Hydrogen Mobility

HYDROGEN MOBILITY IN THE UAE

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Contents

Environmental Situation Today

Global economies are in consensus to the need of mitigating the increase of global temperatures. The average global temperature could increase by 2-5 °C by the next century, if greenhouse gases emissions are not mitigated. Transportation is a major contributor to this increase, as it accounts for 24% of global GHG emissions (in 2017) and is expected to grow with the high rates of urbanization. In 2015, 195 countries, including the UAE, joined the Paris Agreement that limits the increase of temperature to "well below 2°C above pre-industrial levels". The agreement requires all parties to set mitigation strategies post-2020 and review the targets every 5 years.

Accordingly, the UAE is effectively contributing to its international commitment by setting targets to reduce emissions and increase contribution of clean energy in its energy mix. In the near-term, the UAE Vision 2021 National Agenda aims to establish the country as a leading nation. Among the six pillars, there is significant emphasis on implementing green strategies and increasing reliance on clean energy, while maintaining a balance with strong economic development. The National Agenda sets a target of 27 percent share of clean energy and 15% reduction of CO_2 emissions. The ambitious leap from 0.02% share of clean power generation in 2011 to 27% could only be achieved with concrete actions to develop and implement clean energy technologies.

Announced by H.H. Sheikh Mohammed bin Rashid Al Maktoum, Vice-President and Prime Minister of the UAE and Ruler of Dubai, the UAE's 'Energy Strategy 2050' launched in 2015 aims to increase the contribution of power generation from renewable energy to 50 percent, while reducing carbon emissions by 70 percent. UAE is looking to diversify energy sources, diverting from heavy reliance on oil and gas to a mix of 44 per cent clean energy, 38 per cent gas, 12 per cent clean coal, 6 percent nuclear. These visions are closely linked to building a green economy with low carbon footprint, while maintaining strong economic growth and preserving resources.

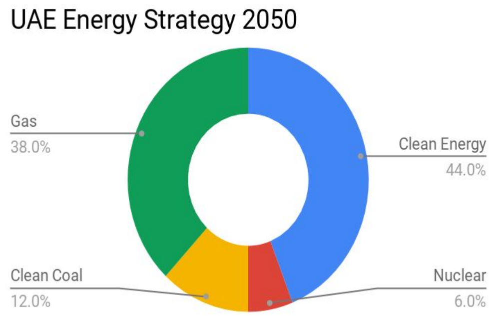


Fig 1 - UAE Energy Strategy 2050

International green incentives have set targets for flourishing a low carbon economy to meet two-degree scenario through conversion to alternative fuels. Hydrogen is a popular alternative widely utilized among nations due to its emission-free characteristic.

Japan is pursuing a hydrogen-based economy in efforts to reduce the burden on the environment and achieve (Two Degree Scenario) 2DS. The vision of a “Hydrogen Society” where hydrogen is the major power source is promoted by financial assistance from the government. Tokyo Metropolitan Government is investing a USD 348 million fund to establish hydrogen infrastructure and fuel stations. This vision is targeted to achieve reduction of GHG emissions along with energy security and a beneficial economic ripple caused by shift to a new energy source.

Germany’s Climate Action Plan 2050 targets to lead the country to a CO2-neutral economy by 2050. The plan sets strategies to decrease CO2 emissions on a sector-by-sector basis. The National Innovation Programme for Hydrogen and Fuel Cell Technology contributed to the massive growth of the hydrogen economy, where the government invested USD 1.6 billion into the program.

France targets 75% reduction of its 1990 CO2 emission levels in its Climate Action Plan 2050. In efforts to reach this goal, the French government launched a strategic plan for the deployment of a hydrogen economy and earmarked an investment of USD 116 million in

2019 to decarbonize the transport, industry and energy sectors. Also, the sale of petrol and diesel cars will be banned in 2040 to motivate car manufacturers' innovation in the field.

Achieving two-degree scenario target requires a global shift from fossil fuel-based economies to major reliance on clean fuels in power generation and transportation. This energy transition is inevitable, and hydrogen is an integral enabler of the process. The worldwide trend of conversion to clean energy will decarbonize the transportation sector and as a result, the availability of Internal Combustion Vehicle (ICE) vehicles will gradually decrease. Worldwide adoption of zero-carbon vehicles facilitates this transition. EVs dominate the early phase of this transition with an increase of 50% of light-duty sales in 2017 relative to 2015. Although EVs have a high well-to-wheel efficiency, a feasibility study conducted by Masdar on the penetration of Electrical Vehicles (EVs) in the UAE showed key technical challenges that limit its application. Hydrogen fueled Fuel Cell Electric Vehicles (FCEVs) could compliment this industry to fill in for EVs limited adoption in the UAE and allow deep decarbonization of the sector. The abundance of hydrogen from local sources facilitates a hydrogen economy in the UAE, which contributes to the demand of clean energy and fuel. The use of local existing sources in the first phase of implementing the hydrogen road map is economically convenient, however, the final term goal is to utilize 100% green hydrogen.

Need for Hydrogen Mobility

Transportation sector today relies heavily on fossil fuels, producing 20% of the world's CO2 emissions. Decarbonizing the transport sector is a necessity rather than an option. The deployment of hydrogen vehicles is already in progress and expanding in global economies. Japan is leading the way with 91 refueling stations accessible publicly. Japan has set targets of 40,000 FCEVs and 160 stations in 2021, with an increase to up to 800,000 FCEVs and 900 stations in 2030. Germany ranks next with 45 stations, followed by USA with 40 stations. The figures below show the international activities of FCEV utilization, which are expanding drastically with forecast of CAGR of 28%. The magnitude of the market eventually will decrease the price of hydrogen to an economically attractive price point for the end user.

Fig 2 - international activities of FCEV utilization

UAE leaders launched incentives that aim to diversify energy sources to increase energy security and political independence. The UAE energy is heavily powered by natural gas rather than oil, which is imported from neighboring countries. To diversify energy sources, national incentives encourage private sectors to take initiative in improving technologies to harness and utilize renewable energy.

