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Technical Analysis of Hydrogen Energy Production

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Abstract

Hydrogen has a great potential in the near future to be one of the primary energy fuel due to its relatively high energy weight ratio and because it is emission-free at the point of use. There is increasing interest in the use of hydrogen as a means of transportation fuel around the globe. The combustion of hydrogen doesn't emit any greenhouse gas like carbon dioxide, carbon monoxide, nitrogen dioxide etc. The report aim is to analyse the technical aspect of hydrogen fuel for urban transportation system (hydrogen-powered buses). Hydrogen storage and dispensing unit has been discussed as part of production & distribution. The purpose of this project is to establish a full carbon emission free plant with the integration of renewable energy source (wind energy). Alkaline electrolyser technology has been selected for this project.

Keywords

Renewable Energy, Hydrogen Energy, Electrolyser, Hydrogen Storage, Wind Energy

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1. Introduction

Hydrogen is the simplest element in the periodic table. Hydrogen gas is also one of the lightest i.e. 14 times light compare to air and 57 times lighter than gasoline. Apparently, hydrogen covers 75% of universe's mass. Hydrogen gas has a very high flammable range (between 4%-75% in air) contrast to traditional fuels. Using hydrogen as alternative fuel to conventional fuel could lead to a new era of cheap, clean and renewable energy. Unlike other traditional fuels, when hydrogen is burned with oxygen, it doesn't emit any carbon base by product. The output of hydrogen combustion with oxygen is water, electricity and heat energy. Therefore, Hydrogen can serve wide range of energy services like producing electricity from fuel cell for transportation of hydrogen fuel cell vehicles [1]. Many countries like Canada, Scotland, Germany, and Norway have already started to use the hydrogen as an alternate transportation fuel to diesel and petrol. Recently VanHool company is about to build 40 hydrogen buses for Germany [2]. Many advantages of hydrogen vehicle over diesel buses such as zero-emissions, comparable durability with no compromise in vehicle performance, range of 450km between refueling, fuel economy compared to diesel buses (1.5x) and CNG buses (2x) etc have raised the popularity [3]. The U.S. Department of Transportation's (DOT's) Federal Transit Administration (FTA) has recently initiated number of projects like National Fuel Cell Bus Program ($180 million), Transit Investments for Greenhouse Gas and Energy Reduction ($225 million), Low or No Emission Vehicle Deployment Program ($186.9 million) for research, developing zero emission bus services [4]. Aberdeen, California, Reykjavik Oslo, and Cologne have already seen a successful demonstration of hydrogen fleet bus services. Major European cities, including London, Paris, Madrid, Copenhagen and Athens are also planning to replace diesel vehicles to improve the air quality. Hundreds of fuel cell buses are expected to be deployed in the coming years around the world [5]. This report briefly explains the technical aspects of the whole project about hydrogen

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production, storage and usage.

2. Methodology

There are many processes available in the market to produce hydrogen. 95% of total world's hydrogen production (65 million tonnes) is done by natural gas reforming/combustion. Another easiest way of producing hydrogen is water Electrolysis. The potential of hydrogen from the renewable energy source (such as solar, wind, hydro etc) is getting popular recently. Different types of electrolyser are used to produce hydrogen depending on the purpose and production target. [6].

Hydrogen can't be found individually in the environment. It is almost always combines with other materials like carbohydrates or water etc. thus it is needed to fabricate hydrogen though a process which requires energy. Later this energy can be recovered via combustion, fuel cell or electrochemically etc. that is the reason why hydrogen is not a source of energy rather it is means of storing energy and often refers to an energy carrier or energy vector.

It is found that the performance of fuel cells is quite good enough to make the commercially viable. Many areas have weak electricity infrastructure, hydrogen can be an alternate solution to these remote areas.

If hydrogen can be produced from renewable sources, then hydrogen can play a significant role to decarbonise our energy system. Hydrogen is easily produced from water by electrolysis, a process which uses electricity to break the bonds between water's constituent elements, hydrogen and oxygen, and releases them as gas. Hydrogen gas can be burned to run buses with almost no negative impact on the environment, unlike power produced by burning fossil fuels. Another fact about hydrogen is that it is the lightest gas thus it rises and disperses rapidly. Hydrogen is non-toxic. 1 kg of hydrogen has about the same energy content as 1 gallon (3.2 kg) of gasoline which means hydrogen has high energy [7].

