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ECONOMIC FEASIBILITY OF GREEN HYDROGEN TECHNOLOGY IN NEPAL

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ABSTRACT:

Hydrogen is being produced in some serious quantities over the years. Hydrogen is being used in diversified field. Its use varies from industrial feedstock, heat generation, transport and mobility to the various sectors. Hydrogen being produced today, mainly are from coal gasification or steam methane reforming which requires more energy and produces a huge quantity of carbon dioxide, which is one of the major responsible gases for greenhouse effect. Green hydrogen, hydrogen produced from the electrolysis constitute a very small portion in it. Green hydrogen does not produce carbon dioxide. This method of hydrogen production if applied, helps to reduce the carbon footprints by great amount. In order to achieve the decarbonization goal, there is no any alternative to green hydrogen for energy generation in various diversified field. Nepal is expected to have about 8 GW electricity generation by the Year 2030. We should keep our focus on exploring the use of surplus electricity to make the various hydropower projects economically and financially viable. Hence, this paper gives the possible prospects of green hydrogen production and shows its feasibility in the context of Nepal. The green hydrogen plant constructed is projected to reduce carbon footprints by 2,92,45,720 kg under its operation for 15 years.

INTRODUCTION

Hydrogen is a solution for the energy need of the world. It can be categorized as important tool when it comes to meeting the goal of de-carbonization. The advantages shown by the hydrogen is that it provides lower emissions and gives a way for excessing the renewable generation. It is evident that the hydrogen is one of the clean sources of energy. With the growing concern of the fuel crisis and global pollution, hydrogen promises a secure clean energy future. The development in the sector of hydrogen shows it potential in the sector of fuels for aircrafts and vehicles, home and office heating etc. It is safe to say that the hydrogen can replace all the existing fossil fuels. Green hydrogen**,** also known as 'renewable hydrogen', is hydrogen that is produced with sustainable energy. The best known is electrolysis, in which water (H_2O) is split into hydrogen (H_2) and oxygen (O_2) via green electricity. The electricity for electrolysis is obtained from renewable sources, therefore, produce energy without emitting carbon dioxide into the atmosphere. There is no separate color for electrolysis using fossil fuel electricity so sometimes what called green hydrogen may not be actually green.

This technology is based on the generation of hydrogen, a universal, light and highly reactive fuel, through a chemical process known as electrolysis**.** This method uses an electrical current to separate the hydrogen from the oxygen in water. As the IEA points out, this method of obtaining green hydrogen would save the 830 million tonnes of CO_2 that are emitted annually when this gas is produced using fossil fuels**.** Likewise, replacing all grey hydrogen in the world would require 3,000 TWh/year [1] from new renewables, equivalent to current demand of Europe. However, there are some questions about the viability of green hydrogen because of its high production cost; reasonable doubts that will disappear as the decarbonization of the earth progresses and, consequently, the generation of renewable energy becomes cheaper.

Nepal being a country which is enormously rich in water resources, green hydrogen technology can be the better alternative to solve the energy related problem in the country and even can boost the country's economy from it. This study attempts to explore the prospects of applying hydrogen in the specific context of Nepal. Nepal's electricity and transport sector both are likely to make a case for hydrogen application case here. This study includes a description of the potential hydrogen value chains in Nepal, which are technically based on producing hydrogen from water and electricity generated by surplus hydropower. It also provides a brief cost analysis of the hydrogen supply chain. Overall, this preliminary study aims to serve as a baseline for further detailed studies on hydrogen deployment in Nepal and in other developing member countries that have abundant renewable resources but have no or limited progress in hydrogen-related initiatives.