Solar power generation is a major focus in the UAE due to its decreasing cost and availability. Advancement in solar technologies and economies of scale due to high manufacturing demand result in rapidly declining CAPEX, which facilitate their utilization versus other power generation routes. Masdar and its partner, EDF, submitted the world's lowest proposal for generation at a rate of 1.7 US cents per kWh for the solar project in Saudi Arabia. The UAE receives an average of 10 hours of daily sunlight and 350 sunny days per year. Solar projects in the UAE include Shams 1 solar plant in Masdar already feeding the grid since 2013. The Mohammed bin Rashid Solar Park in Dubai will be the world's largest single-site solar plant with a total capacity of 5000 MW to be completed by 2030. Another project expected to be completed by 2026 is Sweihan utility-scale solar plant in Abu Dhabi, with a planned capacity of 5700 MW generating electricity at a rate of 2.42 US cents per kilowatt hour.

Hydrogen is a core source in the energy transition. As the energy mix is increasing with renewables, hydrogen plays a vital role in the storage of renewable energy and enables growth of intermittent supply. With solar projects in the UAE increasing, it is estimated that solar will contribute to 25% of the power output in UAE by 2030. Through renewable electrolysis of water into hydrogen and oxygen, hydrogen provides an energy storage medium, until its fed into a fuel cell for electricity generation. A “hydrogen battery” allows long time storage of electricity surplus in low demand hours efficiently and therefore is integral in the energy transition. The following graph demonstrates an example of PV production and usage . The excess energy generated daily can be stored using hydrogen to fulfil usage needs during low production hours.

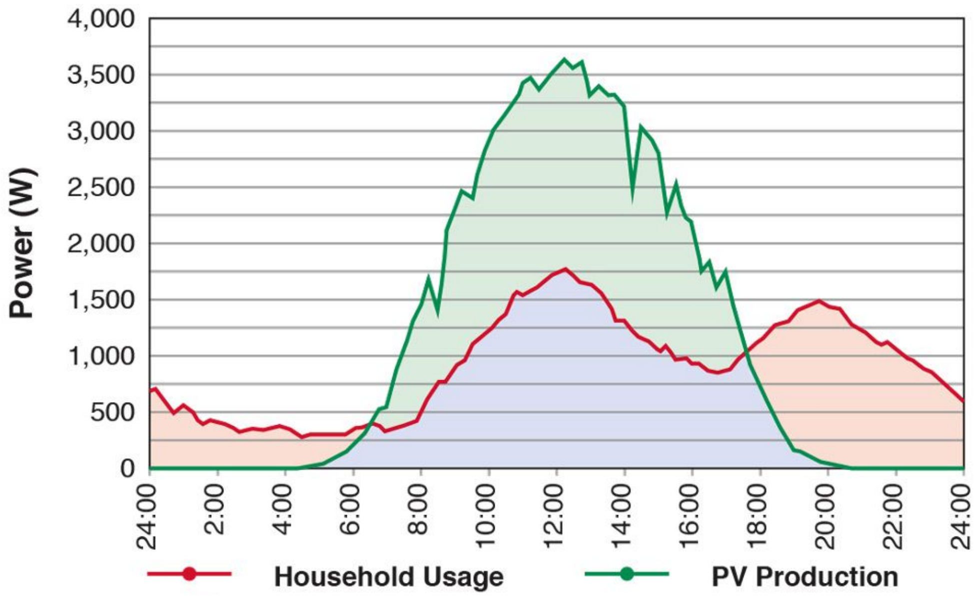


Fig 3 - Example of PV production and usage

Solution: Hydrogen mobility

About Fuel Cell Electric Vehicles

The demand of renewables is rapidly increasing across nations bringing in visions of an inevitable clean disruption. Alternative cheap energy routes will redefine the industry we know today, wiping extraction-based resources. With this global shift to renewables, the abundance of hydrogen makes it a core energy source of the future. Although hydrogen does not exist in a direct fuel form, hydrogen available in feedstock such as natural gas, H2O, and H2S can be derived through several production technologies. It is currently largely produced as a byproduct in industrial operations and is available for utilization. Today, hydrogen's existing applications include use for chemical and petroleum refining, food processing, metal production and fabrication, and ammonia production for agriculture. However from source to application, hydrogen being the lightest gas of the periodic element, is challenging to store and transport. Storage technologies, such as compression, liquefaction, and storage in metal hydrides, are used to reduce the volume and therefore facilitate logistics. Also, applications require a certain level of purity which adds another processing step in the hydrogen chain.

