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Economic Feasibility of Green Hydrogen Technology in Nepal

by

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A THESIS

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis **e**ntitled **“Economic Feasibility of Green Hydrogen Technology in Nepal”** submitted by Utsab Acharya (078MSESP14) in partial fulfillment of the requirements for the degree of Master’s of Science in Energy System Planning and Management.

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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. Green hydrogen, hydrogen produced from the electrolysis constitute a very small portion in it. This method of hydrogen production if applied, helps to reduce the carbon footprints by great amount. 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. Preliminary study shows that if we are to produce green hydrogen from the excess electricity that we are exporting, we need 116 MW hydrogen plant. This plant will produce 27,231,870 kg of hydrogen per year. Detailed study shows that hydrogen plant will have mean breakeven point of 10,566 tonnes of hydrogen and mean benefit cost ratio of 3.54 which suggests that the project is economically viable. The green hydrogen plant constructed is projected to reduce carbon footprints by 254,000,000 kg under its operation. Further, the research and development in electrolyzer is bound to decrease the capital and operating costs of the electrolyzer which will eventually make the technology more viable, economical and sustainable.

Keywords*:* Hydrogen, Greenhouse, electricity, decarbonization, hydropower, carbon footprints

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LIST OF SYMBOLS

\$	Dollar
CH_4	Methane
CO_2	Carbon Dioxide
e^-	Electron
GW	Giga Watt
H^+	Hydrogen ion
H_2	Hydrogen
H_2O	Water
H_2SO_4	Sulphuric acid
Ktoe	Kilo tons of oil equivalent
KW	Kilo Watt
kWh	Kilo watt hour
m^3	Cubic meter
MW	Mega Watt
O_2	Oxygen
OH^-	Hydroxyl ion
Rs.	Rupees
TW	Tera Watt

LIST OF ACRONYMS AND ABBREVATIONS

ALK	Alkaline
CapEx	Capital Expenditure
CSS	Carbon Capture and Storage
Er.	Engineer
FCEVs	Fuel Cell Electric Vehicles
GH	Green Hydrogen
GHG	Green House Gas
GoN	Government of Nepal
Gov	Government
IEA	International Energy Agency
LCOH	Levelized Cost of Hydrogen
LHV	Lower Heating Value
Mr.	Mister
NRB	Nepal Rastra Bank
OpEx	Operating Expenditure
Org	Organization
P2G	Power to Gas
PEM	Proton Exchange Membrane
SOEC	Solid Oxide Electrolysis Cell

CHAPTER ONE: INTRODUCTION

1.1 Background

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 clear that the hydrogen is amongst 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.

Hydrogen is the most common element of the universe. Its abundance compared to other element is well known. The sun too has the hydrogen elements in abundance and consumes 5 million tons each second to produce the light and heat energy. (nasa.gov, n.d.) of it each second. The hydrogen is abundant only when it is check relative to the universe whereas in earth, its large reservoirs cannot be found. Hydrogen atoms are not found in the independent state but are seen to be bonded with other elements. Thus, hydrogen cannot be used as the primary source. The extraction of the hydrogen requires external energy. It is equivalent to the generation of electricity as the energy is spent to channel the energy to where it is needed. Hydrogen can easily reduce our dependency on the hydrocarbon fuels as it is a environment friendly and sustainable source of energy. It is the simplest element and once it is separated from the molecules, it is clean energy carrier. It can be extracted from water, fuels and biomass. Its use in the aviation sector is now heavily researched. By 2040, the commercial aircraft is expected to be fully powered by GH fuel (McKinsey, 2020).

The whole world is now advancing towards the hydrogen-based economy. Thus, Nepal too needs to work its way for hydrogen energy implementation. The need for the research and scientific exploration is utmost at the Nepalese academic institutions. The starting phase would be to transfer the knowledge and adapt hydrogen energy in local level. The sooner is the initiation, shorter will be the transition period of technology transfer.

When comparing the weight and content of fuel in the hydrogen, it has the highest fuel content despite having the lowest energy content. This property of high fuel content allows it to be effectively employed in the Fuel cell and rockets. GH energy is the hydrogen that is obtained from the electrolysis of water. The most significant property of GH energy is that it has no harmful emissions at all. Also, when compared to fossil fuel, it has three times the heating value. The figure of current and future hydrogen demand is given below. It covers different applications of the hydrogen. The expectation is shown up to 2050. The current trend is taken from 2015. Hydrogen demand is expected to increase by 10 times 2050 from current period. (www.statista.com, 2021)

The demand is expected to be high from the transportation and industrial energy sector. In the current context, the demand of hydrogen from these sectors is very less. Further diving into the topic of hydrogen energy, it can be said that the GH energy can be utilized properly for meeting the global emission target. From 2040 to 2050, the cost of electrolyzer is projected to be half and it is expected to rise form megawatt to gigawatt. The renewable electricity cost is expected to fall continuously. The trend shown in the figure shows that the renewable hydrogen will become in demand for the green field applications. Similarly, it also shows that the innovations for better fuel cells are much needed in GH. It is also considered to heart of GH system.

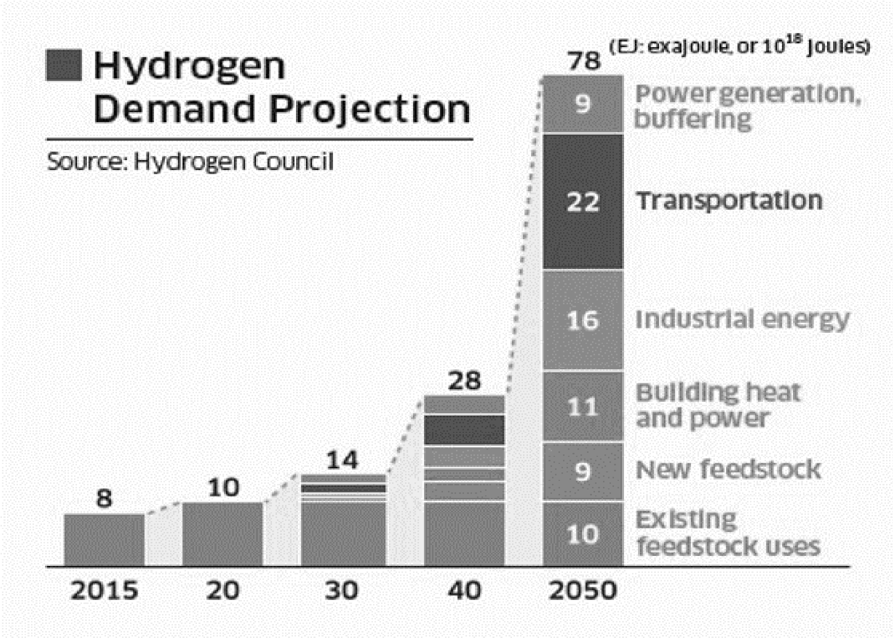

Figure 1.1 Hydrogen demand projection

(Hydrogen; The renewable energy perspective, 2019)

1.1.1 Types of Hydrogen

Energy Policy Act of 1992 considers hydrogen as alternative fuel. (www.leg.state.nv.us, 1992). Hydrogen has garnered attention as a substitute fuel for vehicles due to its capacity to power fuel cells in fuel cell electric vehicles (FCEVs) with zero emissions, its short filling time, its potential for domestic production, and its high efficiency. In actuality, a fuel cell and electric motor combination is two to three times more efficient than a gasoline-powered internal combustion engine. Hydrogen has the potential to function as an internal combustion engine fuel.

Speaking about the method by which hydrogen is produced, hydrogen is basically divided into following: Black, Brown, Grey, Blue and Green, Yellow and Turquoise Hydrogen. (www. utilityanalytics.com, n.d.)

The first method of creating hydrogen is gasification of coal. Carbon monoxide, hydrogen, and carbon dioxide are produced during the gasification process from carbonaceous sources that are either organic or fossil-based. At temperatures above 700°C, gasification is accomplished without combustion and with regulated levels of steam and/or oxygen. The carbon monoxide then undergoes a water-gas shift reaction with the water to produce carbon dioxide and more hydrogen. Using adsorbers or specialized membranes, the hydrogen in the syngas produced by coal gasification can be isolated from the other constituents. Depending on the type of coal used—brown (lignite) or black (bituminous) coal—this hydrogen is referred to as either brown or black.

The most prevalent color of hydrogen is grey. The majority of hydrogen produced today is derived from natural gas; it forms a bond with carbon and can be separated from it using a water-based process known as "steam reforming," but the extra carbon produces CO_2. When the excess CO_2 is not absorbed, this hydrogen is referred to as grey. Today, most of the production is of grey hydrogen. When hydrogen is produced from fossil fuels without absorbing greenhouse gases, it is sometimes referred to as "grey" hydrogen. Brown or black hydrogen differs from grey hydrogen only in the tiny quantity of emissions produced during the process.

