NISE. This report is a culmination of their sustained efforts and contributions. NISE gratefully acknowledges their support and contributions. NISE is thankful to untiring efforts of a team of Scientists of NISE i.e., Dr. Joydev Manna, Shri Prakash Jha and Shri Rudranath Sarkhel, led by Dr. M. R. Nouni, Senior Consultant, who coordinated various activities of the Joint Group and also in finalisation of the Report. The valuable comments and constant support of Dr. Chandan Banerjee, DDG NISE is especially acknowledged. Administrative support provided by Shri Ankeshwar Mishra, Deputy Director, NISE is also acknowledged.
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Joint Working Group and the Team

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List of Abbreviations

ABB: ASEA Brown Boveri

AECs: Alkaline Electrolysis Cells

ASEAN: Association of South-East Asian Nations

AWE: Alkaline Water Electrolyser

BAIC: Beijing Automotive Industry Holding Co. Ltd.

BARC: Bhabha Atomic Research Centre

BASF: Badische Anilin und Soda Fabrik Co.

BCD: Basic Custom Duty

BEE: Bureau of Energy Efficiency

BEV: Battery Electric Vehicle

BHEL: Bharat Heavy Electricals Limited

BHU: Banaras Hindu University

BMS: Battery Management System

BMW: Bavarian Motor Works

BP: Bharat Petroleum

CAFÉ: Corporate Average Fuel Economy

CAGR: Compound Annual Growth Rate

CAPEX: Capital Expenditure

CATL: Contemporary Amperex Technology Co. Limited

CBU: Completely Built Unit

CEA: Alternative Energies and Atomic Energy Commission, France

CECRI: Central Electrochemical Research Institute

CFCT: Centre for Fuel Cell Technology

CIMFR: Central Institute of Mining and Fuel Research

CKD: Completely Knocked Down

CNG: Compressed Natural Gas

CO_2: Carbon dioxide

CSTEP: Center for Study of Science Technology and Policy

CSIR: Council of Scientific and Industrial Research

Cu-Cl: Copper Chlorine

DHI: Department of Heavy Industry

DIPP: Department of Industrial Policy and Promotion

DOE: Department of Energy

DSIR: Department of Scientific and Industrial Research

DST: Department of Science and Technology

EGR: Exhaust Gas Recirculation

EOI: Expression of Interest

ERDA: Electrical Research and Development Association

EU-REI: European Union's Resource Efficiency Initiative

EVs: Electric Vehicles

EVSE: Electric Vehicle Supply Equipment

e-buses: Electric buses

e-mobility: Electric Mobility

FC: Fuel Cell

FCA: Fiat Chrysler Automobiles

FCV: Fuel Cell Vehicle

FAME: Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles

GHG: Greenhouse Gases

GM: General Motors

GoI: Government of India

GSPC: Gujarat State Petroleum Corporation

GT: Giga Tonnes

GW: Gigawatt

GWh: Gigawatt-hour

H-CNG: Hydrogen – Compressed Natural Gas

HEV: Hybrid Electric Vehicle

HFC: Hydrogen Energy and Fuel Cell

HFV: Hydrogen Fuelled Vehicle

HICE: Hydrogen Internal Combustion Engine

HICEV: Hydrogen ICE Vehicle

HP: Hindustan Petroleum

HRS: Hydrogen Refuelling Station

IACS: Indian Association for the Cultivation of Science

ICE: Internal Combustion Engine

ICEV: ICE Vehicle

ICT: Institute of Chemical Technology

IEA: International Energy Agency

IICT: Indian Institute of Chemical Technology

IISc: Indian Institute of Science

IIT: Indian Institute of Technology

IOCL: Indian Oil Corporation Limited

IP: Industrial Processes

IS: Iodine-Sulphur

ISRO: Indian Space Research Organisation

JNTU: Jawaharlal Nehru Technological University

KPMG: Klynveld Peat Marwick Goerdeler

kW: kilowatt

kW_{th}: kilowatt thermal

LCC: Life Cycle Cost

LCO: Lithium Cobalt Oxide

LCVs: Light Commercial Vehicles

LDVs: Light-Duty Vehicles

LFP: Lithium Iron Phosphate

LIB: Lithium Ion Battery

Li-Ion: Lithium Ion

Li-S: Lithium Sulphur

LMV: Light Motor Vehicle

LPG: Liquefied Petroleum Gas

LS: Lock Smart

LTO: Lithium Titanium Oxide (Referred to Lithium – titanate battery)

LUCF: Land Use Change and Forestry

M&M: Mahindra & Mahindra

MCRC: Shri AMM Murugappa Chettiar Research Centre

MHIPE: Ministry of Heavy Industries and Public Enterprises

MIT: Massachusetts Institute of Technology

MMT: Million Metric Tonne

MNRE: Ministry of New and Renewable Energy

MoF: Ministry of Finance

MoHUA: Ministry of Housing and Urban Affairs

MoP: Ministry of Power

MoRTH: Ministry of Road Transport and Highways

MoUs: Memorandum of Understandings

MT: Metric Tonne

Mtoe: Million Tonnes of Oil Equivalent

MW: Megawatt

NCA: Nickel Cobalt Aluminium

NCR: National Capital Region

NEERI: National Environmental Engineering Research Institute

NEMMP: National Electric Mobility Mission Plan

NHER: National Hydrogen Energy Roadmap

NITs: National Institute of Technologies

NISE: National Institute of Solar Energy

NITI: National Institution for Transforming India

NMC: Nickel Manganese Cobalt

NMH: Nickel Metal Hydride

NO_X: Oxides of Nitrogen

OEC: ONGC Energy Centre

OPEX: Operating Expenses

PEM: Polymer Electrolyte Membrane

PEMC: Polymer Electrolyte Membrane Cells

PEMFC: Polymer Electrolyte Membrane Fuel Cell

PHEV: Plug-In Hybrid Electric Vehicle

PM: Particulate Matter

PMP: Phased Manufacturing Programme

POx: Partial Oxidation

PV: Photovoltaic

R&D: Research and Development

RD&D: Research, Development and Demonstration

RE: Range Extension

RPO: Rated Power Output

SHV: Strong Hybrid Vehicle

SKD: Semi Knocked Down

SMEV: Society of Manufacturers of Electric Vehicles

SMR: Steam Methane Reformation

SNAM: Società Nazionale Metanodotti

SOECs: Solid Oxide Electrolyser Cells

SPV: Solar Photovoltaic

SSF: SPIC Science Foundation

SUV: Sport Utility Vehicle

TML: Tata Motors Ltd.

Toe: Tonnes of Oil Equivalent

UNIDO: United Nations Industrial Development Organisation

US$: United States Dollar

V2G: Vehicle-to-Grid

WEVC: Wireless Electric Vehicle Charging

EXECUTIVE SUMMARY

India was the fifth largest economy of the world in 2019. Strong economic growth coupled with growing population is contributing to rapid increase in its energy demand. India continues to rely heavily on fossil fuels for meeting its growing energy requirement in spite of noteworthy achievement made in renewable energy sector. India’s reliance on imported hydro-carbons continues to grow due to limited indigenous production and increasing demand. It is the third largest importer of crude oil globally in 2018. It imports about 70% of its crude oil from the Middle East, which is geo-politically a very sensitive region and thereby has been impacting crude oil import bill of the country adversely.

2. India was the 3rd largest emitter of greenhouse gases (GHGs) globally after China (28.6%) and the USA (14.75%) with 2.299 GT (6.94%) of energy related CO_2 emissions during 2018. Nearly 70% of GHGs are contributed by thermal power plants, transport sector, construction and fugitive emissions. As per World Air Quality Report 2019 compiled by IQAir AirVisual, out of the 30 most polluted cities in terms of air quality, 21 cities are located in India and 18 of these cities are in the National Capital Region (NCR) region.

3. The estimated total potential for power generation from renewable resources is 1100 GW in India. Renewable energy-based power generation capacity of about 86 GW has been established as on 31.12.2019 with contributions from wind and solar as 37.505 GW and 33.73 GW respectively. Renewable energy can provide sustainable solution for mitigating climate change and worsening air quality related issues, apart from reducing dependence on hydrocarbons and thus offering energy security. For decarbonising transport sector, energy carriers like electricity and hydrogen are seen as promising options. Government of India (GoI) has been working on developing an eco-system for manufacture and deployment Electric Vehicles (EVs) by bringing out favourable policy regime. With a view to encourage development of hydrogen energy and fuel cell technologies, GoI has been supporting a broad based Research and Development (R&D) programme on hydrogen production, its storage and applications for transport and power generation applications for more than two decades. These efforts have led to development of prototypes of Hydrogen Fuelled Vehicles (HFVs) in India. However, for deployment of large number of EVs and introduction of HFVs, several challenges will have to be overcome in the country.

4. In EV domain, pure Battery Electric Vehicles (BEVs or simply EVs), Plug-in Hybrid Electric Vehicles (PHEVs) and Hybrid Electric Vehicles (HEVs) are attracting a lot of attention in the recent years in view of better fuel economy in comparison to conventional vehicles and no/reduced emissions at the point of use. In some countries, adoption of EVs is growing at a faster pace due to dropping cost of EVs. However, inadequate charging infrastructure and long recharging time are still major barriers for faster adoption of EVs in most of the countries.

5. Number of electric cars in use globally has increased by nearly four times from 12.5 lakh in 2015 to 51.2 lakh in 2018. Nearly 20 lakh electric cars were sold in 2018 alone, of which two-third were BEVs. China is the leading market for electric cars, followed by Europe and the USA. In comparison, India has a very small market for electric cars presently with their cumulative numbers being about 10,600 in 2019. The global market for electric cars is expected to grow very rapidly and is projected to reach more than 6 crore units by 2040. There is a huge market for electric two and three wheelers with China as the major market and India having about 6 lakh electric scooters and around 24 lakh e-rickshaws on its roads by the end of 2018. The global stock of electric buses was about 4.6 lakh units in 2018. In view of the financial incentives being offered by the GoI under the second phase of its Faster Adoption of Manufacturing of (Hybrid &) Electric Vehicles (FAME) programme, market for electric scooters and three wheelers is expected to grow quite rapidly in comparison to electric cars and buses in the coming five years. FAME also addresses the issue of widening the network of charging infrastructure by providing financial incentives, as there are reported to be only around 500 charging stations in the country presently.

6. Among different HFVs, Fuel Cell Vehicles (FCVs) have been preferred globally due to higher efficiency and no emissions. A number of automobile companies such as Toyota, Honda and Hyundai have commercially introduced Fuel Cell (FC) cars a few years back. FC buses and forklifts have also been deployed worldwide. Hydrogen fuelled trains, aeroplanes and boats have also been demonstrated. Total global stock of the FCVs has reached 11,200 by the end of 2018. In contrast to global trend, India preferred to focus on development of Hydrogen-ICE (HICE) vehicles in comparison to FCVs in view of challenges like high cost and durability associated with FCs, when the National Hydrogen Energy Roadmap (NHER) was developed in 2005. This resulted in development of HICE based motorcycles, three wheelers and mini-buses by collaborative efforts of academic institutions and industry. Simultaneously

efforts were also made for development of dual fuel [Hydrogen- Compressed Natural Gas (H-CNG) and hydrogen-Diesel] vehicles with twin objectives of reducing emissions and improving performance. One of the auto companies in India has also developed prototypes of FC bus in India. These prototypes have undergone limited field trials due to availability of very limited number of Hydrogen Refuelling Stations (HRS) in the country. There is a need for having a suitable programme for demonstration of various HFVs, developed in India, at suitable locations.

7. Among different battery technologies, Lithium Ion Batteries (LIBs) have higher energy density, zero-memory effect, higher open circuit voltage, and long lifespan, which make them suitable for EVs. LIB is also preferred battery technology for electronics and grid level energy storage applications. Li-ion cells have already achieved energy density of 330 Wh/kg with a future target of 400 Wh/kg. With sustained R&D efforts, prices of LIB have fallen to a level of about US$ 210/kWh in 2019 from a level of more than US$ 3000/kWh two decades back. Based on preliminary life cycle analysis, cost of delivered electricity from LIB could be in excess of Rs. 20/kWh depending on initial capital cost and cost of electricity used for recharging. This downward trend in prices of LIBs is likely to continue in coming years. The US Department of Energy (USDOE) predicts that once battery costs fall below US$125/kWh, owning and operating an EV will be economical to a conventional car. The global manufacturing capacity and demand for LIBs were estimated to be around 285 GWh and 190 GWh respectively in 2019. About 60% of the total demand during 2019 could be attributed to all kinds of EVs. Considering the average battery pack size of 50 kWh per vehicle, this would have been sufficient for production of about 2.3 million EVs. China is the major manufacturer of LIBs with a number of companies engaged in manufacturing and R&D of LIBs. USA, South Korea, Japan and some of the European countries are other leading centres having manufacturing facilities for LIB cells and batteries.

8. Research activities are devoted to develop some new chemistries of LIBs. Driven by the need for lower costs and higher energy density, efforts are directed towards commercialising nickel-rich cathodes to reduce use of expensive cobalt, including starting production of NMC 811 (Ni:Mn:Co::8:1:1) in 2019-20. NMC materials are expected to dominate the global LIB market in coming years. Cobalt is an expensive metal with very limited reserves, 59% of which are estimated to be in Democratic Republic of Congo.

9. LIB technology has some limitations. These batteries lose their capacity with ageing as well as due to overcharging or discharging beyond a limit. Safety concern is a major issue of LIBs. However, Lithium Iron Phosphate (LFP) battery technology is safe and does not have major concerns related to safety. The critical materials required for manufacturing LIB have finite reserves that are not evenly distributed globally and are mainly concentrated in certain parts of the world. Most of these materials are not available in India. Therefore, securing supplies of these materials at an affordable price on sustainable basis may be a challenge in the years to come. It is possible to recycle used LIBs to recover materials used for making LIBs and this could be another option for meeting requirement of raw materials for making of LIB in India.

10. LIB market in the country is expected to grow rapidly in the coming years due to upward uptake of EVs and consumer electronics and growing demand for grid-based energy storage. Presently Li-ion cell/battery is not manufactured in India, which imported US$1.23 billion worth of LIBs from China, Taiwan and South Korea during 2018-19. GoI has put in place a favourable policy framework to encourage setting up of manufacturing units for LIBs by providing incentives to build a total manufacturing capacity of 50 GWh in the country.

11. It is estimated that around 20 crore electric 2 wheelers and 4 crore EVs are going to hit the Indian road by 2030. Accordingly, the LIB market in the country is expected to be in the range of 922 – 2322 GWh by 2030 from about 3 GWh in 2018. The cost of LIB is also expected to come down to around US$150 /kWh, if LIBs are manufactured in the country. A lot of policy initiatives have been taken by various government bodies in the country as well as the states for smooth transition towards electric mobility. Many Indian companies have also announced their plans for undertaking manufacturing of Lithium ion cells/batteries and packs to meet the demand. In this regard, Indian Space Research Organisation (ISRO) has already decided to offer developed technology of LIB to Indian manufacturers. Some efforts have also been initiated for recycling of used LIBs for recovery of materials required for making LIBs.

12. Hydrogen is a versatile energy carrier and feedstock for a variety of industrial applications. It can be used as a fuel in almost all sectors of economy including power, transport, industrial and household. Global demand for hydrogen gas was estimated to be more than 700 lakh metric tonnes (MMT) during 2018 with main application in petroleum

refineries and ammonia synthesis. Hydrogen market in India was valued at US$ 50 million in 2017, and is expected to reach US$81 million by 2025. Requirement of hydrogen in fertiliser plants in India was estimated at 25.6 lakh MT during 2017-18. There is hydrogen production capacity of about 30 lakh MT in over 40 petroleum refineries in India. In addition, the installed production capacity of by-product hydrogen in chlor-alkali units was estimated at 1 lakh MT during 2017-18.

13. More than 95% of global hydrogen requirement is met by reformation of fossil fuels such as natural gas, oil and coal due to economic considerations. Hydrogen produced by reformation of natural gas is the most economical with its cost being less than ₹ 200/kg (₹ 6.06/kWh_{th}) in India. Price of by-product hydrogen produced by chlor-alkali units is also comparable. The delivered cost of hydrogen could be about ₹ 800/kg (₹ 24.24/kWh_{th}). Hydrogen can be produced using renewable resources such as biomass and bio-wastes and also by splitting water using electricity generated from renewable energies like solar and wind. Electrolytic hydrogen production is energy intensive and therefore, cost of hydrogen produced by this method is comparatively high. With increasing penetration of renewable electricity into the grid, hydrogen can be used as an energy storage medium for balancing the grid. Surplus renewable electricity could be used for producing hydrogen using electrolysers for injecting into natural gas pipelines. Surplus hydrogen available from petroleum refineries and chlor-alkali units can be used for introducing HFVs in the towns where these industries are located or in towns in their vicinity as transporting hydrogen is expensive due to it low density. A number of institutions in the country have been engaged in carrying out R&D for developing hydrogen production processes through renewable resources.

14. Hydrogen is the lightest element and therefore, a properly designed hydrogen storage system for on-board storage of adequate quantity of hydrogen in HFVs is needed. Hydrogen can be stored as gas or liquid. It can also be stored on the surfaces of solids (adsorption) or within solids (absorption). HFVs generally use gaseous hydrogen that is stored in tanks at very high-pressure to increase the storage density. Composite materials that are light in weight and can withstand very high pressure of 350 bar (Type-III) and 700 bar (Type-III & IV) are used for construction of hydrogen storage tanks. Such tanks are not manufactured in India due to lack of demand presently. HFVs and on-board hydrogen storage cylinders are equipped with

appropriate features to ensure safety of the vehicle and occupants in the event of any leakage or accident.

15. It is estimated that for a mix of 1000 HFVs (65% buses, 20% three wheelers, 10% cars and 5% 2-wheelers) in India about 4150 MT of hydrogen would be required annually and for dispensing this hydrogen about 60-70 Hydrogen Refuelling Station (HRS) may be needed in the country. This would involve consumption of about 45,000 MT of water, if required hydrogen is produced through electrolysis. The initial capital investment needed for setting up a typical onsite HRS of 100-140 kg/day capacity is in the range of US$ 2.73 – 4.6 million based on the different projects undertaken in the USA. In comparison, cost of setting up a HRS in Japan, which is the leading country in terms of setting up such stations, is higher by a factor of 2-3 times due to stringent regulations. In case, hydrogen is produced in a centralised facility, adequate infrastructure for storage and transportation of hydrogen to the refuelling station will have to be put in place. The cost of hydrogen dispensed by different HRS set up in the USA was in the range of US$10-33/kg, depending on the source and process of producing hydrogen. The cost of providing electrolytic hydrogen is the highest, among the different options examined.

16. As energy carriers, electricity and hydrogen are well suited for transport applications on three counts: GHG emission reduction, energy security and reduction of local air pollution. Between the two technologies (EVs and HFVs) using these energy carriers, EVs have the potential for the lowest fuel costs and GHG emissions due to their higher efficiency throughout the fuel supply chain and the vehicle's lower fuel consumption. A comparison of specific power consumption (kWh/km) and range (km) for different electricity and hydrogen technologies for transport sector indicates that electrical propulsion based on presently available EVs has a very efficient fuel cycle but have a limited range. HICE vehicles could increase the range considerably, but at the cost of fuel cycle efficiency. In comparison, FC vehicles would have better efficiency and range.

17. Gravimetric energy density of hydrogen-based system is in the range of 1.47 to 1.83 kWh/kg, depending on the volumetric capacity of the storage vessel used and storage pressure, though its energy content is 33 kWh/kg - the highest among known fuels. In comparison, energy density of commercial LIB is in the range of 100-265 Wh/kg. Therefore, for storing same amount of energy, LIB based storage system would be relatively about ten

times heavier. This makes a hydrogen storage system much lighter than LIB for providing a given driving range to a vehicle. In addition, HFVs can be refuelled as quickly as similar petrol/diesel vehicles with hydrogen filling rate of about 1 kg/minute in comparison to several hours taken for charging a LIB pack of an EV, depending on mode of charging.

18. HFVs have higher capital and operating costs in comparison to EVs, with current FCVs models around twice as expensive. However, EVs have range constraint and for similar driving range both EV as well as FCV would have more or less similar cost. The high FCV cost is primarily due to the use of platinum (Pt) catalysts and current low production volumes. Although loadings of Pt have been getting progressively reduced, yet it still remains a significant challenge for FCV makers.

19. In the coming years, the increasing volume of LIBs would in turn; lead to a growing capacity of 'spent' batteries in the ecosystem, which if left untreated would lead to health and environmental hazards. To date, India does not have any specific regulations or guidelines around for effective disposal and recycling of LIBs. Even India's e-waste guidelines have no mention of LIBs. Clear guidelines have to be laid out for collection, storage, transportation and recycle of waste batteries. Detailed instructions for both consumers and battery suppliers also have to be laid out and implemented.

20. Based on the BEVs that are currently available in the Indian market, they have advantage in terms of lower initial cost, lower maintenance cost due to very few moving parts, higher efficiency of power-train and lower running cost per km compared to HFVs. However, range of EVs is constrained by battery size and weight and time taken for recharging of LIBs may take several hours, depending on type of charging (slow or fast). The problem further aggravates for hauling higher payloads over longer distances. On the other side, HFVs could be refuelled in a few minutes like conventional petrol or diesel vehicles and have no range anxiety, except in smaller vehicles such as three wheelers and compact cars, where the amount of on-board stored hydrogen could be limited due to capacity of hydrogen storage tank.

21. EVs have advantages both in terms of energy consumption per km (due to higher efficiency of electric drive trains) and minimum fuel cost per km. For some niche areas, where hydrogen may be available easily and at a competitive rate of about Rs. 200/kg, some HFVs may be competitive to similar fossil fuelled vehicles in terms of fuel running cost. In terms of

energy consumption per km of vehicle operation, electric bus is the best option and FC bus is a better option compared to low entry diesel and CNG buses, provided hydrogen cost is Rs. 200/kg. However, diesel fuelled ICE vehicles are better compared to HICE vehicles in view of higher brake thermal efficiency of diesel engine compared to hydrogen engine.

22. In terms of lifetime cost of ownership, EVs have advantage over their competitors. On the lines of BEVs and creation of charging infrastructure, HFVs would require financial incentives in India both for acquisition and also for lowering fuel cost to make them attractive in terms of life cycle cost of ownership vis-à-vis other options as cost of HFVs as well as hydrogen as an automotive fuel are high presently as there is hardly any demand for HFVs in India and infrastructure for supply and dispensing of hydrogen is non-existent. Incentives are being provided for making initial cost of HFVs affordable to buyers in countries like Japan and South Korea and some incentives are also being offered for lowering the cost of hydrogen as an automotive fuel.

23. EVs and HFVs are complementary and both of them can co-exist for different category of vehicles and applications.

CHAPTER 1: INTRODUCTION

1.1 Introduction

India is one of the fastest growing economies of the world and was the fifth largest economy in 2019. It is expected to leapfrog to the second position by 2050. Indian population was about 1.37 billion in 2019 and is projected to reach about 1.64 billion by 2050 with growth @ 0.59% annually during 2019-2050. Strong economic growth coupled with growing population is contributing to rapid increase in its energy demand. India is, therefore emerging as a major market for energy globally. India will account for 25% of the rise in global energy demand by 2040. A study undertaken by National Institution for Transforming India (NITI) Aayog estimates that demand for supply of total primary energy in India to increase by nearly 2.5 times in 2042 from about 700 Mtoe in 2017. For better understanding of the current scenario, macro-economic indicators of India are given in Table 1.1.

Table 1.1: Macro-economic indicator of India

Indicators	Key statistics	Amount
Population	(billion, 2019)	1.37[a]
GDP	(US$ trillion, 2018)	2.72[b]
GDP/capita	(US$, 2018)	2010
Total primary energy supply	(Mtoe, 2018)	933[c]
Energy consumption per capita	(toe/person, 2018)	0.64
CO_2 emissions	(million tonnes, 2019)	2299[c]
CO_2 emissions per capita	(tonnes, 2019)	1.678

a: UN, b: world bank, c: IEA- Global Energy and CO_2 Status Report

India has reported a considerable progress in terms of providing energy access, per capita energy and electricity consumption in recent decades. India continues to rely heavily on fossil fuels for meeting its energy requirement across different sectors of the economy in spite of noteworthy achievement in renewable energy sector. India's reliance on imported hydro-carbons continues to grow due to limited indigenous production and increasing demand. At times, supply concerns arise due to geo-political reasons. Growing concerns about climate change and worsening ambient air quality are also prompting countries like India to develop and deploy green alternatives. In the recent years, downward trend in energy generation costs from wind and solar technologies have been witnessed. Therefore, in the current scenario, the focus of energy sector in India is centred on achieving energy security by harnessing domestically available renewable resources in sustainable manner. The following sections discuss the current energy scenario and status of development of renewable energy resources in India.

1.2 Current energy scenario of India

In 2017-18, among different energy sources, coal was the major source of energy (56%), followed by crude oil (30%) and natural gas (6%), as shown in Fig 1.1.

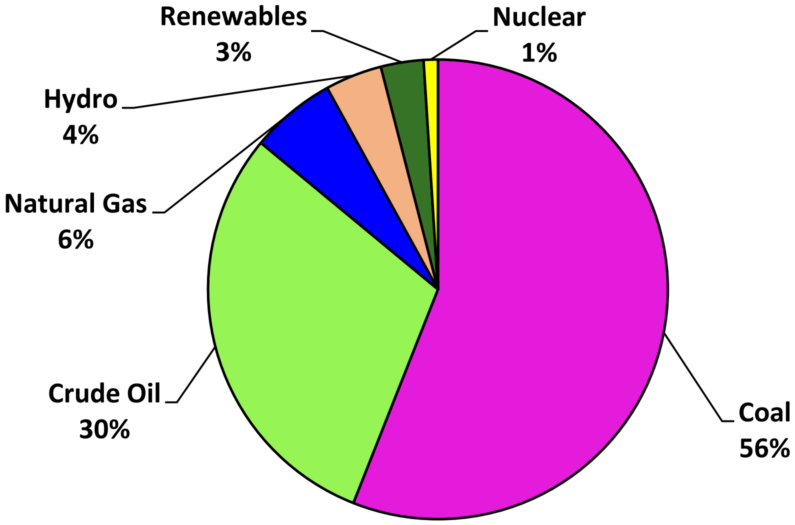

Fig. 1.1: Energy mix of India (2018)

India had around 148.79 billion tonnes of proven coal reserves as of 2018. The estimated coal consumption was around 896.34 MMT during 2017-18, of which around 214.61 MMT was imported. Against Compound Annual Growth Rate (CAGR) of 5.01% in consumption during 2008-2017, production grew at 3.2% and to bridge the deficit between demand and domestic supply, import grew at 13.44% during the same period. The maximum raw coal consumption was for electricity generation (64%), followed by steel industry during 2017-18. CAGR of lignite production as well as consumption increased by 3.62% and 3.70%, respectively, during 2008-09 to 2017-18.

India was the third largest importer of crude oil in 2018. The production of crude oil and natural gas increased by 0.63% and (-) 0.06%, whereas consumption increased by 4.59% and 4.82% respectively, during the period from 2008-09 to 2017-18. During the same period, the imports of natural gas and crude oil increased at CAGR of 9.44% and 5.20% respectively. India imported 229.5 MMT of crude oil, worth US$ 111.9 billion in 2018-19. The trend of import of crude oil in MMT per annum during 2012 to 2019 is shown in Fig. 1.2.

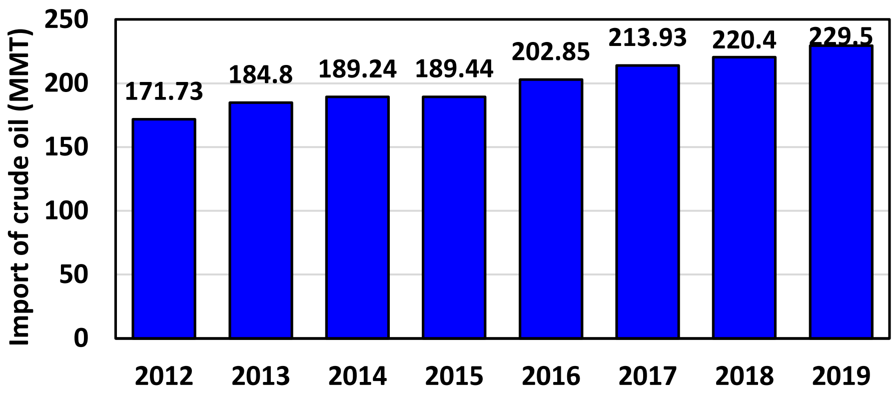

Fig. 1.2: Import of crude oil by India (2012 – 2019)

The consumption of crude oil has steadily increased from 160.77 MMT during 2008-09 to 251.93 MMT during 2017-18 with CAGR of 4.59%. High speed diesel accounted for 39.3% of total consumption (excluding refinery fuel and losses) of all types of petroleum products in 2017-18. This was followed by petrol (12.7%), Liquefied Petroleum Gas (LPG) (11.3%), and others.

Sector-wise consumption of different petroleum products reveals that reseller/retail contributed 54% in the total consumption followed by domestic sector (18%) in 2018. The maximum use of natural gas was in fertiliser industry (28%) followed by power generation (23%) and fuel for transport sector (16%), as shown in Fig. 1.3.

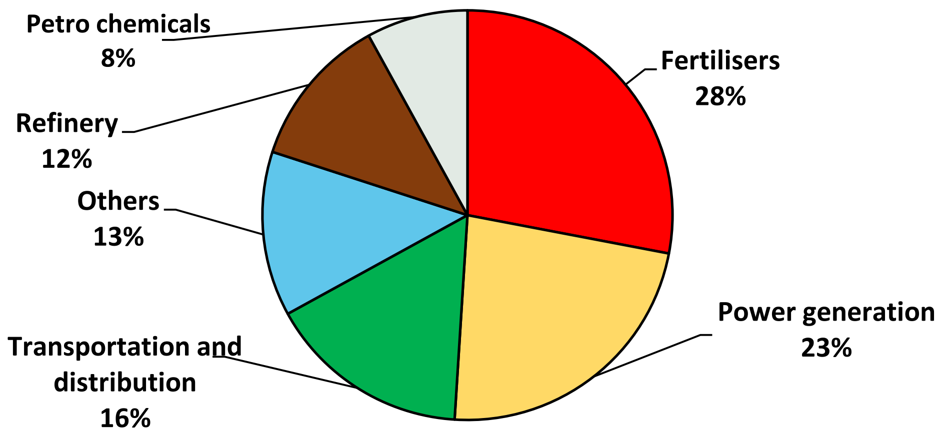

Fig. 1.3: Sector wise use of natural gas in India (2018)

India's power sector is growing rapidly. The share of various energy sources in the context of overall Indian power scenario is shown in Fig. 1.4. The total installed power generating capacity of the country was 368.78 GW (as on 31.12.2019), of which the share of renewable was about 23.3%, which is around 86 GW. Electricity generation was 1376.095 billion units during 2018-19, of which share of renewable energy sector was about 9.2%.

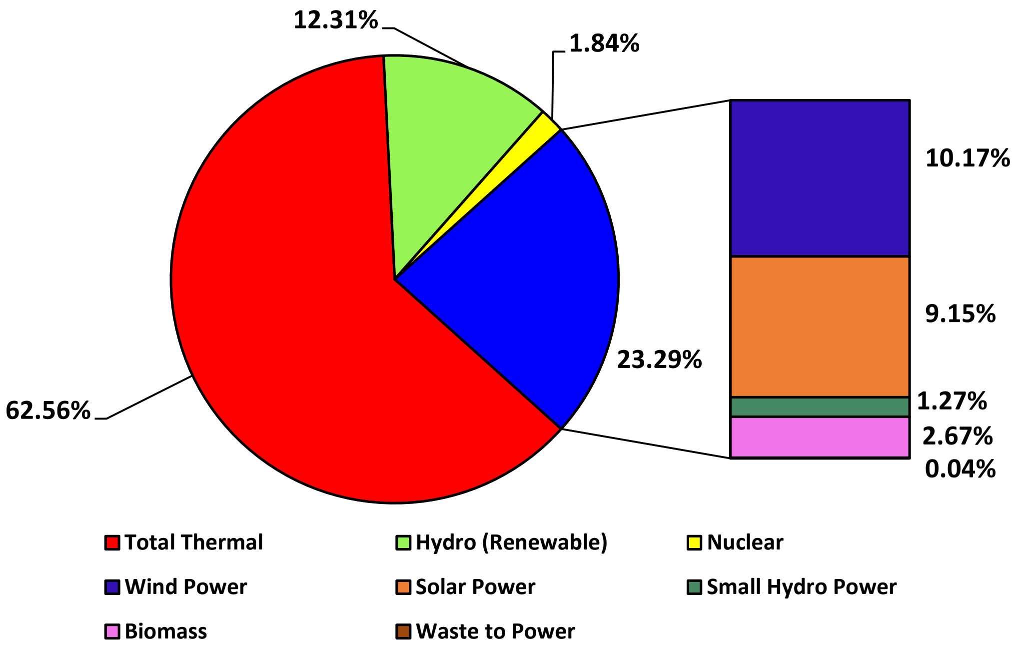

Fig. 1.4: Installed power generation capacity in India by source as on 31.12.2019

1.3 Geopolitical impact on energy security of India

India is poorly endowed with proven reserves of crude oil and natural gas. Therefore, the energy demand of transport, agriculture and industrial sectors is met by imports. It is estimated that India's total imports are expected to rise from 36% of primary consumption to 55% by 2040. During 2019, domestic production of crude oil and natural gas decreased by 6% and 1.5%, respectively. India mainly imported about 70% of crude oil from the Middle East countries such as Iraq, Saudi Arabia and Iran during 2018-19. Share of import of crude oil by India from different geographical regions is shown in Fig. 1.5. Middle East region is geo-politically highly sensitive and therefore international prices of crude oil fluctuate quite sharply due to any geopolitical development, which has adverse impact on India's crude oil import bill and also on its economy. Efforts for reducing import dependence have been initiated by GoI by way of development of alternative fuels and improvement in energy efficiency.

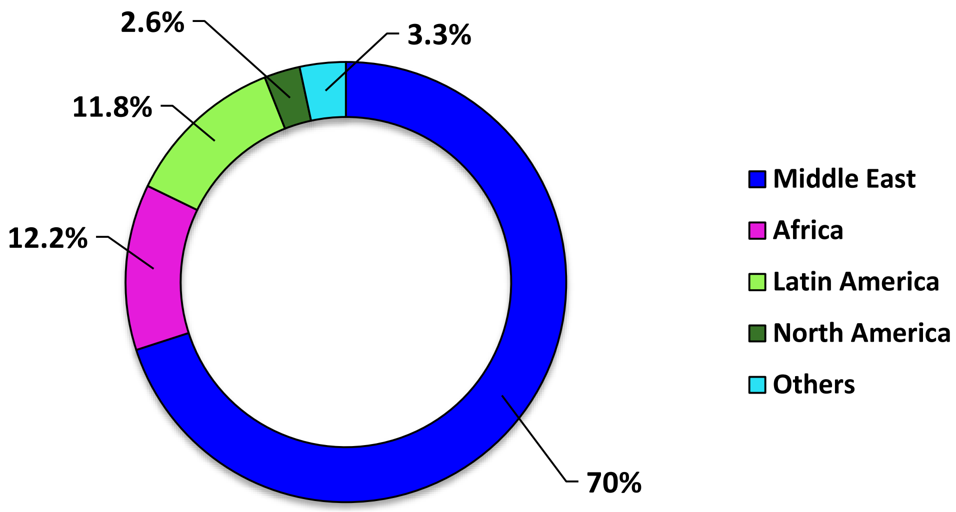

Fig. 1.5: Region wise import of crude oil by India (2018 – 19)

1.4 Carbon footprint of India

India was the 3rd largest emitter of GHGs globally after China (28.6%) and the USA (14.75%) with 2.299 GT (6.94%) of energy related CO_2 emissions during 2018. Sector wise GHG footprint profile (2014) of India is shown Fig 1.6.

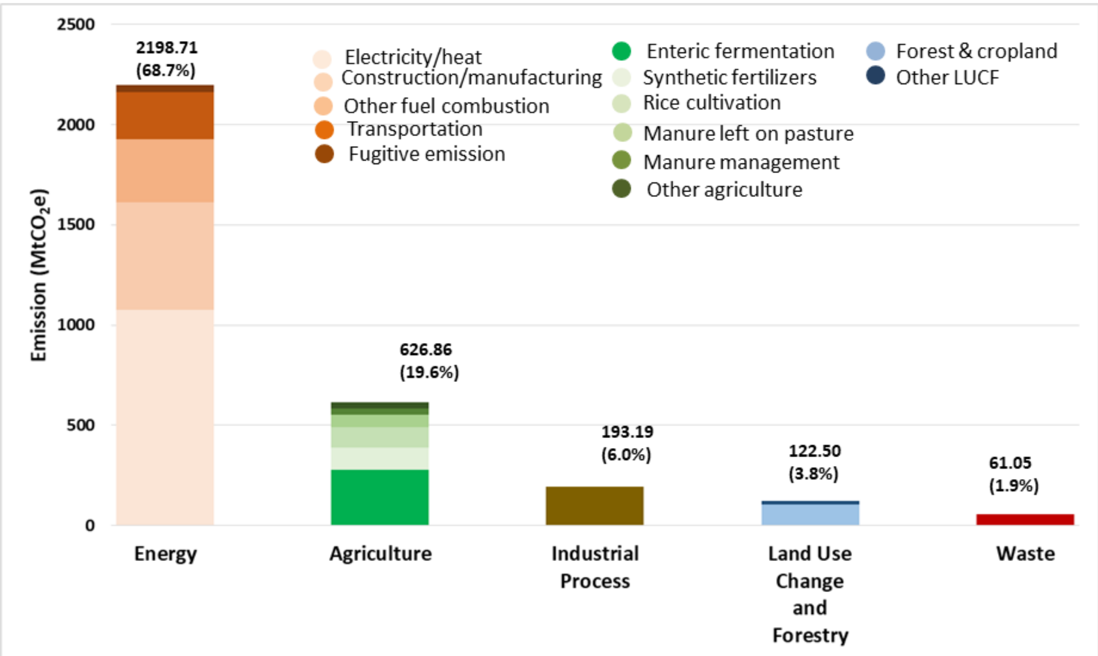

Fig. 1.6: Sector wise GHG emission in India (2014)

It is clear from Fig. 1.6 that the most of the emissions (68.7%) came from coal power plants, transport sector, construction and fugitive emission. Around 19.6% of pollution was caused by agriculture sector, whereas 6% was from the industrial processes (such as refineries, fertiliser plants, cement plants etc.). Within the energy sector, 49% of the emissions were caused by production of heat and electricity, followed by 24% from manufacturing and construction. Transport sector caused around 7% of total emissions. Industrial Processes (IP), Land Use Change and Forestry (LUCF), and waste contributed 6%, 3.8% and 1.9% of total emissions, respectively.

1.5 Air Quality

Air pollution constitutes the most pressing environmental health risk faced by the global population. As per 2019 World Air Quality Report, compiled by IQAir, Particulate Matter 2.5 (PM2.5) air quality in India in 2019 was estimated to be 58.1 µg/m^3, which is the fifth poorest among different countries and out of the 30 most polluted cities globally in terms of air quality, 21 cities were located in India and 18 of these cities are in the NCR region (Table 1.2). Among capital cities, New Delhi was the poorest in terms of air quality with annual average PM2.5 air quality as 98.6 µg/m^3 in 2019.

Table 1.2: List of most polluted cities in 2019

1. Ghaziabad, India	2. Hotan, China	3. Gujaranwala, Pakistan	4. Faisalabad, Pakistan	5. Delhi, India
6. Noida, India	7. Gurugram, India	8. Raiwind, Pakistan	9. Greater Noida, India	10. Bandhwari, India
11. Lucknow, India	12. Lahore, Pakistan	13. Bulandsahar, India	14. Muzzafarnagar, India	15. Baghpat, India
16. Kashgar, China	17. Jind, India	18. Faridabad, India	19. Coraut, India	20. Bhiwadi, India
21. Dhaka, Bangladesh	22. Patna, India	23. Palwal, India	24. South Tangerang, Indonesia	25. Muzzafapur, India
26. Hisar, India	27. Muridke, Pakistan	28. Kutail, India	29. Jodhpur, India	30. Moradabad, India

1.6 Potential of renewable energy in India

The total potential for power generation from renewable resources in India is estimated to be 1100 GW. This includes power generating potential of 750 GW (68.33%) from solar, 30 GW (27.58%) from wind, 19.75 GW (1.80%) from small-hydro, 17.54 GW (1.60%) from biomass, 5 GW (0.46%) from bagasse-based cogeneration in sugar mills and 2.6 GW (0.23%)

from waste to energy. India was the fourth in the world in terms of installation of renewable energy based power generating plants in 2018, just behind China, the US, and Germany. Renewable energy-based power generation capacity was about 86 GW as on 31.12.2019 with contributions from wind, solar, small hydro and bio-energy being 37.505 GW, 33.73 GW, 4.671 GW and 10 GW respectively. India aims for having 40% of its installed capacity from low carbon routes like renewable or nuclear by 2030. For decarbonising transport sector, use of electricity generated from renewable energy sources for electric mobility makes a lot of sense. Electricity generated by renewable sources could also be used for producing hydrogen by splitting water using electrolyser. Moreover, curtailed electricity from wind and solar farms could also be used for producing hydrogen which can be used either as an energy storage medium for grid balancing or as an energy carrier in the different sectors of the economy. In addition to energy carriers like electricity and hydrogen, biofuels could be other alternative fuel that may be of interest for decarbonising transport sector.

