HYDROGEN REFUELLING STATIONS IN INDIA: CURRENT STATUS,CHALLENGES,FUTURE ASPECTS AND PROPOSED MODEL

Nitish Kumar Jena, Yadav Ajay Ram Avadh, Mohan Lal Thakur

Department of Mechanical Engineering, Lovely Faculty of Technology & Sciences, Lovely Professional University Phagwara, Punjab

ABSTRACT

Over the course of the last few decades, the growing dependency on conventional fuels is a rising concern for many countries. Hydrogen has demonstrated itself as a possible replacement of fossil fuels of its net zero environment pollution properties. The hydrogen-based transportation has depicted a huge expansion consolidating the commercialization of Fuel Cell Electric Vehicles and this paves a new path for the future aspects of mobility of new age vehicles. The above examined concerns demystify the sensitive and unavoidable capability of the prominent hydrogen-based market in road transport. To this extent, as in-depth scrutiny of the progressing technology, practically equivalent to hydrogen refueling stations' segments and categories is presented. Eventually, the resulting predictions regarding the showcasing of hydrogen infrastructure and its respective budgetary allocations is categorized by a short postulation.

Keeping an eye over the subject highlighted above, this audit associated the hiking drift in the expansion in hydrogen infrastructure, notwithstanding at this phase, is at the phoenix of development. This is so for the substandard desire towards the hydrogen fuel regarding the transport. However, on the basis of the in-hand information, and the survey over the accessible facts, a setup in the hydrogen fuel demand later on, requiring huge investment regarding the framework, which may rise above several billion EUR for the requisites. Concerning the prior discussed, the ongoing studies stipulated a number of hydrogens refueling stations for upcoming decades. Now, it is perfectly clear that there exists a bidirectional connection between the hydrogen infrastructure and the vehicles. The investment regarding the hydrogen refueling system will go profitable and will be beneficial as per the augmentation in the fuel cell vehicles and vice-versa.

1. INTRODUCTION

With the advent of industrial revolution and modernisation, accompanied by the rapid economic developments worldwide, the requirement for energy resources is also increasing exponentially. Right now, humankind relies totally upon non-sustainable assets like flammable gas, coal, and oil to satisfy energy needs. The choice reliance on non-sustainable power sources has twofold results: the persistent consumption of fuel sources at a disturbing rate and the unfavourable wellbeing and ecological effects. These repercussions have constrained researchers, technologists, business analysts, and strategy creators to look for substitute, reasonable, and less-dirtying energy sources.

Hydrogen is considered as a perfect and feasible energy carrier, which at last can supplant non-sustainable petroleum products and consequently can resolve the accessibility, ecological, and wellbeing worries of the last mentioned. Nonetheless, the execution of an energy economy dependent on this supportable and clean fuel isn't straight forward yet endures serious obstacles in the creation, stockpiling (storage), conveyance, and use of hydrogen. Among the different issues that exist in the fruitful emergence of hydrogen fuel-based economy, the definition of a protected, affordable, and proficient hydrogen stockpiling technique represents the most defying challenge. This is especially evident, if the use of hydrogen fuel in the transportation area is thought of. The transportation area as of now depends solely on refined oil-based goods that are progressively excessively expensive. This reliance can be disposed of by utilizing hydrogen as the transportation fuel.

Hydrogen (H_2) is right now utilized basically in the compound business for the creation of smelling salts and methanol. Sooner rather than later, hydrogen is relied upon to turn into a critical fuel that will generally add to the nature of air, hydrogen as a substance component (H) is the most far and wide one on the earth and as atomic dihydrogen (H_2) can be acquired from various sources both inexhaustible and non-sustainable by different cycles. The current energy emergency, climate debasement and the pressing factor of environmental change has committed the world economies to investigate cleaner fuel choices like hydrogen, which is universally recognized as an expense productive and compelling other option and will be an answer for these issues.

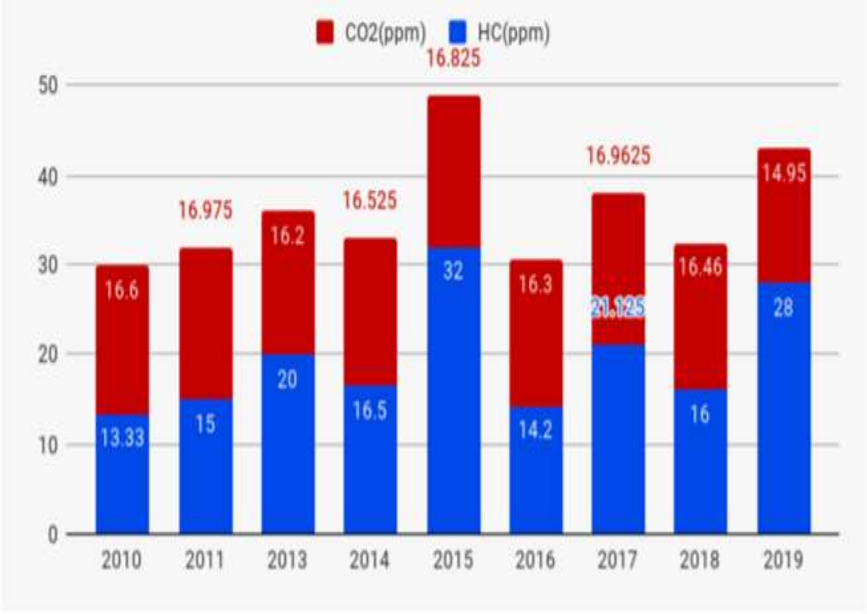


Figure 1: Average emissions for petrol vehicles over nine years

The development of hydrogen as a spotless and green option in-contrast to regular petroleum derivatives is promising, as it also offers high octane evaluations, energy content and further an enormous base hotspot for creation. For the most part, treatment facilities use hydrogen to decrease the sulphur substance of engine energizes, utilize petroleum gas and naphtha to deliver hydrogen. Nations like the US, Germany, Japan, South Korea and China have effectively conveyed and are running an armada of hydrogen-fuelled vehicles and transports in their separate nations.

Unlike the Internal Combustion engines, a hydrogen run fuel cell vehicle does not produce any harmful gas which may later result in environment pollution. India is slowly moving forward to adopt to cleaner methods of energy production. The hydrogen fuel cell-based vehicles have the capability to give tough competition to the existing internal combustion engine vehicles.

HYDROGEN – A FUEL FOR THE FUTURE

Right now, humanity relies totally upon non-renewable sources like natural gas, coal, and petroleum to satisfy the energy needs. This dependence on non-sustainable power sources has twofold results: the persistent exhaustion of fuel sources at a disturbing rate and the antagonistic wellbeing and natural effects. These repercussions have compelled researchers, technologists, financial experts, and strategy creators to look for substitute, practical, and less-polluting fuel sources.

Hydrogen is considered as a perfect and sustainable energy carrier, which eventually can supplant non-renewable petroleum products and accordingly can resolve the accessibility, ecological, and wellbeing worries of the last mentioned. Nonetheless, the execution of an energy economy dependent on this maintainable and clean fuel isn't straight forward yet endures serious obstacles in the creation, stockpiling, conveyance, and use of hydrogen. Among the different issues that exist in the effective appearance of hydrogen fuel-based economy, the detailing of a protected, conservative, and productive hydrogen stockpiling technique represents the most going up against challenge. This is especially obvious, if the use of hydrogen fuel in the transportation area is thought of. The transportation area as of now depends solely on refined oil-based goods that are progressively excessively expensive. This reliance can be dispensed with by utilizing hydrogen as the transportation fuel.

The current energy emergency, climate corruption and the pressing factor of environmental change has committed the world economies to investigate cleaner fuel choices like hydrogen, which is worldwide recognized as an expense proficient and compelling other option and will be an answer for these issues.

The development of hydrogen as a perfect and green option in contrast to ordinary petroleum derivatives is promising, as it also offers high octane evaluations, energy content and further an enormous base hotspot for creation. By and large, processing plants use hydrogen to lessen the sulfur substance of engine powers, utilize gaseous petrol and naphtha to deliver hydrogen. Nations like the US, Germany, Japan, South Korea and China have effectively sent and are running an armada of hydrogen-fuelled vehicles and transports in their separate nations.

Recently in India, the National Hydrogen Mission has been announced which will be followed up with a mission draft over the next couple of months to provide a roadmap for using hydrogen as an energy source in India.

The ongoing initiatives on Transport and power generation include

i) GIFT – Green Initiative for future transport - to develop and show hydrogen-controlled IC motor and energy unit-based vehicles.

ii) GIP – Green Initiative for Power Generation – it focusses on creating hydrogen-controlled IC motor/turbine and power module.

Indian automakers have also set their foot in this field – Tata motors and Mahindra have initiated the hydrogen run vans and buses in their R&D labs. Power major NTPC (National Thermal Power Corporation) is operating pilot projects to run 10 hydrogen fuel –cell based electric cars in Leh and Delhi. Also, the Indian Oil Corporation (IOC) is planning to set up a dedicated unit to produce hydrogen run buses at its R&D centre in Faridabad.

As a supporting regulatory framework, the Ministry of Road Transport and Highways, last year issued a notification proposing amendments to the Central Motor Vehicles Rules, 1989, to include safety evaluation standards for hydrogen fuel cell – based vehicles.

2. LITERATURE REVIEW

India Country Status Report on Hydrogen & Fuels Cells published in March 2020 gives a fundamental analysis on the various aspects of hydrogen production, Storage and Transportation parameters. The ongoing projects by the government and the other private firms to adopt Hydrogen Economy in India needs to be addressed. Hydrogen, being available in abundant forms and its non-zero environment pollution properties paves a new way to meet the energy requirements of our nation. Government Schemes, Private Firms and Start-ups should be encouraged to invest in Hydrogen Energy projects.

This literature review emphasizes the general concepts of utilising hydrogen in the transportation fields. The required infrastructure developments that are much needed to adapt to a hydrogen economy are also addressed.

This review paper contains the fundamental aspects of production, storage and transportation of hydrogen-based fuels in addition with the refuelling stations in India – its current status, future scope and the challenges faced in the hydrogen economy altogether.

2.1. HYDROGEN PRODUCTION:

The most abundant element in the universe is hydrogen. However, since hydrogen does not occur in its purest form, it is still a compound, generating and processing pure hydrogen for automobiles is unquestionably a challenging challenge that necessitates ability and experience. Hydrogen is developed in a variety of ways.
The thermochemical processes include:

i) Coal Gasification:

During the gasification process, oxygen and steam are blown through the coal, which is also heated (and is few cases pressurized). In the event that the coal is heated by an external heat source the cycle is designated “autothermal”, while “autothermal” process assumes heating of coal by means of exothermal chemical reactions happening inside the gasifier itself. It is fundamental that the oxidizer provided is lacking for complete oxidizing (burning) of the fuel. During the responses referenced, oxygen and water atoms oxidize the coal and produce a vaporous combination of carbon dioxide (CO_2), water vapor (H_2O), carbon monoxide (CO), and molecular hydrogen (H_2). (Some results like tar, phenols, and so on are additionally conceivable final results, contingent upon the particular gasification innovation used.) This interaction has been led in-situ inside regular coal creases (alluded to as underground coal gasification) and in coal treatment facilities. The ideal final result is generally syngas (i.e., a mix of H_2+CO), however the delivered coal gas may likewise be additionally refined to create extra amounts of H_2:
3C (i.e., coal) + O_2 +H2O → H_2 + 3CO
On the off chance that the purifier needs to deliver alkanes (i.e., hydrocarbons present in flammable gas, gasoline, and diesel fuel), the coal gas is gathered at this state and steered to a Fischer-Tropsch reactor. Assuming, nonetheless, hydrogen is the ideal finished result, the coal gas (fundamentally the CO item) goes through the water gas shift response where more hydrogen is delivered by extra response with water vapor:
$CO + H_2O \rightarrow CO_2 + H_2$
Synthesis gas is created by reacting coal with high temperature steam and oxygen in a compressed gasifier, which is changed over into vaporous segments.

ii) Bio-Mass derived liquid reforming:

The liquids produced from the biomass resources like bio-oils and ethanol can be reformed to extract H2. The biomass resources can also be converted into cellulosic ethanol, bio-oils and other liquid biofuels. A majority of these liquids can be shipped at a low cost to a refuelling station or other point of use, where they could be reformed to produce hydrogen. Bio-oils may be reformed on-site. Biomass-derived liquids are easier to transport than its biomass feedstocks, allowing for semi-central or higher-probability hydrogen production at fuelling stations. Biomass-produced liquid reforming is a process of mid-term pathway technology.