When emissions from the steam reforming process are extracted and stored underground through industrial carbon capture and storage (CCS) to prevent atmospheric dispersal, the gas hydrogen is referred to as blue. Because of this, blue hydrogen is frequently regarded as a carbon neutral energy source, though the term "low carbon" would be more appropriate given that only 10% to 20% of the CO_2 produced cannot be captured.

Turquoise hydrogen, also known as "low carbon hydrogen," is hydrogen generated from natural gas by the so-called molten metal pyrolysis process. When molten metal passes through natural gas, solid carbon and hydrogen gas are released. The latter has a practical use in tyres for automobiles, for instance. The first pilot plant for this technology won't be operational for at least ten years; it is currently only in the lab stage. Pink is a common colour for hydrogen produced by nuclear energy electrolysis.

'Renewable hydrogen' or 'green hydrogen' is hydrogen generated from sustainable energy sources. The most well-known is electrolysis, which uses green electricity to split water (H_2O) into hydrogen (H_2) and oxygen (O_2). Since the energy needed for electrolysis comes from renewable sources, no carbon dioxide is released into the atmosphere during the process. 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 chemical process known as electrolysis, which produces hydrogen—a fuel that is lightweight and extremely reactive. The hydrogen and oxygen in water are separated using an electrical current in this method. The IEA notes that this process of producing green hydrogen would prevent the 830 million tonnes of CO2 emissions that occur each year from the production of this by fossil fuels

Similarly, 3,000 TWh/year (www.iberdrola.com, 2021) from new renewables would be needed to replace all of the grey hydrogen in the world, which is equal to the current demand of Europe. Due to the high cost of production, there are some concerns regarding the viability of green hydrogen; however, these are legitimate concerns that will be dispelled as global decarbonisation advances and, as a result, the cost of producing renewable energy decreases.

Solid oxide electrolysis cells (SOEC), proton exchange membrane (PEM) electrolyzers, and alkaline (ALK) electrolyzers are the three primary types of electrolyzer technologies. The features of these electrolyzer are compiled in the table below.

Table 1.1 Techno-Economic characteristics of ALK, PEM and SOEC electrolyzer

Description	ALK			PEM			SOEC		
	2019	2030	Long term	2019	2030	Long term	2019	2030	Long term
Electrical Efficiency (%, LHV)	63–70	65–71	70–80	56-60	63-68	67-74	74-81	77-84	77-90
Operating pressure (bar)	1-30			30-80			1		
Operating temperature (°C)	60-80			50-80			650-1000		
Stack lifetime (1000 operating hours)	60-90	90-100	100-150	30-90	60-90	100-150	10-30	30-60	75-100
Load range (%, relative to nominal load)	10-110			0-160			20-100		
CAPEX ($/kW)	500-1400	400-800	200-700	1100-1800	650-1500	200-900	2800-5600	800-2800	500-1000

(Jim Hinkley, 2016)

For nearly a century, hydrogen has been utilized by the industry primarily for non-energy purposes, particularly in the production of fertilizers and chlorine. ALK technology is fully developed and commercially available. ALK electrolyzers can operate at full design capacity or at a minimum load of 10%. Because precious materials are not used in ALK electrolysis, it has comparatively lower capital costs than other electrolyzer technologies. With the majority of installed capacity globally, it holds the top spot in the electrolyzer market. (Navarro, 2015)

A new technology is the PEM electrolyzer. The commercial utilization of it has commenced, primarily focusing on relatively smaller and medium sized scale use. They offer potential solutions to address certain operational limitations observed in ALK electrolyzers. Some of the advantages of PEM electrolyzers include their ability to produce highly compressed hydrogen suitable for decentralized production and storage at refueling stations, a wider operating range spanning from 0 to 160% of design capacity, the use of pure water which eliminates the need for recovering and recycling the potassium hydroxide electrolyte solution typically used in ALK electrolyzers, and their relatively compact size. (Francisco Boshell, 2019) .PEM electrolyzers' shorter lifespan and greater cost are its major drawbacks.

Since SOEC is still in the demonstration stage and has not been commercialized, it is the least developed technology when compared to ALK and PEM. Because ceramics are used as the electrolyte, SOEC requires less material than ALK and PEM, despite currently having a higher capital expenditure (CAPEX). Although SOEC has a high electrical efficiency, its long-term economic competitiveness may be limited by the need for a high-temperature heat source (Francisco Boshell, 2019). SOEC (Solid Oxide Electrolysis Cell) electrolyzers have the advantage of being able to operate in reverse mode as a fuel cell, allowing them to convert hydrogen back into electricity. This operational flexibility gives SOEC electrolyzers an edge over ALK (Alkaline) and PEM (Proton Exchange Membrane) electrolyzers. Consequently, when coupled with hydrogen storage facilities, an SOEC electrolyzer could provide grid balancing services. Consequently, it may be possible to raise the overall utilization rate (cip.nea.org.np, 2018).

By electrolyzing renewable energy sources to produce hydrogen (H2) and oxygen (O2) from water molecules, the ALK electrolyser creates green hydrogen (H2). To conduct electricity, salts and minerals must be present in the water. A DC current is applied to both rods that are submerged in water and connected to a power source. When ions with the opposite charge to the electrodes are drawn to them, hydrogen and oxygen dissociate. Because of the electricity's effect, an oxidation-reduction reaction takes place during the electrolysis.

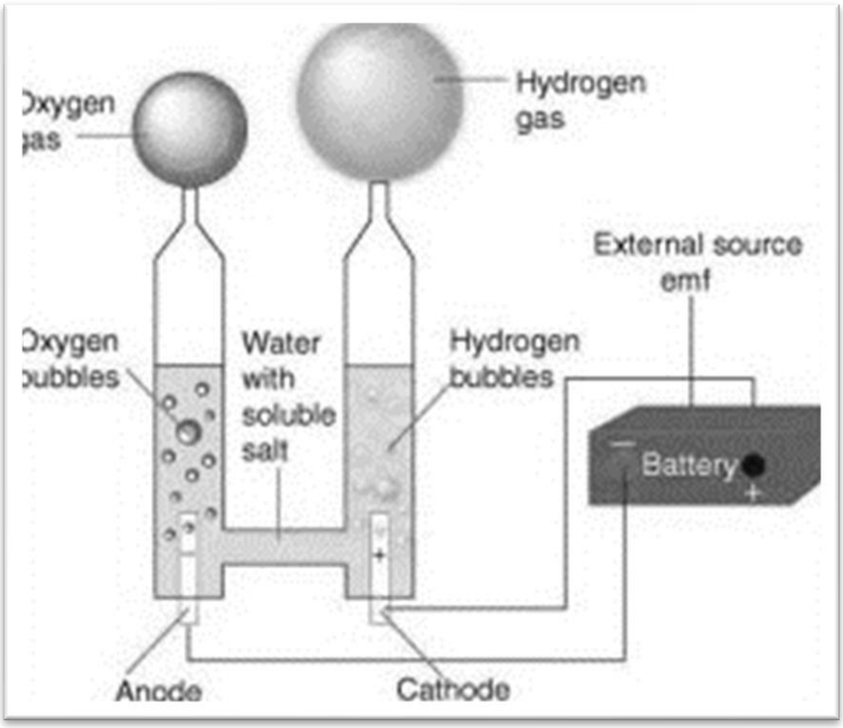

Figure 1.2: Electrolysis of water

(Fachrizza, Research Gate, n.d.)

Hydrogen and oxygen gases are produced when water is electrolyzed. A tiny quantity of an electrolyte, such as H2SO4, should be added to two platinum electrodes that are submerged in water to form the electrolytic cell. Because pure water lacks ions, it cannot carry a sufficient charge. This is why an electrolyte is required. Water is oxidised to produce hydrogen ions and oxygen gas at the anode. H2 gas and OH^- ions gets formed at the cathode.

The reactions take place as:

$$H_2O\ (l) \rightleftharpoons H^+\ (aq) + OH^-\ (aq)$$

Anion i.e. OH^- moves towards the anode and oxidizes to oxygen gas whereas cation i.e. H^+ moves towards the cathode and reduces to hydrogen gas.

At anode (oxidation):

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

At Cathode (Reduction):

$$2H^{+} (aq) + 2e^{-} \rightarrow H_2 (g)$$

Overall reaction:

$$4OH^{-} (aq) + 4H^{+} (aq) \rightarrow O_2 (g) + 2H_2 (g) + 2H_2O (l)$$

$$4H_2O (l) \rightarrow O_2 (g) + 2H_2 (g) + 2H_2O (l)$$

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

The reduction half-reaction was multiplied by two to equalise the electrons and obtain the overall reaction. Water is created when the hydroxide and hydrogen ions generated in each reaction combine. The reaction does not use up the H2SO4.

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 makes an effort to investigate the potential uses of hydrogen in the particular setting of Nepal. Both the transport and electricity industries in Nepal are probably going to contend for the use of hydrogen in this situation. The potential hydrogen value chains in Nepal are described in this study. These value chains are essentially based on the production of hydrogen from surplus hydropower-generated electricity and water. It also offers a succinct financial breakdown of the hydrogen supply chain. The motto regarding this preliminary study is about setting the stage for more in-depth research on the installation of hydrogen in Nepal alongside other member countries which are enriched in a wealth of renewable energy resources but little to no progress in initiatives related to hydrogen.