STATEMENT OF PROBLEM

Nepal's primary energy supply is dominated by biofuels and waste, which are in the form of firewood, agricultural waste, and animal dung. Other main sources of primary energy include oil products, coal, and hydropower. Out of the total primary energy supply of Nepal in which biofuels and waste accounted for 72%. [2] Over 99% of total electricity generation in Nepal was by hydropower. The residential sector accounted for the largest share (74%), having consumed 10,373 kilotons of oil equivalent (ktoe) [3] The transport sector was the second, and the industry sector was the third largest energy consumer, accounting for 13% and 11%, respectively. [4] While the shares of transport and industry sectors remain minor as compared to the residential sector, these sectors have been growing fast and their energy consumptions have been increasing accordingly.

While nearly 95% of the energy consumption by the residential sector was met by indigenous biofuels and waste resources available in the country, the industry and transport sectors were heavily dependent on imported coal and oil products. The share of oil products consumption by the transport sector in total consumption of oil products by all sectors of Nepal has been increasing considerably over the past decade.

The combustion of fuels generates greenhouse gas (GHG) emissions. Excluding methane (CH_4) and nitrous oxide (N_2O) emissions caused by combusting biomass by commercial, institutional and residential sectors, the total carbon dioxide (CO_2) emissions from Nepal's energy end-use sectors in 2011 was 4.67 ($MtCO_2e$), of which transport sector accounted for 36% [3] This share is further increasing with respect to time.

All these facts signify the critical challenges regarding that Nepal is facing in energy sector and therefore there is a valid point stating need to prioritize it on Nepal's climate and energy agenda. From this perspective, this paper chooses residential, industry and transport sector as a key energy end-use sector of Nepal for preliminary analysis of potential hydrogen application.

LITERATURE REVIEW:

The use of hydrogen gas for generating energy is in apply over the past years. Hydrogen being gift in extensive quantity within the earth, are often the foremost supply of energy within the future. Green gas is expected to be the foremost contributor in economy among 2050. [5] Since GH being comparatively new, there are several opportunities furthermore as many challenges to beat. As industries begin to grow, the one with optimum evaluation, selling and money ways is anticipated to be the most prolific player. Researchers finding out the chance of manufacturing gas fuel in Asian country say the country encompasses a potential of mercantilism this fuel to Europe among a decade.

Green Hydrogen is today's big talk of the town. In the context of Nepal too, various seminars and panel discussions have been done regarding GH technology. Prof. Govinda Raj Pokhrel has talked about the use of surplus electricity in 'Safa Tempo'. Along with it, he believes city transport, ambulances and bus services can be run through GH. [6]. Prof. Bhakta Bahadur Ale shares his take on importance of hydrogen production through a different approach. He pointed to the fact that hydroelectricity in Nepal is RoR so when there is no demand at night the energy will go to waste. He adds, "Food Processing, Fertilizers and meat processing are the areas for hydrogen in Nepal". He further states that fuel cell technology cannot replace electric vehicle as of now but initiatives should be taken today. Further the importance of electricity charges reduction to promote production of hydrogen will also play a significant part. [7]

Talking about the growing investments in this sector, Api Power Company Limited and the Indian Company GreenZo Energy had signed a Memorandum of Understanding to develop 50 MW green hydrogen plants across Nepal by 2025. API Power is a famous leading company in energy sector based on Nepal to working in renewable energy while GreenZo Energy is one of the leading companies in renewable energy in India with 1,500 MW of solar projects in its portfolio. Sanjeev Neupane, managing director of API Power, said Nepal is rich in hydropower with 20,000 MW of projects under development and the seasonal nature of resources from the vast network of 6,000 rivers necessitates hydrogen storage. The MoU includes API Power to invest Rs 10 billion in green hydrogen projects of 50 MW that can generate 4,000 tons of hydrogen annually. Bardaghat, Chanauta, Kawasoti, Dhalkebar, Parwanipur, Simara and Chandranigahapur are among the proposed sites of the company's hydro and solar projects to be used for the hydrogen initiative. Both the companies have agreed to start piloting of the hydro project with one megawatt power at Naugarh Gad Hydroelectric Project (8.5 MW). For GreenZo Energy, the MoU with API strengthens its mission to become a pioneer in electrolyser manufacturing and green hydrogen production. [8]