The reforming biomass-derived liquids to hydrogen process is comparatively same to that of natural gas reforming. The various steps include:

- The liquid fuel is treated with steam at very high temperatures in the presence of a catalyst to produce a reformate gas mainly composed of hydrogen, CO, and few amounts of carbon dioxide.
- The extra hydrogen and carbon dioxide are produced in the process react with the carbon monoxide with high-temperature steam in the "water-gas shift reaction."

- Finally, the hydrogen is separated out and further purified.
  $C_2H_5OH + H_2O$ (+ heat) → $2CO + 4H_2$

  $CO + H_2O \rightarrow CO_2 + H_2$ (+ small amount of heat)

iii) Solar thermochemical hydrogen

Thermochemical water splitting measures use high-temperature heat (500°–2,000°C) to produce a series of chemical reactions that can produce pure hydrogen. The chemicals used are reusable within each cycle, making a closed circle that consumes water and produces hydrogen and oxygen. The temperatures required for the process can be generated by the following steps:

- Concentrating sunlight onto a reactor tower utilizing a field of mirror "heliostats,"
- Using waste heat from cutting edge nuclear reactors.

iv) Natural Gas Reforming:

Steam reforming is right now perhaps the most inescapable and simultaneously most economical cycles for hydrogen production. Its benefit emerges from the high productivity of its activity and the low operational and production expenses. The most every now and again utilized crude materials are flammable gas and lighter hydrocarbons, methanol, and other oxygenated hydrocarbons. The organization of changing responses for hydrocarbons and methanol utilized as feedstock is the accompanying:

$$C_mH_n + mH_2O\,(g) \longrightarrow mCO + (m + 0.5\,n)\,H_2 \qquad (1)$$

$$C_mH_n + 2mH_2O\,(g) \longrightarrow mCO_2 + (2m + 0.5\,n)\,H_2 \qquad (2)$$

$$CO + H_2O\,(g) \longleftrightarrow CO_2 + H_2 \qquad (3)$$

$$CH_3OH + H_2O\,(g) \longleftrightarrow CO_2 + 3H_2 \qquad (4)$$

The entire cycle contains two phases. In the primary stage, the hydrocarbon crude material is blended with steam and fed in a tubular catalytic reactor. During this interaction, syngas (H_2/CO_2) is created with lower content in CO_2 ((1) and (2)).

The necessary response temperature is accomplished by the expansion of oxygen or air for combusting a piece of the crude material (heating gas) inside this reactor. In the subsequent stage, the cooled item gas is fed into the CO catalytic converter, where carbon monoxide is changed over generally through steam into carbon dioxide and hydrogen (3). The steam changing reactant measure requires a crude material liberated from sulfur containing compounds to stay away from deactivation of the catalyst used. The SR interaction requires humble temperatures, for instance, 180° C for methanol and oxygenated hydrocarbons and more than 500° C for most customary hydrocarbons. The catalyst utilized can be separated into two sorts: nonprecious metal (ordinary nickel) and valuable metals from Group VII components (commonly platinum or rhodium). Because of serious mass and heat transfer restrictions, ordinary steam reformers are restricted by the adequacy factor of pelletized catalyst, which is regularly under 5%. Consequently, energy is seldom the restricting component with customary steam reformer reactors, and, accordingly, more affordable nickel catalyst is utilized mechanically.

By reacting natural gas with high-temperature steam, synthesis gas, a combination of hydrogen, carbon monoxide was made. The carbon monoxide is reacted with water to create extra hydrogen.

v) Partial Oxidation:

Partial oxidation is an exothermic process—it gives off heat. In most cases, the process is much quicker than steam reforming and requires a smaller reactor tank. In chemical reactions of partial oxidation, the process initially produces less hydrogen per unit of the input fuel than is obtained by steam reforming of the same fuel. In partial oxidation, the methane and hydrocarbons in natural gas react with a restricted amount of oxygen which is unable to completely oxidize the hydrocarbons to carbon dioxide and water. With less than the stoichiometric amount of oxygen accessible, the reaction products contain primarily hydrogen and carbon monoxide and a small amount of carbon dioxide and other compounds. Along with these, in a water-gas shift reaction, the carbon monoxide reacts with water to form carbon dioxide and hydrogen.

$CH_4 + ½O_2 \rightarrow CO + 2H_2 + \Delta$ (partial oxidation of methane)

$CO + H_2O \rightarrow CO_2 + H_2 + \Delta$

vi) Bio Mass Gasification

In the near future, biomass has demonstrated to become the most renewable organic substitute to petroleum. Biomass is available from a wide range of sources - animal wastes, crop residues, sawdust, aquatic plants, short rotation woody crops, municipal solid wastes, agricultural wastes etc. Basically, gasification reactors are developed on a large scale and require huge amounts of input to be fed continuously. Due to their low heating values, they can easily access efficiencies of 40-50%.

Gasification process is used with biomass and coal as fuel and is advanced -basically used in many processes. It is an alternate of pyrolysis which concentrates on partial oxidation material into a mixture of H_2, methane, higher hydrocarbons, CO, N_2 and CO_2 particularly "producer gas". The gasification process undergoes from a low thermal efficiency as moisture content in the biomass also needs to be vaporized. The process can be performed without a catalyst either in a fixed-bed or fluidized-bed reactor. The problems of this technology are that a large number of resources must be used to contain the large amounts of biomass to the central processing plant. Presently, the high logistics costs of gasification plants and the removal of "tars" to minimum levels for pure hydrogen production limit the commercialization of biomass-based hydrogen production. Future development of smaller efficient distributed gasification plants is required in technology for cost effective hydrogen production.

Comparative as coal gasification to change biomass over to a blend of carbon monoxide, CO_2 hydrogen and methane.

vii) Electrolysis with grid-based electricity:

A reliable and efficient method for the production of hydrogen could be water electrolysis. Presently, only 4% of hydrogen worldwide is produced by this process. The electrolysis of water into hydrogen and oxygen is a genuine and efficient method for producing pure hydrogen.

Electrolysis is a process in which a direct current passes through two electrodes in the water solution resulting in the breaking of the chemical bonds in water molecule into H_2 and O_2:

The electrolysis process takes place at the room temperature. Sulphuric acid is a well-known electrolyte and the electrodes used are platinum (Pt), which does not react with sulphuric acid. The process is ecologically clean as no greenhouse gases are produced in this process, and the oxygen formed has further industrial applications. Comparatively the foregoing methods of electrolysis energy requirements are much more than the other processes.

The efficiency of the electrolysis of water is near 50–70%. It is because of the conversion of electrical energy to chemical energy in the form of hydrogen, with oxygen as a beneficial by- product. SOEC electrolysers are the most electrically efficient. But this type of technology has challenges with corrosion, seals, thermal cycling and chrome migration. PEM electrolysers are more efficient than alkaline and do not have corrosion problems.

viii) Photo electrolysis/ Photolysis:

Photo-electrolysis is one of the sustainable methods of hydrogen production, displaying promising effectiveness and expenses, despite the fact that it is as yet in the period of test advancement. At present, it is the most economical and the best technique for hydrogen creation from sustainable assets. The photo-electrode is a semiconducting gadget engrossing sun-based energy and all the while making the fundamental voltage for the immediate disintegration of water particle into oxygen and hydrogen. Photo-electrolysis uses a photo-electrochemical (PEC) light assortment framework for driving the electrolysis of water. On the off chance that the semiconductor photo-electrode is lowered in a fluid electrolyte presented to sun powered radiation, it will produce sufficient electrical energy to help the created responses of hydrogen and oxygen. While producing hydrogen, electrons are delivered into the electrolyte, though the age of oxygen requires free electrons. The response relies upon the sort of semiconductor material and on the sun-oriented power, which delivers a current density of 10-30mA/cm^2. At these current densities, the voltage vital for electrolysis is around 1.35V.

The photo-electrode is included photovoltaic (semiconductor), synergist and defensive layers, which can be displayed as free segments. Each layer impacts the general proficiency of the Photo-electrochemical framework. The photovoltaic layer is delivered from light retaining semiconductor materials. The light retention of the semiconductor material is straightforwardly corresponding to the presentation of the photo-electrode. Semiconductors with wide groups give the fundamental potential to the parting of water.

The synergist layers of the photo-electrochemical cell likewise impact the presentation of the electrolysis and require reasonable catalyst for water parting. The encased layer is another significant part of the profoundly straightforward to have the option to give the most extreme sunlight-based energy, with the goal that it could arrive at the photovoltaic semiconducting layer.
Utilize sun-oriented ability to create hydrogen straightforwardly through photolysis of water with certain catalyst.

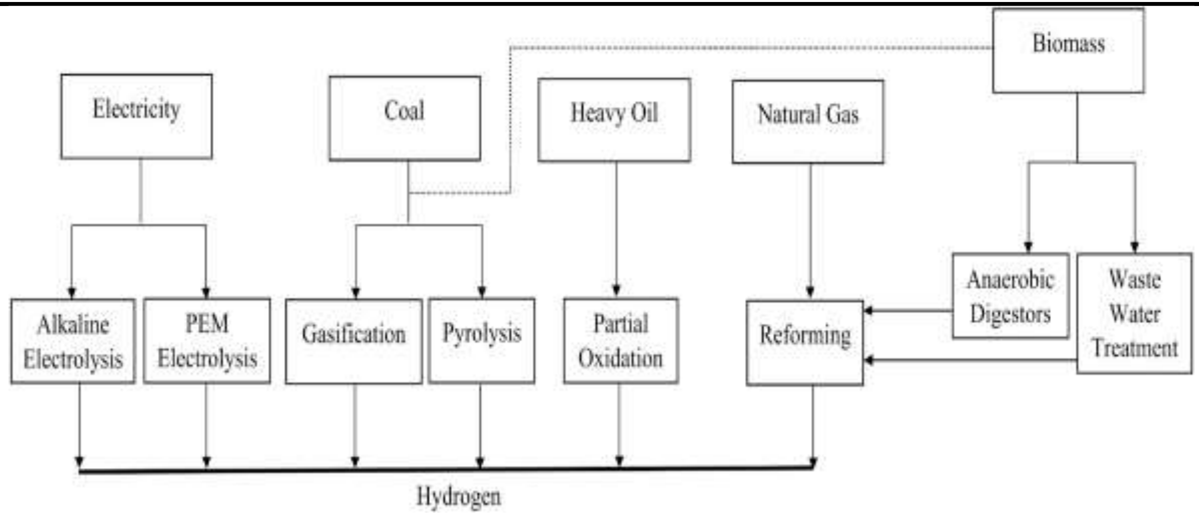


Figure 2: Different methods of producing hydrogen in a refuelling station

2.2. HYDROGEN STORAGE IN REFUELLING STATIONS:

Hydrogen powered fuel cells are the most efficient solutions to provide clean delivery of electricity for automobiles with a by-product of water. However, it needs a reliable source of transport and storage for on-board applications. Hydrogen storage methods are broadly categorised into physical storage and chemical storage methods. The physical storage methods include compressed gaseous hydrogen, liquefied hydrogen and cero compressed processes, while the chemical storage methods include the use of metal and complex hydrides processes.

