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Assessment of The Potential Use of Hydrogen Fuel for Thermal Applications in Nepalese Industries

by

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A THESIS

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ABSTRACT

Global attention has shifted towards climate change and environmental impacts due to carbon emissions. Efforts are made to reduce emissions and attend zero carbon emissions by 2050 being in line with the Paris Agreement and implementing a green economy. Hydrogen has taken the limelight that could change the energy sector and replace fossil fuels. Nepal is expected to have surplus electricity by 2030. Green Hydrogen can be produced from surplus electricity that can be used in various energy-intensive sectors and change the source of energy into green and renewable, limiting the environmental damage. A promising approach has been taken to study the assessment of green hydrogen in the industries of Nepal. However, the energy consumption scenario is not known. Considering this, a linear study is carried out to find the energy scenario in industries, and their fuel composition, and a systematic model is created to predict the energy consumption pattern in the future using MAED with the possibility of hydrogen penetration. Numerous field data from different types of industries are taken to analyse and predict energy transition. This research works as a stepping stone towards the applicability of hydrogen in industries of Nepal utilizing the surplus electricity.

Carbon emission with and without hydrogen penetration is calculated and the hydropower capacity required is predicted in accordance to the electricity required for the hydrogen production that could replace the conventional fossil fuel in different rations in different years. The result obtained highlights the importance of hydrogen application in the industries of Nepal which could limit the import of fossil fuel, carbon emissions and energy dependency on foreign countries. The projected thermal energy demands in industries are expected to increase to 257.82 PJ, 567.49 PJ, and 1,189.41 PJ by 2050 under low, medium, and high growth scenarios respectively. The CO_2 equivalent emission will be approximately 20.91MMT, 98.47 MMT by 2050 under low and high economic growth scenario respectively. The target industries would require approximately 150.64 PJ, 351.36 PJ and 734.32 PJ by 2050 under low, medium, and high economic growth scenario respectively.

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ACRONYMS AND ABBREVIATIONS

AEPC	Alternative Energy Promotion Centre
CAGR	Compound Annual Growth Rate
CCC	Climate Change Connection
CEA	Combustion Engineering Association
CH_4	Methane
CO_2	Carbon Dioxide
GHG	Green House Gases
GON	Government of Nepal
GWh	Giga-watt hour
IEA	International Energy Agency
kWh	Kilo-watt hour
LCOH	Levelized Cost of Hydrogen
LTS	Long Term Strategy
MAC	Marginal Abatement Cost
MJ	Mega Joule
MMT	Million Metric Ton
N_2O	Nitrous Oxide
NAP	National Adaptation Plan
NDC	Nationally Determined Contribution
NESC	Nepal Energy Sector Vision
NOC	Nepal Oil Corporation

NPC	National Planning Commission
NZE	Net Zero Emission
PJ	Peta Joule
RD & D	Research Development and Demonstration
RDI	Research Development and Innovation
ROR	Run off River
SDG	Sustainable Development Goals
TJ	Terra Joule
TWh	Tera-watt hour
UNFCCC	United Nations Framework Convention on Climate Change
WECS	Water and Energy Commission Secretariat

CHAPTER ONE: INTRODUCTION

1.1 Background

With the rise in global population, the consumption of fuel for energy has increased drastically over some decades in various sectors. Conventional fossil fuel covers around 80% of the present energy demand which is a major cause of CO2 emission and GHG (Liu, Zuo, Wang, Xue, & Ren, 2021).Carbon dioxide emissions are responsible for 2/3rd of the global emissions. The energy-related global CO2 emission in 2022, is about 36.8 Gt, which is grown by 0.9% from last year (IEA, 2023). Global emission has soured at an alarming rate. Global warming has become a severe issue in the 21st century which results in several impacts such as climate change; impacts to an extent that has never been seen before in history. To mitigate this impact, several nations and organizations have brought different strategies, targets, and policies at a global level. Even in the instance of Nepal, the government of Nepal has clearly intended in its second Nationally Determined Contribution to raise the percentage of renewable energy (15%) in the entire energy mix (GON, 2020). The Government of Nepal has set a goal of achieving Net Zero Emission by 2045 and focused its activities towards sustainable development goals (GON, 2021).

Around 63.2% of the total energy consumption in Nepal is from the residential sector followed by the industrial sector which is about 18.3%. Within the industrial sector a large proportion is occupied by fossil fuels like coal, diesel, furnace oil, and petrol which is around 65% of total industrial consumption that is primarily used for thermal heat (WECS, 2021/2022). The emissions from the industrial sector alone amounted to 9.2 Gt (IEA, 2023).The industrial sector is a highly thermal intensive sector. The most convenient and cost-effective method is combustion of fuels in the system. The convenience of this method and the prominent use of fossil fuels has made this sector one of the hard-to-abate sectors. Therefore, there is an urgent need for alternative fuel to decarbonize the industrial sector whilst sustaining the energy demand.

Various research and development are carried out in the transport sector for the application of hydrogen as the future fuel whereas this may be the viable alternative fuel that can reduce the current emissions and decarbonize the industrial sector providing a clean and sustainable fuel for the future (Zhou, Zhou, & Manandhar, 2020). In the present context, hydrogen produced by an electrolysis process using renewable power is regarded as green since it emits no greenhouse gases and has a very small carbon impact. Green hydrogen fuel research and development are advancing quickly in response to the growing trend of switching to renewable energy sources.

1.2 Problem Statement

In the present scenario, to limit global warming and to shift towards renewable energy technology various countries have aimed to restrict the use of fossil fuel in coming future. With various strategies being implement, there is no way out other than the alternative fuel for fossil fuels. Nepal has very limited coal reserve which is not yet being explored and no petroleum reserves. These fossil fuels are consumed exclusively by industrial sectors like brick, lime and cement production for thermal applications like heating and boiling as well as in steel industries for processing. Import of fossil fuel is rapidly increasing which cause trade deficit and huge amount of money is being wasted. The primary consumption of coal was 746 short tons in 2019 which was an 8.23% increment from 2000. Nepal Rastra Bank reports that the country imported coal worth Rs. 27.19 billion in the fiscal year 2020-2021. At present, the monthly net loss of Nepal Oil Corporation (NOC) is NPR 3.09 billion, which is the highest loss in the history of the state's oil monopoly. The government has subsidized NRs 665 per cylinder on LPG, NRs 16.28 per liter on petrol, and NRs 11.78 liter on diesel according to NOC report 2022. Huge amount of money is wasted to subsidies the fossil fuel to bring it to accepting level in market by government. This trend goes increasing every year. There is great threat to Nepal in aspect of energy security. Thus, energy switching is must.

Nepal has more than 6000 rivers having huge potential in hydropower. Most of the hydropower present are Run-off River (ROR) type (~90%) having with low-capacity factor ~48 % due to which energy demand cannot be fulfilled during dry season whereas case of electricity surplus is seen during wet season which is spilled out due to unavailability of storage technology. According to Nepal's White Paper on Energy, issued in May 2018, the total installed hydropower generation capacity in Nepal is planned to reach 3,000 MW in 3 years, 5,000 MW in 5 years, and 15,000 MW in 10 years (MoEWRI, 2075). By 2030, almost 3000MW of hydroelectricity is projected to spill. Considering this scenario, NEA is more focused towards Storage type of hydropower. However, the economic weightage is quite high and environmental concerns related to storage has made its public acceptance to a lower level. Thus, there is extreme need of storage technology that can balance the energy supply and demand.

Utilization of surplus electricity for the production of Green Hydrogen and its utilization in the industries for the thermal application seems to be the best solution which can lower the peak load and replace fossil fuel and impacts related to it. Nepal Government has also put forward programs in its national policy and budget of 2079/80 for the first time in clause 36 and 257. Which focus on the green hydrogen for overall development of nation. NOC and Kathmandu University has also signed MOU and agreement has been made to initiate the project "Technology Transfer and Local adaptation for Developing NOC as hydrogen fuel producing and distributing company ". The levelized cost of hydrogen production (LCOH) is going down. But still the energy mix scenario in industries is unknown. Study and analysis of conversion and economic viability with proper road map can bridge the application of hydrogen on industries for thermal application in future.

1.3 Objectives

The main objective of the study is to carry out the study on green hydrogen fuel for thermal applications.

The specific objectives are as follows:

- To analyze the present scenario of the energy mix in different industrial thermal applications
- To perform the hydrogen production analysis from surplus electricity and penetration of hydrogen fuel in the industrial thermal sectors in various case scenarios
- To analyze the GHG emission by the intervention of green hydrogen-based alternative fuels in the industrial sector

1.4 Limitations

If the current energy consumption pattern persists, a significant amount of fossil fuels, primarily coal, will need to be imported in the future to meet the thermal energy demand in industries. This will have detrimental effects on the country's economy and the environment, given the substantial greenhouse gas emissions. Therefore, the introduction of alternative clean energy sources is crucial, and hydrogen stands out as the cleanest commercially available option. Presently, hydrogen use in industries in Nepal is nonexistent, but its integration must be made feasible to gain widespread adoption. This can be achieved by utilizing excess electricity generated during the wet season, which has the potential to produce significant amounts of green hydrogen.

The study includes possibilities for using hydrogen in various industries based on their thermal heat requirements. But it identifies several barriers and obstacles, such as economic viability, value recognition, and inadequate infrastructure for hydrogen production, storage, transport, and consumption. Various study has been done in Nepal theoretically likewise, this study is one of them. Some of the limitation this study has are listed below:

- A demonstrative study about the production, storage and utilization in the industrial thermal would be more realistic and helpful for the hydrogen fuel development.
- The efficiency of the different fuel for the application in boiler and furnace are taken constant which could be different in different specific plant and purpose of use.
- Whole calculation is based on the GDP and energy consumption pattern. The GDP is itself a forecast thus overall calculation is the assumption based on assumptions. The energy mix scenario is found from different year and different agency has done the study. Thus, the energy mix could have some errors.
- Assumptions are done according to NZE, which could be or couldn't be viable.
- Energy conversion is done based on the efficiency of present technology which could improve with time in future.
- Evaluating emissions involves a complex process of considering both useful energy and penetration scenarios. However, conducting this assessment through LEAP would simplify the procedure.
- Penetration of Green Hydrogen in Industries for thermal application is a limited area for the study, a broader topic would be best.

CHAPTER TWO: LITERATURE REVIEW

2.1 Energy sector overview

According to the International Energy Agency, the overall energy consumption in the world in year 2019 was 418 million TJ out of which the oil products as a fuel has the highest share whereas industry and transportation consumed highest energy (IEA, 2021a). The global energy consumption scenario by sector and source is shown in Figure 2.1. As energy consumption and emissions are related, the major emission is due to industrial and transportation sector while the coal as a fuel contributes to the highest emission. Glancing at the energy related emission, the emissions in 2021 increased by 6% and reached 36.3 billion tonnes. Coal was major contributor for the increase in emission and accounted for more than 40% of the overall growth in global CO_2 emission reaching 15.3 billion tonnes (IEA, 2021b).

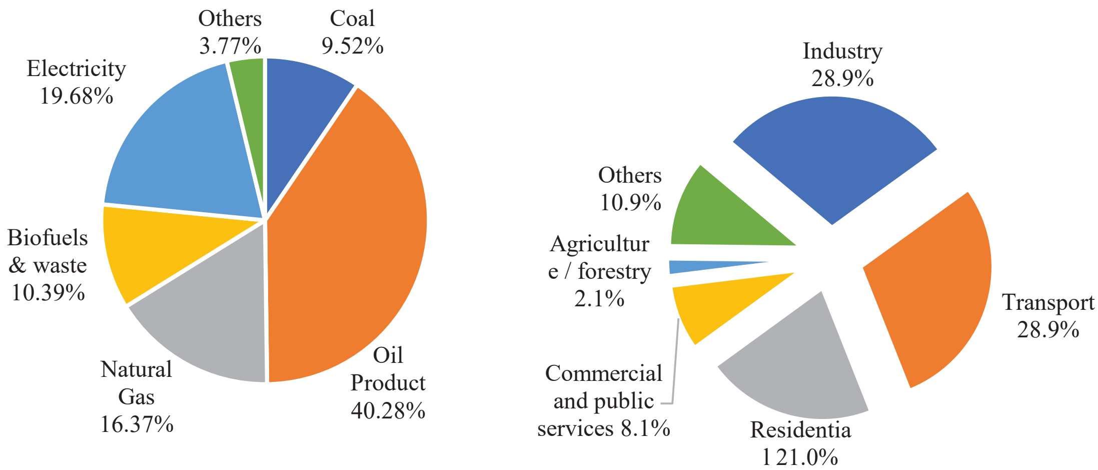

Figure 2.1 Global energy supply status (by fuels and economic sectors)

The global energy mix scenario is led by the fossil fuels. Nepal has different case as it doesn't have any gas reserves and extraction of coal hasn't started yet in considerable amount, neither the government has any aims at the establishment of nuclear power plants. However, Nepal is one of the richest countries in water resources thus, has a great potential in hydropower. In spite of that only 5 % of the total economic capacity has been harnessed (NEA, 2022). The detail energy situation of Nepal is shown below.

Energy consumption in Nepal has been steadily increasing, reaching 626 PJ in 2021 at a compound annual growth rate (CAGR) of 10.60%. Traditional fuels (Fuel wood, agricultural residue and animal waste) account for 66.26% of the nation's overall energy consumption, while commercial fuels (electricity, coal and petroleum products) account for 31.34% and renewable fuels (Biogas, solar, wind and off grid micro and mini hydro) only make up 2.40% of the country's energy mix. From the Figure 2.2 (IEA, 2022), it is seen that the share of hydropower still low and is increasing in the lower rate.

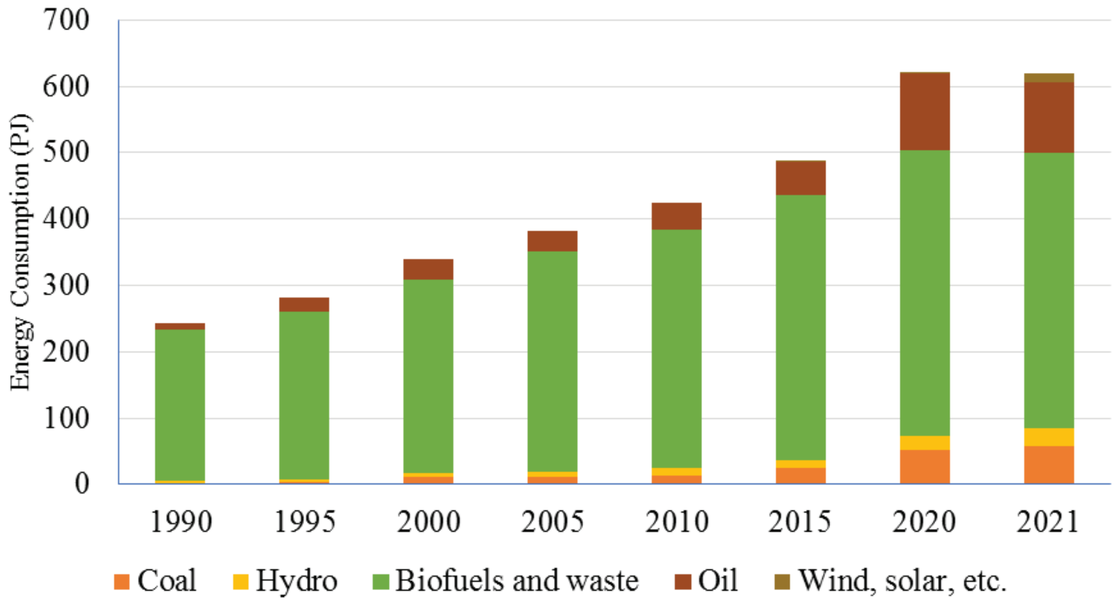

Figure 2.2 Energy Consumption by fuel type (1990-2021)

Looking at the different economic sectors, we can see that the residential sector uses 63.2% of all the energy, followed by the industrial sector at 18.3% (WECS, 2021/2022). Because of their frequently use in boilers and furnaces, traditional fuels, particularly biomass, dung cake, and agricultural waste, are widely used in the industrial sector. As a result, 84.87% and 52.48% of the energy used in boilers and furnaces in the industrial sector is now provided by conventional fuels such biomass, dung cake, and agricultural residue.

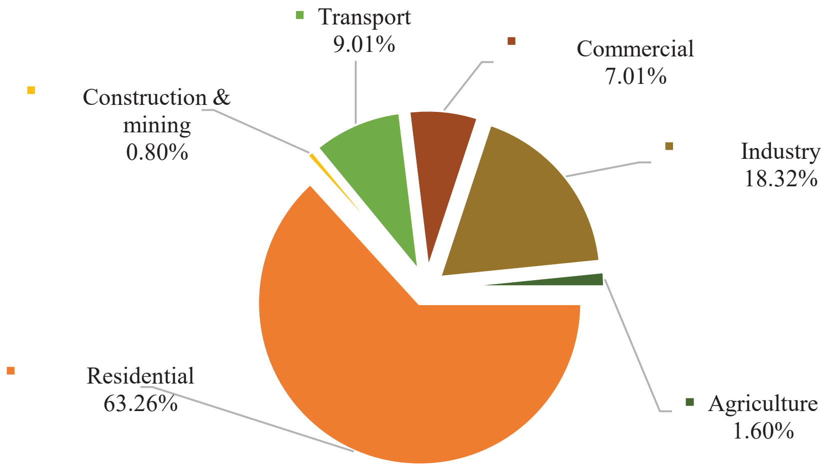

Figure 2.3 Energy Consumption by Economic sectors

Out of the total industries 3,280 manufacturing related industries were registered by the fiscal year 2022 (DOI, 2079/80). Figure 2.4 illustrates the percentage of manufacturing industries by category type in 2022. The industries based on textiles, ready-made clothing, and leather items are the most registered which accounts for more than 30%, followed by those based on food, beverages, and tobacco products which account for about 24%. Chemical and Cement, brick, concrete, and clay product-based businesses are the industries that are registered 3rd and 4th.