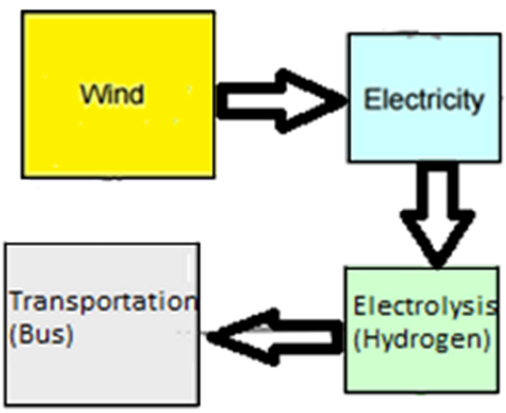

Figure 1. Process to produce hydrogen and end use.

3. Project Description

The hydrogen can be produced in many ways. Here is this project; renewable energy (wind energy) has been selected as primary source of electricity to feed electrolyser for hydrogen production.

Wind power plant will supply the primary electricity to run the alkaline electrolyser. The additional electricity can be exported to grid if needed. The electrolyser will produce hydrogen gas which will be compressed and stored in a cylinder. Finally this stored hydrogen will be dispensed to hydrogen powered buses. As the end use of hydrogen is fuel cell bus, making the project twice as efficient compare to combustion engine. Though efficiency will be lost in each step and it is necessary to estimate the efficiencies of all steps to calculate the overall efficiency of the project. The loss of energy will start from wind energy (capacity factor 30%), electrolyse (65% efficient), and some energy will be lost during the compression of hydrogen (15%).

3.1. Wind Energy Source

The plan is to design a carbon free hydrogen production plant to achieve the goal of zero emission. Sustainable energy can be achieved if the energy consumed by the electrolyser is fed by the renewable energy instead of fossil fuel. Target is to run the whole hydrogen plant by renewable energy source for example here wind plant will be used as the main source of electricity. Normally, grid electricity has been using to produce hydrogen in the past. But solar, wind or hydro plant can be used to feed the whole plant. In this project wind has been used over solar because big solar plant requires large land. Other reason to use wind over solar is that in UK the average sunlight is around 2 hrs in winter season which is not enough to run the project on its own. On the other hand, wind is clean and can be restless energysource for long time (if the specific area is windy enough) [8].

Approximately, 16MWh energy is needed to run the big electrolyser every day. Approximately 1MWh energy will be used for other purposes like compression, fuel refilling station etc. Currently production of hydrogen through water electrolysis is considered to have the lowest life cycle GHG emission among all hydrogen pathways. Wind has lower cost of electricity after hydro.

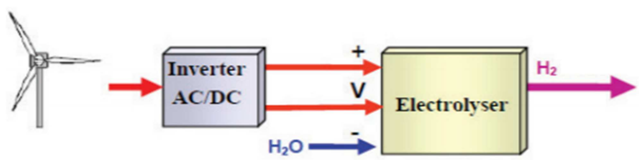

Figure 2. Wind energy production for electrolyser.

The potential site should have enough wind speed to run the turbines. The turbine rating is 3 MW. The capacity factor of the project is considered around 30%. In this system, firstly wind energy is converted into mechanical energy through turbines to produce electricity. An AC/DC converter is required before feed the electrolyser. Then the dc power can be used for water electrolysis process for hydrogen production by passing electricity through two electrodes. The other basic components are grid interconnector, max power tracker, battery bank, power supply control and switch etc. Though, coupling renewable source with water electrolyser is an ongoing research and need further development for better performance [9].

3.2. Water Purification Process

All the negative and positive charged ions must be removed before the water can be used for hydrogen production. Positively charged ions are known as cations and negatively charged ions are known as anions.

Deionization filtration can be done by exchanging positive hydrogen molecules for the positive contaminants and negative hydroxyl for the negative contaminant molecules in the water. Sodium, calcium, iron, copper are positively charged chemicals whereas iodine, sulphates, chloride are negatively charged contaminants.