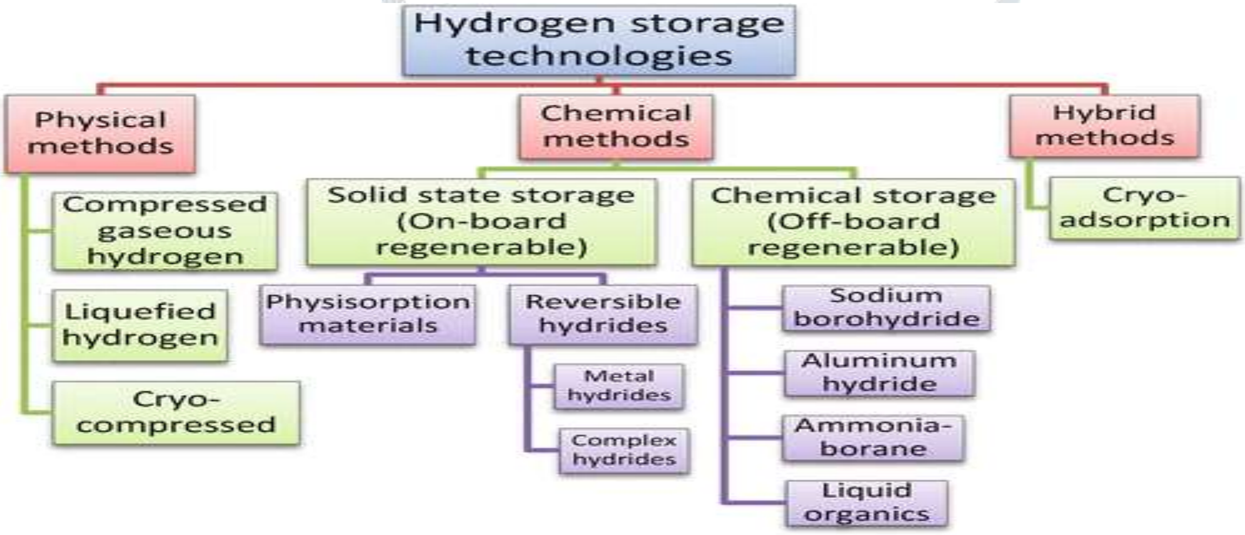


Figure 3: Different Methods to store hydrogen in a refuelling station

I. Compressed Gas Storage:

The simple method of storing hydrogen in refuelling stations is compressed Gas Storage. The equipment for this process is a compressor and a pressure vessel. The challenge with compressed gas storage is the low storage capacity which depends on the storage pressure. The capital cost of the pressure vessel dominates at higher volume when the critical factor is the cost of electricity for compression at low productions rates. One alternative is to raise the system's operational pressure. For short times, there is a balance between the costs, at longer times the capital cost reduction is the dominating factor.

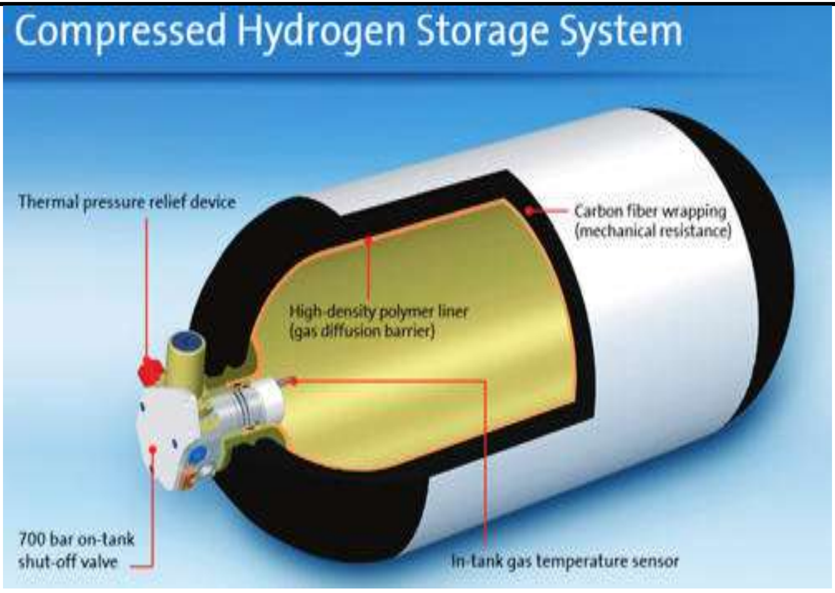


Figure 4: Compressed Hydrogen gas storage system

Although low-pressure liquid hydrogen is commonly used for bulk hydrogen storage and transportation near the usual boiling point of 20 K, there is currently little interest in using it for onboard automotive use. Though compressed hydrogen is usually stored at near-ambient temperatures, researchers are looking into "cold" (below 150 K) and "cryogenic" (below 150 K) compressed hydrogen storage due to the higher hydrogen densities that can be reached at lower temperatures.

II. Underground Storage:

Underground storage has proven itself one of the best ways to store a large amount of energy (electricity) after converting it into hydrogen because of its higher energy content per unit mass than other gases. To store the gas, a wide cavern or place of porous rock with an impermeable caprock above it is needed. Abandoned natural gas wells, solution mined salt caverns, and manmade caverns are some of the other options. UHS is the cheapest method at all production rates and storage times because of the low cost of the caravan and the largest cost item is electricity cost that is required for the compression. Underground storage may be useful for seasonal storage or supply protection.

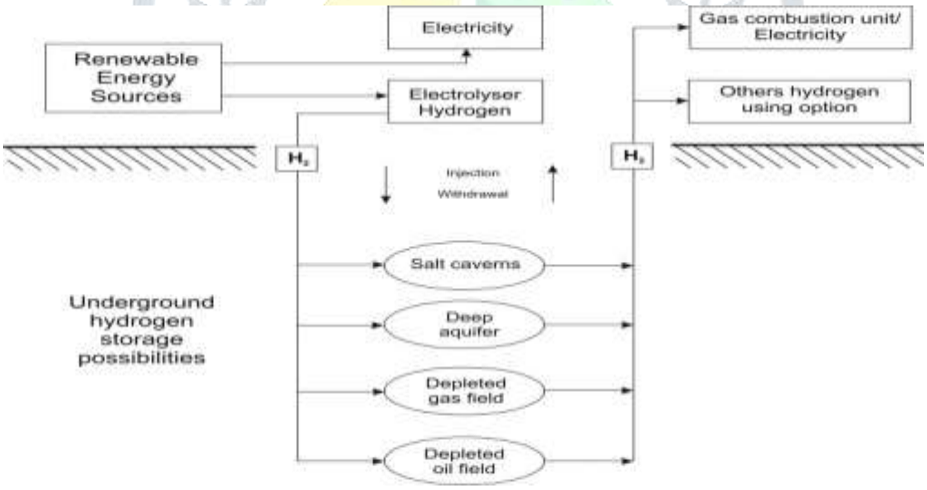


Figure 5: Underground Hydrogen Storage

III. Liquid hydrogen Storage:

Liquefaction is the process of turning a gas into a liquid by cooling it. To attain the desired cooling, liquefaction processes employ a mixture of compressors, heat exchangers, expansion engines, and throttle valves. The simplest liquefaction process is the linde cycle or Joule-Thompson expansion cycle. The gas is compressed at atmospheric pressure, cooled in a heat exchanger, and then passed through a throttle pipe, where it undergoes isenthalpic Joule-Thompson expansion, resulting in liquid. The cool gas is returned to the compressor through the heat exchanger after the liquid is extracted.

Passing the high-pressure gas into an expansion engine, which consists of an isothermal compressor followed by an isentropic expansion to cool the gas and release a liquid, is an alternative to this method. It's used to calculate the amount of energy required for liquefaction and to compare different liquefaction processes. As extreme liquid formation in the expansion engine will destroy the turbine blades, an expansion engine should only be used to cool the gas stream, not to condense it. Liquid hydrogen storage is inefficient at low production rates (due to the high capital cost of the liquefier) and difficult to compete with compressed gas at higher production rates unless longer storage periods are needed, under which case the lower capital cost of liquid hydrogen dewars versus compressed gas pressure vessels becomes the most important factor.

Figure 6 – Liquid Hydrogen Storage

IV. Hydrogen storage in Pipelines:

Hydrogen gas can be delivered by pipelines in the same manner as natural gas is now. Using existing pipelines to transport gaseous hydrogen is a low-cost choice for shipping vast amounts of hydrogen. The high initial capital costs of building new pipelines are a significant impediment to developing hydrogen pipeline distribution infrastructure.

Piping networks are usually several miles long, but may be hundreds of miles long in some situations. Because of the length and volume of these piping networks, even a small difference in the operating pressure of a pipeline system will result in a significant change in the amount of gas stored within the network. The pipeline can be used to manage supply and demand fluctuations by allowing minor adjustments in operational strain, eliminating the expense of onsite storage.

Figure 7: hydrogen Storage in Pipelines

V. Metal hydride Storage:

Hydrogen is stored in metal hydrides by chemically bonding it to metal and alloys. Hydrides as we know, have unique properties of absorbing H_2 at or below atmospheric pressure and releasing them on heating at significantly higher pressures—the higher the temperature, the higher the pressure. Depending on the alloy, hydrides can operate at a wide range of temperatures and pressures. Cycle life and heat of reaction are two efficiency characteristics that vary between alloys. On increasing the partial pressure of hydrogen, the metal/alloy starts to dissolve and then begins to bond to the metal. During the bonding period the equilibrium or plateau pressure remains constant from the time that 10% of hydrogen has been stored until about 90% of the storage capacity is reached. After the 90%-point, higher pressures are required to reach 100% of the hydride storage capacity. Heat released during hydride formation must be continuously removed to prevent the hydride from heating up. If the temperature is allowed to rise, the equilibrium pressure will rise until there is no longer any bonding. If hydrogen is being recovered from another gas, some hydrogen can be allowed to escape or blow off; taking away any contaminants that did not bond to the hydride.

For recovering hydrogen from the metal, the metal hydride, significant amount of heat is required for breaking the bonds between hydrogen and the metal. The release pressure increases as the temperature rises. At first, the gas pressure is higher as any free hydrogen released and as pressure plateaus the hydride bonds are broken. When only about 10% of the hydrogen remains the equilibrium, pressure drops off.

Metal hydride handling is thought to be inefficient (high capital cost of storage alloy). So, it does not compete with other options at high production rates or long storage times, but may be ideal at low flow rates and short storage times. Since it is considered as the safest storage option, this makes it a leading candidate for on-vehicle storage, subject to achieving satisfactory energy densities.