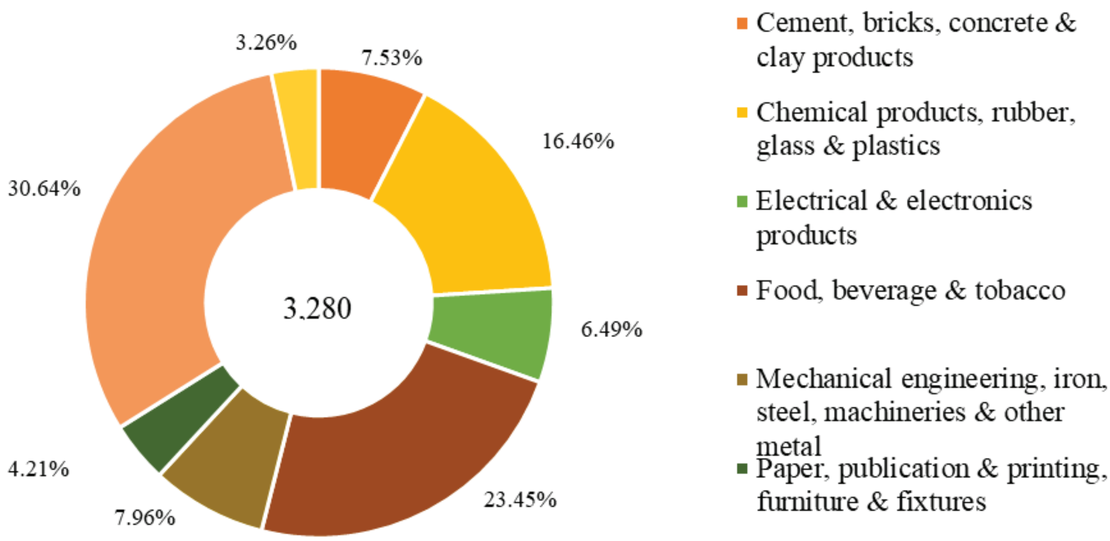

Figure 2.4 Industries in Nepal by category type (2022)

The majority of industries are located in the Bagmati province with 1,718 registered industries where most of the industries are textile, followed by Madhesh where 518 industries were registered with food and beverage being the most common type and Lumbini has third highest with 474 registered industries. The most common type of industries registered are food, beverages, and tobacco in 6 provinces excluding Karnali followed by chemical products.

When examining individual provinces, Bagmati province has the highest number of industries centered around cement, bricks, concrete, and clay products (91), followed by Lumbini (73), Koshi, and Madhesh. On the other hand, Karnali province only hosts eight industries, with three focused on cement, bricks, concrete, and clay products.

The manufacturing industries collectively utilize approximately 92.90 petajoules (PJ) of thermal energy. The distribution of thermal energy sources within the industrial sector is depicted in Figure 2.5. The predominant source of thermal energy for industrial processes is coal, accounting for 31.61 PJ, followed by fuelwood at 18.26 PJ. Agriculture residue is the third most utilized fuel, with furnace oil contributing around 16.14 PJ. Interestingly, there is no recorded usage of briquettes in industries, and the consumption of liquefied petroleum gas (LPG) and petrol remains negligible, both accounting for less than 1%. Conversely, electricity consumption within the sector amounts to approximately 2.66 PJ which is around 3% of energy mix for thermal in industries.

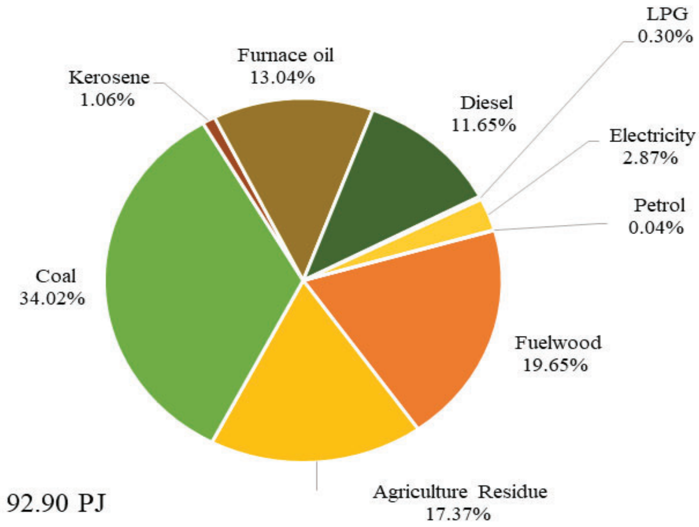

Figure 2.5 Thermal energy mix scenario in manufacturing industries in 2022

Hence, the manufacturing sectors heavily depend on fossil fuels and conventional energy sources, which are responsible for emitting significant amounts of greenhouse gases (GHGs). Notably, electricity which is cleaner option among these energy sources, holds a relatively small portion, indicating that the current industrial practices have a substantial carbon footprint due to their substantial demand for high levels of thermal energy.

2.2 Hydrogen Fundamentals

Hydrogen is the first element on the periodic table exceptionally in Group 1 beside not being metal having the atomic mass of 1.008 atomic mass units. It is one of the most abundant chemical substances in the universe, being in around 90% in all existing atoms. It can be used as an energy carrier as it has the highest energy density i.e., 140 MJ/kg which is more than three times the energy density of other fossil fuels such as petrol, diesel and kerosene (Gorina & Lebedev, 2021). Natural gas, nuclear power, biomass, and renewable power like solar and wind can be used to produce such gas using various methods of production. The hydrogen produced can be stored by pressurization and liquefaction which can be later used for various end use purpose. It can be directly combusted or used as reducing agent in chemical processes emitting very little or no emission in the atmosphere. Moreover, it can be used for various sectors like transport, industries or to produce electricity using fuel cells. Due to its versatility in both production and end use with low to zero emission, hydrogen is an attractive fuel with promising future.

Hydrogen are color coded into various types based on its carbon footprint i.e., the production methods and resource used termed as hydrogen rainbow. Among the rainbow grey, blue and green are most commonly used hydrogen types. Production or extraction of hydrogen by the utilization of natural gas or coal by steam reforming process is termed as grey hydrogen. This is the process where carbon release during production is maximum. If the carbon released are captured and stored to cease carbon emission to atmosphere are termed as blue hydrogen. Whereas the hydrogen produced by the water splitting process through electrolysis using renewable source of energy such as hydropower, wind or solar are termed as green hydrogen. It is one of the cleanest forms of energy which yields only oxygen in its overall production and end use process.

However, the current global trend of hydrogen is still emission intensive. About 94 Mt of hydrogen was produced in the year 2021 which was 5% higher to the previous year (IEA, 2022). About 4 % of hydrogen was produced by water splitting process through electrolysis and remaining 96% was produced with natural gas and fossil fuels. Moreover, the share of renewable energy used for the electrolysis is only 33% making the share of green hydrogen to only 1% (IRENA, 2022).

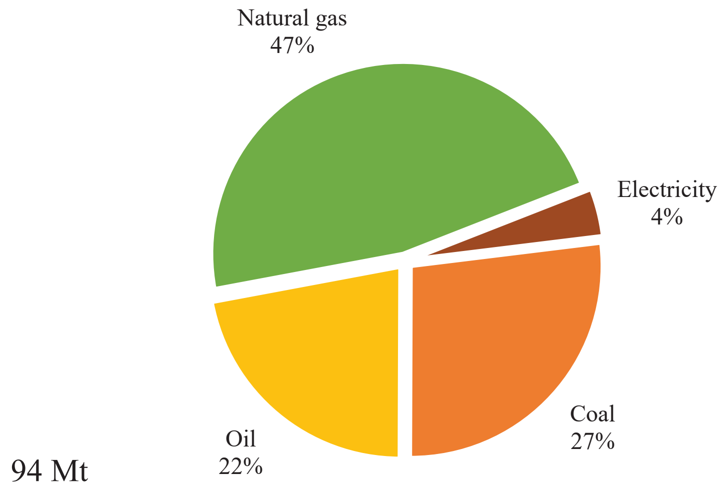

Figure 2.6 Source of energy for global Hydrogen production in 2021

Global leading countries are trying to switch to green hydrogen from grey by utilization of renewable sources for the clean energy. To achieve net-zero emissions from heavy industry and transport green hydrogen has emerged as a key element. The green hydrogen has started gaining momentum with the net-zero commitments by growing numbers of governments because of low-cost renewable electricity, ongoing technological improvements and the benefits of greater power-system flexibility. Green hydrogen can be produced sustainably and cost-effectively in Nepal because of its ample potential in renewable resources like hydropower and solar. Green Hydrogen can be used to replace fossil fuels into renewable energy sources to decarbonize the high heat energy applications in the industrial and transportation sectors. The cost for hydrogen production from a scaled-up industry could be $2/kg and $1/kg in 2030 and 2050 respectively in various part of world (Bloombergy New energy Finance, 2020). India has proposed a plan to produce hydrogen by 1$/kg by the end of 1 decade. Hydrogen can be produced in Nepal at much cheaper rate and has a competitive advantage over other nations as excess hydro energy is at the risk of being spilled, can be utilized for production of green hydrogen thus reducing the energy cost. The excess electricity if provided at a discounted rate, the production cost for 1 kg of hydrogen would come down significantly to US$ 1.17- US$ 2.55 for different time-of-day tariff rates (Thapa, Neupane, Yang, & Lee, 2021) . The peak time load can be decreased by the intervention of green hydrogen and assisting in flattening of the load curve by acting as an energy storage from hydroelectricity during the excess production and utilizing that energy at the time of peak load and low generation.

2.3 Hydrogen Production possibility in Nepal

The technical feasible hydropower capacity of Nepal is 72.54 GW, whereas the techno-economic capacity of Nepal is about 32.68 GW (WECS, 2019) out of which only about 2,082 MW of hydropower is harnessed which is only around 5% (NEA, 2022). Electricity production from hydropower is gaining a lot of paces over some years. Solar is also growing in various parts of Nepal. Thus, a great amount of electricity is produced inside a country thus making country self-dependent on energy. In addition, Nepal is exporting electricity to Nepal during wet season. With a current rate of electricity generation and consumption, it is forecasted that there will be electricity surge in near future. Thus, Nepal has enormous hydrogen production possibility using the electricity.

Hydrogen holds a crucial role in the future energy scenario. The cleanliness of green hydrogen, spanning its entire production-to-consumption cycle, makes it an ideal option. The surplus electricity can be efficiently utilized to generate green hydrogen, which can then be employed in industries for thermal applications. The international levelized cost of green hydrogen is estimated to be $4 to $6 which primarily depends on electricity costs (IEA, 2022). The cost-effective production of green hydrogen by with the utilization of Nepal's abundant hydroelectric resources can be the key elements to decarbonize industries and transport.

According to the recent study, utilizing 20% to 100% of surplus electricity could yield hydrogen ranging from 63,072 tons to 3,153,360 tons by 2030 which can replace current fossil fuel consumption (Biraj Singh Thapa, 2021). Which in deed can drive Nepal towards a path of decarbonization. Another study suggests a levelized cost of hydrogen production in Nepal ranging from 3.8€/kg to 4.5€/kg (Bhandari & Subedhi, 2023). Government intervention, particularly in reducing electricity tariff rates for hydrogen production, could further diminish the levelized cost of hydrogen (LCOH) which could make the industrial applications economically feasible.

2.4 Hydrogen Value chain

Value chain is the series of consecutive step that a product goes where its value gets added. It is sequential process from production, processing, storage, distribution and finally to the end use application. For the hydrogen to be used in industries a hydrogen value chain needs to properly understood. The hydrogen value chain offers Nepal's industries a possibility to undergo decarbonization, leading the path towards a more environmentally friendly and sustainable future.

Nepal can leverage its renewable energy potential, decrease carbon emissions, and improve its global industrial competitiveness by implementing a well-coordinated series of steps including hydrogen production and utilization. The generalized hydrogen value chain is as shown in Figure 2.6 (Subedi & Thapa, 2023).

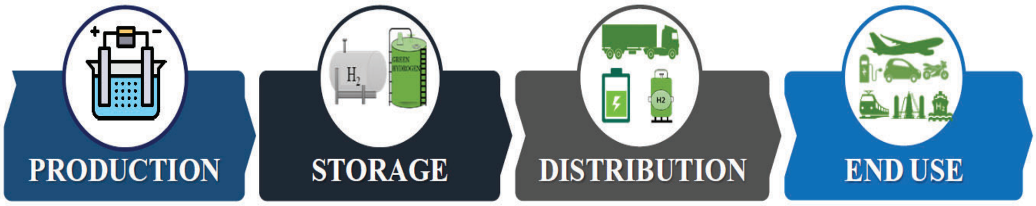

Figure 2.6 Hydrogen Value Chain

The path for emission reduction by the hydrogen utilization in Nepal is described below.

- **Electricity Generation and transmission:**

  The process starts with Nepal's enormous hydropower potential producing electricity. Nepal's commitment to sustainable energy production is aided by hydropower plants, which use the energy of flowing water to generate clean, renewable electricity.

  The generated electricity is distributed smoothly and reliably throughout the nation by the strong, wide spread and effective transmission lines. Building a strong infrastructure for the transmission of energy is essential to provide power to the hydrogen value chain.

- **Water electrolysis and hydrogen conditioning:**

  The electricity is feed to the electrolyser where the water (H_2O) is split into hydrogen gas (H_2) and oxygen gas (O_2) at the anode and cathode respectively in the process called electrolysis. Around 9 liters of water and 50kilowatt-hour (kWh) of electricity is needed to ensure the production of 1Kg of hydrogen (European Patent Office, 2022).

  To improve its storage and transportation properties, the generated hydrogen is further compressed and liquefied. This guarantees that significant amounts of hydrogen can be effectively stored and transported to various sites or sectors as needed. The oxygen produced as a byproduct of electrolysis is also used in a variety of ways, which increases the total advantages of the hydrogen manufacturing process.

- **Storage and Transportation:**

  After being compressed and liquefied, the liquid hydrogen is either delivered to the intended businesses using pipe lines or kept in specialized storage facilities. Considering hydrogen's special characteristics as a cryogenic and combustible gas, several safety precautions are used when handling and transporting the gas.

- **Utilization in industries for thermal heat:**

  Utilizing hydrogen in industries for thermal heat applications is one of the last phases of the hydrogen value chain. Hydrogen is a feasible replace for conventional fossil fuels in high-temperature industries like chemical production, steel, and cement. Hydrogen application can lower their carbon emissions in the process, while supporting Nepal's larger initiatives to fight climate change and meet sustainability targets.

  Hydrogen value chain uses Nepal's renewable energy resources to produce clean hydrogen for high-temperature industrial processes, thereby demonstrating a comprehensive approach to industry emission reduction. Hydropower and hydrogen technologies combined offer Nepal a strong chance to shift its industrial sector to one that is low-carbon and conscious of the environment. To fully realize the potential of hydrogen as a clean and sustainable energy carrier in Nepal, strong collaboration between the government, private sector, and research institutions is needed, in addition to supportive policies and investments.

2.5 Thermal heat from Hydrogen

The industrial sector requires high thermal heat for various applications which cannot be provided by the electricity. For high thermal heat demand, hydrogen has the potential to power the industrial sectors being the clean fuel with low to no emission. Depending on the temperature, industrial heats are classified into three grades: low grade, which is below 1000^0C, medium grade, which is between 1000^0C and 4000^0C, and high grade, which is over 4000^0C. High-grade heat at around $2{,}045^0$C can be produced by the combustion in the air (Helmenstine & Marie, 2019). Around 95% of high-temperature heat are produced by fossil fuels and combustible by-products (IEA, 2019). Electrical heating has advantages such as precise temperature control and lower maintenance costs, its application requires major capital expenditure and industrial equipment makeover. Hydrogen can be used which requires minimum redesign over existing infrastructure.

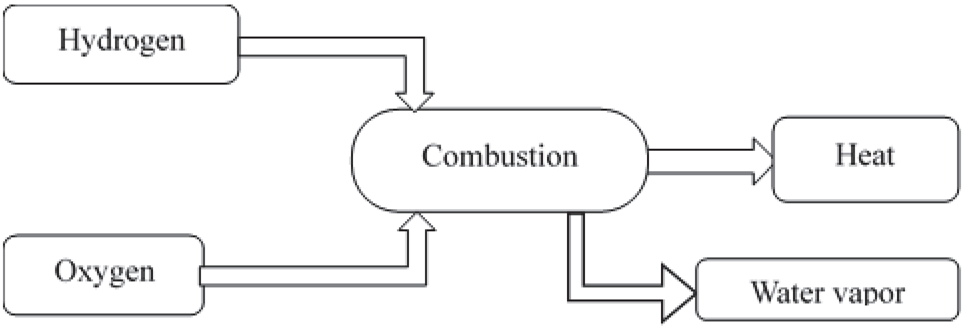

Figure 2.7 Combustion of hydrogen for thermal purposes

There are various challenges to using hydrogen for high-temperature heat. The color of hydrogen flame is pale blue which is almost invisible to the naked eye. The high flame temperature produced during burning of hydrogen does cause the generation of NO_x. The flame velocity and combustion temperature are different to commercial fuel which makes the remodeling of present furnaces mandatory. Controlling of the hydrogen flame in the combustion chamber is very difficult than the commercial fuels due to very low density of Hydrogen. Replacing natural gas with hydrogen, may cause reduction of as much as about 11% in flue gas flow which affects the radiation flux.

2.6 Industrial Emission

Three greenhouse gases (GHGs) taken into account are methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2). N_2O emission equivalent for 1 kg is around 298 kg of CO_2 into the atmosphere, whereas CH_4 equivalent for 1kg is 84 kg of CO_2 (CCC, 2020). Approximately 7.4 million metric tons (MMT) of CO_2 equivalent is estimated in the reference year. These emissions are distributed across various industrial categories, as illustrated in Figure 2.8. The most significant contributor to these emissions is the cement, brick, concrete, and clay products sector, primarily due to its high thermal energy consumption. These industries primarily rely on coal as their main fuel source. Consequently, there is an urgent need to transition from coal to cleaner energy alternatives like electricity and green hydrogen, as indicated by the emission levels in the reference year. The next highest emission-intensive industries include those involved in food, beverage, and tobacco products, followed by mechanical engineering, iron, steel, machinery, other metal-based sectors, as well as chemical products, rubber, glass, and plastics-based industries. The electrical and electronics products-based industries are environmentally friendly, generating no emissions. On the other hand, the remaining industries all contribute varying amounts of GHG emissions.