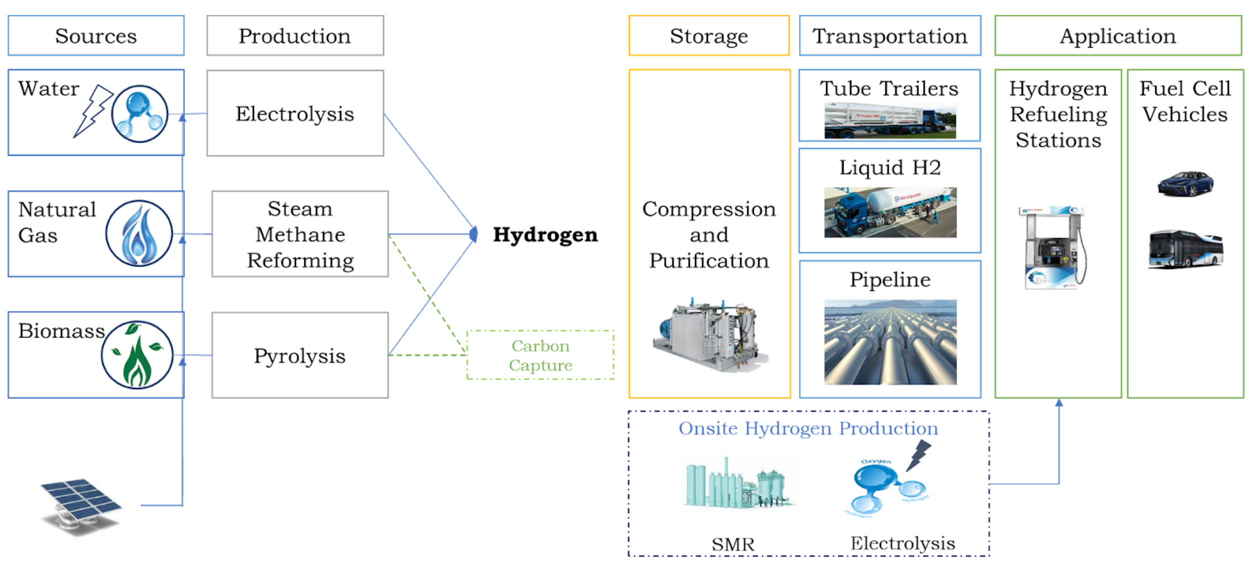


Fig 4 -

In the last decade, hydrogen as a transportation fuel has gained a lot of momentum for its emission-free property. A fuel cell is used to convert hydrogen into energy that runs an electric motor in vehicles, known as Fuel Cell Electric Vehicles (FCEV). Similar to Battery Electric Vehicles (BEV), FCEVs are zero-exhaust emission, however only producing byproduct of water. Introducing fuel cell and electric vehicles is recommended for deep decarbonization of the transportation sector and minimizing emissions, which serves UAE's visions of a low carbon economy. Although battery operated vehicles have been a hype here in the UAE, there are some limitations including the charging time required, the autonomy of the battery compromised with the hot ambient temperature, and limited range of mileage. Available payload of vehicles, especially trucks, is reduced with BEVs due to the weight of the battery. Studies show a decrease of available payload in electric trucks ranging from 19-87%, relative to fuel cell trucks. Also, the deposition of replaced batteries, which is estimated to have a lifetime of 5 years, introduces an environmental challenge.

Results of a feasibility study conducted by Masdar Institute on electric vehicle penetration in Abu Dhabi suggest that deployment requires tackling five major technical challenges which include:

- Matching the EV to the use case, to challenge the limited mileage offered by EVs.
- Upgrading the power grid to handle simultaneous EV charging locations without exceeding static limits of distribution-system transformers and lines.

Hydrogen technology could compliment BEVs by overcoming these challenges with only a few minutes to fill up a tank and a mileage range comparable to petrol. Hydrogen powered cars and buses have reached technological maturity, while development of vans, trucks and trains is under process. Current manufacturers include Honda, Hyundai, Toyota, Mercedes, and BYD with more joining to expand model choices. Commercially available vehicles include Toyota Mirai, Honda Clarity, and Hyundai Nexo, all which have passed safety certifications and regulations and are on the road.

Fig 5 - H2 possible usage in Transports

Al Futtaim Motors, the exclusive distributor of Toyota in UAE, has imported 55 Toyota Mirais for trial purposes which refuel at the first Hydrogen Refueling Station in UAE, installed by Air Liquide. This pilot phase aims to demonstrate the potential of a hydrogen market in the UAE by connecting all partners across the hydrogen chain. The UAE provides an optimal platform for hydrogen energy market development with the availability of large energy source. Also, with the population density centralized in Abu Dhabi and Dubai, an approximation of 12 hydrogen refueling stations is estimated to be sufficient to cover the nation's hydrogen fuel demand. Abu Dhabi Police announced that the entire fleet of police vehicles will be converted from fossil-fuel powertrain to fuel cells by 2057. Also, Dubai Taxi Corporation and Abu Dhabi police entities are test driving the Toyota Mirai for use in their fleet. Another HRS is set to start construction in Masdar, Abu Dhabi in the first half of 2019.

Hydrogen sources in the UAE

Air Liquide is leading the hydrogen mobility market in the UAE with efforts in developing potential infrastructure that connects hydrogen production sources and utilization routes. The aim is to distribute hydrogen at the country scale building a hydrogen mobility roadmap with multiple sourcing to increase reliability. AL is working to organize localized existing sources of hydrogen that are not fully utilized, to cover the country with a reliable network and supply of hydrogen.

Steam Methane Reforming (SMR) provides an economical route for hydrogen production. Methane sourced from natural gas is reformed into hydrogen with CO2 as byproduct. For cleaner production, solar assisted SMR can result in significant reduction of emissions for the process. According to a study conducted by Giaconia et al, a reduction of 38 percent of CO2 emissions is estimated, conservatively. Another route for green production is through implementing carbon capture technologies on the SMR, where captured CO2 can be redirected for several applications, including pH control for desalination plants, agricultural applications and oil production Enhanced Oil Recovery (EOR). SMR units already exist in the UAE in the petroleum refining industry, producing excess hydrogen that can be redirected for fueling the mobility market.

An alternative green hydrogen production technology is water electrolysis; utilization of solar power to decompose water into hydrogen and oxygen to provide green hydrogen. The cost of hydrogen produced by electrolysis depends largely on the price of electricity used to power the unit, which can contribute to 60% of the total cost. With the expansion of solar energy planned in the UAE and reduced electricity costs, electrolysis provides an economically attractive and viable production route.

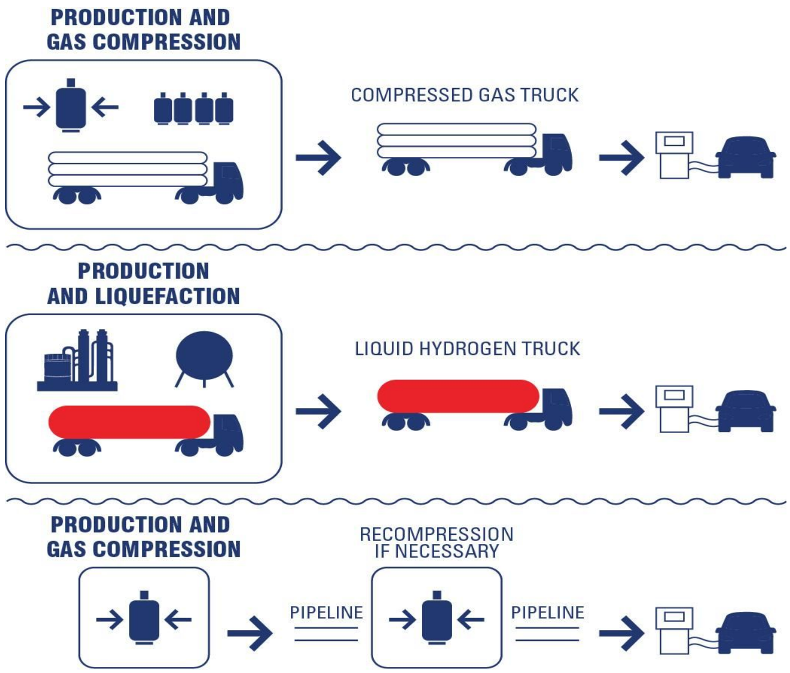
Hydrogen sulfide H2S is produced in large quantities in the UAE as a by-product of gas sweetening process; for example, Shah gas field has 23 percent levels of H2S. Thermal decomposition of H_2S molecule to produce hydrogen is a feasible route; however, the process is not commercial because of the high cost of hydrogen produced.