RESULT AND DISCUSSION:

Hydrogen as a potential option

Government of Nepal is making efforts to materialize its announced policies, strategies, and project development plans for its energy sector and major energy end-use sectors such as transport sector. It is advisable that alternative solutions are explored to supplement proven technologies and established practices, contributing to address the challenges facing the various sectors of Nepal. In particular, the abundance of its hydropower resources and with the growing development in hydropower sector. To estimate the total hydropower installed capacity by 2025, it is necessary to refer to the White Paper issued by the Government of Nepal in 2018. [9] While the White Paper has set the plan of having total installed capacity reach 3 GW in 3 years, 5 GW in 5 years, and 15 GW in 10 years, it is considered that these time-bound targets will be achieved as planned. As a conservative approach, this study discounts the targets and assumes that the total installed capacity would be 3 GW by 2025 and 8 GW by 2030. Thus, it is the best time to explore the alternative use of electricity to make hydropower projects financially feasible. The stored electricity can also be utilized to power vehicles, contributing to achieving Nepal's announced objectives of electrifying and decarbonizing its transport sector. From this perspective, hydrogen offers a technological option that is potentially viable in Nepal's context.

Possible Hydrogen production in Nepal

The hydrogen gas produced can be used as energy carriers in various places in various forms. From the calculation shown in the annex section, it is estimated that the plant will produce about 26,50,995 kg of hydrogen in a year for which it requires about 1,05,278 MWh of energy. From the amount of hydrogen gas produced, we can produce about 1,04,449 MWh of energy. Although the amount of energy produced is slightly less than the amount of energy required, green hydrogen technology do not release greenhouse gas like carbon dioxide which is being produced as by product in the process of generating energy by the industrial, transport and hydropower sector. For the same amount of energy produced, burning of coal and natural gas would have produced about 4,73,01,465 kg of carbon dioxide which the green hydrogen technology will totally eliminate.

Cost Analysis

The production cost of hydrogen plays a key role in choosing between whether to go for the green hydrogen production or not. The Power to Gas (P2G) system for hydrogen production is considered over here for the cost analysis part. The electrolyzer used is alkaline electrolyzer for the generation of green hydrogen. The production cost including the capital and operating expenditure and electric cost is calculated to be Rs. 576.25 per kg of hydrogen and the total revenue generated when expressed in terms of hydrogen is calculated to be Rs. 1215 per kg of hydrogen. The detailed calculation for the costs is shown in annex section.

Storage cost

The costs associated with hydrogen storage and transportation can make a difference to the economic competitiveness of hydrogen. The choices of hydrogen delivery infrastructure and the associated costs are therefore strategically important to the prospect of hydrogen production and utilization in Nepal.

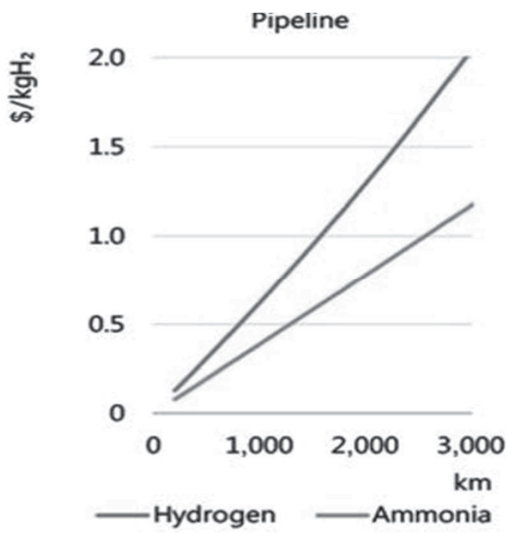
In general, the most appropriate storage medium for hydrogen depends upon the volume and duration of storage, the required speed of discharge, and the geographic availability of different options. For the use in transport in Nepal, it is straightforward to consider the option of storing hydrogen as a gas in pressurized containers, which currently is the most commonly used storage option for small-scale mobile and stationary applications. As a well-established technology, containers storing compressed hydrogen have high discharge rates and efficiencies of around 99%, making them appropriate for short-term smaller-scale applications where a local stock needs to be readily available, such as refueling stations. Currently the levelized cost of storage by pressurized containers ranges from $0.09–$1.19/kilogram of hydrogen (kgH_2), depending upon pressure, operating lifetime and cycles. [10] For the use in Industry in Nepal, it would require much longer-term and larger volume storage as the hydrogen produced from hydropower will be used to bridge major seasonal variations in electricity supply and/or to provide power system resilience.