1.7 Alternative fuels and technologies for vehicular applications in India

There were a total of 25.3 crore registered motor vehicles in India as on 31.3.2017. Two wheelers and cars/jeeps/taxis, which are termed as Non-Transport vehicles accounted for 73.86% and 13.3% respectively. The number of registered "Transport" vehicles, both goods and passengers were 22.539 million accounting for 8.9% of total registered vehicles. Amongst the Transport Vehicles, the respective shares of LMV (Goods), LMV (Passengers), trucks, taxis and buses were 30.6%, 25.1%, 19.3%, 12% and 5.9%. India is witnessing a rapid urbanisation with growing population and mobility aspiration of the people is also changing with more emphasis on individual mode of transport instead of public transport, with the exception of the cities, where metro rail network has come up in the recent years. The strategy for decarbonising the transport sector in India has, therefore, to take into account the above-mentioned mix of different kinds of motorised vehicles in India and individual preferences. Promoting use of alternative fuels that are renewable, environmentally benign and provide energy security is the cornerstone of policy of GoI. The next section discusses the status of the alternative fuels for vehicular applications in India.

1.7.1 Electric Vehicles (EVs)

Electrification of the transport sector provides twin objectives of reducing dependence on imported hydrocarbons thereby contributing to energy security and also improving energy efficiency; and air quality. Generally, EVs are more expensive than the current fossil fuel-based vehicles. With the cost of electricity generated by renewable energy sources becoming competitive vis-à-vis conventionally generated electricity, EVs utilising renewable electricity can address all the above issues. However, EVs suffers from challenges such as low driving range and long charging time. In addition, a new charging infrastructure also needs to be put in place before deploying EVs in full stream. Further, load profiles of electric grid would also require close monitoring to avoid any disturbance due to widespread use of EVs.

The GoI has promoted the uptake of EVs under a national mission named as National Electric Mobility Mission Plan (NEMMP) 2020. Under NEMMP, a scheme viz. Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME) in India was adopted to promote manufacturing of EVs and battery technologies. The first phase of this scheme (FAME I) was launched in April, 2015 and extended till March 2019. Under this scheme buyers were given financial incentive for acquisition of EVs. About 2.78 lakh EVs were supported by incentives of around ₹ 343 Crore. Also, 465 electric buses were sanctioned to various cities under this scheme. The second phase of the same scheme (FAME II) has been approved with an outlay of ₹ 10,000 Crore for a period of 3 years (from 1st April, 2019). This scheme targets to deploy 7000 electric buses, 5 lakh three–wheelers, 55000 four–wheeler passenger cars and 10 lakh two-wheelers.

Around 30 lakh EVs were in operation on Indian roads in 2019. Most of these EVs are e-rickshaws, e-carts and two-wheelers. Electric rickshaws are preferred for short journeys within the cities and towns.

1.7.2 Development of biofuels in India

India proposed a National Policy on Biofuels in 2007 with a target of 20% blending of bio-fuels (biodiesel and bioethanol) by 2017. The policy promoted fuels derived only from non-edible plants to avoid the conflict between energy security and food security. Ethanol blend percentage of 6.2% has been achieved in 2018 – 19, whereas 330 crore litres of ethanol was required in 2018-19 for achieving blending ratio of 10%. The updated policy (2018) proposed an achievable target of 20% blend of ethanol and 5% of biodiesel by 2030.

1.7.3 Development of hydrogen energy in India

Realising the importance of hydrogen for meeting energy needs for transport sector and also for distributed power generation, GoI has been supporting broad based Research and Development (R&D) activities in the country for about three decades. With a view to accelerate development and commercialisation of hydrogen energy in the country, the Ministry of New and Renewable Energy (MNRE) prepared the NHER for the country in 2005.

Specific project based on Public-Private partnership to facilitate the generation of resources were targeted in the roadmap. The main objective was to identify the pathways for development and introduction of hydrogen energy and also to facilitate creation of hydrogen energy infrastructure in the country. The development of various components of the hydrogen energy system, ranging from production, storage, transport, delivery, applications, safety and standards were targeted. The Roadmap had made very ambitious projections for introducing one million Hydrogen Fuelled Vehicles (HFVs) on the roads and establishing 1000 MW aggregate hydrogen-based power generating capacity in the country, by 2020. The various milestones envisaged by way of contributions in terms of R&D, involvement by the industry and financial support by the Government and other stakeholders were inadequate and therefore these targets could not be even attempted. Till date, few sets of two wheelers, three wheelers and catalytic combustion cooking systems and small power generating systems based on hydrogen as fuel for residential and industrial purposes along with HICE and FC buses have been developed and underwent limited field trials in the country. Few examples of hydrogen fuelled technologies developed and hydrogen refuelling systems installed in India are shown in Fig. 1.7.

1.8 Hydrogen as fuel

Hydrogen is the most abundant and the lightest element in the universe. It is widely used as feedstock in petrochemical units and refineries, fertiliser, steel and other industries. Hydrogen can be extracted from water, methane or other hydrogen containing compounds. It is also considered as an alternative fuel or energy carrier where energy can be stored and delivered when needed using FC or ICE. Hydrogen has high energy density (120.7 MJ/kg) which is 2.7 times of energy density of petrol. It is also environmentally attractive as it does not cause any emission except for water vapour at the point of use. The term "*Hydrogen*

Economy" is often used to describe the hydrogen-based society where conventional fossil fuels would be completely replaced by hydrogen. HFVs are already in use in some countries such as United States, Japan, South Korea, China, and Germany.

Fig. 1.7: Hydrogen fuelled technologies developed in India (a) H-CNG Dispensing Station set up at Dwarka, New Delhi, (b) Fuel cell bus developed by Tata Motors, (c) Hydrogen fuelled 3-wheeler developed jointly by IIT Delhi and Mahindra & Mahindra, (d) H-CNG Dispensing Station set up at Faridabad, and (e) Hydrogen-Diesel dual fuel vehicle developed by Mahindra & Mahindra.

1.8.1 Challenges of hydrogen

Hydrogen as an alternative fuel has several challenges, which hinder its widespread use. The main issues are: sustainable and cost-effective production of hydrogen, storage of adequate hydrogen for on-board application in view of its very low volumetric density, purity of hydrogen desired for use in FCs, absence of proper infrastructure for its production, supply and storage for distributed applications, and safety concerns. Hydrogen does not exist in free form in nature and therefore needs to be produced from hydrogen containing compounds and associated processes are energy intensive and expensive.

Density of hydrogen is also low at ambient conditions and, therefore, it needs to be compressed at high pressure to improve its gravimetric energy density. Cryogenic storage is energy intensive and loss of hydrogen occurs due to boil off. The cost of hydrogen storage tanks is high due to current low demand and high cost of the materials used for manufacturing such tanks. Hydrogen storage in solid materials (metal hydrides, carbon materials etc.) is an alternative. However, gravimetric storage capacity of these solid-state materials is also low and often these materials are non-recyclable and therefore, need further development.

Hydrogen is also an extremely flammable and explosive gas. The odourless hydrogen and almost invisible hydrogen-flame cause safety and detection issue. However, several hydrogen detectors have been developed which could detect presence of small quantity (ppm level) of hydrogen, in case of any leakage. The lack of hydrogen infrastructure also acts as a barrier for its adoption.

1.9 Scope of the current report

The current report entitled "Comparison of Electric and Hydrogen Fuelled Vehicles, including Lithium Ion Batteries and Hydrogen" attempts to compare different aspect of EVs and HFVs as mentioned in the title of the report. For that current national and international status of R&D and implementation of LIB technology for EVs and hydrogen production, storage, use and supply system have been discussed and analysed critically. A detailed comparison of the two technologies i.e. LIB and hydrogen, are listed out in terms of their feasibility, technical capabilities, cost analysis, environmental impact, life cycle etc. Comparative study of the aforesaid technologies is also reported keeping in mind the Indian scenario for their application. A preliminary analysis for estimating 'Cost of ownership' of electric and hydrogen fuelled vehicles has also been attempted.

1.10 Layout of the report

Chapter 1 of this report discusses current energy scenario, carbon footprint and renewable energy potential of India. It also provides a brief overview of alternative fuels for vehicular applications in India. Chapter 2 reports the present national and international status of development of EVs and HFVs in detail. Chapter 3 discusses the national and international status of LIBs for EVs. Chapter 4 provides insight about the present status of LIBs in India and projected growth of same by 2030. Chapter 5 explains the status of hydrogen production, storage technologies and availability of infrastructure for hydrogen energy in India. Chapter 6 compares the properties and possibilities of LIBs and hydrogen as fuel in terms of economy, life cycle etc. for vehicular application. Chapter 7 focuses on the comparison of EVs and HFVs in Indian scenario. Chapter 8 contains results of a preliminary analysis for cost of ownership based on life cycle cost of EVs and HFVs. Chapter 9 provides some recommendations emanating from this study.

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CHAPTER 2: INTERNATIONAL AND NATIONAL STATUS OF DEVELOPMENT OF ELECTRIC AND HYDROGEN FUELLED VEHICLES

2.1 Introduction

Among different alternative fuels such as bio-diesel, compressed natural gas, ethanol, methanol, electricity, hydrogen, etc. are considered as the best suited to decarbonise the transport sector and also to address the issues relating to better energy efficiency, energy security, climate change, worsening air quality, minimising transport induced noise and meeting transport requirement due to rapid urbanisation. Recent developments that include increasing penetration of renewable energy in the power mix of the countries, evolution of shared mobility solutions which optimise utilisation of transport assets that have high initial cost and advances in battery chemistries have created a favourable environment for development and deployment of EVs and HFVs.

2.2 Electric vehicles

EVs were among the earliest automobiles that were commercialised in the USA in the early 1900s before the emergence of ICE vehicles, powered by fossil fuels. There are three main types of EVs. These are: (a) Battery Electric Vehicles (BEVs) or simply Electric Vehicles (EVs), which use only batteries for energy storage and must be plugged in to be recharged; (b) Plug-in Hybrid Electric Vehicles (PHEVs), which have both electric motors - batteries and internal combustion engine - fossil fuel storage/refuelling systems; and (c) Hybrid Electric Vehicles (HEV), which are similar to PHEV without provision for recharging of batteries from the grid.

In BEVs, the batteries provide power to one or more electric motors and their driving range depends on the capacity of batteries. If the range of BEV is not adequate, PHEV is a better option. In PHEVs, battery packs provide all-electric driving initially for shorter distance (about 20-80 km) before switch over to a fossil fuel engine takes place. In addition to charging from the electrical grid, batteries of EVs and PHEVs are charged in part by regenerative braking, which generates electricity from some of the energy normally lost when braking. In HEVs, the engine and electric motor simultaneously turn the transmission, which power the wheels. In HEVs, the presence of the electric power-train is intended to achieve either better fuel economy than a conventional vehicle or better performance. In all these cases, the electric motor is very efficient, using about 90% of the input energy for propulsion of the vehicle. Currently, a total of two-thirds of the EVs plying on roads are BEVs.

In pure EVs, there is no emission of GHGs at the point of use. But the use of batteries poses two main challenges for EVs: their high cost and limited driving range. Most current models of BEV do not store enough energy to provide “normal” driving range and are limited to below 250 km per recharge. However, some new and forthcoming EVs offer substantially higher range, up to 600 km. PHEVs already offer driving range of 500 km or more due to the availability of fossil fuel operated ICE. Both technologies – EVs and PHEVs are expensive, with battery costs in India estimated around US$ 250-260/kWh (Fig. 2.1) and the cost of a hybrid system of several thousand dollars in PHEVs.

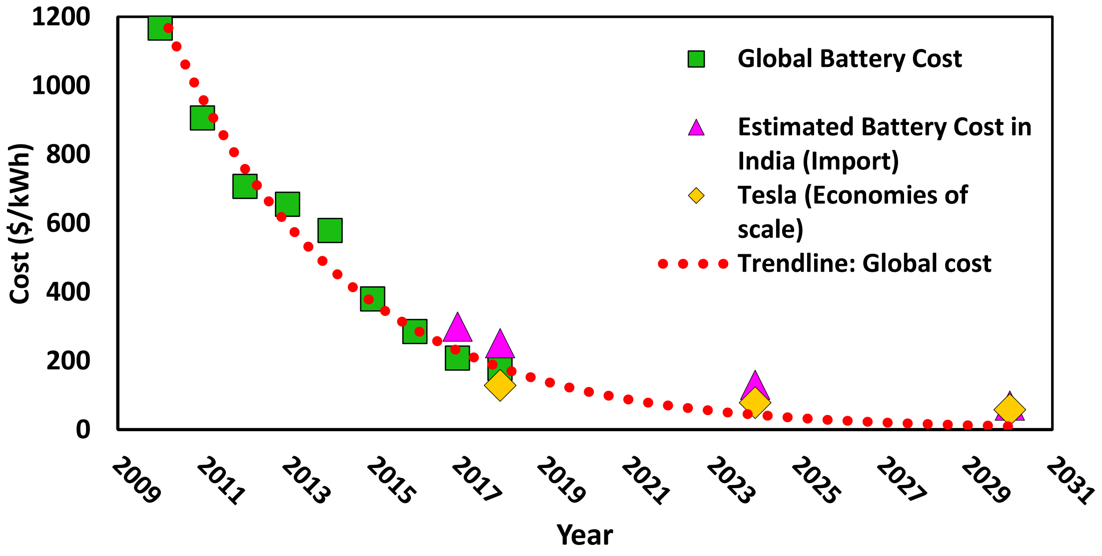


Fig. 2.1: Trend of declining Li-ion battery cost

A typical BEV with 40 kWh of battery capacity that alone costs about US$ 10,000 may lead to a vehicle having incremental cost of at least US$ 8,000 compared to similar ICE vehicle, depending on retail mark-ups, incentives and other factors. Fortunately, strong policies, trend of reduction in cost of batteries and thereby EVs, availability of EVs with higher driving range and expansion of infrastructure for public charging have helped the growth of EVs.

2.3 Global growth of EV market

EVs and PHEVs have been gaining attention of the policy makers and users due to their ability to deliver multiple environmental, societal and health benefits. While in some countries the transition to electric mobility is still in an initial stage, in several of the world’s largest personal vehicle markets, adoption of EVs is growing at a fast pace due to dropping cost of batteries and expansion of charging infrastructure for EVs of different kinds that includes cars, buses, taxis and shared vehicles, light-duty vehicles (LDVs), two/three-wheelers and heavy-duty vehicles with short range requirements such as urban deliveries.

2.3.1 Electric cars

According to International Energy Agency (IEA), the number of electric cars in use globally has seen almost four-fold increase from 12.5 lakh in 2015 to 51.2 lakh in 2018. The number of electric cars added during the year and cumulative number of such cars in use globally during this period is shown in Fig. 2.2. There has been an increase of 63% in the global fleet of electric cars in 2018 from 2017 as compared to 57% and 60% in 2017 and 2016 respectively. Considering these figures, electric car market has grown at the rate of about 42% during 2015-2018.

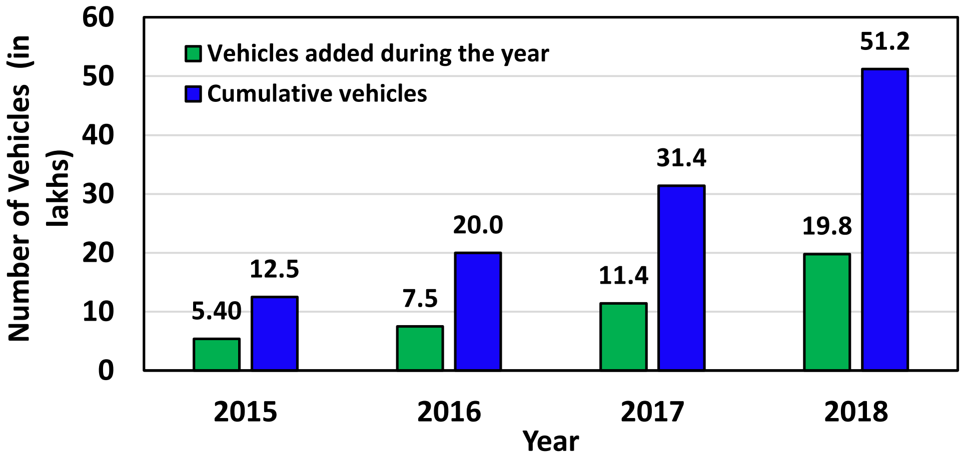


Fig. 2.2: Electric car stock added and total stock during last 4 years

As shown in Fig. 2.3, China with about 45% share of the global fleet of electric cars (51.2 lakh) in 2018, leads the electric car market followed by Europe and the USA, which accounted for shares of 24% and 22% respectively.

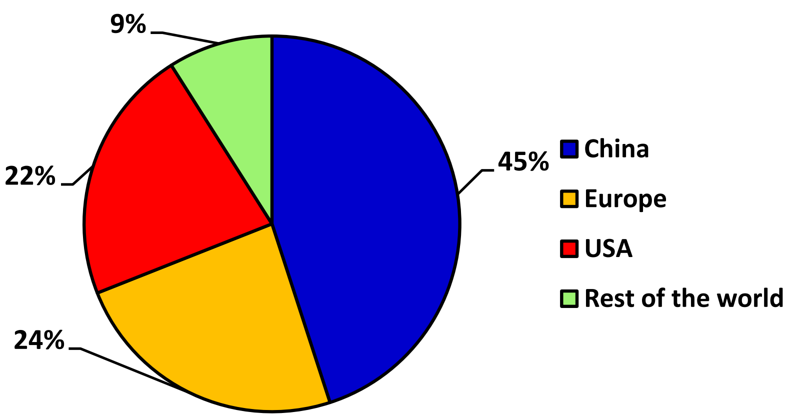


Fig. 2.3: Countries with major share in global fleet of electric cars in 2018

In 2018, there were only five countries, Norway (10%), Iceland (3.3%), Netherlands (1.9%), Sweden (1.6%) and China (1.1%) which had more than 1% of electric car fleet in total cars sales as depicted in Fig. 2.4.

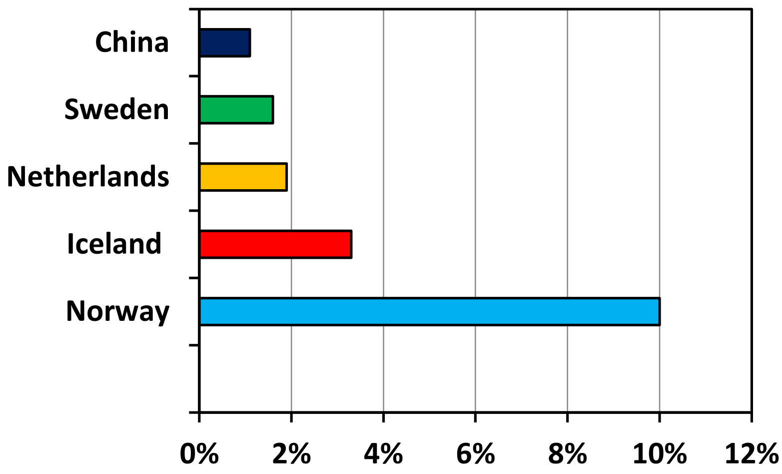


Fig. 2.4: Leading countries with more than 1% of electric car fleet in total car sales in 2018

In terms of total electric car sales of about 19.8 lakh globally in 2018, China was the leader with sales of 11 lakh, followed by Europe (3.85 lakh) and the USA (3.61 lakh). In Europe, Norway achieved penetration of about 50% in terms of electric car sales in 2018. Iceland (17.2%) and Sweden (7.9%) followed Norway.

Globally, more than two-thirds of electric car sales in 2018 were BEVs. This share has been steadily increasing from 50% in 2012 to 68% in 2018. This is consistent with China's rapid electric car sales growth, as it is a BEV-dominated market (76%). The share of PHEVs in sales dropped in the USA from 47% in 2017 to 34% in 2018, due to strong BEV sales. Europe remained a strong market for PHEV sales. PHEV sales dominated in Finland (86%), Sweden (75%) and United Kingdom (69%). In contrast, the PHEV share in EV sales significantly decreased in 2018 compared to 2017 in Japan (47% versus 67%) and the Netherlands (14% versus 22%).

According to the IEA, the global EV sales are projected to be in the range of 2.3 to 4.3 crore in 2030 under different scenarios. China, Europe and Japan would be the leading markets for EVs. Another forecast, made by Bloomberg's Electric Vehicles Outlook projects that by 2040, share of EVs will be 50% of the total vehicle sales. The total sales of electric cars are expected to grow by more than 6 crore per year in 2040 as shown in Fig. 2.5.

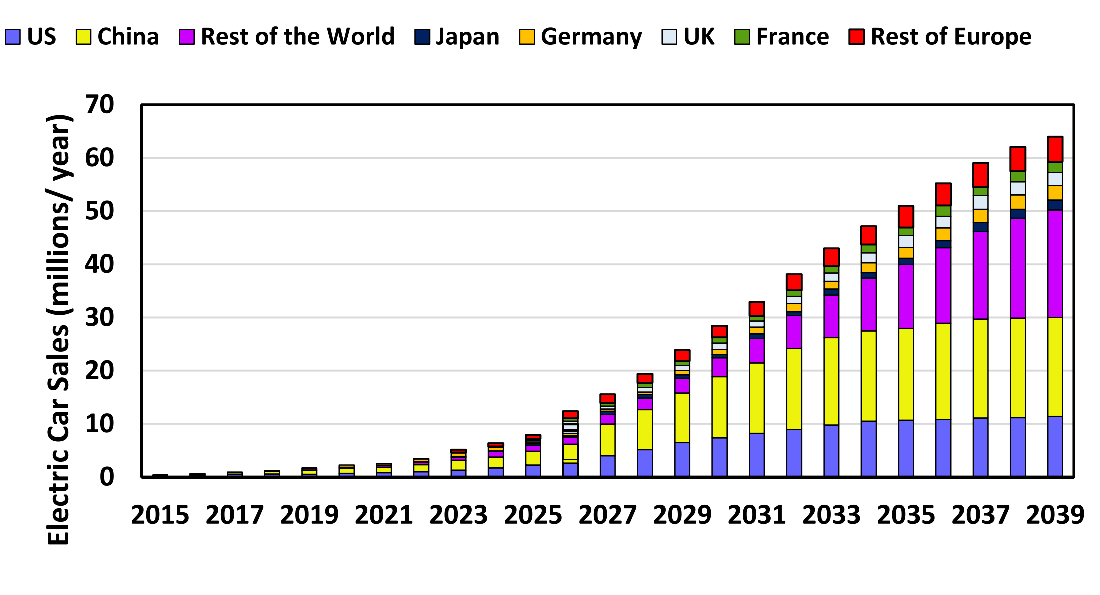


Fig. 2.5: Forecast for electric cars sales

2.3.2 Electric light commercial vehicles

In 2018, almost 2.5 lakh electric light commercial vehicles (LCVs) were plying on the roads globally. This was only 5% of the total electric car fleet of the world. In the LCV segment, China had the largest fleet which accounted for share of 57% (1.38 lakh) of the total global stock. Europe held share of 38% (0.92 lakh) of the LCVs market globally and France (41,000) and Germany (16,500) were the leading European countries in this segment.

2.3.3 Electric two and three wheelers

As far as two-wheeler market is concerned, China, India and ASEAN countries are way ahead of other countries. Total motorised two-wheeler stock is about 80 crore globally and about 25% of them are in China only. Vietnam, India, Thailand and Indonesia were other countries where two-wheeler segment has been witnessing a significant growth. In Vietnam, two-wheeler fleet size was around 9 lakh and in India, it was about 6 lakhs. China is also the leader in three-wheeler segment with 5 crore vehicles while India is home to about 24 lakh electric three wheelers (e-rickshaws).

2.3.4 Electric buses

Electric buses (e-buses) saw a rise of 25% in 2018 compared to the previous year and total global stock reached to 4.6 lakh units. China had a stock of 99% of the total global stock of e-buses. Other than China, about 900 e-buses were in Europe, more than 300 in USA and Latin America had around 240 e-buses.

2.4 Indian EV scenario

Indian automobile sector ranks the 5th in the world and it is rapidly expanding its fleet to cater to the needs of its increasing population. Among major initiatives taken by the GoI for decarbonising transport sector, one is concerning the transition towards electric mobility (e-mobility). A report by NITI Aayog states that by employing e-mobility in the country, 64 % of the energy consumed in mobility can be saved and about 37% carbon emissions can be reduced by 2030.

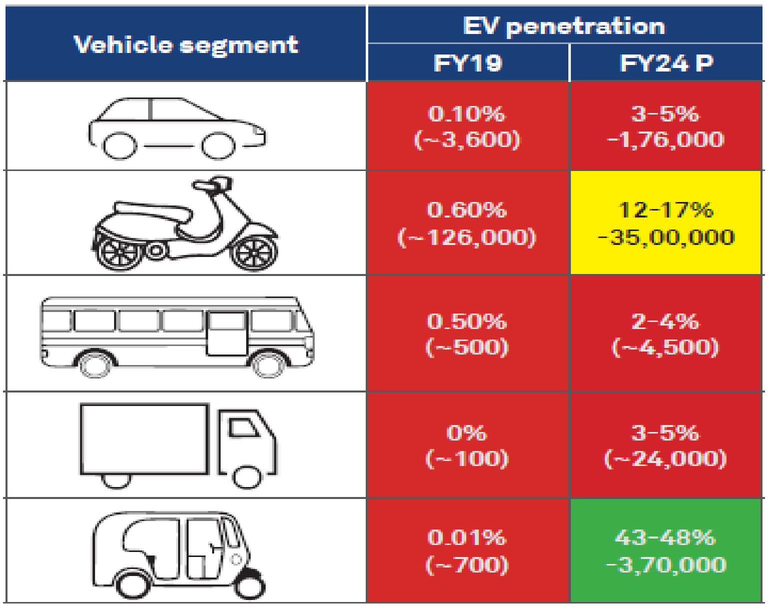
In India, e-mobility initiatives were started by Ministry of Heavy Industries and Public Enterprises (MHIPE), which launched NEMMP in 2013 and FAME in 2015. The government's focus is mainly on promoting the public transport fleet before moving to private vehicles. After launching of these initiatives by GoI, a number of states have announced their EV policies.

India has a very small share of electric car which was about 10,600 cars (2019) against a total estimated population of registered cars of about 3.40 crore at the end of FY 2018-19. Currently, there are only few key players like TATA, M&M, MG, Hyundai etc. in EV market.

GoI has selected 11 cities each having more than 1 million population for the deployment of 465 e-buses for public transit. Delhi government has also approved procurement of 1000 e-buses to its fleet of public transport buses.

Electric two and three wheelers accounted for 99% of the EV stock in the country. In electric two-wheeler segment, India saw a tremendous growth from the previous year to 1 lakh (>50%) in 2018. The total electric two-wheeler fleet in the country reached about 6 lakh. A variety of electric two-wheelers are available in the Indian market presently. To name a few, Hero Electric, Revolt RV400, Bajaj Chetak etc. are some electric two-wheeler available in Indian market. As per Society of Manufacturers of Electric Vehicles (SMEV), the Indian electric three-wheeler share amounts to 24 lakh (almost all of them e-rickshaws).

As per a study undertaken by CRISIL Research, presently penetration of EVs (cars, two-wheelers, buses, LCVs and three-wheelers excluding e-rickshaws) in India is very low and is projected to substantially increase for three-wheeler and two-wheeler in the next five years, as shown in Fig. 2.6.



Vehicle segment	EV penetration	
	FY19	FY24 P
	0.10% (~3,600)	3-5% ~1,76,000
	0.60% (~126,000)	12-17% ~35,00,000
	0.50% (~500)	2-4% (~4,500)
	0% (~100)	3-5% (~24,000)
	0.01% (~700)	43-48% ~3,70,000

Source: CRISIL Research

Fig. 2.6: Present and projected penetration of different EVs in India

2.5 Incentive for EVs and EV infrastructure in India under FAME II

Under the FAME II scheme, an outlay of ₹10,000 crore has been allocated for deployment of EVs and improving the charging infrastructure. An extended uniform incentive of ₹10,000 per kWh was proposed for all EVs including PHEVs and Strong Hybrid Vehicles (SHVs), except e-buses. To encourage public transport an incentive of ₹20,000 per kWh was proposed for e-buses. These incentives would be reviewed annually on the basis of price trends and market parameters. The incentives under FAME-II for EVs are listed in Table 2.1.

Table 2.1: Incentives for EVs under FAME II scheme of GoI

Vehicle segment	Approx. battery capacity (kWh)	Total approx. Incentives (₹)	Max ex-factory price to avail the incentives (₹)	Maximum numbers of vehicles to be supported	Total support (₹ in crore)
e-2 wheeler	2	20,000	1,50,000	1,000,000	2,000
e-3 wheeler	5	50,000	5,00,000	500,000	2,500
e-4 wheeler	15	150,000	15,00,000	35,000	525
4W SHV	1.3	13,000	15,00,000	20,000	26 C
e-bus	250	50,00,000	2,00,00,000	7090	3,545
Total incentives					8,596

Around ₹1000 crore is allocated for setting up of 1000 charging stations in 62 cities across 24 States and UTs as per the expression of interest (EOI) invitation under FAME II scheme (launched in September 2019). The amount of allotted incentive is subject to the type of recharging infrastructure classified as follows:

Category A: Charging stations established at public places for commercial purpose and available to any individual without any restrictions.

Category B: Charging stations established within the premises of a state or central government office complex, government hospitals/clinics/educational institutes or any other public office for non-commercial purpose and available to any individual without any restrictions.

Category C: Charging stations established within the semi-restricted premises for commercial and non-commercial use and available to any individual without any restrictions.

The amount of incentives will be provided to each of the categories of recharging stations as given in Table 2.2.

Table 2.2: Incentives allocated for charging station under FAME II scheme

Category of charging stations	FAME II incentives	Local Govt./city incentives
A	70%	30%
B	100%	NIL
C	50%	50%

A detailed cost estimation for a typical public charging station has been carried out by Plug in India and shown in Table 2.3.

Table 2.3: CAPEX and OPEX for EV charging station in India

Chargers	Power output (kW)	Approx. cost with 18% GST (₹)	No. of EVs can be charged
CAPEX			
1 CCS	50	14,50,000	1
1 CHAdeMo	50		1
1 Type 2 AC	22	1,25,000	1
1 Bharat DC – 001	15	2,40,000	1
1 Bharat AC – 001	3 x 3.3	70,000	3
Swap station	15	-	-
New electricity connection and software		7,90,000	-
Civil works + security		2,80,000	-
TOTAL CAPEX		29,55,000	-
OPEX		₹ 8 – 10 Lakh	-

It has been estimated that around ₹ 29.5 lakh will be needed to set up a charging station comprising 1 CCS, 1 CHAdeMo, 1 type 2 AC, 1 Bharat DC – 001, 1 Bharat AC – 001 and 1 swap station. As the capital investment is quite high, incentives under the FAME II scheme will attract private investor for setting up these charging stations. From the point of view of revenue project, it has been estimated that with the provided subsidies this could be an attractive business model.

2.6 Status of hydrogen fuelled vehicles

Hydrogen Fuelled Vehicles (HFVs) can be broadly classified in the following two categories:

(a) Internal Combustion Engine (ICE) based vehicles
(b) Fuel Cell Vehicles (FCV)

HICE vehicles can further be classified as: (a) Dual fuel vehicles and (b) 100% hydrogen fuelled vehicles. In dual fuel category, it could be either hydrogen-diesel or hydrogen-compressed natural gas (H-CNG), as shown in Fig. 2.7.

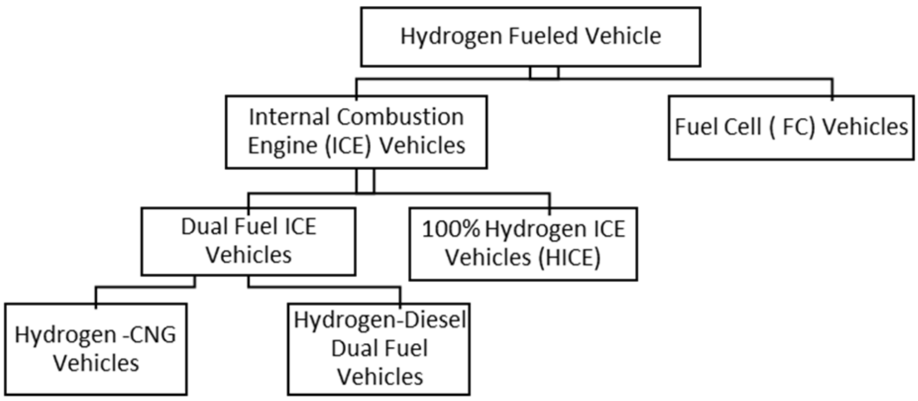


Fig. 2.7: Classifications of Hydrogen Fuelled Vehicles

2.6.1 Global HFV scenario

Among different HFVs, FCVs have been preferred globally except for initial efforts made by BMW to develop HICE car some years back. The factors which are responsible for growth of FCVs over HICE vehicles are high energy conversion efficiencies and no tail pipe emissions. FCVs at international level have generally experienced the following four phases of development:

- Before 2000: FCV concept design, demonstration and testing of the basic principles, and validation;
- 2000-2009: extensive FCV R&D as well as technology validation and demonstration;
- 2010-2014: early commercial niche-market deployment; and
- After 2015: early commercialisation with passenger FCVs' first selling to private users in selected areas, introduction of large capacity FC trucks for long haulage

FCVs are EVs without need for charging batteries. The refuelling time of FCVs is about 5 minutes compared to several hours (in case of slow charging) for an EV. In recent years, some major global automobile companies have taken major initiatives for commercialisation of FC cars. Toyota Motor Corporation developed a Fuel Cell car 'Mirai', with a driving range of about 500 km at the end of 2014. Mirai has on board storage of about 5 kg of hydrogen in Type IV cylinder at 700 bar pressure. Other active players in FC car market include Honda Motor Company and Hyundai Motor Company which launched commercial versions of their hydrogen FC cars Honda FCX Clarity and Hyundai ix35 FCEV respectively. In 2018, Hyundai Motor Company introduced NEXO FC car. Apart from road transport, FCs have also been used for propelling an airplane and running a train (Fig. 2.8). In September 2016, a four-seat passenger aircraft 'HY4' took off its first official flight from Stuttgart Airport. This was the world's first aircraft powered by a hydrogen FC. In the same year, Alstom exhibited "Coradia iLint"- a zero emission train at Berlin during a trade fair. Germany proposes to launch "Hydrail" commercially in its market. FC forklifts have made significant inroads in material handling market in the USA during the last five years.

(a) (b) (c)

Fig. 2.8: Different transport vehicles based on Fuel cell (a) HY4 Aircraft (b) Coradia iLint, a zero-emission train developed by Alstom (c) Hyundai NEXO.

With the sale of 4000 FCVs in 2018, the global stock reached almost 11,200 units by year-end 2018. The USA, Japan and European Union are the major markets for fuel cell cars. By 2030, China plans to deploy 10 lakh FC cars and South Korea has set a target of 6.3 lakh such cars. Japan plans to deploy 500 FCVs in 2020 Olympics in Tokyo. The vehicles include Toyota 'Mirai' and FC bus 'Sora' (Fig. 2.9) and have set a target of 8 lakh FCVs by 2030. Globally 175 FC buses are operating out of which about 100 are in China. About 28,000 FC based forklifts are also operational globally.

Fig. 2.9: 'Mirai' – A fuel cell Car and 'Sora'- A fuel cell bus developed by Toyota

2.6.2 Indian HFV scenario

With a view to accelerate the hydrogen development in India, NHER was prepared in 2005 by MNRE with involvement of all stakeholders. In view of issues like high cost and durability associated with FCs, HICE was considered to be the best option for introducing hydrogen in the country as an automotive fuel. Moreover, it was also expected to act as a transitional technology before making a switch over to FC technology, once it matures.

Based on the suggestion made in NHER, it was decided to introduce H-CNG based vehicles of different types (Fig. 2.10) in the country under a demonstration project. These vehicles were not only expected to have reduced emissions and improved performance but also pave the way for introduction of HFVs in the country. The results were not conclusive in terms of bringing down NOx emissions, though other emissions were reduced.

Fig. 2.10: H-CNG Vehicles developed and demonstrated in India

The technology of single cylinder hydrogen fuelled engine for stationary power generation, developed by Indian Institute of Technology (IIT) Delhi, was adopted by Mahindra & Mahindra (M&M) for developing a hydrogen fuelled three-wheeler (Hy-alfa) that was demonstrated in Pragati Maidan, New Delhi (Fig. 2.11). This project was implemented in two phases. Phase-I was supported by United Nations Industrial Development Organisation (UNIDO) and Phase-II was supported by MNRE.

Fig. 2.11: Hydrogen Fuelled ICE Three-Wheelers developed by IIT Delhi and M&M

In addition to IIT Delhi, Banaras Hindu University (BHU), Varanasi had also developed and demonstrated hydrogen fuelled two-wheelers and three-wheelers (Fig. 2.12). Hydrogen in these vehicles is stored in metal hydride based storage system instead of a Type-3 composite cylinder used in the three wheelers developed by M&M.

Fig. 2.12: Hydrogen fuelled three-wheeler and Motor-cycle developed by BHU, Varanasi

Under a Mission Project supported by MNRE and implemented by IIT Delhi and M&M, prototypes of two HICE buses were developed and underwent limited field trials at Indian Oil Corporation Ltd. (IOCL), Faridabad (Fig. 2.13)

Figure 2.13: HICE Mini Bus and Hydrogen-Diesel Dual Fuel Vehicle developed by M&M

M&M was also involved in development of 5 numbers of hydrogen – diesel dual fuel vehicles with an objective of reducing emissions and improving the performance of diesel vehicles. These vehicles underwent demonstration and trial runs at NISE (Fig. 2.13). In hydrogen-diesel dual fuel vehicles, diesel can be replaced by bio-diesel, which can be produced from locally available renewable resources, for making it a green vehicle. Some R&D on this aspect has been carried out in IIT Delhi.

Tata Motors Ltd. (TML) has developed FC buses with the imported FC stack, composite cylinders for on-board hydrogen storage, traction motors and other critical components (Fig. 2.14). This project was partially supported by the Department of Scientific and Industrial Research (DSIR). Two such buses were demonstrated at IOCL, Faridabad, where a hydrogen dispensing facility is available.

Fig. 2.14: Fuel Cell Bus developed by Tata Motors

2.7 Way Forward for HFVs in India

Prototypes of both HICE vehicles and FC buses have been developed in India with collaborative effort of the academic institutions and industry under the projects supported by the GoI. These vehicles have also undergone limited field trials due to availability of limited facilities for hydrogen dispensing in the country. HFVs, especially for public transport, could be promoted at suitable locations under a demonstration programme to be developed and implemented for this purpose.

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CHAPTER 3: INTERNATIONAL AND NATIONAL STATUS OF LITHIUM ION BATTERIES FOR ELECTRIC VEHICLES

3.1 Introduction

Battery development dates back to more than 200 years. Batteries differ in their chemistry with typical cell voltage of 1.0-3.6 V/cell. Batteries consist of mainly two electrodes and an electrolyte. Properties of a battery can vary depending on materials used for electrodes and electrolyte.

Batteries can be classified as (a) primary battery - that is not rechargeable and (b) secondary or rechargeable battery. The lead acid battery is the oldest rechargeable battery and is still in use. Batteries are named as per materials used in their construction and most common batteries are lithium, lead, and nickel-based. Batteries are advancing on two fronts, reflecting in increased *specific energy* for longer runtimes and improved *specific power* for high-current load requirements. Improving one characteristic of a battery may not automatically strengthen the other and there is often a compromise. Fig. 3.1 shows the status of current battery technologies in terms of their specific energy and specific power.

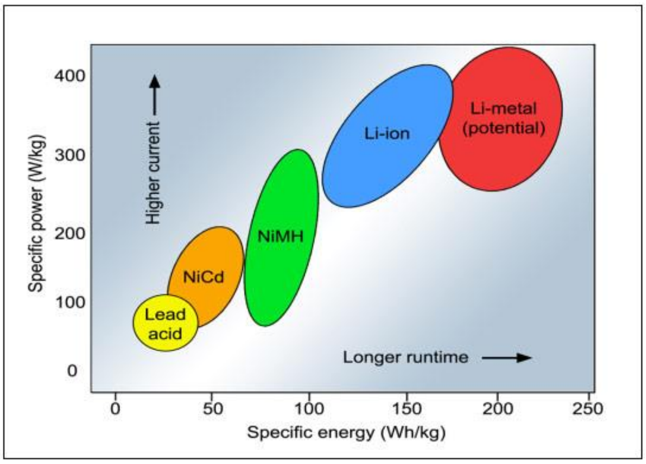


Fig. 3.1: Specific energy and specific power of rechargeable batteries.