Biomass produced in large quantities in the UAE could be a potential supply of hydrogen. UAE has a daily per capita municipal solid waste of 1.9 kg/day, which is one of the highest in the world (National Bureau of Statistics, 2013a, 2011). Gasification of the organic waste in a high-temperature gasifier with controlled levels of oxygen produces another reliable source of H_2 with CO_2 as byproduct. Japan is reforming sewage sludge into pure hydrogen; microorganisms break down solid waste releasing biogas which is then transformed into hydrogen. A wastewater treatment plant in Fukuoka, Japan, produces 300 kg of hydrogen per day, enough to fuel 65 Toyota Mirai vehicles, and could be scaled to produce enough hydrogen for 600 vehicles.

The maximum energy content of 1 Nm^3 of hydrogen is 3 KWh. Therefore, economic feasibility of production routes can be analyzed by comparing the amount of energy spent on producing 3 KWh. Electrolysis, for example, have a rate of approximately 5 KWh energy (as electricity) to produce 1 m^3 of hydrogen, while SMR utilized 4 KWh (as natural gas). Efficiency of production rate is higher when hydrogen is produced as a by- product in refining processes such as catalytic reforming, propane dehydrogenation, and steam cracking. Borouge, subsidiary of ADNOC, runs a refinery plant with the largest steam cracking facility in the world, and produces hydrogen off gas that could be utilized in the hydrogen mobility context.

Hydrogen Transportation

Hydrogen transportation from source to application can be achieved by road or pipeline. However, the low density of the gas introduces a challenge as it requires high compression or liquefaction power for transport. Compressed gaseous hydrogen is transported in bundles, tube trailers or by pipeline, while liquid hydrogen is transported in liquid H_2 trailers. The economic advantage of each transportation method depends on the volume of H_2 transported to justify the investment.



Source: Hydroville

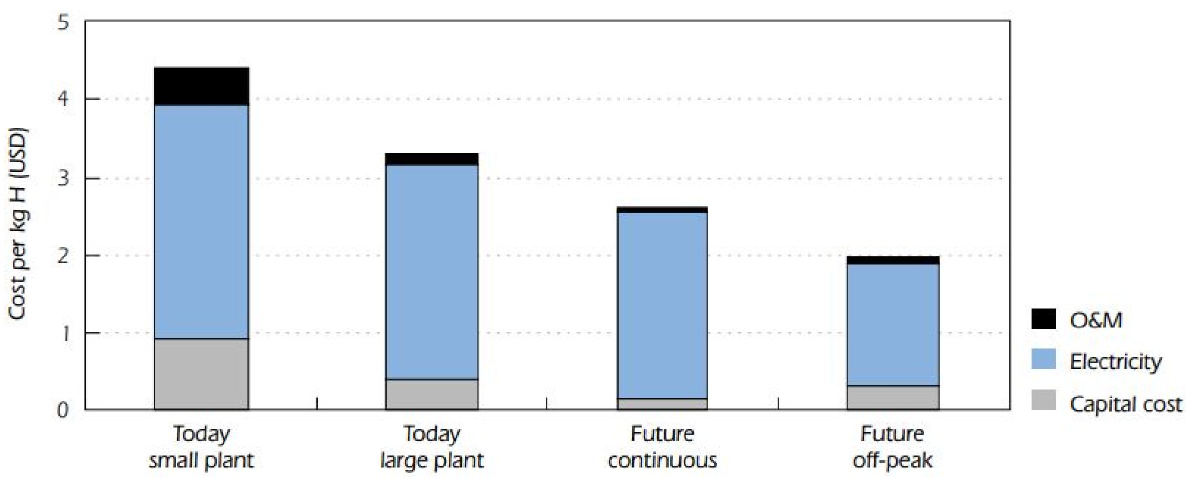
Fig 6

Gaseous hydrogen is transported in bundles of pressurized gas cylinders stacked in trucks, commonly known as tube trailers. The gas is compressed to 200 bars into long cylinders, which are bundled on a trailer inside a protective frame. To withstand the high pressure of content, the tubes are usually made of steel. Another alternative is the use of composites tube trailers, which are utilized for high volumes to justify their premium cost. The high net weight of steel challenges the mass of hydrogen transported due to legal payload restrictions. This route provides flexibility in operation; however, it is only practical for small to medium quantities of hydrogen as it gets expensive with more pressurized cylinders required for larger quantities. For larger volumes, cryogenic tanks or pipelines could prove more economically attractive.

Alternatively, liquified hydrogen can be transported by liquid hydrogen trailers. Compared to gas cylinders, liquid cylinders can hold substantially more hydrogen, as the density of liquid hydrogen is higher, almost a thousand times, than that in gaseous form. However, liquefaction process requires cooling hydrogen to -253 °C which is energy intensive and costly. Also, cryogenic tanks are required to hold liquid hydrogen at -253 °C, making liquid trailers four times more expensive than gaseous trailers. The equipment required for this mode of transportation makes it a relatively expensive route. Therefore, it is only cost-effective to transport liquid hydrogen for longer distances and larger volumes. The liquefaction process is offset by lower trucking costs.

For a large-scale hydrogen market, a pipeline network provides the best option to connect energy source with hydrogen fuel stations. Pipelines could be used to meet the growth in demand and provide a stable route of transportation. However, the capital cost to install a pipeline infrastructure requires high level of investment. Hydrogen pipelines cost is equivalent to three tube trailers per kilometer. Therefore, a large volume of cars that correspondingly consume enough hydrogen are required to pay off a hydrogen pipeline network. Hydrogen pipelines are widely utilized globally, with more than 4500 km in operation since 2006. Air liquide Arabia (ALAR) operates a 21 km pipeline designed to transport large volumes of hydrogen to customers in the city of Jubail. The ALAR pipeline provides a stable and reliable supply to several industries, such as refining, petrochemicals, polysilicon, glass and steel.