Generally this deionization process is done by two oppositely charged ionised resin beds: cationic resin and anionic resin. During exchange of ions, positively charged ions are replaced by the same numbers of hydrogen ions. Hydroxide ions are similarly being replaced by the negatively charged contaminants during ions exchange process. Apparently hydrogen and hydroxide are being introduced in this process to make the water pure for hydrogen production. This is one of the economic solutions for producing high purity water [10].

3.3. Alkaline Water Electrolyser

Producing hydrogen using alkaline water electrolyser is one of the simple and oldest methods. Currently 95% of hydrogen production is done from fossil fuel like reforming natural gas, gasification of coal etc, with an average worldwide consumption of approximately 40 million tonnes. But recently different types of electrolysers like Alkaline Electrolyser/ Proton Exchange Membrane Electrolyser/ Solid Oxide Electrolyser have been using for hydrogen production for various purpose to reduce the green house gas. The main usage of hydrogen has been in fertilizer industry, pharmaceutical industry, petroleum refining etc so far. But recently researchers have found out that hydrogen can be used as one of the efficient vehicle fuel. The main reason behind that is the output of hydrogen fuel is water which has no harmful impact on the environment.

Alkaline Electrolyser is reliable, safe and well establishes process for hydrogen production in large scale. It has a better overall conversion efficiency of approximately 50%-60%. Compared to the conventional methods of hydrogen production, Alkaline Electrolyser can achieve extremely pure hydrogen production of >99.9% [11].

The basic structure of an alkaline electrolyser consists of a water electrolysis unit, an anode, cathode, an external DC power supply and immersed in a conducting electrolyte. When a DC current is applied through the system, electrons stared to flow from the anode to cathode where they consumed by the hydrogen ions (protons) to form hydrogen gas. To keep the electrical charge in balance, hydroxide ions (anions) move through the electrolyte solution to anode. In the anode section, the OH- ions release electrons which return to the positive terminal of the power source.

KOH is most commonly used conducting electrolyte in this process to avoid the corrosive losses caused by acid electrolytes. Generally Ni (nickel) is used as electrodes as it is low in price and has high activity during hydrogen production. By using diaphragm, gas collectors can receive the oxygen gas and hydrogen gas separately.

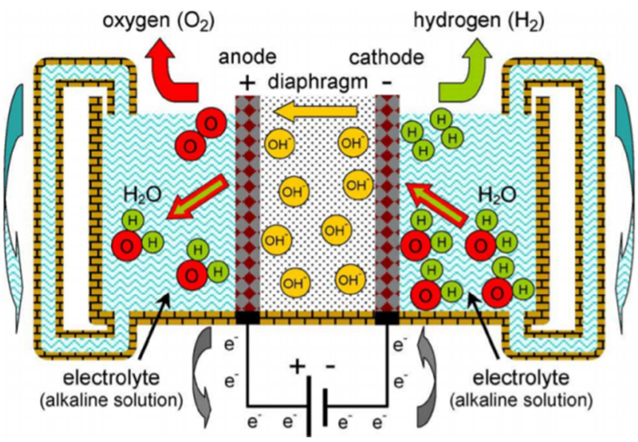

Figure 3. A schematic illustration of a basic alkaline water electrolysis system.

The processes that take place at the electrode's surface are described below [12]:

Cathode (reduction): $4H_2O(l) + 4e^- \rightarrow 2H_2(g) + 4OH^-(aq)$

Anode (oxidation): $4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$

Overall reaction: $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$

Though producing hydrogen from water electrolysis is energy intensive procedure, but here the input energy to electrolyser comes from renewable energy to make it fully sustainable energy method. The voltage Requirement to split water is 1.24 V. In every 10°C, the voltage can decrease by 0.82 milivolts (0.82 m V) with rising cell temperature and increases by 44.4 mV per 10°C if the pressure is increased ten times. Conventional electrolysers operate at 70°c to 90°c with current densities of around 2 kilo amps per square meter. The alkaline has lower current density capacity than PEM electrolyser. The requirement of the energy input is 4.2kWh - 4.8 kWh for eachcubic meter of hydrogen production. Energy needed for pumping and other stuffs also included in this 4.8 kWh. But sometimes this energy can be for the electrolysis procedure can be varied over a wide range. Higher the flow of current to the system, lower the voltage becomes in relation to it. Thus the efficiency of electrolyser is increased. However, if the input current increased, the current density on the electrodes also increased. This increases the resistance in the electrodes. Electrode thickness therefore is minimized at 0.00001 cm (0.000004 in) or less [13].