1.2 Statement of problem

The main sources of energy in Nepal are waste and biofuels, which come in the form of animal dung, firewood, and agricultural waste. The following are additional primary energy sources: hydropower, coal, and oil products. Seventy-two percent of Nepal's primary energy supply comes from waste and biofuels. (www.iea.org, 2021). More than 99 percent of Nepal's electricity was produced using hydropower. 74% of the total came from the residential sector, which used 10,373 kilotons of oil equivalent (ktoe). (www.iea.org, 2021). With 13% and 11% of the total energy consumed, the transportation and industry sectors were ranked second and third, respectively. (www.iea.org, 2021). Despite still having smaller shares than the residential sector, the transport and industrial sectors have been expanding quickly, and as a result, so too have their energy consumptions.

The country's waste resources, and native biofuels provided almost 95% of the total energy used by residential sector, but the transportation and industrial sectors largely relied upon imported coal and oil products. Over the past decade, there has been a noticeable rise in oil consumption specifically within the transportation sector in Nepal, when compared to the overall consumption of oil products across all sectors.

Greenhouse gas (GHG) emissions are produced during fuel combustion. Putting methane and nitrous oxide aside, total carbon dioxide (CO2) emitted in 2021 is 4.67 (MtCO2e), out of that 36% comprised the transportation sector (www.iea.org, 2021). This share is further increasing with respect to time.

These facts underscore the considerable challenges that Nepal currently faces in the energy sector, underscoring the need to prioritize it on Nepal's energy and climate agenda. Given this context, the paper specifically examines the residential, industrial, and transportation sectors as crucial energy sectors in Nepal. It conducts an initial analysis to investigate the potential utilization of hydrogen in these sectors.

1.3 Objectives

1.3.1 General objectives

The general objective of this thesis is to study about the economic feasibility of green hydrogen technology in Nepal. The thesis is focused on analyzing whether green hydrogen technology can be a better option to utilize the surplus hydroelectricity generated.

1.3.2 Specific Objectives

The specific objectives of the research are:

- To know about the economic feasibility of using hydrogen to support integration of renewable energy,
- To study about the hydrogen chain value and its possibilities by transforming it into other forms.

1.4 Significance of the Study:

Nepal possesses tremendous potential of green hydrogen due to the availability of free-flowing rivers. Although the hydroelectric potential has not been met to its extent, it is increasing exponentially. The surplus electricity can be used to generate green hydrogen which is a clean source of energy. This study will help to explore the future possibilities in the sector of generating clean hydrogen energy. Green hydrogen technology can be a better alternative source of energy for the context of developing country like us which are rich in water resources. This study on the prospects of green hydrogen technology in Nepal could be of great help for the concerned stakeholders who are related to this field which will surely open the door for the further research on the prospects of green hydrogen in Nepal. On top of this, the green hydrogen produced can be used in various areas to solve the energy crisis of Nepal.

Another application for green hydrogen is the decarbonisation of commercial and residential heating systems, which are significant contributors of carbon emissions. Green hydrogen is blended with natural gas as a "ultimate choice" to cut emissions associated with heating. Fuel-cell vehicles are powered by green hydrogen. Though green hydrogen fuel-cell cars haven't gained much traction in the automotive industry, this use case is one of the most frequently mentioned applications of the renewable energy source.

As per Ministry of Agriculture and Livestock Department, annual demand of chemical fertilizer of Nepal is about 7,85,000 metric tons which we are importing from India as Nepal does not have any significant fertilizer plants. This import is costing USD 186.6 million per annum. This cost can be significantly reduced to upto USD 90 million per annum if we shift on chemical fertilizer plant as of now. (ibn.gov.np, 2021)

Table 1.2: Comparison of Generation, Consumption, Imports and Exports of energy in GWh in FY 79/80

Month	Demand (GWh)	Generation (GWh)	Import (GWh)	Export (GWh)	Surplus-Deficit Scenario (GWh)
Shrawn	1050.52	1276.61	25.46	251.56	226.09
Bhadra	1063.92	1298.73	20.86	255.67	234.81
Ashwin	909.22	1184.07	6.12	280.97	274.85
Kartik	722.16	923.89	0.52	202.25	201.73
Mangsir	758.82	827.93	18.69	87.8	69.11
Poush	915.9	713.61	202.88	0.39	-202.29
Magh	863.71	552.72	310.99	0	-310.99
Falgun	873.95	555.48	318.47	0	-318.47
Chaitra	919.5	583.96	335.54	0	-335.54
Baisakh	1083.24	687.51	395.73	0	-395.73
Jestha	1192.06	1031.86	184.4	24.2	-160.2
Ashadh	1194.45	1389.64	34.88	230.07	195.19
Total	**11547.45**	**11026.01**	**1854.54**	**1332.91**	

(NEA, 2023)

Electrical Energy scenario of Nepal for 2023 suggests us that we are having an electricity surplus in the wet season (Ashadh-Mangsir). This can be clearly visible from the surplus deficit scenario in the table below. Upon closely observing the demand, generated, imported, and exported electricity, it can be observed that we have exported electricity 1333 GWh of electricity to India in this fiscal year. Using this electricity in green hydrogen plant will not only be a better option, it also supports the cause for meeting net zero emissions target set by the government. With the continuous completion on hydroelectricity projects and addition of it to the national grid, the amount if electricity exported is bound to increase in the days to time. Thus, it is right time to shift our focus on generating green hydrogen from this surplus hydroelectricity.

In the industrial sector, green hydrogen can serve as a boon which can be used in steel industries. As noted in a previous Fuel Cell and Hydrogen Energy Association (FCHEA), The steel industry is starting to experiment with using hydrogen to lower emissions during the production process. In order to achieve the high temperatures and chemical reactions needed for steelmaking, coal is usually used. In this process, hydrogen can be used in place of both the necessary heat and the chemical reactions. Utilizing clean hydrogen has the potential to significantly lower emissions because steel is a basic component of modern construction and industrial operations.

In light of the global environment, it is more likely that green hydrogen will be significant for other uses in the upcoming ten years than for the replacement of internal combustion engines in automobiles. On the other hand, industries and manufacturing that depend on forklift trucks and other material-handling vehicles might see a surge in the use of fuel cell vehicles.

CHAPTER TWO: 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. Though gas is in extensive amount within the earth, it's not found in free state. There are different ways are used to extract gas, most typical of that being the combustion of coal and natural oil that generates carbon dioxide gas as the byproduct that is one in every of the foremost constituents of gas inflicting the global warming phenomenon that has resulted within the world temperature rise and altered the atmospheric condition across the globe. This concept of hydrogen generation by electrolysis is comparatively new concept where the clean gas is obtained by the electrolysis of water. Water is in extensive amount in earth, regarding seventy-one of the planet is roofed with water (www.usgs.gov, 1984). This water can be used to generate the clean hydrogen which can be used for number of process.

It's period of time for renewable gas, however the potential is big, and several other nations have a watch on the driver's seat. These days, there are opportunities to test every new gas for low-emission transportation solutions and fuel cells for remote power supply in developing nations. Ammonia- and methanol-based cell technologies are becoming more and more specialized in China, India, Indonesia, the Philippines, and other African countries. (Assistance, 2020) systems for the telecommunications sector.

Smaller stationary cell systems have also started to be tested in Asian and African countries for residential and commercial users. In Uganda, Madagascar, Martinique, Argentina, and other places, various larger gas or cell systems are being tested to provide stationary power solutions. Regarding quality, cell buses are being tested in China, Costa Rica, and Malaya; Bulgaria, Indonesia, and India have placed orders for them. Even the pilot programmes for gas and cell (Energysector, 220) systems for material handling forklifts have started in China and Africa. The compelling features of those products vary depending on the situation, but they generally reflect the fact that, given hydrogen's higher energy density than electricity, gas may be more engaging than electricity-based storage systems in certain applications.

Green gas is expected to be the foremost contributor in economy among 2050. (www.reogma.com, 2021) 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. (Economy S. G., 2020). 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 meta 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. (Ale, 2020)

For the study, Katmandu University and Nepal Oil Corporation, the government-run fuel distribution monopoly, have partnered (Dhungana, 2021) . Now that the study has officially started, the members of the team say they are expecting positive outcomes. The study's principal investigator, academician Biraj Singh Thapa of the KU Green Hydrogen Lab, notes that if the nation can generate hydrogen fuel as anticipated, it will also be able to avoid spending millions of rupees annually on fossil fuel. "There is a possibility of meeting the demand for fuel completely by utilizing the electricity that would otherwise go to waste," he says, "We see Nepal can achieve prosperity by selling this clean energy as its demand is high in the world." (Thapa) Furthermore, Pushkar Manandhar has also studied the aspects of solving the load shedding problem of Nepal by using green hydrogen to generate electricity. A green hydrogen lab has also been setup at Manmohan Memorial Polytechnic, Biratnagar to research about the prospects of green hydrogen in Nepal. The lab has just been setup and this will test the quality of hydrogen produced and its scope in other areas of the country (Chaudhary, 2021).