A decentralized hydrogen system in fueling stations, where hydrogen generation is onsite, could avoid the cost of hydrogen transportation. Distributed hydrogen production utilizes small scale water electrolyzers and SMR. A fully integrated hydrogen chain, for example in bus stations, can be utilized where renewable energy powers onsite generation units to produce hydrogen quantities required for fleet. It is worth noting that the cost of hydrogen production is highly sensitive to the scale. Therefore the cost of hydrogen generation on site is higher for small capacity units and the efficiency is lower than full scale plants. The graph demonstrates current and potential costs of electrolytic hydrogen, showing the trend as volumes scale, the cost decreases. Distributed production could be only be economically viable if it overcomes cost of long transportation distances. It is important to note that for gaseous H2, the cost per kg is about one-third production, and two-thirds purification, compression and transport. Thus, optimizing the transport route holds significant economical advantage.



Source: US DoE

Fig 7

Hydrogen Refueling Station

Hydrogen fuel, being the lightest gas, makes refueling stations complex relative to petrol stations. The hydrogen from source to the inlet of the pump undergoes the following steps:

1. Hydrogen gas is delivered to the refueling station in cylinders or tube trailers at a pressure of 200 bar.
2. H2 is compressed onsite to 300/700 bar, in a compressor skid of three stages. Compression of hydrogen releases heat, therefore a chiller is utilized to cool down the hydrogen between stages of compression.
3. After the hydrogen is compressed, it is stored in buffer tanks. The buffer allows stable supply to the inlet of the dispenser.
4. Before distribution, H2 is cooled using a heat exchanger which utilizes cooling water from a chiller to -40 Celsius.
5. A dispensing system is designed to supply fuel to the vehicle's tank, filling it in 3-5 minutes.

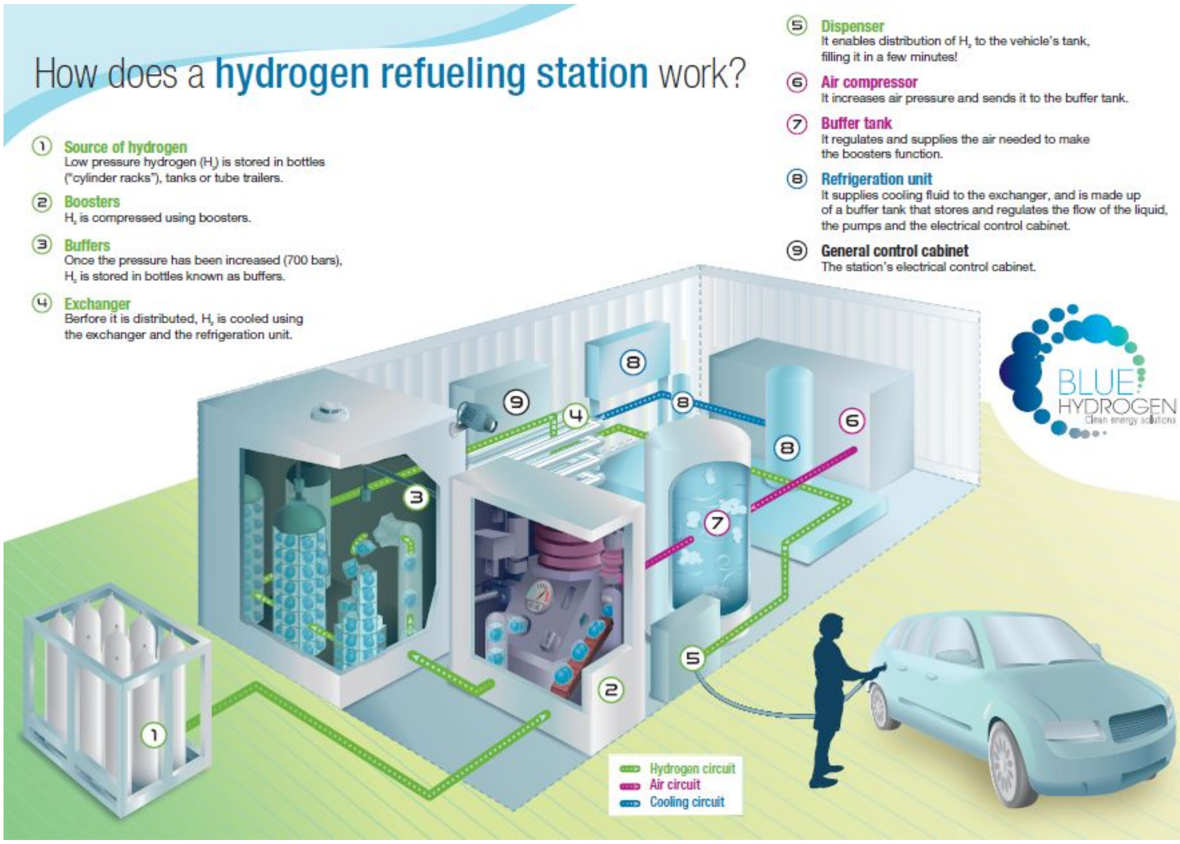
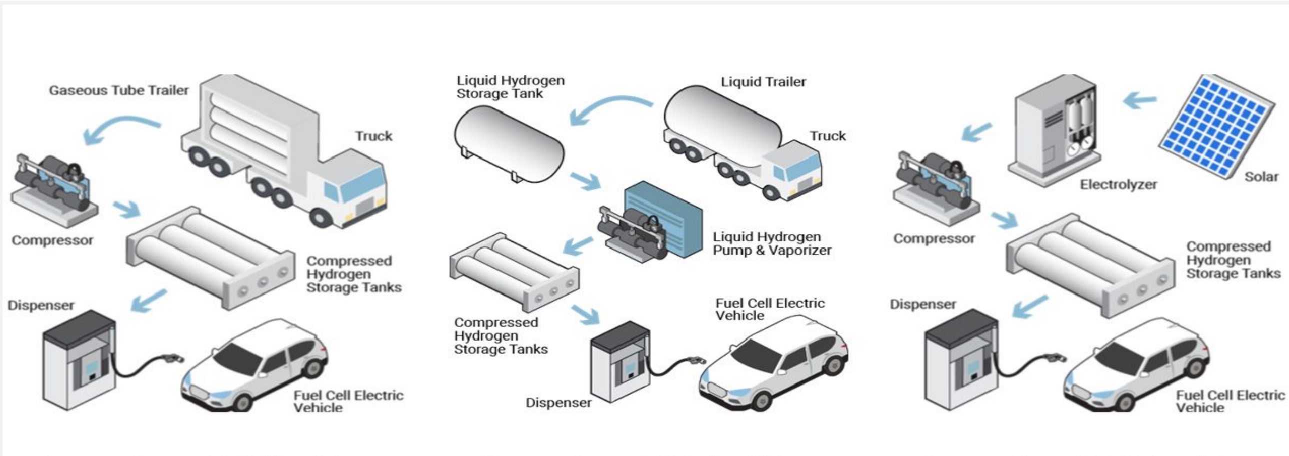