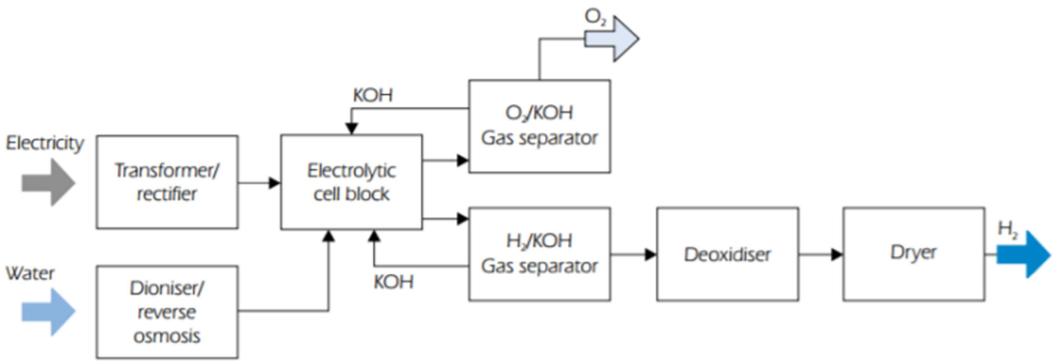

Figure 4. Full electrolysis process.

Electricity and deionised water is feed into the alkaline electrolyser as input to split water. After the production of oxygen gas in anode and hydrogen gas in cathode, both gases has been collected through a gas collector. But later it is required to separate KOH and hydrogen gas. To make this hydrogen gas pure up to 99%, deoxidiser and dryer are used. The advantages of alkaline electrolyser are; reliable and safe, most extended technology at a commercial level, still promising and robust process for large scale hydrogen production [14].

Alkaline electrolyser is popular for commercial production of hydrogen in a large scale. NEL A-300 alkaline electrolyser has been selected to the production of hydrogen. This electrolyser runs with DC current and the pressure of hydrogen is around 250 bars after compression. Around 10 litre deionise water is required to produce 1 kg of hydrogen [15].

Table 1. Specification of NEL alkaline electrolyser.

Capacity / Nominal Flow Rate	A-300
Capacity range per unit	151 – 300 Nm^3 H_2/hr
DC power consumption	3.8 – 4.4 kWh/Nm^3 H_2
H_2 purity	99.9% ± 0.1
H_2 outlet pressure after compressor	Max 250 bar
Operating temperature	80 °C
Electrolyte	25% KOH aq. solution
Feed water consumption	0.9 litre / Nm^3 H_2

NEL alkaline electrolyser has been picked because it requires less time (<10 min) to startup and operates between 20%-100%. So it can be said that the production will be continuous and never be lower than 20%. The efficiency of a typical commercial water electrolyser is below 80%. The cell efficiency of electrolyser can be limited by overvoltage and parasitic currents. [16].

3.4. Compression and Storage of Hydrogen Gas

Hydrogen has high energy content by weight, but not by volume, thus makes it particular challenge for storage. Like any other fuel, hydrogen fuel also requires proper storage process. There are many ways available to store hydrogen as mentioned below;

a. Gaseous Hydrogen

b. Liquid hydrogen

c. Metal hydride

d. Carbon structures etc.

e. Through other means of chemical storage

Storing Hydrogen in a liquid form is an energy intensive process which can be up to 8.5kWh/kg. The temperature and pressure requirements are 20°K and 0.1 MPa respectively. 25%-30% more energy is needed of its energy content to store hydrogen in liquid form. Cryogenic vessels are generally are used to store liquid fuel which requires very efficient insulator. Storing Hydrogen in a liquid form is an energy intensive process which can be up to 8.5kWh/kg. The temperature and pressure requirements are 20°K and 0.1 MPa respectively. 25%-30% more energy is needed of its energy content to store hydrogen in liquid form. Cryogenic vessels are generally are used to store liquid fuel which requires very efficient insulator. The liquid hydrogen has a gravimetric density of 7.1 wt%. But liquid form can hold three times more energy than that of petrol in term of volumetric term [17].