India has considered Green Hydrogen as key major to achieve Net Zero Emission goal by year 2070. With the goal of becoming the global hub for the production, use, and export of green hydrogen and its derivatives, India has launched the National Green

Hydrogen Mission. In order to do this, the mission will develop the capacity to produce at least 5 million metric tonnes annually by 2030, with the possibility of increasing that capacity to 10 million metric tonnes annually as export markets expand (Energy, 2023). Recent years have seen the start of pilot programmes in India to produce green hydrogen from biomass using thermochemical and biochemical processes, as well as through electrolysis of water using renewable electricity. The mission is to advance and expand the technology for producing green hydrogen, making it widely available and reasonably priced. Upgrading the manufacture and application of high-performance electrolysers in sufficient quantities will be another crucial intervention. As of right now, only 2-4 GW of commercial electrolysers are produced annually in the world. Over the last three years, numerous industrial groups and national governments have declared plans to deploy over 200 GW of electrolyser capacity by 2030.

As a result, the capacity to produce electrolysers worldwide is expected to increase quickly. However, it is essential to establish a strong domestic electrolyser manufacturing ecosystem in India in order to reduce reliance on imports and guarantee supply chain resilience in the industry. The Mission suggests actions to support home industry in order to guarantee much cheaper electrolyser production in India. Additionally, this will make Made in India Green Hydrogen more competitive in global markets. (Energy, 2023)

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. (Energetica, 2022) 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 a hydropower powerhouse, with 20,000 MW of projects currently under development. However, due to the seasonal nature of the resources from the extensive network of 6,000 rivers, hydrogen storage is required. 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. (urjakhabar, 2022)

2.1 GH as fuel cell

Hydrogen bus is a talk of town in countries as it can pave path for sustainable transport. Green Hydrogen has been considered as keyway of mass transportation on road by tackling air pollution. Hydrogen buses on the road are on its way in many countries like Denmark, UK, Japan and Norway. (GreenHydrogenLab, n.d.) They offer replacement for electric vehicles as they are emission free, provide longer range, gets refueled quickly and can easily operate under extreme conditions. There are few cons to it. Highly flammable nature of hydrogen and its low density makes storage and transportation challenging. However, various research are going on intending to develop ways to overcome these challenges.

2.2 GH in Industries

Cement Industries contribute about 5% to global CO2 emissions. Carbon dioxide is mainly emitted from calcination of limestone. In these areas, carbon dioxide and green hydrogen can be mixed to create synthetic methanol, which can then be processed to create carbon-neutral synthetic kerosene. Further, green hydrogen can be burned to heat the chambers all well.

2.3 Hydrogen Powered Turbines

Hydrogen-powered electricity turbines can also be one of the area that we can focus on. This has been already practiced in Mitsubishi Power where a gas turbine has been developed that runs on 30% hydrogen and 70% natural gas mix. It has been found that it produced around 10% less CO2 than those powered by natural gas alone. The team is working to develop one that is by completely powered by hydrogen by 2025. (Mitsubishi, 2023)

2.4 Green Financing

Due to the elimination of carbon footprints, there is a great possibility for green financing for the project. Development of green finance in Nepal is regulatory driven. "Guidelines on Environmental and Social Risk Management for Banks and Financial In situations (ESRM)" issued by the NRB in 2018 has been the guiding force behind

Nepal's regulatory driven development of green finance. (UNDP, 2021). Monetary policy for 2020/21 has provisioned for the issuance of Energy bond by the Bank and Financial Institutions to comply with the regulatory requirement of investing in energy sector. These all policies suggest that green bond can be issued for financing the project.

2.5 GH as a cooking fuel

Hydrogen as a cooking fuel experiment has been successfully completed in Kathmandu University Lab in Dhulikhel. "From the 18-month long experiment, food was cooked in seven minutes using hydrogen fuel in the newly designed stove.", Biraj Thapa Claims it. "The study in Nepal for one and a half years has led to a breakthrough in the use of hydrogen fuel. Probably for the first time, we have also been able to build hydrogen stoves in Nepal," Thapa said, adding, "The study has been successful in conveying the message that hydrogen, which has immense potential in Nepal, can now be used as an alternative to cooking gas at home." Even though there are various challenges regarding the transmission and storage of hydrogen, this study has made clear that we can use hydrogen as a cooking fuel in homes.

2.6 Crystall Ball

Crystall ball is an important software which is used as external add-in with Microsoft Excel. Crystall ball allows to make calculations based on simulations. Various assumptions regarding our input data can be made in crystall ball. The data model supported are uniform distribution, normal distribution, poission distribution, lognormal distribution, Weibull distribution and many more. Based on the nature of availability of data, CB allows user to model the data. Based on the assumptions made under CB, it also allows user to define the forecast for the value that we are looking for. It works on Monte Carlo simulation which runs the calculation for number of possible cases defined within the range and confidence interval and gives the output based on that. For this preliminary study, uniform distribution has been used.

2.7 Economic Indicators

Benefit Cost Ratio is an economic tool which gives the relationship between the benefits offered by the proposed project and costs associated to it. It is simply the ratio of benefits to cost in terms of monetary value. Here, present values of both benefits and costs are taken into account for the calculation. Benefit cost ratio of greater than 1 signifies that the proposed project will deliver positive net present value whereas less than 1 signifies that the project will deliver negative net present value. Breakeven analysis is another important economic tool. It gives the quantity that proposed project should produce in order to compensate the costs incurred during the production. In simple terms, it is the least amount of product that the project should produce in order to be positive in terms of cash flow. It is simply calculated by the ration of fixed cost to the variable costs per unit subtracted from the revenue generated per unit. Lesser the break-even quantity, more likely the project would be economically viable.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Theoretical Framework

Research methodology is a planned approach to solving a research problem. Stated differently, research methodology pertains to the techniques and approaches used throughout the entirety of the study. The term "research methodology" describes the various sequential actions that an investigator must take in order to learn a drag with clearly defined objectives.

3.2 Methodology Chart

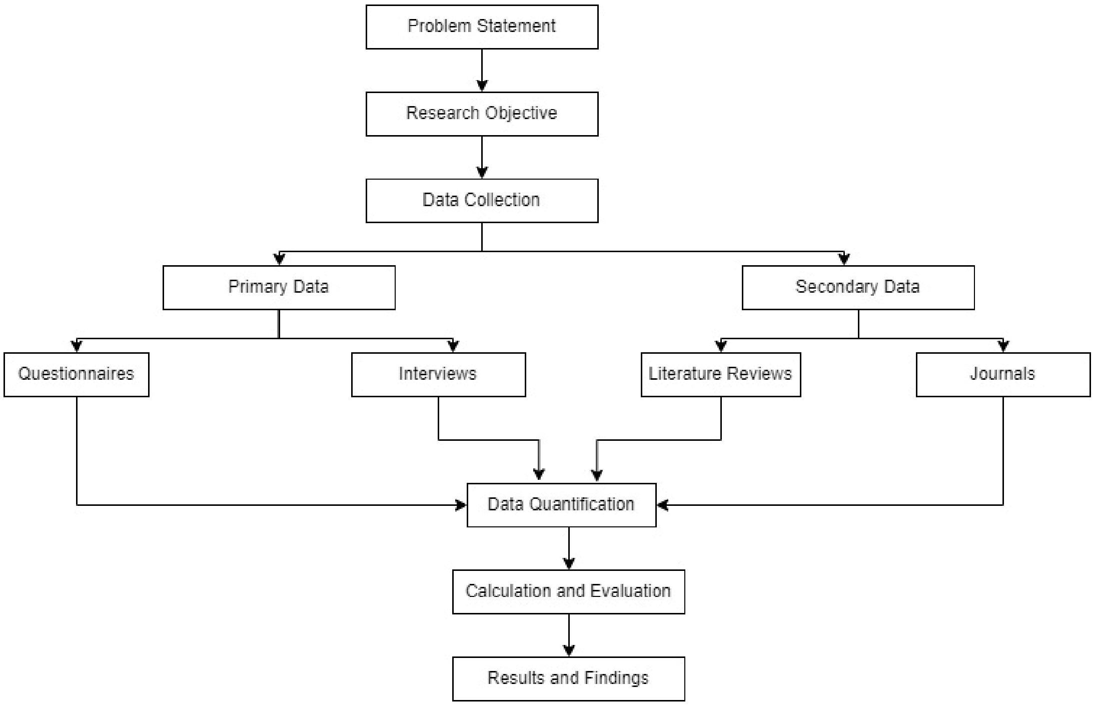

Figure 3.1: Methodology Chart

For this research, problem statement was defined after studying the various literatures. This problem statement was converged to generate a primary research objective. There were various other specific objectives associated with the primary one. Various articles, manuals, books, journals and websites related to green hydrogen are the basic source of data collection. The study was done to analyze and find out the technical parameters involved in the production of green hydrogen along with the cost of hydrogen and oxygen gas in the market. From this study, the researcher tried to find out the national as well as global context regarding the production of green hydrogen.