As shown in Fig. 3.1, potentially lithium metal battery has the highest specific energy or energy density as well as specific power. However, as lithium metal is highly reactive, design and development of Li-metal battery is challenging and tricky. Therefore, currently, the best performing and developed battery technology is the secondary LIB. The LIB research dates back to the 1970s when it was initially developed and since then a number of chemistries have been developed and commercialised.

EV architecture requires a high energy density battery system with fast charging technology. LIBs have higher energy density, zero-memory effect, higher open circuit voltage, and long lifespan, which make them suitable for EVs. Accordingly, EV manufacturers have adopted LIBs for EVs.

3.2 Materials, performance and cost of LIBs

Increase in demand for EVs coupled with dependence on LIBs has led to vigorous research efforts. Historically lithium's appeal as the most reducing element and the lightest metal in the periodic table that promises high operating voltage, low weight, and high energy-storage density has increased its application as the battery material. The focus of research has been on two main components of the cells namely anodes and cathodes. Anodes are primarily made of graphite, which contains additives like hard carbon and soft carbon. These materials are both cheap and effective. For cathodes, most battery packs for EVs use a variation of Nickel Manganese Cobalt (NMC) or Nickel Cobalt Aluminium (NCA) due to high storage capacity, voltage, and relative safety; although electronics tend to use Lithium Cobalt Oxide (LCO) for its higher energy density.

LIBs are dominating the applications in electronics, EVs and also energy storage. Currently the lithium ion technology is based on insertion-reaction electrodes and liquid electrolytes. The focus on increasing energy density and optimising other parameters including cycle life has resulted in research work on new electrode materials like silicon graphite and lithium anodes and also solid electrolyte. Current scientific research of LIB is mainly focused on the following areas:

- Increase in cell voltage
- Increase in storage capacity - Moving from insertion/extraction reaction to conversion reaction electrodes like in silicon graphite anodes. Similar Examples of conversion-reaction cathodes are sulphur (or Li_2S) and oxygen (or Li_2O_2 or Li_2O). High nickel cathodes are becoming increasingly important due to challenges in conversion-reaction cathodes

Internationally, work on anodes and cathodes have continued since 1970's. Initially Li metal anodes were used. However, there were challenges in the safety due to dendrite formation and cycle life. Subsequently, graphite anodes were introduced in Li batteries. In recent years, silicon graphite anodes are being used in order to have higher energy density. Many research organisations have worked on the development and commercialisation of LIB chemistries like, Lithium Iron Phosphate (LFP), Lithium Nickel Cobalt Oxide Aluminum (NCA), Lithium Nickel Manganese Cobalt Oxide (NMC), etc. Fig. 3.2 shows the development of LIBs in terms of its reducing cost and improving energy density over a period of 25 years.

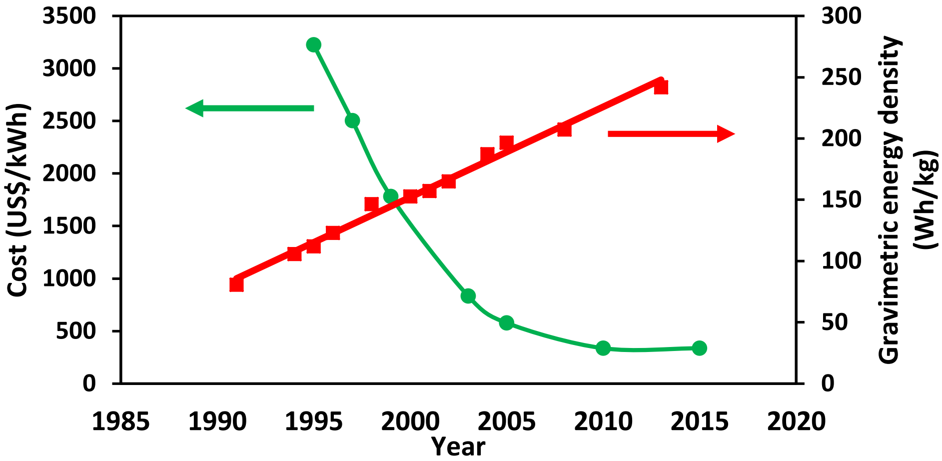


Fig. 3.2: Development of Lithium Ion batteries during the period 1990-2015.

The trend of falling prices of LIB is likely to continue and prices are set to fall below US$ 140/kWh by 2023, thereby making them much more cost-competitive (Fig. 3.3). The USDOE predicts that once battery cost falls below US$ 125/kWh, owning and operating an EV will be economical than a petrol car in most parts of the world. However, cost of imported LIBs in India is in the range of Rs. 18500-21500 /kWh. A preliminary life cycle analysis considering useful life of 2000 cycles for LIB and prevailing electricity cost of about Rs. 7/kWh indicates that delivered cost of electricity using LIB would be in excess of Rs. 20/kWh.

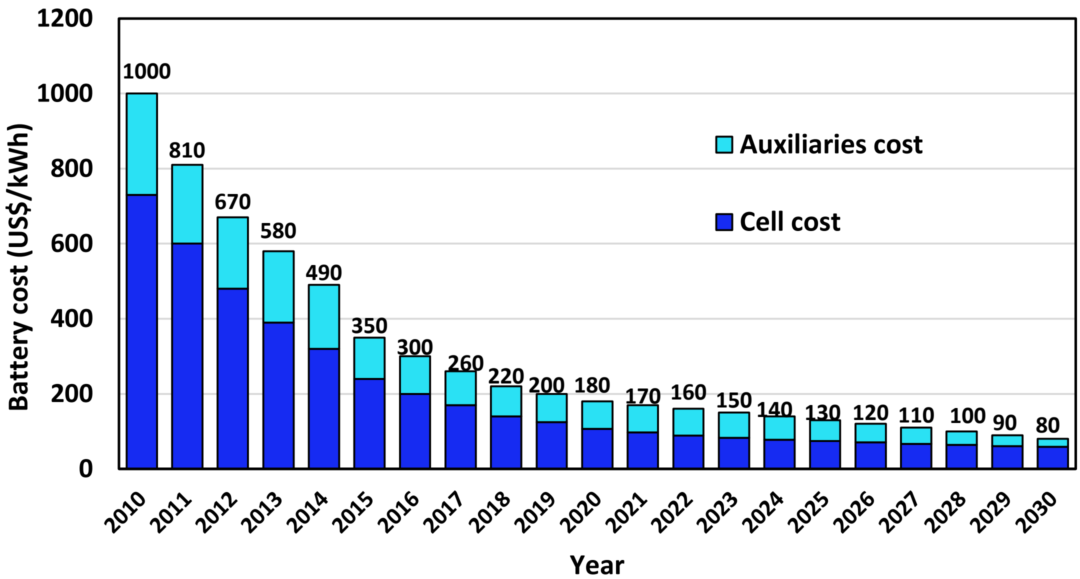


Fig. 3.3: Total battery pack costs

3.3 Growth opportunity for LIBs

Lithium ion and lead acid batteries are used mainly for energy storage presently with the former taking over as main energy storage system within coming few years. Currently, graphite-based LIBs are used for electronics and other energy storage systems. Fig 3.4 shows past, present and estimated future global market share of LIBs for various applications, including applications in electronic devices and EVs. The future share is estimated using some projections and also historical market data and trend. The global production capacity and demand for LIBs were estimated to be about 285 GWh and 190 GWh respectively in 2019. About 60% of the total demand i.e. about 115 GWh during 2019 could be attributed to requirement for all kinds of EVs. Considering the average battery pack size of 50 kWh, it would have been sufficient for production of about 2.3 million EVs. Share of LIBs for e-mobility is projected to increase up to 70% in the years to come.

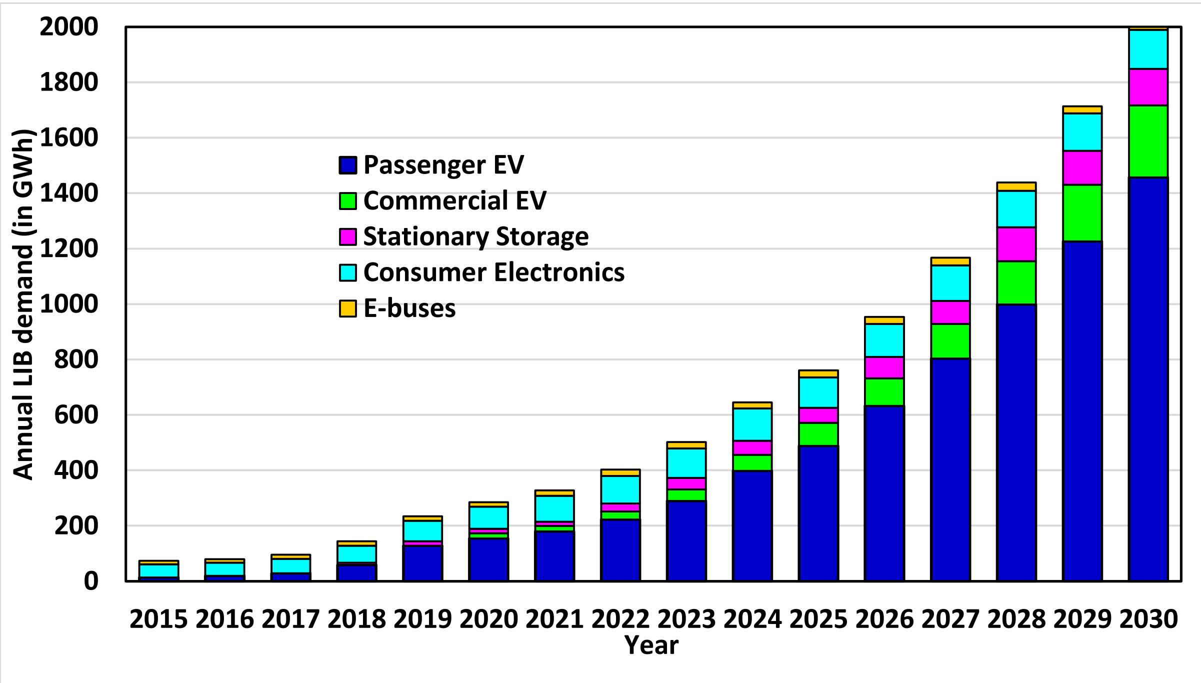


Fig. 3.4: Global markets for Lithium Ion batteries

According to IEA, the global EV market has increased from just 1800 vehicles in 2005 to more than 5 million by 2018 (Fig 3.5). The number of charging points is estimated to be around 5.2 million at the end of 2018. Fig 3.6 shows, position of EV fleet in India in 2019.

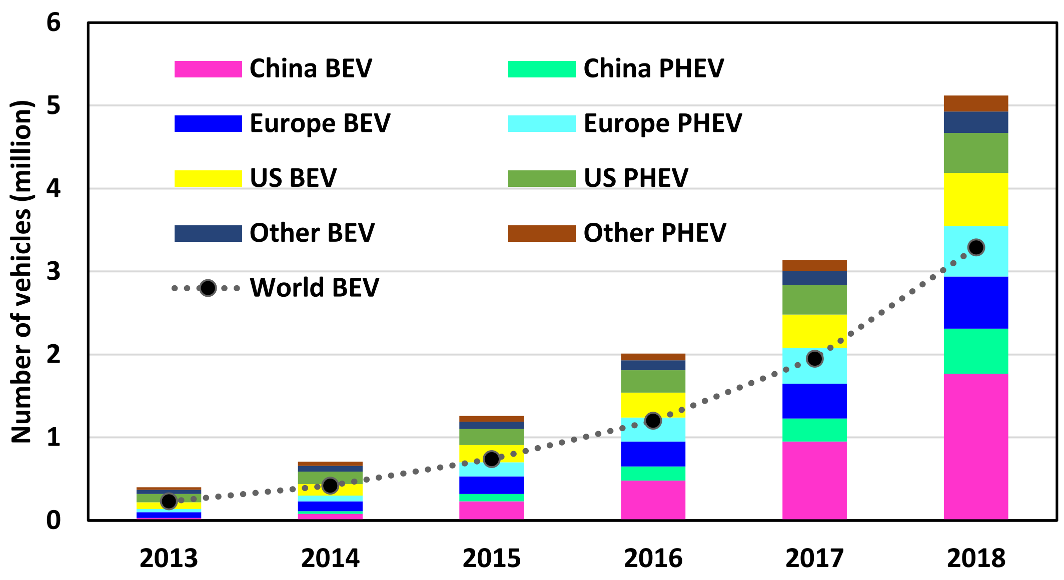


Fig. 3.5: Global Electric Car Sales and Market Share

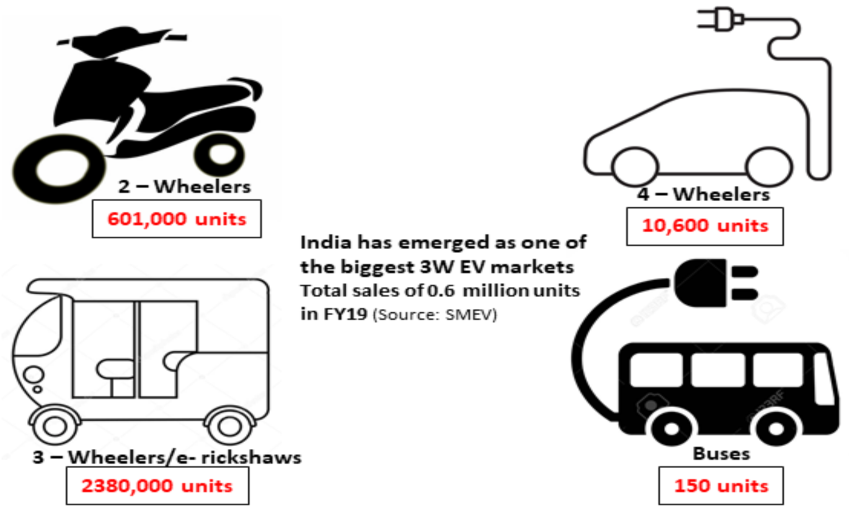


Fig. 3.6: EV Fleet in India 2019

3.3.1 Emerging Chemistries of Li ion Batteries

Research activities to develop some new lithium-based technologies (e.g. lithium-air, lithium-sulphur, lithium-polymer and solid-state lithium) are underway. However, a significant advancement in these technologies is needed before considering them for vehicular applications. Driven by the need for lower costs and higher energy density, efforts are directed towards commercialising nickel-rich cathodes to reduce use of expensive cobalt. Many LIB manufacturers are trying to start NMC 811 (Ni:Mn:Co::8:1:1) production in 2019-20. NMC materials will dominate the global LIB market in coming years.

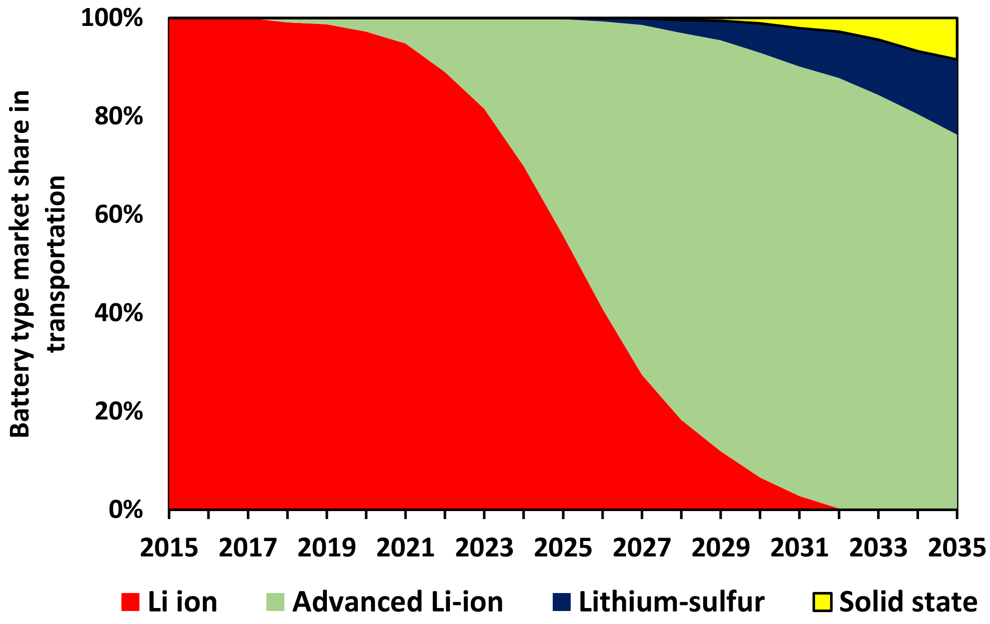


Fig. 3.7: Battery type market shares in transportation between 2015 and 2035

As indicated in Fig. 3.7 lithium-sulphur and solid-state batteries are expected to make market penetration by 2030 in transportation. Li-ion would dominate for some more years, when advanced Li-ion chemistries are expected to take over. Advanced Li-ion is defined as a varied mix of higher-voltage and higher storage capacity materials.

3.4 Growth drivers for Lithium Ion Batteries

The worldwide applications of LIBs are growing both in EVs and energy storage on account of the following factors:

- Requirement for higher energy density leading to lower weight battery and higher range.
- Development of infrastructure required for EVs and existence of basic electric network for transmission and distribution
- Renewable energy integration in the grid and its increasing penetration
- Need to have higher storage to balance the grid

3.4.1 Energy density

The energy density of LIBs has been steadily increasing. Fig 3.8 shows the currently achieved levels and targets in the coming years. Current cells have already achieved up to 330 Wh/kg with target to achieve 400 Wh/kg in near future.

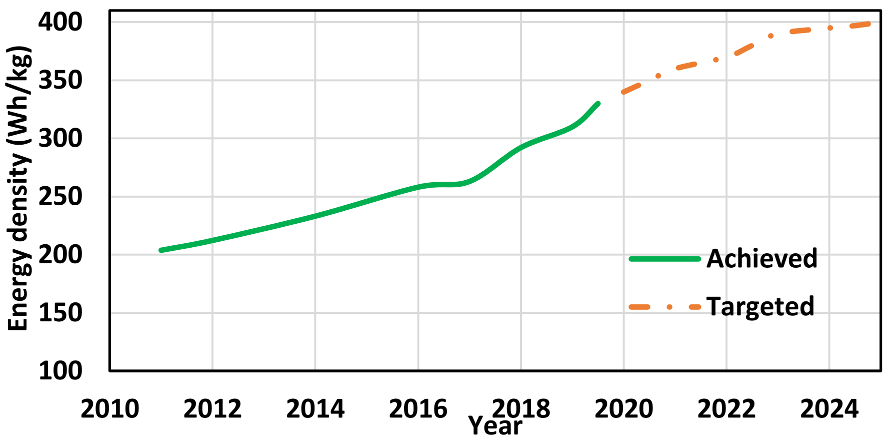


Fig. 3.8: Year-wise energy density growth of LIB

3.4.2 Charging Infrastructure

It takes about three minutes to fill up tank of a petrol or diesel car at a filling station with enough fuel to travel about 500 km. For covering same distance in a small electric car, three full charges of a typical 25 kWh battery, used to power these vehicles would be needed. The solutions don't just involve the development of chargers; they involve the design and roll out of a network of public and private charging stations with associated developments in billing systems, public safety, international standards and electricity grid to cater to increased load. Consumers rank not having enough access to efficient charging stations as the third most serious barrier to EV purchase, behind price and driving range. The EV charging market will grow at tremendous rate and projected to reach US$ 27.7 billion by 2027 at a CAGR of 34.7% (Fig 3.9). The EV market in North America and Asia Pacific is

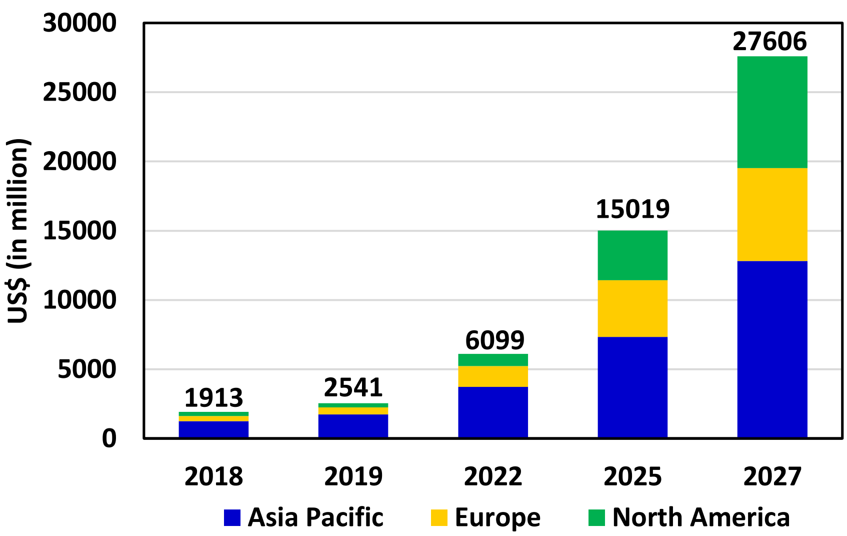


Fig. 3.9: Estimated EV charging markets in EU, North America and Asia pacific till 2027

expected to grow at the fastest rate while the European market will experience a steady growth. However, the projected growth rates may alter depending on the government's and public sector's policies as the initial investment, overhaul, and maintenance cost is high for this sector. It is also expected that the portable charger will also become a potential market where chargers could be carried with the EV and could be charged whenever needed.

3.4.3 Renewable integration

The contribution of renewable power is growing worldwide and e-mobility using renewable electricity would almost make the transport sector a zero-emission sector. Fig. 3.10 shows break-up of global renewable power generating capacity of 2377.3 GW in 2018. Most of the renewable power capacities are contributed by the hydro and wind. Recently solar energy-based power generating capacity, both thermal and photovoltaic, is increasing rapidly in recent years.

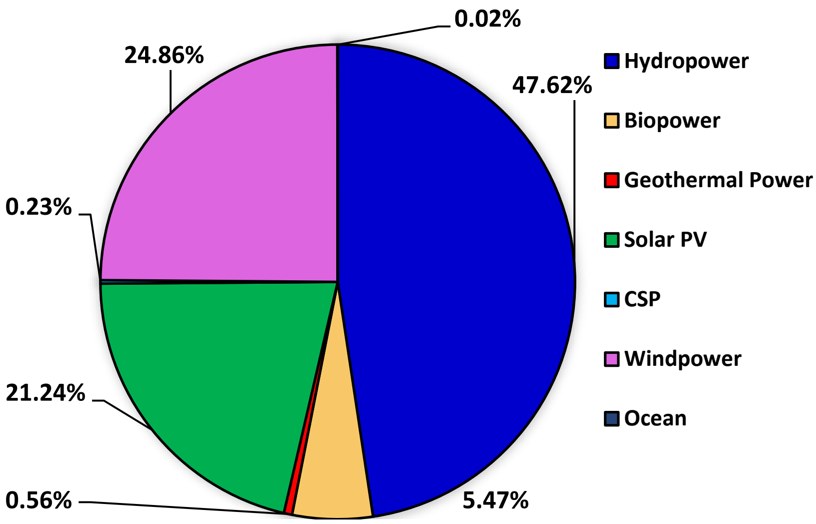


Fig. 3.10: Global renewable energy share (2018)

India is one of the few countries with significant power generating capacity based on renewable energy, which was about 86 GW as on 31.12.2019 and was about 23.3% of the total installed power generating capacity of 368.78 GW. The share of various renewable energy sources in total renewable power generating capacity is shown in Fig. 3.11. India aims to achieve 175 GW renewable energy power generating capacity by 2022 and plans to enhance it to 450 GW by 2030. Worldwide Solar Photovoltaics (SPV) installations have increased significantly during the past few years. As of 2018, globally 505 GW of SPV power was installed. Growth of solar SPV and worldwide distribution of SPV is shown in Fig. 3.12

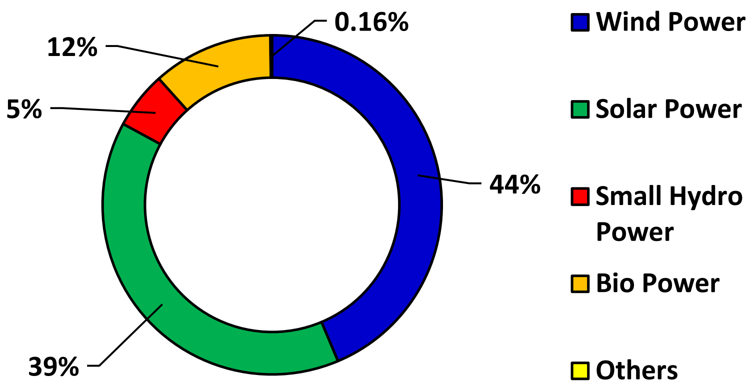


Fig. 3.11: Renewable energy share of India (2019)

and Fig 3.13, respectively. As can be seen from the Fig 3.13, India's SPV installation is around 6.5% of the global installation. GoI has targeted installation of total capacity of 100 GW solar based power generation by 2022.

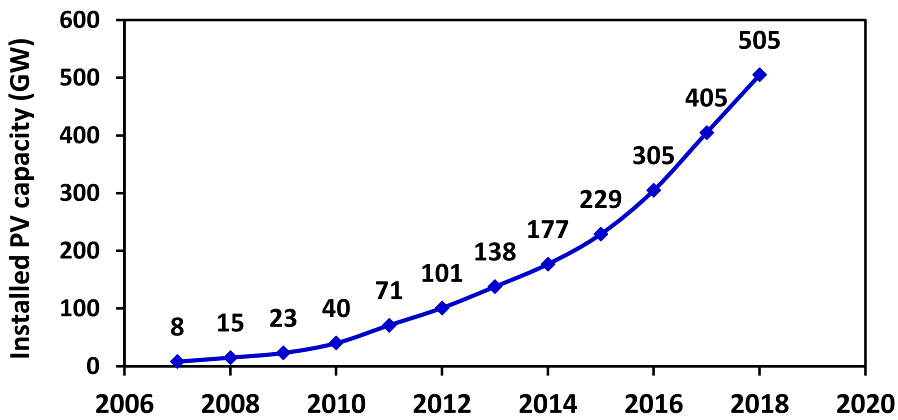


Fig. 3.12: Growth of Solar PV Capacity Globally

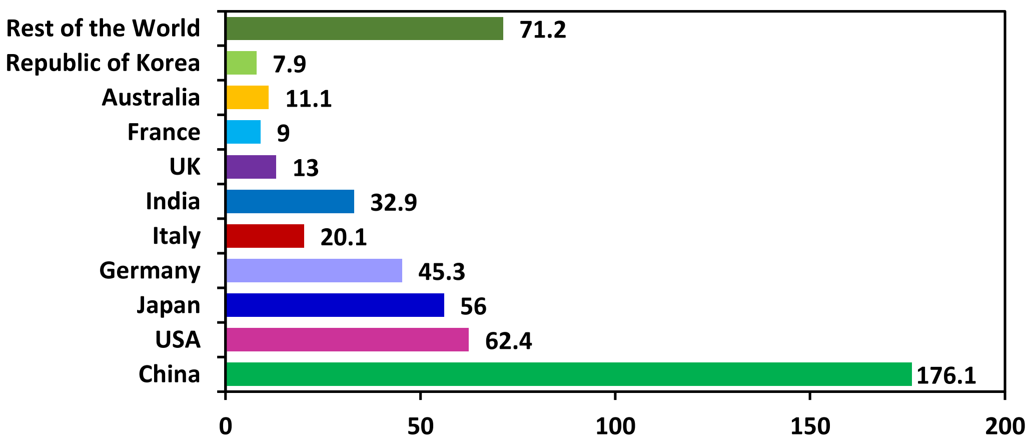


Fig. 3.13: Country wise solar PV installation capacity (GW) in 2018

In recent years, Indian wind power generation capacity has increased significantly and has reached 35.1 GW, which is the fourth largest installed wind power in the world. As of 2018, the total installed wind power capacity was 591 GW globally, as shown in Fig. 3.14.

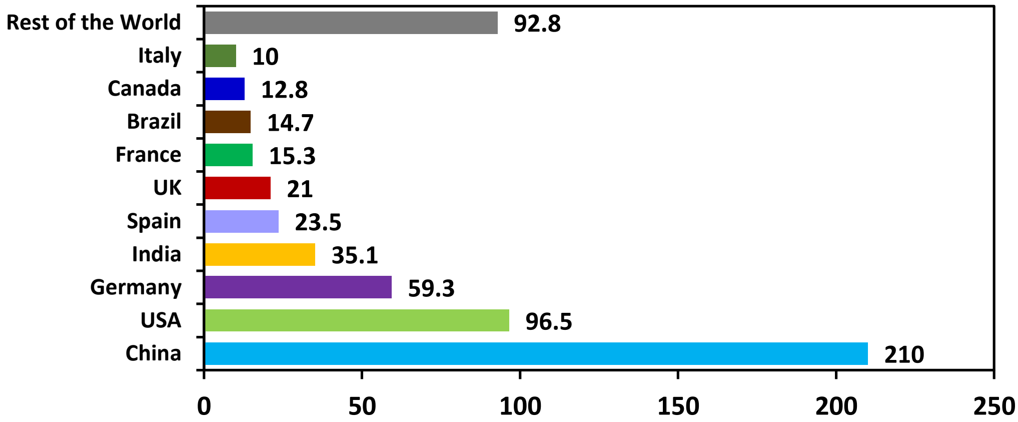


Fig. 3.14: Country wise wind power installation capacity (GW) in 2018

However, the renewable energy resources (*e.g.* solar and wind) are variable and intermittent. In spite of development of forecasting tools, they can still be unpredictable and make the grid unstable. This necessitates storage technologies, which would mitigate variable nature of the renewable resources. To avoid such uncertainty, batteries could be used to store the electricity. Surplus renewable electricity could be stored when electricity generation is surplus than the demand and it could be returned to the grid, in case of deficit in generation from renewable resources.

3.4.4 Grid storage

Depending on the time of the day, generation and consumption of electricity varies. The excess electricity generated could be stored in batteries and sent to the grid when needed using smart grid communication infrastructure – this method is commonly known as grid storage. Grid storage could benefit in several manners:

- Stable price – The cost of electricity would not vary much if the energy demand is fulfilled using the stored energy during peak hours.
- Emergency or vital needs can be met even without transmission or generation of electricity.
- Shut down of the power generation systems (PV, wind or thermal etc.) could be avoided by storing the energy when energy consumption is low or zero.

- Optimise resource utilisation – Peak generation or transmission capacity can be reduced by using the energy storage units.

LIBs are suited well for most of these applications (*i.e.* e-mobility, grid energy storage, portable electronics etc.) due to their unmatchable combination of high energy and power densities. However, looking in the future, it is doubtful that LIBs would be able to meet requirement of all the energy storage needs. This is mainly due to raw material constraints of lithium and other transition metals required for making LIBs.

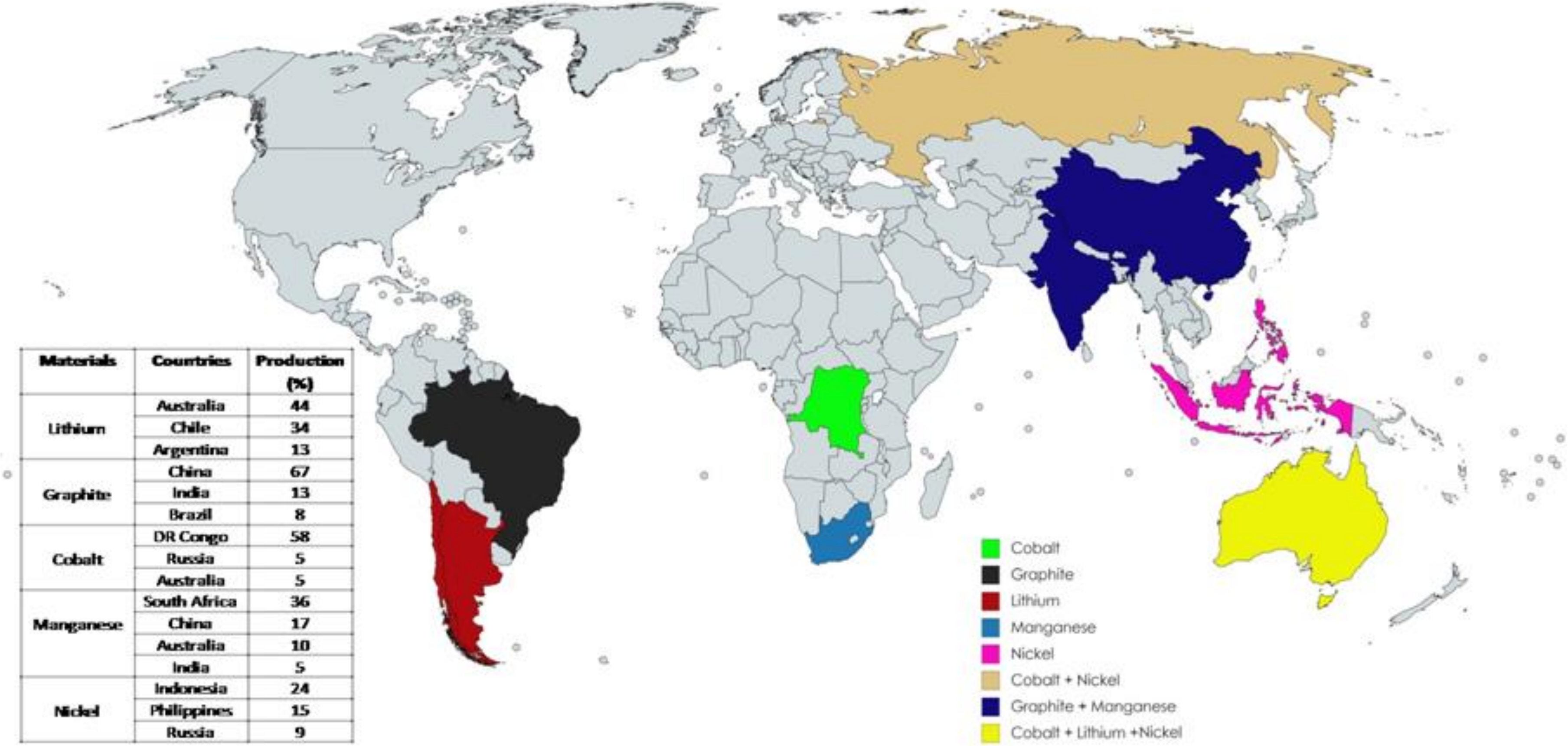
3.5 Sources of raw materials

The critical materials required for manufacturing LIBs are lithium, nickel, graphite, cobalt and manganese. These naturally occurring materials are available in only certain parts of the world and have finite known reserves. The availability of these materials in terms of global share of production is shown in Fig. 3.15. Cobalt and lithium are highly concentrated in a few countries. Worldwide lithium reserves in 2020 are estimated to be 17 million tonnes as per the US Geological Survey report. More than 80% of global lithium production comes from Australia, Chile, and Argentina. More than 60% of manganese is mined in South Africa, China, and Australia. An average of 53% of global mined cobalt production came from the Democratic Republic of Congo. Most cobalt deposits are also found in the Central African Copper belt (DRC, the Central African Republic, and Zambia).

3.6 LIB work in the Industry

The industry has been working on EVs and batteries for EVs and HEVs for many years. All the major global automotive players like GM, Ford, Toyota, BMW, Volkswagen, Nissan, Chrysler and Honda have been working on EVs and HEVs. Cell production capacity has seen phenomenal rise in the Chinese market. The following graph (Fig 3.16) shows the cell production capacity geographically.

LIB manufacturing capacity has increased in recent years in China, Korea, the USA and Japan. Major players like CATL, BYD, Panasonic, LG, Samsung and SKI have installed manufacturing capacities in China, Korea and Europe. Tesla and Panasonic have announced 35 GWh/year facilities in the USA. Tesla has also announced GWh factories in China and Germany. Similarly, NorthVolt has announced plans for manufacturing in Europe.



Materials	Countries	Production (%)
Lithium	Australia	44
	Chile	34
	Argentina	13
Graphite	China	67
	India	13
	Brazil	8
Cobalt	DR Congo	58
	Russia	5
	Australia	5
Manganese	South Africa	36
	China	17
	Australia	10
	India	5
Nickel	Indonesia	24
	Philippines	15
	Russia	9

Fig. 3.15: Global share of various raw materials needed for LIB production in 2018 with production % in the inset table

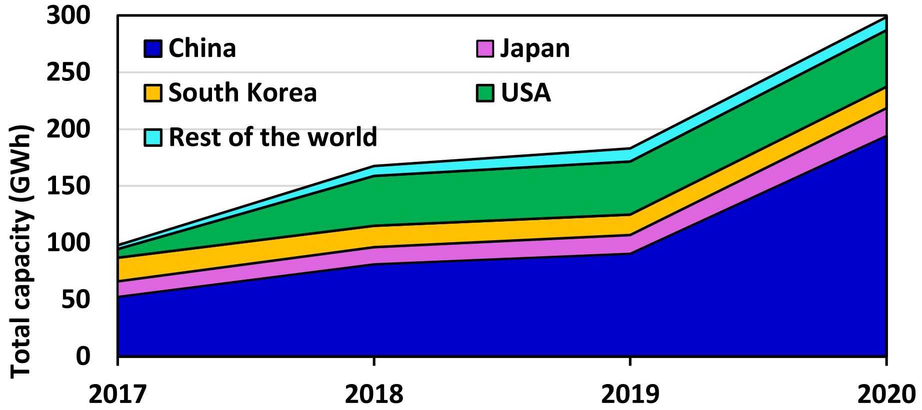


Fig. 3.16: Geographic distribution of LIB cell production capacity (GWh)

Fig 3.17 gives the planned (2018) and installed (2017) capacity for top 15 manufacturers in the world.

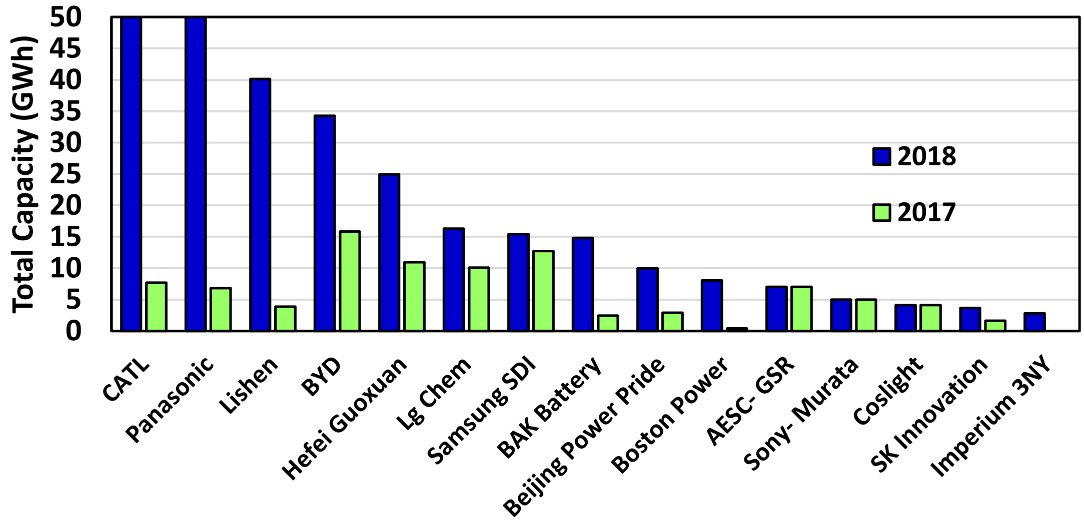


Fig. 3.17: Top 15 Large Li-ion manufacturers worldwide

The major LIB manufacturers and their status on this aspect are as follows:

- **CATL:** Contemporary Amperex Technology Co. Limited (CATL) was founded in 2011. The planned manufacturing capacity of CATL is 50-80GWh. CATL maintains R&D team of 3400 and has co-operation with number of Chinese academic institutions. Until December 31, 2017, CATL has applied for over 2,300 patents, including more than 907 authorized ones.
- **BAK:** Founded in 2005, Shenzhen BAK Technology is headquartered in Longgang District, Shenzhen, Guangdong. It has lithium battery; EV and battery recycle as its core three business lines. They have a product range which covers rechargeable Li-ion, Li polymer and LFP batteries. The total battery capacity of Shenzhen and Zhengzhou

bases is 8 GWh. The company has 800 full time R&D staff and have filed 1000+ patent applications

- **BYD:** BYD is fully integrated company from mines to manufacture of EVs. Founded in February 1995, BYD has grown from 20 employees into a global company with 240 thousand employees. The company has established over 30 industrial parks across six continents and has manufacturing units in China, Europe and India. They have installed capacity of 24 GWh and have recently launched another 20 GWh.
- **LG Chem:** LG Chem manufactures battery cells and packs for EVs and HEVs. They have established EV joint venture with GM, USA. LG Chem has a combined R&D strength of 5300 personnel. LG has plans to set up 60-70 GWh capacity factory in Poland and a 30 GWh plant in USA for GM.
- **Samsung:** Samsung produces battery cells for EVs, PHEVs. They are also world's leading supplier of battery packs for EVs. They have partnered with global top automakers in automotive battery pack projects including BMW, Volkswagen, Porsche, Renault, Ford, FCA (Fiat Chrysler Automobiles), and Scania.
- **Farasis:** Farasis Energy is a manufacturer of Li-ion cells and packs for Chinese automakers. It supplies BAIC and other Chinese automakers with packs from its production facility said to have between 3 GWh and 10 GWh of capacity; the company is planning to expand to 20 GWh in China and build a new facility in Germany. Founded in 2002 and based in Hayward, California, USA. It has 46 patents applied for and granted covering cathode and anode materials, cell design and manufacturing, and recycling both in the USA and in China
- **Hefei Guoxuan High-Tech:** Hefei Guoxuan High-Tech is a manufacturer of LFP cathode material, LIB cells, battery management systems, and battery packs. It has granted 26 invention patents, including both invention patents and utility model patents with another 86 patent applications are pending.
- **BASF:** It is a leading worldwide cathode material supplier to battery manufacturers for EVs. Primarily they have started with NCA chemistry and now focusing on making NMC chemistry. They are also working to bring Li-Mn rich NMC (LMR-NMC) cathode materials to market in the coming years. BASF also invested in development of next-generation battery material, such as high energy lithium-metal anodes.