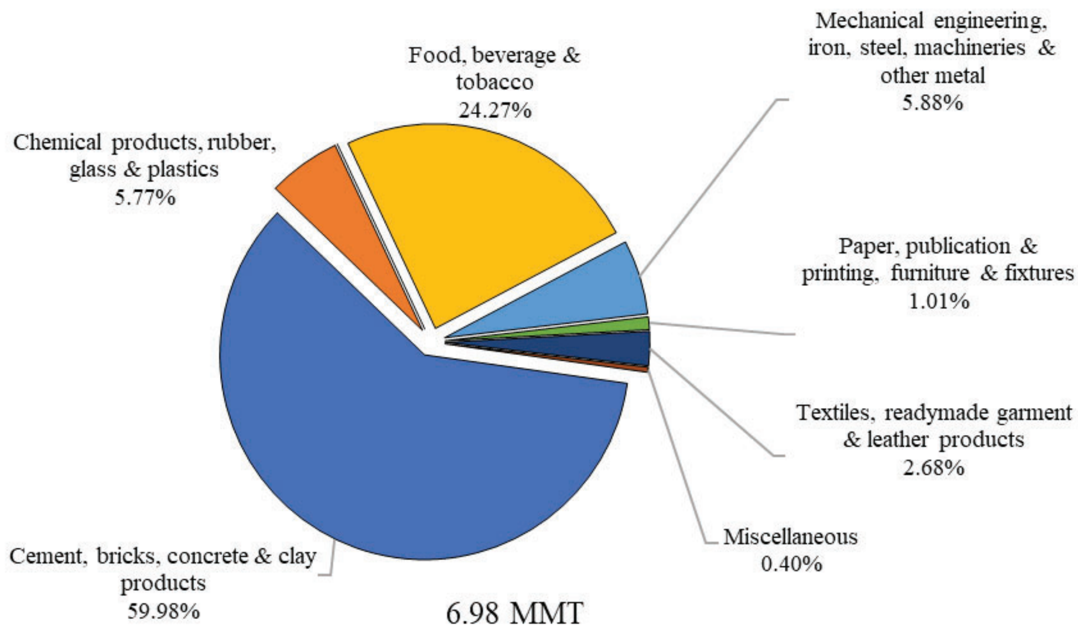

Figure 2.8 Emission mix status by different industrial types (CO_{2eq})

The emission by industries is calculated by multiplying the energy mix scenario with the emission factor of corresponding fuel which is shown in Table 2.1 (MoST, 2014). The most emitted GHG is Carbon dioxide, which is largely produced by cement, bricks, concrete & clay products-based industries, followed by food, beverage & tobacco industries.

Table 2.1 Emission factor of different fuel

Category	N_2O	CO_2	CH_4	CO_2 equivalent
Fuelwood	4	112000	30	115712
Agriculture Residue	4		30	3712
Coal	1.5	92600	10	93887
Kerosene	0.6	71900	3	72331
Furnace oil/fuel oil	0.6	77400	3	77831
Diesel/ HS Diesel or L diesel	0.6	74100	3	74531
LPG/ from residential	0.1	63100	1	63214
Electricity				0
Petrol/ Other petroleum	0.6		3	431
Briquette	4	112000	200	129992

2.7 Fifteenth Plan

Nepal Planning Commission has formulated the 15^{th} plan after the implementation of 14 prior plans. The Plan defines various plan strategies and goals that the government has undertaken in various sector for the prosperity and happiness. The fifteenth plan has aimed to take Nepal to middle income country by 2030 along with advanced country by 2043 AD. It has formulated long-term vision to realizing the goal of "Prosperous Nepal, Happy Nepali", which is a 25-year long term vision. The government will construct various plans, policies and programs to achieve the economic, social and physical infrastructure targets. For the all-round development, the sustainable development goals are localized and internalized to federal, provincial and local level. The targets projections and estimation which are listed here are more likely to be achieved in the future as the government itself sets them in a practical and feasible way. The target that has been taken in per capita electricity consumption and electricity generation is given in Table 2.2. (NPC, 2020)

Table 2.2 Electricity consumption and generation target

Year	Per capita electricity consumption (kWh)	Installed capacity for electricity generation (MW)
2019	245	1250
2024	700	5820
2030	1500	15000
2044	3500	35000

CHAPTER THREE: METHODOLOGY

This research provides the study of hydrogen fuel for thermal application in industries of Nepal. The research consists of the three main objectives for which a systematic approach is followed throughout the process. In the first place, the present energy mix scenarios for the thermal process in the industries of Nepal is calculated. Afterwards, using the present energy mix scenarios, the energy is forecasted up to 2050. The entire process flows in a systematic way from beginning to the end. Thus, the methods and procedures that was used to produce the desired objectives can be show in the framework.

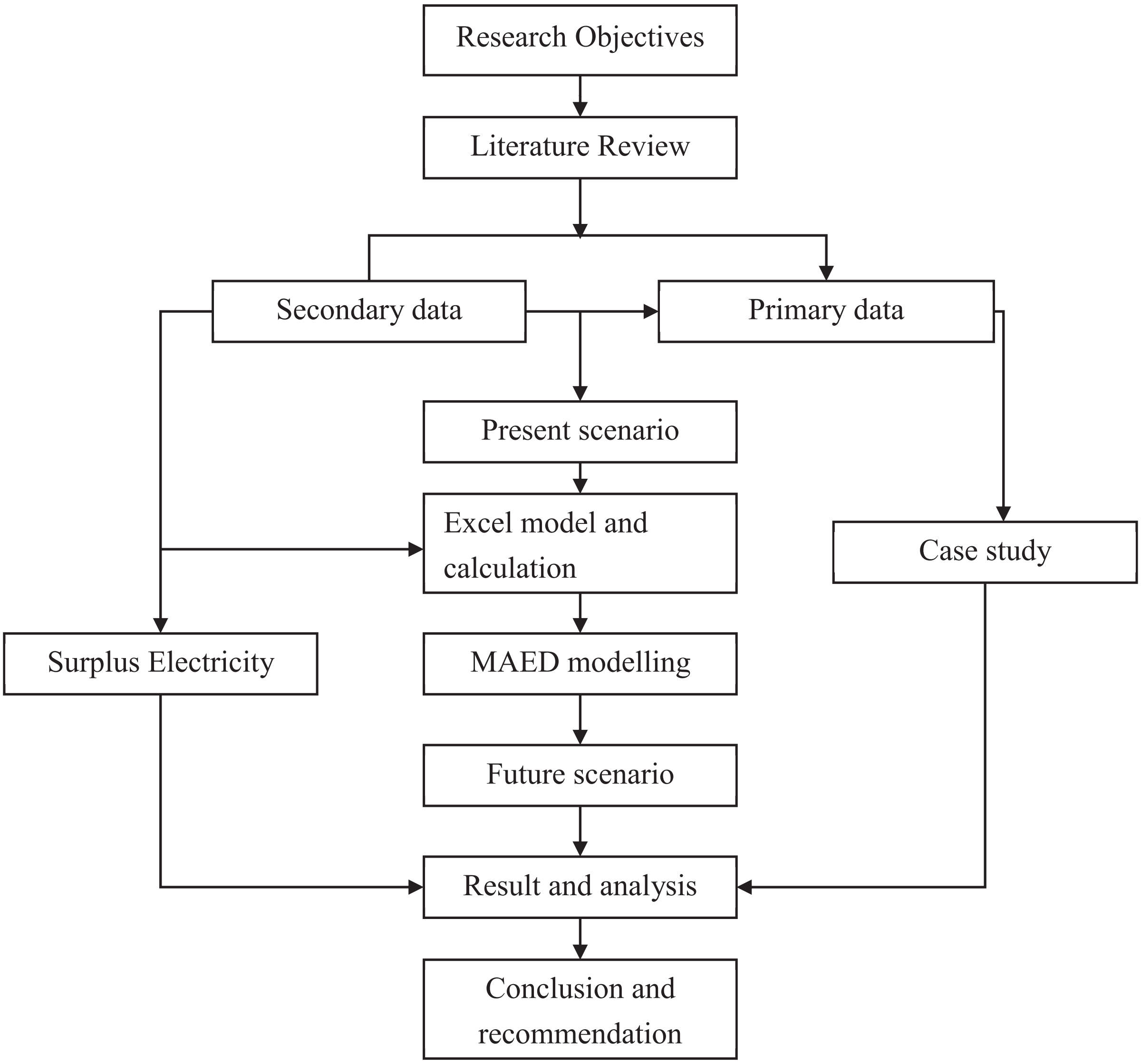

Figure 3.1 Framework Of methodology

3.1 Literature review and desk study

Literature review and desk study is the starting point and acts as the baseline to gather information and knowledge regarding the situation, regulations, plan and policies etc. regarding the emission, technology and fuels. The review of various plans, policies, regulations and guidelines related to penetration of alternative fuels including hydrogen fuel was required.

3.2 Primary data

For the collection of the primary data, several industries were visited of different categories such as cement, chemical, food and processing, paper etc. The list of industries that were visited are listed below in the Table 3.1.

Table 3.1 Roster of visited industries

Categorizations	Name of industry
Food, beverages, and tobacco	• Shree Nawa Prabhat Dairy Pvt. Ltd, Patan • Pokhara Noodles Pvt. Ltd, Kaski
Wood and paper products	• Paana Paper Works, Birgunj
Cement, Bricks and Clay products	• Hetauda Cement Factory, Makawanpur • Harati Mata Itta Udhyog, Lalitpur
Chemical products, rubber, glass & plastics	• Supreme Industries, Patan
Textiles, apparels and leather products	• Aarnica Processing Industries Pvt. Ltd, Birgunj
Steel and metal	• Himal Iron and Steel Industries Pvt. Ltd, Birgunj

A questionnaire was prepared beforehand and the response of the related person of the corresponding industry was noted. Questionnaire include different socioeconomic information of the respondent and firm along with the current pattern of energy use and their willingness to shift to green hydrogen-based fuels in different industries. The questionnaire developed was pretested and any further modifications were made. The contents in questionnaire are presented in Figure 3.2.

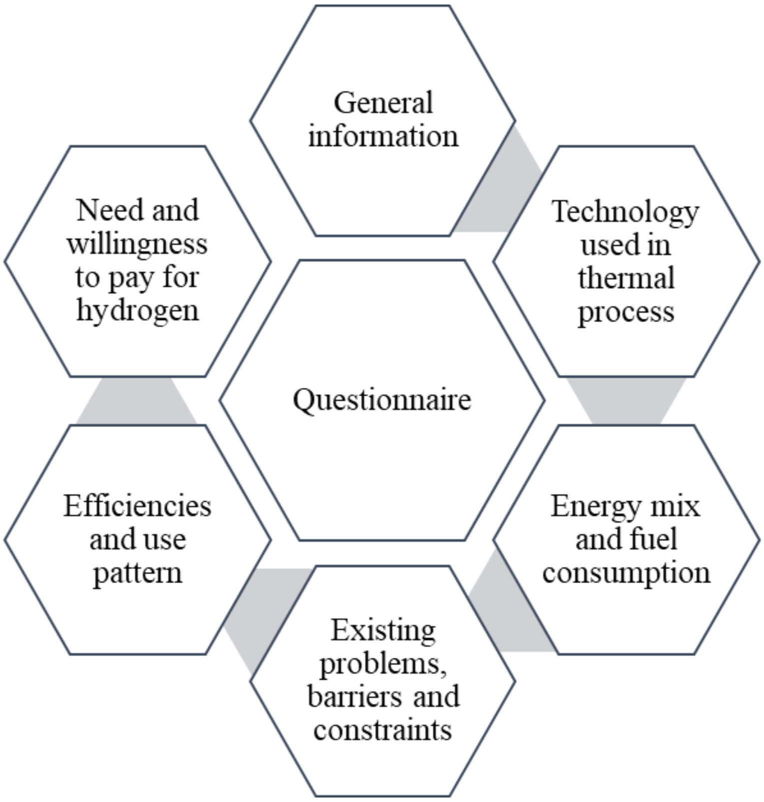

Figure 3.2 Content in questionnaire

3.3 Secondary data

The secondary data were taken from different official sites and reports. The energy mix scenario is taken from the different regional reports published by Water and Energy Commission Secretariat. The data related to population and statics are taken from the official site of Central Bureau of Statics of Nepal. The energy related data are taken from different reports of International Energy Agency (IEA). Various international policies and strategies are reviewed for the formulation of roadmap and strategies for their implementation. National and international journals are taken in consideration about the hydrogen technology, its economic aspects and its applicability.

3.4 Modelling

Scenario development is a crucial step in forecasting energy demand and analyzing different models. It is the basic prerequisite for the formulation of integrated energy policy, preparing the plan and defining the activities for implementation. Scenario based planning is a planning technique introduced in 1970 and is used for projection and forecasting of the energy use in different economic sectors. The scenario-based projection while does not indicate the exact pattern for the energy use, it gives an approximation to energy use pattern thus assisting the policy makers and planners to develop the plans and policies for sustainable and low emission development. The scenario-based projection conducted in this study is based on the economic and demographic parameters as the driving factors. Since the growth in industrial sector is directly dependent on the population growth and gross value added, these parameters are considered as the driving factors for the energy projection.

In this study three scenarios namely, (i) Low economic growth (ii) Medium economic growth (iii) High economic growth have been considered. The growth rate for the scenarios has been based on the various reports and documents published by the government of Nepal (WECS, 2023). The GDP growth rate for different years considered in these scenarios is shown in Table 3.2.

Table 3.2 GDP growth rates considered for three scenarios at different years

Scenario /Year	2022	2023-25	2026-30	2031-35	2036-40	2041-45	2046-50
Low	2.7%	4.5%	5.0%	5.0%	5.0%	5.0%	5.0%
Medium	3.1%	7.0%	7.5%	8%	8.5%	8.3%	8.0%
High	7.5%	9.5%	10.0%	12.0%	11.5%	11.0%	10.5%

The modelling is done by using the Model for Analysis of Energy Demand (MAED-2) which is generated by the International Atomic energy Agency (IAEA) in 2005. For the model, 2022 is considered as the base year. A model is constructed up to 2050 with the five-year gap starting at 2025. The population growth rate considered in this study is based on the current population growth rate of Nepal and follows the similar pattern of projected growth rates as published by the United Nation Department of Economic and Social Affairs (UNDESA) (UN, 2022). Similarly, the growth in gross value added

(GVA) for different scenarios have been considered based on several national studies of Nepal such as the Long-term strategy for Net Zero Emissions, Sustainable Development Goals, 15th Periodic Plan, and Energy Sector Vision 2050 etc.

The total thermal energy is converted to useful thermal energy by multiplying with the conversion efficiencies of fuel during their use in boiler and furnace. The table provides the conversion efficiencies (WECS, 2021).

Table 3.3 Efficiency of different fuel in boiler and process heat

Efficiency	Fuelwood	Agriculture	Coal	Kerosene	Furnace oil	Diesel	LPG	Electricity	Petrol	Briquette
Boiler	0.7	0.7	0.85	0.8	0.8	0.8	0.75	1	0.8	0.85
Process heat	0.35	0.35	0.35	0.35	0.35	0.35	0.35	1	0.35	0.35

Along with the useful energy, GDP per sector is forecasted up to 2050 by using the previous data of 1996, 2006 and 2011. The energy intensity i.e., kWh/NRs is calculated for the base year and assumed that the intensity remains constant for coming year. Share of useful thermal energy in furnace and boiler in various manufacturing industries is also kept constant. The efficiency and share of fuel are categorized into 4 basic group as traditional, fossil fuel, electricity and modern fuel.

The final energy (TJ) of fuel type from the model is calculated for the defined period into the 4 categorized. By using the share of penetration that was used earlier, the individual fuel is estimated. For calculating the final energy according to end use, the total useful energy is given from MAED in two categories i.e., steam(boiler) and furnace by using the penetration of boiler/furnace in each fuel categories and multiplying by the efficiency from the base year we obtain the final energy in each fuel category in each sector i.e., boiler/ furnace. Finally, the sum of each category gives the final energy in each end use type.

For calculating the emission in various year with or without hydrogen. The estimated fuel in the given year is multiplied with the emission factor given in the Table 2.1 (MoST, 2014). Targets have been set that the hydrogen shall replace 20% of fuels (excluding electricity) by 2030 and 95% by 2050 in cement and chemical industries.

Only after 2025, hydrogen penetration starts at large scale, therefore, in up to 2025, there is no industrial application of hydrogen. For calculation related to hydrogen, the efficiency of hydrogen in boiler is used 95% whereas its value decreases drastically to 37% in furnace (Power Engineering, 2022). The amount of hydrogen is calculated by dividing the total useful energy by the hydrogen energy available. The amount of electricity is calculated based on the data that 50 MWh of electricity is required to produce 1 tonne of hydrogen (Ale B.B, 2009). Furthermore, the plant capacity is calculated based on the amount of electricity needed and plant factor 64.56 % (NEA, 2022).

3.5 Hydrogen production potential from surplus electricity

This study estimates the electricity surplus by calculating the electricity generation and demand at different years considering 2022 as the base year. The surplus electricity is utilized to estimate hydrogen production in different scenarios.
Electricity generation potential is calculated based on the fifteenth plan set by the National Planning Commission by considering 2022 AD as the base year up to 2050 AD. The total electricity generation in GWh is calculated by multiplying the installed capacity by the overall plant factor. The electricity demand is calculated by multiplying per capita electricity consumption with the forecasted population. The population growth rate considered is based on the current population growth rate of Nepal and follows a similar pattern of projected growth rates as published by the United Nation Department of Economic and Social Affairs (UNDESA).

Surplus electricity is remaining electricity that is assumed to exist after fulfilling the electricity demand of the entire nation which if not exported to foreign countries could be used for hydrogen production at cheaper rates. Surplus electricity is calculated from the demand and generation of electricity in the respective year.