Secondary data sources include a wide range of reports, scholarly articles, books, customer surveys, media, and press releases. After the review of the journals, various necessary data were collected. They were studied thoroughly; calculations were performed, and the conclusion was drawn from it.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Data Collection

4.1.1 Storage of Hydrogen

The transportation and storage costs of hydrogen can have an impact on how economically viable hydrogen is. Thus, the outlook for hydrogen production and utilization in Nepal hinges on the strategic decisions made regarding infrastructure and the corresponding costs involved.

The best method of storing hydrogen is typically determined by the amount and length of storage, the needed discharge speed, and the accessibility of various options geographically. Considering the context of transportation in Nepal, it is logical to consider the storage of hydrogen in pressurized containers in the form of a gas. Currently, compressed hydrogen storage containers are widely adopted as the preferred storage solution for both mobile and stationary applications. These containers have established themselves as a reliable technology, offering high discharge rates and impressive efficiencies of around 99%. As such, they are suitable for small-scale, temporary applications like refuelling stations where a local supply must be easily accessible.

Pressurised container storage currently has a levelized cost of $0.09 to $1.19 per kg of hydrogen (kgH2), depending on operating conditions, lifetime, and cycles (T. Ramsden, 2009). Because the hydrogen generated from hydropower will be used to provide power system resilience and/or bridge significant seasonal variations in electricity supply, much longer-term and larger volume storage would be needed for its use in Nepalese industry.When it comes to large-volume ang long-term storage, storing hydrogen via Carbon Capture and Storage is often considered the most suitable option. This can be achieved through various methods, including utilizing depleted oil or gas reservoirs, aquifers and salt caverns. However, given the limitations imposed by geological availability, it is not anticipated that these will be applicable to Nepal. Chemical storage, such as the conversion of hydrogen to ammonia, is typically the least costly option for greater term and bigger volume storage when geological storage is not feasible. This is mainly because of its relatively low CAPEX. Water electrolysis is already a well-established method for producing ammonia. (Joakim Andersson, 2019).

To address the fluctuations in renewable power generation throughout different seasons, several viable options exist for larger duration along with bigger capacity energy storage. In Nepal, considering that geological conditions may not be suitable for underground compressed hydrogen storage, storing hydrogen as ammonia could be a feasible solution.

4.1.2 Transportation of Hydrogen

There should be coordination between hydrogen transportation and storage options. Provided that Nepal does not have infrastructure for natural gas and does not include it in its energy mix, the possibility of using existing gas pipelined for transmitting compressed hydrogen, where hydrogen can be mixed with natural gas streams, is not applicable or significant for the country. Creating a new, dedicated hydrogen transmission pipeline is a workable substitute. When accounting for all capital and operating expenses, the cost of transporting compressed hydrogen over a distance of 1,500 km would be approximately $1/H2.

Ammonia is frequently transported via pipeline, and the cost of building new ammonia pipelines is less than that of building new hydrogen pipelines (www.iea.org, 2021). Even though compressed hydrogen seems to be more expensive than ammonia transported via pipeline, the expense associated with converting ammonia will increase the cost of transmitting ammonia by approximately $1.50 per hour.

The transmitted hydrogen is delivered to end users through local distribution. Analogously to transmission, the main considerations for assessing distribution options appropriate for Nepal's context are distribution volume, distance, and end-user requirements. Trucks, which are comparatively expensive, and specialized hydrogen distribution pipelines, which are more and more cost-competitive, are the two options available for compressed hydrogen distribution over longer distances. Road tankers can be used for the distribution of ammonia. If there is a high demand for ammonia, pipeline distribution might also be an option. The cost of several hydrogen distribution options is compared to a centralized facility in the figure below.

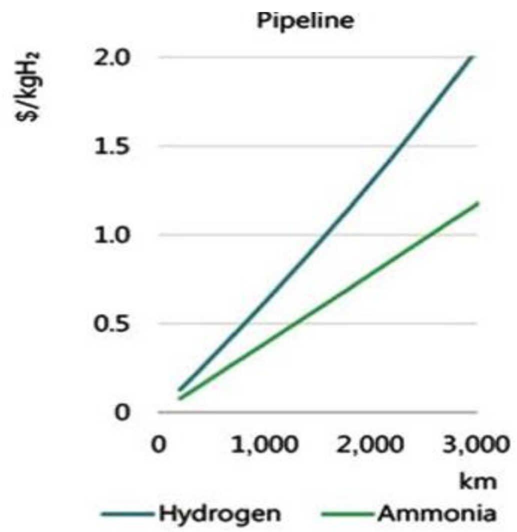

Figure 4.1: Cost comparison of transportation of hydrogen and ammonia

(Economy H. , 2016)

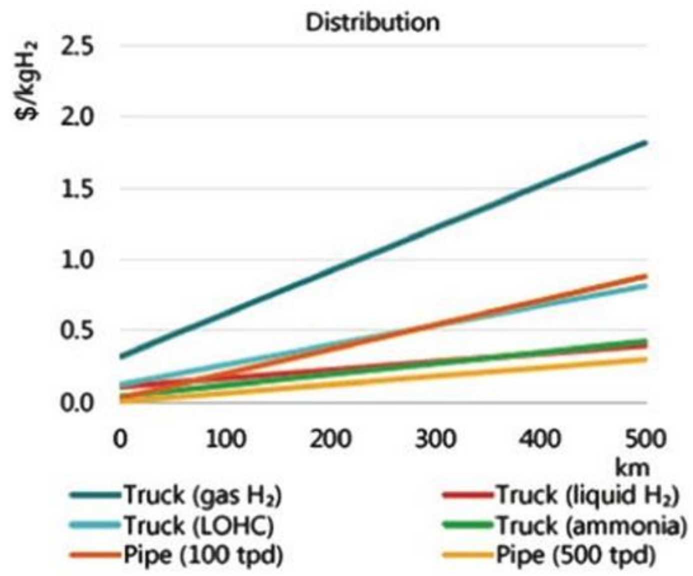

Figure 4.2:Cost Comparison of transportation of hydrogen by different media

(Economy H. , 2016)

4.2 Hydrogen as a potential option

The government of Nepal is actively engaged in the implementation of its energy sector policies, strategies, and project development plans. It is advisable to consider innovative solutions in addition to well-established technologies and practices to effectively tackle the challenges faced by various sectors in Nepal.

With an abundance of hydropower resources and the increasing development in the hydropower sector, the total installed hydropower capacity by 2025 can be estimated by referring to the Government issued White Paper in 2018. The White Paper sets ambitious targets of achieving a total installed capacity of 3,5 and 15 GW in 3,5 and 10 years respectively, and it is highly likely that we will be meeting this targets. However, this study takes a conservative approach and pertains that the installed capacity will reach 3 GW by 2025 and 8 GW by 2030. (cip.nea.org.np, 2018) Therefore, it is an opportune time to explore alternative uses of electricity to financially support hydropower projects. One possible option is to utilize stored electricity for powering vehicles, which aligns with Nepal's objectives of decarbonizing and electrifying the transportation sector. Considering this perspective, hydrogen stands out as a promising technological option that has the potential to be effective in Nepal.

One common molecular element in nature is hydrogen. Hydrogen is odorless, nontoxic, and has the highest energy content (almost three times that of gasoline) of all common fuels by weight. Although it is not naturally occurring, hydrogen can be created from a variety of primary energy sources, such as biomass or fossil fuels, or from secondary energy sources, such as electricity, depending on the resources that are available in the area. The produced hydrogen can be used as a fuel in various end-use applications within the energy, transportation, industrial, and building sectors of the economy. As an example, a fuel cell is an electrochemical device that can operate continuously by utilizing hydrogen and oxygen from the surrounding air to generate electricity and can also generate electricity from vice versa. From this angle, it's critical to remember that hydrogen, like electricity, is an energy carrier with a wide range of applications and flexibility rather than an energy source. Hydrogen has the potential to be an energy carrier with almost zero emissions because it doesn't contain carbon. Moreover, oxygen gas, which is produced as the by product in electrolysis process carries a huge monetary value. This oxygen can be processed to make medicated oxygen which is high in demand for the hospitals.

From the research that is being carried out in the Manmohan Polytechnic Institute regarding Green Hydrogen, Er. Ranjan Chaudhary is optimistic regarding how things have been going over there. The lab has been set up, but the sample production has not been started yet. From my interview, I found out that a lot of problems that the lab has faced from scratch till date. The electrolyser imports and setup do carry a significant role. For the research, is has been difficult to maintain the adequate pressure and temperature that favors the chemical reaction. As per Chaudhary, he wants government to make ample changes in policy related to import of such innovative ideas which will eventually draw more researchers in this field. Moreover, proper policy for green financing will obviously aid in the research which will then lead to the mass production. We should itself focus on finding ways for proper storage and transportation of green hydrogen in Nepal’s scenario. Proper market needs to be analyzed and we should make trade open with our neighboring countries regarding green hydrogen. It can obviously trade in energy exchange market. We can develop new form of certificates like RECs which will recognize its worth and make ourselves stand across the globe.