To meet the requirement of long-term and large volume storage, the subsurface storage of compressed gaseous hydrogen is generally the best option, with the specific options being salt caverns, aquifers, and depleted gas/oil reservoirs. However, these are not expected to be relevant to Nepal due to the constraint of geological availability. When geological storage is not possible, chemical storage through converting hydrogen to ammonia tends to be the most cost competitive alternative for long-term and large volume storage, due primarily to its relatively low CAPEX. The synthesis of ammonia based on water electrolysis is already an established process. [11] There are various potential options that can serve the purpose of long-term and large-scale energy storage to balance seasonal variations in renewable power generation. Storing electricity in the form of ammonia appears to be a potentially viable option for Nepal in the absence of suitable geological conditions for underground storage of compressed hydrogen.

Transportation Cost

The options for transportation of hydrogen shall be aligned with options for hydrogen storage. For transmission of compressed hydrogen, the option of using existing natural gas grids in which hydrogen can be blended into natural gas stream is not relevant to Nepal, because the country has no natural gas infrastructure and natural gas is not part of Nepal's energy mix. A viable alternative is to develop new dedicated hydrogen transmission pipeline. The cost of transporting compressed hydrogen for 1,500 km would be around $1/$H_2$, taking into account all capital and operating costs. For ammonia, it is often transported by pipeline, and new pipelines for ammonia would be cheaper than new pipelines for pure hydrogen. [12] Although pipeline transmission of ammonia appears to be cheaper than compressed hydrogen, the cost required by ammonia conversion will increase the cost of ammonia transmission by about $1.50/$H_2$.

Local distribution delivers the transmitted hydrogen to final users. Similar to transmission, distribution volume, distance and end-user needs are major factors for evaluating distribution options relevant to Nepal's context. For compressed hydrogen, the possible options would include trailer trucks for short distances, which are a relatively costly option, and dedicated hydrogen distribution pipelines for large volume distribution over longer distances, which become increasingly cost-competitive. For ammonia, it can be distributed by road tanker. Distribution by pipeline may also be an option provided that there is large demand for ammonia. Figure below compares the cost of various options of hydrogen distribution to a centralized facility.



[13]

Figure 1: Cost comparison of transportation of hydrogen and ammonia

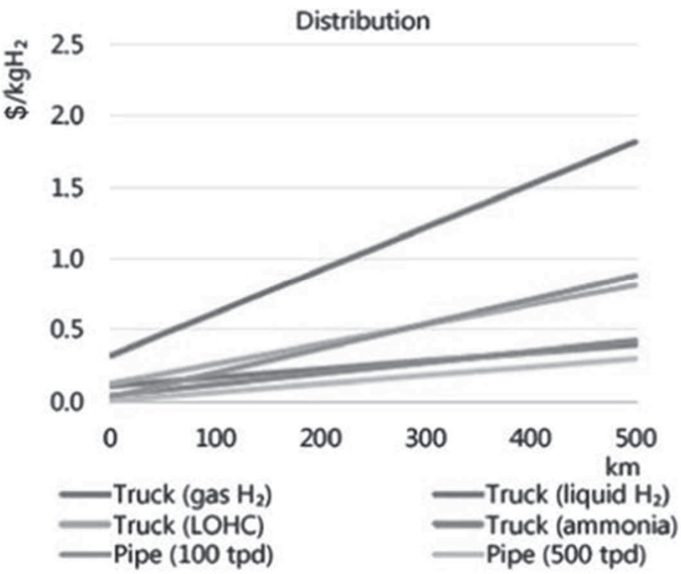


Figure 2: Cost Comparison of transportation of hydrogen by different media

CONCLUSION:

Production of green hydrogen is being increased globally. With the increased urbanization and industrialization all over the world, resources are being used in exponential manner and this has resulted in the increased emission of greenhouse gases, carbon dioxide in a huge amount. Coal and oil were burnt excessively in the early and mid-industrialization phase as they were comparatively cheaper means to produce energy. The environmental and health challenges induced by emissions are forcing the effects of Nature to liftoff the carbon footprints from the energy and economy ecosystem. The Green Hydrogen based economy is the future of the sustainable solution to balance the economy and environment. There is a need for research and innovation to make the GH systems technically and financially feasible as the replacement of fossil fuel. Nepal being rich in hydro sector, and NEA projecting that we will have electricity surplus by the year 2030 AD, it is the perfect time to lay the foundation for the research on green hydrogen technology so that we will be prepared enough by the time when we will be having the production of electricity exceeding the peak demand.

In the context of Nepal, we too can move forward in the path of producing green hydrogen to utilize the surplus hydroelectricity being generated rather than trading it at the cheaper price in the Energy Exchange market. The study made shows that we can generate a revenue of Rs. 1215 per kg of hydrogen for the cost of Rs. 576.25 per kg of hydrogen which can be substantial in uplifting the overall economy of the country. On top of that, storage and transportation of hydrogen is a matter of serious concern. Since we do not have pipeline system for the transmission of natural gas, it is highly suggested for the construction of pipeline across the country for its distribution. Although the capital expenditure will be high, it will have huge impact on boosting up the county's renewable energy scenario and in turn will uplift the economy as a whole. For short term and small volume, it can be stored and transmitted in the compressed cylinder, but the pipeline is must for the transportation of hydrogen in big quantities.

After proper analysis and inspection, we should make ourselves prepared to enter the Green Hydrogen era. The development of hydropower systems to produce GH for commercial applications can change the value chain of hydropower development in the country. Moreover, there is possibility of linking hydrogen chain to various areas. Hydrogen to fuel, hydrogen to industry and hydrogen to economy are the major areas where we should keep our focus on.

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ANNEX

In terms of monetary value,

We are interested in the cost of hydrogen production obtained from green electric energy and using a Power to Gas (P2G) system. The technical specifications of one of the commercially available P2G system is tabulated below.

Table 1: Technical specification of one commercially available P2G plant

Technical Parameters	Value
Nominal Power	1 MW
Net production Rate	Upto 300 m^3 H_2/h
Power Consumption	3.8-4.4 kWh/ m^3 of H_2

[14]

The production cost of hydrogen consists of two parts:

- cost related to Capital Expenditure (CapEx) and Operating Expenditure (OpEx) of P2G system equipment and maintenance.
- cost of electric energy for operation of P2G system and hydrogen generation.

From the above table considering Alkaline Electrolyzer technology, as it is the most common method for the production of green hydrogen,

For various calculations, the following data about hydrogen are used:

Density: 0.08988 kg/m^3

Lower heating value (LHV): 119.96 MJ/kg (i.e., 33.32 kWh/kg or 3.00 kWh/Nm^3). [15]

We know that,

Density = mass/volume

Mass of hydrogen produced = 0.08988*300

= 26.9 kg/h

= 26.9*365 = 645.6 kg/day

Total hydrogen production in 15 years is calculated, considering it to be under operation for 75% of time,

Total Hydrogen Produced = 645.6*365*15*.75

= 26,50,995 kg of H_2

Electric power consumption = 4.4 kWh/ m^3 of H_2

= 4.4/0.08988

= 48.95 kWh/kg of H_2

Efficiency of P2G system = Hydrogen energy/ Hydrogen production energy

= 33.32/48.95

= 0.6809 = 68.09%

For Alkaline Electrolyzer technology,

CapEx = ($500-$1400) per kW [16]

Taking CapEx as $800 for the plant,

CapEx for 1 MW palnt = 800*1000

= $800000 = Rs. 800000*115 = Rs. 9,20,00,000

OpEx is 10% of CapEx in general.