Fig 8

Worldwide, 375 hydrogen fuel stations were announced by 2017 increasing up to 5300 by 2030. Air Liquide installed over a 100 stations in the world, including one in Dubai. The station launched in 2017, was in collaboration with Al Futtaim Motors, and serves as a starting point for developing a mobility roadmap in the UAE. Currently, the station fuels 55 Toyota Mirais imported by Al Futtaim for trial purposes, and has a capacity of 40 kg/day. A second station is set to start construction in Masdar, Abu Dhabi in 2019, for 200 kg/day. The station is in collaboration with ADNOC, Masdar and Al Futtaim Motors. Renewable energy supplied from Masdar's solar park will partially power an electrolyzer to produce hydrogen onsite, and feed the inlet of the HRS. According to some internal study within Al Futtaim Motors, a network of 10-12 stations could be sufficient to provide reasonable nationwide coverage (cf Fig 10).

The cost of a hydrogen refueling station ranges between approximately 1.0 - 2.0 millions USD Turn Key in the UAE, varying between the capacity and the flexibility of HRS. This compares to a 300,000 USD standard petrol station. In large scale, economies of scale will cause cost reductions as the number of stations increase globally.



Each hydrogen delivery system requires different equipment which contribute to HRS cost.
Source: CALIFORNIA FUEL CELL PARTNERSHIP

Fig 9

Similar to petrol stations, hydrogen arrives to the station on a truck. However, from the truck to the FCEV, H2 fuel requires compression, which releases heat, and thus cooling. The ambient temperature and heat condition in UAE add additional cooling requirement to get the fuel to the target temperature. For this reason, compressors, chillers, and heat exchangers are employed making the fueling station complex and costly. Both hydrogen and petrol sit in storage tanks, however, hydrogen tanks are above ground while petrol is stored underground. Hydrogen trailers are often used as storage, while petrol uses static storage. Hydrogen stations are compatible with existing petrol stations and can be integrated into the existing and developed infrastructure. Germany inaugurated a multi fuel station in Wendlingen, and the upcoming Expo 2020 in Dubai should feature a “service station of the future”, which has multiple energy sources including hydrogen fuel.

Safety Measures for Hydrogen Utilization

As with all combustible fuels, hydrogen is associated with inherent dangers that require engineering control for mitigation. Hydrogen has been safely used for decades in industries such as food, energy production, electronic combustion, petrochemistry refining, metallurgy, spatial glass and space rocket launching. Therefore, the risks associated with hydrogen application have been thoroughly controlled, and its relatively new utilization in the mobility sector does not introduce new risks. Guidelines and safety requirements are established by the International Organization for Standardization (ISO) and Industrial Gases Associations such as EIGA in Europe.

The Hydrogen Council is a global initiative with a united vision of utilizing hydrogen as a key enabler of the energy transition. The Council comprises, at date, of 59 global companies, which have joined to provide solutions for flourishing a low-carbon economy by developing and commercializing hydrogen as a core fuel of the future.

Understanding the molecule's properties assist in designing a safe hydrogen system. Conveniently, some properties make hydrogen fuel safer to handle than gasoline or petrol. Hydrogen is not toxic, corrosive or carcinogenic. Also since it is the lightest of all gases, any leaks rise and disperse rapidly. Unlike gasoline leaks, which pool to the ground increasing probability of ignition and hazard levels. However, other properties require additional safety regulations.

- Hydrogen is flammable in the presence of an oxidant and ignition source. It has lower ignition energy than other fuels.
  - Avoid hydrogen leaks by ensuring good design and regular maintenance.
  - Avoid sources of ignition by employing anti-static ATEX equipment.
  - Avoid sources of oxygen by evacuating and purging hydrogen circuits.
- Hydrogen can displace oxygen in air.
  - Danger of asphyxia can be maintained using ATEX hydrogen sensors.

- Hydrogen molecules are small and therefore diffuse through almost any material.
    - Welded stainless steel is recommended to avoid leakage of hydrogen.
    - Hydrogen leaks should be maintained by employing leak detection systems.
    - Hydrogen sites should be open-air or well-ventilated if stored underground.

Elements important for safety (EIS), including pressure safety valves, grounding system, detectors, and emergency shutdown, are enforced in refueling stations to ensure safety of operations and personnel. A safety interlock is set to automatically stop refueling process in case of a leak. Choice of appropriate material for hydrogen systems is essential to limit hydrogen embrittlement. In addition to design considerations, training for safe hydrogen practices is crucial. Hydrogen fueling has been made easy by standardizing its application through applying uniform plugs and pressure for all fuel cell vehicles, unlike BEV which have a wide range of different voltages and plugs.

Potential Target Consumers

Near term adoption of hydrogen-powered vehicles in the medium and heavy-duty markets will pave the way for long term adoption of individual ownership of FCEVs. Buses, trucks, trains and marine vehicles have fixed routes and therefore would only require a centralized hydrogen station at the base. Additionally, this market will allow consumption of large quantities of hydrogen required to decrease the cost. For these reasons, the barriers to entry into medium and heavy-duty mobility are relatively easier to overcome compared to passenger FCEV market.