4.3 Possible Hydrogen production in Nepal

For the production of Hydrogen, there are various established technologies. Various methods are producing rainbow of hydrogen: black, brown, blue, pink, green, turquoise all depending upon the source from where the gas is produced, emissions from the process and the capturing of those emissions produced. Hydrogen formed by the electrochemical process of water electrolysis, which separates water into hydrogen and oxygen. As of right now, water electrolysis accounts for only 4% to 5% of the total hydrogen produced globally; this is primarily from the production of chlorine, of which hydrogen is a byproduct. (Gielen, 2020). According to the International Energy Agency (IEA), dedicated hydrogen production through water electrolysis currently accounts for only 0.1% of the global (www.iea.org, 2021). This relatively low percentage is attributed to cost and efficiency challenges associated with this production method. However, considering Nepal's abundant hydro resources and surplus electricity during the rainy season, a report suggests that water electrolysis could be a technically feasible approach for hydrogen production in the country.

Among the three available technologies available for green hydrogen production, Alkaline (ALK) Electrolyser is considered for hydrogen gas extraction. ALK electrolyser was chosen as it is fully mature and commercial electrolyser which is in use in chlorine and fertilizer manufacturing. Moreover, it can run from minimum 10% of capacity to its full potential. Comparatively, it is cheaper than other electrolyser and its specification data can be easily extracted. These all things led to use the ALK electrolyser for hydrogen gas extraction.

4.4 Cost Analysis

For finding the costs associated with hydrogen production from electricity, following parameters of the plant has been considered. The technical specifications of one of the commercially available P2G system is tabulated below.

Table 4.1: 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

(Jovan & Gregor Dolanc, 2020)

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). (www.engineeringtoolbox.com, 2003)

We know that,

Density = mass/volume

Mass of hydrogen produced from 1 MW plant = 0.08988*300

= 26.9 kg/hr

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

= 4.4/0.08988 = 48.95 kWh/kg of H2

Table 4.2:Comparison of Imported Energy (GWh) from India in different FY

FY	77/78	78/79	79/80
Shrawn	27.98	3.02	251.56
Bhadra	3.9	37.67	255.67
Ashwin	0.81	81.23	280.97
Kartik	0.49	33.38	202.25
Mangsir	0.01	28.18	87.8
Poush	0	0	0.39
Magh	0	0	0
Falgun	0	0	0
Chaitra	0	0	0
Baisakh	0	0	0
Jestha	0	69.66	24.2
Ashadh	0.1	240.47	230.07
Total	**33.29**	**493.61**	**1332.91**

(NEA, 2023)

From the above table, we can see that we have exported 1333 GWh of electricity to India in the FY 79/80. As of now, considering this amount of electricity for green hydrogen production, total electricity available for green hydrogen production if we stop exporting electricity would be 1333 GWh of electricity.

We know,

48.95 KWh of electricity is required to produce 1 kg of H_2.

Amount of H_2 that can be produced in year = 1333*10^6 /48.95

= 27231870 kg of H_2

Amount of H_2 that can be produced hourly = 27231870/365/24

= 3108 kg of H_2 per hour

Capacity of H_2 plant needed = 3108/26.9 = 116 MW

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.

For Alkaline Electrolyzer technology,

CapEx = ($500-$1400) per kW (Jim Hinkley, 2016)

OpEx is 10% of CapEx in general.

Therefore,

Electricity cost = Rs.10455 * 10^6 (Revenue Generated from Export of electricity to India) (NEA, 2023)

Storage Cost = $0.19 - $1.19 per kg of H_2 (T. Ramsden, 2009)

Transportation Cost = $1-$1.5 per kg of H_2 (Economy H. , 2016)

Cost of Hydrogen per kg = $4- $5 (HydrogenShot, 2022)

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

27231870 kg of hydrogen ~ 32/4* 27231870 kg of oxygen

= 217854960 kg of oxygen

Present market price of oxygen ranges from Rs.80-90 per kg (www.amazon.in, 2021)

Considering exchange rate of $1 = Rs.133 (NRB, Nepal Rastra Bank, 2023)

Substituting all these assumptions in crystal ball and defining the forecast for benefit cost ratio,

$$\text{B/C ratio} = \frac{\text{Present Value of all Benefits}}{\text{Present Value of all Costs}}$$

Considering Minimum Attractive Rate of return to be 8.5 % (NRB, Monetary Policy for 2022/23, 2022)

Table 4.3: Parameters used for calculation in CB model

Description	Cost	Unit
Mass of hydrogen produced form 1MW Plant	26.9	kg/hr
Capacity of H2 plant needed	116	mw
Annual Hydrogen Production	27231870	kg
Capex For 1 KW (Assumption defined in CB)	126350	Rs
Capex for 16 MW	2021600000	Rs
Annual Operating Cost	202160000	Rs
Annual Electricity Cost	10455000000	Rs
Electricity Cost Per kg	383.9251583	Rs/kg
Storage Cost per kg (Assumption defined in CB)	85.12	Rs
Annual Storage Cost	2317976774	Rs
Transportation Cost Per kg (Assumption defined in CB)	166.25	Rs
Annual Transportation Cost	4527298388	Rs
Total annual costs	17502435162	Rs
Revenue per kg of hydrogen (Assumption defined in CB)	665	Rs
Revenue per kg of oxygen (Assumption defined in CB)	85	Rs
Total Annual revenue	27368029350	Rs

This will result in cash flow as below:

Table 4.4: Net Cash flow for the project

Year	Annual Revenue	Annual Costs	Net Cash Flow
1	27368029350	17502435162	9865594188
2	27368029350	18990142151	8377887199
3	27368029350	20604304233	6763725117
4	27368029350	22355670093	5012359257
5	27368029350	24255902051	3112127299
6	27368029350	26317653726	1050375624
7	27368029350	28554654292	-1186624942
8	27368029350	30981799907	-3613770557
9	27368029350	33615252899	-6247223549
10	27368029350	36472549396	-9104520046

The key metrices obtained after 10000 simulations with 95% confidence limit in crystal ball from above cash flow are;

Initial Investment = Rs. 2,021,600,000.

Mean Value PV of Costs = Rs 14,964,792,413.

Mean Value of PV of Benefits = Rs. 179,571,166,238.

Base Case Value of BC Ratio = 3.59

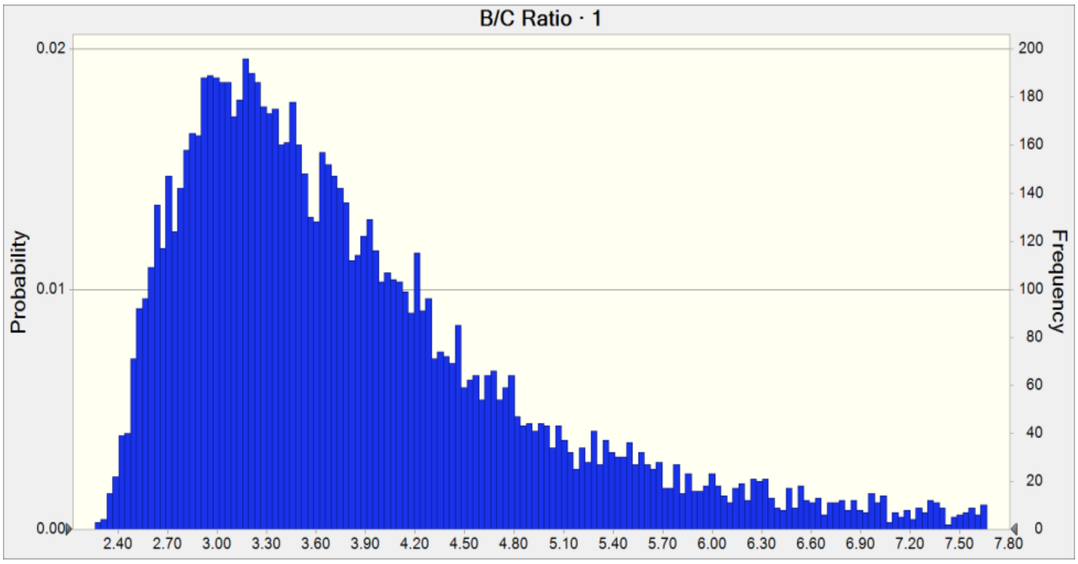

Figure 4.3: CB Forecast Chart for Benefit Cost Ratio

Forecast report shows with 100% certainty that the BC ratio lies in the range of 2.4 to 7.6. This basically suggests that our project would have the least BC ratio of 2.4 in extremely unfavorable conditions whereas the project will have benefit cost ratio of 7.6 in extremely favorable conditions. Even in unfavorable circumstances, project is having benefit cost ratio of 2.4 which suggests that net present value of benefits is 2.4 times that of costs, thus making the project financially and economically viable.