Figure 8– Metal Hydride Storage

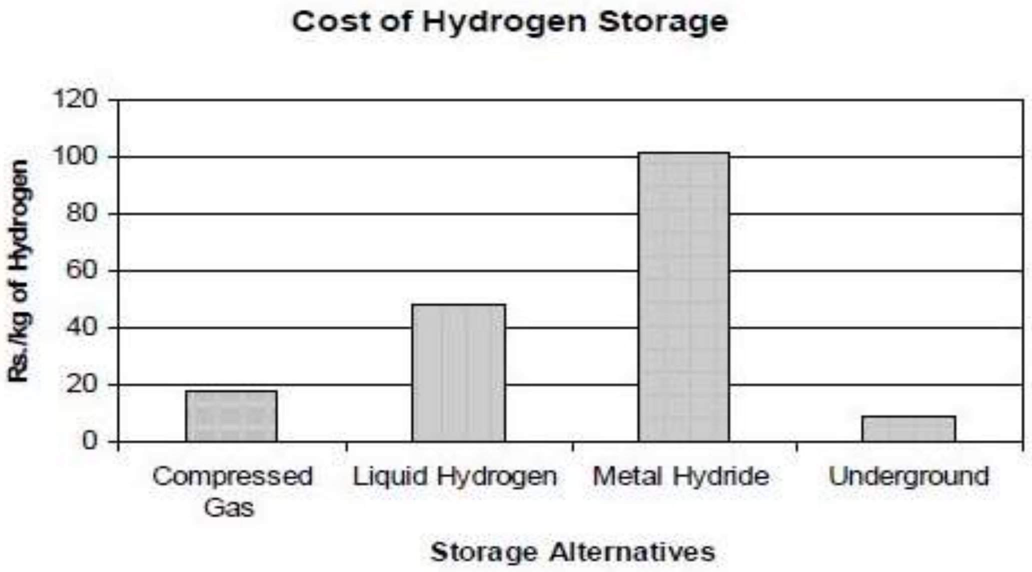


Figure 9 – Cost of hydrogen storage in India

2.3 HYDROGEN TRANSPORTATION:

Hydrogen can be produced, transported, stored, and used in a variety of ways. The optimal selection of these technology-pathways is a critical step toward achieving the goal of a reliable hydrogen-powered transportation infrastructure. The current research aims to provide such a strategy.

I. Compressed Gas Transportation

The compressed H_2 gas can be transported by high pressure cylinders, pipelines and tube trailers. Hydrogen, when transported as a gas, it has to be compressed to a very high pressure in order to maximize the tank capacities. The high-pressure gas cylinders rated as 40 Mpa can gold about 1.8 kg of hydrogen, but the main disadvantage is they are very expensive to handle and transport. The tube trailers, consisting of several steel cylinders can mount to a protective framework, can configure to hold 63-460 kg of Hydrogen depending upon the number of tubes having the operating pressures of 20-60 Mpa.

II. Liquid Hydrogen Transportation

Liquid Hydrogen is generally transported using special double walled insulated tanks in order to prevent boiling off of the liquid H_2. Tankers use liquid N_2 heat shields for cooling the outer wall of the liquid hydrogen vessel to further minimizing the heat transfer. They can carry 330-4500 kg of liquid hydrogen whereas the rail cars have capacities to carry 2300-9100 kg of H_2. Boil off rates for trucks and rail cars are 0.3%-0.6%/day. Long-distance hydrogen transport has been considered using barges or seagoing waterways. The liquid hydrogen acts as a refrigerant for superconductor and would allow long distance transport of electricity without the high current losses of conventional power lines. The main problem with this would be the specialized insulating requirement and losses from pumping and re-cooling the liquid hydrogen along the way.

III. Metal Hydride Transportation

The transportation of hydrogen through metal hydrides can be done by absorbing H_2 with the metal hydride and later on loading the entire container to a truck or a railcar to transport to the required site where it can be exchanged with an empty hydride container.

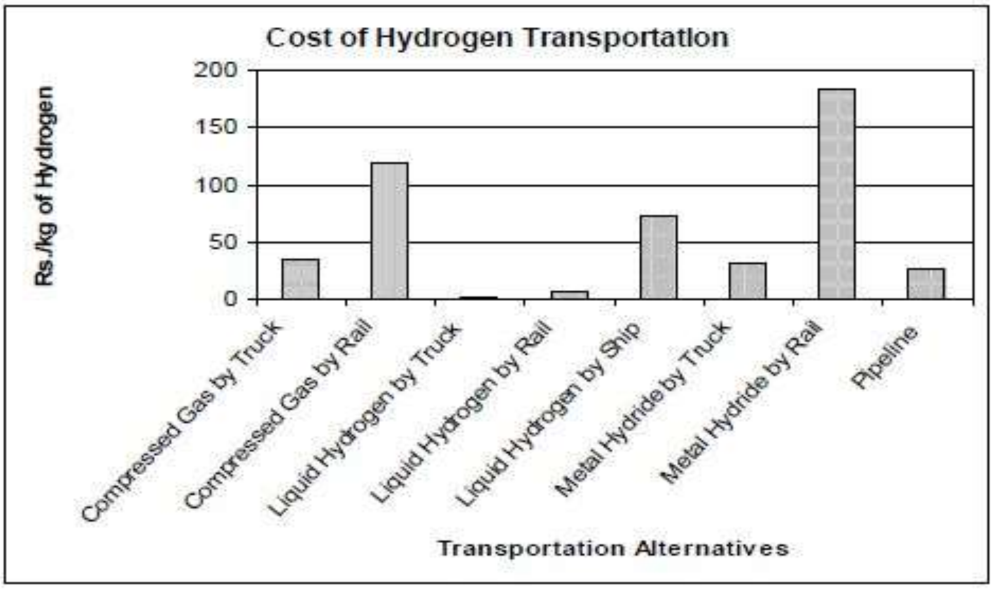


Figure 10 – Cost of hydrogen transportation in India

2.4. STATION CATEGORIES

I. OFF-SITE HYDROGEN PRODUCTION:

The primary type of HRSs include all the stations where hydrogen is supplied from a central production unit through road transport or specific pipelines. The delivery trucks carry out the delivery process where the H_2 is stored in specialized tube trailers as compressed gas of pressures more than 170 bar, or as liquid in tanks at cryogenic temperatures of around -250ºC for transporting to longer distances. But the method of H2 transportation through the cryogenic tanks is much more costly than gaseous H_2 delivery because of the high amount of energy required to liquefy hydrogen and therefore it is not currently used for supplying hydrogen to the refuelling stations. The gaseous hydrogen is first produced in large industrial facilities at very low-pressure rates around 30 bar and is then compressed to 180 – 210 bar for delivery through trucks and 70 bar for pipeline transportation. Pipeline H_2 transportation is considered a low-cost solution in the case of an existing pipeline network; otherwise, the high initial cost of new pipelines' construction consists of a major barrier for a network's expansion. This is related to the inherent characteristics of hydrogen concerning its molecular properties that approves the use of certified equipment.

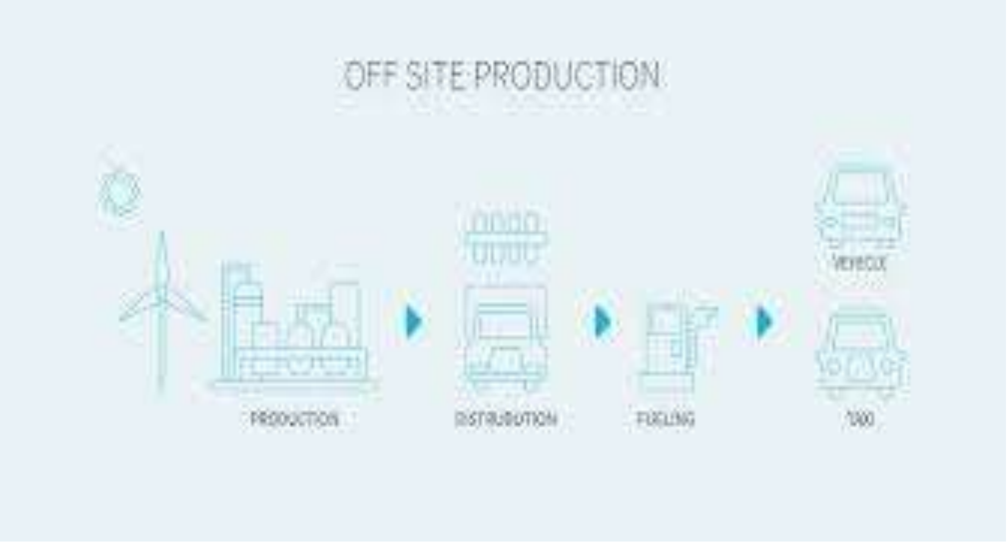


Figure 14 – Off site hydrogen production in HRS

II. ON-SITE HYDROGEN PRODUCTION:

The other type of HRSs is similar to the first one in terms of operational and technical stages, but the hydrogen used to refuel the FCEVs is supplied locally. The on-site hydrogen producing refuelling stations present technical limitations which is mostly dependent on H_2 generators, that ranges between 100 kg/day to 1000kg/day. However, current operating on-site HRSs do not present daily H_2 production capacities above 400 kg, with the most predominant systems being in the order of 100 kg H_2/day. The process includes also a water-gas shift reaction where the produced CO reacts with water vapour to form CO_2 and hydrogen. Thus the SMR operation requires water and heat sources. Water electrolysis on the other hand, is the process where water splits to hydrogen and oxygen with the application of direct current electric voltage. The processes that are commonly used in the on-site hydrogen production are alkali and proton exchangers. Apart from an adequate electric power input, both applications require a deionised water input along with a cooling framework for preventing the operational temperature of electrolysis to reach values above 100 °C. The alkaline electrolysers operate at 70^{o} C – 110^{o} C, whereas the commercialised PEM electrolysers temperature doesn't go beyond 100^{o} C to protect the Nafion membrane from dehydration that may result in lower proton conductivity. However, research on PEM systems indicates that operation under temperatures of 130 °C through the utilisation of enhanced membranes contributes to higher cell current density and therefore hydrogen production rates increase. The produced hydrogen from both. To this end, it is mandatory to introduce a hydrogen purification system.