Given the cost sensitivity of hydrogen in relation to volumes produced, large consumption is essential to reduce cost of hydrogen. A disruption of the mobility market could occur with the commercial use of FCEV in fleets of taxis and buses. Decarbonization of transportation in the UAE could begin by employing hydrogen-powered vehicles in its ports, Jebel Ali and Kizad Ports, or in public transport, fleets of taxis and buses. This route will allow large consumption of hydrogen and demonstrate the technology with minimal infrastructure requirements. As the

FCEV market develops, the infrastructure would mature to meet the demand of mass deployment.

To increase FCEV utilized, sufficient HRS should be available to supply hydrogen for the customers. Simultaneously, to increase HRS, adequate FCEVs should be deployed to justify the investment for investors. This sensitive balance should be addressed by synchronizing approaches between ventures responsible for supply and delivery of hydrogen fuel and distributors of FCEVs.

Projection of FCEV Utilization in UAE

A major barrier challenging the hydrogen market is the price of hydrogen to the consumer, which heavily depends on cost of hydrogen production and availability of vehicles. By importing adequate volume of cars, the increase in volumes of hydrogen consumed will dilute the cost of hydrogen. The graph projects hydrogen cost linked to FCEV progression depending on the type of sourcing route. An important trend to note is that scaling the process with an increase of FCEVs running eventually decreases the hydrogen cost to a target price below $10/kg, which is comparable to petrol cost..

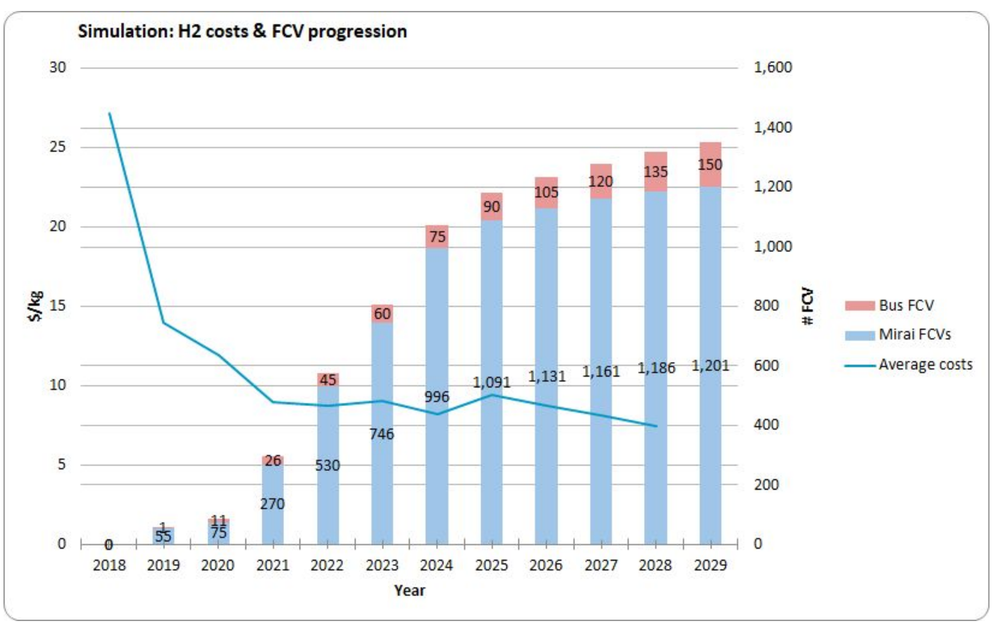


Fig 10 - Simulation of H2 costs and relative FCEV progression

As the technology matures, both BEV and FCEV will acquire significant share of the automobile market to reach reduction in CO_2 emission targets. The two zero-emission power trains compliment each other by offering advantages suited for various applications.

Implementing the Solution

Refueling Stations

Today, hydrogen mobility in the UAE is in its preliminary phase with massive potential to develop into a major economy driving the nation closer to its green goals. Currently, a number of FCEVs (Toyota Mirais) are available in the market for trial purpose and can be refueled at Al Badia's hydrogen station in Dubai. A second station is planned to be constructed in Q3 2019 and another to be commenced in EXPO 2020. Developing the market further requires a synchronized increase of stations and FCEVs, which could be achieved by government-organization partnerships. Establishing a hydrogen infrastructure is a costly investment with associated risks, especially while consumption is still low. Therefore, coordination between governmental entities and the related organizations increase visibility by linking production capacity to consumption potential. In Most countries and regions, developing hydrogen mobility, such as Japan, US, Germany, France, and many more, public authorities have contributed financial support to develop the market, especially with funding refueling stations. Also, long term plans along with policies that enforce a sustainable transportation sector provide a roadmap for scaling the market.

Availability

Toyota has a major market share of FCEVs in the UAE, while other manufacturers such as Honda and Hyundai are gradually penetrating the market. An increase of hydrogen vehicles availability in terms of models and volumes is essential to decrease cost and increase efficiency. Accordingly, state funding for research and development facilitates improving the technology and supporting the hydrogen mobility.

Fleets

Barriers to entry for fuel cell vehicles are gradually overcome with governmental procurement in public transportation. Utilizing hydrogen powered buses, trucks and taxis would consume enough quantities of hydrogen to scale production and thus dilute cost. Next, individually owned cars can be targeted with financial subsidies and policies favorable to low carbon transport. Future deployment in even more heavy duty markets, such as aircrafts and ships, is possible with developing innovative technologies.

Production

Local sources of hydrogen are available nationwide from byproduct of refining process, and production through steam methane reforming. Alternative technologies to produce green hydrogen by solar powered electrolysis are taking shape with projects such as DEWA's. Biogas reforming are emerging but require a first industrial pilot for implementation in the UAE context. The challenge in sourcing lies in connecting the available resources with consumption demands and creating a strong, reliable and with homogenous purity hydrogen network.

Expertise from industrial gas supply operators such as Air Liquide is key to facilitate production and efficiency studies and develop a strong infrastructure for hydrogen value chain.

Transport

For the introductory phase of hydrogen mobility, gaseous hydrogen is transported to destination in tube trailers, which are also used as storage. As the market scales however, alternative routes for hydrogen transportation and storage should be considered to accommodate larger quantities efficiently. For the large scale application, technologies such as, liquid hydrogen, high pressure (>500b) or a pipeline delivery system could provide more economically attractive routes. A techno-economic analysis is essential to reach an optimal transportation and storage system.