The hydrogen production potential is based on the expected surplus electricity that could be used for the production of hydrogen. The energy required for the unit kg of hydrogen production is considered constant and the electricity required for the electrolyser is taken 50.067 kWh. Different five scenarios namely 1,2,3,4 and 5 are considered where different share of surplus electricity is considered to be used for the production of hydrogen. In Scenario 1, 20% of surplus electricity is used for hydrogen production while in Scenario 2, 40% of surplus electricity is used for hydrogen production. Likewise, Scenarios 3,4, and 5 are created which use 60%, 80%, and 100% of surplus electricity respectively.

CHAPTER FOUR: RESULTS AND DISCUSSION

Systematic approach has been followed for finding the results. The literature review is considered as the base line for the study; and the study is followed by questionnaire development. Field visit was conducted by presenting the questionnaire with the respondent, who were the representative of the concerned industry. In the other hand, data from provincial energy mix scenario was taken to construct the model of thermal energy that is consumed in the manufacturing industries. MAED was used for the forecast of energy that is presented below.

4.1 Present Scenario

Current energy mix scenario is important for the penetration of hydrogen in the coming future as it is the baseline of the study. Based on the present scenario and forecasted GDP scenario, the model present use the data related to useful energy in the specific sector. All other aspects are derived based on the forecasted energy.

4.1.1 Consumption by category type

The consumption of thermal energy within different industries is varied due to the specific processes and products they manufacture. Industries involved in the production of cement, bricks, concrete, and clay products heavily rely on furnaces for processes like burning and drying, where there is significant use of coal and furnace fuel.

The breakdown of energy demand by different fuel types in industries is presented in Table 4.1. Among these categories, industries in Nepal primarily consume non-renewable energy sources, constituting approximately 63% of the total, followed by traditional fuels. The adoption of modern biomass for thermal energy is not common in industries. Moreover, the utilization of electricity remains below 3%, indicating that the industrial sector in Nepal is predominantly characterized by high emissions due to its substantial reliance on non-renewable energy sources.

Table 4.1 Total thermal energy demand of industries by fuel types in 2022

Sub category	Traditional fuels	Non-Renewables	Electricity	Total
Cement, bricks, concrete & clay products	7,369	32,217	84	39,669
Chemical products, rubber, glass & plastics	1,545	3,735	1,146	6,426
Electrical & electronics products	-	-	142	142
Food, beverage & tobacco	13,706	14,038	834	28,577
Mechanical engineering, iron, steel, machineries & other metal	2	4,875	30	4,906
Paper, publication & printing, furniture & fixtures	5,225	83	165	5,474
Textiles, readymade garment & leather products	5,579	328	205	6,112
Miscellaneous	972	566	57	1,595
Total	34,397	55,841	2,664	92,903

4.1.2 Consumption by end-uses

When considering the specific purposes for which energy is utilized, there are distinct energy compositions for boilers and process heating for. The distribution of energy consumption across different end-use applications in industries is outlined in Table 4.2. Boilers are used extensively in the food, beverage, and tobacco industries, while industries like cement, bricks, concrete, and clay products predominantly employ thermal energy in furnaces for their process heating needs. For mechanical engineering, iron, steel, machinery, and other metal-related industries, furnaces constitute the primary mode of energy utilization. In a present context, process heat applications consist the largest share of thermal energy consumption in industries, accounting for approximately 66.45% of the total energy usage.

Table 4.2 Thermal energy consumption in industries by end-use applications

(Terajoule)

Sub category	Boiler	Process heat	Total
Cement, bricks, concrete & clay products	2,096	37,573	39,669
Chemical products, rubber, glass & plastics	1,786	4,641	6,426
Electrical & electronics products	88	54	142
Food, beverage & tobacco	16,268	12,309	28,577
Mechanical engineering, iron, steel, machineries & other metal	-	4,906	4,906
Paper, publication & printing, furniture & fixtures	5,320	154	5,474
Textiles, readymade garment & leather products	4,518	1,594	6,112
Miscellaneous	1,090	506	1,595
Total	31,166	61,736	92,903

For each thermal applications, the energy mix scenario is different where boilers are heavily dependent on agriculture residue while furnaces (process heat) are dependent on coal which is shown in Figure 4.2 and Figure 4.1 respectively. Second most used energy source for thermal use in boiler is fuelwood, followed by diesel. The primary source of thermal energy in boilers are traditional fuels. Coal is the primary fuel used on furnaces, at 31.46 PJ, followed by furnace oil (11.83 PJ) and diesel (7.11 PJ). This shows that the fossil-based fuels are mostly used for furnaces in industries of Nepal.

The consumption of electricity in the both applications are of little considerable with around 3%.

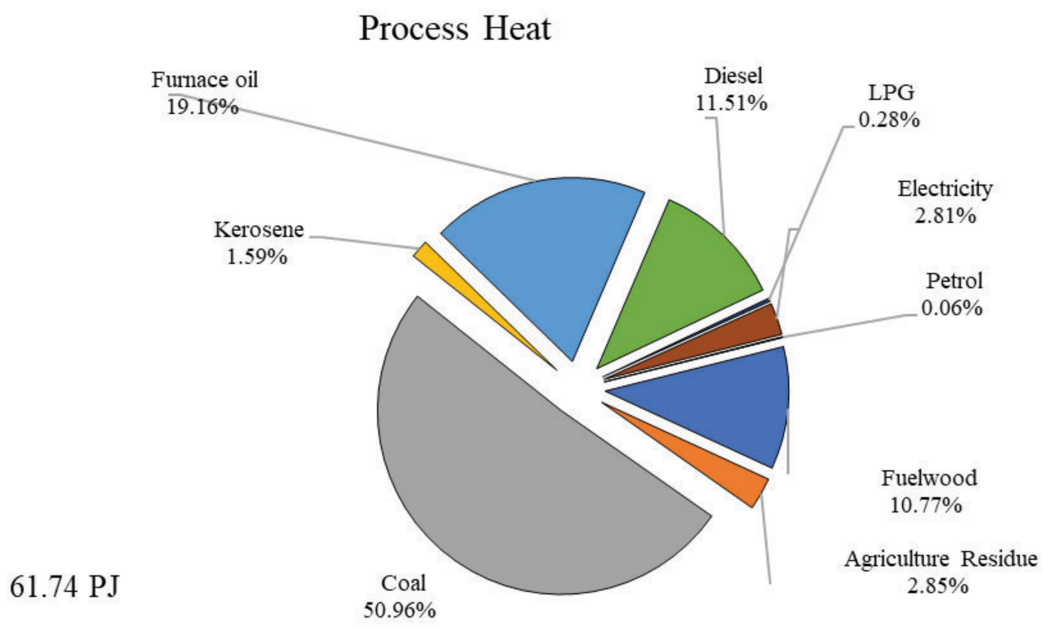

Figure 4.1 Energy mix scenario in process heat applications

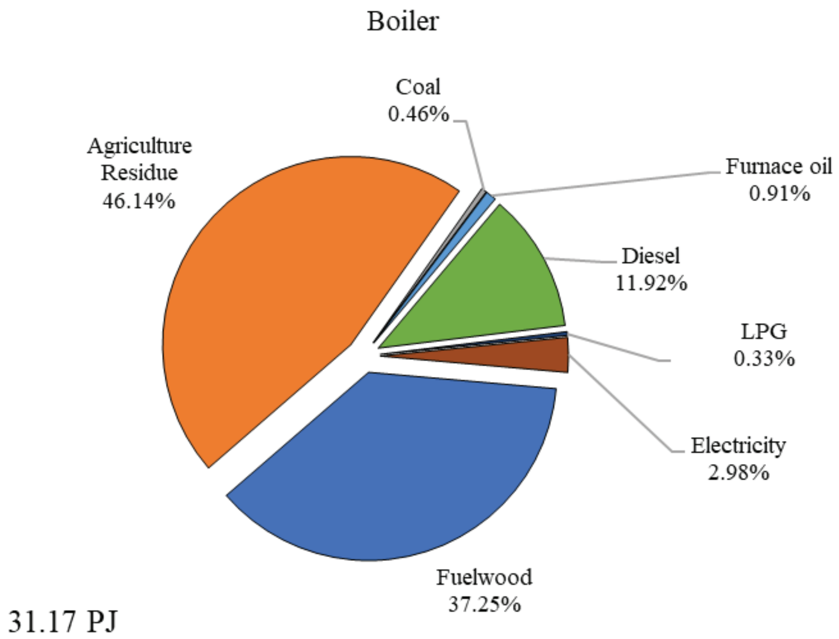

Figure 4.2 Energy mix scenario in boilers

4.1.3 Industrial Application

The major application of thermal uses includes several end-uses such as boilers, process heat, and space heating. For space heating low-grade heat is required which can be effectively provided by electricity whereas boilers and furnaces requires medium and high-grade heat respectively. But electricity cannot provide required high-grade heat effectively. Thus, the combustion of hydrogen emerges as a more suitable alternative.

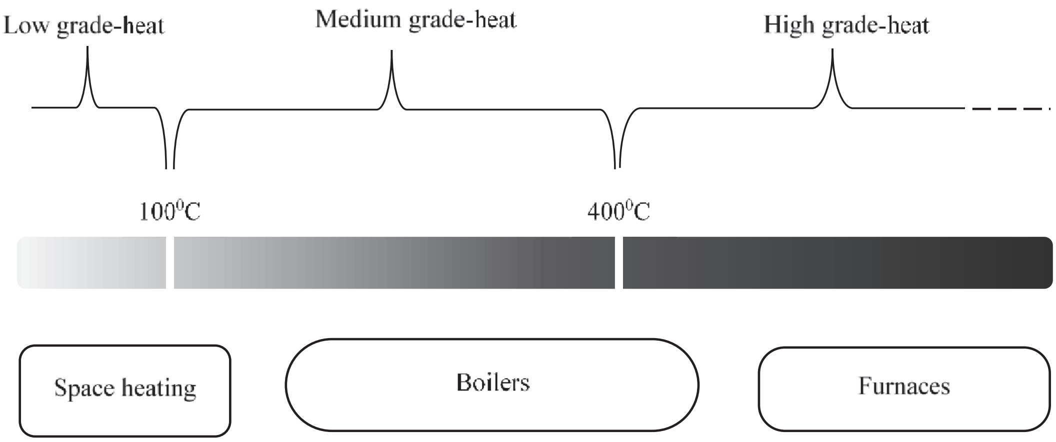

Figure 4.3: Different thermal technologies used in industries

Industries, such as cement, bricks, concrete, clay products, chemical products, rubber, glass, and plastics require high-grade heat in the furnace at different stage of production. Adaptation of hydrogen can be the excellent alternatives due to their specific technology and combustion needs. In such system electrification would require a complete technological switch. However, can be used in for industries requiring low and medium grade heat.

4.1.4 Immediate application of hydrogen

For the immediate application of hydrogen, the cement, bricks and chemical based industries would need the complete replacement of fuels other than electricity in the base year. Figure 4.4 .shows the end use amount of hydrogen in tons required for boiler and furnace in the targeted industries. Around 244 thousand tons of hydrogen is required for cement, bricks, concrete & clay products-based industries whereas chemical based industries will need almost five times less hydrogen The hydrogen demands in boilers is subsequently low for both cement based and chemical based industries.

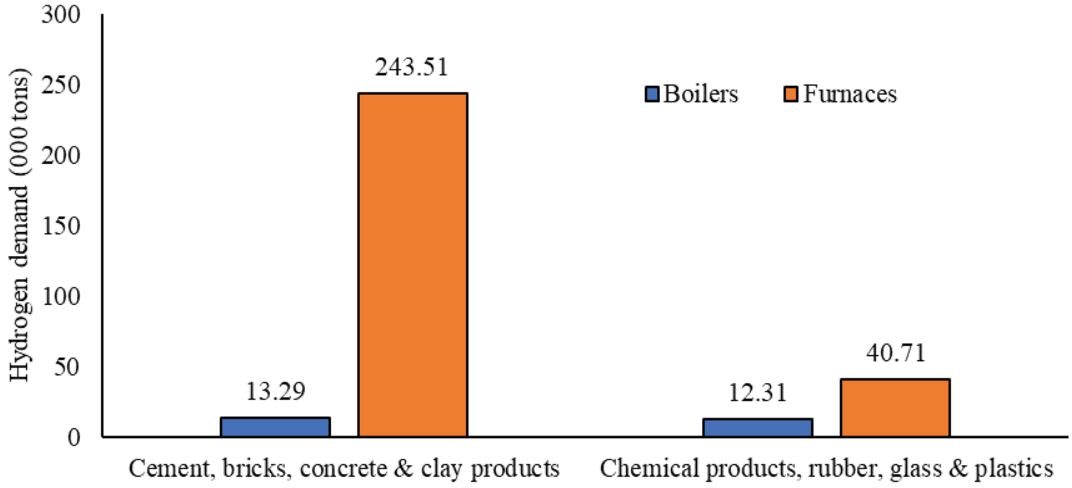

Figure 4.4: Immediate application of hydrogen in industries

Furnaces in industries requires more than ten-fold the hydrogen for boilers and are energy intensive end users. Table 4.3 represents electricity consumption for hydrogen production in electrolysis plant and the dedicated hydropower capacity. If immediate hydrogen implementation is carried out then the electricity from installed hydropower plant capacity in the base year would be required for the hydrogen production only. This represents that for the sustainable development careful planning is necessary which balance the present energy mix scenario. The immediate application of hydrogen could be abrupt to the energy mix scenario thus a gradual and calculated introduction is needed. Introducing the hydrogen should initiate green economy in the industries while ensuring the future stability.

Table 4.3: Electricity demand for immediate hydrogen application

Industries	Electricity demand (TWh)	Hydropower capacity (MW)
Cement, bricks, concrete & clay product	14.60	2,581
Chemical products, rubber, glass & plastics	3.01	533
Total	17.61	3,114

4.2 Penetration of Green Hydrogen

The thermal energy forecast is done according to the GDP presented in three scenarios i.e., low, medium and high. According to the thermal energy other variables such as hydrogen application, emission, and electricity required and hydropower to produce hydrogen is calculated. The result of each case is shown below:

4.2.1 Low growth scenario

In the base year, the total energy demand was 92.90 PJ and is expected to increase to 119.58 PJ by 2030, and further rise to 257.82 PJ by the year 2050 as per the low growth scenario. Keen observation and examination show that the growth rate will be increased greatly reaching 3.92% by 2026-2030, climbing to 3.94% by 2036-2040, and finally settling at about 3.88% by 2046 to 2050.

The expected fuel consumption until 2050 is shown in Figure 4.5. Fuels are categorized into their 4 basic types; Traditional, fossil, modern, and electricity. Fuelwood and agriculture residue are examples of traditional fuels, and briquette is considered a modern biofuel. Fossil fuels are expected to be the primary source of energy supply for years to come. The demand for fossil fuels is estimated to increase rapidly from year 2025 to 2050 whereas the slope of modern biomass and electricity is not that steep. By 2050, the demand for fossil fuels is projected to be around 170 PJ, while that of traditional fuels is expected to be about 77 PJ. Therefore, to meet thermal end-use needs, it will always be a necessity to import large amounts of fossil fuels. It should be noted that the levels of demand for electricity in 2030 and 2050 are projected to be 3.89PJ and 11.57PJ respectively which are relatively low. Hence, it becomes very significant to replace the use of fossil fuels with hydrogen in Nepal's industries.

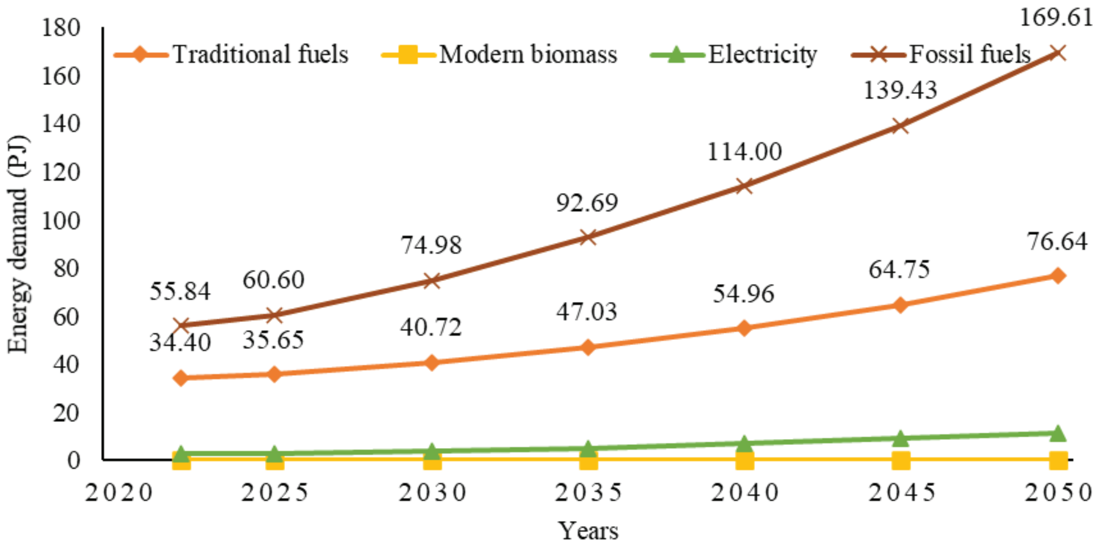

Figure 4.5: Energy demand growth trend of different fuels for low growth scenario

Table 4.4 shows the estimated future thermal energy needs for targeted industries after the hydrogen application for low growth scenarios. It is predicted that the industries based on cement, bricks, concrete, and clay products will increase their consumption to 57.2 PJ by 2030 with hydrogen accounting only around 7.7 PJ and around 50% by 2050. However, industries based on chemical products, rubber, glass, and plastics are forecasted to increase the demand up to 14.61 PJ by 2050 where around 95% will be accounted to hydrogen.