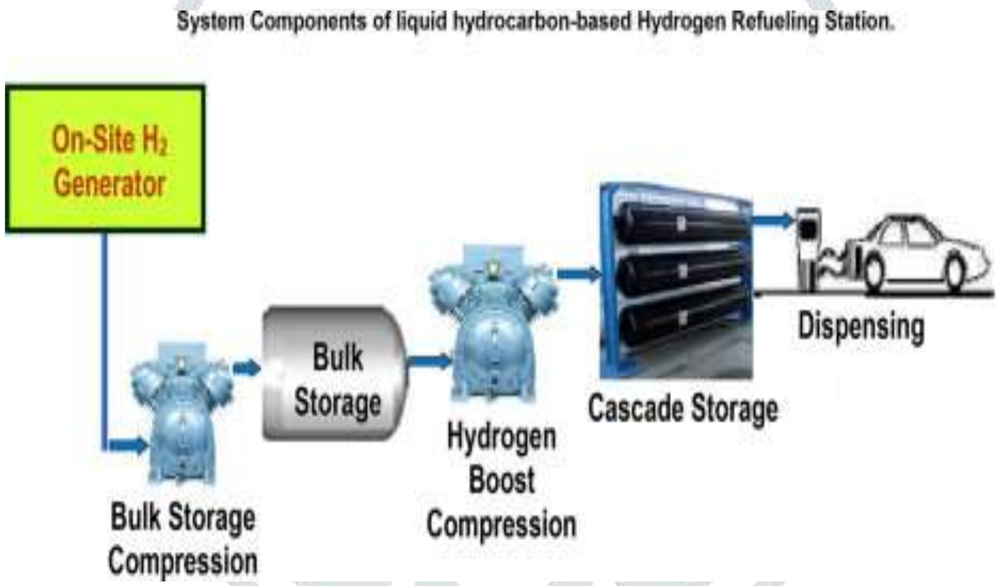


Figure 15 – On site hydrogen production in HRS

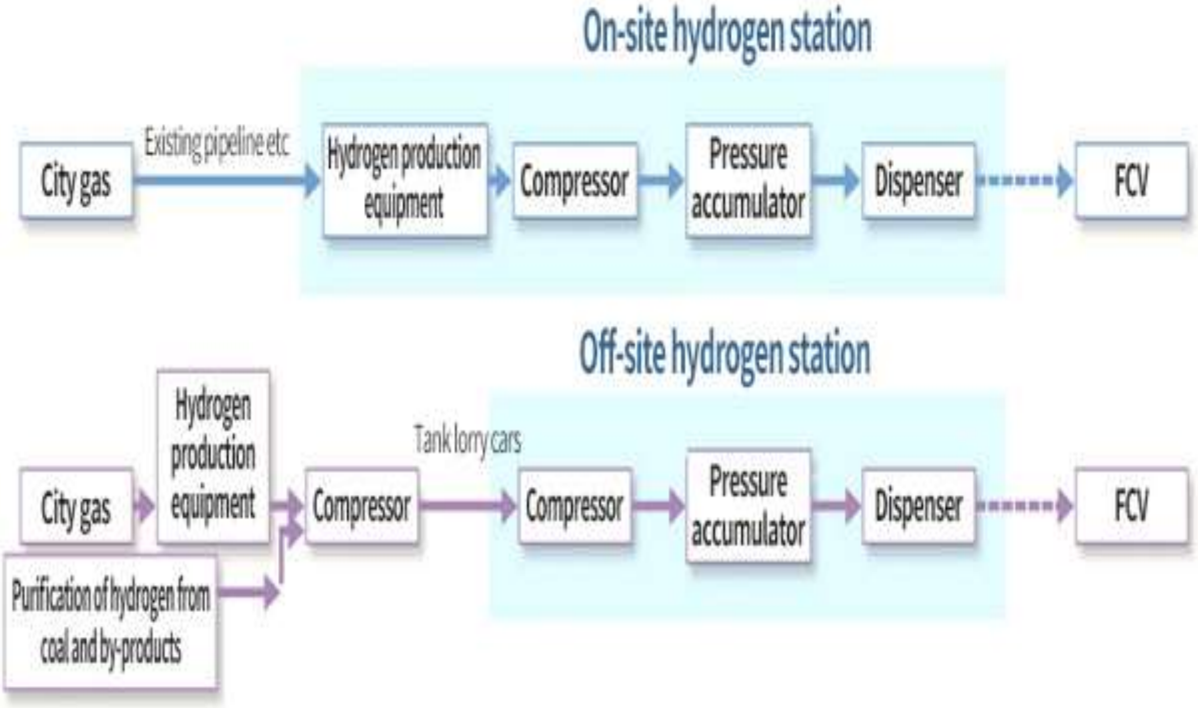


Figure 16 – Comparison between off site and On site hydrogen production

2.5. HYDROGEN DELIVERY PATHWAYS

The hydrogen delivery pathways are setup on the basis of different states from which hydrogen can be delivered. The three main hydrogen delivery pathways are - gaseous hydrogen, liquid hydrogen, and a possible spectrum of solid or liquid hydrogen carriers. Compressors, dispensers, gaseous tube trailers, liquefiers, cryogenic liquid trucks and storage vessels are the important components of the delivery pathway.

I. GASEOUS HYDROGEN PATHWAY:

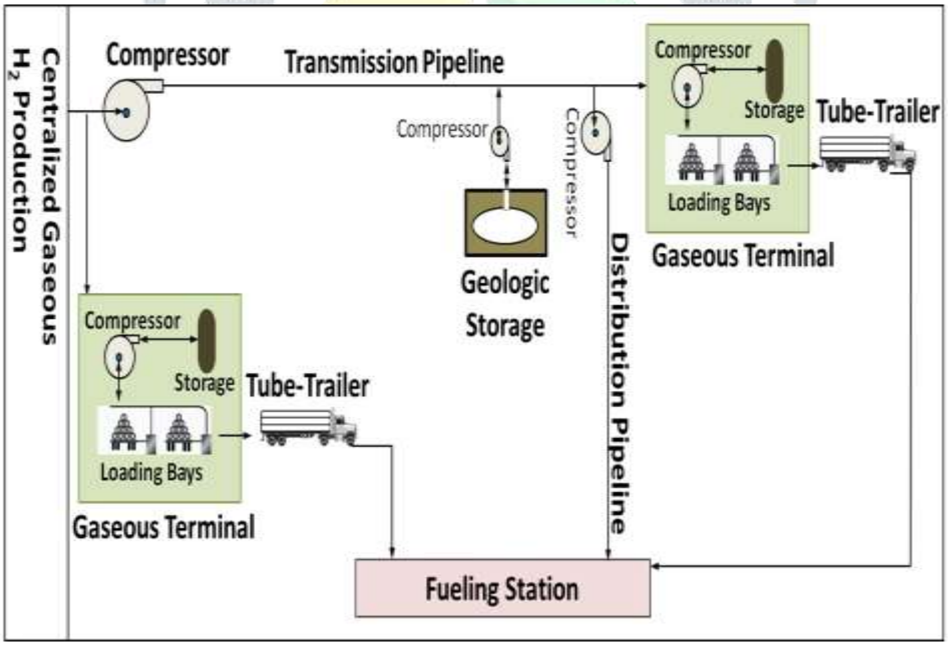


Figure 11 – Gaseous Hydrogen Pathway

II. LIQUID HYDROGEN PATHWAY:

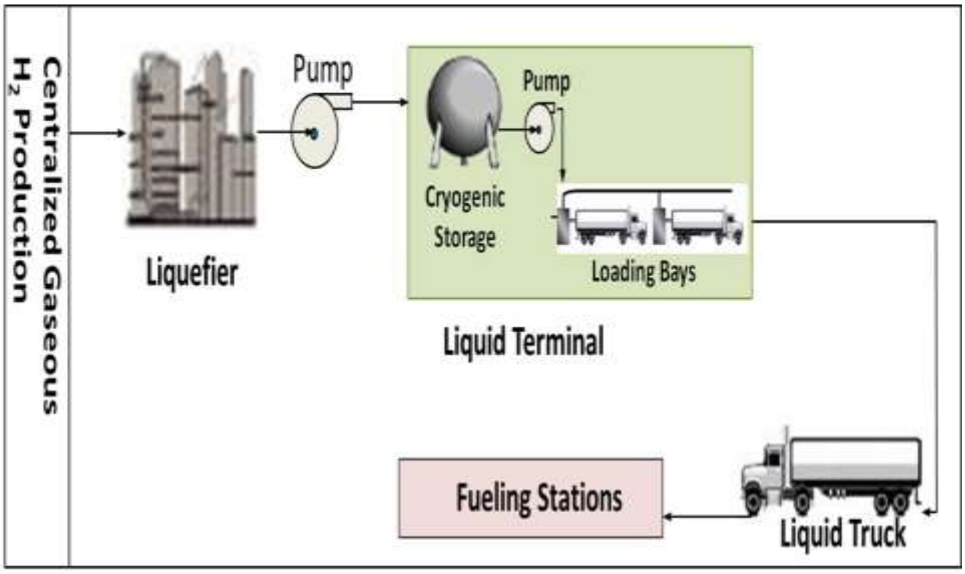


Figure 12 - Liquid Hydrogen Pathway

2.6. REFUELLING STATIONS:

One of the most important sectors in the hydrogen infrastructure is the Hydrogen refuelling Stations. The design of these stations can be categorised based on the type of hydrogen production technology used and the fuel generation location, which is either onsite or produced and delivered from a central production unit. The Refuelling stations that will be set up in India in the coming years, need to have these essential features:

- A hydrogen production unit.
- Hydrogen compressors for high pressure storage inside the station's main H_2 tanks.
- Compressed or liquid hydrogen tanks for storing the hydrogen in the stations.
- A purification unit is required in order to secure that hydrogen purity meets the standards for supplying fuel cells (purity above 99.97%).
- Hydrogen gas booster, which regulates pressure to 350 bar or 700 bar during the refuelling procedure.
- Cooling unit to reduce hydrogen gas temperature down to −40 °C in order to ensure that during fast refills the vehicle's hydrogen tank does not exceed 85 °C and ensure safety. Safety equipment like pressure relief valves, hydrogen sensors, and waterless fire suppression are essential for the safety of these stations.
- Mechanical as well as electrical equipment such as valves, piping, control panels, and high voltage connections.
- Dispensers used to supply the vehicles' H2 high pressure tanks from the station's compressed storage tanks.

Figure 13 – A hydrogen refuelling station set up in Delhi by Air Products

2.6.1. HYDROGEN REFUELLING STATION PLANNING:

For developing an appropriate HRS installation plan, different approaches are purposed:

1st approach – Regional area based

Considering an average driving capacity/range of a HFC car at full tank is 500 kms. Here the area of a particular region is divided by a specific radius (depending upon the area of region the radius shall be selected; smaller regions must have smaller radius or else the HRS will not be easily accessible for everyone in the entire region) in which only 1 HRS shall be placed. For example:

Delhi: Total area of Delhi is 1,484 km^2, this entire region will then be divided a region of radius of 60km, which will give the number of regions which will have a radius of 60km, which is 1,484 / 60 = 24.73 ~ 25, therefore 25 HRS shall be installed in entire Delhi region, and each HRS should be covering a region of 60km radius.

Pune: Total area of Pune is 331.3 km^2, this entire region will then be divided a region of radius of 40km, which will give the number of regions which will have a radius of 40km, which is 331.3 / 40 = 8.28 ~ 9, therefore 9 HRS shall be installed in entire Pune region, and each HRS should be covering a region of 40km radius.

Bangalore: Total area of Bangalore is 709 km^2, this entire region will then be divided a region of radius of 50km, which will give the number of regions which will have a radius of 50km, which is 709 / 50 = 14.18 ~ 15, therefore 15 HRS shall be installed in entire Bangalore region, and each HRS should be covering a region of 50km radius.

To estimate the maximum number of HFCVs that each station can serve per day, the maximum number of HFCVs refuelled at one station per day and refuelling period were estimated.

- The maximum number of HFCVs that can be refuelled at one station per day was calculated by multiplying the maximum number of HFCVs that a station can hold per hour with given operating hours.
- The maximum number of HFCVs that a station can hold per hour was calculated by dividing the capacity of the station by operating hours and refuelling amount.
- The refuelling period was estimated using the average driving distance of a vehicle in a day and the maximum driving distance from 5 kg of hydrogen.
- The maximum number of HFCVs that each station can serve per day was estimated by multiplying the maximum number of vehicles refuelled at one station per day, refuelling period, and operation rate.

Assuming that the average driving distance of a vehicle in a day is 40 km in India and a vehicle can run near about 500 km between refuelling, it has to be refuelled in every 12.5 days (500/40).

2nd approach- HRS for Highways:

Considering an average driving capacity /range of a HFC car at full tank is 500 kms, and assuming that the highway driving conditions are more favourable for the overall efficiency of the vehicle. Keeping in mind the above two things, it is safe to say that the need for refuelling is less as compared to the city driving conditions, however to minimize the subconscious range anxiety of the driver, placing a HRS near about every 200-250 kms will be effective, as everyone doesn't wait until the fuel gauge indicates 'E', to refuel their vehicle and to be on the safe side most people are likely to refill their vehicles once they cross the half way mark.

If a vehicle uses multiple highway routes, it is counted multiple times. The total number of cars using an expressway per day can be calculated using the collected data. Given the total supply of HFCVs for general roads, $N_{general}$, the number of HFCVs using the expressway $N_{expressway}$, was calculated by:

$$N_{expressway} = N_{general} \times \Sigma_l V_l / RV$$

It is necessary to estimate the number of HFCVs for each highway route, N_l. The number of HFCVs for each highway route was estimated by:

$$N_l = N_{expressway} \times V_l / \Sigma_l V_l$$

On each highway route, the number of HFCVs for demand sources was estimated. Because the demand sources are defined as gas stations in rest areas, the proportion of vehicles using a demand source to the total vehicles traveling on the highway route can be estimated from sales data of gas stations.

Like with general roads, Euclidean distance was employed to calculate the traveling distance between demand sources and candidate sites. However, the authors assumed that HFCVs could be refuelled at stations that are located within 50 km from demand sources on an expressway rather than after 15min.Thereason for assuming a different driving tolerance from general roads is due to the characteristics of expressways, where relatively less fuel is consumed, and vehicles can drive longer distances.