Break Even Analysis:

We know that,

Break Even Point = Fixed Cost / (Revenue per unit – Variable cost per unit)

Now,

Mean Value of Fixed Cost = Rs. 2,021,600,000.

Mean Value of Revenue Per unit = Rs.598.5 + 4 * Rs. 85

= Rs. 938.5

Variable Cost is composed of four different costs i.e. Electricity Cost, Operational cost, transportation cost and storage cost.

We have,

Electricity Cost Per unit = Rs. 10455 * 10^6 / 27231870 = Rs. 384

Mean value of annual operational cost per unit = Rs. 5

Mean Value of Annual Transportation Cost Per Unit =Rs. 166

Mean Value of Storage Cost Per Unit = Rs. 185

Now,

Mean Value of Total Variable Cost per unit = Rs. 384 + Rs. 55 +Rs. 166 + Rs. 185

= Rs. 620

Thus,

Mean Value of BreakEven Quantity = 10,556,155 kg

= 10,556 tonnes of Hydrogen

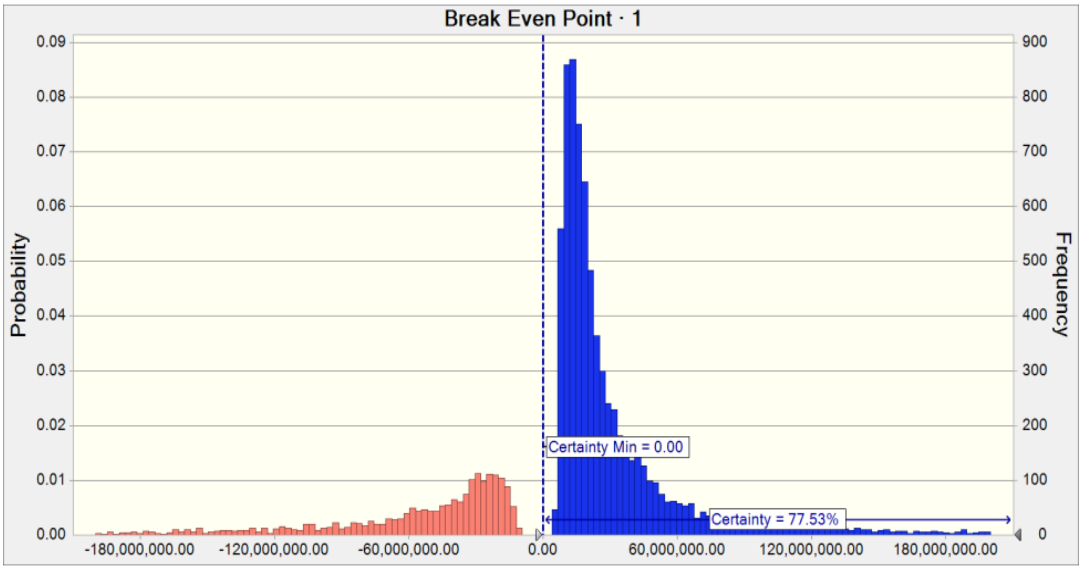

Figure 4.4: CB Forecast Chart for Breakeven Quantity

Amount of Carbon footprints reduced:

We know,

Lower heating value (LHV): 119.96 MJ/kg (i.e., 33.32 kWh/kg or 3.00 kWh/Nm^3). (www.engineeringtoolbox.com, 2003)

Amount of energy that can be generated = 33.32 * 27231870 kg

= 9.07 * 10^8 kWh

For generating 1 kWh energy by burning fuel oil, 0.28 kgs of CO_2 is produced. (www.epa.gov, 2016)

For 9.07 * 10^8 kWh energy ~ 0.28*9.07*10^8 kg of CO_2 = 2.54 *10^8 kg of CO_2

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This preliminary study suggest that we need to setup green hydrogen plant of 116 MW capacity if we are to produce hydrogen from the excess electricity that we are exporting to India. The plant will produce 27,231,870 kg of green hydrogen per year. From this preliminary study, we can see that the project would have mean benefit cost ratio of 3.59, which is significant. Green Hydrogen will result in reducing carbon footprints. For the same amount of energy produced, burning of coal and natural gas would have produced about 2,54,000,000 kg of carbon dioxide which the green hydrogen technology will eliminate.

Green Hydrogen also supports integration of renewable energy. The off grid solar and wind plants can be mounted alongside green hydrogen plant to use the electricity generated from them during their peak time. This will result in the low levelized cost of electricity from solar and wind energy as batteries will not be needed to these renewable sources to store energy. Moreover, green hydrogen can be a center point for supply chain of the energy to various forms. Hydrogen can be directly used to generate energy, can be used to capture carbon dioxide, used to run hydrogen-based turbines, used as a source of fuel and many more. This will directly result in marching Nepal towards the net zero goal target set by the government.

This preliminary study suggests that we need to enter in the Green Hydrogen era. After proper analysis and inspection, we should make ourselves prepared to enter the Green Hydrogen era. The value chain of hydropower development in the nation may shift if systems are developed to generate GH for commercial use. 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.

5.2 RECOMMENDATIONS

It is recommended to use the study's preliminary findings as a starting point for more in-depth research regarding the technical and economical feasibility of developing hydrogen chain here in Nepal. The research will result in exploring every corners of possibilities and involve the government to explore the prospects of hydropower to green hydrogen production in Nepal. Recommendations for further study have been mentioned below:

- Research on the potential for future cost savings across various electrolyzer types;
- Determine the approximate amount of excess hydropower that could be available in Nepal during the wet season that can be used for electrolysis;
- Develop efficient system of storage of hydrogen for long term and focus on the method of storing the hydrogen by converting it to ammonia;
- Assessing hydrogen supply chain alternatives in relation to possible hydropower to various pathways. Viable possibilities include the implementation of hydropower plants combined with large-scale off-grid hydrogen projects.

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CHAPTER SIX: ANNEXES

ANNEX A: CHARTS

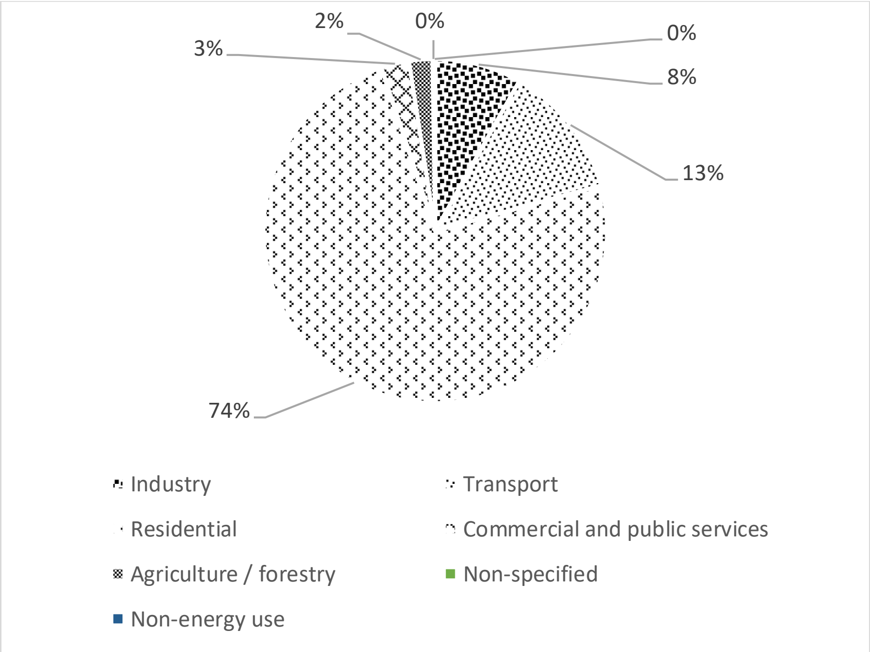

Figure 6.1: Total final consumption of energy by sector, 2021 A.D

(www.iea.org, 2021)

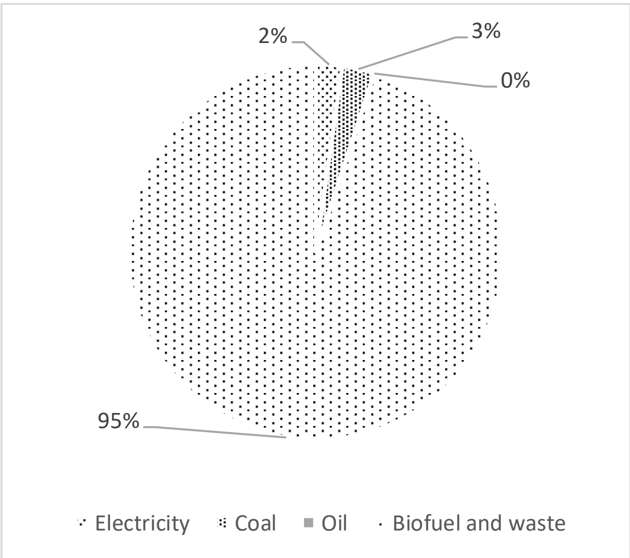

Figure 6.2: Share of total energy consumed in residential sector, 2021 A.D.