Table 4.4: Energy demand in different industries for low growth scenario

(Petajoule)

Category	Energy	2022	2025	2030	2035	2040	2045	2050
Cement, bricks, concrete & clay products	Total energy	39.67	44.5	57.3	73.1	92.56	116.1	144.56
	Hydrogen energy	-	-	7.70	17.3	30.73	48.75	72.88
Chemical products,	Total energy	6.43	6.64	7.53	8.70	10.25	12.20	14.61

Category	Energy	2022	2025	2030	2035	2040	2045	2050
Rubber, glass & plastics	Hydrogen energy	-	-	1.54	3.43	5.99	9.39	13.87

Hydrogen being the cleanest energy option, is targeted to be used in chemical and cement industries. Figure 4.6 presents the required amount of hydrogen based on different penetration rates in different years according to the developed scenario. The largest consumer is the cement industry. From 2026 to 2030, approximately 0.23 MMT of green hydrogen is expected to be used which will soar to 3.11 MMT from 2046 to 2050. Here, the energy demand for the cement industry in each period is about 5 times more than that of the chemical energy industry and thus the hydrogen required and the electricity consumed. 12.96 TWh of electricity is estimated to be utilized for hydrogen production during 2026-2030. And as one moves forward, cumulative electricity consumption continues to escalate.

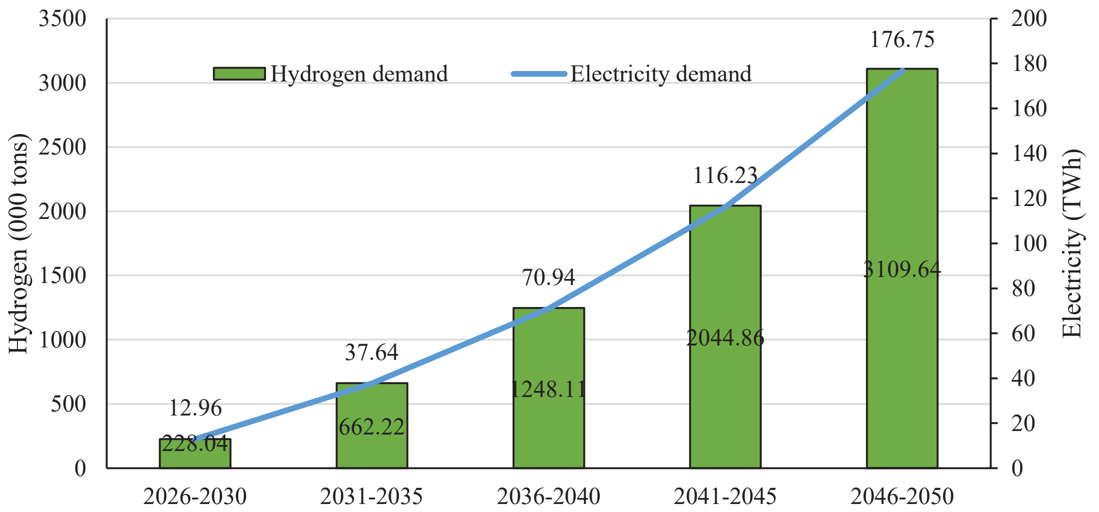

Figure 4.6: Hydrogen and electricity demand in low growth scenario

The use of hydrogen gets wider and for that, the demand for electricity for the production of hydrogen also increases. In the period 2026-2030, electricity share is expected to be about 5.04% reaching up to 11.74 % by 2031-2040 and hitting 19.94% by 2041-2050. Table 4.5 illustrates the hydropower capacity that will be required in various years for hydrogen production. It is estimated that by 2035, the hydropower plant capacity needed for hydrogen production alone will be approximately 1.7 GW which rises to 3.07 GW by 2040 and reaches 7.27 GW by 2050.

Table 4.5: Hydropower capacity needed in low growth scenario in Mega Watt

Category/Year	2030	2035	2040	2045	2050
Cement, bricks, concrete & clay products	644.88	1,456.07	2,573.42	4,083.35	6,103.85
Chemical products, rubber, glass & plastics	129.00	287.39	501.76	786.65	1,161.95
Total	773.88	1,743.46	3,075.19	4,870.01	7,265.81

Figure 4.7 shows the projected emissions by industrial sectors for different years in the presence and absence of hydrogen adaption based on a low economic growth scenario. It is expected that the emission increases with the energy demand. Emissions are expected to reach 11.63 MMT by 2035 and increase to 20.91 MMT by 2050. As hydrogen is introduced, the emission will decrease to 8.26 MMT by 2030 and 8.97 MMT by 2050 as the share of hydrogen will be maximum in the energy mix by 2050 reducing the emission. The emission by 2050 will be less than that by 2040 which will support the emission control.

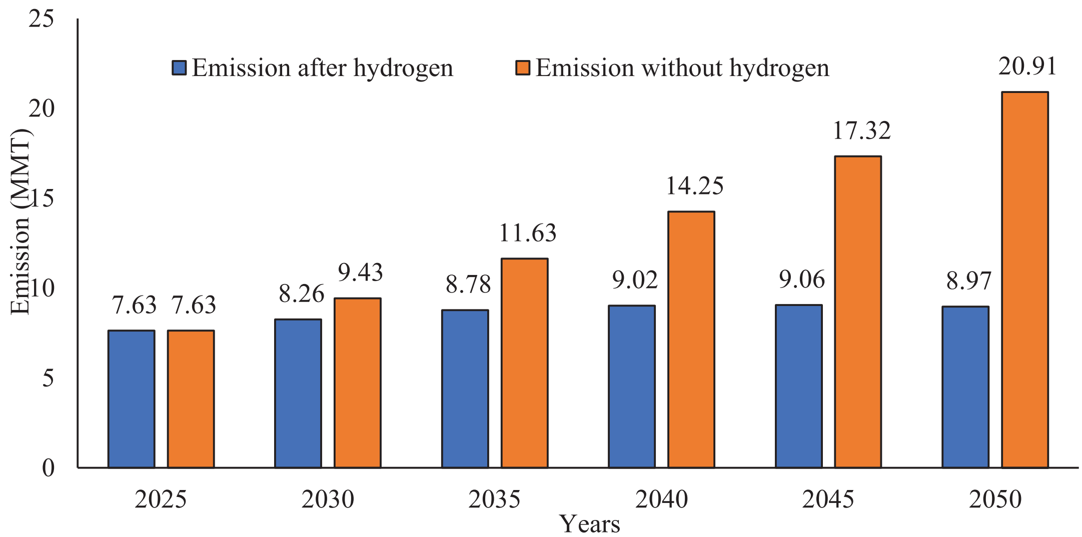

Figure 4.7: Emission by industries in low growth scenario

4.2.2 Medium growth scenario

The upward trend of energy demand in Figure 4.8 shows the growing dependence on various fuels. The consumption of fossil fuels is expected to rise significantly from 65.39 PJ by 2035 to 90.01 PJ by 2040 at the rate of 9.29%. Similarly, demand for traditional fuels will rise to 168.70 PJ by 2050 which is relatively lower than that of fossil fuels being 373.33 PJ by the same year. In each decade, electricity consumption shows a gentle growth rate which finally reaches up to about 25.66 PJ by 2050. And straight trendline of modern biomass represents a low growth rate in its demand. In the medium growth scenario, the total energy consumption will rise significantly to 144.40 PJ by 2030 and 567.49 PJ by 2050 emphasizing the need for sustainable alternatives.

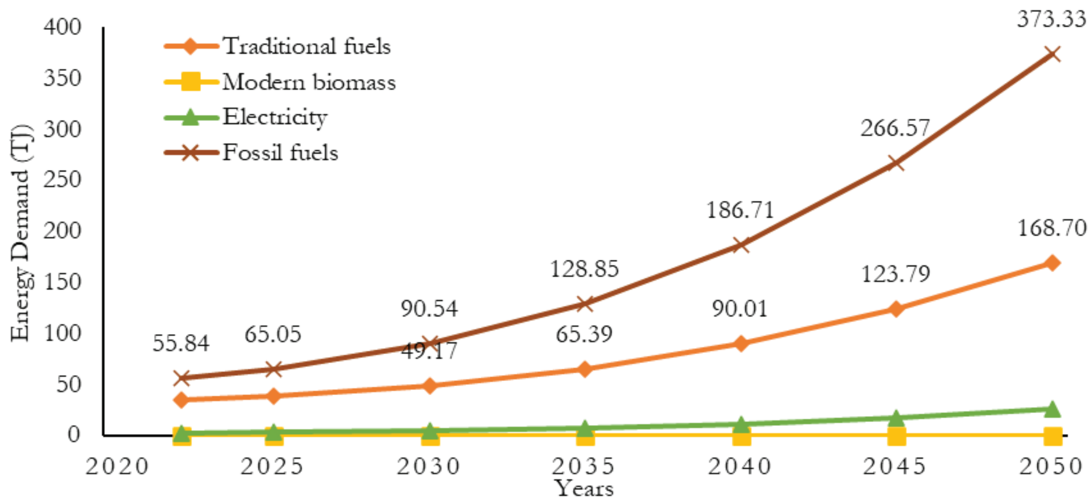

Figure 4.8: Energy demand growth trend of fuels for medium growth scenario

Table 4.6 shows the expected energy consumption in various industries. A massive difference is seen in the growth of energy demand among those industries. Cement, bricks, concrete, and clay products-based industries are expected to reach levels higher than the total energy used in the starting year by 2035. Hydrogen is becoming considerably important and is expected to supply an immense amount of energy of about 160.41 PJ by 2050. On the other hand, there will be more than eight times increase in the base year demand for chemical products, rubber, glass and plastics-based industries by 2050.

Table 4.6: Energy demand in different industries for medium growth scenario

(Peta Joule)

Category	Energy	2022	2025	2030	2035	2040	2045	2050
Cement, bricks, concrete & clay products	Total energy	39.6	47.7	69.21	101.6	151.60	222.0	318.19
	Hydrogen energy	-	-	9.30	24.17	50.32	93.21	160.41
Chemical products, rubber, glass & plastics	Total energy	6.43	7.12	9.09	12.10	16.78	23.33	32.17
	Hydrogen energy	-	-	1.86	4.77	9.81	17.96	30.54

Figure 4.9 illustrates the demand for hydrogen changes over time which in turn influences the amount of electricity needed for hydrogen production. Hydrogen is emerging as a significant contributor in the field of energy. With each passing year, the utilization of hydrogen in cement and chemical industries will go up, reaching about 271 thousand tons during the period 2026-2030 to 6.51 MMT by the period 2046-2050. From 2026-2030, electricity demand is projected to be about 15.40 TWh and peak at about 370.11 TWh by the period between 2046-2050. In sum, figure 4.9 anticipates a significant rise in electricity demand for hydrogen production over different periods.

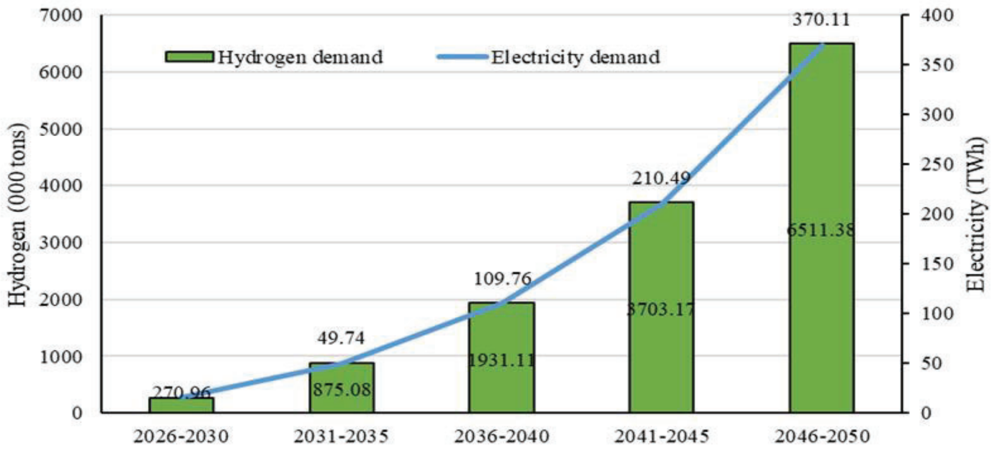

Figure 4.9: Hydrogen and electricity demand in medium growth scenario

With the increasing demand for hydrogen production, electricity production should rise sidewise. The need for dedicated hydropower capacity changes along with it for the sustenance of hydrogen production as shown in Table 4.7. The hydropower capacity needed in 2035 will be similar to what was in base year 2022. And by 2040 and 2050, about 9.5 GW and 16 GW of hydropower capacity will be needed for producing hydrogen alone. However, it needs more electricity for storing and other related tasks.

Table 4.7: Hydropower capacity needed in medium growth scenario

(Mega Watt)

Category/Year	2030	2035	2040	2045	2050
Cement, bricks, concrete & clay products	778.71	2,024.2	4,214.87	7,807.03	13,435.22
Chemical products, rubber, glass & plastics	155.77	399.52	821.81	1,504.02	2,557.58
Total	934.48	2,423.7	5,036.68	9,311.04	15,992.80

With the increasing demand for hydrogen production, electricity production should rise sidewise. The need for dedicated hydropower capacity changes along with it for the sustenance of hydrogen production as shown in Table 4.7. The hydropower capacity needed in 2035 will be similar to what was in base year 2022. And by 2040 and 2050, about 9.5 GW and 16 GW of hydropower capacity will be needed for producing hydrogen alone. However, it needs more electricity for storing and other related tasks.

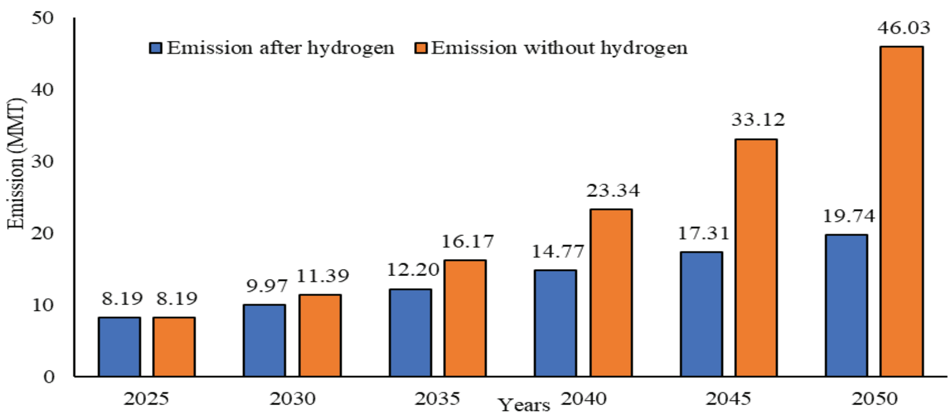

Figure 4.10: Emission by different industries for medium growth scenario

4.2.3 High growth scenario

The upward trend of energy demand as in figure 4.11 shows the increasing dependance on various fuels with increase in economy. Fossil fuels will play a major role. Its consumption is projected to rise huge with 108.86 PJ by 2030 and reaching 782.46 PJ by 2050. Consumption of traditional fuels will grow significantly. By 2035, it will surpass the total energy used in the base year and its demand will reach to 353.58 PJ by 2050. The electricity demand will rise steadily reaching 53.37 PJ by 2050. And straight trendline of modern biomass represents a low growth rate in its demand.

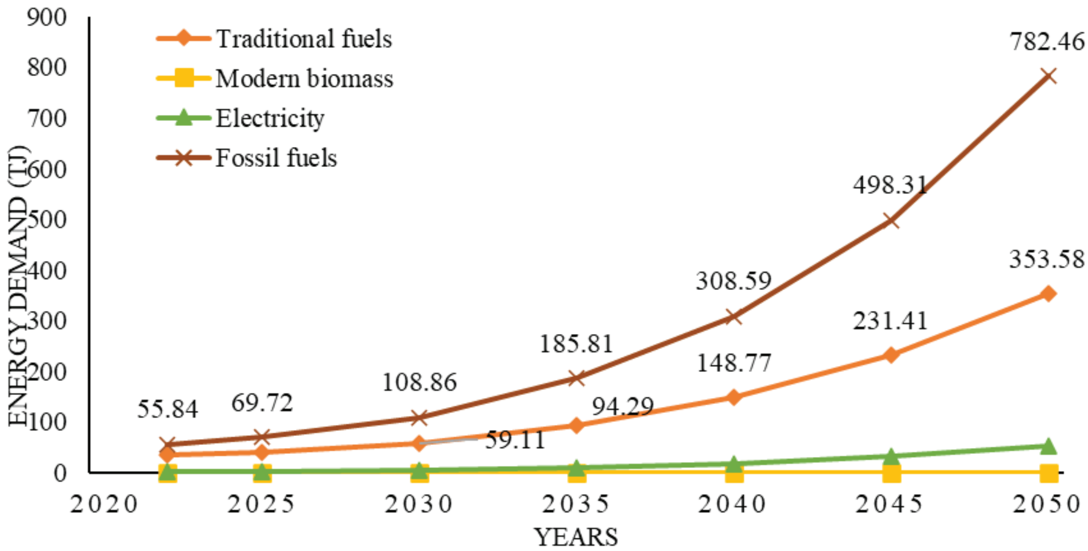

Figure 4.11: Energy demand growth trend of different fuels for high growth scenario

Some industries are using more and more energy each year, especially cement, bricks, concrete, and clay products. Hydrogen is becoming an important source of energy for these industrial sectors. Table 4.8 shows how energy consumption in various industries is changed in various years as per the high growth scenario. In those industries, the total energy consumption will reach about 666.9 PJ by 2050 out of which 36% will come from hydrogen. But when it comes to industries based on chemical products, rubber, glass, and plastics, the total energy demand will be lower than in other industries which is about 6.43 PJ by 2022 and reach 67.42 PJ by 2050 for which 55% of the total energy needed will come from hydrogen fuel.

Table 4.8: Energy demand in different industries for high growth scenario

(Peta Joule)

Category	Energy	2022	2025	2030	2035	2040	2045	2050
Cement, bricks, concrete & clay products	Total energy	39.6	51.2	83.21	146.6	250.5	415.0	666.9
	Hydrogen energy	-	-	11.18	34.85	83.17	174.2	336.2
Chemical products, Rubber, glass & plastics	Total energy	6.43	7.63	10.93	17.45	27.73	43.61	67.42
	Hydrogen energy	-	-	2.24	6.88	16.22	33.57	64.00

Figure 4.12 illustrates the demand for hydrogen changes over time which influences the amount of electricity needed for hydrogen production as per high growth scenario. With each passing year, the utilization of hydrogen in industries will go up, reaching about 306 thousand tons during the period 2026-2030 to 13.12 MMT by the period 2046-2050. The increased demand for hydrogen will in turn increase the electricity demand. From 2026-2030, electricity demand is projected to be about 17.37 TWh and peak at about 745.59 TWh by the period between 2046-2050. In sum, figure 4.12 anticipates a significant rise in electricity demand for hydrogen production over different periods.