The number of HFCVs for demand sources was calculated for each highway route. Since demand sources are classified as gas stations in rest areas, sales data from gas stations can be used to measure the proportion of vehicles using a demand source to the overall number of vehicles driving on the highway route.

Similarly, for buses, an average driving capacity/range of a HFC bus at full capacity is considered as 800 kms. Acknowledging the fact that an inter-state bus on highways usually travel non-stop at least for 200 to 300 kms and are less likely to stop for refuelling before reaching the destination, however considering the precautionary refuelling, possible detours and road driving conditions, placing a HRS near about every 500-600 kms will be effective, as there are possibilities that there might be an intermediate bus stop which is of grid, and there is an absence of HRS. Moreover, an alternative method for the HRS for buses can be figured, in which the buses only refuel at the origin and destination points [which are Inter State Bus Terminals (ISBT)] which on an average is easily achievable with the 800 kms range of the HFC bus. Also, a supporting fact can be that there is always an intermediate destination, where if necessary, the buses can be refuelled.

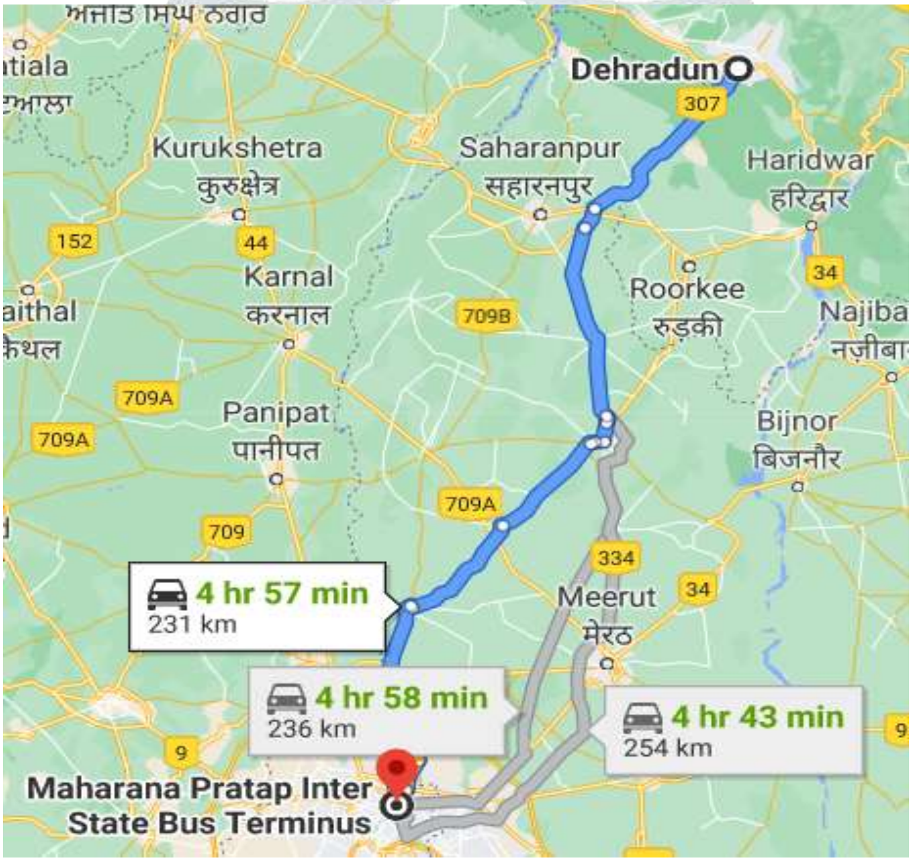


Figure 18 - distance between Dehradun and Maharana Pratap Inter State Bus Terminal Delhi

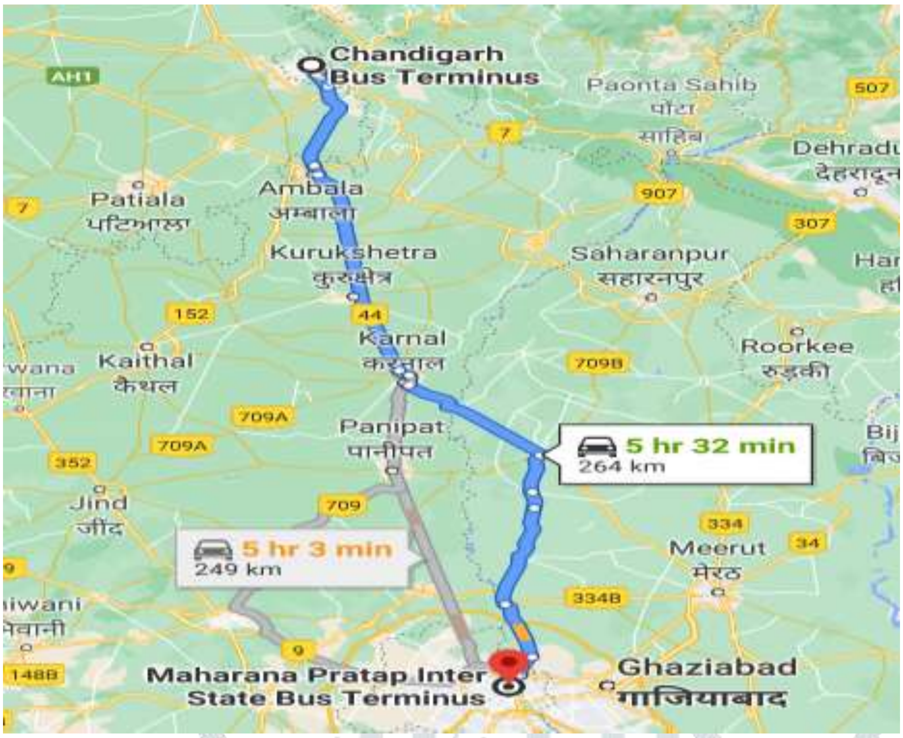


Figure 19 - distance between Chandigarh Bus Terminal and Maharana Pratap Inter State Bus Terminal Delhi

Figure 20 - 42 candidate sites for the HRS installation exclusively for buses

If this alternative is made applicable there will be an overall 42 major ISBT points where the HRS will be installed specifically for the buses and no other vehicels shall be permittted.

In order to make an appropriate HRS installation plan, Korea has adopted a Developmet Optimization Algorithm(DOA), which has estimation of demand and 3 mathematical models. The outcome of each module works as an input of the consecutive module.

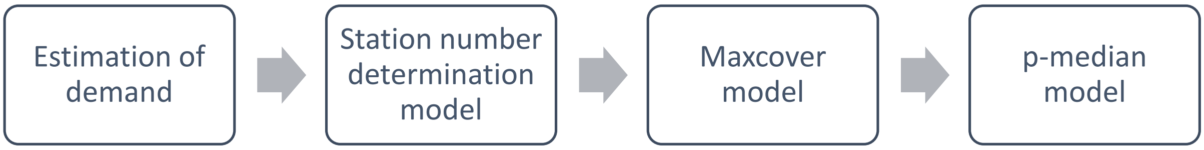


Figure 21 - Development Optimization Algorithm

2.7. STATION NUMBER DETERMINATION MODEL:

The HRSs that are needed to be installed to satisfy the target cover criteria when all HFCVs cannot be covered within a limited budget. So, it is very important to determine the minimum number of HRSs.

The method for determining the station number is as follows:

Sets:

I -set of locations for demand sources, i€I
J- set of locations for candidate sites, j€J
Ja -set of locations for candidate sites that are already active or to be installed, j€Ja

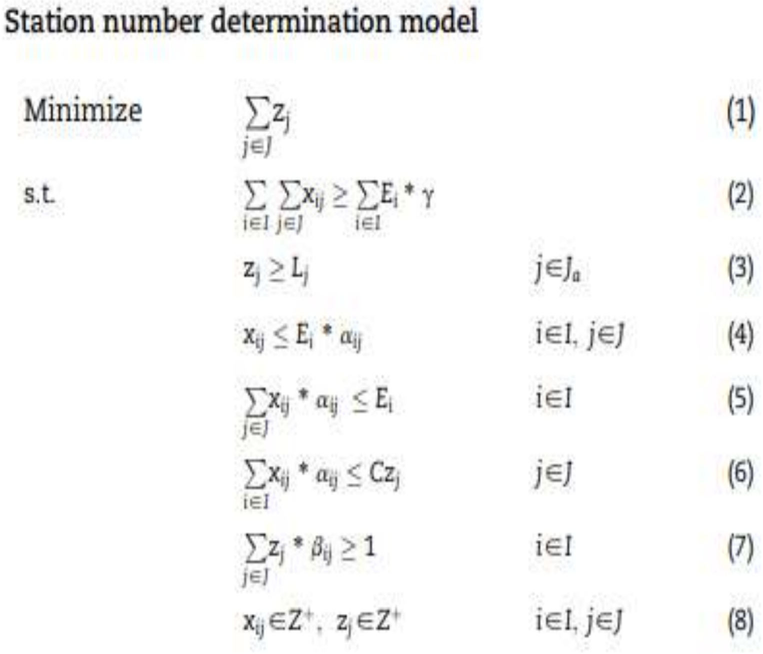
Parameters:

Lj	number of refuelling stations already active or to be installed at candidate site, j€Ja.
tij	required travel time from demand source i to candidate site j
Ei	HFCVs (demand) of demand source i
C	capacity of hydrogen refuelling station
R	travel time restriction between covered HFCVs and the refuelling stations.
S	travel time restriction between uncovered HFCVs and the nearest refuelling station

αij 1, if tij is within R; otherwise, 0
βij 1, if tij is within S; otherwise, 0
γ target covering ratio

Decision variables:

X_{ij} number of vehicles at demand source i assigned to candidate site j.
Z_j number of refuelling stations to be installed at candidate sit



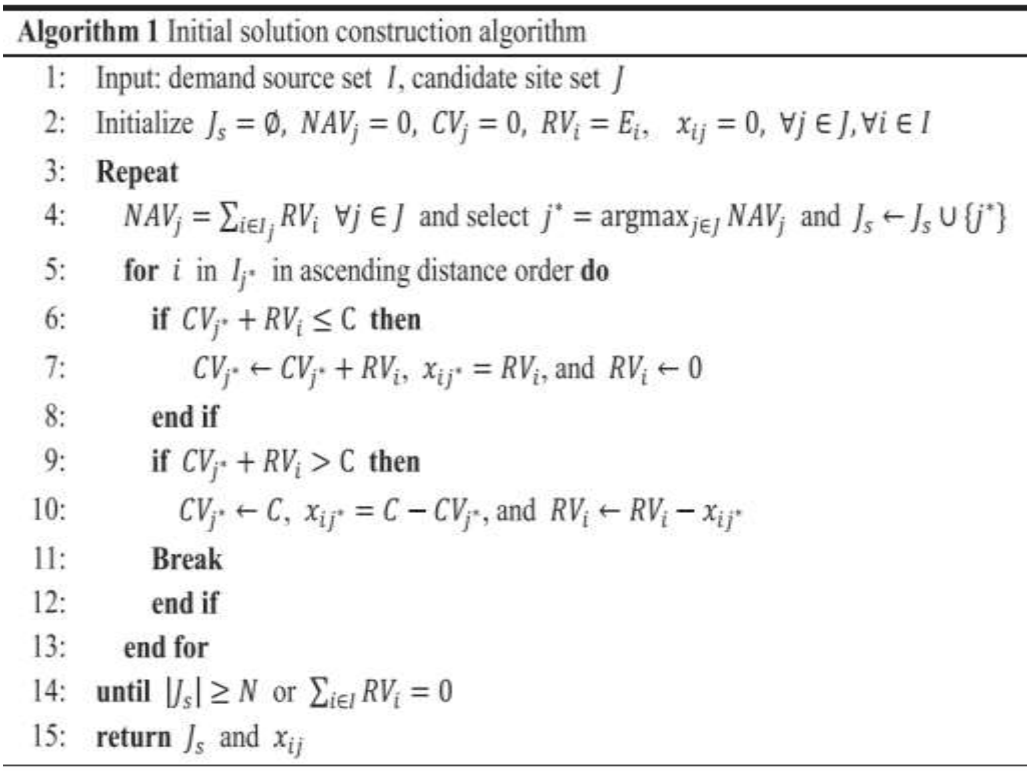
Station number determination model

$$\begin{array}{llll}
\text{Minimize} & \sum_{j\in J} z_j & & (1) \\
\text{s.t.} & \sum_{i\in I}\sum_{j\in J} x_{ij} \geq \sum_{i\in I} E_i * \gamma & & (2) \\
 & z_j \geq L_j & j\in J_a & (3) \\
 & x_{ij} \leq E_i * \alpha_{ij} & i\in I,\ j\in J & (4) \\
 & \sum_{j\in J} x_{ij} * \alpha_{ij} \leq E_i & i\in I & (5) \\
 & \sum_{i\in I} x_{ij} * \alpha_{ij} \leq Cz_j & j\in J & (6) \\
 & \sum_{j\in J} z_j * \beta_{ij} \geq 1 & i\in I & (7) \\
 & x_{ij} \in Z^+,\ z_j \in Z^+ & i\in I,\ j\in J & (8)
\end{array}$$