Metal hydride offers other effective way of storing hydrogen in a solid form. Under a moderate temperature and pressure the hydrogen combines with some certain alloys. Though this reaction is reversible but conventional hydrides requires high temperature to release the hydrogen makes it non convenient for vehicle application. Metal hydrides show better volumetric performance but poorer gravimetric performance of 1-2 wt%. Among these, the most common way to store hydrogen is probably in gas form. But hydrogen gas is one of the lightest substances and its energy per unit volume is low. Therefore it needed high pressure to store gaseous hydrogen in a cylinder. Compressed hydrogen gas is stored and delivered in a variety of containers depending on the requirements. Traditional cylinders are made from steel that has a gravimetric density of ~1 wt% and can hold pressure at 200bar. But carbon fiber wrapped composite cylinder can sustain gas pressure of 700bar and gravimetric densities of ~ 6 wt%.

For using hydrogen as vehicle fuel and to store in gas form, the hydrogen required to be compressed. Alkaline water electrolyser can be divided into two types of electrolyser depending on the level of pressure at which the electrolysis is taking place. One is atmospheric electrolyser and other one is pressurized electrolyser. The facility has alkaline electrolyser to produce hydrogen at 250 bars. Later some this hydrogen is compressed to 700 bars with gravimetric densities of ~ 6 wt% for a long term storage [18].

The main challenge in storing and using hydrogen is its low energy density. That's why compression is required to increase the density. After the compression of gaseous hydrogen, it is transferred to a pressurized gas cylinder with a valve. The required energy for compression is 7%-9% of the energy that is supplied to produce hydrogen. Hydrogen can be stored in various ways like as a compressed gas in cylinders, cryogenic liquid, metal hydride, in carbon structures or other means of chemical storage. There are many types of cylinders available in market to store hydrogen in gas form. Hydrogen gas is generally stored in high pressure cylinders. This "type 4" cylinder is made of carbon fiber with a polymer liner. Each hydrogen storage cylinder has a maximum void space capacity of 82 litres (for the 450 bar). See below the technical characteristics of the proposed hydrogen cylinders 450 bar cylinders.

Single stage compression has been chosen instead of multi stage compression because the electrolyser produces hydrogen in high pressure which is releasing at 250 bars. Multi stage compression is generally used to make sure that the hydrogen gas doesn't heat to extreme temperature which may damage the equipments that is flowing through. This may ultimately decrease the energy density of the hydrogen gas. Since the pressure for hydrogen gas is already comparatively high while producing in electrolyser, so it will take less energy to compress further [19].

A cooling unit will be included after the compression process to cool down the gas. A flow controller will allow controlling the flow manually from 10%-100% to minimize the losses. This compressor will be located behind the refueling station.

Maximum buffer storage pressure of 440bar is typically required to refuel vehicles with 350 bar storage, in order to account for the temperature increase in the vehicle storage due to the fast filling. 700bar compression system has also been considered if it is required to store extra hydrogen. Though it will increase the cost of the project but huge amount of hydrogen can be stored under high pressure [20].

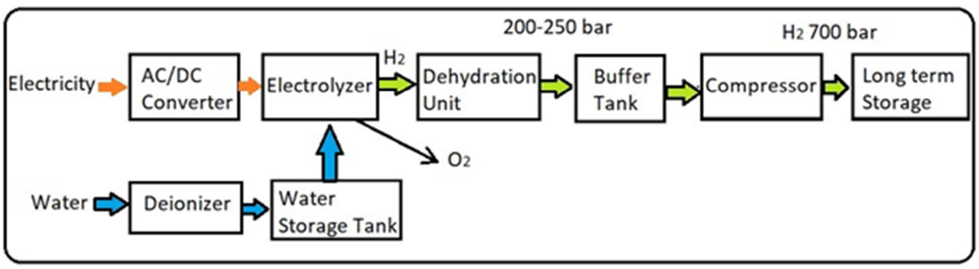

Figure 5. Compression process of hydrogen gas.