- **Panasonic:** Panasonic Corporation is focused on cylindrical NCA Li-ion cells, although they also produce NMC Li-ion cells for stationary applications. Panasonic is key partner of Tesla in the Gigafactory and has the world's largest Li-ion manufacturing facility to date. They have 7,000 patents awarded in the battery space. Panasonic became one of the first cell manufacturers to use silicon-carbon composite anodes in the 2015 Tesla Model S. Most other major cell manufacturers now offer a silicon-containing anode, albeit at lower volumes
- **Toshiba:** Toshiba Corporation is one of the leading players in the LTO batteries. They are closely working with Toyota and Suzuki on hybrid vehicles technology. They are also working with a number of bus companies. Toshiba has recently announced plans for manufacturing LTO cells in India for Toyota and Suzuki.

3.7 Major international R&D in Li-ion technology

A number of organisations are working around the world for betterment of the battery technology. Given below is a list of some of the organisations working in this field

- **USDOE:** The Vehicle Technologies Office, USDOE is working on number of areas in the battery technology: reduction in cost, volume and weight of batteries, improvement of batteries' performance, next generation high-energy LIB materials.
- **Faraday Institute, UK:** It conducts research on projects to reduce battery cost, weight, and volume; to improve performance and reliability, and to develop whole-life strategies including recycling and reuse of LIBs.
- **Argonne National Laboratory, USA:** With more than 250 battery technologies available for licensing and thousands of publications in scientific journals, Argonne is a global leader in battery research and development in LIBs. Presently, researchers at Argonne are working on the development of next generation battery — super-batteries that are a leap beyond the current lithium-ion.
- **Dalhousie University, Canada:** They are working on the fundamental understanding of LIB failure due to electrolytes. They have developed the method for adding additives and coatings to extend the cycling life of LIB.
- **University of Oxford, UK:** They are evaluating the possibility for replacement of liquid electrolyte by ionically conducting solids (solid state Ionics).

- **Nanyang Technological University, Singapore:** They are working on development of graphite anode (negative pole) of LIBs and fluoride ion batteries.
- **University of Texas, USA:** They have developed the first all-solid-state battery cells that could lead to safer, faster-charging, longer-lasting rechargeable batteries.
- **MIT, USA:** MIT researchers are working on next generation cathode materials, which are smaller, safer, and faster lithium-rich ceramic electrolyte "Hybrid" cathodes could provide more power for a given weight and volume for future LIB's.
- **CEA, France:** Here researchers are focusing on the entire value chain of LIB: from the synthesis of new active compounds, to component and cell manufacturing, extending all the way to final battery pack assembly of LIB. Larger part of their efforts is on doubling battery life with their Lithium-sulphur battery technologies.
- **Fraunhofer, Germany:** Battery technology application centre of Fraunhofer works not only on fundamental issues of electrode processing but also on the cost optimisation of battery.
- **Tokyo University:** This group is mainly working on the development of novel electrode materials, superior electrolyte, and assessment of the reaction mechanism.

3.8 Major R&D on LIBs in India

The R&D efforts in India in the field of Energy Storage are led by CSIR-Central Electrochemical Research Institute (CECRI) followed by few groups at Indian Institute of Science (IISc), Bengaluru; IIT Hyderabad; ARCI laboratory (IIT Madras Campus) and IIT Bombay. There is a structured R&D effort which is primarily driven by needs of Indian space programme by ISRO which has delivered excellent results in terms of product delivery. Few Indian industries have received this technology and are trying to make cells from it and scale up on their own. Most of the R&D efforts in India are focused on basic R&D (In LIB, sodium battery, cathode active, solid state electrolyte and many new areas).

3.9 Status of LIB technologies in EV manufacturing industries

First LIB based EV was introduced in 2002. At that time, some of EV models with lead acid batteries and nickel metal hydride were also introduced. Battery technologies used in recent EVs are summarised in Table 3.1. Most of the vehicle manufacturers around the world are working in EVs and have introduced models with full electric or hybrid technology.

Table 3.1: List of battery companies, their vehicle of application and battery material

Sr. No.	Battery Company	Vehicle of Application (Company/Model)	Battery material (Anode + Cathode)
1	AESC	Nissan/ Leaf	Graphite + LMO-NCA
2	LG Chem	Renault/ Zoe	Graphite + NMC-LMO
3	Li-Tec	Daimler/ Smart	Graphite + NMC
4	Li Energy Japan	Mitsubishi/ i-MiEV	Graphite + LMO-NMC
5	Samsung	Fiat/ 500	Graphite + NMC-LMO
6	Lishen Tiajin	Coda/ EV	Graphite + LFP
7	Toshiba	Honda/ Fit	LTO + NMC
8	Panasonic	Tesla/ Model S	Graphite + NCA

A list of companies, currently working on development of Li-ion based EVs are as follows:

- **Toyota:** Toyota is in the forefront of battery materials and as LIB manufactures. Toyota Motor has one of the world's foremost solid-state battery development programme. Toyota Group holds the most extensive patent portfolio in LIB technology with 3,840 IP assets.
- **GM:** It wants all-electric models by 2023, eventually phasing out petrol and diesel-powered cars altogether. To fulfil this commitment, GM will set up its own Gigafactory in joint venture with South Korea's LG Chem.
- **Ford:** It is focusing on advanced driver assist and light weight mobility with self-driving taxis.
- **BMW:** It is investing €200 million over four years in new Battery Competence Centre in Munich, Germany.
- **Volkswagen:** They have set out on ambitious aggressive vehicle electrification programmes. They have committed US$1 billion to invest in start-up Northvolt and setting up a joint venture with the company to produce batteries for its vehicles. The expected capacity will be 16 GWh in 2024 and later on expanding to 32 GWh.
- **TESLA:** Tesla was founded in 2003 and has become the leading player in the EV space. They have also made their presence felt in the stationary energy storage space with their home and grid storage application products. Tesla has designed and launched many grounds up EV models and these have become very popular. They have also installed 35 GWh factory in the US and announced factories to be installed in Germany and China.

- **Ather:** Ather Energy is one of the Indian start-ups which designs and manufactures two-wheel electric scooters with non-removable LIB. They have developed their own battery management system (BMS) and LIB pack. Ather also owns and operates a system of charging stations called AtherGrid; all Ather scooters can charge for free at these stations and within its operating cities. Ather Energy aims for its riders to never be more than 4 km away from an Ather-owned charging point. Currently they operate in Bengaluru and Chennai, but would be expanding operations to other 30 cities in India by 2023.

3.10 Lithium ion battery: limitations and safety

As discussed earlier, LIB offers some distinct advantages and improvements over other form of battery technologies. However, like all technologies, LIBs have also their limitations. LIBs are not as robust as other batteries. They should be protected from being over charged and discharged beyond a limit. For better performance, operation of LIBs in their safe operating limits is to be ensured. This could be achieved using a protection circuit. Ageing of LIBs is another major disadvantage. Capacity of LIBs deteriorates not only with time but also with the number of charge– discharge cycles. Storage in cool place (288K) can slower down the ageing process. With development of new electrode materials, useful charge-discharge cycle life is increasing but still it is a major concern of this technology. LIBs along with other battery technologies do have safety risks. In fact, Sony had to recall their almost six million batteries due to some reported fire hazard in 2006.

3.11 Conclusions

LIBs have become the technology of choice for applications in E-mobility and stationary storage space. A number of research organisations have been working in this field and continuing their efforts to further improve different aspects of LIBs. Commercial activities in the domain of LIBs are being carried out on a large scale in China, Japan, Europe, the USA and Korea. Several organisations in these geographies are producing raw materials, cells and batteries. The activity has grown prominently in China, with the policy support for EVs. A number of players have emerged in China and Korea for manufacturing of Li-ion cells. Large manufacturing capacities have been created by players like CATL, BYD, LG, Samsung and others. The raw materials required for manufacture of LIBs are naturally available but are concentrated in certain parts of the world. Therefore, research for reducing the content of these materials is being pursued worldwide by several organisations. India does not manufacture Li-ion cells and is reliant upon their import presently. For countries like India, those wish to have an ambitious programme for EVs and energy storage for grid storage and balancing, must establish domestic facilities for manufacture of Li-ion cells and packs. However, ensuring stable supplies on long-term basis of raw materials that are needed for manufacture of LIBs at a reasonable price would be a challenge. As recycling of materials of used LIBs is possible, it could be another option for securing supply critical materials. Infrastructure required for charging of EVs do require heavy investments. However, this requires augmentation of the existing basic electric network for transmission and distribution.

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CHAPTER 4: LITHIUM ION BATTERY: PRESENT STATUS OF MANUFACTURING IN INDIA AND PROJECTED GROWTH IN PRODUCTION

4.1 Introduction

The emergence of EV market is expected to be the major driver for new demand for LIBs in India. The other application segments *i.e.* energy storage systems for both commercial and residential applications which include energy storage for solar power plants, military, telecom, power tools, etc. account for the largest share of LIB market in India presently. The demand for energy storage for power generating plants harnessing variable renewable is expected to grow considerably with increasing share of renewable power in the power mix of India in the coming years. The EV market, from its current infancy, is expected to occupy an important position in the Indian automotive sector in view of various initiatives undertaken by the GoI for promotion of EVs. Recognising such opportunities for LIBs in the country, Indian industries have reacted in a positive manner and many of them have announced their plans to undertake manufacturing of LIBs and battery packs in India. Some of the major companies include Exide Industries Ltd., Amara Raja Batteries Ltd, Toshiba Corporation, and Tata Chemicals. In the last two years, there have been announcements and launches of EVs by some major automotive players like Tata Motors, M&M, Hyundai, Hero, Ather Energy, Bajaj, Ashok Leyland and others.

4.2 Present status of LIBs in India

Presently, there are no lithium ion cell manufacturing plants in India. Most of the lithium ion cells are imported from overseas (mostly China, Taiwan and South Korea) and assembled in the country. Around 1 GWh of battery assembly capacity exists in the country presently. India imported US$1.23 billion worth of LIBs during 2018-19, which was six times higher than imports in 2014-15. Current dependence on imports and likely demand for LIBs in the country has led the Indian government to create a policy framework to encourage setting up of manufacturing units for LIBs in the country. GoI approved a “National Mission on Transformative Mobility and Battery Storage” in March 2019. This mission envisages, a five-year Phased Manufacturing Programme (PMP) till 2024. The aim of this programme is to support setting up of large-scale, export-competitive GW-scale manufacturing plants in India. This will help the country to localise manufacturing of the entire EV value chain. In the proposed plan, domestic and overseas manufacturers can set up a part of the total targeted manufacturing capacity of 50 GWh for LIBs in the country. Financial incentives in the form of subsidies and duty cuts will be provided by the government for establishing these plants.

A list of LIB suppliers who are providing LIBs for EVs and storage applications in India is given in Table 4.1. It may be noted that the most of the listed companies mainly assemble batteries, while cells are imported. One company namely, Vrinda Lithium Ion Batteries, supplies materials *e.g*. lithium iron phosphate, lithium carbonate, lithium titanate, lithium acetate dihydrate, lithium hydroxide monohydrate etc. related to LIBs.

Table 4.1: Li-ion battery suppliers in India

Sr. No.	Company	Products related to LIB	Location
1	Amptek India	LIB pack, E bike battery, $LiFePO_4$ battery	Gurugram, Haryana
2	Bharat Power Solutions	LIB pack, $LiFePO_4$ batteries,	Noida, UP
3	Elecorev Energy	LIBs, EV battery pack, Battery management system	Ahmedabad, Gujarat
4	Explore Energies	EV battery pack and accessories, $LiFePO_4$ battery pack	New Delhi
5	Explore Synergy Synocare	LIB, EV battery, E-cycle battery	New Delhi
6	Future Hi-tech batteries	LIB pack, EV battery, chargers	Mohali, Punjab
7	Litihimax	LIB, EV battery, E-scooter battery	Thane, Maharashtra
8	Micromax Energy	$LiFePO_4$ battery pack, Lithium NMC pack	New Delhi
9	Okaya power	Lithium batteries	New Delhi
10	Pastiche Energy Solutions	$LiFePO_4$ battery, Battery pack	Panchkula, Haryana
11	Synergy Intact Pvt Ltd	LIB, $LiFePO_4$ battery	Mohali, Punjab
12	Vrinda Lithium ion batteries	LIB materials	Mumbai, Maharashtra

After the unveiling of NEMMP in 2013, a lot of encouraging steps have been taken up for implementation of the programme. First e-bus was launched in Bengaluru in 2014. Ashok Leyland launched its e-bus in October 2016. Tata Motors launched a pure e-bus (Starbus Electric 9m) and a hybrid (StarBus Electric 12m) EV in 2017. Himachal Pradesh Transport Corporation is running 25 e-buses from September 2017. First intercity e-bus of India was inaugurated on September 2019 which is running between Mumbai and Pune. Many two-wheeler and three-wheeler manufacturers are offering various models in India. These are available through various dealers in different cities as mentioned in Table 4.2.

Table 4.2: List of two, three and four wheelers (electric) manufacturers in India

2 – Wheelers manufacturers	22 KYMCO iFlow; Altigreen; Ather Energy; Atom Electric; Avan Motors; Avon Cycles; Bajaj; Emflux Electric; Evauto; Jitendra New EV; Menza Motors; Okinawa; Revolt Motors; Sun Mobility; Tork YO Xplor
3 – Wheelers manufacturers	Altigreen; Atul Auto; Hero; Kinetic green; Lohia; Mahindra; Scooters India Ltd.; Speedways Electric; Sun Mobility; Terra motors Vikram EV
4 – Wheelers and bus manufacturers	Ashok Leyland (buses); Force Motors; Hyundai (Kona EV); JBM (buses in association with Solaris); Mahindra (2 EV models); MG Hector (ZS EV); Olectra-BYD – (buses); PMI (buses); Sun Mobility (buses; Tata Motors (Tigor EV, Nexon EV and buses); VE Commercial Vehicles

4.3 EV Component and their manufacturers

The main components for EV are battery, motor, chargers, inverters etc. Due to surge in demand for EVs, Indian manufacturers along with their foreign collaborators are coming forward to improve the characteristics of EV component and this is also getting support from GoI in terms of subsidies. A list of LIB cells and EV manufacturers is shown in Table 4.3.

Table 4.3: EV Component manufacturers in Indian market

EV component	Manufacturer name	Key notes
Cells/Battery Packs	Mahindra & Mahindra	• Partnered with LG Chem to develop cells exclusively for Indian applications and expected to go into production line soon.
Cells/Battery Packs	Exicom	• Current deployment of 600 MWh in storage applications and plans to scale up capacity to 1 GWh
Battery Packs	Reliance	• The company is looking to establish 25 GWh Gigafactory in India at estimated investment of US$ 3.5 Billion
Motor	Borg Warner	• The company will invest in India when demand picks up
Motor	Hitachi	• Plans to sell technology to other customers as well with an investment of US$ 44.69 millions • Honda announced joint venture with Hitachi to design, develop and manufacture motors for future EVs
Motor	BHEL	• Signed an agreement with Ashok Leyland and Tata Motors for developing a propulsion system for buses
Chargers	Ather Grid	•Signed an agreement with Sanmina Corporation, a leading integrated manufacturing solutions company headquartered in San Jose, California • Manufactures slow AC home charger for their e-bikes and fast DC chargers for their public charging stations
Chargers	ABB	• A pilot 50 kW fast charger with nine OEMs installed in NITI Aayog premise & plans to setup 4,500 charging stations in India
Chargers	Exicom	• Installed AC and DC charger in MoP office, Delhi • 1,080 AC chargers of 3.3 kW and 100 DC fast chargers of 15 kW to be supplied for charging of Tata Motors' Tigor and Mahindra & Mahindra's eVerito cars being procured by EESL.

Chargers	Delta Electronics India	• Installed first 15 kW DC fast charger in Maharashtra and plans to invest US$150 Million in India
Chargers	BHEL	• BHEL and Delta to supply 100 DC chargers under EESL tender
Chargers	SBD Green Energy & Infra	• To supply 720 AC chargers under EESL tender

4.4 Forecast of LIB market in India

With focus on e-mobility in India, the LIB market is expected to grow rapidly in the next five years in the country. A number of organisations have projected the scenarios for growth of LIB market in India. As per the estimates of JMK Research and Analytics, LIB market in India is expected to increase from 2.9 GWh in 2018 to about 132 GWh by 2030. The market for LIBs in India is expected to grow at a CAGR of 34.8% during the forecast period of 2019 – 2024. As per a report by Avalon Consulting, India may reach EV sales volume of more than 1.6 million in FY23 (Figure 4.1). NITI Aayog report indicates that India's vision of a shared, electric, and connected mobility system could create a US$ 300 billion domestic market for EV batteries by 2030.

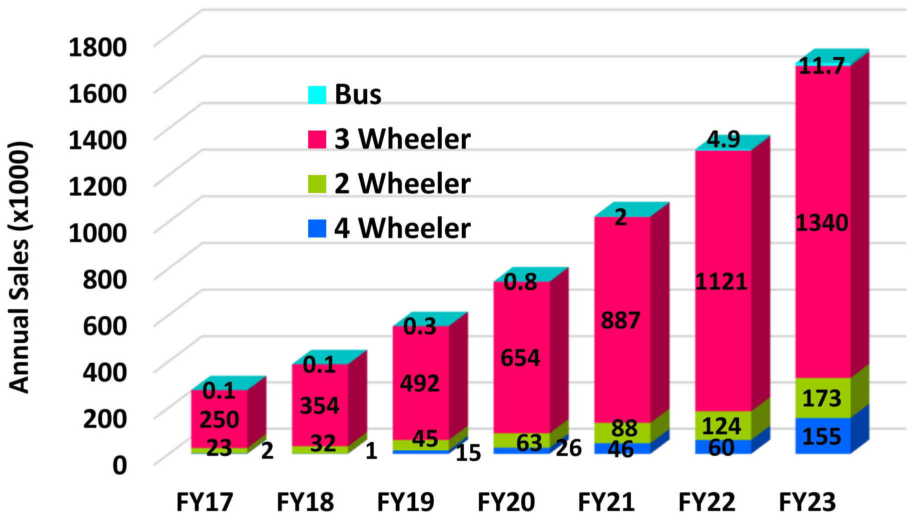

Fig. 4.1: Projected annual sales of EV in India

A report by European Union's Resource Efficiency Initiative (EU-REI) Project on "Towards Resource Efficient Electric Vehicle sector in India", year wise estimates of the share of EVs across the different categories of vehicles on Indian roads is given in the Fig. 4.2, which indicates a steady rise from few thousands to around 250 million vehicles by 2030.

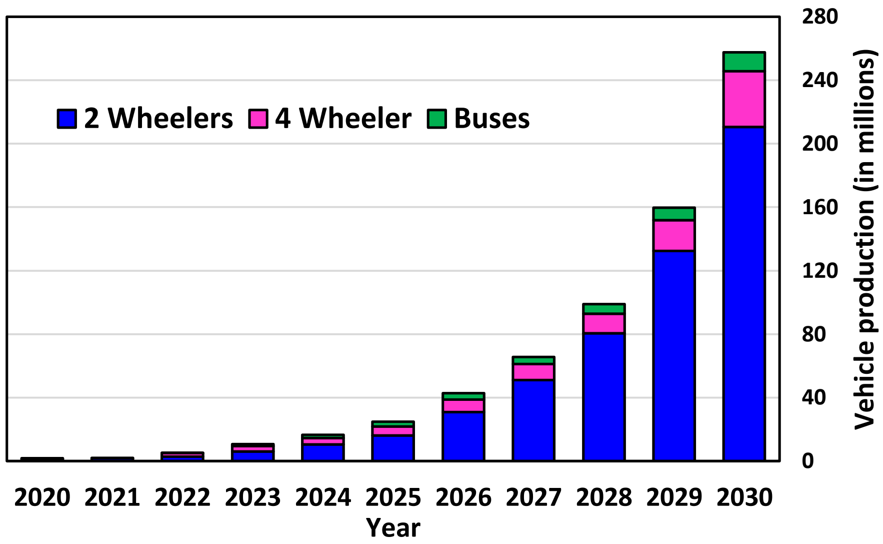

Fig. 4.2: Estimated share of electric vehicle production in India

In the report on "India's electric mobility transformation – Progress to date and future opportunities" by NITI Aayog & RM Institute, the EV sales penetration for various types of vehicles is projected to grow as shown in Fig 4.3. This report indicates that EV sales penetration of 70% for commercial cars, 30% for private cars, 40% for buses, and 80% for 2 and 3 wheelers could be attainable by 2030.

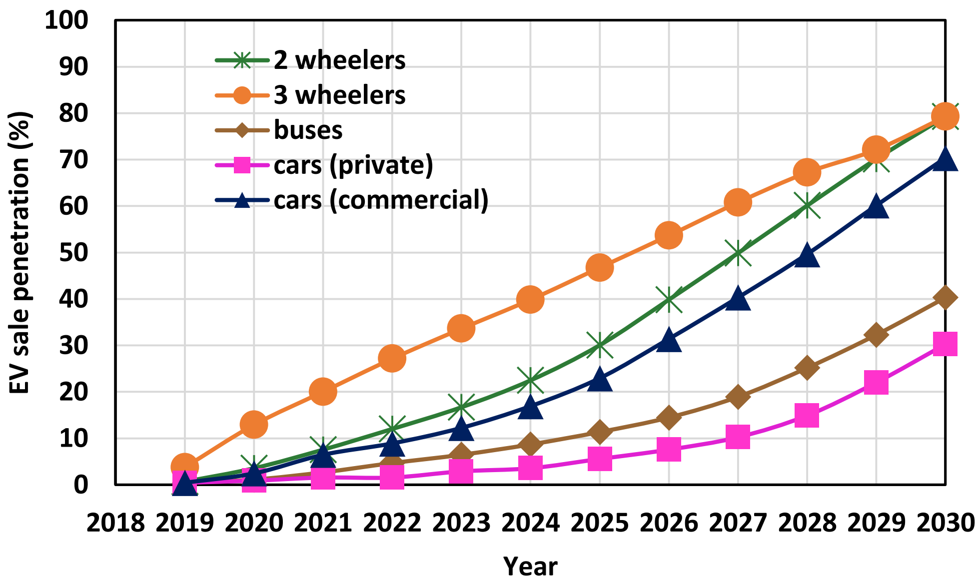

Fig. 4.3: Projected EV sales penetration for various types of vehicles

Another report on "Indigenisation of Lithium-ion Battery Manufacturing: A Techno-economic Feasibility Assessment" by Center for Study of Science Technology and Policy (CSTEP) estimates the energy storage demand for EVs and electricity grid in the country. The projections are indicated in Table 4.4.

Table 4.4: Projected energy storage demand in India by 2030

EV (considering 30% penetration by 2030)		
Transportation sector	Energy storage per vehicle	Energy storage requirement
2 wheelers: 200 million	1 – 2.7 kWh	200 – 540 GWh
4 wheelers: 40 million	10 – 20 kWh	400 – 800 GWh
Busses: 3 million	100 – 324 kWh	300 – 970 GWh
Energy storage demand for EVs in 2030	900 – 2300 GWh	
Energy storage demand in grid sector by 2030	22 GWh	

These projections have considered a 30% penetration of EVs for each type of vehicle to estimate the battery requirement. The storage requirement per vehicle was decided based on the NEMMP guidelines. Based on this approach the number of vehicles on the road by 2030 was estimated as 200 million electric two wheelers and 40 million electric four wheelers. Similarly, for grid-scale applications, the energy storage demand of 22 GWh was estimated in such a way that it would be able to provide 1–3 hours of power back-up. The scenario has assumed that Vehicle-to-Grid (V2G) technologies would mature to enable a large fleet of EVs to operate as virtual power plants. As indicated in the Table 4.4, the total battery demand is projected to be 922 GWh to 2322 GWh.

Table 4.5: Basic custom duty on CBU, SKD and CKD

Sr. No.	Item Description	Basic Custom Duty during FY 2019-20	Basic Custom Duty during FY 2020-21 (effective 1.4.2020)
1.	Completely Built Units (CBU) of electric commercial vehicles such as buses and trucks	25%	40%
2	Semi Knocked Down (SKD) forms of electric passenger Vehicles and three wheelers	15%	30%
3.	Semi Knocked Down (SKD) forms of EVs such as buses, trucks and three wheelers	15%	25%
4.	Completely Knocked Down (CKD) forms of EVs such as passenger vehicles, buses, trucks, three wheelers and two wheelers	10%	15%

4.5 Projected price of LIBs based on domestic production and imports

In order to promote domestic manufacturing of LIBs in the country, GoI has notified a phased increase in basic customs duty on imported lithium-ion cells and packs in March 2019. In this notification, GoI has imposed custom duty on the import of LIBs. In 2019-20, the Basic Custom Duty (BCD) applicable on Li ion cells and battery packs is 5%, which will increase to 10% for Li-ion cells and 15% for battery packs from 1st April 2021. In addition, on some of the parts such as motors, charger, controllers etc. required for manufacturing of EVs will also attract BCD @ 15% w.e.f. 1st April 2021, whereas on such components "Nil" BCD is levied presently. In addition, to give further push to make in India, the BCD on Completely Built Units (CBU), Semi Knocked Down (SKD) units and Completely Knocked Down Units (CKD) forms of EVs is also proposed to be increased as per details given in Table 4.5.

Therefore, the impact of increase in cost of LIBs due to increase in custom duty rate has been studied, if BCD is increased annually by 5% and a constant IGST of 28%. The impact of increase in the custom duty on imported LIB on cost of LIBs is shown in Fig 4.4.

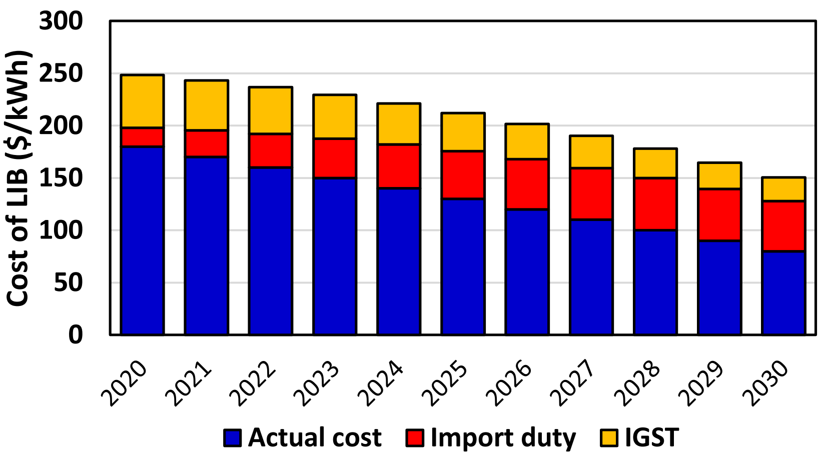

Fig. 4.4: Impact of custom duty and IGST on Cost of LIB

CSTEP has also estimated the cost of LIBs if they are built indigenously in the country. According to their estimation, the cost of LIBs, manufactured in a 50 GWh plant, will be around US$ 148/kWh without considering any subsidies from the GoI (Fig. 4.5). However,

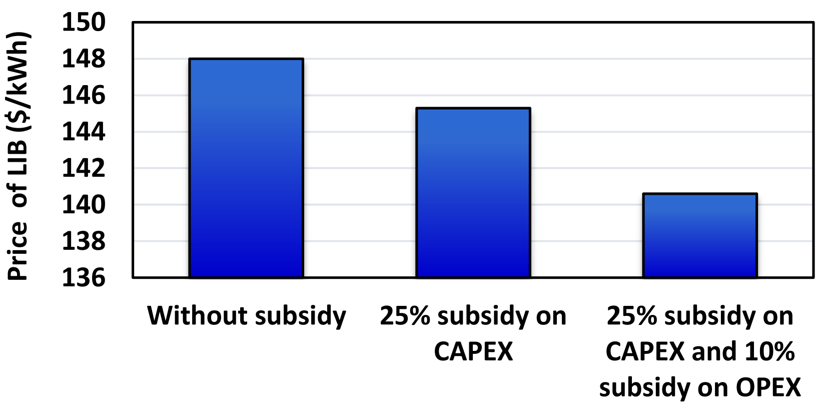

Fig. 4.5: Estimated Cost of indigenously manufactured LIB in India

considering subsidy on capital expenditure (CAPEX) and operating expenses (OPEX), as announced by GoI, the cost of LIBs will reduce. It has also been estimated that battery costs will decrease with the increment in the production capacities. According to this estimation, for a 200 GWh plant, the cost of the batteries will be as low as US$84/kWh considering CAPEX and OPEX subsidies.

4.6 Indian EV policy

India's NITI Aayog proposes to push for full conversion to EVs from ICE for three-wheelers by 2023 and two-wheelers (for engines with or below 150 cc capacity) by 2025. To complement this thrust of GoI, 10 States and Union Territories have published draft or final policies for EVs aligned with the economic and demographic realities of each region. Policies continue to have a major influence on the adaption of EVs. Several Ministries and Departments of GoI have been supporting the electric mobility transition, including the Ministry of Road Transport and Highways (MoRTH), Department of Heavy Industry (DHI), Department of Industrial Policy and Promotion (DIPP), Ministry of Finance (MoF), Ministry of Housing and Urban Affairs (MoHUA), Ministry of Power (MoP) and Department of Science and Technology (DST). The Ministries/Departments of GoI have announced various policies in support of transition to e-mobility. Table 4.6 summarises the policies of various Ministries/ Departments to give a boost to the efforts directed at making transition towards e-mobility.

Table 4.6: Policy measures undertaken by the Ministries and Departments of GoI for promotion of e-mobility

Organisation	Policy
MoP	Charging EVs will be considered as service; therefore, **no license is required to operate EV charging stations**. The policy permits private charging at residences and offices.
MoRTH	Battery-operated vehicles, both private and commercial, will be given **green license plates** (GSR 749 (E)). All battery-operated transport vehicles will be **exempted from the requirement of permits** (S.O. 5333). **Licenses to be given for age group 16–18 years** to drive gearless electric scooters and bikes up to 4 kWh battery size (GSR 1225 (E)).
DST	Launched a **Grand Challenge for developing the Indian Standards** for Electric Vehicle Charging Infrastructure.
ISRO	Ten firms have been shortlisted for **commercialization of indigenously developed LIB technology** on transfer of technology.
MoHUA	Released an **amendment of building code and town planning rules for provisioning of EV charging stations** in private and commercial buildings.

NITI Aayog	Released a concessionaire Agreement for public private partnership in operation and maintenance of electric buses in cities through Operating Expenditure (OPEX) model. The **National Mission on Transformative Mobility and Battery Storage** aims at creation of a **Phased Manufacturing Programme (PMP)** for five years: support to set up of **large-scale cell-manufacturing plants in India**.
MoF	**Rationalized the customs duty** for all categories of vehicles, battery packs and cells to support Make in India and incentivize uptake of EVs
DHI	Faster Adoption and Manufacturing of (Hybrid &) Electric vehicles second phase [**FAME II**] has been approved with a total outlay of ₹ 10,000 crores on the purchase of EVs and to support the development of charging infrastructure.

As a part of creating coherent policy on transformative mobility in the country, 27 states have formulated strategies for transforming their mobility systems and several states have formulated or are in the process of formulating their EV policies. The policies announced by various states of India are summarised in Table 4.7.

Table 4.7: EV policies of some states in India

State	Key policy elements
Andhra Pradesh	10 lakh EVs by 2024, 1 lakh slow and fast EV charging stations by 2024
NCT of Delhi	25% of new vehicle registrations to be electric by 2023, 50% of entire public transport targeted to be electric by 2023
Karnataka	100% of three and four-wheelers used for moving goods - transition to be electric by 2030, Incentives for first 100 fast chargers
Kerala	1 million EVs in the state by 2022; 2,00,000 two-wheelers, 50,000 three-wheelers, 1,000 goods carriers, 3,000 buses and 100 ferry boats by 2022
Maharashtra	EV registrations in Maharashtra to be 5 lakh; ₹ 25,000 crore investment for the manufacturing of EVs
Telangana	100% electric buses by 2030 for intra-city, intercity and interstate transport, first 100 fast charging stations in Hyderabad municipality and other cities in a phased manner.
Uttar Pradesh	1,000 electric buses deployed in the state by 2030, 100% electrification of auto rickshaws, cabs, school buses/vans, etc., by 2030 in five cities: GB Nagar, Lucknow, Kanpur, Varanasi and Ghaziabad
Uttarakhand	Developing green highways in Dehradun, Haridwar, Rishikesh, Haldwani, Rudrapur and Kashipur, Term loans of ₹ 100 million to ₹ 500 million will be provided in manufacturing EVs

4.7 Recycling of LIBs in India

The global consumption of LIB raw materials (e.g. cobalt, lithium, and copper) is expected to increase by 20 times by 2030. Known reserves of these raw materials are confined to selected regions of the world and mostly located outside India. Also, most of these metals are hazardous to human health as well as nature. Therefore, it will be a better policy to recycle the used LIBs to reclaim these precious metals for LIB manufacturing. In addition, "second life use" of EV batteries for other applications such as in households or energy backups may also be considered. Recycling in a closed-loop process gives an opportunity to minimise the cost of the batteries as well as waste of these precious metals. There are mainly three developed industrially closed loop recycling process:

(a) Mechanical process - crushing and physical separation and recovery of each component.
(b) Pyro-Metallurgical – recovery at high temperature by loading batteries directly into furnaces.
(c) Hydrometallurgical – recovery after mechanical pre-treatment using chemical processes.

Effectiveness of these processes has been tested for separation of the metals from used batteries and the obtained results are given in Table 4.8.

Table 4.8: Percentage of LIB materials recovered using various industrial processes

Material	**Pyrometallurgical & Hydrometallurgical**	**Hydrometallurgical**	**Pyrometallurgical**
Battery type	**NMC & LFP**	**NMC**	**LFP**
Lithium	57	94	81
Nickel	95	97	NA
Manganese	0	~ 100	NA
Cobalt	94	~ 100	NA

Currently, various companies [*e.g.* Sony, Nippon (Japan), Inmetco (USA), Retriev (Canada), Dusenfeld, Accurec (Germany), SNAM, Recupyl (France), Brunp, GEM, Anhua – Taisen (China)] are recycling spent batteries worldwide using these techniques. The recycling market of LIBs materials in India offers an estimated US$1000 million business opportunity by 2030. Few Indian companies (Tata Chemicals, Raasi Solar and Mahindra Electric etc.) have already planned to venture in the recycling market. Tata Chemicals is reported to have successfully carried out LIB recycling operations in Mumbai. A 300 MWh plant on LIB recycling along with battery assembling and cell manufacturing will be set up by Raasi Solar. Mahindra Electric is also keen to set up EV battery recycling process plant.

4.7.1 Second Life Use of Lithium Ion Battery

Second life is a term used when a battery after the end of its first life (e.g. EV) is collected and refurbished before putting it back to use in another application (e.g. stationary telecom tower) where it can still serve the intended purpose. Life cycle of a battery for vehicle application is reported to be approximately 500-2000 cycles (equivalent to cumulative 1.30 lakh to 5 lakh km of operation). After about 10 years in a vehicle, LIB can be reused for another purpose and thereby begin a "second life". Second life reduces the GHG emission impact by ~15% (Fig. 4.6).

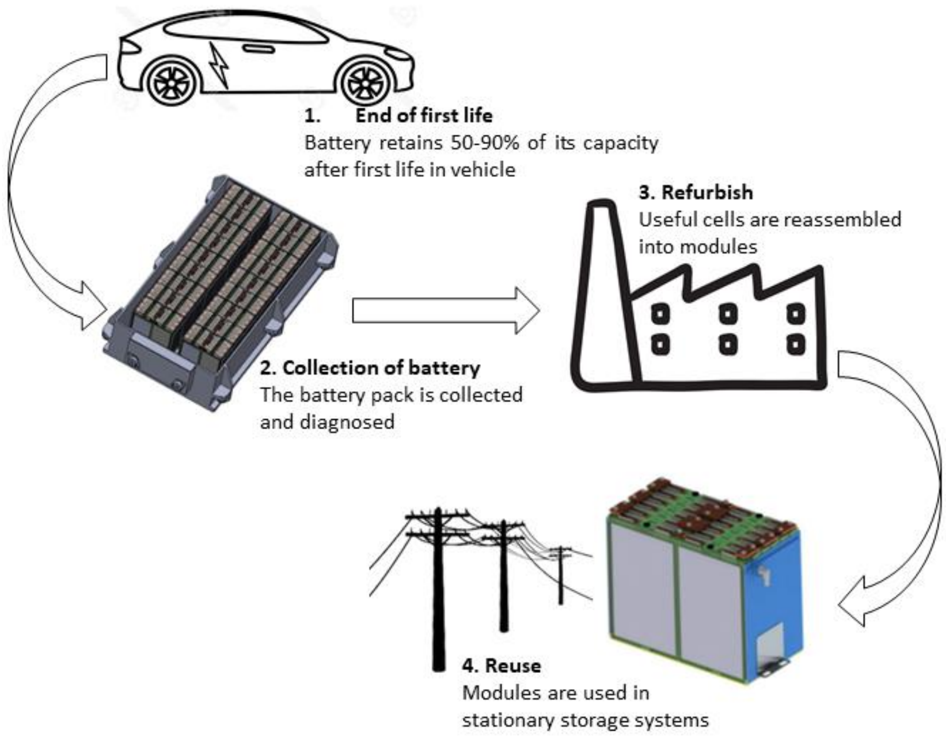

Fig. 4.6: Second life of lithium ion battery

4.8 Forthcoming projects in India based on public domain news

Considering the importance that the LIBs have assumed around the world, a lot of activities by the Indian companies and research organisations have come to notice. There are public announcements from several companies in this connection, which are mentioned below:

a. M&M announced its plans to manufacture all key components that go into EVs, including LIB solutions in collaboration with LG Chem.

b. Tata Chemicals has announced plans to set up a manufacturing plant for LIB in the state of Gujarat. The company has signed MoUs with CSIR-CECRI and ISRO.

c. Amara Raja plans to set up a pilot plant to assemble battery packs with Lithium technology for electric two-wheeler and three-wheeler vehicle segments.

d. Tata Autocomp has announced and started making battery packs for EVs under collaboration with a Chinese company Guoxuan Hi-Tech.

e. ARCI-Center for Automotive Energy Research has announced the scale up and testing of LIB pilot plant facility set up at IITM- Research Park.
f. CECRI- Chennai and Karaikudi units are working on various aspects of LIBs chemistry. CSIR-CECRI has developed indigenous fabrication technology for 18650 cells and pouch cells. It is the India's first pilot plant facility which will manufacture the Li-ion cells with a capacity of 1500 mAh/3.7 V and is dedicating its efforts to improve capacity of LIB.
g. Exide Industries is investing ₹ 1100 crore for manufacturing LIB in Gujarat, by 2019-20.
h. Suzuki has announced its plans to set up a LIB manufacturing plant in Gujarat in a joint venture with Toshiba and Denso.
i. BHEL is expected to set up a production plant with support from ISRO. BHEL is in discussion with an Australia-based company Libcoin to build a 1 GWh LIB plant. The manufacturing capacity may be scaled up to 30 GWh in future.
j. Raasi solar power and CSIR-CECRI have signed a MoU for the transfer of technology for LIB project. The plant is going to be set up in Tamil Nadu.
k. Adani Group will invest into an "integrated lithium battery manufacturing complex" in Gujarat.
l. Bajaj Auto plans to localise two-wheeler Chetak's Lithium Battery Assembly in Pune, Maharashtra and has expressed interest in setting up LIB plant.
m. ISRO has selected ten companies for transfer of its Lithium-ion cell technology.
n. Livguard Energy Technologies has invested US$20 million for setting up a LIB assembly unit in Manesar, Haryana.

4.9 Conclusions

It can be safely concluded based on the information contained in this Chapter that demand for LIBs is likely to increase significantly for EVs and other energy storage applications in India in near future. This is corroborated by the amount of interest shown by the industry in pronouncing their plans on this matter. In the Indian context, the challenge would be securing supply of raw materials required for manufacturing LIB batteries on long term basis and develop strategies for recycling of materials from used batteries to reduce dependence on import of raw materials. A critical issue would be to produce LIB battery cells and packs at an economical and competitive cost in India and thereby ward off the Indian industry from the onslaught of the international suppliers who would be able to supply such batteries at lower cost. It would also be imperative to establish infrastructure for manufacturing of the entire value chain for LIBs in the country at the earliest to enable Indian industry to be benefitted from rapidly expanding market for LIBs and EVs. The lessons learnt from deployment of predominantly imported solar photovoltaic panel based power plants in India on a large scale be taken into consideration for encouraging manufacturing of LIBs in India at a cost competitive price need, though GoI has announced policy measures in this regard.