Figure 22 - station number determination model.

a) The objective function (1) is to minimize the required number of refuelling stations to be installed.
b) Constraint (2) ensures that more than the ratio g of HFCVs is covered for HRSs to be installed. The ratio g can be given by the policy manager.
c) Constraints (3) ensure that candidate sites that are already active or to be installed must be selected as HRSs.
d) Constraints (4) indicate that an HFCV cannot be assigned to a candidate site that cannot be used due to travel time constraints.
e) Constraints (5) ensure that at most Ei HFCVs can be assigned to candidate sites at the demand source i2I.
f) Constraints (6) guarantee that the number of vehicles allocated to candidate site j2J cannot exceed the open station capacity.
g) Constraints (7) guarantee that all HFCVs, including uncovered ones, must be within travel time S of an installed station.
h) Constraints (8) give non-negative integer restrictions.

The objective function value of the solution of the station number determination model is let's say 'N', Max cover and p-median models determine the location of the N station, the max cover and p-median models are used simultaneously to get the final result. But before using the max cover and p-median models an initial solution construction algorithm is used, and the solution obtained from this algorithm is the initial solution to utilized in the next mathematical model.

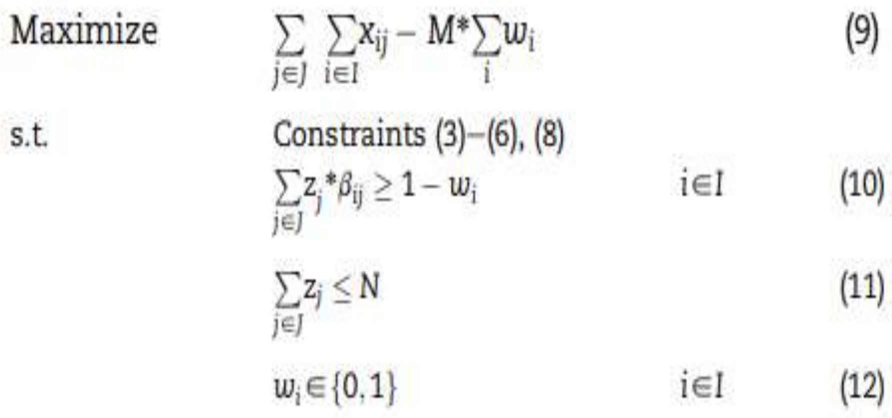


Algorithm 1 Initial solution construction algorithm

```
Input: demand source set $I$, candidate site set $J$
Initialize $J_s = \emptyset,\ NAV_j = 0,\ CV_j = 0,\ RV_i = E_i,\ \ x_{ij} = 0,\ \forall j \in J, \forall i \in I$
Repeat
  $NAV_j = \sum_{i \in I_j} RV_i\ \ \forall j \in J$ and select $j^* = \text{argmax}_{j \in J} NAV_j$ and $J_s \leftarrow J_s \cup \{j^*\}$
  for $i$ in $I_{j^*}$ in ascending distance order do
    if $CV_{j^*} + RV_i \le C$ then
      $CV_{j^*} \leftarrow CV_{j^*} + RV_i,\ x_{ij^*} = RV_i$, and $RV_i \leftarrow 0$
    end if
    if $CV_{j^*} + RV_i > C$ then
      $CV_{j^*} \leftarrow C,\ x_{ij^*} = C - CV_{j^*}$, and $RV_i \leftarrow RV_i - x_{ij^*}$
      Break
    end if
  end for
until $|J_s| \ge N$ or $\sum_{i \in I} RV_i = 0$
return $J_s$ and $x_{ij}$
```

Figure 23 - Initial solution construction algorithm

MAXCOVER MODEL:



$$\text{Maximize} \quad \sum_{j \in J} \sum_{i \in I} x_{ij} - M^* \sum_{i} w_i \qquad (9)$$

$$\text{s.t.} \quad \text{Constraints (3)–(6), (8)}$$

$$\sum_{j \in J} z_j {}^* \beta_{ij} \ge 1 - w_i \qquad i \in I \qquad (10)$$

$$\sum_{j \in J} z_j \le N \qquad (11)$$

$$w_i \in \{0, 1\} \qquad i \in I \qquad (12)$$

Figure 24 - Max cover model

a) The objective function (9) is to maximize the number of covered HFCVs as well as to minimize the number of demand sources that cannot be reached to any installed site within time S. M is a large number and is set to the total demand P $\Sigma_{i \in I} E_i$.

b) Constraints (3)-(6) and (8) in the Station number determination model are also contained in Max cover model.

c) Constraints (10) classify the demand sources according to whether any installed site can be reached with travel time S or not.

d) Constraint (11) ensures that at most N HRSs can be installed.

e) Constraints (12) give binary variable restrictions.

f) After the Max cover model, the p-median model is used simultaneously.

P-MEDIAN MODEL:

$$\text{Minimize} \quad \sum_{j \in J}\sum_{i \in I} t_{ij}x_{ij} + M^* \sum_{i} w_i \qquad (13)$$

$$\text{s.t.} \quad \text{Constraints (3)–(6), (8), (10)–(12)}$$

$$\sum_{j \in J}\sum_{i \in I} x_{ij} \geq K \qquad (14)$$

Figure 25 - p-median model

a) The objective function (13) is to minimize the sum of the travel time between HFCVs and HRSs, taking into account the penalties as in the Max cover model.

b) Constraints (3)-(6), (8), and (10)-(12) in the Max cover model are also contained in the p-median model.

c) Constraint (14) guarantees that the number of covered HFCVs obtained from the p-median model is greater than the first term of the objective function value of the Max cover model. It ensures that the solution of the p-median model cannot be worse than that of the Max cover model.

3. CURRENT STATUS OF HRS IN INDIA

In the next few years India is planning to adopt the Hydrogen Economic policy and for that, Hydrogen production, storage and most importantly the distribution of hydrogen to the refuelling stations must be thoroughly planned considering all the safety constraints. The current status is that the perfect hydrogen advances are accessible, costs are descending, and proficiency and execution are improving. The prerequisite is to show the scaled adaptation at a quicker rate, this will fabricate a trust in financial backers and will get public acknowledgment. Further the developing of strategies, framework and abilities will help in more extensive acknowledgment, decreasing apparent hazards, improving certainty, expanded ventures, bringing down costs. Government can assume an essential part with strategy support by making foundation, hazard decrease, making hydrogen market and giving advantages over utilization of low carbon energy chain. When the take-off is accomplished, the rest cost decrease and expanded multiplication could be accomplished by economies of scale. There can be obvious focuses for example emanation decrease standards and guidelines for different areas which will additionally encourage interest.. The job that Government can play is towards making a drawn out arrangement structure which could develop trust in private speculation, encourage market interest with strategy mediations, create principles and guidelines which ought not obstacle the development, give upgraded R&D help. The hydrogen refuelling centres play an important part in the hydrogen supply chain. The small refuelling stations can refill 10 -20 vehicles, having capacity 50-100 kg/day But after the market expansion, there will be a need of larger refuelling stations needing 200 kg/day.

Although the government is taking many positive moves to improve the current activity of hydrogen production and delivery in India, but is still an order of magnitude below where it needs to be to fully take benefits from a transition to hydrogen technologies, with manufacturing focussed mostly in India. In terms of the requirements in the investments, if India plans to deploy green hydrogen as a clean energy solution for key sectors, by 2050, this would need significant investment in electrolysers. Apart from this, an extra investment in renewable electricity is required, at a time when demands for electricity in India is emerging rapidly. This is undoubtedly is a clear challenge to deliver, that is why it India needs to scale up in the fields of hydrogen technologies.

HYDROGEN REFUELLING STATIONS IN INDIA

Location	**Fuel**	**Project**	**Partners**	**H2 production techniques**	**Comments**
Faridabad, India	HCNG blend & pure h2	Hydrogen Fueling at Indian Oil Corporation Ltd's R&D Centre	Air Oil Corporation Ltd, Air Products and Chemicals, INOX air products	APCI's HCNG mixing unit and dual dispensing unit that can fuel vehicles with either a HCNG blend or pure H2	Station opened by Indian Oil Corporation, First phase of India's development of its hydrogen economy.
Dwarka, Delhi, India	H_2, HCNG	Indian Oil Corporation hydrogen station	Indian Oil Corporation	Will deliver a 20:80::hydrogen: CNG mix	Capable of fuelling 100 vehicles

Table 1 – Hydrogen Refuelling Stations in India

4. FUTURE PROSPECTS

The future of hydrogen energy looks promising in India. The government in this year's financial budget has given possible hopes for the National Hydrogen commission in India. A well-planned roadmap is required to acquire the benefits of hydrogen economy. Though hydrogen is abundantly available, its extraction processes are much complex. Market giants like Tata and Reliance are planning to carry out pilot processes for the production and distribution of hydrogen. Reliance has announced to set up the largest Hydrogen Refinery in the coming years. IOCL has patented a new technology for producing H-CNG (18% hydrogen in CNG) which will change the Indian transport system. Power major NTPC ltd is also operating pilot projects to run 10 hydrogen fuel cells electric cars in Leh and Delhi.

The scope for hydrogen refuelling stations in India is vast. Taking the account of the IH_2A (Indian Hydrogen Alliance) formed recently, they have set certain objectives to build new hydrogen refuelling stations in India. The panel works on the areas which include – to develop a roadmap for 2021-2030, to identify nationally large H_2 demonstration stage projects and to create hydrogen production, storage and distribution, industrial and transport use cases and standards. The infrastructure developments are much needed to establish the hydrogen refuelling stations in India. The big companies like Indian Oil Corporation IOC) , Gujarat State Petroleum Corporation(GSPC), Hindustan Petroleum(HP) , Bharat Petroleum(BP), Reliance Petroleum(RP) and Shell Hydrogen will be the key players in setting up the refuelling stations in India. The pathways and specific locations for refuelling stations are yet to be decided.

The companies like Linde Air Limited, Aditya Birla Chemicals, Praxair, DCW limited, Air Products, Fuel Cells Energy, Air Science, Air liquid, Bhoruka etc can be of great help in producing and storing hydrogen in the refuelling stations.