3.5. Dispensing Unit

The last stage of hydrogen production is to dispense hydrogen fuel to the vehicles.

To facilitate the hydrogen dispensing, few requirements should be taken into account like:

1. Reducing the probability of realising hydrogen gas
2. Reducing the chance of accident if any leakage happens

The dispensing unit consist of a cabinet with single delivery hose, side mounted nozzle. The hydrogen gas is delivered at a pressure of 350 bars. But FCEVs are designed in such way that it can accept both 350 bars and 700 bar pressure. High pressure provides greater range. The refuelling process involves in transferring gas at high pressure [21].

A safety interlock is an important component of the dispensing facility. The system must be designed in such a way that it can shut down to prevent over filling or in the event of an accidental release. A construction permit is required which will define the construction condition and an operating permit is issued to allow the facility to operate in a safety mood.

This project is designed not only for producing hydrogen commercially but also includes pump station for refueling buses. The refueling station dispenses hydrogen at 350 bars to the vehicles.

The hydrogen fuel-cell vehicles tanks are measured in kilograms. A typical car can hold 3-5 kg of hydrogen where as a bus can hold up to 40kg hydrogen. The averagehydrogen price is around $13.99 per kg for 700 bar fueling system [22].

4. Calculation

4.1. Energy Production

Each of this bus can hold up to 40 kg of hydrogen fuel and can run a distance of 260 miles. Therefore each bus can run 6.5 miles in 1 kg of hydrogen [23].

Wind turbine rating = 3MW = 3000 kWh energy in each hour

For a wind farm, it is also required to consider the capacity factor. Now if we consider the capacity factor around 30% for the wind turbine in Cardiff, then the energy production will be = 0.3*3000 kWh = 900 kWh per hour. If the turbine runs around 20 hours /day, then total energy per day = (20 hr x 900 kWh) = 18 MWh/day. So, the annual production will be 6.57 GWh.

Now if electrolyzer takes 800 kWh in each hour to produce hydrogen, then, {800 kWh / (4.4 kWh/ $N.m^3$ h_2)} = 181.8 $N.m^3$ h_2 / hr = 16 kg h_2 /hr (4.4 kWh energy needed to produce 1 $N.m^3$ h2).

i.e. 1 $N.m^3$ h_2 /hr = 0.089 kg h_2 /hr.

The Capacity range per unit for the electrolyser is 151 – 300 $N.m^3$ h_2.

If the electrolyzer runs 20 hour a day then, total production / day = 16 kg/hr x 20 hr = 323 kg h_2

So, ultimately out of 20 MWh energy, electrolyzer will use = 800kWh x 20 = 16 MWh energy /day.

The energy needed for compression, storage, and dispensing at the fuelling station is estimated to be 2.2 kWh/kg = 323 kg x 2.2 kWh/kg= 0.71 MWh / day

So, (18 MWh – 16 MWh - 0.71 MWh) = 1.3 MWh energy /day is excessive for other tasks / export to grid. So annually 1.3 MWh x 365 days= around 470 MWh energy can be exported to grid.

4.2. Carbon Saving

This project will contribute in carbon saving in two ways. In the first place, wind plant will save lot of carbon emission to the environments. The amount can be estimated. From the table of Specific CO_2 Emission ($kgCO_2$/kWh), it is found that the conversion factor for each kWh produced from coal base power station is 0.34 kg CO_2 [24].

Carbon saving = (total generation KWh from the system*value of CO_2 Emission/kWh)

= 6570000 kWh * 0.34 $kgCO_2$/kWh

= 2233800 $kgCO_2$

= 2233.8 ton CO_2

The lastly as hydrogen bus has been used for transportation, therefore lot of carbon will be saved as well. From the experiment it is found that diesel fuel release 2.68 kg of CO_2 from each litre. From the project target it is calculated that total around 300 kg hydrogen fuel is required on a daily basis [25].