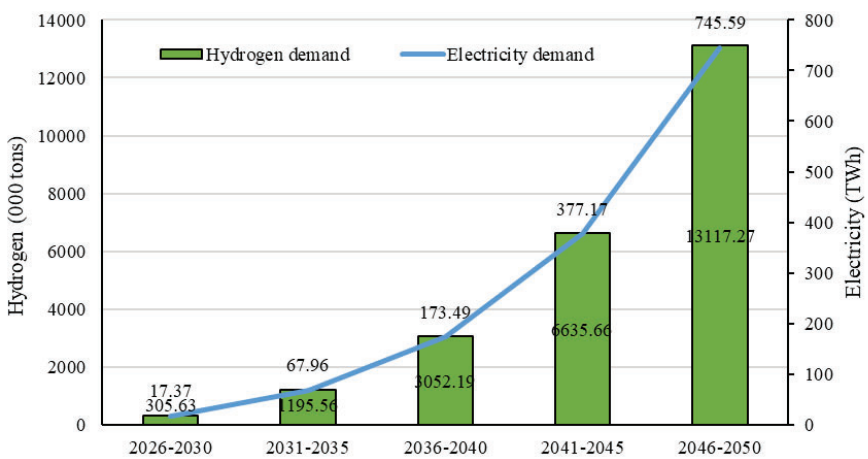

Figure 4.12: Hydrogen and electricity demand in high growth scenario

Electricity production should increase with the increasing demand for hydrogen production and so is the need for dedicated hydropower capacity along with it for sustenance of hydrogen production as shown in table 4.9. The hydropower capacity needed in cement industries alone by 2035 will be more what was in base year 2022. And by 2040 and 2050, about 17 GW and 33 GW of total hydropower capacity will be needed for producing hydrogen alone. However, it needs more electricity for storing and other related tasks.

Table 4.9: Hydropower capacity needed in high growth scenario

(Mega Watt)

Category/Year	2030	2035	2040	2045	2050
Cement, bricks, concrete & clay products	936.24	2,919.02	6,966.15	14,593.7	28,159.1
Chemical products, rubber, glass & plastics	187.28	576.13	1,358.25	2,811.47	5,360.48
Total	1,123.52	3,495.15	8,324.41	17,405.2	33,519.61

Replacing traditional and fossil fuels with hydrogen checks the emissions. If the trend of using fuels is not replaced, it leads to significant rise in emissions reaching 96.47 million metric tons by 2050 which was only 8.78 by 2025 as shown in figure 4.13. The introduction of hydrogen reduces the emissions limiting it to 41.38 MMT by 2050.

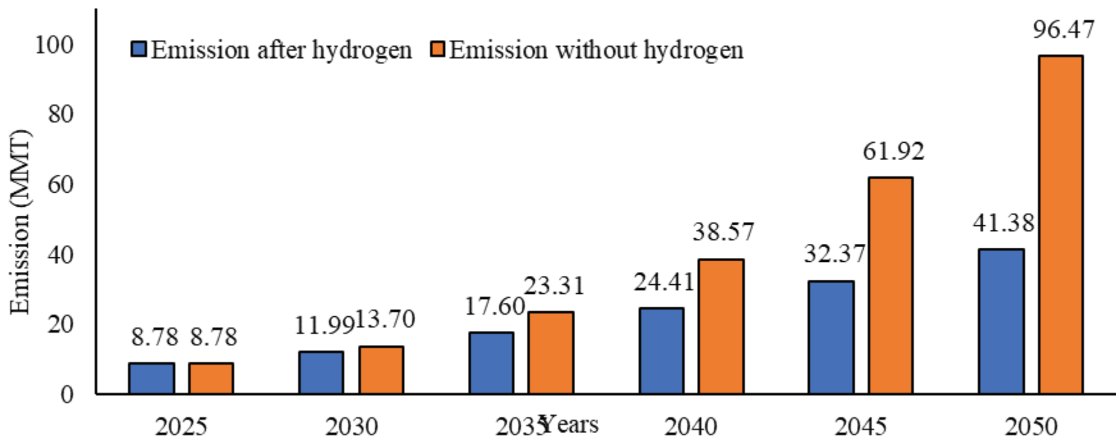

Figure 4.13: Emission by different industries for high growth scenario

4.2.4 Comparison of scenarios

The total thermal energy demand without the use of hydrogen is shown in Figure 4.14 is predicted on the basis of the three distinct scenarios. The energy demand line for the high scenario has steeper curve whereas for the low scenario is almost like a linear line. The total energy demand is projected to be around 120 PJ, 144.4 PJ and 173.6 PJ for low, medium and high growth scenarios respectively for year 2030. The energy demand increases subsequently and rises to 257.82 PJ, 567.49 PJ and 1,189.41 PJ for the year 2050 for three scenarios.

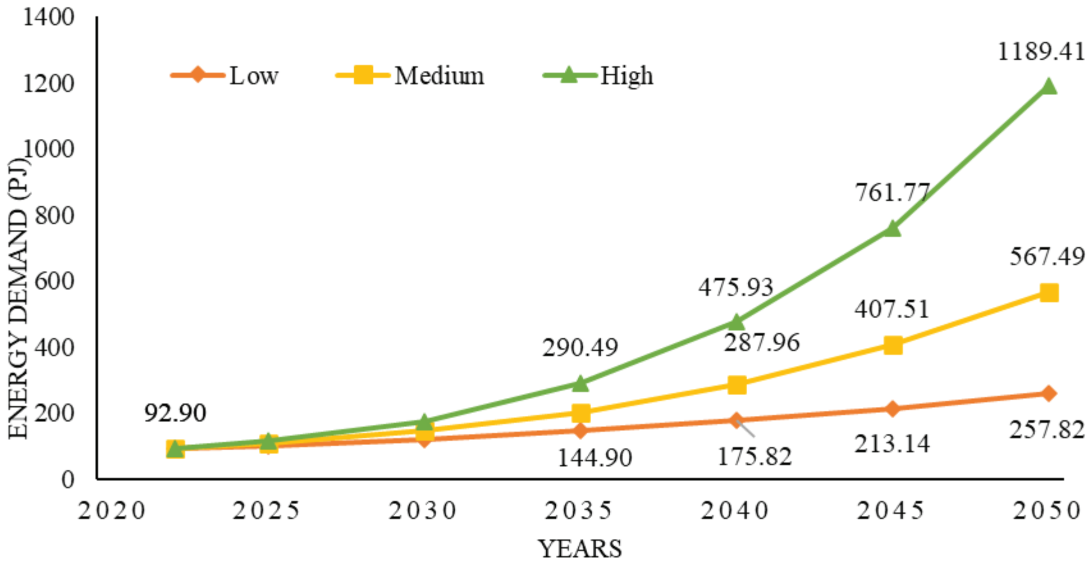

Figure 4.14: Total thermal energy demand in industrial sector

The fuel consumption used in industries for the base year has been forecasted by taking account of different energy demand of various past year records. Electricity in Nepal is considered to be the cleanest source of energy as it is being produced from hydropower. Electricity is one of the best energy sources required to decarbonize various sectors like cement and chemical. The share of electricity in the base year for industrial demand is 2.87% which is expected to rise to 4.27% by 2030 and finally reaches to 7.92% by 2050. In this context, industries other than cement and chemical industries have been considered to be amenable by electricity to decarbonize them. Hydrogen has the potential to substitute fuels with excessive emissions. The specific amount of hydrogen needed in different years and scenarios is shown in Figure 4.15. The least amount of hydrogen required is for the year 2026-2030 in low economic growth scenario which is around 228 thousand tons of hydrogen whereas the highest amount of hydrogen required is for high growth scenario at the period of 2046-2050 which is around 13117 thousand tons.

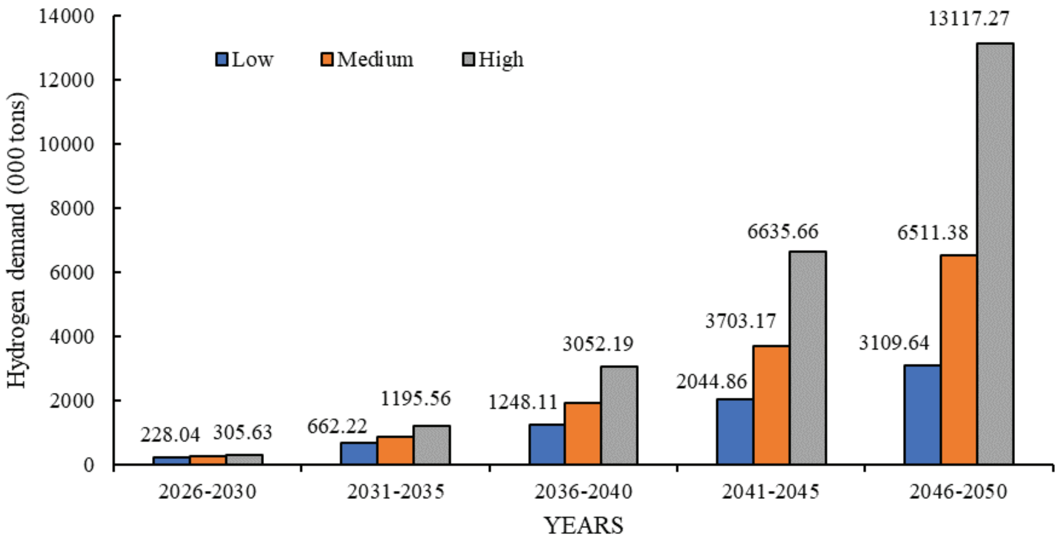

Figure 4.15: Hydrogen demand in different scenarios

The emissions in the industrial sector can be reduced in future by replacing traditional, modern and fossil fuels with hydrogen except electricity. The emission that the industrial sector can produce is given by the Figure 4.16 for three different scenarios in various years after using hydrogen. The low growth scenario seems manageable which can be achieved with hydrogen application alone where the emission looks under control. Therefore, the emission can be limited in the low growth scenario due to hydrogen application alone. Whereas for other scenarios the hydrogen application alone doesn't seems manageable Thus some added measures might be applied like clean energy transition (electrification) or wide use of hydrogen in industries broader than cement and chemicals. The energy source can change with time towards cleaner and more sustainable alternatives.

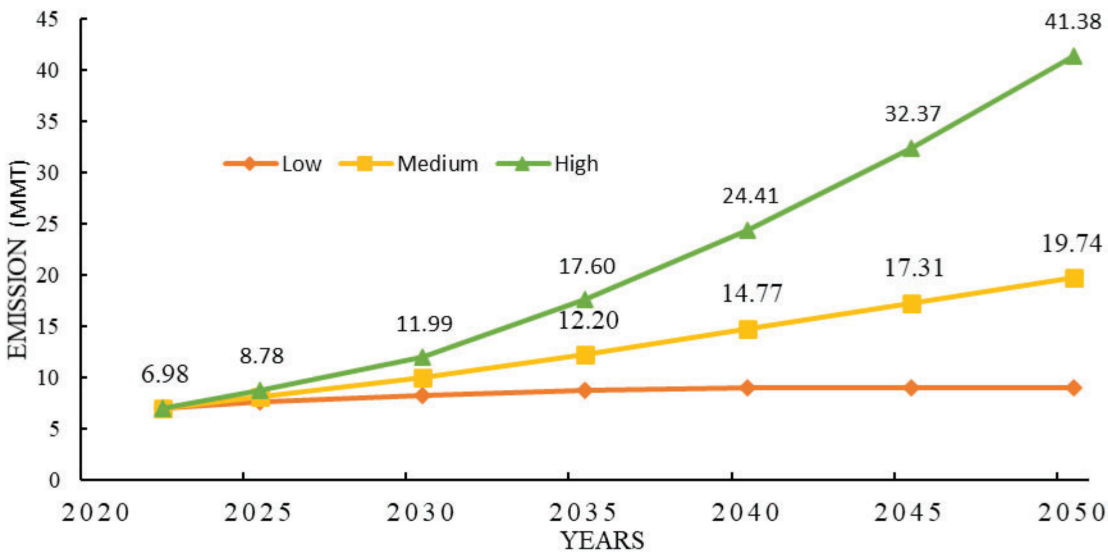

Figure 4.16: Estimated GHG emission forecasts from industries for different scenarios

4.3 Hydrogen production from surplus electricity

The electricity consumption is increasing every year but the increase in electricity generation is more which will cause electricity surplus if not exported. The surplus electricity if used for production of hydrogen, emission from industries can be drastically reduced.

4.3.1 Electricity generation forecast

The future electricity generation is estimated based on the targets on installed capacity set fifteenth plan, SDG and NESV. The electricity generation potential in different years up to 2050 is as shown in Figure 4.17.

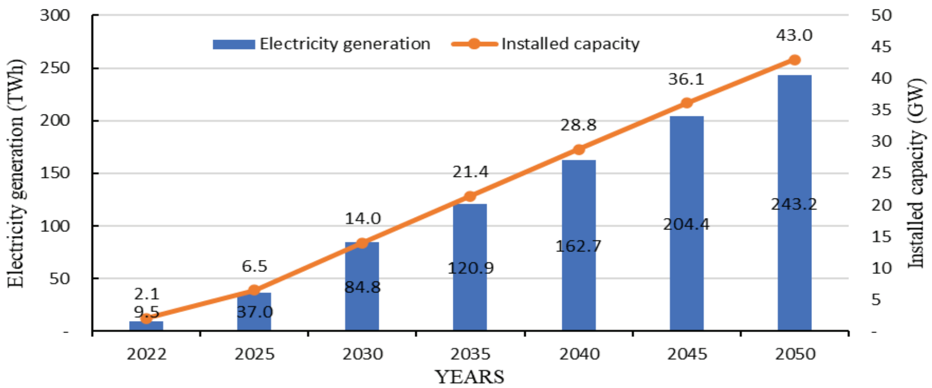

Figure 4.17 Electricity generation

The electricity generation profile shows that the generation continues to grow. The electricity generation in 2025 will be around 37 TWh which is more than thrice the generation in 2022 which is around 9.5 TWh. The electricity generation growth rate gradually decreases as the installed capacity is estimated to reach the economically feasible hydropower capacity in 2050 generating around 243 TWh of electricity annually.

4.3.2 Electricity consumption forecast

The consumption forecast in different years in Nepal is as shown in Figure 4.18 which is calculated by using the method explained above in methodology section.

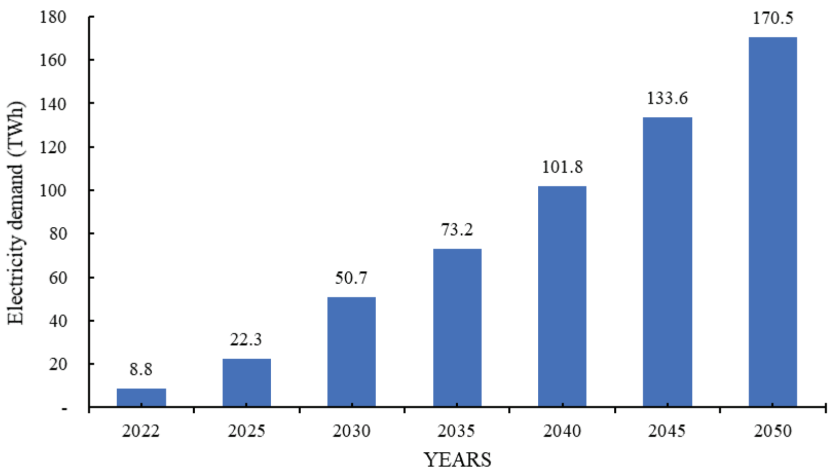

Figure 4.18 Electricity demand forecast

The electricity consumption in the base year was about 8.82 TWh, with increase in population and per capita electricity consumption the total electricity demand will also increase. However, the growth rate of electricity demand is estimated to decrease gradually with the years to pass. The demand is estimated to rise up to 50.69 TWh by 2030, 101.81 TWh by 2040, and eventually 170.51 TWh by 2050. The rate of consumption has been estimated to rise rapidly up to 2030 and then remain more or less stationary from then on.

4.3.3 Estimated surplus electricity

Surplus electricity is based on the above generation profile and demand forecast for different years. The amount of surplus electrical energy that is estimated to occur in the future along with the summary of electrical energy generation and demand forecast is shown in the table below.

Table 4.10 Estimation of surplus electricity

Year	Electricity generation	Electricity demand	Surplus (TWh)
2022	9.52	8.82	0.70
2025	37.03	22.34	14.69
2030	84.83	50.69	34.14
2035	120.94	73.17	47.77
2040	162.74	101.81	60.93
2045	204.44	133.64	70.80
2050	243.18	170.51	72.67

Electricity demand and generation are almost balanced in the base year but the surplus electricity increases with the years to pass. The surplus electricity has been estimated to amount to 14.69 TWh by 2025 which has been forecast to increase all the way up to 72.67 TWh in 2050 which is more than seven-fold of the total internal generation in the base year.

4.3.4 Hydrogen Production possibility

Though the pattern of electrical energy that is going to be surplus in the future looks optimistic, all the electrical energy might not be available for hydrogen production due to the fact that electricity may be exported to some extent and the hydrogen technology may not be mature and large enough. In order to account for these aspects, five different scenarios for using surplus energy have been developed.