5. CHALLENGES

- Due to the high installation cost of HRSs, it is challenging to install sufficient refuelling stations simultaneously. Hence, a limited number of HRSs are initially installed. Since only a few stations can handle all HFCVs, determining how many and where to mount HRSs is critical.
- A strong and safe hydrogen delivery infrastructure would need a means to detect any hydrogen leaks. This is very important from both safety and economic views. Odorants are needed for regulation in today's urban natural gas distribution pipelines for both resident and commercial use. However, odorants may be problematic for hydrogen because they need to be removed because of the tough quality requirements for fuel cells, unless one could be developed that did not interfere with the hydrogen fuel cell performance.

- Lack of fuelling station infrastructure - fuel cell cars refuel in a similar way to conventional cars but cannot use the same station

- Hydrogen is pressurized and stored in a cryogenic tank, from there, it is fed to a lower –pressure cell and put through an electrochemical reaction to generate electricity which is extremely dangerous.

- One of the difficulties of encouraging market entry of hydrogen vehicles is the high cost of low-volume hydrogen production and refuelling. The cost of delivered hydrogen in dollars per kilogram decreases as station capacity increases. Thus, the stations that are entering the market first will have the disadvantage of producing hydrogen at a higher cost in the future due to their smaller size.

- Therefore, the primary challenges we need to finally meet is scaling up the technology, reduction in cost, increased adoption and the sustainable growth of hydrogen-based technologies. Government's role plays an essential role towards creating a long-term efficient policy framework which would build up confidence in private firm's investments, creating market demand with various scheme implementations, developing standards and regulations which should not hurdle the growth, also would provide enhanced R & D support.

6. RESULTS AND DISCUSSIONS:

The strategy and cost of hydrogen conveyance is exceptionally identified with where hydrogen is produced, which can be characterized into centralized, semi-centralized or distributed ways. Centralized production alludes to enormous focal hydrogen offices, which expects transportation to the last refuelling station, while distributed pathway alludes to creation close to the refuelling facilities. Semi-centralized production alludes to intermediate sized hydrogen production facilities (5,000 - 50,000 kg/day) situated in nearness (40 – 161 km) to the mark of utilization. These facilities can give a degree of economy of scale as well as limit hydrogen transport expenses and framework.

Hydrogen conveyance pathways are ordinarily evolved dependent on the different actual states which hydrogen can be conveyed. Correspondingly, compacted gaseous hydrogen is normally conveyed through truck/tube trail or pipeline; fluid hydrogen is frequently moved by truck and by alternate methods of transport, for example, by rail or barge, which is regularly utilized in significant distance transportation event as it is more financially savvy than gaseous hydrogen conveyance strategy. Solid hydrogen is for the most part conveyed inside profoundly explicit tanks, however is right now at different formative stages and require more innovative upgrades for mass selection. Today, fluid gaseous hydrogen through tube trailers and gaseous hydrogen by means of pipelines are the three essentials techniques for conveying hydrogen.

Generally, hydrogen is stored in three different manners: compressed gaseous hydrogen by either engrossing or reacting with metals or chemical compounds or storing in an elective chemical form. However, the measure of energy needed to compress hydrogen into fluid by super-chilling it off to -250° C outcomes in ~40 % efficiency loss with 100% gaseous tube trail, liquid tube trail pipeline current technology. Gaseous hydrogen storage is the most developed storage innovation today, and has the benefit of quick charge/discharge and low energy misfortune. Solid hydrogen, with a hypothetical energy effectiveness higher than fluid hydrogen however lower than gaseous hydrogen, requires a higher technology intracity is still at the test stages.

Here the method which is considered as the most suitable for the production, transportation and storage of hydrogen are mentioned.

Centralized hydrogen production- hydrogen produced in central hydrogen facilities and transported to the refuelling stations. The produced hydrogen would be stored in the form of compressed gaseous hydrogen and liquid hydrogen.

Hydrogen pipeline

- Suitable for significant distance and enormous scope hydrogen transportation
- Mainly for gaseous hydrogen
- Large initial capex with low operation cost
- Delivering through pipeline has most noteworthy energy effectiveness
- Established distance of hydrogen pipelines- global: >5,000 km; US: 2.600 km, EU: ~1,500 km, China: 300 – 400 km.

Challenges

- Installed capital cost, -management of pipelines integrity (e.g. potential for hydrogen embrittlement), -pipeline compressor cost and reliability

Tube trail/ truck/ ship – For gaseous and liquid hydrogen, suitable for different distances and scales relying upon strategy for transportation.

Challenges

-High capital expense of composite cylinder trailers, -DOT weight limit of 36.3 metric tons, -Cost and footprint of tube trailer terminals (compressing buffer storage and high-volume compressor)

Storage of hydrogen at the Hydrogen Refuelling Stations

Compressed gaseous hydrogen

- Most normally utilized and most developed hydrogen storage innovation
- Simple construction, low energy effectiveness, quick in refueling
- Safety could be a worry in nations with immature foundation and arrangements

- Low energy misfortune in contrast to liquid hydrogen

Liquid hydrogen

- Liquefied hydrogen with high pressure and low temperature, makes it proficient in storing and transporting
- Large volume specific capacity and higher transport efficiency by volume

Challenges

- Capital cost of liquification, -energy intensity of liquification, -Boil-off losses

Overall challenges

- Hydrogen purity
- Leak detection
- Safety
- Education (counting improvement of a talented labour force just as training of key partners, for example, local authorities having jurisdiction and potential station operators)
- Supply chain for key components

7. CONCLUSION

As a benefaction to the after effect of emerging hydrogen market in the transportation phase, this analytic constituted a document retrieval concerning the hydrogen infrastructure for portability in India. Hydrogen refuelling stations play a vital role in the changeover to hydrogen-based economy by reinforcing the exposure of the hydrogen-based vehicles into the transport system. However, for a voluminous expansion of the concerned market, the development of the refuelling system along with the introduction of the commercial hydrogen vehicles should be treated as the first and foremost priority. This report has lime lighted the perseverance of the critiques and other such facts, regarding the present status of hydrogen infrastructure and its upcoming anticipations in India. The topics discussed in this project provide a brief understanding that the hydrogen mobility is still at the pioneer, although it possesses a bright future; i.e. the transition to a low emission era in Green Mobility. Here, it should be worth noting that the hydrogen technologies are efficiently opportunistic, as compared to the others.

Hence, the sustainability of the hydrogen system can be kept under consideration. To this extent, a survey over the different predictions, provided concerning the facts with respect to the possible scenarios of HRSs and FCEVs upcoming deployment in the major parts in India, give a marvellous blueprint for fuel cell electric based transport. The main conclusion indicates that the factors, linked up with the deployment of hydrogen in transport limit to two co-ordinates viz: FCEVs and Hydrogen Refuelling stations development. Nowadays, numerous nations are developing network of HRSs for promotion and growth of hydrogen mobility. However, this will reduce the ownership cost of FECVs, to be competent with other segments. The manufacturer of the concerned switches to stations with higher capacities per dispenser for maintaining reasonable affordability at the consumer end. Under any circumstances, it will go highly profitable to promote the hydrogen infrastructure as compared to a growing fleet of FCEVs by the impulsive vehemence of more research and studies, exploring "Hydrogen Refuelling Stations – their characteristic and future aspects in the Indian market" Assuredly, hydrogen will play a pretentious role in upcoming mobility, and will obviously assist the arduous speculation of a zero/low emission-based transportation at a stone's throw.

8. REFERENCES

1. IPCC, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual (Volume 3) – Energy, 1996. http://www.ipcc-nggip.iges.or.jp/public/gl/invs6a.htm
2. IOCL. (2020). Hydrogen Economy: Global Imperatives
   a. and Indian Initiatives. 2nd Indo-Japan Workshop on
   b. Hydrogen and Fuel Cell. Delhi.
3. Koljonen, Tiina, Pursiheimo, Esa, Gether, Kaare and Jørgensen, Kaj, "System analysis and assessment of technological alternatives for Nordic H2 Energy Foresight", Nordic Hydrogen Energy Foresight, Risø National Laboratory, Denmark, 2004, http://www.h2foresight.info/Systems%20analysis%20report%20170505.pdf
4. Ramage, M.P., "The hydrogen economy: Opportunities, costs, barriers, and R&D needs", National Research Council of the National Academies, 2004. http://www.house.gov/science/hearings/full04/mar03/ramage.pdf.
5. International Energy Agency. CO2 emissions from fuel combustion highlights. Paris:
   a. France; 2017
6. Rifkin, Jeremy, "The Hydrogen Economy-After Oil, Clean Energy From a Fuel-Cell-Driven Global Hydrogen Web", emagazine.com, January/ February 2003. http://www.emagazine.com/view/?171

7. R.B. Moore and V. Raman, “Hydrogen Infrastructure for Fuel Cell Transportation,” *International Journal of Hydrogen Energy*, Vol. 23, No. 7, pp. 617-620, 1998.
8. C.E. Thomas et al, “Hydrogen Infrastructure Report Prepared for The Ford Motor Company,” July 1997
9. https://auto.economictimes.indiatimes.com/news/industry/govt-mulls-plan-to-bring-fame-like-scheme-for-hydrogen-powered-systems-niti-aayog-member/79450907
10. Fuel Cell Today. ‘Fuel cell history’, 2018 Accessed http://www.fuelcelltoday.com/
    a. history#Origins, Accessed date: 17 March 2018

11. TUV SUD. ‘92 new hydrogen refuelling stations worldwide in 2016’ 2017 Accessed
    a. https://www.tuv-sud.com/news-media/news-archive/92-new-hydrogenrefuelling-
    b. Stations-worldwide-in -2016, Accessed date: 29 January 2018 www.tuvsud.com

12. Wattfuelcellcom. 2019. what-is-a-fuel-cell.Availablefrom: https://www.wattfuelcell.com/portable-power/what-is-a-fuel-cell/
13. Rosen, M.A. & Koohi-Fayegh, S. Energ. Ecol. Environ. (2016) , The prospects for hydrogen as an energy carrier: an overview of hydrogen energy and hydrogen energy systems. Available from: https://link.springer.com/article/10.1007/s40974-016-0005-z
14. Thought Co. A History of the Automobile. Available from: https://www.thoughtco.com/who-invented-the-car-4059932
15. Florida Solar Energy Centre (n.d.). Hydrogen Basics. Available from: http://www.fsec.ucf.edu/en/consumer/hydrogen/basics/index.html

16. Hydrogenicscom. 2019. Hydrogen Technology. Available from: https://www.hydrogenics.com/technology-resources/hydrogen-technology
17. Machineryequipmentonlinecom. 2016. Electrical power generation. [Online]. [12 August 2019]. Available from: http://machineryequipmentonline.com/electricalpower-generation/fuel-cellsfuel-cell-principle/
18. Myautotime, Hydrogen in internal combustion engines. Available from: https://chejiahao.autohome.com.cn/info/3340139/ 8. Science & Technology Review (2017), Fuel cell drive the future
19. DOE Hydrogen Program (2006), Hydrogen fuel cells fact sheet
20. H. Ren, J. Chae, in Wireless MEMS Networks and Applications, 2017. Fuel cells technologies for wireless MEMS. Available from: https://www.sciencedirect.com/ topics/engineering/proton-exchange-membrane-fuel-cells
21. Fuelcelltodaycom. 2019. about Fuel Cells. Available from: http://www.fuelcelltoday.com
22. GMHeritageCentre.Availablefrom: https://history.gmheritagecenter.com/wiki/index.php/1966_GM_Electrovan
23. ZHAO, YANG, &GAO, Major countries and energy companies around the world are accelerating the distribution of hydrogen energy industries. Available from: http://www.famens.com/news-355055.html
24. Fuelcelltoady.com, History. Available from: http://www.fuelcelltoday.com/history
25. Fuel Cell Vehicle Technologies, Infrastructure and Requirements, Electric Vehicle Transportation Centre, 2017.Availablefrom: https://www.pnas.org/content/pnas/suppl/2019/02/20/1804221116.DCSupplemental/pnas.1804221116.sapp.pdf