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CHAPTER 5: HYDROGEN PRODUCTION, STORAGE AND ITS AVAILABILITY FOR TRANSPORT SECTOR IN INDIA

5.1 Introduction

Hydrogen is a versatile energy carrier and feedstock for a variety of industrial applications. It has been used in ammonia-based fertiliser synthesis and oil refining since mid-20th century. The four major industrial applications of hydrogen are oil refining and production of ammonia, methanol and steel.

5.1.1 Global Hydrogen Demand

Global demand of hydrogen gas has grown by more than three-fold since 1975 and was more than 70 MMT during 2018 (Fig. 5.1). It has been estimated that hydrogen demand in refineries will grow by 7% and reach 41 MMT by 2030.

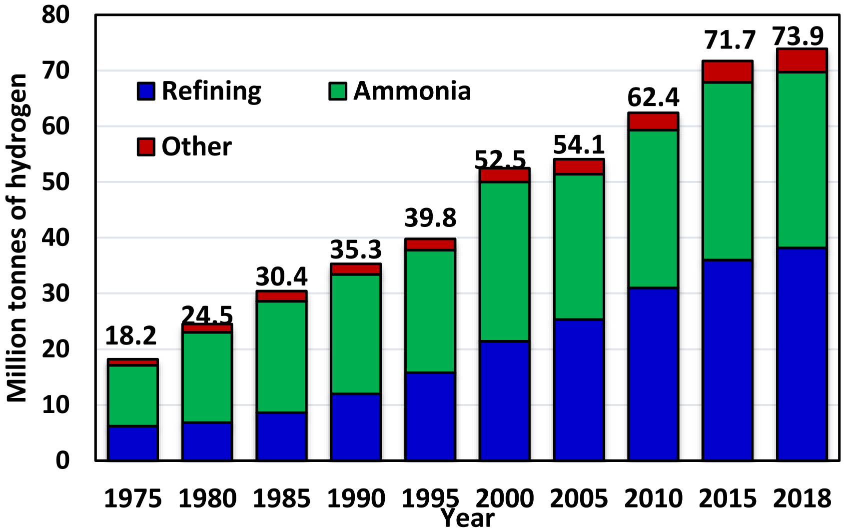

Fig. 5.1: Global hydrogen demand in various sectors during 1975-2018

In chemical industry, most of hydrogen gas is used as feedstock for ammonia and methanol production. Around 31 MMT of hydrogen was consumed in 2018 for ammonia synthesis. Most of the synthesised ammonia (80%) is used to produce fertilisers (urea, ammonium nitrate/phosphate etc.). A small amount of hydrogen is also used in some other chemical synthesis such as polymers (ethylene, propylene) and solvents (benzene, toluene) etc. Other applications of hydrogen are in glass, semiconductor, synthetic fuel and food processing industries.

5.1.2 Hydrogen Production and Demand in India

Hydrogen market in India was valued at US$ 50 million in 2017, and is expected to reach US$81 million by 2025, growing at a CAGR of 6.3% from 2018 to 2025. The data for hydrogen demand and production for India is not available in a consolidated form. It has been estimated for the major consumers and producers of hydrogen in India. About 25.6 lakh MT of hydrogen was estimated to have been consumed to produce 242.51 lakh MT of urea during 2017-2018.

Table 5.1: Hydrogen Production Capacity of Chlor-Alkali Units in India as 31.3.2017

Sr. No.	Name of Corporate	CS Installed Capacity (MT/year)	Hydrogen Capacity (kg)
1	Atul Ltd. Valsad, Gujarat	38,325	9,64,498
2	Century Rayon, Thane, Maharashtra	22,500	5,66,241
3	Chemfab Alkalis Ltd., Kalapet, Puducherry	42,000	10,56,984
4	Chemplast Sanmar Ltd., (Karaikal & Puducherry)	1,12,200	28,23,656
5	DCM Shriram Ltd., (Jhagadia & Kota)	4,59,250	1,15,57,613
6	DCW Ltd., Sahupuram, Tamil Nadu	1,00,000	25,16,628
7	Durgapur Chemicals Ltd., Durgapur, West Bengal	33,000	8,30,487
8	Grasim Industries Ltd., (Ganjam, Karwar, Nagda, Rehla, Renukoot, Veraval, Vilayat)	9,31,410	2,34,40,122
9	Gujarat Alkalies & Chemicals, (Dahej & Vadodara)	4,29,050	1,07,97,591
10	Gujarat Fluorochemicals Ltd., Dahej, Gujarat	1,46,000	36,74,276
11	Hindustan Paper Corpn. Ltd., (Cachar & Nagaon), Assam	-	-
12	Lords Chloro Alkali Ltd., Alwar, Rajasthan	90,729	22,83,311
13	Meghmani Finechem Ltd., Dahej, Gujarat	1,66,600	41,92,702
14	Nirma Ltd., Bhavnagar, Gujarat	2,05,200	51,64,120
15	Orient Paper Mills (CS Unit), Amlai, M.P.	40,250	10,12,943
16	Punjab Alkalies & Chemicals Ltd., Naya-Nangal, Punjab	99,000	24,91,461
17	Reliance Industries Ltd., Dahej, Gujarat	1,68,150	42,31,710
18	Siel Chemical Complex (A Unit of Mawana Sugars Ltd.), Rajpura, Punjab	82,500	20,76,218
19	Sree Rayalaseema Alkalies & Allied Chemicals, Kurnool, AP.	1,56,950	39,49,847
20	Tamilnadu Petroproducts Ltd., Manali, Tamil Nadu	56,100	14,11,828
21	Tata Chemicals Ltd., Mithapur, Gujarat	36,000	9,05,986
22	The Andhra Sugars Ltd., Saggonda, A.P.	1,32,000	33,21,949
23	The Travancore-Cochin Chemicals Ltd., Kochi, Kerala	57,750	14,53,353
24	UPL Limited., Jhagadia, Gujarat	56,940	14,32,968
	TOTAL	**36,61,904**	**9,21,56,491**

There are 23 petroleum refineries in India, which are located in Bathinda, Barauni, Bina, Bongaigaon, Digboi, Guwahati, Haldia, Jamnagar, Kochi, Koyali, Manali, Mangalore, Mathura, Mumbai, Nagapattnam, Numaligarh, Panipat, Paradip, Tatipaka, Vadinar, and Vishakhapatnam. All these petroleum refineries have hydrogen production facilities of 0.4 – 1 lakh MT/annum with total hydrogen production capacity of about 30 lakh MT from over 40 production facilities and these can easily meet demand and supply of hydrogen for various applications. Many of these refineries have some surplus capacities presently. Even a small fraction of 0.025 of the total hydrogen production capacity from petroleum refineries, if spared would be able to provide one lakh MT of hydrogen annually for vehicular and other applications.

There are 31 chlor-alkali units (Table 5.1) in the country with installed production capacity of 36.62 lakh MT/year of caustic soda (sodium hydroxide) as on 31.3.2017 with projection of about 10% increase in installed production capacity during 2017-18, as per Alkali Manufacturers Association of India (AMAI). The actual production of caustic soda during 2016-17 was 30.23 lakh MT with operating efficiency of 82.5%. Considering by-product hydrogen production rate of 289 Nm^3/MT of caustic soda, the rated hydrogen production capacity during 2016-17 from the chlor-alkali units was 0.92 lakh MT and the actual production was 0.76 lakh MT. The rated hydrogen production capacity would have increased to 1.01 lakh MT as on 31.3.2018 and with operating efficiency at the same level as 2016-17, the actual production of hydrogen during 2017-18 was estimated at 0.84 lakh MT.

Demand for hydrogen in India is likely to increase substantially in the near future for the existing industrial applications and also for emerging applications in transport and stationary power generation.

5.2 Hydrogen Production Methods

Hydrogen can be produced from a variety of carbonaceous feed stocks and/or water using a variety of technologies. Coal, natural gas, petroleum fractions and biomass can be converted to hydrogen through pyrolysis/gasification and reforming using several technologies like steam methane reforming, partial oxidation/auto-thermal reforming as depicted in Fig. 5.2. Globally, about 95 % of the current hydrogen requirement is met from fossil fuel sources. These hydrogen production technologies are discussed briefly in the following sections.

5.2.1 Steam Methane Reforming (SMR)

Industrially, most of hydrogen is produced by the SMR process. In SMR process, initially syngas ($CO + H_2$) is produced which is followed by water gas shift reaction to generate further quantities of hydrogen. Typically, efficiency of SMR process is 70-85%. In this process, around

9 to 12 tonnes of carbon dioxide is produced (depending upon the quality of feedstock) per tonne of hydrogen.

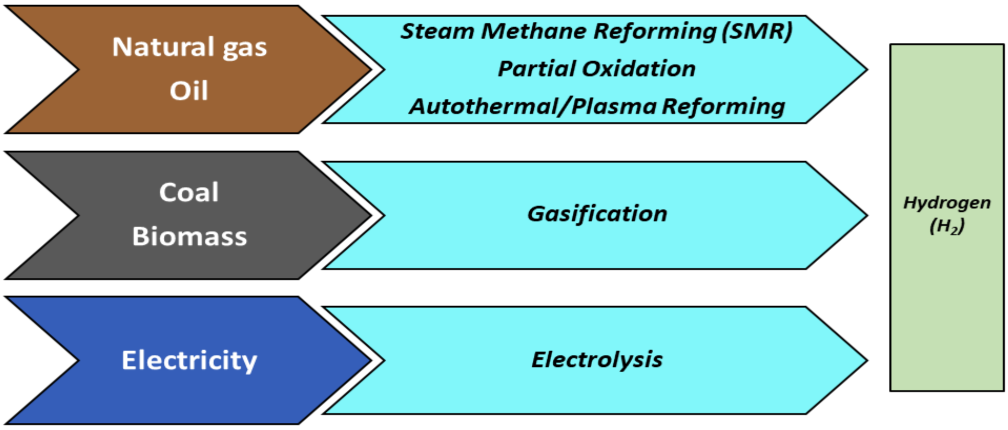

Fig 5.2: Industrial hydrogen production methods

5.2.2 Partial Oxidation

Natural gas and other heavy hydrocarbons usually furnace oil, whose further treatment and utilisation is difficult, are used to produce syngas using limited amount of oxygen. The thermal efficiency of this process is generally 60-75%. This process also releases a substantial amount of GHGs.

5.2.3 Coal gasification

In coal gasification process, steam and a carefully controlled concentration of air/oxygen is used to burn coal to form syngas. This process is known for the last couple of centuries and was used to produce "town gas" or "coal gas" for municipal lighting and heating purposes. It has been estimated that around 25% of the world's ammonia and more than 30% of the world's methanol are being produced via gasification process presently. Typical thermal efficiency of this process is 35-50%. The process for hydrogen production from biomass gasification is similar to coal gasification.

5.2.4 Petroleum coke gasification

Petroleum coke can also be used to produce hydrogen rich syngas using similar process as coal gasification. However, the syngas obtained from the petroleum coke gasification is a mixture of H_2, CO and hydrogen sulphide (H_2S) gas.

5.2.5 Electrolysis

Electricity can be used to split water in an electrolyser to produce hydrogen gas. Globally about 4% of hydrogen is produced by electrolysis. Conversion efficiency of electrolysis is around 52-69% which is expected to reach up to 80% by 2030.

There are three main types of electrolyser cells *i.e.* alkaline electrolysis cells (AECs), polymer electrolyte membrane cells (PEM) and solid oxide electrolyser cells (SOECs). These electrolysers function in slightly different ways, mainly due to the different type of electrolyte materials involved. Alkaline electrolyser is a proven and well-developed technology. PEM electrolysis cells are commercially available and their acceptance is increasing due to their smaller footprint. SOECs are in developing stages and operate at high temperatures (800°C). Hydrogen produced via electrolysis can be absolutely green, depending on the source of the electricity used. The basic materials and state-of-the-art operating conditions of the three types of electrolysers are shown in Table 5.2.

Table 5.2: Comparison of different types of electrolysers

Attribute	Electrolyser Type		
	Alkaline	PEM cell	SOEC
Status	Well established	Established	Developing
Electrolyte	KOH/NaOH	Polymer	Y_2O_3 doped ZrO_2
Cell temperature	60-80°C	50-80°C	700-800°C
Stack pressure	<30 bar	<30bar	-
Cell voltage efficiency	52-69%	57-69%	-
System lifetime	20-30 years	10-20 years	-

5.3 Sustainable hydrogen production

The current hydrogen production methods based on fossil fuels are responsible for emission of around 830 MT of CO_2 annually**.** For sustainable hydrogen production, the energy and feed stocks used ought to be renewable in nature. Also, the method of hydrogen production must be cost-effective.

Ideally, generation of hydrogen using renewable sources such as solar and wind should be the preferred option. Solar light and heat both can be used directly or indirectly to produce hydrogen using various processes such as: electrolysis, thermolysis, photolysis, thermo-chemical and biological conversion (Fig. 5.3).

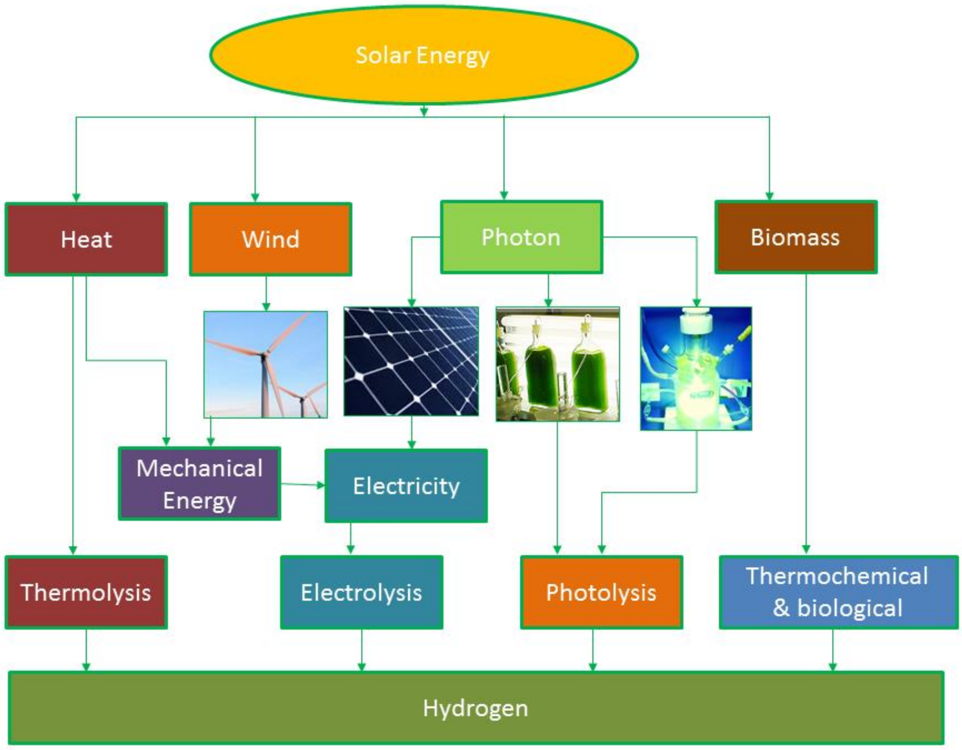

Fig. 5.3: Renewable hydrogen production methods from solar energy

Electrolytic hydrogen generation by splitting water using solar or wind generated electricity is the only green and established technology to produce hydrogen in large quantities without any greenhouse gas emission.

Hydrogen generation using solar thermal energy could possibly be the most efficient solar path. But this technology is in development state presently.

Photo-electro-chemical water splitting is a promising technology, which is under development and is capable of splitting water for hydrogen production in a single step instead of two step process involved in a typical SPV system. Organisms containing hydrogenase enzyme (e.g. cyanobacteria and green algae) can be used to produce hydrogen without any input or output of carbon-based molecules. Both technologies are in the development stage.

The solar energy stored in biomass could be converted to hydrogen gas using various processes such as: gasification, pyrolysis, and fermentation. These processes could also be used to produce hydrogen from waste materials (e.g. sewage, cellulosic biomass). Thus, solar energy can be used to produce hydrogen in the form of heat (thermo-chemical), light (photo-chemical) or electricity (electrolysis).

5.3.1 All hydrogen production processes involve consumption of water in varying quantities. The maximum theoretical water consumption would be about 9 kg of water for producing 1 kg of hydrogen through electrolysis process. However, it may be feasible to use brackish water for hydrogen production through electrolysis route. Therefore, requirement of water for hydrogen production will have to be considered while developing any project for hydrogen production.

5.4 Potential use of hydrogen in different sectors – power, transport and household

Hydrogen has the potential to be used in the transport, buildings, iron and steel production and power sectors, if the costs of production and utilisation processes become favourable relative to the available options.

5.4.1 Power sector

There is a huge potential for use of hydrogen in power sector for electricity generation using fuel cells, conventional ICE, hydrogen-fired gas turbines and combined-cycle gas turbines. In the current gas turbine technology, gas mixture containing 3-5% hydrogen could be used. A successful demonstration of using maximum of 30% hydrogen gas mixture in a modified gas turbine was performed by Mitsubishi Hitachi Power Systems. The power industry is highly confident that gas turbines entirely run on hydrogen could be developed by 2030.

FCs are versatile and can also be used for power generation. In the last ten years, several stationary FCs have been installed for power generation with current global installed capacity of around 1.6 GW. The FC units have been mostly installed in Japan, Germany, Korea and the United States. Japan aims to reach 1 GW of power generating capacity based on hydrogen by 2030. Korea has a goal of 1.5 GW installed FC capacity in the power sector by 2022 and 15 GW by 2040. Hydrogen is an excellent energy storage medium with variable renewable power generation systems based on solar and wind and FC using stored hydrogen could be used for power generation, depending on needs.

5.4.2 Transport sector

Currently, EVs and HFVs are the only options with no GHG emissions at use point as the energy carriers used for their operation can be generated using renewable sources. HFVs offer similar driving range and lower refuelling time as available with fossil fuel-based IC engine vehicles (ICEV). The potential of hydrogen in transport sector is huge and different types of vehicles can be powered by either FC or HICE technologies. It has been estimated that about 300 MT H_2/year of hydrogen will be needed, if all current vehicles are completely replaced by hydrogen economy. Nevertheless, high cost of hydrogen and FCs and technical/infrastructure challenges associated with hydrogen production, transportation and storage are inhibiting introduction of HFVs and their rapid market deployment. Hydrogen could also be used in the maritime sector. Around 2.5% of global energy-related CO_2 emissions are caused by the maritime freight. Rail sector is mostly run by electricity and alternative fuels could be used instead of diesel in those portions of the tracks where electrification is difficult. Germany is already using two hydrogen FC trains which can travel 800 km/day on a single refuelling and they intend to run 14 such trains by 2021. Austria, France, Japan and UK have plans to deploy hydrogen trains by 2022. For operation of material handling equipment like forklifts, hydrogen has already emerged as an attractive option in the USA. Hydrogen could also be used in future for other rail yard and logistics hub machinery. Aviation sector is responsible for around 2.8% of global CO_2 emissions (2017) and it will increase further. Alternative fuels such as biofuels and hydrogen are among the best options to avoid increase in emissions from this sector. Although, feasibility tests and demonstration have been performed for using hydrogen in small planes, significant R&D on refuelling, storage infrastructure and aircraft design are needed to use 100% hydrogen fuelled engine in the aviation sector. Hydrogen-based liquid fuel could be used in the current aircrafts with a little or no modifications.

5.4.3 Household applications

Natural gas is the current source for heating in buildings and a huge amount of gas is consumed every year. Hydrogen could be blended in existing natural gas networks for heating of buildings. Local district energy networks could also use hydrogen for cooling or heating their building networks. In fact, complete use of hydrogen in household applications such as cooking, heating, cooling etc. could significantly reduce environmental impact, caused by current use of fossil fuels.

5.4.4 Iron and Steel Production

Iron and Steel plants produce a large quantity of hydrogen mixed with other gases such as coke oven gas, which are largely used within the iron and steel plants. These gases are produced by reformation of fossil fuels. Efforts are underway to make use of hydrogen in iron and steel industry as a reducing agent in place of carbon monoxide. Commercial steel plants making use of hydrogen are likely to become operational within a decade.

5.5 R&D in India on hydrogen production

With a view to develop sustainable hydrogen production technologies based on renewable energy sources, GoI has been supporting R&D activities at academic institutions ranging from IITs and Universities, Council of Scientific and Industrial Research (CSIR) laboratories, public and private research organisations for more than two decades. These efforts got momentum after NHER was prepared in 2005. Some notable efforts made by the different organisations related to R&D of hydrogen production in the country are mentioned in this section.

In the area of hydrogen production from carbonaceous feed stocks, the Indian Institute of Chemical Technology (IICT), Hyderabad designed and developed a methanol reformer to produce around 10,000 L/h hydrogen for coupling with 10 kW FC. Central Institute of Mining and Fuel Research (CIMFR), Dhanbad developed a novel process to produce hydrogen from renewable and fossil fuel-based liquids (soybean oil, methanol and ethanol) and gaseous hydrocarbons by non-thermal plasma reformation technique. IIT Hyderabad worked for transforming greenhouse gases like methane and CO_2 into syngas/H_2 by low temperature plasma catalysis.

Indian Institute of Science (IISc), Bangalore developed a process for oxy-steam gasification of biomass for hydrogen production with hydrogen yield of about 100 g/kg of biomass. National Institute of Technologies (NITs), Calicut and Rourkela also made efforts in the area of hydrogen production through biomass gasification. It is worth noting that India generates 683 MMT of dry biomass every year, of which only 178 MMT (26%) was found to be surplus. This has estimated potential to produce 15-17 MMT of hydrogen through biomass gasification route.

As mentioned earlier, water electrolysers are going to play an important role for sustainable hydrogen production by utilising renewable energies. In this direction, Bhabha Atomic Research Centre (BARC) has developed water electrolysers up to 30 Nm^3/h capacity with high current density based on indigenously developed advanced electrolytic modules incorporating porous nickel electrodes. It is learnt that the technology has been transferred to an industry for commercialisation. While, Energy Research and Development Association

(ERDA), Vadadora has demonstrated the concept of utilising electricity generated by small wind turbines for hydrogen generation using commercial alkaline water electrolyser (AWE) , NISE, Gwal Pahari, Gurugram has utilised solar photovoltaic systems for production of hydrogen using an AWE. CSIR- CECRI has developed a PEM based water electrolyser system and the know-how has been transferred to an industry. SPIC Science Foundation (SSF), Chennai and Centre for Fuel Cell Technology (CFCT), Chennai developed PEM based water electrolysers for hydrogen generation using water-methanol as a feedstock instead of water. Jawaharlal Nehru Technological University (JNTU), Hyderabad has also developed indigenous PEM based water electrolyser. R&D Centre of IOCL at Faridabad is producing hydrogen by using a PEM based water electrolysis unit.

In India, first dedicated pilot-scale bio-hydrogen production unit using distillery effluent was installed by Shri AMM Murugappa Chettiar Research Centre (MCRC) at Nellikuppam, Tamil Nadu. IIT Kharagpur along with five other organisations explored hydrogen production through dark and photo fermentation routes and installed two pilot bioreactors of 10 Nm^3 capacity each at IIT Kharagpur and IICT, Hyderabad using distillery effluent and kitchen waste respectively for delivering about 30-50 Nm^3/day of hydrogen. IIT Kharagpur has also transferred the technology for industrial application. Indian Association for the Cultivation of Science (IACS), Kolkata undertook basic research for development of bio inspired catalysts that would efficiently catalyse hydrogen evolution reaction in water splitting process.

In the area of thermo-chemical hydrogen production using solar and nuclear heat, a number of cycles have been developed globally. High temperature reactor-based Iodine-Sulphur (I-S) thermo-chemical cycle offers a promising approach to the high efficiency production of large volumes of hydrogen from water. In this direction, BARC has initiated the efforts and made some progress so far. BARC is also engaged on studying various aspects of 3-step Copper Chlorine (Cu-Cl) cycle for hydrogen production. Thermo-chemical hydrogen production using waste heat from nuclear reactors may emerge as an inexpensive method for producing large quantity of hydrogen along with production of drinking water in near future. ONGC Energy Centre (OEC) is also working on some aspects of I-S process along with IIT-Delhi and CSRI-CECRI, Karaikudi. They are also working on Cu-Cl process along with Institute of Chemical Technology (ICT), Mumbai.

A number of research groups are engaged in developing catalysts that are suitable for providing high hydrogen production rate through photo-electro-chemical route by splitting water. Their efforts are focussed on developing low cost and durable catalysts that can work in the visible range of solar spectrum for making the process economically viable.

5.6 Cost of Hydrogen as Fuel

Cost of hydrogen varies considerably depending on process, by which it is produced, purity of hydrogen, capacity of the production facility and transportation cost which primarily depends on the distance between the point of production and delivery apart from other factors. Fig. 5.4 shows the cost of hydrogen that is available from different sources in India.

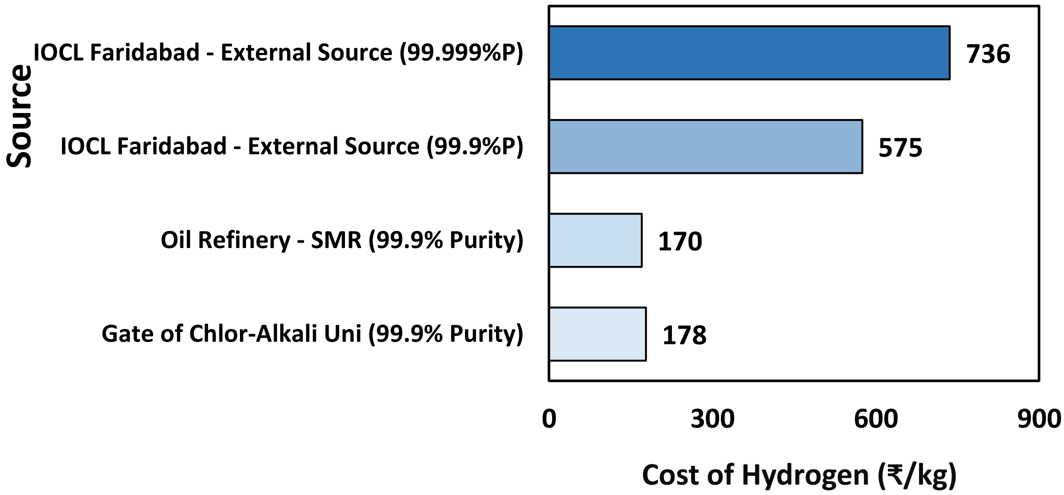

Fig. 5.4: Cost of Hydrogen from some sources in India

As mentioned earlier, petroleum refineries are one of the largest producers and consumers of hydrogen globally and hydrogen is produced in these refineries by SMR process. Hydrogen produced by SMR method is the most economical. Cost of natural gas and unit size of SMR reactors installed in refineries influence cost of producing hydrogen.

5.7 Hydrogen requirement projections

This section attempts to give some idea about the requirement of hydrogen, if certain numbers of vehicles are deployed on-road in India. For this purpose, four categories of vehicles have been considered: two-wheelers, three-wheelers, cars and buses. For two-wheelers, use of metal hydride canister for hydrogen storage may be preferred. For other three types of vehicles, total consumption of hydrogen is calculated with a constant duty cycle of 200 km/day except for two-wheelers for which duty cycle of 50 km/day is considered and 300 days of annual operation for each vehicle. A certain number of vehicles (growing from 100 to 10,000 over a period of 10 years with a mix of 65% buses, 20% three wheelers, 10% cars and 5% 2-wheelers) have been considered and their annual hydrogen requirement is estimated. Fig 5.5 shows amount of hydrogen needed for running of these vehicles. It can be noted that for each 1000 number of vehicles around 4150 tonnes/year of hydrogen will be needed. As discussed in Section 5.1.2, availability of one lakh tonne of hydrogen/year from petroleum refineries would be sufficient for operation of 24093 HFVs.

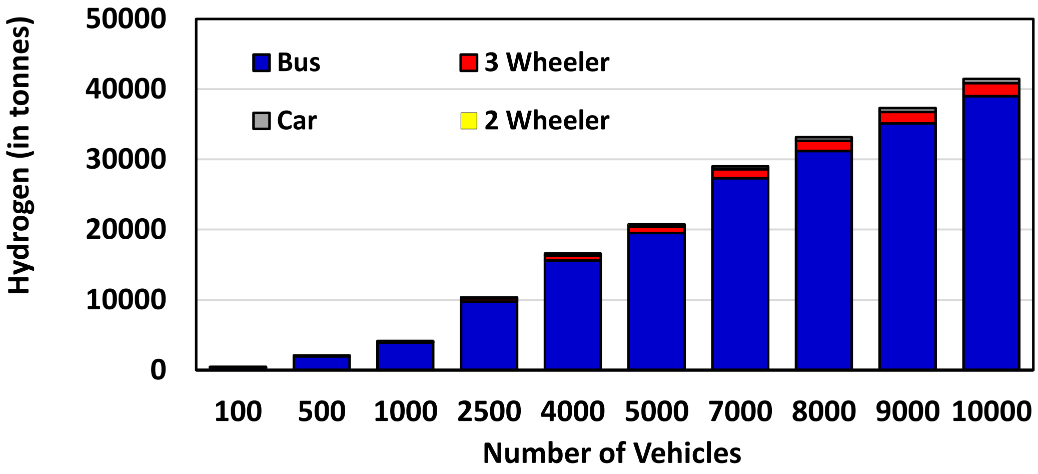

Fig. 5.5: Annual hydrogen requirement to run certain number of hydrogen fuelled vehicles

5.8 Current available hydrogen infrastructure for transport sector in India

Hydrogen FC buses have been developed and demonstrated in India by Tata Motors Ltd. (TML) in collaboration with the ISRO and IOCL. Further, Hyundai Motors is also considering launching its first FC SUV in India by 2021 and its plans for sourcing hydrogen for its operation in and around Delhi-NCR area are worked out. It has further shown interest in introducing hydrogen powered trucks in India, if GoI is favourably disposed for promotion of hydrogen fuelled vehicles in India. IOCL has initiated a pilot project along with Delhi Transport Corporation for using hydrogen enriched compressed natural gas (H-CNG) in city buses. H-CNG has been found to be more suited than CNG in terms of reducing emissions. IOCL has developed a single-step reactor for producing required blend of hydrogen in CNG. The Supreme Court of India has directed IOCL to complete this pilot project soon and favourable outcome of the pilot project is expected to pave the way for introduction of H-CNG buses in Delhi in 2020.

India is working on development of different types of hydrogen fuelled vehicles that will help the country to meet CO_2 emissions targets by 2030. In order to achieve this, in 2015 the first solar-powered HRS was established at NISE, Gurugram with financial support from MNRE. There are two other HRS, which have been installed by IOCL at Faridabad and Dwarka (West Delhi) using PEM and alkaline electrolyser technologies. Another station was set up at Pragati Maidan, New Delhi for completion of field trials of hydrogen fuelled three wheelers and it was dismantled subsequently on account of redevelopment of Pragati Maidan. TML has desired to set up a hydrogen dispensing station at Sanand, Gujarat for demonstration of some FC Buses. A preliminary estimation was made to assess numbers of refuelling stations that may be required to be set up in India for meeting refuelling requirement of HFVs that have been considered in Section 5.7. The growth for HRS is shown in Fig. 5.6.

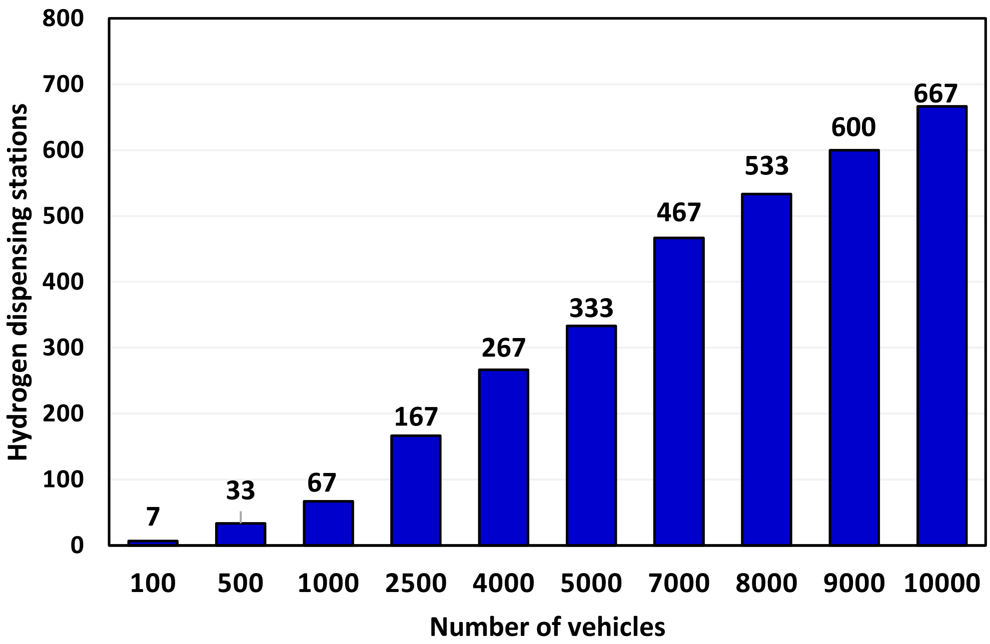

Fig. 5.6: Number of HRS needed for certain number of vehicles

5.9 Cost for hydrogen infrastructure and FCVs

This section aims to provide an idea on the cost for development of some of the elements of a *hydrogen society* after consideration of the government incentives. Information on provisions of incentives at international level are reported as hands on information on the costs of HRSs and hydrogen fuel.

In Japan, around 100 HRSs have been installed to refuel 2000 numbers of FC cars and two hydrogen buses as of 2018. The initial capital expenditure (CAPEX) for HRSs were around

US$ 4.5-5.4 million with an operational expense of around US$ 450,000. Japanese government have allocated around US$ 106 million for development of hydrogen infrastructure along with additional subsidies on FCVs. The government has provided around 50% incentives on the CAPEX of HRS and consequently the cost of installation of HRS became around US$ 2.5 million. In North America and Europe, a number of HRSs have been installed by various developers (Table 5.3). It can be noted that the cost of HRS is highly dependent on the average daily capacity as well as station technology. The cost of generated hydrogen may also vary with the station development cost. It is in the range of US$ 10/kg to US$ 33/kg. In UK and Japan delivered cost of hydrogen was reported as US$ 10-13/kg in the recent past.

Table 5.3: List of developed HRS in USA with their cost and specifications

Station Developer	No. of station funded	Station technology	Avg. capacity (kg H_2/ day)	Total cost (million US$)	Cost of H_2 (US$/kg)
First Element	19	Delivered H_2 gas	180	2.05	13.00
Air products	10	Delivered H_2 gas	180	1.93	12.40
Linde	7	Delivered liquid H_2	350	2.78	9.90
HyGen	3	Onsite electrolysis	130	3.25	24.00
Air Liquide	2	Delivered H_2 gas	180	3.26	13.80
ITM Power	1	Onsite electrolysis	100	2.73	22.70
H_2 Frontier	1	Onsite electrolysis	100	4.61	33.3
HTEC	1	Onsite electrolysis + delivered H_2 gas	140	3.25	17.90
Ontario CNG	1	Onsite electrolysis	100	2.51	18.30

5.10 Options for India

5.10.1 Hydrogen Production

With cost of electricity generation from renewables becoming attractive in India, penetration of renewables in the electricity grid is increasing year after year. This is causing the problem of curtailment of power from solar and wind projects and also grid balancing. There is need for promoting setting up of hydrogen production facilities based on electrolysers that would use curtailed power. Hydrogen so produced could be utilised for meeting requirement of industrial, transport, power generation and household sectors. This will create demand for electrolysers and for meeting the demand, efficient and reliable electrolysers will have to be manufactured within the country. Technologies for hydrogen production from other renewable resources such as biomass and wastes also needs to be scaled up from pilot scale level for adoption by the industry.

5.10.2 Supply and Utilisation of Hydrogen

For introduction of HFVs in India, the following strategy may be considered as it lays emphasis in sourcing hydrogen from existing hydrogen production infrastructure at chlor-alkali units and petroleum refineries:

Hydrogen from chlor-alkali units is considered suitable for use in FCVs. Surplus hydrogen from chlor-alkali units, including that is currently being used as fuel for in-situ applications and/or that is being sold in bottled form be used in the cities and towns, where such units are located to minimise cost of transportation of hydrogen. This would only involve creating a suitable hydrogen supply infrastructure from the chlor-alkali unit to the site of HRS at the same town or city, where the chlor-alkali unit is located without making any fresh investment for hydrogen production. In the HRS provisions for hydrogen compression and its storage will have to be created. Hence, total investment for this option may be lower as compared to a new hydrogen production, storage and dispensing facility.

Surplus hydrogen available from petroleum refineries, after some processing for improving its purity to the desired level could be used as fuel in HFVs. Some HFVs in the locations, where petroleum refineries are located, could be introduced to make use of such hydrogen.

Once the demand for hydrogen increases with increasing stock of HFVs, setting up of centralised hydrogen production facilities that offer economies of scale, could be considered along with creation of infrastructure for storage and transportation of hydrogen to HRSs using tube trailers, trucks, pipelines etc.

5.11 Hydrogen Storage

The main issue with hydrogen is its low density at ambient temperature, which results in release of low energy per unit volume for on-board applications. Therefore, a proper hydrogen storage system is needed to improve its energy density. The hydrogen storage systems needed should have some important properties and selection criteria such as, high volumetric and gravimetric hydrogen capacity, operation in ambient condition, fast refuelling, minimum energy loss during operation or otherwise and low cost. USDOE has set a technical performance targets (Table 5.4) for hydrogen storage systems for onboard light-duty vehicles. Current available storage options, R&D done in India and available options for the country are discussed in the following sections.

Table 5.4: USDOE hydrogen storage target for on-board vehicles

Storage parameter	Units	2025 target	Ultimate target
System Gravimetric Capacity	kWh/kg (kgH_2/kg system)	1.8	2.2
System Volumetric Capacity	kWh/L (kg H_2/L system)	1.3	1.7
Storage System Cost	$/kWh net ($/kg H_2)	9	8
Fuel cost	$/gge at pump	4	4
Operating ambient temperature	°C	(-) 40/60	(-) 40/60
Operational cycle life	Cycles	1500	1500
Min delivery pressure from storage system	Bar	5	5
Max delivery pressure from storage system	Bar	12	12
System fill time during charging	Min	3-5	3-5

5.12 Established technologies for hydrogen storage

5.12.1 Compressed storage of hydrogen

Hydrogen can be stored physically as gas or liquid. It can also be stored on the surfaces of solids (adsorption) or within solids (absorption). Gaseous storage of hydrogen requires high-pressure to increase the storage density. Compressor for raising pressure and pressure vessel (tanks) for storage of compressed hydrogen are needed. Hydrogen tanks for storage of compressed hydrogen at 350 bar and 700 bar pressure are used globally.

5.12.2 Hydrogen storage in liquid state

Cryogenic temperature is needed to store hydrogen in liquid state because of very low boiling point of hydrogen at atmosphere pressure (−252.8°C). This process is energy intensive and loss of hydrogen gas occurs due to boiling off at atmospheric conditions. Insulated cylinders with safety features have been developed to store hydrogen in liquid state. BMW developed and used their liquid storage tanks with 170 L liquid hydrogen capacity having bi-layered highly insulated tank in BMW Hydrogen 7 car. Japan has also developed a liquid hydrogen storage site in Kobe port where hydrogen is liquefied at -253°C and stored at -162°C. Liquid hydrogen is also used in spacecraft as a fuel.

5.13 Technologies appropriate for hydrogen storage

5.13.1 Compressed storage tanks

As mentioned earlier, compact, reliable, safe, and cost-effective hydrogen storage systems are one of the barriers for commercialisation of hydrogen fuelled vehicles. Compressed gas storage is the well-established technology and available storage tanks can be classified based on their types. Table 5.5 provides features of each type of hydrogen storage tank.

Table 5.5: Types of hydrogen storage tanks for compressed storage purpose

Type	Material	Maximum pressure (bar)	Cost (US$/kg)	Gravimetric density (wt%)
I	Metals (steel-aluminum)	200	83	1.7
II	Metal tank with composite overwrap	200	86	2.1
III	Metal liner with full composite overwrap	700	700	4.2
IV	All composite (carbon fiber)	700	633	5.7

Type III and IV pressure vessels are suitable for on-board hydrogen storage in HFVs. In these cylinders (Fig. 5.7), expensive carbon-fibre composite material is used to provide strength to withstand high pressure of the hydrogen gas. These cylinders are 70% lighter than steel cylinders, safe, durable with lifespan of around 20 years. However, use of carbon fibre composites increases the cost of the hydrogen storage tanks.