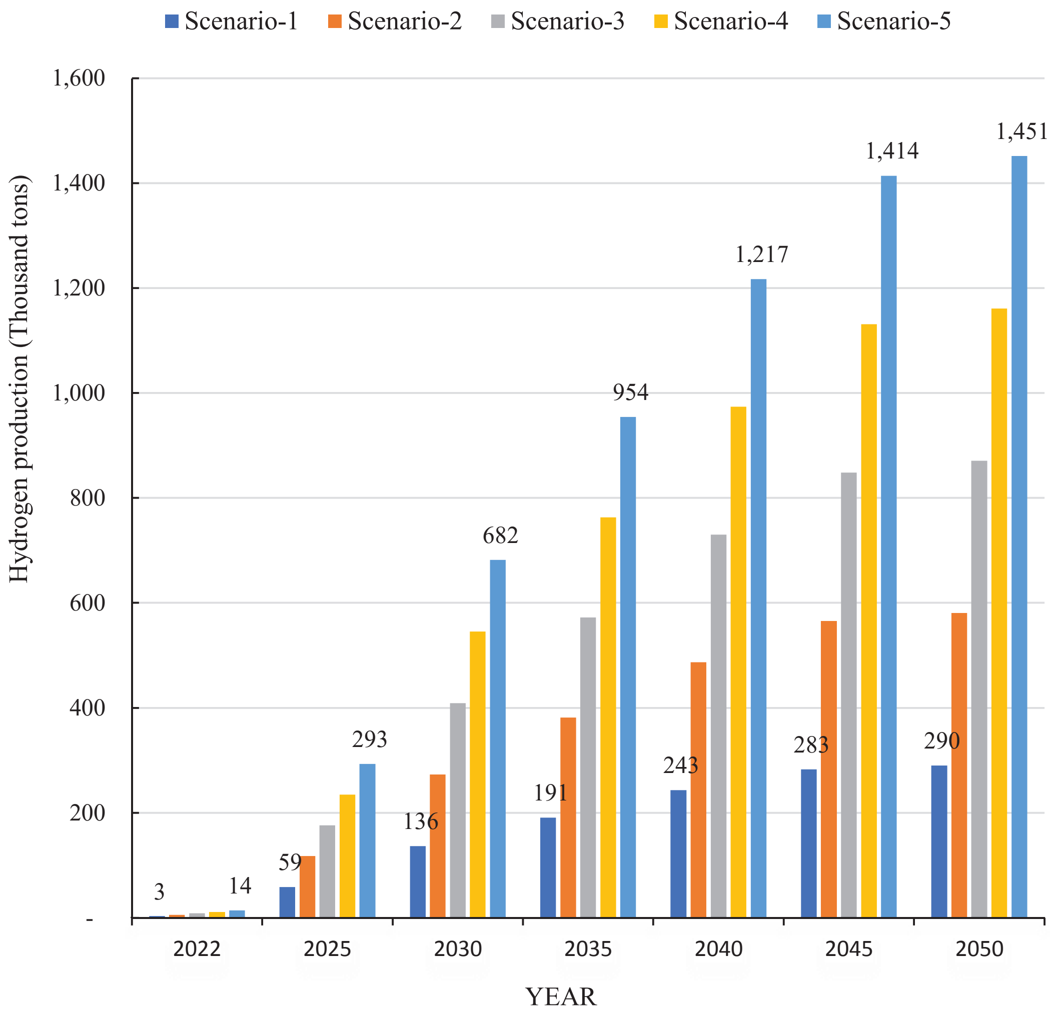

Figure 4.19 Hydrogen production in different scenario

On the basis of the above scenarios, the possibility of hydrogen production in different years has been estimated which is as shown in Figure 3. Even, using only 20% of surplus electricity in the future, hydrogen production has been estimated to be around 136,372 tons in 2030, 243,402 tons in 2040, and 290,290 tons in 2050. If all the surplus energy (Scenario-5) is to be used in 2050, hydrogen production would be massive at around 1,451,450 tons.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Following conclusions has been drawn from the study

- Thermal energy is primarily used for space heating, boilers, and process heat, with boilers and process heat consuming 31.17 PJ and 61.74 PJ, respectively where Boilers heavily rely on traditional fuels (83.39%) and furnaces on fossil fuels (83.57%)
- The projected thermal energy demands in industries are expected to increase to 119.58 PJ, 144.40 PJ, and 173.61 PJ by 2030 under low, medium, and high growth scenarios respectively, and to 257.82 PJ, 567.49 PJ, and 1,189.41 PJ by 2050
- The CO_2 equivalent emission will be approximately 9.43 MMT, 20.91 MMT in 2030 and 2050 respectively under low economic scenario which will be approximately 13.70 MMT, 98.47 MMT in 2030 and 2050 respectively under high economic scenario while with the hydrogen application in target industries the CO_2 equivalent emission will be approximately 8.26 MMT, 8.97 MMT in 2030 and 2050 respectively under low economic scenario which will be approximately 11.99 MMT, 41.38 MMT in 2030 and 2050 respectively under high economic scenario.
- The target industries would require approximately 67.45 PJ, 102.14 PJ, and 150.64 PJ in 2030, 2040, and 2050, respectively, under the low growth scenario, out of which hydrogen will provide 9.24 PJ, 36.72 PJ, and 86.75 PJ respectively whereas under medium and high growth scenarios, the thermal energy requirement for target industries is projected to be approximately 78.30 PJ and 94.14 PJ in 2030, increasing to 351.36 PJ and 734.32 PJ by 2050, respectively whereas around 46.66%, 22.2% and 11.06% of hydrogen demand of industries in low growth, medium growth and high growth scenario can be fulfilled by 100% of surplus electricity in 2050.

5.2 Recommendations

Following recommendation can be provided;

- A broader field of application of Hydrogen in context of Nepal could be better topic of study at the present time. Limiting it to the industrial sector couldn't provide overall theme of Hydrogen development and policy development.
- A study of Hydrogen valley/hub in Nepal could be conducted including the life cycle assessment and value chain could be the area of study.
- For calculation of emission from industries, LEAP could be the better than MAED modelling.
- A study regarding immediate application of Hydrogen can be conducted corresponding to the study of a plant for the production of Hydrogen.
- The energy source transition for this study is considered constant which changes with time so a better model can be created with forecast of energy transition over time.
- Levelized cost of hydrogen, Marginal abatement cost and economic aspects can be calculated.

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APPENDIXES

Appendix-A: Case studies

The production of hydrogen by using electricity can be done by applying various kinds of electrolysers but the alkaline electrolyser has been preferred as it is the most matured technology among all and meets the requirement that is crucial for the industries such as scope for expansion, cost-benefit, etc. While calculating the impact of the immediate application of hydrogen, various assumptions were made. The industrial energy consumption data were collected from the industrial visit. The total energy was calculated by multiplying the energy resource with the calorific value. The useful energy that was used for the thermal application was derived by multiplying the total energy with the efficiency of conversion of such resources. The amount of energy that needs to be produced by the hydrogen is useful energy but there is a certain loss during the conversion of hydrogen to thermal energy. To calculate the hydrogen mass the total useful energy provided by the hydrogen was divided by the lower heating value of the hydrogen (LHV). We have considered the following values for the calculation,

- The Heating value of hydrogen has been considered to be 120MJ/kg (LHV)
- The efficiency of furnace using hydrogen is 48.8% (Gupalo, Yeromin, Kabakova, & Kulikov, 2023)
- The efficiency of boiler using hydrogen is 95% (Lara, 2022)
- The levelized cost of hydrogen (LCOH) is NRs. 568 (Bhandari & Subedhi, 2023)
- The cost of energy sources has been based on the response of the interview

1. Harati Mata Itta Udhyog (Brick)

Harati Mata Itta Udhyog is bricks manufacturing industry, located in Harisiddhi -28, Lalitpur. It was established in 2064 B.S by Prem Gopal Maharjan. It is spread over 50 ropani of land where the kiln occupies around 4 ropani. It produces about 35 lakhs of bricks annually where around 150 persons are engaged directly. The factory runs for 24 hours for continuous 7 to 8 months mostly during the winter season. During the start of the season, initial firing is done with the help of fuelwood, and the fire is sustained by the mixture of agriculture residue (Bhusa) and coal in the ratio of 2:3 by volume. A blower is used to provide a continuous flow of air which consumes electricity and during power cuts, diesel can also be used. Bricks are molded manually, which are piled up with space for heating, and enclosed by brick lining with the arrangement of a feeder and blower.

Fuel consumption in Harati Mata Itta Udhyog

S. N.	Fuel	Rate (NRs. Thousand/ton)	Quantity (tons)	Cost (in NRs. thousand)	Total energy (GJ)
1.	Coal	28.3	300	8,490	7,536
2.	Agriculture Residue	8	7.5	60	94
3.	Fuelwood	10	7	70	117
Grand Total			314.5	8,620	7,747

According to the interview, a sum of approximately NRs 8.6 million is spent annually for fuel use only, most of the cost attributed by coal consumption.

Possibility of replacement with green hydrogen

Prior to this interview, Mr. Maharjan did not have any idea in regards to the use and potential of green hydrogen. After short introduction to this new clean technology, he acknowledged that he would consider it as alternative fuel in his industry provided that the technology is safe and beneficial. As for barriers, he suggested that any types of technology like this, had to have the reliability and availability aspect strong because if they started to use this new fuel and suddenly there came a shortage this could damage the production of the industry irreversibly. On the subject of incentives, he said that "Government must make proper policies and laws which will ensure the availability and sustainability of the fuel. In order to make this transition, the government must provide subsidies."

Concerning the hydrogen requirement, the industry needs 46 tons of hydrogen annually to replace the current use of fuels. Using LCOH, this would cost the industry around NRs 26,301 million which is more than three times the current expenditure. The current technology and system used in the industry is not compatible for hydrogen combustion. Therefore, the industry needs completely new technology to make use of green hydrogen. This may also add to the cost. Therefore, the government needs to work on the policy making, subsidizing this technology with reduction in electricity prices and conducting RD & D to make this technology viable and sustainable.

2. Himal Iron and Steel Industries Pvt. Ltd

This company is one of the pioneering companies in Nepal's iron and steel industry which is led by Jyoti Group. Basu Dev Shrestha responded to the questionnaire and provided his utmost assistance in data gathering. Its production factory is located at Jyoti farm, Parwanipur, Birgunj which produces cold twisted Torsteel Bar and high strength TMT tempcore bars. Established in 2018 B.S., annually about 21,000 tons of iron and steel are processed with around 350 employees actively engaged in the industry. The factory runs for 20 hours a day for 10 months a year. Prime Iron billets are used which are imported from India, and processed by using high thermal heat inside a blast furnace. Line production is present where the heated iron billets are passed through different machines and are treated chemically which converts them into desired shape and quality. Coal and furnace oil are used for high thermal heat in the industry.

Fuel consumption in Himal Iron and Steel industries Pvt. Ltd.

S.N.	Fuel	Rate (NRs. Thousand/ton)	Quantity (tons)	Cost (in NRs. thousand)	Total energy (GJ)
1.	Coal	28.3	500	14,150	12,560
2.	Furnace Oil	162	14	2,268	7,162
Grand Total			514	16,418	19,722

Coal is used as the major source of thermal energy which is imported from India. The annual expenditure on fuels alone amounts to about NRs 16 million, with most of the cost contributed by coal use.

Possibility of replacement with green hydrogen

Mr. Shrestha informed that he had heard about the green hydrogen technology in a meeting where members from India talked about its reliability and availability. In addition to this, he had no idea about this technology. Costing, reliability and feasibility were pointed out to be the main barriers in the interview. He affirmed his willing to make the shift to this green technology but again it had to be feasible and reliable. Moreover, he manifested his willingness to support the pilot projects related to green hydrogen in his industry. He emphasized that policies had to be proper and long-term as the volatile policies had the history of making the industries bankrupt. According to him, government has to provide subsidies, tax cut-offs, proper policy and planning.

In order to replace the current fuels, the amount of hydrogen needed has been estimated to be around 118 tons with cost amounting to NRs 67 million. This cost is about four times the current expenditure, without government subsidies, penetration of hydrogen in the industry is unviable. Therefore, government has to invest and subsidy the industry to make the green hydrogen use feasible and sustainable.

3. Shree Nawa Prabhat Dairy Pvt. Ltd (Food)

The company is situated in Patan Industrial Area, Lalitpur and was established in 2057 B.S. Manoj Humagain, the manager of the company responded to the questionnaire and briefly explained the process. The company process about 20,000 liters of milk daily and convert it into various products like milk, yogurt, ghee, ice cream, cheese, paneer and many more products. It runs for 8 hours a day for 365 days with 75 employees working in it. It has 2 boilers with a 750 kg/hour rating running on two different fuel types, biomass, and diesel. Biomass pellet type boiler is generally used and preferred to diesel boiler as the biomass pellet is cheaper. The diesel generator is used during power cuts. The Steam produced by the boiler is used in different parts of operation which is carried by pipelines. There is also a provision of solar PV system which has been used for basic lighting systems inside the facility. Besides this, the maximum energy utilized is electricity for cold storage and processing which is brought through a 500KVA transformer.

Fuel consumption in Shree Nawa Prabhat Dairy Pvt. Ltd.

S. N.	Fuel	Rate (NRs. Thousand/ton)	Quantity (tons)	Cost (in NRs. thousand)	Total energy (GJ)
1.	Biomass Pellet	34	360	12,240	6,286
Grand Total			360	12,240	6,286

Possibility of replacement with green hydrogen

Mr. Humagain had not heard about the green hydrogen technology prior to this interview. He affirmed that the company would consider it as alternative to current fuels if and only if the technology is economically feasible. The main barriers to this technology in his opinion are poor technology, unavailability and cost in Nepal. His response indicated his willingness to shift to the green technology. If the production does not get hampered, pilot projects will be allowed to run. Public awareness and the technology-focused interactions need to be run by government, he remarked. In context to production, he proposed that the production should not be inside the company as it may require additional spaces.

The hydrogen requirement for the replacement of current use of fuel is estimated to be 91 tons. For this, around NRs 52 million will be expended annually which is around more than 400% of the current annual expenditure on fuel. Thus, subsidies will be required to make this transition possible.

4. Pokhara Noodles Pvt. ltd

This industry is situated in Pokhara Industrial State, Pokhara, Kaski. The industry was established in 2048 B.S. where around 62 people are directly engaged. Specifying on noodles products, about 180 tons was produced last year. The industry runs for 8 hours a day for 300 days a year. Mani Ram Pandey, production and maintenance engineer responded to the questionnaire and explained the plant layout and system. The industry uses a biomass-based boiler which produces steam that is used at various stages in the processing of the product. Agricultural residue is used in the boiler as the energy source to produce steam of about 180^{0}C at the rate of 14 kg/hour. Electricity is another energy source that is mostly used to run conveyors, mixers, chillers, exhaust, etc.

Fuel consumption in Pokhara Noodles Pvt. Ltd

S. N.	Fuel	Rate (NRs. Thousand/ton)	Quantity (tons)	Cost (in NRs. thousand)	Total energy (GJ)
1	Furnace Oil	162	240	38,880	10,610
Grand Total			240	38,880	10,610

The total annual energy consumption amounts to about 10,610 GJ. By the estimation of the price of the energy sources, the annual cost of thermal energy has been estimated to be 38.8 million.

Possibility of replacement with green hydrogen

Prior to this interview, the manager has not had any idea regarding the green hydrogen and its potential. According to the response, the main barrier to this technology is the lack of information and awareness. He emphasized that the incentives by government were needed to make the fuel cheaper. If the fuel gets cheaper and viable to use, he said that he was willing to make this transition. He also added that the in-house production of hydrogen is better for the industry.

The amount of green hydrogen required to replace the current use of fuel is estimated to be around 145 tons. The cost of using green hydrogen has been calculated to be around NRs 82 million which is more than two times the current annual expenditure for fuel. Without proper policy and subsidies, the industry is not ready to consider green hydrogen as alternative fuel.

5. Hetauda Cement Factory

Hetauda Cement factory is government run industry, situated in Lamsure-9, Hetauda. The company produces OPC and PPC cement which has a usual production capacity of 220,000 tons but the quantity produced last year was around 95,000 tons. The industry was established in 2033 B.S. Bishow Prasad Lamichhane, electrical and electronics engineer, responded to the questionnaire and explained the plant and system used. Heat is used in different stages of cement production but the most heat-intensive process is clinker production where calcium silicate is produced by a chemical reaction that occurs due to the heating of preheated raw meal. Coal is used to produce high heat (~1450^{0}C) in the kiln-type furnace in this industry. At first, fuelwood is used for start the fire (firing), which is then sustained by using Coal. Furnace oil was used for firing some decades back but this system is completely replaced by fuelwood.

S.N.	Fuel	Rate (NRs. Thousand/ton)	Quantity (tons)	Cost (in NRs. thousand)	Total energy (GJ)
1	Coal	28.3	20000	566,000	502,400
2	Fuelwood	10	1.6	16	27
Grand Total			20,002	566,016	502,427

The major source of energy used was Coal which was imported from the neighboring country. The price of the energy resources was thus estimated to be around NRs 566 million for thermal energy alone.

Possibility of replacement with green hydrogen

The engineer had the idea about this green technology before. Initial investment cost might be the main barrier according to his response. He was willing to shift to the green hydrogen technology. "Economic incentives are needed to make this new technology enter the industrial sector," he said. Pilot projects are needed to run successfully to make this technology reliable. As for production, he admitted the fact that the production should be centered at a location and supplied as LPGs.

Around, 3,003 tons of hydrogen is needed to provide the fulfill the current energy demand. This would cost the government about NRs 1.71 billion to use hydrogen as the thermal fuel in this case. To make this expenditure viable, the government must work on RD & D.

6. Paana Paper Works

Paana Paper Works is a paper industry which is located at Adarsh Nagar, Birgunj. Subash Kumar Patel, the supervisor responded to our questionnaire and described the process and plant that was present in the industry. It produces packaging carton boxes (corrugated cartons) for various products like noodles, oil, electronics, beer, etc. Around 60 people are directly engaged in the industry which runs for 8 hours a day, 8 months a year. The flute i.e., the middle-waved section which is glued to the side wall to provide strength is used to prepare the carton. High-temperature steam is produced which is used in various processes such as recycling the carton, gluing the flute, and drying the intermittent products. The agricultural residue (Bhusa) which is locally available, is used to produce steam from the boiler. Several other electric heaters were also used in the industry for drying.

S. N.	Fuel	Rate (NRs. Thousand/ton)	Quantity (tons)	Cost (in NRs. thousand)	Total energy (GJ)
1.	Agriculture Residue	8	210	1,680	2,638

Grand Total	210	1,680	2,638

The agriculture residue which is readily available nearby is used for the thermal energy. This amounts to about 2.64 TJ of energy. Current annual expenditure for the fuel is estimated to be around NRs 1.68 million.