Communication

Hydrogen mobility development has been ongoing since decades; however, its commercialization is rather new. The UAE consumer market should be educated on this novel technology to gain acceptance and allow penetration. An efficient communication strategy begins with setting examples of utilization through deployment of fleets such as taxi or a police force. This allows the consumer market to become familiar with and gradually incorporate fuel cell vehicles in the transportation sector. Financial incentives and privileges for consumers would also increase conversion to hydrogen powered vehicles.

Beyond Hydrogen Mobility

Looking at the bigger picture of the hydrogen value chain, developing a mobility market could eventually develop a hydrogen economy.

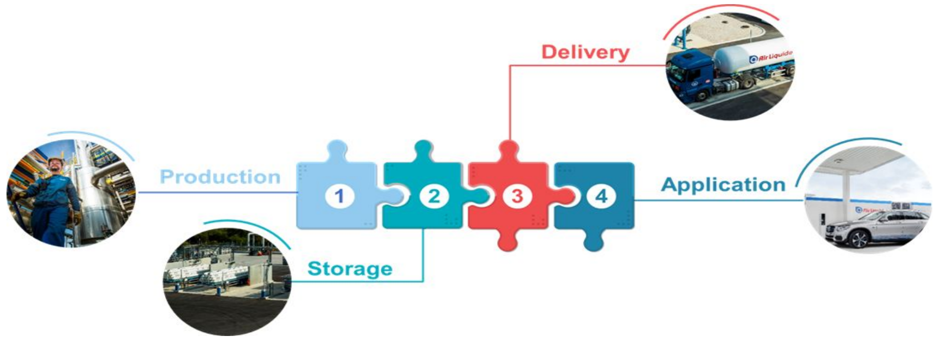


Fig 11

1. Hydrogen production routes, currently dominated by SMR, produce a byproduct of CO2. Utilizing carbon capture technologies, CO2 can be captured for greener production and redirected for utilisation applications. Identically, electrolysers produce oxygen as a byproduct. This O2 could be used for other applications such as aquaculture, biological water treatment, medical use, combustion optimisation reducing CO2 and other polly agents such as Nox even further. Implemented wisely and its full possible potential, Hydrogen could therefore be at the center of an even greener circular economy.
2. Strategic storage could be deployed underground in the long term to ensure consistent hydrogen supply.
3. Transportation by gaseous tube trailers or liquid hydrogen trucks could deploy hydrogen-powered trucks to further develop the hydrogen mobility market.

4. Hydrogen fuel is versatile, therefore, developing a strong hydrogen infrastructure supports its many applications. Hydrogen fuel cell is not limited to transportation, rather, it can power heating and cooling utilities, store and transport renewable energy, and facilitate potable water production. The currently used alternatives all involve natural gas, hence hydrogen provides a sustainable route.

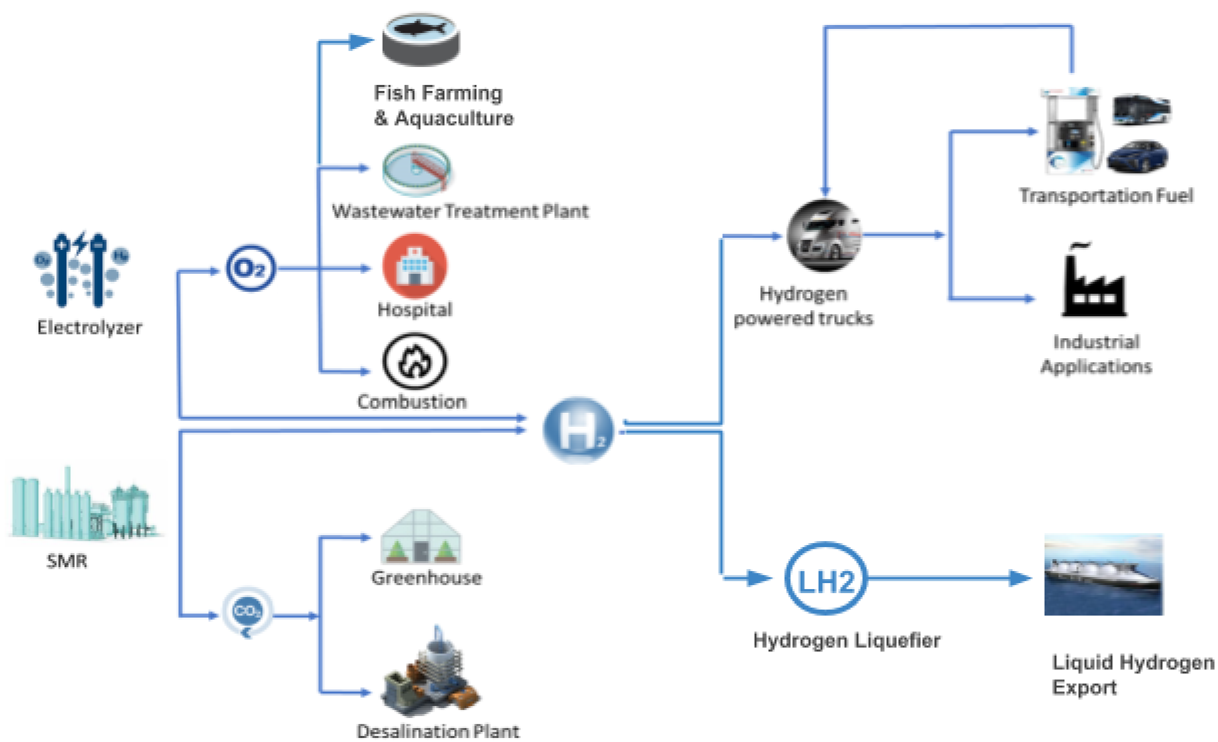


Fig 12

APPENDIX

Fig 8 assumptions:

- Mix of various hydrogen sources:
  - Remote électrolyser
  - Remote SMR
  - on-site électrolyser
- Various energy sources and costs:
  - grid and dedicated PV electricity,
  - Natural Gas
- Hydrogen transport as gas in Dedicated 200b Tube Trailers.
- All production assets depreciated on 15 years.

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