Therefore,

OpEx = Rs. 92,00,000 per year

Now, cost related to CapEx and OpEx = (Rs. 9,20,00,000+ 15* Rs. Rs. 92,00,000)

= Rs. 23,00,00,000

= Rs. (23,00,00,000 / 26,50,995) per kg of H_2

= Rs. 86.75 per kg of H_2

Storage Cost = Rs. 135 per kg of H_2

Transportation Cost = Rs. 175 per kg of H_2

Cost of Electricity for operation

Cost = electric energy price × hydrogen production power consumption

= Rs.13 * 48.95 = Rs. 636.35 per kg of H_2

Total Cost = Rs.1033.1 per kg of H_2

Now, from stoichiometric relation, we have,

$2H_2O \rightarrow O_2 + 2H_2$

From mole concept,

2 moles of water produce 1 mole of oxygen gas and 2 moles of hydrogen gas.

2 moles of hydrogen ~ 1 mole of oxygen

(2*2) = 4g of hydrogen ~ 32g of oxygen

26,50,995 kg of hydrogen ~ 32/4*26,50,995 kg of oxygen

= 2,12,07,960 kg of oxygen

Present market price of green hydrogen ranges between $2.5-$6.8 per kg. [17]

Total price of hydrogen generated = Rs. 5*115* 26,50,995 = Rs. 1,52,43,22,125

Present market price of oxygen ranges from Rs.80-90 per kg [18]

Total price of oxygen generated = 80*2,12,07,960 = Rs. 1,69,66,36,800

When the revenue generated by both hydrogen and oxygen is expressed in terms of hydrogen produced,

Revenue generated per kg of H_2= $\frac{\text{Rs.1,52,43,22,125+Rs.1,69,66,36,800}}{\text{26,50,995}}$ per kg of H_2

= Rs. 1215 per kg of H_2

Moreover, with the continuous advancement and researches in this sector, the price of electrolyzer will further decrease with respect to time. Thus, the project seems to be financially feasible.

In terms of energy,

In standard conditions, for 1 mole of water,

Minimum energy required = 286 kJ per mole of water (including energy for entropy and Gibbs free energy) [19]

Total hydrogen produced in the plant in 1 year = 26,50,995 kg

= 2650995*1000/2 moles of Hydrogen

= 1,32,54,97,500 moles of Hydrogen

From stoichiometric relation we have,

$2H_2O \rightarrow O_2 + 2H_2$

From mole concept,

2 moles of water produce 1 mole of oxygen gas and 2 moles of hydrogen gas.

2 moles of water ~ 2 moles of hydrogen

1 mole of hydrogen ~ 1 mole of water

1,32,54,97,500 moles of hydrogen ~ 1,32,54,97,500 moles of hydrogen

Total energy required to carry out the process = 286*1,32,54,97,500

= 3.79* 10^11 kJ = 1,05,278 MWh

We know that,

Energy that can be obtained from 1 kg of Hydrogen = 39.4 kWh/kg [15]

Total energy produced = 39.4*2650995 = 10449203 kWh = 1,04,449 MWh

Amount of Carbon footprints reduced

For generating 1 kWh energy by burning fuel oil, 0.28 kgs of CO_2 is produced. [20]

For 1,04,449 MWh energy ~ 0.28*1000*104449 kg of CO_2 = 2,92,45,720 kg of CO_2