So, the carbon saving, = total annual hydrogen fuel burnt from bus x value of CO_2 Emission/litre

= (300*365) x 2.68

= 293.4 ton CO_2

So, annually this project can save up to approximately 3000 ton CO_2 emission from being released into the environment.

5. Conclusion

It can be said that hydrogen is one of the efficient and promising energies carried for both stationary and vehicle application. Hydrogen-powered vehicles offer many operating advantages. They are 25% more fuel efficient compared to gasoline-fuelled internal combustion engine (ICE). With very few costs and technical issues limiting commercialization and deployment, hydrogen-powered vehicles can help create the demand needed to support the development of a hydrogen refuelling infrastructure. This research also helps to achieve towards the zero-emission target. Hydrogen can be produced from a wide variety of renewable resources such as solar, wind, and biomass. Processes of producing hydrogen from a renewable source not only help to save carbon emission but also reduce the dependency on fossil fuels.

References

[1] E4tech, Introduction to hydrogen energy projects.

[2] Vanhool (2018), available: https://www.vanhool.be/en/news/van-hool-bouwt-40-waterstofbussen-voor-keulen-en-wuppertal-duitsland-copy

[3] Ballard Power Systems (2018), available: http://ballard.com/markets/transit-bus

[4] Leslie Eudy, Matthew Jeffers (2018), Zero-Emission Bus Evaluation Results: King County Metro Battery Electric Buses.

[5] Ballard Power Systems (2017), Hydrogen Fuelling for Fuel Cell Bus Fleets.

[6] University of Glasgow (2017), Hydrogen Production Breakthrough Could Herald Cheap Green Energy.

[7] Katarzyna Sobotka (2009), A wind-power fuel cell hybrid system study

[8] Benjamin L. Varner (2008), A Report on wind energy.

[9] Martin Best, Andy Brown, Pete Clark, Dan Hollis, Doug Middleton, Gabriel Rooney, Dave Thomson and Clive Wilson (2008), Small-scale wind energy Technical Report.

[10] Evoqua (2017), Deionized Water: High Purity On Demand

[11] Santos, Diogo M. F., César A. C. Sequeira, and José L. Figueiredo (2017). Hydrogen Production By Alkaline Water Electrolysis.

[12] Zeng, Kai, and Dongke Zhang (2010), Recent Progress In Alkaline Water Electrolysis For Hydrogen Production And Applications, Progress in Energy and Combustion Science 36 (3), 307-326.

[13] Laboratory of Hydrogen & Energy (2014), Novel Developments In Alkaline Water Electrolysis.

[14] International Energy Agency (2006), Hydrogen production and storage.

[15] Nel Hydrogen (2017), available: http://nelhydrogen.com/product/electrolyser

[16] Joonas Koponen (2015), Review of water electrolysis technologies and design of renewable hydrogen production systems

[17] Elam, C. C., Padró, C. E. G., Sandrock, G., Luzzi, A., Lindblad, P. and Hagen, E. F. (2003), Realizing the hydrogen future: the International Energy Agency's efforts to advance hydrogen energy technologies, *International Journal of Hydrogen Energy*, 28 (6), pp. 601-607.

[18] Xiao, J., Tong, L., Yang, T., Bénard, P. and Chahine, R. (2017), Lumped parameter simulation of hydrogen storage and purification systems using metal hydrides. *International Journal of Hydrogen Energy*, 42 (6), pp. 3698-3707.

[19] Midilli, A., Inac, S. and Ozsaban, M. (2017), Exergetic sustainability indicators for a high pressure hydrogen production and storage system, *International Journal of Hydrogen Energy*, 42 (33), pp. 21379-21391.

[20] NREL (2014), Hydrogen Station Compression, Storage, and Dispensing Technical Status and Costs

[21] My Air Products, Hydrogen Fueling Stations

[22] California Energy Commission (2015), Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California.

[23] H_2 Aberdeen (2015), Aberdeen City Region Hydrogen Strategy & Action Plan

[24] German Energy transition (2015), Statistics, available: https://www.volker-quaschning.de/datserv/CO2-spez/index_e.php

[25] University of Exeter, available: https://people.exeter.ac.uk/TWDavies/energy_conversion/Calculation%20of%20CO2%20emissions%20from%20fuels.htm