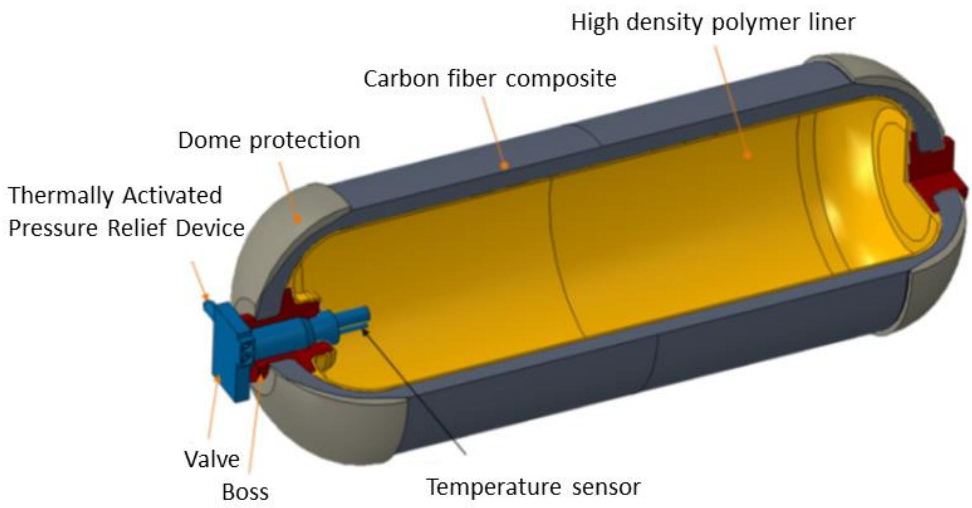

Fig. 5.7: Type IV hydrogen storage tank

5.13.2 Metal hydride

Hydrogen can be stored in metal hydrides as solid-state materials. This hydrogen can be released close to ambient conditions by application of heat. Metal hydrides such as $LaNi_5$, TiFe etc are tested for hydrogen storage applications and have shown reversibility at ambient conditions. Operating conditions (temperatures and pressures) of metal hydrides could be in wide range depending on the metal alloy. R&D on metal hydride storage materials has been carried out extensively in India and has led to improvement in the hydrogen storage capacity of metal hydrides to about ~2.5 wt%. Complex hydrides (alanates, boranes etc.) are other categories of solid storage materials.

5.14 R&D in India on hydrogen storage

The technology for realising the carbon composite with aluminium liner cylinder, Type III, is not readily available in the country. Currently, such cylinders are being imported for various applications, mostly for non-energy applications. The more popular, metal liner with Kevlar fibre wound type is the kind which is widely used in the country. The agencies/personnel who use such items today include ISRO, DRDO, aviation industry, medical institution for emergency oxygen, divers etc. Use of carbon composite wrapped metal liners has also been initiated. In-house developed technology for Kevlar composite titanium bottles for space application is already there with VSSC-ISRO which is used typically with Helium gas. Design, manufacturing, testing and use of these are already well established. Globally, Type IV cylinders are also available on commercial scale. Its use in the country is yet to start. For hydrogen storage in liquid state, a liquid H_2 plant is installed near Trivandrum. ISRO has planned to build the largest liquid H_2 storage tank (120 kilo litres) in Sri City, Andhra Pradesh. No R&D efforts to test of liquid H_2 in vehicular transport or power generation have been made in the country so far, except for space applications. National Environmental Engineering Research Institute (NEERI), Nagpur has developed several active and selective dehydrogenation catalysts, a specific catalytic reactor to handle endothermic reactions and a complete process flow sheet for liquid organic hydride that offer attractive hydrogen storage capabilities.

Decades of R&D efforts undertaken in the country has led to development of different types of hydrides for hydrogen storage. These include magnesium and magnesium hydride - a promising material for which absorption and desorption temperatures and kinetics are to be improved; amides, alanates etc. BHU, Varanasi, IIT Bombay, IIT Madras, NFTDC Hyderabad are the premier institutes which have been working on development of metal hydride-based hydrogen storage materials. Extensive studies on AB_5 type metal hydrides, complex hydrides and Mg based composite materials have/are being carried out at BHU under a programme named 'Hydrogen Storage in Hydrides'. In IIT Bombay, magnesium hydrides and other complex hydrides (alanates, boranes) were studied for hydrogen storage application. IIT Madras and CFCT Chennai have extensively worked for development of carbon-based material for hydrogen storage and achieved hydrogen storage of about 4.5 wt%.

5.15 Cost of compressed hydrogen storage system

An overall compressing unit will need a compressor, some storage tank and a chiller system. Compression cost mainly depends on power consumption of the system. Power of the compressor varies with their inlet pressure, outlet pressure, and flow rate. Cost can increase with increase in the operating pressure also. Generally, reciprocating compressors are used for hydrogen compression. Sometimes, centrifugal compressors are also used. Efficiency and cost both are higher for reciprocating compressor compared to a similar centrifugal compressor. Cost of compressor could vary in the range US$ 650 – 6600/kW depending on the size of the compressor. An establishment cost is needed for the first time for a compression unit. First cost of establishment of compressed systems for six such units is shown in Table 5.6. Another cost component is concerning the cost of the work required (in kWh) to compress 1 kg of H_2. Energy consumed for compressing hydrogen up to 400 bar to allow dispensing at 350 bar is estimated in the range of 2-4 kWh/kg. The operation and maintenance cost for gauge checks, lubrication and inspections is around US$ 2000 – 3000/year.

Table 5.6: Establishment cost for compressor unit

Station	Compressor cost (US$)	Chiller cost (US$)	Tanks cost (US$)	Total (US$)
NREL, USA	82,845	4,251	165,598	252,694
Humboldt State U	46,600	-	45,100	91,700
University of Montana	61,000	-	84,000	145,000
Sunline Thousand Palms	159,000	1,000	160,000	260,000
Chula Vista	47,682	1,000	75,000	123,682
California State Univ	159,000	1000	18000	340000
NISE, Gurgaon, India*	-	-	-	491,010
*Total cost including cost of compressor, tanks and dispenser unit (without chiller)				

Cost of hydrogen storage vessels (Type III) are collected from Luxfer Uttam India Pvt Ltd. and shown in Table 5.7.

Table 5.7: Cost of Type III hydrogen vessels

Sr. No.	Volume (L)	Working pressure (bar)	H_2 capacity (kg)	Price Ex works (US$)
1	74	350	1.75	2048
2	116	350	2.75	2208

5.16 Options for India for on-board Hydrogen Storage

While for smaller sized vehicles such as scooters, motor cycles and three wheelers, hydrogen storage in swappable metal hydride canisters may be preferred option, for larger sized vehicles such as three wheelers, cars and buses, hydrogen stored in Type-III and Type -IV cylinders appears to be an attractive option, as is being practiced globally. However, there is need to set up manufacturing facility for such cylinders in the country as these are currently imported and therefore their cost is very high. Such technology could also be useful for CNG and H-CNG vehicles to increase their driving range between refuelling.

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CHAPTER 6: COMPARISON OF LI-ION BATTERIES AND HYDROGEN AS FUEL FOR TRANSPORT SECTOR

6.1 Introduction

Resolving the twin problems i.e. meeting supply of increasing fuel requirement and containing emissions associated with road transport call for new solutions for use of energy in vehicles. The principal options are demand-side measures, development and use of more efficient vehicles and use of cleaner alternative fuels that are sustainable. The prevailing oil prices, heavy dependence on imported crude, finite indigenous oil reserves, absence of no new major oil reserves, increasing demand for oil coupled with stagnant domestic petroleum oil production are prompting researchers and policy makers to look for alternatives in India.

Hydrogen has been attracting a lot of attention of the policy makers, environment lovers, researchers, automobile companies and others for quite some years in view of its potential to play a significant role in providing low-carbon future solutions to many issues faced by the global energy system. Hydrogen looks promising for transport applications on three counts: GHG emissions reduction, energy security and reduction of local air pollution. Hydrogen is the main competitor in this respect to electricity, as it offers the same benefits. Of all the alternatives, EVs have the potential for the lowest fuel costs and GHG emissions due to their higher efficiency throughout the fuel supply chain and the vehicle's lower energy consumption. In the present perspective, battery and hydrogen (FC/ICE) appear to be long term options for resolving challenges faced by transport sector. A comparison of specific power consumption (kWh/km) and range (km) for different electricity and hydrogen technologies for transport sector indicates that electrical propulsion based on presently available EVs has a very efficient fuel cycle but also a limited range. HICE vehicles could increase the range considerably, but at the cost of fuel cycle efficiency. In comparison, FCV would have better efficiency and range.

6.2 Hydrogen as an energy carrier

Hydrogen offers a range of benefits as a clean and sustainable energy carrier, if produced from renewable sources such as solar, wind, biomass etc. Hydrogen is emission-free at the point of final use and thus avoids the transport-induced emissions of both CO_2 and air pollutants. Being a secondary energy carrier that can be produced from any (locally available) primary energy sources (unlike other alternative fuels, except electricity), hydrogen can contribute to a diversification of automotive fuel sources and supplies and offers the long-term possibility of being solely produced from renewable energies. Hydrogen could further be used as a storage medium for electricity from intermittent renewable energies such as wind and solar power.

Hydrogen is considered as viable alternative fuel which can counterbalance electricity as a zero-carbon energy carrier that can be easily stored and transported; enabling a more secure energy system with reduced fossil fuel dependence; with the versatility to operate across the transport, heat, industry and electricity sectors. While electricity is proving comparatively easy to decarbonise due to downward trend in the cost of electricity generation, resulting in upward share of renewable power in the energy mix of different countries; hydrogen is way behind in the race and is performing catching up job in the last few years. Fig. 6.1 demonstrates the versatility of hydrogen as an energy carrier, in terms of its production from different feed stocks ranging from fossil fuels to biomass and also electricity, distribution and end use for electricity generation, as a transport fuel, in industry and buildings.

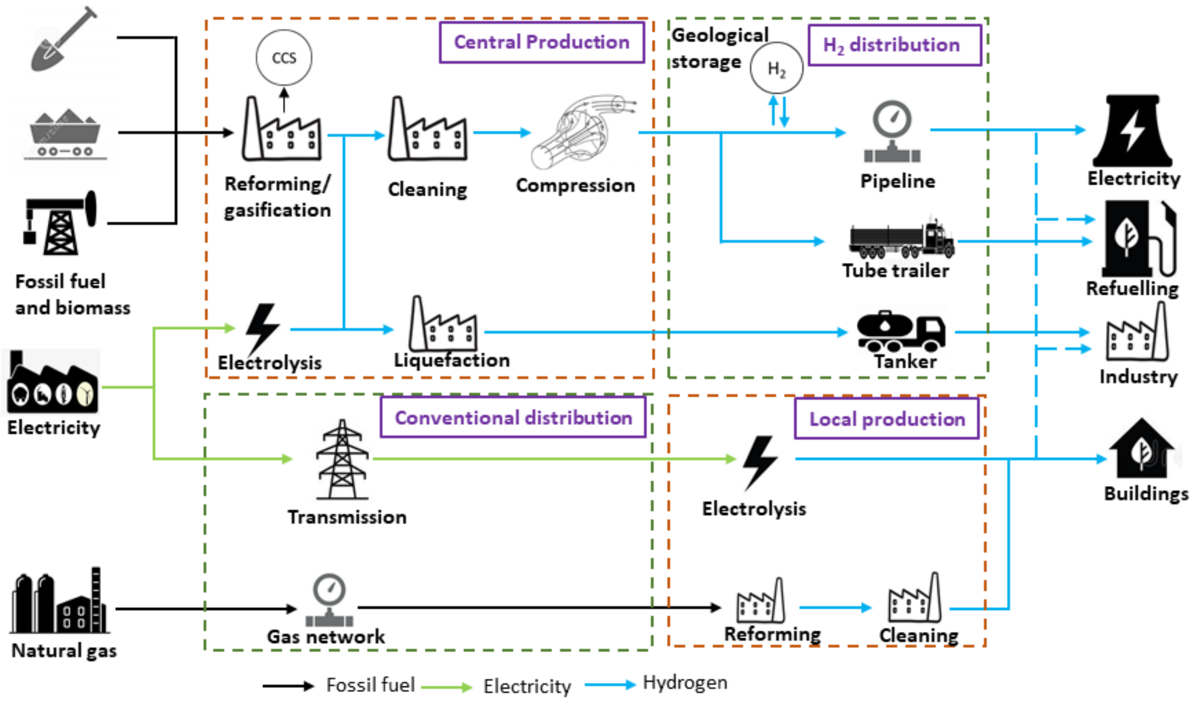

Fig. 6.1: Hydrogen production, distribution and applications

6.3 Combustion characteristics of Hydrogen as fuel

Hydrogen is the lightest element. It is colourless, odourless, tasteless and non-toxic gas found in the air at the concentrations of about 100 ppm (0.01%). It is the most abundant element in the universe, making up 75% of the normal matter. Table 6.1 compares properties of hydrogen as a fuel along with other conventionally used fuels. The ability of HICE to burn cleanly and operate efficiently is owed to the unique combustion characteristics of hydrogen. The properties that contribute to its use as a combustible fuel are its wide range of flammability, low ignition energy, small quenching distance, high auto-ignition temperature, high flame speed at stoichiometric ratios, high diffusivity and very low density. Fig. 6.2 shows relative heating value of hydrogen and other fossil fuels.

Table 6.1: Properties of Different Fuels

Property	Hydrogen	Gasoline	Natural Gas	Liquefied Petroleum Gas
Density (kg/m^3)	0.084	4.4	0.651	1.87
Density relative to air	0.07	4	0.55	1.52
Molecular Weight	2	107	16	44
Diffusion Coefficient in air (cm^2/s)	0.61	0.05	0.16	0.12
Ignition Energy (mJ)	0.02	0.24	0.29	0.26
Ignition Temperature (°C)	585	228- 471	540	410-580
Explosive Energy (MJ/m^3)	9	407	32	93
Flame Temperature (°C)	2045	2197	1875	1970
Flame Speed (cm/s)	346	42	43	47

Hydrogen has a wide flammability range of 4 to 75% by volume with air in comparison to methane and petrol. As a result, hydrogen can be combusted in an engine over a wide range of fuel-air mixtures, including on a lean mixture, which helps in complete combustion, better fuel economy and reducing the amount of pollutants such as NO_x due to lower combustion temperature. If hydrogen is combusted at close to its stoichiometric ratio, high temperatures are created, which results in formation of NO_x from nitrogen present in air. Hydrogen has very low ignition energy (0.02 MJ), which enables hydrogen engines to ignite lean mixtures and ensures prompt ignition. Unfortunately, the low ignition energy also means that hot gases and hot spots on the cylinder can serve as sources of ignition, creating problems of premature ignition and flashback. The wide flammability range of hydrogen means that almost any mixture can be ignited by a hot spot. Hydrogen has a small quenching distance about three times smaller than petrol. The smaller quenching distance can increase the tendency for backfire. Hydrogen has a relatively high auto-ignition temperature, which allows larger compression ratios to be used in a hydrogen engine than in a hydrocarbon engine thereby positively impacting thermal efficiency of the engine. Hydrogen has high flame speed.

Hydrogen has very high diffusivity in air, which facilitates the formation of a uniform mixture of fuel and air and rapid dispersal of hydrogen in the event of any leakage.

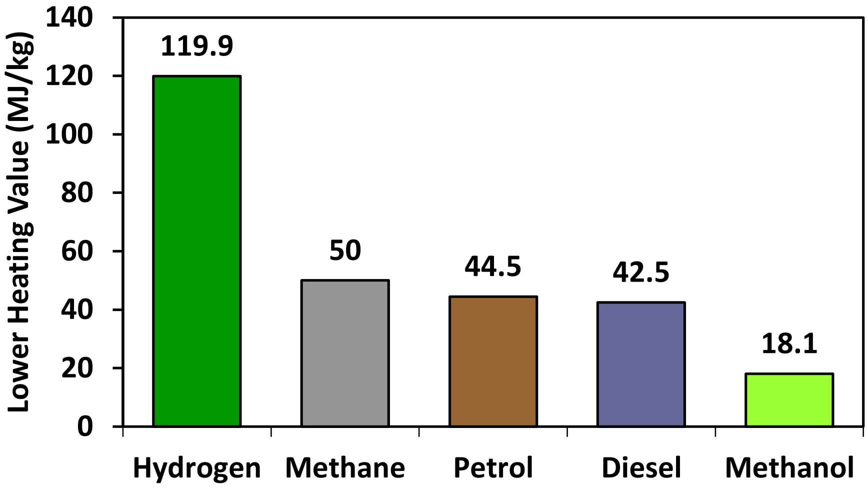

Fig. 6.2 Heating Values of commonly used Fuels

A FC being an electro-chemical energy conversion device, does not involve combustion of hydrogen for electricity generation and therefore most of the problems associated with hydrogen combustion in engines, including formation of NO_x are not associated with FCVs.

Hydrogen and HFVs technologies have the added advantage in the transition to a low-carbon economy, given their similar performance, operation and consumer experience to fossil-fuelled technologies. Hydrogen represents one of three main options for low-carbon transport alongside biofuels and electrification of vehicles. Hydrogen avoids the land-use and air quality impacts of biofuels, and the limited range and long recharging times associated with EVs. However, electric cars are several years ahead of HFVs in terms of maturity due to their lower costs and relatively readily-available infrastructure.

6.4 Electricity as an energy carrier

EVs either attached to the grid or powered by a battery can do most of on-land transport tasks for which we are mainly dependent on fossil fuels currently. In addition to zero emissions at end use, electricity has benefits of higher efficiency and easy availability. Electric generators can be built to use a wide variety of energy (heat, light, mechanical energy) to create the highly usable and flexible energy carrier i.e. electricity. In other words, electricity is the ultimate “flexible-fuel.” All renewable energies (wind, solar, geothermal heat, wave, tidal, biomass etc.) can be converted into electricity with existing technologies. In addition, renewable energy-based power generation can be easily integrated into the existing infrastructure of transmission and distribution of electricity. Existing electrical generation technologies convert a fairly large amount of the primary energy into electric energy. Harnessing solar energy directly for power generation using SPV is highly efficient in comparison to energy conversion through photosynthesis or other routes, wherein biomass is initially converted to gaseous or liquid fuels and thereafter for electricity generation. For a given power output, electric motors are very compact compared to equivalent ICE. Additionally, electric motors are highly efficient (90-95%) at generating torque, the useful product of engines and motors as compared to an ICE (20-30% efficient). Electricity can also be used for a huge variety of functions for the end user: generating mechanical movement, heat, light, and sound. So, electricity is both flexible-fuel and flexible-use. Electricity's weakness has been that electrical energy storage systems such as batteries are bulky and heavy in comparison to the portable liquid fuels to which it is often compared. Energy storage systems, usually batteries, are essential for all types of EVs. Different types of batteries are used as energy storage systems in EVs.

6.5 Batteries for EVs

Lead-acid batteries are one of the most widely used batteries and can be designed to be high power and are inexpensive, safe, and reliable. However, low specific energy, poor cold-temperature performance, and short useful life limit their use in EVs, except for two wheelers and e-rickshaws.

Nickel-Metal Hydride batteries (NMH) have a much longer useful life than lead-acid batteries and are safe. These batteries used routinely in computer and medical equipment, offer reasonable specific energy and specific power capabilities. These batteries have also been widely used in hybrid EVs. The main challenges with NMH batteries are their high cost, high self-discharge and heat generation at high temperatures, and the need to control hydrogen loss.

LIBs are currently used in most portable consumer electronics such as mobile phones and laptops because of their high gravimetric energy density in comparison to other electrical energy storage systems. They also have a high power-to-weight ratio, high energy efficiency, good high-temperature performance, and low self-discharge. Most components of LIBs can be recycled, but the cost of material recovery remains a challenge for the industry. Most of currently produced EVs use LIBs, though the exact chemistry often varies from that of consumer electronics batteries. R&D efforts are underway for cost reduction and extending their useful life.

Other type of rechargeable batteries based on lithium (e.g. Li–S, Li–air etc.) and zinc (e.g. Zn–Air) are also considered as favourable options for EVs. However, most of these technologies are in developing stages. Lithium sulphur (Li – S) batteries are considered as an alternative to LIBs as they have higher energy density and lower cost due to the use of sulphur. Sony has recently commercialised first Li – S battery and may introduce it in market soon for portable electronic applications. Li – air batteries are favourable in terms of higher energy density. However, Li – air battery technology suffers from many disadvantages such as, low stability and efficiency (due to irreversible secondary reaction which forms stable lithium peroxide), incomplete discharge (due to blockage on the cathode side) etc. Zn – air batteries are also promising for EV applications due to their light weight, high energy density and low cost. However, reversibility of the Zn – air battery is difficult due to the formation of stable zinc oxides. Use of catalysts, mechanical recharging by removing the oxides are suggested for implication of this battery technology which is cost effective.

6.6 EV battery technologies and ownership models

EVSE (Electric Vehicle Supply Equipment) performs dedicated function of supplying electric energy from a fixed electrical installation to an EV for the purpose of charging. There are different ways to classify an EVSE depending on power supply (AC or DC), power rating levels, speed of charging and communication and connector type.

6.6.1. By type of charging

6.6.1.1 Rapid fast charging

Chargers providing high power output capable of charging a vehicle to 80% in as little as 15 minutes is known as rapid fast chargers and are available in 20-50kW range.

6.6.1.2 Battery swapping

Swapping of batteries can be done at a swapping station, where discharged battery from the vehicle can be replaced by a charged battery. The battery is owned by the swapping company which provides this service. The vehicle therefore neither need to be fast-charged nor has very large battery.

6.6.1.3 Range extension (RE) systems

RE systems are incorporated as a vehicle designed with a small built-in fixed battery and a removable secondary battery called range-extension swappable Lock Smart (LS) batteries (or RE battery). The smaller battery can be regularly charged for catering to smaller driving distances and in case of a long-range journey, the RE battery can be swapped in for extending the range. RE systems result in reduced upfront costs of a vehicle and reduces the weight which is a key efficiency metric in EVs.

6.6.1.4 Wireless charging

Qualcomm Technologies, introduced Halo Wireless Electric Vehicle Charging (WEVC) system, enabling quick charging with high power WEVC, supporting wireless power transfers at 3.7 kW, 7.4 kW, 11 kW and 22 kW with a single primary base pad. The main drawbacks in wireless charging are the EV-charger alignment issue and foreign object interference.

6.6.1.5 Renewable energy charging

Use of renewable energy such as wind, solar energy etc. based charging for EVs will increase reduction of GHG emissions

6.6.2 By EVSE output - AC or DC

In case of AC EVSE, the vehicle has on-board charger that converts AC into the DC first. AC EVSE comes in different power rating ranging from 3.3 kW to 43 kW. DC EVSE can supply higher power rating ranging from 10 kW to 240+ kW.

6.6.3 By EVSE power rating – Level 1, 2, 3

AC and DC chargers come with different power ratings and accordingly are classified into Level-1, Level-2, and Level-3 (Table 6.2).

6.6.4 By charging speed – slow, fast, or ultra-fast

Slow charger takes charging time of four to eight hours. Fast charger takes 1 hour and ultra-fast charger takes less than 30 minutes to charge the battery. The type of chargers to be used depends on the size, thermal management of battery, type of battery used and the connections present in charger.

Table: 6.2 Power ratings of chargers

Type	AC Chargers	DC Chargers
Level 1	120V single phase AC up to 1.9 kW (up to 16A)	200-450V DC up to 36 kW (up to 80A)
Level 2	240V single phase AC up to 19.2 kW (up to 80A)	200-450V DC up to 90 kW (up to 200A)
Level 3	Greater than 20 kW	200-600 V DC up to 240 kW (up to 400A)

6.7 Comparison of battery and hydrogen for transportation

Electrical energy is stored inside a battery as chemical energy and can be extracted by connecting to the load. When batteries are connected to an external electric load, a redox reaction occurs and the free-energy is delivered to the external circuit as electrical energy. In case of hydrogen, the stored chemical energy can be extracted by burning it to get thermal energy or using it in a FC to get electrical energy. For transportation, hydrogen can be used in either ICE or FC to power the vehicle. A FC operates in a similar way as a rechargeable battery. The FC stack is designed to contain enough cells to provide the necessary power for the automotive application. A FC stack produces power as long as fuel is available, similar to an ICE. The electricity generated by the FC stack powers the electric motor that propels the vehicle.

FCs and batteries are devices that transform chemical energy from a substance or compound into electricity through electrochemistry. The electrochemical reactions in batteries and FCs are controlled and produce virtually zero pollutants. The difference between the two technologies lies in the storage of fuel. A battery converts a finite amount of a chemical compound stored internally into electricity. The chemical substance consumed in the battery to produce electricity is regenerated when the battery is recharged. A FC, on the other hand, converts a chemical compound stored externally into electricity. That chemical compound is generally hydrogen, stored in a tank on board of a HFV.

Increased specific energy or lower energy storage cost is needed for EVs with longer driving ranges and lower cost, while fast charging, power grid compatibility and safe operation are must for high-utilisation EVs. Characteristics of the technologies regarded as candidates for new EVs, in addition to those of LIBs and hydrogen, are compared in Fig. 6.3. In the figure, the upper bounds of the specific energy, energy density and specific power ranges represent estimates of what can be practically achieved, whereas the lower bounds indicate what has already been achieved (vice versa for energy storage cost). Cycle life, calendar life, energy efficiency, self-discharge and operating temperature ranges represent upper and lower values observed in commercial or prototype cells. Energy storage cost refers to the cost of the battery pack or system, while specific energy, energy density and specific power refer to cell-level values. For hydrogen FCs, energy-related characteristics apply only to hydrogen within a typical hydrogen storage tank without considering FC and specific power applies only to the FC without considering hydrogen storage. Cycle life and self-discharge rates are not applicable to hydrogen FCs, and thus are not included. Safety, fast-charging compatibility and power grid compatibility are qualitative ratings between 0 (worst) and 10 (best). Separate safety ratings are assigned to the solid-state versions of LIBs due to the replacement of flammable, liquid electrolytes with solid, non-flammable electrolytes. Qualitative safety ratings were determined by the type of electrolyte (flammable or non-flammable), potential for over-heating, and potential for toxic or corrosive material release. Fast-charging capability for each battery was rated semi-quantitatively from its specific power, while each battery's power grid compatibility was rated semi-quantitatively from its energy efficiency. Hydrogen FCs have the highest fast-charging and power grid compatibility owing to the ability to transfer hydrogen gas quickly without disrupting power grids.

Gravimetric energy density of hydrogen is in the range of 1.47 to 1.83 kWh/kg, depending on the volumetric capacities of the storage vessels used and storage pressure. In comparison, energy density of Li-ion batteries is in the range of 100-265 Wh/kg. Therefore, for storing same amount of energy, Li-ion based storage system would be relatively about ten times heavier. Thus, for providing a given driving range to a vehicle, hydrogen storage system will be lighter than Li-ion batteries. Coupled to it, hydrogen vehicles can be refuelled as quickly as similar petrol/diesel vehicles with hydrogen filling rate of about 1 kg/minute in comparison to several hours taken for charging a LIB, depending on slow or fast charging.

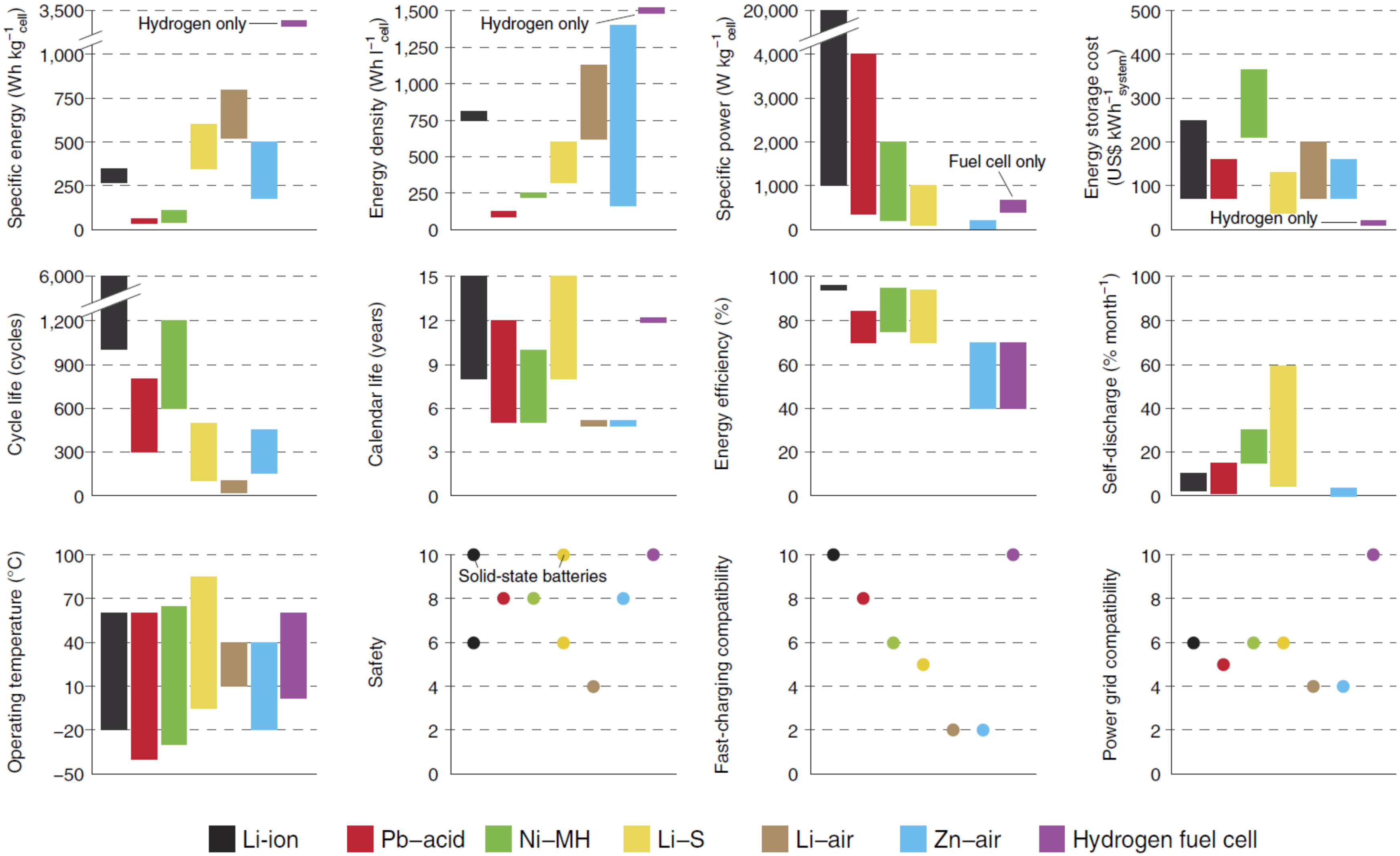

Fig. 6.3: Characteristics of rechargeable batteries and hydrogen FCs

Hydrogen vehicles, therefore do not pose any “range anxiety” fears but finding a HRS is going to be a big concern till infrastructure for HRS is developed.

FCVs offer many advantages over EVs such as, very fast refuelling time (3 - 5 min), freedom from ‘range anxiety’ with up to 600 km between refuelling, greater longevity (>200,000 km), better driver experience, and safety. However, FCVs still have higher capital and operating costs when compared with EVs, with current models around twice as expensive. However, for similar driving range both EVs as well as FCVs would have more or less similar costs. The high FCV cost is primarily due to the use of platinum (Pt) catalysts and current low production volumes. Although precious metal loadings have been getting progressively in the last decade, but it still remains a significant issue.

6.7.1 Energy conversion efficiency of primary energy into electricity and hydrogen

Electricity and hydrogen are secondary energy sources and can be generated from primary energy resource like, coal, natural gas etc. Electricity is mostly generated in thermal power station using either coal or natural gas as fuel. These power stations convert the heat energy of combustion into mechanical energy, which then gets converted into electricity by turbo-generators. For coal fuelled power station, steam turbines are used; whereas for natural gas, a combination of gas turbines and steam turbines (known as combined-cycle power plants) are used. Efficiency of these thermal power stations is limited by the Carnot efficiency and consequently waste heat is generated. The waste heat generated in the gas turbines can be reused in waste heat boilers to generate steam for running turbines. Thus, overall efficiency of natural gas fuelled power plant is comparatively higher than that of coal fuelled power plants. Typical thermal efficiency for coal-fuelled power station is around 32 to 46% depending on technology and up to 60% for combined-cycle gas-fuelled power stations.

As discussed in Chapter 5, hydrogen can be generated using various processes such as, coal gasification, steam methane reforming (SMR), partial oxidation (POx) etc. It has been reported that the energy conversion efficiency for hydrogen production by these methods is comparatively higher than that of the electricity generation using thermal power station. Efficiency of hydrogen generation by various process is tabulated in Table 6.3.

Table 6.3: Energy conversion efficiencies of various hydrogen production methods

Process	Feedstock	Efficiency (approx.)
Steam reforming	Methane / Natural gas	70-85%
Gasification	Coal / biomass	35-50%
Partial oxidation	Natural gas	60-75%

6.7.2 Comparison of different vehicle technologies

FCVs predominantly use PEMFC, offering high efficiency, high power density and cold start capabilities. A 60 kW FC is typical for European cars, which is substantially larger than for residential FCs (~1 kW). Competing power-trains include conventional ICEs and EVs, which mainly use LIBs. FCVs are compared to alternatives vehicles (EV and ICE) in Table 6.4.

Table 6.4: Comparison of vehicles with different technologies

Attribute		ICE	FCV	EV
Lower is better	Current capital cost	$	$ $ $	$ $
	Fuel cost	$ $	$ $ $	$
	Maintenance cost	$ $ $	$	$
	Infrastructure needs	$	$ $ $	$ $
	Emissions	🌢 🌢 🌢	🌢	🌢
Higher is better	Efficiency	👍	👍 👍	👍 👍 👍
	Range	👍 👍 👍	👍 👍 👍	👍
	Refuelling speed	👍 👍 👍	👍 👍 👍	👍
	Lifetime	👍 👍 👍	👍 👍 👍	👍 👍
	Acceleration	👍 👍	👍 👍 👍	👍 👍 👍

6.8. Drawbacks of hydrogen and battery in transport sector

6.8.1 Safety concern of hydrogen and battery

Auto manufacturers are committed to building FCVs that are as safe as or safer than conventional vehicles by meeting the standards set by the Society of Automotive Engineers and other standard development organisations. FCVs have essential safety systems designed to protect passengers and first responders in case of an accident. Safety systems for FCVs differ from conventional vehicles largely due to the FC stack and battery pack—two sources of high-voltage electricity—and the fuel storage tanks containing high-pressure hydrogen gas.

The FC stack and high-voltage battery pack in FCVs also pose no additional risks over a conventional vehicle. Both the FC stack and battery pack are sealed separately in metal cases and electrically insulated from the vehicle's metal body. There are a number of safety systems designed into the vehicle to prevent high voltage hazards. High-voltage circuits are also colour-coded orange and posted with warnings to advise of their presence.

Hydrogen fuel is stored at high pressures (up to 700 bar) in tanks much stronger than typical petrol fuel tanks. The hydrogen storage tanks are designed to withstand twice the maximum pressure to avoid rupture. Sensors are located throughout the vehicle and, in conjunction with the safety systems, ensure that the driver and the vehicle are safe in the unlikely event of a hydrogen leak.

Fire and explosion related safety issues are associated with LIBs and these are caused by overcharge, overheating, short circuit, internal cell failure and manufacturing deficiencies. However, Lithium Iron Phosphate (LFP) battery technology is safe and does not have major concerns related to safety issues.

6.8.2 Scarcity of battery materials

Despite the euphoria surrounding India's EV programme, speed bumps in the policy and corporate landscape remain. One such hindrance is that India does not have enough reserves of key raw materials (such as, lithium, cobalt, manganese etc.) for manufacturing of LIBs. This could lead to a substantial change in the country's energy security priorities, with securing these precious metals supply, key raw materials for EV batteries, becoming as important as buying oil and gas fields overseas. But some believe that the limited availability of these materials in India will not be a deal breaker as cost of these materials is comparatively lower than that of the cells or battery packs.

Another related risk is that of EV charging leading to a surge in electricity demand which in turn may put at risk India's already stretched electricity distribution networks. This calls for careful planning in the backdrop of India's worst blackout that left nearly 620 million people across 19 states and three Union territories without electricity for hours together in July and August of 2012.

6.8.3 Grid dependence of EVs

The EV load is non-linear and can cause harmonic distortion, DC offset, phase imbalance, and voltage deviations in the distribution network. However, with approximately 5000 MW, which would be equivalent to approximately 1.35% of the total current installed capacity (more than 368 GW as on 31.12.2019), of EV related additional load expected to come on to the system, at the national grid level, the impact is negligible.

In one of studies, Matlab/Simulink platform was used to analyse the effect of charging of batteries on different feeder systems. Based on EV charging profiles considered in the simulations; a baseline 50% loaded commercial feeder can safely absorb up to 20% of additional EV load from fast charging, similarly the residential feeder, can be safely handle a ratio of 60%:40% from Residential load and EV load (fast charging) respectively. However, the peak co-incident charging scenario showed that a loading of around 20% from fast chargers should be the threshold. This implies that should such high loading conditions occur; the distribution licensees should build resilience by network expansion. The impact from slow charging on both the feeders was negligible.

Distribution licensees should not perceive EVs as an additional burden on the grid, which could hinder the large-scale adoption of EVs. Similarly, regulators need to create an enabling framework and attractive rate structures for charging, such that peak hour charging is avoided and is shifted to off-peak hours. Hence it is very important to equip both regulatory and utility personnel with the technical and managerial aspects of the EV landscape. Electricity distribution companies across the world have played a pro-active role in development of EV ecosystems. Utilities offer discounted electricity prices for EV charging, especially to encourage grid friendly charging. Time-of-day tariffs are used as price signals to promote off-peak charging.

EVs are clearly an additional source of revenue for electricity distribution companies and with proper planning, can result in more efficient and less costly operation of the grid. EVs will also provide ancillary services, lower electricity prices for ratepayers and facilitate greater integration of renewable energy resources. EVs can offer the dual benefit of RE integration as well as load flattening for discoms. EVs are a "flexible load," i.e. their charging times can be coordinated with renewable energy generation, to ensure effective uptake of RE in the grid thus allowing discoms to meet their RPOs as well as for load flattening.

6.9 Available infrastructure in India: Refuelling of H_2 or recharging of EVs

In the push for 30% EV and green mobility by 2030, the government of India has approved amendments in the EV charging guidelines and specifications in 2019. Under the new guidelines, Bureau of Energy Efficiency (BEE), Ministry of Power has been nominated as the Central Nodal Agency. Also, a provision for State Nodal Agency of the respective states has been provided for in the guidelines. These nodal agencies will act as the key facilitator in installation of charging infrastructure for EVs throughout the country. In order to address the range of issues of the EV owners, a phase-wise installation of an appropriate network of charging infrastructure throughout the country has been envisaged in the guidelines. The development of EV charging infrastructure in India is currently at its nascent stage. Today there are around 500 EV charging stations spanning major metropolitan cities like Delhi, Mumbai, Bengaluru, and Kolkata. At international level, the numbers of charging points are estimated to be 5.2 million units.

In comparison to 432 HRSs that were operational worldwide as on 31.12.2019, the hydrogen fuelling infrastructure in India is almost non-existent except for three stations. The cost of producing and delivering hydrogen fuel to service stations is currently high at low volumes, and it is still far cheaper to produce hydrogen from fossil fuels than from renewable energy in India. Although PHEVs are being commercialised more rapidly, these attributes ensure that hydrogen FCVs remain an appealing long-term strategy, especially for larger and longer-range vehicles. New HRS can be established adjacent to existing gasoline stations, which means that hydrogen dispensers may be placed adjacent to or on the same island as the gasoline dispenser.

6.9.1 Hydrogen refuelling station

India’s first HRS was opened in 2005 at IOCL R&D Centre, Faridabad. The first fleet of hydrogen fuelled three-wheelers was launched in January 2012. A total of 15 vehicles were refuelled from a station at Delhi’s Pragati Maidan. The Hydrogen powered vehicles and refuelling station were part of UNIDO supported DELHY-3W project to demonstrate hydrogen technologies. Key list of industrial hydrogen players is shown in Table 6.5.

6.9.2 EV charging options in India

EV technology is on ascendency in India. The established players in EV sector are working on technologies to increase the range and reduction of charging time. India has so far developed two charging specifications – AC-001 charger for AC charging, and DC-001 charger for DC charging. Both have a charging voltage level under 100 V and use custom GB/T communication protocol over CAN mode. AC-001 charger can give max 15 A charging current with 3.3 kW power, while DC-001 can give max 200 A current with 15 kW power. Between both the chargers, above charging range for two-wheeler, three-wheeler and four-wheeler can get closely covered.