(www.iea.org, 2021)

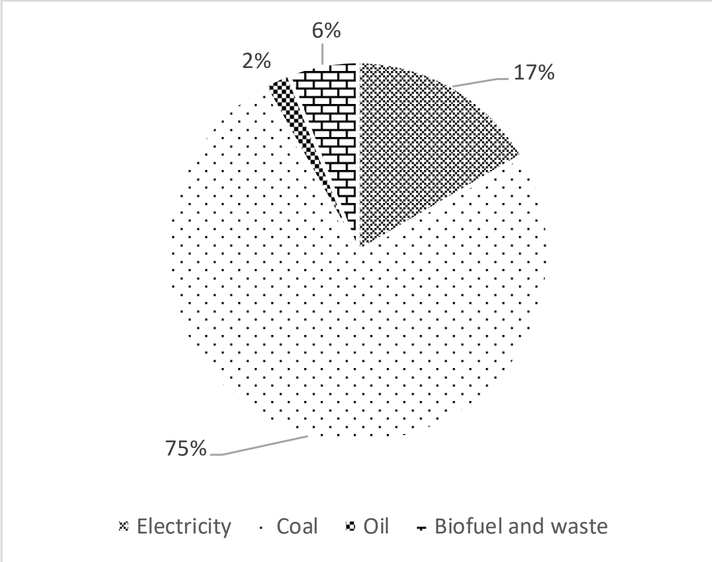

Figure 6.3: Share of total energy consumed in Industrial sector, 2021 A.D.

(www.iea.org, 2021)

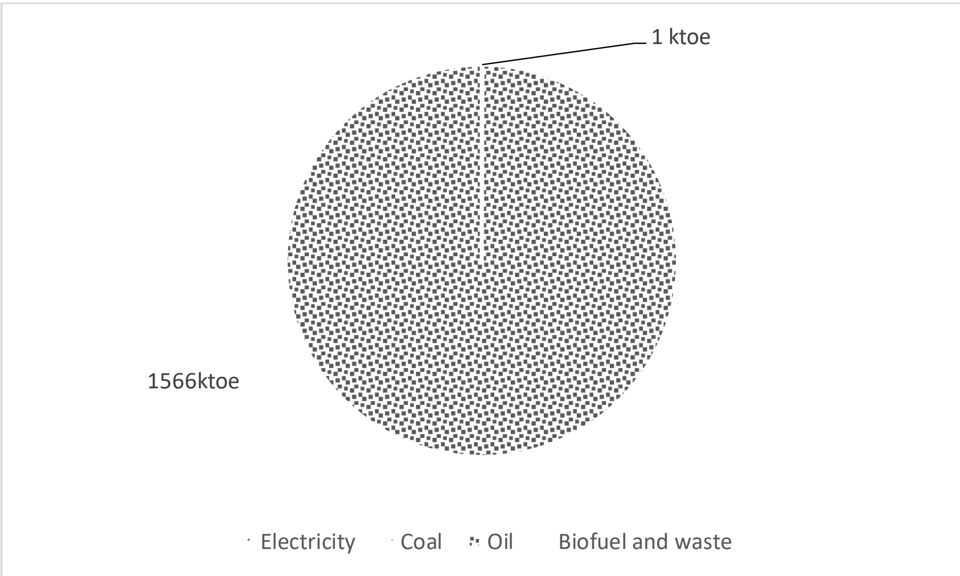

Figure 6.4: Share of total energy consumed in Transport sector, 2021 A.D.

(www.iea.org, 2021)

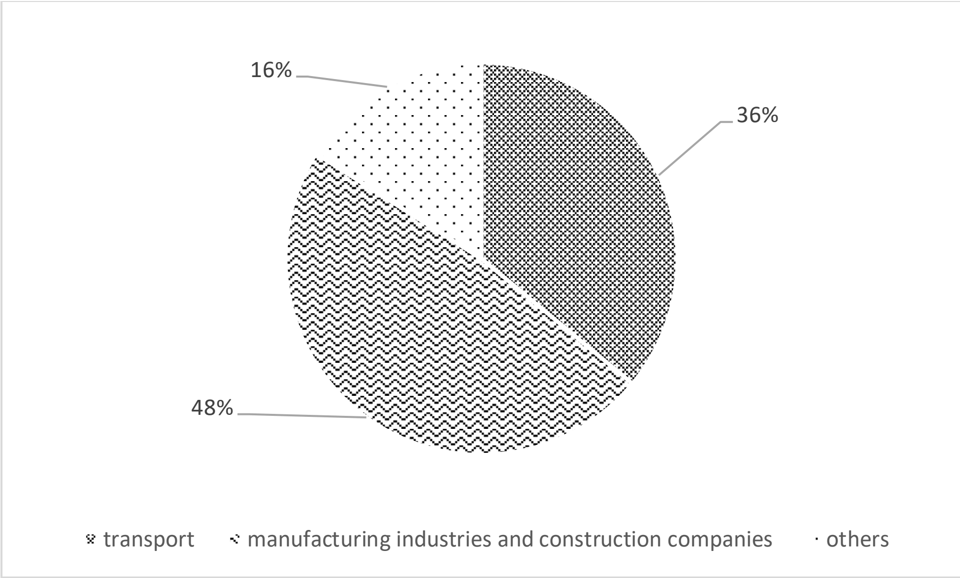

Figure 6.5: Share of Carbon dioxide emission by various end users, 2021 A.D.

(www.iea.org, 2021)

ANNEX B: CALCULATION REPORTS

Crystal Ball Report - Forecasts
Simulation started on 12/2/2023 at 8:59 PM
Simulation stopped on 12/2/2023 at 8:59 PM

Run preferences:	
Number of trials run	10,000
Monte Carlo	
Random seed	
Precision control on	
Confidence level	95.00%
Run statistics:	
Total running time (sec)	2.94
Trials/second (average)	3,397
Random numbers per sec	16,987
Crystal Ball data:	
Assumptions	5
Correlations	0
Correlation matrices	0
Decision variables	0
Forecasts	1

Forecasts

Worksheet: [BC ratio.xlsx]Sheet1

Forecast: B/C Ratio · 1

Summary:
Entire range is from 2.26 to 18.51
Base case is 3.59
After 10,000 trials, the std. error of the mean is 0.01

Statistics:	Forecast values
Trials	10,000
Base Case	3.59
Mean	3.94
Median	3.59
Mode	---
Standard Deviation	1.33
Variance	1.77
Skewness	2.44
Kurtosis	14.06
Coeff. of Variation	0.3371
Minimum	2.26
Maximum	18.51
Range Width	16.25
Mean Std. Error	0.01

Crystal Ball Report - Forecasts
Simulation started on 12/2/2023 at 10:17 PM
Simulation stopped on 12/2/2023 at 10:17 PM

Run preferences:	
Number of trials run	10,000
Monte Carlo	
Random seed	
Precision control on	
Confidence level	95.00%
Run statistics:	
Total running time (sec)	4.92
Trials/second (average)	2,033
Random numbers per sec	10,166
Crystal Ball data:	
Assumptions	5
Correlations	0
Correlation matrices	0
Decision variables	0
Forecasts	1

Forecasts

Worksheet: [Break Even Point.xlsx]Sheet1

Forecast: Break Even Point · 1 **Cell: D29**

Summary:
Certainty level is 77.53%
Certainty range is from 0.00 to ∞
Entire range is from -145,108,251,177.07 to 134,386,804,822.36
Base case is 28,694,213.08
After 10,000 trials, the std. error of the mean is 27,798,499.12

Statistics:	Forecast values
Trials	10,000
Base Case	28,694,213.08
Mean	10,556,155.36
Median	16,048,326.29
Mode	---
Standard Deviation	2,779,849,912.41
Skewness	-2.92
Kurtosis	1,771.77
Coeff. of Variation	263.34
Minimum	-145,108,251,177.07
Maximum	134,386,804,822.36
Range Width	279,495,055,999.43
Mean Std. Error	27,798,499.12

ANNEX C: QUESTIONNAIRES AND INTERVIEWS

Under primary sources of data collection, below questions were asked in interview to Er. Ranjan Chaudhary. The questions have been listed below:

1. What is the present scenario of Green Hydrogen Lab in ManMohan Polytechnic Institute?
2. Have you started the sample production in the Lab? If yes, what is the present status of the production?
3. What are the challenges that you faced from scratch of this research till date?
4. How do you justify the importance of Green Hydrogen in the context of Nepal?
5. What are the policy level changes that government should do in order to facilitate green hydrogen technology in Nepal?
6. What needs to be done to scale up the project to a larger extent?
7. What are the challenges for using Hydrogen in transport sector?
8. Do you see any challenges in exporting Hydrogen provided that we are capable of producing it in excess quantities?
9. What future do you see for Green Hydrogen in Nepal?
10. What are your feedback and suggestions to the government regarding making suitable environment to boom Green Hydrogen Market?

Economic feasilibity of Green Hydrogen technology in Nepal

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