Table 6.5: Hydrogen players in India

Hydrogen gas distributors	Hydrogen refuelling station set up companies
Indian Oil Corporation (IOC)	Inox AP (Air Products)
Gujarat State Petroleum Corporation (GSPC)	Air Liquide
Hindustan Petroleum (HP)	Praxair
Bharat Petroleum (BP)	Linde presence through old BOC
Reliance Group	Eden (Hythane/Hyradix/Larsen and Tubro)
Shell Hydrogen	

For buses, India has developed another charger (under development) that gives 50 A current and 30 kW power. There are other two higher voltage/power level charging standards that are under development, to be called AC-002 and DC-002, that can provide further fast charge (within one hour). It will be important for India to define and use the standard chargers across vehicle categories, to witness EVs' scale-up. Battery chemistry and battery temperature highly influence use of slow vs. fast charging. Low cost NMC battery life is likely to degrade if it is charged fast (less than an hour) at higher than 45-degree ambient temperatures, while LTO batteries can support such fast charging.

6.10 End-of-Life considerations for Li ion Batteries

India's ambitious electric vehicle plans could throw up challenges of environmental hazards if used batteries are not handled properly. The country does not have regulations on scrapping of EV batteries as of now. The automobile industry is moving towards the use of LIBs instead of lead-acid batteries to offer quicker charging and higher range. LIB recycling is hazardous because of the highly reactive nature of lithium ions. The proper scrapping of batteries will not only alleviate possible environmental concerns but will also act as an enabler to locally

available source of chemical elements of the batteries such as lithium, nickel, manganese, cobalt, and titanium, thereby increasing the cost-effectiveness of the supply chain. Everybody thinks that somebody will take care of the used batteries. Some experts believe that the life of a battery after use in vehicles can be used for static storage applications for at least an additional three to five years, thereby increasing the life-cycle of the battery usage.
The contents of LIBs are less toxic than most other battery types, which makes them easier to recycle. But lithium is a highly reactive element. These batteries have a flammable electrolyte and pressurised contents that could lead them to bursting into flames.

It's especially risky when LIBs end up in the back of a dry recycling truck surrounded by paper and cardboard. Pressure or heat, especially during the summer, could cause them to spark, starting a fire.

As the popularity of EVs starts to grow, so does the pile of spent LIBs that once powered those cars. As per research estimates, the LIB battery market in India is expected to increase from 2.9 GWh in 2018 to about 132 GWh by 2030 (CAGR of 35.5%). The increasing volume of LIBs would in turn, lead to a growing capacity of 'spent' batteries in the ecosystem, which if left untreated would lead to health and environmental hazards.

To date, India does not have any specific regulations or guidelines around the effective disposal and recycling of LIBs. Even India's e-waste guidelines have no mention of LIBs. Clear guidelines have to be laid out for collection, storage, transportation and recycle of waste batteries. Detailed instructions for both consumers and battery suppliers also have to be laid out and implemented. To overcome this, FCVs are better alternative of Pure EVs. They will use batteries in them, but just as energy buffers and not as a main source of energy. Batteries used in FCVs are of much lesser capacity compared to EV for the same range of vehicles. Hence, recycle volume and risk of potential environment hazard during recycling is way too less than pure EV vehicles. Also, batteries in FCVs are used at very optimum operating points, they tend to have longer life span compared to same batteries used in pure EVs. Hence, FCVs makes strong case as far as cleanliness of the fuel is concerned over an entire cycle.

6.11 Way Forward

Hydrogen and LIBs could play complementary role in transport sector. While LIBs used in EVs may be ideally suited for conditions where daily duty cycle of the vehicle is lower, especially for intra city use, hydrogen is suited for vehicles that are heavy, require relatively longer range and needs to be refuelled quickly.

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CHAPTER 7: COMPARISON OF ELECTRIC VEHICLES AND HYDROGEN FUELLED VEHICLES FOR INDIAN SCENARIO, INCLUDING THEIR EMISSIONS

7.1 Introduction

In India, environmental concerns, desire to reduce reliance on imported fuel, legislation, stringent norms for CAFÉ (Corporate Average Fuel Economy) and consumer perception have been the main contributors towards exploration of alternatives for conventional fossil fuels. EVs (BEV, PHEV, and FCV) and HICE have been explored for adoption. Higher vehicle cost, lower vehicle range and lack of adequate charging infrastructure have been the main issues that have hampered progress of EVs. However, the focus has now shifted towards those applications (two-wheeler, three-wheeler, Taxis, Buses etc.) wherein either daily average vehicle range requirement is lower, or route/operation times are fixed, utilisation can be optimised by opting for sharing the vehicle and can be planned for better to make them cost effective.

In India, a lot of research work has already been undertaken on utilisation of hydrogen as a transportation fuel through support of the GoI (MNRE and DSIR). Some of the projects include development and field trials of hydrogen fuelled 3-wheelers and mini buses developed jointly by IIT Delhi and M&M. TML has successfully developed India's first hydrogen FC-powered bus and undertook field trials in collaboration with R&D Centre of IOCL.

7.2. Comparison of conventional ICE vehicle, HICE vehicle, FCV & BEV

The FCVs have been preferred over HICE vehicles owing to their high energy conversion efficiencies and no tail pipe emissions. However, India opted for HICE technology development, mainly due to:

(i) Inexpensive modifications required in the existing ICE technology to use hydrogen as fuel;

(ii) HICE vehicles have higher efficiency and lower emissions in comparison to petrol engines;

(iii) no capital investment would be required for making a transition to hydrogen fuelled engines as the existing facility for ICE can be utilized for manufacturing of HICE; and

(iv) HICE could act as an intermediate technology for making transition from conventional vehicles to FCVs.

The following table (Table 7.1) shows a brief comparison of the salient characteristics of conventional ICEV (ICE Propelled Vehicle), Hydrogen ICE Vehicle (HICEV), Fuel Cell Vehicle (FCV) and Battery Electric Vehicle (BEV).

Table 7.1: Comparison of vehicles with different power-train options

Parameter	Conventional ICEV	HICEV	FCV	BEV
Vehicle Cost (e.g. mid-size vehicle)	Baseline	~ 2.5x	~ 2.5x	~ 1.33 – 1.5x (For EV models currently being sold with lower range, 1.15-1.2 times conventional ICEV) ~ 2.5x (For EV models with similar range as ICEV)
Maintenance Cost	Baseline	Similar	Lower (Battery & tyres would be the major components)	Lower (Battery & tyres would be the major components)
Tailpipe Emissions (Tank to Wheel)	High	NOx is the only concern	Nil	Nil
Lifecycle emissions	High	Depends on - Material Source: H_2 from Fossil fuel or Water - Electricity Source: Renewable/ Non-renewable in case of electrolysis	Depends on - Material Source: H_2 from Fossil fuel or Water - Electricity Source: Renewable/ Non-renewable in case of electrolysis	Depends on - Electricity Source: Renewable/ Non-renewable
Range (km)	High	Typically, not a concern for Sedans, SUVs, Trucks and Buses. However, for 3-Wheelers (3W) and compact cars the range would be limited by the capacity of H_2	Typically, not a concern for Sedans, SUVs, Trucks and Buses. However, for 3-Wheelers (3W) and compact cars the range would be limited by the	Constrained by battery size & weight

		cylinder that can be accommodated.	capacity of H_2 cylinder that can be accommodated.	
Infrastructure required	Well - developed infrastructure exists	Hydrogen supply and dispensing infrastructure required to be developed. For this purpose existing fuelling stations can be utilised	Hydrogen supply and dispensing infrastructure required to be developed. For this purpose existing fuelling stations can be utilised	Charging stations or battery swapping facilities required to be developed, where existing electrical network can be used. Even home chargers could be used
Refuelling time	<5 min	3-5 minutes	3-5 minutes	Typically, in hours (depends on slow/fast charging)

The availability of energy to wheels in an EV and an FCV is shown in Fig. 7.1 considering 100 units of electricity from the grid. The energy available to wheels after considering different losses in various sub-systems stands out to be 52.24 kWh for EV and 22.21 kWh for FCV. Therefore, in terms of overall efficiency of energy utilisation an EV is a better option compared to an FCV and HICEV.

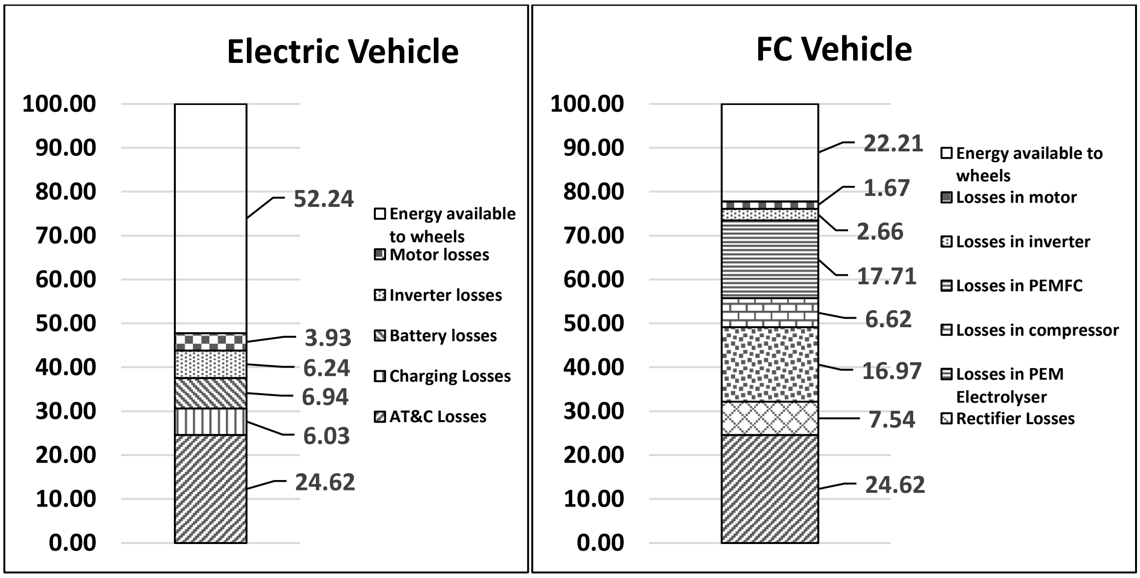

Fig. 7.1: Comparison of Energy Utilisation in an EV and an FCEV

7.2.1 Challenges associated with EV acquisition

Fig. 7.2 illustrates some of the challenges in adoption of EVs. Globally, customers rate high price (35%), lack of charging infrastructure (24%) and vehicle range (18%) as the top three issues that prevent them from buying a BEV. Other issues, though minor include uncertainty about technological developments in the future and suitability of EVs for daily use. Similar challenges exist for HICEV (H_2 Infrastructure and availability) and FCV (Cost) as well.

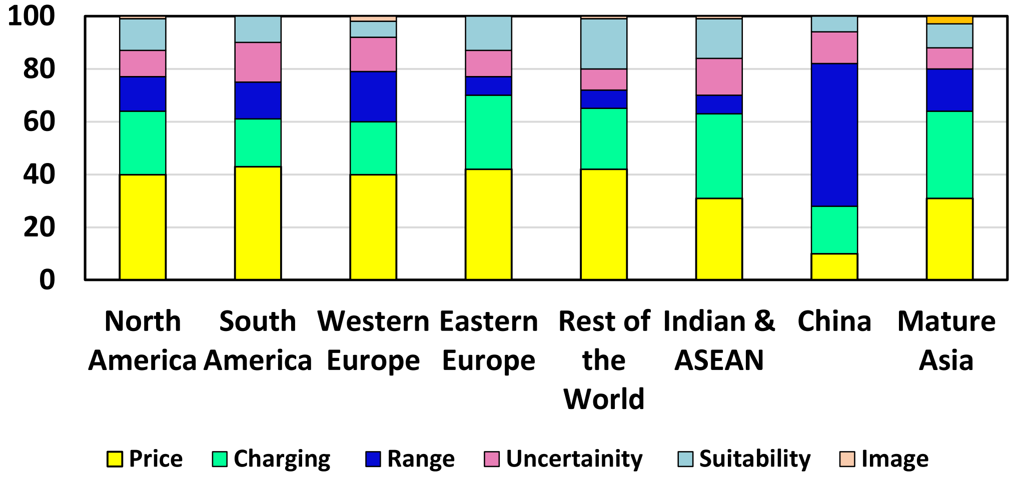

Fig. 7.2: Challenges as per prospective buyers of EVs

7.3. Cost analysis

This section dwells on cost issues related to vehicle acquisition, components and maintenance for HFVs and EVs.

7.3.1 Vehicle cost

The key power-train components in a conventional ICE driven vehicle are the engine, gear box and the driveline. The cost of power-train as percentage of total vehicle cost for ICE vehicle is about 18 – 26%. In comparison, battery pack, e-motor (with reduction gear) and associated power electronics constitute the power-train in an EV. The typical cost of an EV power-train is about 50 - 60% of the total vehicle cost. Table 7.2 compares the relative vehicle cost (for Sedans/SUVs) of ICEV, HICEV, FCV and BEV by considering ICEV as the baseline (i.e. Cost Factor =1).

7.3.2 Component cost

LIB pack and e-motor costs account for approximately 35-45% and 7-10% of the vehicle cost respectively. Within the battery pack, the main cost is for the battery cells themselves which account for 50% of pack cost. Battery Management System (BMS) and Power Electronics account for 8% and 6% respectively.

Table 7.2: Normalized Vehicle Cost Comparison for Different Powertrains

Vehicle Type	Cost Factor
ICEV	1
ICE PT (Power-train)	0.22
Vehicle	0.78
HICEV	2.5
FCV	2.5
BEV	1.33 – 1.5 (For EV models currently being sold with lower range, 1.15-1.2x of conventional ICEV) 2.5 (For EV models with similar range as ICEV)

Globally, the cost of LIB pack has shown significant drop in the last decade. LIB pack price has reduced by about 80% from 2010 (US$ 1000/kWh) to 2019 (US$ 213/kWh) and is expected to touch US$ 100/kWh in 2025 making it extremely competitive (Table 7.3). In India, since there is no production of Li-ion cells for vehicle applications, they are currently imported. This makes them expensive. For example, the landed cost of a 40 kWh Battery pack is in the range of ₹ 18,500 to 21,500/kWh, which is about 25% to 45% higher than global market. The Indian government has imposed custom duty on the import of Li-ion batteries. In 2019-20, BCD applicable on Li ion cells and battery packs is 5%, which will increase to 10% for Li-ion cells and 15% for battery packs from 1st April 2021. In addition, on some of the parts such as motors, charger, controllers etc required for manufacturing of EVs will also attract BCD @ 15% w.e.f 1st April, 2021, whereas on such components “Nil” BCD is levied presently. This was done to facilitate Indian manufacturers to produce the batteries within the country to have low cost batteries. However, the current GST rate on EVs was estimated to be around 12% on vehicles fitted with Li ion batteries, but the swappable LIB attract 18% GST.

Table 7.3: Battery Price (Li-ion) Trend Analysis

Year	US$/kWh	₹/kWh	Δ%	
2010	1000	71000	Base	
2019	213	15123	-79	Base
2025	100	7100	-90	-53

The global trend for FC cost from year 2006-2017 is shown in Fig. 7.3. The prices were stagnant during 2010 – 2016 due to lack of focus on FC technology. US DOE has given a FC system target of US$ 30 per kW (FC stack = US$ 15 per kW) in 2025 assuming a production volume of 500,000 units per year. The stack constitutes only 50% of the FC (PEM) system cost. Other parts of the system that include water management, thermal management, air management, fuel management and balance of system contribute towards another 50%.

However, currently in India, the landed price of FC stacks of 3 kW and 20 kW are US$ 5000 and US$ 13000 respectively. For a 20-kW unit, this corresponds to stack price of US$ 650/kW and system cost of around US$ 1300/kW.

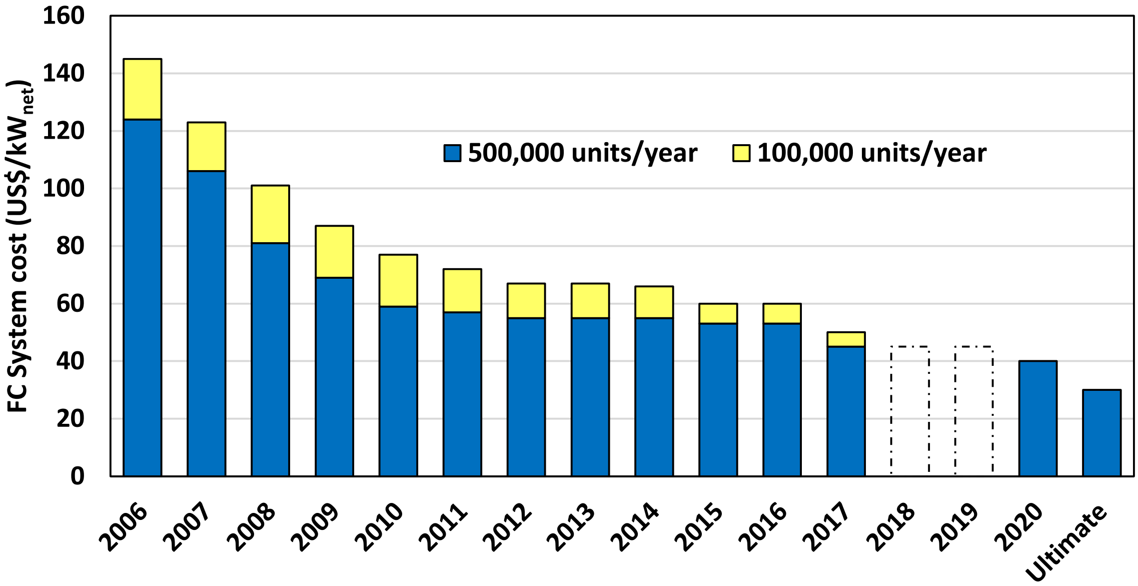

Fig. 7.3: Cost of 80-kW$_{net}$ PEM FC system (US$/kW) based on high-volume manufacturing (100,000 and 500,000 units/year).

7.3.3 Vehicle maintenance cost

Maintenance cost for an EV is cheaper due to fewer moving parts and less wear on the brakes due to energy regeneration. However, we do not yet have enough experience to know the average life of present battery packs. Early data from TESLA vehicle owners' shows that after an initial 5% drop in capacity over the first 40,000 km, most batteries didn't drop below 90% of their original capacity until after 250,000 km. This is more than the expected average distance travelled by a car in India in 10 years. Hence, the maintenance cost calculation of an EV, FCV would depend on the assumed lifespan of vehicle. If the vehicle lifespan is assumed more than 8-10 years, then the cost of replacement of the battery needs to be accounted for (Table 7.4).

Table 7.4: Normalised maintenance cost comparison for different power-trains

Vehicle Type	Maintenance Cost Factor
ICE Vehicle	1
BEV	0.70-0.77
FCV	1.15
HICE	1.15

7.4. Life cycle (well to wheel) emission comparison

7.4.1 GHG emission comparison

GHG emissions for a vehicle that uses electricity either to run the vehicle (EV/PHEV) or utilizes a fuel that needs electricity for its generation (e.g. hydrogen produced by electrolysis) depends on the source of electricity. GHG emissions would be lower if electricity is produced from renewable resources (wind, solar, geothermal etc) as opposed to a case wherein it is generated using fossil fuel.

The USA and European GHG emissions data for Well-to-wheels in terms of gCO_2/unit distance are given in Figures 7.4 and 7.5.

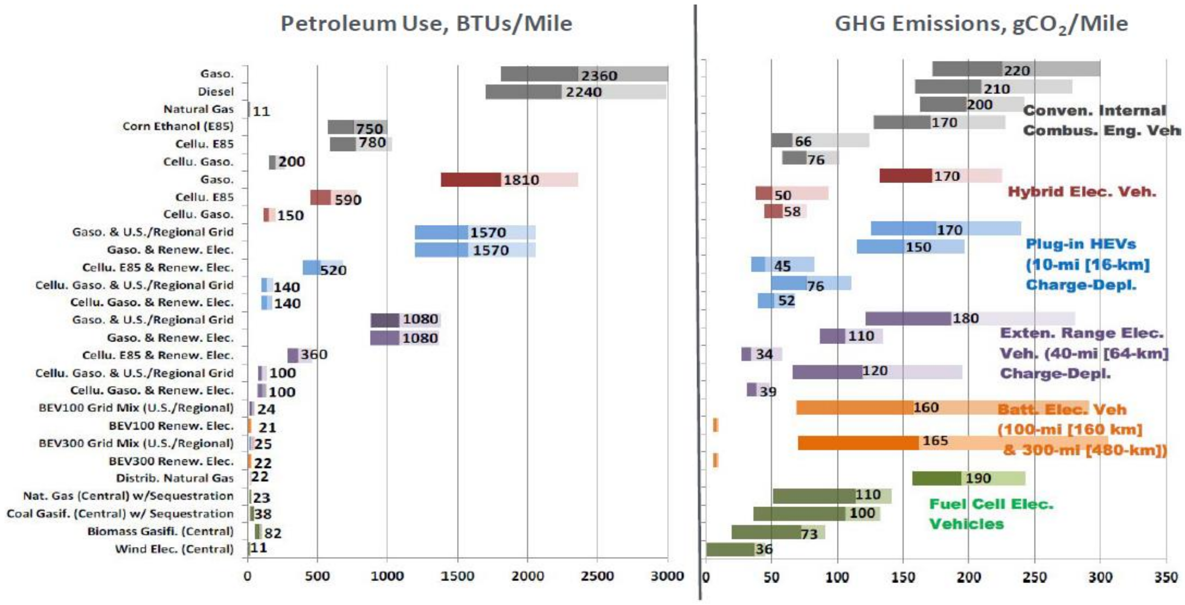

Fig. 7.4: Well to Wheels Analysis (USA)

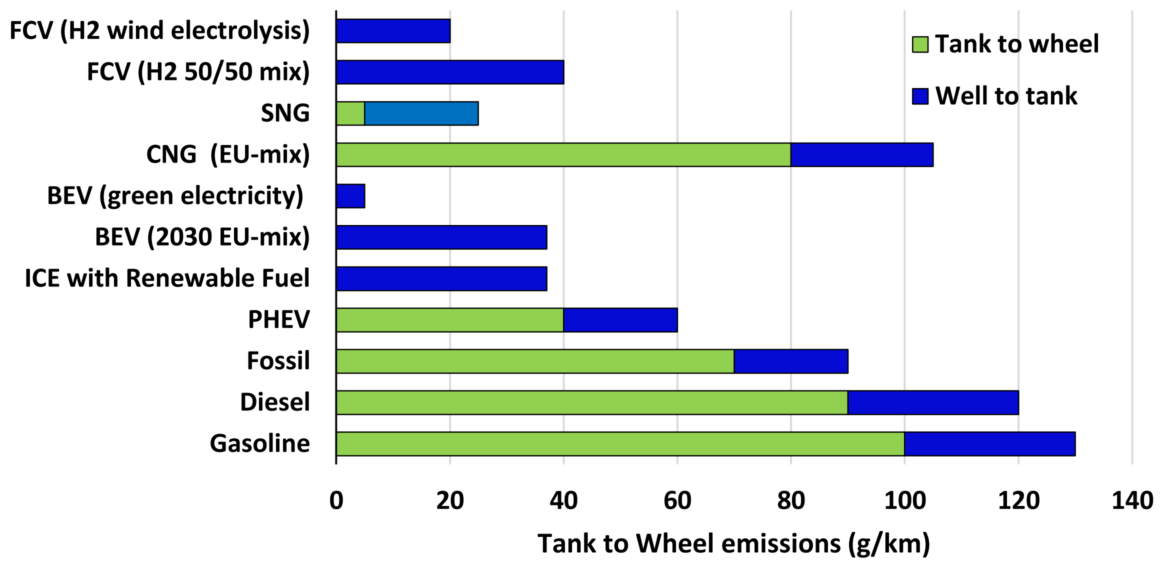

Fig. 7.5: Well to wheels analysis (Europe)

An EV using electricity from renewable source generates on an average 1% of the GHG emissions produced by a conventional ICE driven vehicle. A comparison of well to wheel GHG emissions for different types of vehicles is shown in Table 7.5. A FCV that uses H_2 produced using electricity from wind results in a life cycle GHG emission that is 16.4% of that from a conventional ICE vehicle. This value would be close to 50%, if H_2 were to be sourced from natural gas or coal. It is to be noted that for both EV and FCV, GHG emissions primarily result from well to tank and tank to wheel emissions is zero (negligible).

Table 7.5: Well to Wheel GHG Comparison

Vehicle Type	Well to Wheels GHG (EU and US)	Well to Wheels GHG (India)
ICE Vehicle	1.00	1.00
EV (Grid Mix)	0.75 (US)	1.73 (based on WTW GHG emissions comparison b/w Diesel and BEV mid-sized passenger car)
EV (Green Electricity)	0.01	0.01
FCV (H_2 Fuel from Non-renewable)	0.50	0.89 (based on WTW GHG comparison b/w FCEV operating on H_2 from SMR and conventional ICEV)
FCV (H_2 Fuel from Renewable)	0.16	0.16
HICE PT Vehicle	---	1.88

For EV, the life cycle emission is expected to reduce further by about 30% by using the following technologies (Fig. 7.6).

a) Recharging/Second life

b) Recycling

c) Grid decarbonisation

d) Greater energy density

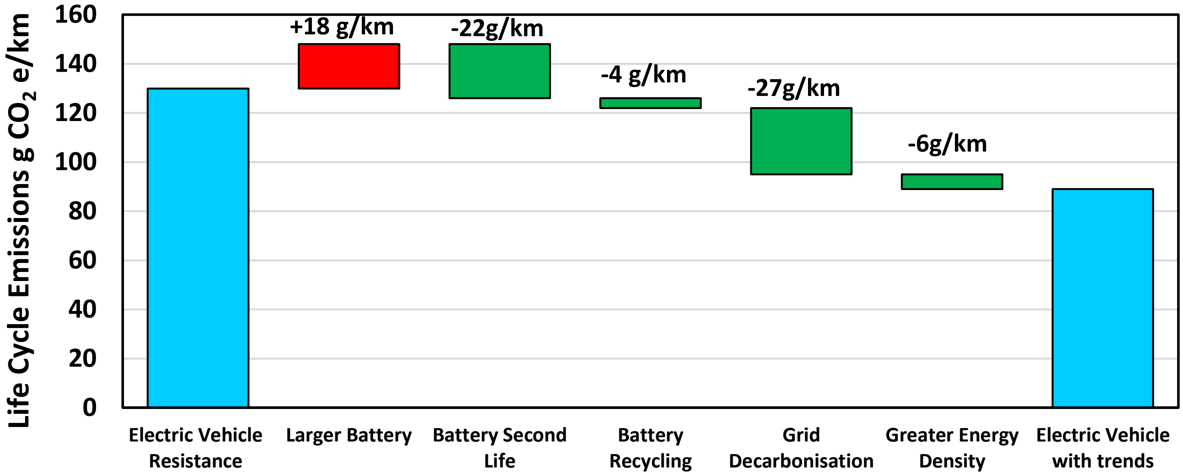

Fig. 7.6: Potential changes in battery manufacturing GHG emissions

7.4.2 Oxides of nitrogen (NO_X)

NO_x emissions from EV and FCV at tailpipe level are nil. However, this is not the case for vehicles that operate on ICE. Even for an ICE vehicle that operates on hydrogen, NO_x emissions are present due to high combustion temperature. Figure 7.7 compares the NOx emissions from a 1-cylinder engine running on gasoline and hydrogen. It is seen that NO_x emissions from hydrogen engine are comparable or lower than a gasoline engine.

IIT Delhi has done extensive research with regards to reduction of NO_x from HICE operated under ultra-lean conditions. In one such study, turbocharger was used to compensate for drop in low speed torque due to ultra-lean operation. A combination of NO_x reduction strategies such as Exhaust Gas Recirculation (EGR), retardation of spark timing and exhaust after-treatment based on hydrogen selective catalyst reduction was successfully used to reduce NO_x. Hydrogen was injected into the exhaust stream according to NO_x concentration generated, to reduce NO_x over Pt/Rh based catalytic converter.

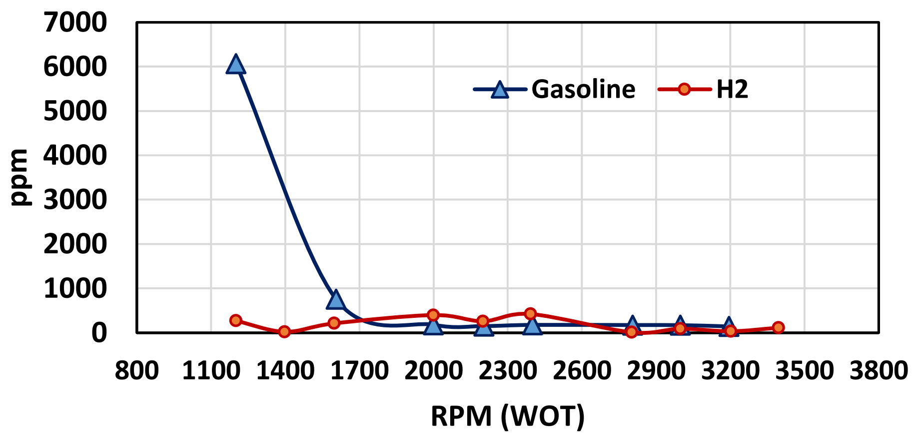

Fig. 7.7: NOx Emission Data for 1-Cylinder Engine

7.5 Effect of range on power-train selection

Power-train selection has a big influence on the desired vehicle range (in km) i.e. distance that can be travelled with one full tank/cylinder of fuel or one full charge of battery. Power-train cost including fuel storage for conventional ICE, EV and FCV is shown in Table 7.6. The cost has two main elements namely:

- Cost for the unit that generates the motive power (e.g. ICE for ICEV, FC Stack + E-motor for FCV and E-motor alone in case of EV)
- Cost of energy storage (e.g. Fuel Tank for ICEV, H_2 Cylinder for FCV and Battery in case of EV)

Table 7.6: Power-train cost for different performance requirements

Vehicle Type	Marginal Cost for Power (US$/ kW)	Marginal Cost for Stored Energy (US$/kWh)
ICE Diesel (mild hybrid)	15	0.4
Electric Propulsion + FC	35 + 40	18
Electric Propulsion + Battery	a. 35 + 0 (for large energy storage b. 35 + 40 (for small energy storage)	a. 250 b. 500 (Power optimized battery)

It is very clear from Table 7.6 that for a given power (kW) and energy storage (kWh), ICEV has the lowest cost for power-train followed by FCV and BEV. In case of BEV, the cost for energy storage is high and hence BEV becomes prohibitively expensive when high energy storage is needed i.e. high range is desired.

Battery costs balloons dramatically with increase in vehicle weight and desired range. In case of a compact SUV (ICEV) that weighs 1500 kg and has a range of 480 km (300 miles), Fig. 7.8 indicates that drive-train costs for a comparable EV would be almost twice or more.

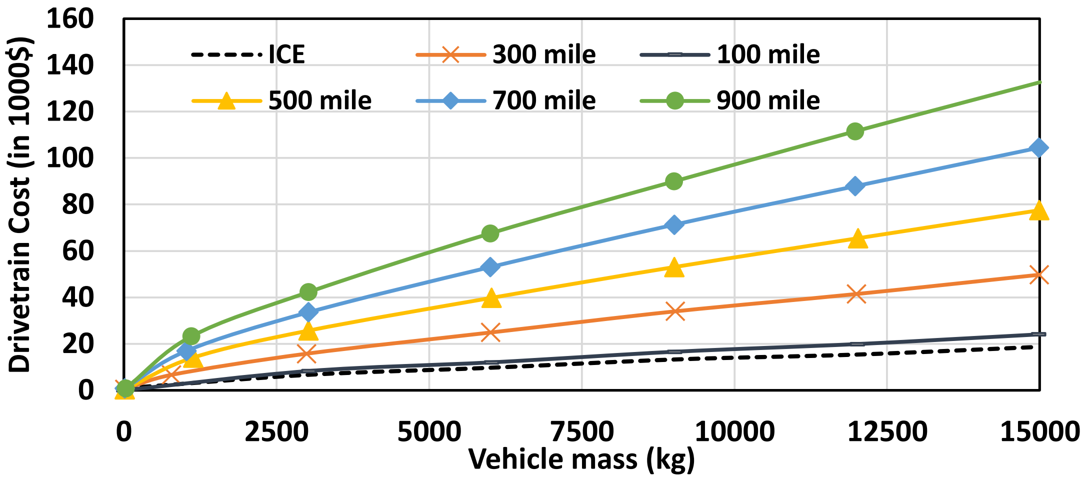

Fig. 7.8: Drive-train cost comparison (ICE vs BEV)

It is clear from the above data that EVs are best suited for shorter ranges, for example, within city limits. When designed for long range applications, EVs tend to become heavier and prohibitively expensive. For longer range, FCV and HICEV are better suited amongst the alternative power-trains. Fig. 7.9 shows the relationship between system cost and vehicle cruising range for EV and FCV.

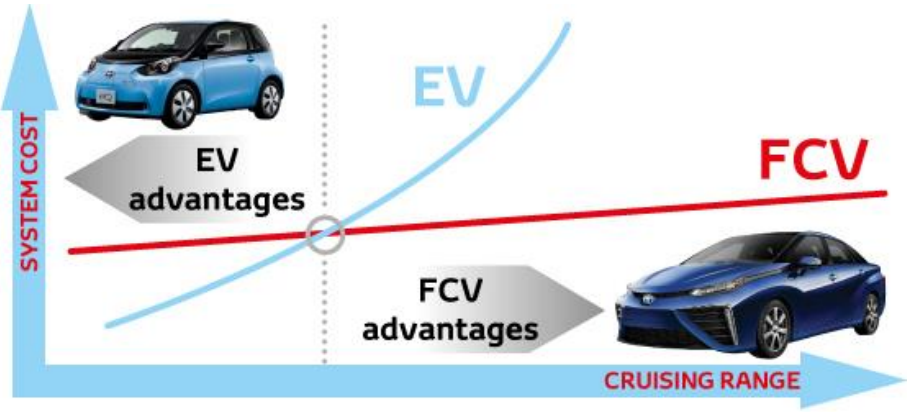

Fig. 7.9: Relationship between system cost and design range for EV & FCV

Based on the above, one possibility for India would be to explore having battery charging stations within city limits and along short well defined routes (e.g. bus routes) while adapting existing fuel pumps (or locations) along highways for dispensing hydrogen to serve FCVs and HICEVs.

7.6 Conclusions

EVs and HFVs are alternatives for conventional ICEVs. However, both groups have their own pros and cons. In case of EVs, major issues are high vehicle cost (for similar range as ICEV), low vehicle range, long recharging time and lack of charging infrastructure. Availability of pure hydrogen at an affordable price and hydrogen infrastructure are the major challenges for HFVs. In FCV, high cost of FC stack is also a challenge. Stacks and other components like composite cylinder, traction motors etc are currently imported as there is presently no domestic demand for FCV.

In India, in view of the above, it is prudent to explore both of these categories of vehicles and apply based on vehicle usage pattern. For example, EV is best suited for shorter range applications like within city and tends to become prohibitively expensive for heavier vehicles and long range applications. HFVs would suit these applications better.

The source of electricity is very important whether it is EV or an HFV running on H_2 derived from electrolysis. Well to wheel GHG data for India (Table 7.5) clearly indicate that both BEV and HICEV may be worse than conventional ICEV if electricity utilised is from a non-renewable source.

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CHAPTER 8: COST OF OWNERSHIP BASED ON LIFE CYCLE COST OF ELECTRIC AND HYDROGEN FUELLED VEHICLES

8.1 Introduction

This report makes an attempt to compare competitiveness of different types of EVs being deployed in India, HFVs developed in India (three wheelers and mini bus using ICE and FC bus) with the similar vehicles operated using fossil fuels (petrol, diesel or CNG). This comparison can be made by estimating the "Cost of Ownership" of the vehicles based on life cycle cost of the different vehicles that are operated using different fuels.

8.2 Cost of Ownership on Life cycle Basis

The total cost of a vehicle during its useful life depends upon the initial investment, the annual operation and maintenance cost and the salvage value of the vehicle at the end of its useful life, as given in the following expression:

$$C = C_o + R_1 * C_i - R_2 * C_n \qquad (8.1)$$

Where C is the life cycle cost of the vehicle for its useful life of n years; C_o is the initial investment made for acquiring the vehicle; C_i is the uniform annual operation and maintenance cost of the vehicle; C_n is the salvage value of the vehicle at the end of n years; R_1 is a factor for estimating present value of recurring uniform yearly expenditure; and R_2 is a factor used for determining the present value of the cash flow that may occur in future. d is discount rate and its value has been assumed to be 0.08. R_1 and R_2 are determined using the following expressions:

$$R_1 = \frac{(1+d)^n - 1}{d(1+d)^n} \qquad (8.2)$$

$$R_2 = \frac{1}{(1+d)^n} \qquad (8.3)$$

The annual operation and maintenance cost considered in the study has been worked out considering only the fuel cost and maintenance cost. Annual Fuel cost (C_f) can be worked out using the following expression:

$$C_f = \frac{X * p}{u} \qquad (8.4)$$

Where X is the average distance covered in km in a year (assumed as 60,000 km); p is the unit rate of fuel in (₹/kg or ₹ /L or ₹ /kWh); and u is the fuel economy of the vehicle (km/L or km/kg or km/kWh). For IC engine vehicles maintenance cost has been considered as per data provided by M&M and for FC bus it has assumed to be about 7% of vehicle cost. For EVs it has been considered as 4% of vehicle cost.

8.3 Initial Cost of Hydrogen Fuelled Vehicles

8.3.1 The prototypes of various HFVs have been developed in India by the automobile companies with financial support provided by the GoI. These vehicles are not being produced commercially in the country presently. Many of the critical components such as composite cylinders and solenoid valves for on-board hydrogen storage for both the ICE and FCVs are being imported. Similarly, for the FCVs, FCs and traction motors etc. have been imported for the prototypes FC buses developed by TML. For EVs, LIB packs are imported. Fig. 8.1 shows ex-works unit cost of HICE three-wheeler for different order sizes to capture the effect of economy of scale and compares it with unit cost of a similar diesel fuelled ICE three-wheeler. Prototypes of HICE three-wheeler has been produced by M&M. Cost of a composite Type III cylinder and solenoid valve, which are imported and are used in HFVs, would be quite significant in comparison to existing fuel tank of diesel operated three-wheeler. It may be one reason for relatively higher unit cost of hydrogen fuelled three-wheeler as compared to unit cost of diesel three-wheeler.

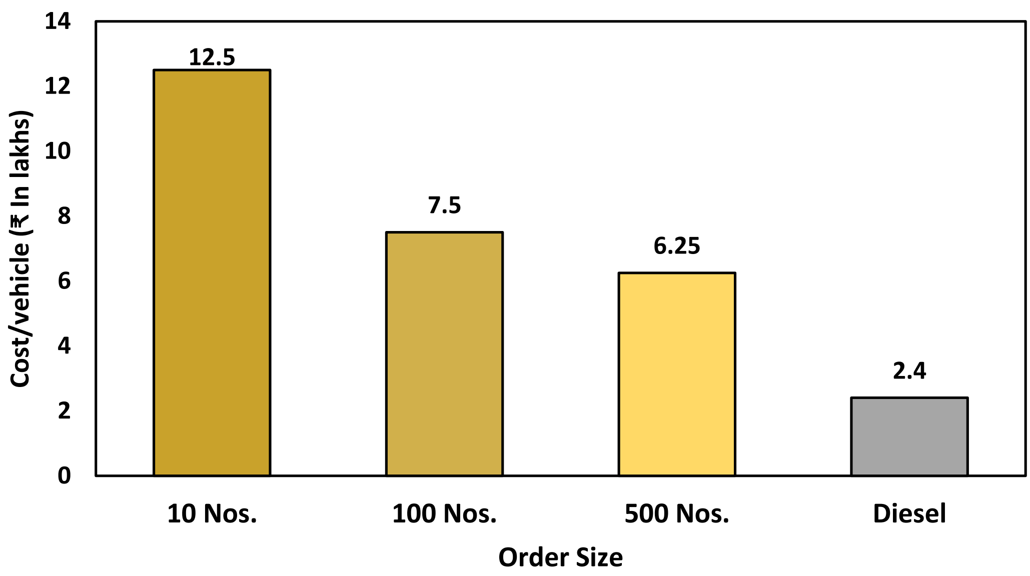

Fig. 8.1: Unit cost of hydrogen ICE 3 Wheeler and similar diesel 3 Wheeler

Unit costs of HICE mini bus (26 seater with length of 6.3 m) for different order sizes along with unit cost of an equivalent capacity diesel bus are shown in Fig. 8.2.

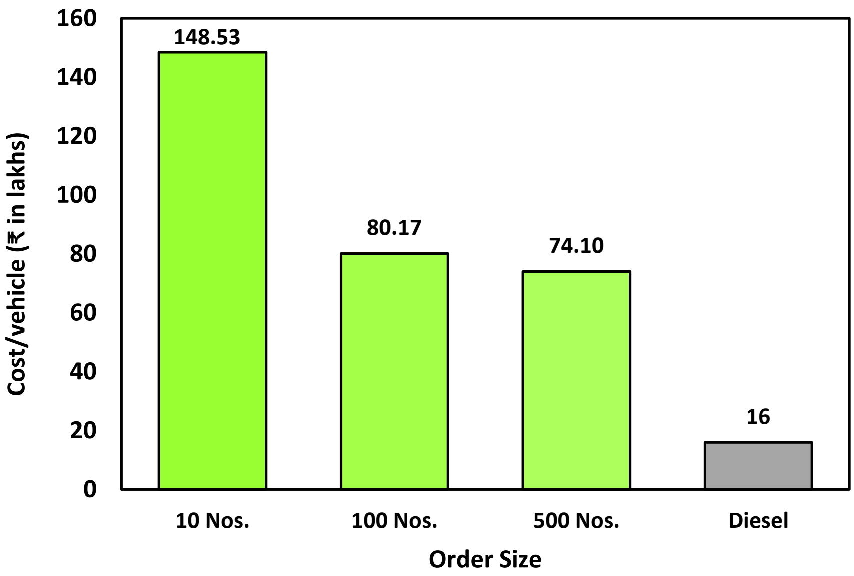

Fig. 8.2: Unit cost of Hydrogen Fuelled ICE Mini Bus and similar Diesel Bus

For hydrogen-diesel dual fuel ICE Sports Utility Vehicle (SUV) i.e. Scorpio, unit costs for different order sizes along with unit cost of similar diesel fuelled vehicle are shown in Fig. 8.3.

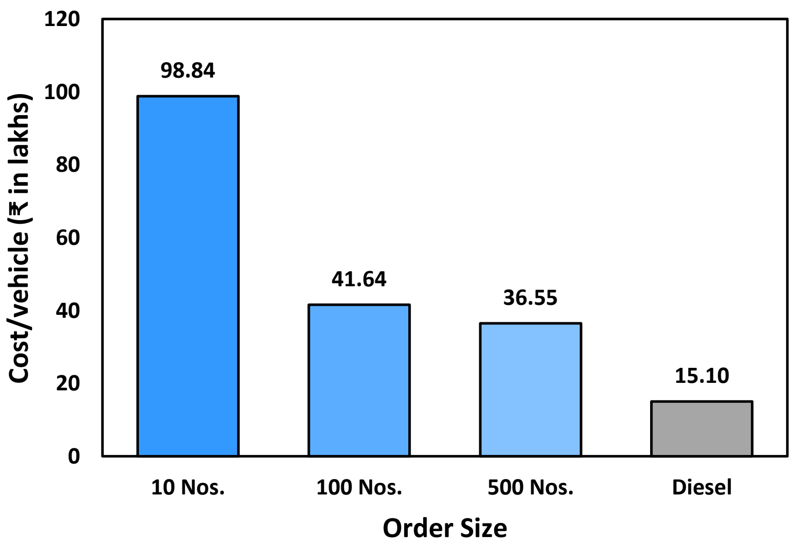

Fig. 8.3: Unit cost of Hydrogen-Diesel Dual Fuel and similar Diesel SUVs

For FC bus (low floor with length of about 12 m), unit costs values for different order sizes along with unit costs of similar low entry diesel and CNG fuelled buses are shown in Fig. 8.4, Fig. 8.5 and Fig. 8.6 respectively.

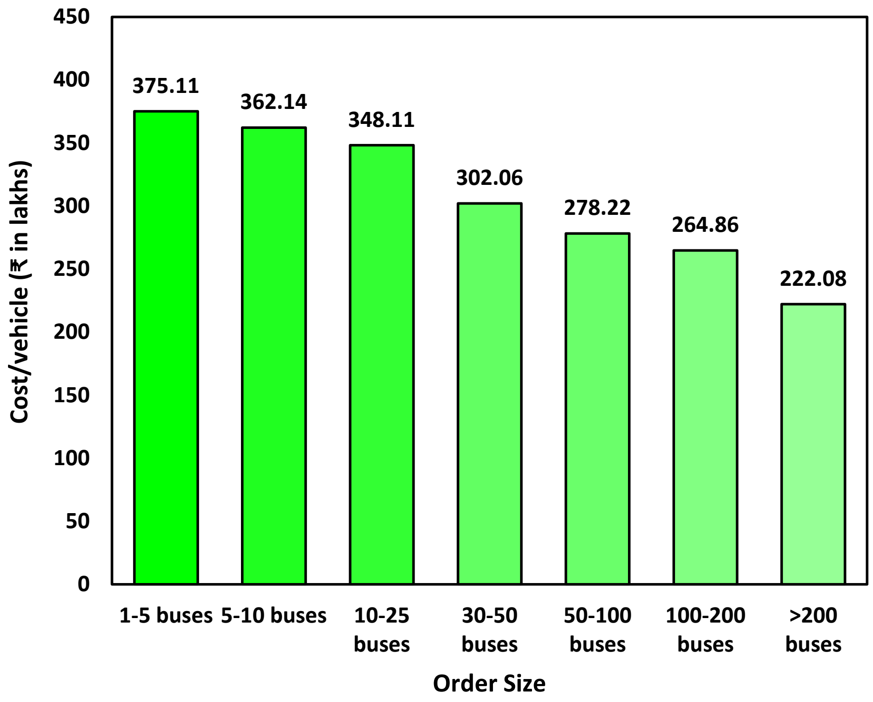

Fig. 8.4: Unit cost of FC Bus

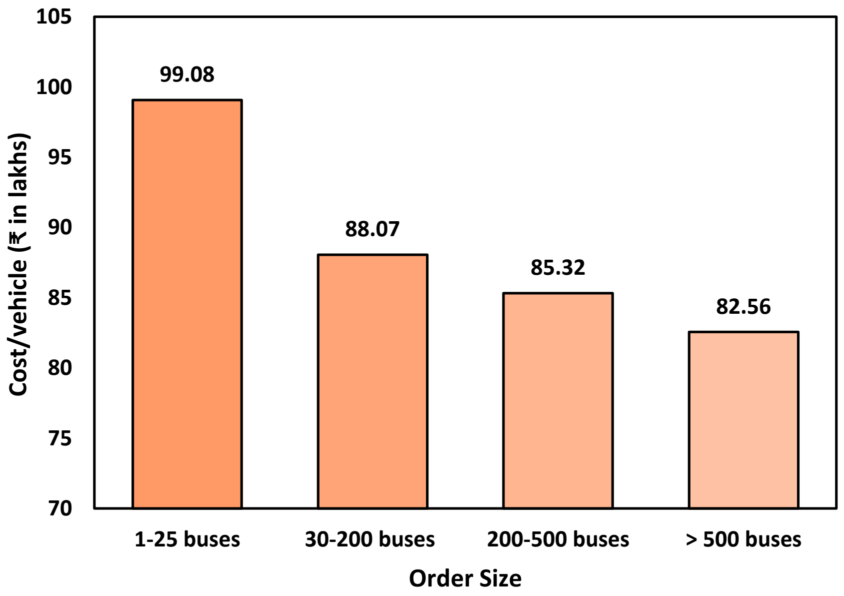

Fig. 8.5: Unit cost of Low Entry Diesel Bus

A typical electric three-wheeler with 7.37 kWh LIB may be costing about ₹ 2.2 lakh in India. Ex-showroom prices of some of the electric cars that are available commercially in the Indian market are shown in Table 8.1, which makes it clear that capacity of LIB has direct impact on the range and Ex-showroom price of the electric car, as depicted in Fig. 8.7.

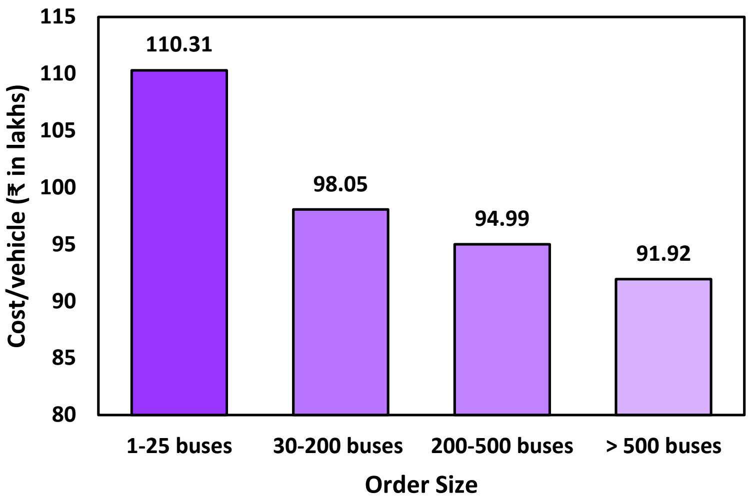

Fig. 8.6: Unit cost of Low Entry CNG Bus

Table 8.1: Ex-showroom price of some of electric cars commercially available in India

Manufacturer	Model	LIBs Capacity (kWh)	Driving Range (km)	Price Range (₹ in lakh)
Hyundai	Kona	39.2	452	23.71 – 23.90
Mahindra & Mahindra	e20 Plus	10.8	100	7.57 -8.33
	eKUV 100	15.9	140	8.25
	Verito	21.2	140	10.11 – 10.47
MG	ZS EV	44.5	340	20.88 – 23.58
Tata Motors Ltd.	Tigor	21.5	213	9.99 – 10.09
	Nexon	30.2	312	13.99 – 15.99

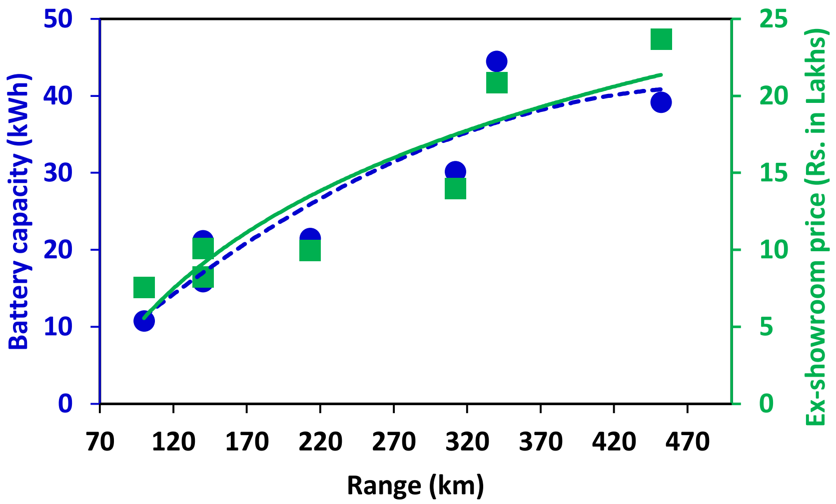

Fig. 8.7: Impact of battery capacity on EV range and price

The price of an e-bus is dependent on its length, range, floor height, seating capacity and battery capacity. Based on the bids invited by various state transport undertakings, Department of Heavy Industries had fixed indicative benchmark prices for e-buses in India in 2018 as indicated in Table 8.2.

Table 8.2: Bench-mark Cost of some electric buses in India

Manufacturer	Length (m)	Range (km)	Floor Height (mm)	Seating capacity (Nos.)	Battery capacity (kWh)	Indicative benchmark price inclusive of all taxes and duties (₹ in lakh)
Tata Motors Ltd.	9	150	900	31	125	74.9
	12	150	900	40	125	88
Goldstone Infratech Ltd	9	200	650	31	162	122.97
	12	300	400	40	320	175
VE Commercial Ltd.	9	80	890	27	124	99.83

It may be seen from the above that the unit cost of purchasing both HFV and EV is higher compared to similar fossil fuel-based vehicle. This can be attributed to a number of reasons, including stage of product life cycle, production volume, dependency on imports for critical items such as composite cylinders and solenoid valves for on-board hydrogen storage, FC stacks, traction motors, LIBs etc.

8.3.2 Internationally Toyota Mirai, Honda Clarity and Hyundai Nexo are being sold in the USA, Europe, Japan and Korea with average selling price as given in Table 8.3.

Table 8.3: Price and specifications of available FC Cars in market

Manufacturers	Model	FC power output (kW)	H_2 storage		Range (km)	Cost (US$)
			Mxm. Pressure (bar)	Mxm. weight of H_2 (kg)		
Toyota	Mirai	114	700	~ 5	483	66,000
Honda	Clarity FC	103	700	~ 5.5	355	67,300
Hyundai	Nexo	95	-	~ 6.3	600	63,000

Internationally, a typical FC bus costs about US$ 1.2 million (₹ 8.50 crore). European studies indicate that the cost of FC bus may be in the range of Euro 625,000 to 1,000,000 (₹ 4.45 to 7 crore) depending on order size. Toyota Sora FC bus costs about US$ 945,000 (₹ 6.7 Crore). There may be some variation in the specifications of FC buses developed and marketed elsewhere and the one that have been developed in India by TML. But in terms of initial capital cost, FC buses developed by TML appear to be quite competitive as the unit cost is in the range of ₹ 2.22 to 3.75 crore, depending on the order size in comparison to the average cost of ₹ 4.45 - 7 crore in the Europe and the USA.

8.4 Break-up of cost of an FCV bus

Purely in terms of the unit cost of HFVs based on the very small order size up to 500 vehicles, these are not competitive vis-à-vis similar diesel and CNG vehicles that are available commercially in the country. Fig. 8.8 shows the relative cost of the different sub-systems of FC bus, developed by TML. The relative cost of the sub-systems that include these critical imported systems such as composite cylinders, solenoid valve, hydrogen injectors, FC stacks, traction motors etc., as shown in Fig. 8.8 is quite significant. However, the potential for bringing down the unit cost of the FC bus may be quite significant if the critical components such as composite cylinders, solenoid valve, hydrogen injectors, FC stacks, traction motors etc. are produced in the country and the demand for the vehicles can be created through regulatory measures and by providing fiscal and financial incentives like other environmentally sustainable and clean energy vehicle technologies.

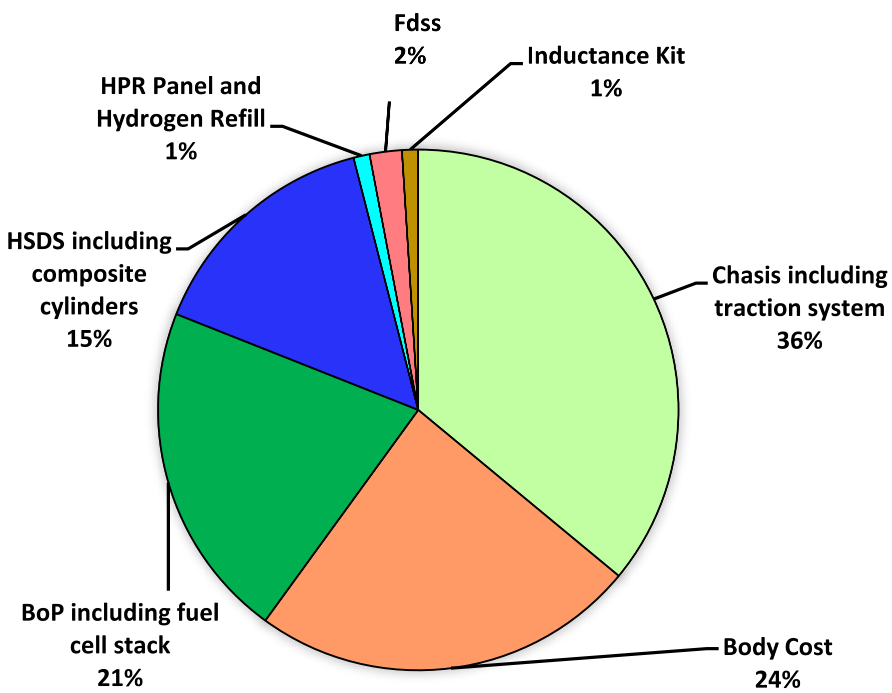

Fig. 8.8: Relative cost of the different sub-systems of FC Bus developed by TML

8.5 Energy content per unit of money for different fuels

For new energy carriers such as electricity and hydrogen that can be used in almost all sectors of the economy, it is better to compare their cost in terms of energy delivered per unit of money (MJ/₹) with other established fossil fuels. Fig. 8.9 shows this comparison. It is clear from Fig. 8.9 that energy content of electricity per unit of money is comparable to petrol, diesel and methanol. However, in case of hydrogen depending on its cost (procured from different sources), energy content per unit of money could be more cost competitive compared to petrol, diesel or methanol.

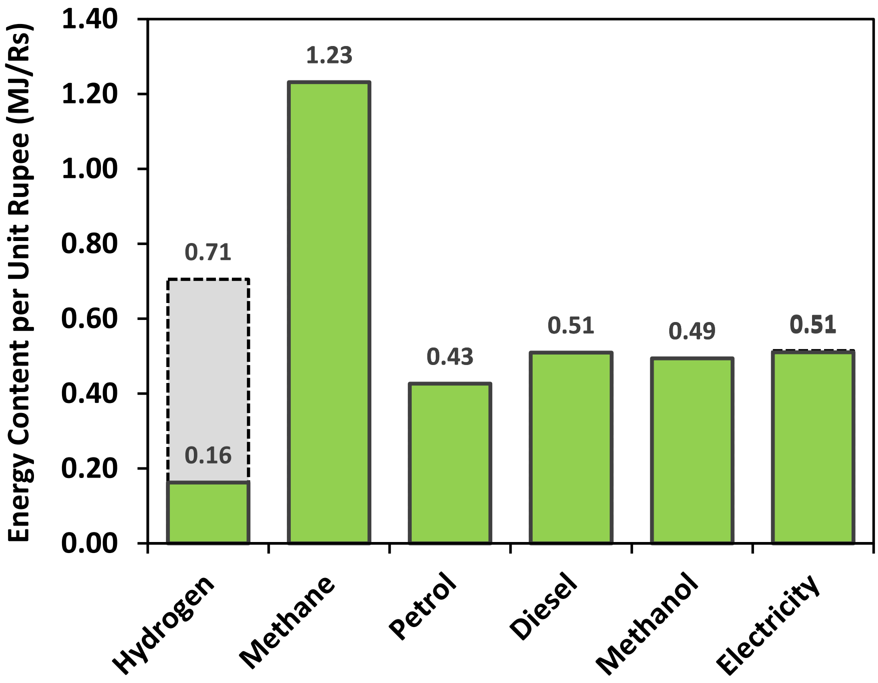

Fig. 8.9: Comparison of energy content per unit money for different fuels

8.6 Energy consumption and fuel cost for operation of different vehicles

Table 8.4 depicts the values for energy consumption and fuel cost for running the vehicle for one km, depending on the calorific value of fuel, prevailing fuel cost and mileage of the vehicles that are commercially available or have been developed as prototypes in India. It emerges very clearly that EVs have advantages both in terms of energy consumption per km (due to higher efficiency of electric drive trains) and minimum fuel cost per km. For some niche areas, where hydrogen may be available easily and at a competitive rate of about ₹ 200/kg, some HFVs may be competitive to similar fossil fuelled vehicles in terms of fuel running cost. In terms of energy consumption per km of vehicle operation, electric bus is the best option and FC bus is a better option compared to low entry diesel and CNG buses, provided hydrogen cost is ₹ 200/kg. However, diesel fuelled ICE vehicles are better compared to HICE vehicles in view of higher brake thermal efficiency of diesel engine compared to hydrogen engine.

Table 8.4: Energy consumption and Fuel Cost for Operation of different Vehicles for 1 km

S. No.	Type of Vehicle	Energy Consumption (MJ/km)	Fuel Cost (₹/km)
1	3 Wheeler – H_2 ICE	1.84	3.08-13.08
2.	3 wheeler - Diesel	1.68	3.30
3.	3 wheeler - electric	0.18	0.35
4.	Scorpio: Hydrogen-Diesel Dual Fuel	11.15	10.38-17.66
5.	Scorpio – Diesel	9.88	8.14
6.	Electric car	0.33	0.64
7.	Mini Bus- H_2 ICE	4.80	8.00-34.00
8.	Mini Bus - Diesel	3.53	6.92
9.	FC Bus – Low Floor	11.99	20.00-85.00
10.	Large Bus – Low Entry AC - Diesel	26.56	43.25
11.	Large Bus – Low Entry AC - CNG	26.32	21.37
12.	9 m urban Electric Bus	3.6	7
13	12 m urban Electric Bus	4.86	9.46

8.7 Life cycle cost of ownership of different vehicles

In order to compare HFVs and EVs with similar fossil fuelled vehicles, an attempt has been made to estimate the cost of ownership of the vehicles by determining the present value of operation and maintenance costs over useful life of eight years. While doing so, different scenarios have been developed based on the cost of hydrogen and initial cost of acquisition of vehicle. HFV being environment friendly has been considered in the same category as other environment friendly vehicles such as EVs, for promotion of which GoI is providing financial assistance or subsidy. In Table 8.5, for different initial cost of acquisition considering different order sizes to take the benefit of economy of scale; varying hydrogen cost and different levels of financial assistance, cost of ownership of HFVs and EVs have been worked out and is compared with similar vehicles fuelled by diesel or CNG. In terms of life cycle cost of ownership, EVs have advantage over their competitors, even without any kind of incentives either for acquisition of vehicle or supply of electricity.

It is worth mentioning here that for promoting acquisition of FCVs, Japan and South Korea are providing very attractive subsidies to buyers. For FC cars, subsidies range from 38% to 54% in

Japan and about 50% in South Korea. For acquiring FC bus, Japan is providing subsidy of about 68% to 87% for different category of users. For making hydrogen fuel attractive to HFV owner, Japan is providing financial assistance for both setting up HRS and also for their operation.

Table 8.5: Cost of Ownership of Hydrogen Fuelled Vehicles and comparison with similar fossil fuelled vehicles

(Amount in lakh of Indian Rupees)

Type of Vehicle	Order size for Vehicles	Unit cost of vehicle	Scenario-I	Scenario-II	Scenario-III	Scenario-IV	Scenario-V	Scenario-VI
3W-H_2 ICE	10	12.50	60.29	25.81	33.43	26.80	31.58	24.95
	100	7.50	55.29	20.81	30.18	23.55	29.08	22.45
	500	6.25	54.03	19.56	29.37	22.74	28.46	21..82
3W-Diesel	-	2.40	14.85	14.85	14.85	14.85	14.85	14.85
3 W-Electric	-	2.22	3.91	3.91	3.91	3.91	3.91	3.91
Scorpio-DF	10	98.42	150.75	125.66	100.09	95.27	85.42	80.59
	100	41.63	93.55	68.45	62.91	58.08	56.81	51.99
	500	36.55	88.46	63.37	59.60	54.78	54.27	49.44
Scorpio-D	-	15.10	44.49	44.49	44.49	44.49	44.49	44.49
Electric car	-	14.00	19.42	19.42	19.42	19.42	19.42	19.42
Mini Bus-H_2	10	148.52	269.50	179.85	159.60	142.24	137.62	120.38
	100	80.17	201.15	111.50	115.17	97.93	103.44	86.21
	500	74.09	195.07	105.42	111.23	93.98	100.41	83.17
Mini Bus-D		16.00	44.02	44.02	44.02	44.02	44.02	44.02
FC Bus	1-5	375.11	765.83	541.72	453.83	410.73	382.92	339.82
	5-10	362.14	749.49	525.37	443.21	400.11	374.75	331.64
	10-25	348.11	731.81	507.69	431.71	388.61	365.90	322.80
	30-50	302.06	673.77	449.65	393.98	350.88	336.88	293.78
	50-100	278.22	643.72	419.61	374.46	331.36	321.86	278.76
	100-200	264.86	626.88	402.76	363.51	320.41	313.86	270.34
	>200	222.08	572.97	348.85	328.47	285.37	286.48	243.38
Bus-Diesel Low entry AC	1-25	99.07	285.38	285.38	285.38	285.38	285.38	285.38
	30-200	88.06	270.24	270.24	270.24	270.24	270.24	270.24
	200-500	85.31	266.45	266.45	266.45	266.45	266.45	266.45
	>500	82.56	262.67	262.67	262.67	262.67	262.67	262.67
Bus-CNG Low entry AC	1-25	110.31	225.39	225.39	225.39	225.39	225.39	225.39
	30-200	98.05	208.54	208.54	208.54	208.54	208.54	208.54
	200-500	94.99	204.33	204.33	204.33	204.33	204.33	204.33
	>500	91.92	200.11	200.11	200.11	200.11	200.11	200.11
E Bus 9m	-	74.9	116.25	116.25	116.25	116.25	116.25	116.25
E Bus 12m	-	88.0	140.85	140.85	140.85	140.85	140.85	140.85

Scenario-I : No subsidy on hydrogen vehicle; Hydrogen cost – ₹ 850/kg
Scenario-II : No subsidy on hydrogen vehicle; Hydrogen cost – ₹ 200/kg
Scenario-III : Subsidy on hydrogen vehicle – 35%; Hydrogen cost – ₹ 425/kg
Scenario-IV : Subsidy on hydrogen vehicle – 35%; Hydrogen cost – ₹ 300/kg
Scenario-V : Subsidy on hydrogen vehicle – 50%; Hydrogen cost – ₹ 425/kg
Scenario-VI : Subsidy on hydrogen vehicle – 50%; Hydrogen cost – ₹ 300/kg

The analysis shows that if 50% financial assistance is provided to FCVs and cost of hydrogen becomes ₹ 300/kg, FC bus may have lower cost of ownership compared to a similar diesel fuelled vehicle. This study clearly shows that not only cost of acquisition of HFVs is presently high in India but even the cost of hydrogen fuel is high in comparison to fossil fuels. High cost of hydrogen vehicle is mainly because of the fact that it is a new technology, where there is hardly any demand at present and a number of critical components are required to be imported. If a favourable ecosystem could be created for these environment friendly vehicles, it would be possible to create demand for them and it would result in bringing down the cost of vehicles. If critical components like FC stacks, traction motors and composite cylinders for on board hydrogen storage are manufactured in India, it would be possible to bring down the cost of production of such vehicles. However, for bringing down the cost of ownership of hydrogen vehicles, financial assistance for vehicles and hydrogen fuel may be essential in initial phase on the similar lines as incorporated in the programme on e-mobility, which has provisions for financial assistance for acquisition of BEV and also for setting up of charging infrastructure. The analysis for cost of ownership carried out in this study is quite preliminary and based on the input data provided by the industry. There is a need for carrying out more exhaustive analysis by professionals.

References

Department of Heavy Industry, GoI (2018), "Recommendation of the committee constituted to decide benchmark price for electric buses to be procured by different STUs, for release of demand incentives"

NISE (2018) "Status of Development of Hydrogen Fuelled Vehicles and Their Cost Competitiveness for Mobility in India"

CHAPTER 9: RECOMMENDATIONS

Energy demand of the Indian economy, which is the fifth largest in the world, is growing due to rapid growth in its economy and population. Energy security, climate change, worsening air quality, balancing of electricity grid due to increasing penetration of variable renewable energy in power mix, falling prices of solar and wind electricity and higher efficiency of energy utilisation in EVs are some of the drivers of growth of e-mobility. EVs have already made impressive growth in terms of their adoption by users during the last five years. GoI is also committed to put in place an eco-system for development and deployment of EVs in the country, including that of LIBs. FCV is also a member of EV family. HFVs that include both FCVs and HICE vehicles have several advantages over conventional fossil fuelled vehicles. For providing a level playing field to HFVs in India, there is a need to put in place a similar eco-system as the one that is being created for EVs and LIBs. For this purpose, the following recommendations are made:

I. Research, Development and Demonstration

1. GoI has been supporting a broad-based R&D programme for development and demonstration of hydrogen energy and fuel cells covering renewable resource-based hydrogen production, its storage and applications of hydrogen for transport and stationary power generation applications for more than two decades. These efforts led to development of laboratory scale technologies for hydrogen production and its storage. Prototypes of HICE and FC based vehicles were also developed, which underwent limited field trials. However, these technologies were not fully ready for commercialisation. Thus, collaborative R&D efforts with involvement of academic institutions and industry for achieving well defined goals are needed to be supported in mission mode for the identified areas of hydrogen energy and fuel cells for bringing them on par with the international status. This would have to be done under a well-developed RD&D programme based on gap analysis to be undertaken through a consultative process with involvement of all stakeholders. This activity needs to be supported for a medium term of about 5-10 years. As one of the components of RD&D programme, the technologies and prototypes that have already been developed needs to be taken up for wider demonstration with proper monitoring. This may be taken up as a short-term activity for 2-3 years and would help in commercialisation of

the technologies. Basic R&D is the backbone of any technology development programme and therefore needs to be supported for a long term of 10-15 years.

2. Demonstration for HFVs for public transport (buses, mini-buses, taxis and three-wheelers) should preferably be taken up at niche areas, where facilities for supply of hydrogen are already available – petroleum refineries and chlor-alkali units, which are located at several places in the country. Such an arrangement will not involve creation of new facility for production of hydrogen. Many of the petroleum refineries have surplus hydrogen production capacity and also surplus by-product hydrogen, including that fraction which is used as fuel in-situ, available from chlor-alkali units could be tapped for operation of HFVs.
3. Among HFVs, FCV and HICE are not mutually conflicting from utilisation point of view. The experience gained through long-term persistent R&D efforts in the country resulting in prototype vehicle development on HICE and HCNG can be taken advantage of by immediately adopting them for demonstration purpose for public transport. This would help in acquiring experience of handling hydrogen as an automotive fuel in a safe manner. These HFVs could be deployed during a transition phase till economically viable India-specific technology of FCVs is mature and ready for deployment on road.
4. If ICE activities are encouraged, hydrogen can be used in existing CI engine-operated vehicle using biodiesel (in place of diesel) from locally available renewable resources. Some R&D activities have already been carried out in this area in IITs. Such an approach can also be adopted for diesel-operated buses and trucks plying on Indian roads till FCV technology mature for widespread applications.
5. Feasibility of converting CNG vehicles into H-CNG may be explored based on the results of a preliminary demonstration project being implemented jointly by IOCL and DTC in New Delhi.
6. Demonstration of FCVs, preferably developed in India, should be undertaken concurrently along with HICE with a view to develop India-specific technology. However, such demonstration projects may be initiated at the niche locations in the country. Availability of inexpensive hydrogen of the desired quality, availability of favourable infrastructure for operation and maintenance of such a new technology and sustainability of operation of FCVs could be some factors for determining suitable locations for demonstration of FCVs.

II. Lithium Ion Batteries

7. India, which has an ambitious programme for development and deployment of EVs and energy storage for grid balancing but does not have infrastructure for manufacture of Li-ion cells must establish domestic facilities for manufacture of Li-ion cells and packs. This would make India self-sufficient in this critical technological area and not remain dependent on imports.
8. The raw materials required for making LIBs are naturally available but are concentrated in certain parts of the world. A long-term supply arrangement needs to be worked out with countries having such reserves to ensure stable supplies of raw materials at a reasonable price.
9. As an alternative, recycling of materials from used LIBs be seriously considered for warding off any problems in disruption in supplies of raw materials.
10. A critical issue would be to produce LIB battery cells and packs at an economical and competitive cost in India and thereby ward off the Indian industry from the competition of the international suppliers, who would be able to supply such batteries at lower cost due to economies of scale of their manufacturing plants. It would also be imperative to establish infrastructure for manufacturing of the entire value chain for LIBs in the country at the earliest to enable Indian industry to be benefitted by rapidly expanding market for LIBs and EVs. The lessons learnt from deployment of predominantly imported solar photovoltaic panel-based power plants in India on a large scale must be taken into account for encouraging manufacturing of LIBs in India at a cost competitive price, though GoI has already announced some policy measures in this regard.
11. A policy for safe disposal of used LIBs by the users and manufacturers be put in place at the earliest in view of toxicity of some materials used for manufacture of LIBs.

III. Hydrogen Production and Storage

12. For hydrogen production, electrolyser is a critical component and it is mainly imported. BARC has developed technology of alkaline electrolysers up to 30 Nm^3/hr capacity, which has been transferred to an industry. There are a few other small-scale manufacturers of electrolysers in the country. However, for making hydrogen production cost competitive, localising production of electrolysers by the reputed manufacturers would be necessary.

13. Hydrogen production through electrolysis is a highly energy intensive process and therefore efficiency of electrolysers to be manufactured in India should be higher than 70% and progressively that should be improved to 80% within a decade.
14. For meeting requirement of large quantities of hydrogen in future, production of hydrogen through thermo-chemical process utilising either waste heat of nuclear reactors or solar thermal energy could be an option.
15. Surplus or curtailed power from wind and solar farms could be utilised for production of hydrogen for injecting into natural gas pipelines, wherever feasible. This is being attempted by the European nations. Hydrogen enriched CNG/PNG would increase availability of CNG/PNG and also bring down GHG emissions from use of such blended fuels. Hydrogen produced through fermentative route of bio-wastes and gasification of woody biomass and agro residues could also be considered for injecting into natural gas pipelines. Hydrogen production through renewable routes will have impact on additional water requirement and the same needs to be considered while planning for such hydrogen production projects.
16. Fertilizer plants and petroleum refineries are the largest consumers of the hydrogen presently and hydrogen is produced there by reforming of hydro-carbon fuels. Efforts may be made to encourage these industries to produce hydrogen from renewable resources. Industries like Iron and Steel that require hydrogen as a reduction agent could make use of low cost hydrogen produced from bio-waste and biomass.
17. Type-III and Type-IV composite cylinders used for on-board hydrogen storage in HFVs are not currently manufactured in India. Such cylinders could also be used in CNG vehicles to increase their driving range. Manufacture of Type-III and Type-IV cylinders in India be undertaken and this would help in bringing down the up-front cost of HFVs.
18. For smaller HFVs such as motor cycles and three wheelers, use of swappable metal hydride-based canisters for hydrogen storage be considered due to space constraints for accommodating a composite cylinder.
19. For storage of large quantities of hydrogen, development of technologies for storage of hydrogen in depleted mines and also in hydrogen carriers like methanol and ammonia may also be considered.

IV. Hydrogen Refuelling Infrastructure

20. GoI may consider providing incentives for setting up of HRS in the country as these would be a pre-requisite for introduction and deployment of HFVs. Incentives are already being provided for setting up of charging infrastructure for EVs in the country. While taking a view on this matter, incentives being provided by other countries like Japan for setting up of HRS and their operation may be taken into consideration. It is estimated that that for operation of about 1000 HFVs with different mix of vehicles, about 4150 MT of hydrogen may be required annually and typically 60-70 HRS may have to be deployed for refuelling of these vehicles.

V. Hydrogen Fuelled Vehicles

21. HICE Vehicles have been developed indigenously with some imported sub-systems for hydrogen storage (composite cylinders and valves) and injectors. FC bus was developed in India by importing FC stack, hydrogen storage system, traction motor, etc. With a view to reduce the cost of production of FCVs in the country, it will be necessary to manufacture PEMFC stacks and other sub-systems of HFVs indigenously. This activity could be supported on the lines of setting up of LIBs.

VI. Regulatory Issues

22. Hydrogen needs to be declared as an automotive fuel in India for commercial deployment of HFVs.
23. Approval process for setting up of HRS and import of composite Type-III and Type-IV composite cylinders along with associated valves needs to be expedited by PESO.

VII. Financial Incentives

24. Both hydrogen and HFVs are new for automotive sector. The cost of acquisition of an HFV and also cost of hydrogen are high presently due to lack of demand. In order to make the upfront cost of HFVs affordable to the consumers and also cost of hydrogen as an automotive fuel competitive vis-a-vis other fuels/energy carrier, incentives in some form may be necessary. This will have to be broadly in line with EVs as EVs and HFVs are complementary.

VIII. Codes and Standards

25. Codes and standards developed by countries having more experience in terms of deploying infrastructure for production and supply of hydrogen for automotive sector

and for on-board storage and use of hydrogen in automobiles be adopted by India to accelerate the process of promotion of HFVs.

ANNEXURES

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National Institute of Solar Energy
(नवीन एवं नवीकरणीय ऊर्जा मंत्रालय, भारत सरकार के अधीन एक स्वायत संस्थान)
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F. No.: 05/02/30/2019-20/HEFC

Dated: 12.09.2019

Subject: Constitution of a Joint Group and its Terms of Reference for preparation of a report for Comparison of Electric and Hydrogen fueled Vehicles.

Hon'ble Minister of State for Power and New & Renewable Energy (I/C), Government of India in a recent meeting with the National Institute of Solar Energy (NISE), Gwal Pahari, Gurugram desired that NISE may prepare a report comparing electric and hydrogen fueled vehicles, including Lithium-ion batteries used in electric vehicles vis-à-vis hydrogen as an automotive fuel in consultation with the concerned industry, academia and other experts.

2. Accordingly, it has been decided to constitute a 'Joint Group' comprising the following members based on the nominations received from the concerned organisations for preparation of the said report:

a) Dr. A. K. Tripathi, Director General, NISE, Gwal Pahari, Gurugram
b) Prof. L. M. Das, (Retd.), Centre for Energy Studies, IIT Delhi
c) Sh. Alok Sharma, Chief General Manager, R&D Centre, IOCL, Faridabad
d) Dr. Muthiah Saravanan, Senior Principal Engineer (Advanced Technology), Mahindra and Mahindra, Chennai
e) Sh. Suresh Arikapudi, General Manager (System Design & Development), Tata Motors Ltd., Pune
f) Mr. Atanu Ganguli, Dy. Executive Director, Society of Indian Automobile Manufacturers, New Delhi
g) Dr. Chandan Banerjee, Dy. Director General, NISE, Gwal Pahari, Gurugram
h) Dr. M. R. Nouni, Sr. Consultant, NISE, Gwal Pahari, Gurugram

3. Other experts, including one on Lithium ion batteries may be co-opted in the Joint Group by NISE for the afore-mentioned work depending on requirement.

4. The Terms of Reference of the Joint Group are given below:

(a) To review international and national status of development of hydrogen fuelled and electric vehicles;
(b) To review international and national status of development of Lithium Ion batteries for electric vehicles;
(c) To review present status of manufacturing of Lithium Ion batteries in India and projected growth in production with increase in demand for electric vehicles by 2030;
(d) To review status of hydrogen production, storage and availability for transport sector in India;

12/09/2019.

(e) To undertake comparison of Lithium-ion batteries and hydrogen as fuel for transport sector;

(f) To undertake comparison of electric vehicles and hydrogen fuelled vehicles for Indian scenario; and

(g) Any other issue that Joint Group may consider relevant for the report.

5. The Joint Group would submit its draft report within two months' time from its constitution. The draft report would be finalised by the Joint Group thereafter by the end of the 3rd month.

6. Members of the Joint Group from academia (retired or serving) and those included/co-opted in individual capacity will be provided Honorarium/ sitting fee and travelling allowance as per the prevailing government norms.

12.09.2019

(Ankeshwar Mishra)
Deputy Director

1. DG, NISE
2. Prof. L. M. Das, B-96, Ground Floor, Sector- 57, Sushant Lok, Phase-III, Gurugram
3. Sh. Alok Sharma, Chief General Manager, R&D Centre Indian Oil Corporation Limited, Sector – 13, Faridabad-121 007, (HR)
4. Dr. Muthiah Saravanan, Senior Principal Engineer (Advanced Technology), Mahindra and Mahindra, Chennai
5. Sh. Suresh Arikapudi, Tata Motors Ltd., Pune
6. Mr. Atanu Ganguli, Dy. Executive Director, SIAM, New Delhi
7. Dr. Chandan Banerjee, DDG, NISE
8. Dr. M. R. Nouni, Sr. Consultant, NISE

राष्ट्रीय सौर ऊर्जा संस्थान
(नवीन और नवीकरणीय ऊर्जा मंत्रालय, भारत सरकार का स्वायत्त संस्थान)
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Gurugram-Faridabad Road, Gwal Pahari, Gurugram - 122 003, Haryana, India

F. No.: 05/02/30/2019-20/HEFC **Dated: 22.10.2019**

Subject: **Inclusion of an Expert Member in the area of Li-ion batteries for electric vehicle in the Joint Group constituted by NISE for preparation of a report for Comparison of Electric and Hydrogen fueled Vehicles**

This has reference to O.M. of even no. dated 12th September, 2019 vide which the Joint Group was constituted by NISE for preparation of a report for Comparison of Electric and Hydrogen fueled Vehicles. Sh. Sameer Kulkarni, Sr. Manager (Engineering), Tata Chemicals, Pune (sskulkarni@tatachemicals.com) is included as an Expert Member in the area of Li-ion batteries for electric vehicle in the aforementioned Joint Group.

2. The second meeting of the Joint Group will be held at 11:00 AM on 6th November, 2019 in Room No. 103, Surya Bhawan, NISE, Gwal Pahari, Gurugram. You are requested to make it convenient to attend the meeting.

(Ankeshwar Mishra)
Dy. Director

To:

a) Director General, NISE, Gwal Pahari, Gurugram (aktripathi@nic.in)
b) Prof. L. M. Das, B-96, Ground Floor, Sector-57, Sushant Lok, Phase-III, Gurugram (lmdas1@hotmail.com, lmdas1@rediffmail.com)
c) Sh. Alok Sharma, Chief General Manager, R&D Centre, IOCL, Faridabad (sharmaa@indianoil.in)
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e) Dr. Muthiah Saravanan, Senior Principal Engineer (Advanced Technology), Mahindra and Mahindra, Chennai (muthiah.saravanan@mahindra.com)
f) Sh. Suresh Arikapudi, General Manager (System Design & Development), Tata Motors Ltd., Pune (arikapudi.suresh@tatamotors.com)
g) Dr. Sameer Kulkarni, Sr. Manager (Engineering), Tata Chemicals, Pune (sskulkarni@tatachemicals.com)
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i) Dr. M. R. Nouni, Sr. Consultant, NISE, Gwal Pahari, Gurugram (mrnouni@gmail.com)

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