Possibility of replacement with green hydrogen

The supervisor had no idea about this technology before this session of interview. He proposed that the financial aspect might be the main cost barrier for this technology transition. Government has to establish proper ecosystem and make planning. Supply of hydrogen from a central production area is preferred by him. The industry has been adopting water saving measures.

The amount of hydrogen needed to keep the industry in working condition is about 16 tons. This would cost the industry around NRs 9.20 million annually. To make this technology transition, government needs to provide adequate amount of support in financial and technological aspect.

7. Aarnica Processing Industries Pvt. Ltd

Aarnica Processing Industries Pvt. Ltd. is the textile production and processing industries which is located in Adarsh Nagar, Birgunj. It was established in 2042 B.S. It produces around 6 lakhs meter of cloth per month. Around 125 people are directly engaged in the industry which runs for 12 hours per day for 200 days in a year. The questionnaire was responded to by Sochan Yadav, general manager of the industry with other technicians. Steam is used in the industry for processing cotton, drying cloth, and ironing clothes. There was a thermic oil heater that produces steam from the burning of agricultural residue (rice husk). The manager said that ash poses the problem to health to the people living around when spread from the chimney. Most of the other operations were done by using electricity as the energy source.

S.N.	Fuel	Rate (NRs. Thousand/ton)	Quantity (tons)	Cost (in NRs. thousand)	Total energy (GJ)
1	Agriculture Residue	8	1000	8,000	12,560

Grand Total	1000	8,000	12,560

This textile company has been using agricultural residue as it was locally available. The total energy to be produced from agricultural residue has been estimated to be 12,560 GJ. The electricity for the industry is imported from India. In sum up, the industry uses thermal fuels of around NRs 8 million.

Possibility of replacement with green hydrogen

Mr. Yadav along with other technicians and engineers, responded that they had no idea about the green technology so far, prior to this interview. He said that the government needs to incentivize this new technology to make the industries use it. He showed his willingness to support the pilot projects in his industry and shift into it. "As commercial person, it should be beneficiary. If the cost of this technology is tolerable, we might want to shift into it for pollution remedy" he said. Currently, there were no measures taken to decrease the use of emission intensive fuels.

The hydrogen required annually for thermal uses in this industry has been estimated to be around 77 tons. This would cost the industry more than five-fold of current expenditure, at around NRs 44 million annually. The industry needs subsidies and support from the government as per the considered price and state of the technology to adopt this technology.

8. Supreme Industries

This polymer industry is located inside Patan Industrial Area, Lalitpur which was established by Saroj Bhusal in 2071 B.S. Bhusal cooperated with the enumerator in providing necessary data. It produces around 300 tons of product per month where 16 people are directly engaged which runs throughout the day for around 300 days. Products like plastic bottles, tiffin boxes, containers, soap boxes, water jars and dispensers, sanitizer bottles, etc. were produced by using electric molding machines. Fossil fuels like diesel were used for transport and operating diesel generators during power cutoffs.

400 kVA transformer was used for providing electricity. Around 375 GWh of electricity was consumed monthly for running 9 molding machines each of 100 HP. There was no use of fossil-based energy sources for the thermal application. The industry was fully

electrical in thermal applications. Thus, the estimation for the hydrogen wasn’t done in this section.

Appendix-B Questionnaire

Questionnaire for assessment of the potential use of Hydrogen fuel for thermal applications in the Nepalese industries

Date:………………..

1. Information of respondent and location

Question	Description
Name of respondent उत्तरदाताको नाम	
Respondent's position उत्तरदाताको पद	
Contact number सम्पर्क नम्बर	
District जिल्ला	
Municipality/Rural Municipality नगरपालिका / गाउँपालिका	
Ward no. वडा नं.	

2. General Information of the organization

Name of industry कम्पनिको नाम	………………………
Establishment date स्थापना मिति	………………………
Company categorization कम्पनिको वर्गीकरण	
Product manufacture उत्पादन	………………
Quantity produced last year उत्पादनको मात्रा	………………

Number of person directly engaged in industry कार्यरत कर्मचारीको संख्या	……………..person
Operation hours per day संचालन हुने समय (घण्टा प्रति दिन)	………………hrs
Annual operation days वार्षिक संचालन दिन	………………days
Total area covered by industry उधोगको जम्मा क्षेत्रफल	………………sq. ft/ ropani/ bigha
Floor space occupied by industry उद्योगको भागको क्षेत्रफल	………………sq. ft/ ropani/ bigha
Total capital of industry जम्मा पूँजी	NRs………………
The approximate revenue generated in the last year गत वर्षको अनुमानित आय	NRs………………

3. Technologies in industries for heating

Technologies	**Fuels**	**Rating**	**Operating duration (hours)**	**Operating temperature (^{0}C)**
Boiler	☐ Electric ☐ Biomass based ☐ Coal based Others	**………………kW** **………………kg** **………………kg** **………………**		

	☐			
Boiler	☐ Electric ☐ Biomass based ☐ Coal based ☐ Others	**………………kW** **………………kg** **………………kg** **………………**		
Boiler	☐ Electric ☐ Biomass based ☐ Coal based ☐ Others	**………………kW** **………………kg** **………………kg** **………………**		
Furnace	☐ Electric ☐ Biomass based ☐ Coal based ☐ Others	**………………kW** **………………kg** **………………kg** **………………**		
Furnace	☐ Electric ☐ Biomass based ☐ Coal based ☐ Others	**………………kW** **………………kg** **………………kg** **………………**		

Furnace	☐ Electric ☐ Biomass based ☐ Coal based ☐ Others	**……………..kW** **……………..kg** **……………..kg** **……………..**		
Heaters	☐ Electric ☐ Biomass based ☐ Coal based ☐ Others	**……………..kW** **……………..kg** **……………..kg** **……………..**		

4. Energy Source Information

Energy sources ऊर्जाको स्रोत	Annual fuel consumption वार्षिक इन्धनको आवश्यकता
Fuelwood दाउरा	……………Tons
Agriculture residue कृषि अवशेष	……………Tons
Animal waste पशुजन्य फोहोर	……………Tons
Coal कोइला	……………Tons
Briquette	……………Tons
Kerosene मट्टितेल	……………Kilo liters
Furnace oil	……………Kilo liters
Petrol	……………Kilo liters
Diesel	……………Kilo liters
LPG	……………Cylinders
Electricity	……………kWh
Solar PV (Solar home system)	……………kWp

Solar water heater	…………… Liter

5. **Energy consumption by end-use**

5.1. Energy consumed for space heating per day प्रति दिन कोठा तताउनका लागि प्रयोग गरिने ऊर्जा

Equipment उपकरण	Number संख्या	Average watt औशत क्षमता (वाट)	Operation hours per day सचांलन हुने घण्टा प्रति दिन
Electric heater			
AC			
Fuelwood	……………kg		
Briquette	……………kg		

5.2. Energy is used for boiler per year प्रति वर्ष ब्याइलरका लागि प्रयोग गरिने ऊर्जा

Energy Source ऊर्जाको स्रोत	Fuel consumption per year प्रति वर्ष इन्धनको उपभोग	Operation hour per day सचांलन हुने घण्टा प्रति दिन
Fuelwood	……..... Tons	
Agriculture residue	……..... Tons	
Coal	……..... Tons	
Kerosene	……..... Kilo liters	
Furnace oil	……..... Kilo liters	
Diesel	……..... Kilo liters	
LPG	……..... Cylinder	
Electricity	……..... kWh	

5.3. Energy is used for process heating per year

Energy Source	Fuel consumption per year	Operation hour per day

ऊर्जाको स्रोत	प्रति वर्ष इन्धनको उपभोग	सचालन हुने घण्टा प्रति दिन
Fuelwood	……... Tons	
Agriculture residue	……... Tons	
Briquettes	……... Tons	
Coal	……... Tons	
Kerosene	……... Kilo liters	
Furnace oil	……... Kilo liters	
Diesel	……... Kilo liters	
LPG	……... Cylinder	
Electricity	……... kWh	

5.4. Back up supply

Generator-1 जेनेरेटर-१	
Capacity of generator जेनेरेटरको क्षमता	……... kVA
Duration of operation सचालन हुने अवधि	……... Hours per day
	……... Days per year
Petrol	……... Kilo liters
Diesel	……... Kilo liters

Generator-2 जेनेरेटर-२	
Capacity of generator जेनेरेटरको क्षमता	……... kVA
Duration of operation सचालन हुने अवधि	……... Hours per day
	……... Days per year
Petrol	……... Kilo liters

Diesel	…….... Kilo liters
Solar PV System सोलार पि.भि सिस्टम	
Panel capacity प्यानलको क्षमता	…….... Watt
Battery capacity ब्याट्रीको क्षमता	…….... Ah
Consumption hours खपत	…….... hrs/day

Barriers and obstacle

Do you any idea regarding the use and potential of green hydrogen ?	
Have you considered using green hydrogen as an alternative to fossil fuels?	
What are the main barriers or obstacles that prevent you from adopting green hydrogen in your operations?	
Are you willing to shift to the green hydrogen technology?	
What are the incentives that are required for you to shift toward green hydrogen	
Are you willing to support the pilot projects related to green hydrogen in your industry	
Remarks regarding policy implication to mainstream green hydrogen	
Which option is better inhouse production of green hydrogen or supply of green hydrogen?	
Any specific targets related to the decrease of the use of fossil fuels within industry?	

Name of company कम्पनिको नाम:………………………………….	Company’s stamp:

Name of Enumerator गणकको नाम:……………………………….	Signature:
Name of field supervisor सुरभाइजरको नाम:……………………..	Signature:
Name of respondent उत्तरदाताको नाम:……………………………	Signature:

Appendix-C Energy consumption data

Thermal energy consumption in industries of Koshi Province by fuel types (TJ)

Category	Fuelwood	Agriculture Residue	Coal	Kerosene	Furnace Oil	Diesel	LPG	Electricity	Petrol	Briquette	Total
Cement, bricks, concrete & clay products	2,064	-	15,557	-	1,162	57	-	7	-	-	18,848
Chemical products, rubber, glass & plastics	-	426	-	-	-	1,339	-	225	-	-	1,990
Electrical & electronics products	-	-	-	-	-	-	-	119	-	-	119
Food, beverage & tobacco	120	72	-	-	4	290	11	123	-	-	619
Mechanical engineering, iron, steel, machineries & other metal	-	-	12	-	1,108	-	-	2	-	-	1,122
Paper, publication & printing, furniture & fixtures	-	1,004	-	-	-	-	-	25	-	-	1,029

Textiles, readymade garment & leather products	-	4,967	-	-	-	-	-	4	-	-	4,970
Miscellaneous	42	446	46	-	-	54	-	27	-	-	616
Total	2,225	6,915	15,615	-	2,274	1,740	11	532	-	-	29,313

Thermal energy consumption in industries of Koshi Province by end-uses (TJ)

Category	Boiler	Process Heat
Cement, bricks, concrete & clay products	-	18,848
Chemical products, rubber, glass & plastics	740	1,251
Electrical & electronics products	80	39
Food, beverage & tobacco	320	299
Mechanical engineering, iron, steel, machineries & other metal	-	1,122
Paper, publication & printing, furniture & fixtures	1,029	-

Textiles, readymade garment & leather products	3,794	1,177
Miscellaneous	555	61
Total	6,517	22,796

Thermal energy consumption in industries of Madhesh Province by fuel types (TJ)

Category	Fuelwood	Agriculture Residue	Coal	Kerosene	Furnace Oil	Diesel	LPG	Electricity	Petrol	Briquette	Total
Cement, bricks, concrete & clay products	368	56	6,917	-	-	32	-	1	-	-	7,373
Chemical products, rubber, glass & plastics	4	161	10	-	208	23	-	20	-	-	426
Electrical & electronics products	-	-	-	-	-	-	-	14	-	-	14
Food, beverage & tobacco	308	897	11	-	-	-	49	3	-	-	1,268

Mechanical engineering, iron, steel, machineries & other metal	-	-	154	-	2,647	-	-	3	-	-	2,805
Paper, publication & printing, furniture & fixtures	274	-	-	-	-	3	-	34	24	-	335
Textiles, readymade garment & leather products	7	13	-	-	-	217	-	176	3	-	417
Miscellaneous	-	-	-	-	-	12	-	-	-	-	12
Total	961	1,126	7,093	-	2,855	287	49	251	27	-	12,649

Thermal energy consumption in industries of Madhesh Province by end-uses (TJ)

Category	Boiler	Process Heat
Cement, bricks, concrete & clay products	-	7,373
Chemical products, rubber, glass & plastics	405	21
Electrical & electronics products	8	6

Food, beverage & tobacco	1,068	199
Mechanical engineering, iron, steel, machineries & other metal	-	2,805
Paper, publication & printing, furniture & fixtures	243	92
Textiles, readymade garment & leather products	42	374
Miscellaneous	-	12
Total	1,767	10,882

Thermal energy consumption in industries of Bagmati Province by fuel types (TJ)

Category	Fuelwood	Agriculture Residue	Coal	Kerosene	Furnace Oil	Diesel	LPG	Electricity	Petrol	Briquette	Total
Cement, bricks, concrete & clay products	1,915	70	1,604	-	-	1	0	2	-	-	3,591
Chemical products, rubber, glass & plastics	551	37	628	-	16	504	18	599	-	-	2,353
Electrical & electronics products	-	-	-	-	-	-	-	8	-	-	8
Food, beverage & tobacco	3,852	910	21	449	3,389	3,576	41	319	0	-	12,558
Mechanical engineering, iron, steel, machineries & other metal	1	-	8	42	102	14	12	21	-	-	200
Paper, publication & printing, furniture & fixtures	4	0	-	-	1	8	5	4	-	-	22

Textiles, readymade garment & leather products	579	13	-	-	-	93	14	25	-	-	725
Miscellaneous	2	8	-	38	-	1	2	0	-	0	52
Total	6,904	1,039	2,2 61	529	3,508	4,19 7	93	978	0	0	19,5 09

Thermal energy consumption in industries of Bagmati Province by end-uses (TJ)

Category	Boiler	Process Heat
Cement, bricks, concrete & clay products	-	3,591
Chemical products, rubber, glass & plastics	309	2,044
Electrical & electronics products	-	8
Food, beverage & tobacco	5,796	6,761
Mechanical engineering, iron, steel, machineries & other metal	-	200
Paper, publication & printing, furniture & fixtures	10	12

Textiles, readymade garment & leather products	682	42
Miscellaneous	11	41
Total	6,810	12,700

Thermal energy consumption in industries of Gandaki Province by end-uses (TJ)

Category	Boiler	Process Heat
Cement, bricks, concrete & clay products	422	623
Chemical products, rubber, glass & plastics	-	19
Electrical & electronics products	-	-
Food, beverage & tobacco	3,447	3,838
Mechanical engineering, iron, steel, machineries & other metal	-	-
Paper, publication & printing, furniture & fixtures	0	2
Textiles, readymade garment & leather products	-	0
Miscellaneous	-	379
Total	3,870	4,861

Thermal energy consumption in industries of Lumbini Province by end-uses (TJ)

Category	Boiler	Process Heat
Cement, bricks, concrete & clay products	1,551	5,902
Chemical products, rubber, glass & plastics	332	1,306
Electrical & electronics products	-	-
Food, beverage & tobacco	3,684	284
Mechanical engineering, iron, steel, machineries & other metal	-	762
Paper, publication & printing, furniture & fixtures	4,037	4
Textiles, readymade garment & leather products	-	-
Miscellaneous	523	13
Total	10,128	8,270

Thermal energy consumption in industries of Karnali Province by end-uses (TJ)

Category	Boiler	Process Heat
Cement, bricks, concrete & clay products	10	36
Chemical products, rubber, glass & plastics	-	-
Electrical & electronics products	-	-
Food, beverage & tobacco	17	10
Mechanical engineering, iron, steel, machineries & other metal	-	18
Paper, publication & printing, furniture & fixtures	0	45
Textiles, readymade garment & leather products	-	0
Miscellaneous	-	-
Total	27	108

Thermal energy consumption in industries of Sudur Pashchim Province by end-uses (TJ)

Category	Boiler	Process Heat
Cement, bricks, concrete & clay products	113	1,200
Chemical products, rubber, glass & plastics	-	-
Electrical & electronics products	-	-
Food, beverage & tobacco	1,934	919
Mechanical engineering, iron, steel, machineries & other metal	-	1
Paper, publication & printing, furniture & fixtures	-	-
Textiles, readymade garment & leather products	-	-
Miscellaneous	-	-
Total	2,047	2,120

Manufacturing Industries registered up to 2022

Category	Koshi	Madhesh	Bagmati	Gandaki	Lumbini	Karnali	Sudur Pashchim	Total
Cement, bricks, concrete & clay products	34	34	91	8	73	3	4	247
Chemical products, rubber, glass & plastics	92	112	211	13	96	3	13	540
Electrical & electronics products	33	27	126	3	20	-	4	213
Food, beverage & tobacco	148	150	269	31	153	2	16	769
Mechanical engineering, iron, steel, machineries & other metal	44	87	65	3	59	-	3	261
Paper, publication & printing, furniture & fixtures	28	23	49	3	32	-	3	138
Textiles, readymade garment & leather products	53	72	846	3	25	-	6	1,005
Miscellaneous	9	13	61	2	16	-	6	107

Total	441	518	1,718	66	474	8	55	3,280

Share of GDPs in industries by ISIC standard

ISIC	Description	1996	2006	2011
15	Food and beverages	22.8%	27.0%	34.0%
16	Tobacco products	12.0%	17.1%	13.1%
17	Textiles	25.9%	10.2%	3.8%
18	Wearing apparel, fur	6.3%	1.4%	0.5%
19	Leather, leather products and footwear	1.3%	0.6%	0.8%
20	Wood products (excluding furniture)	1.4%	1.3%	2.0%
21	Paper and paper products	1.7%	4.2%	1.0%
22	Printing and publishing	1.4%	1.1%	0.6%

ISIC	Description	1996	2006	2011
23	Coke, refined petroleum products, nuclear fuel	0.2%	2.0%	0.4%
24	Chemicals and chemical products	6.0%	8.1%	7.7%
25	Rubber and plastic products	3.0%	4.2%	4.7%
26	Non-metallic mineral products	7.2%	7.9%	14.1%
27	Basic metals	1.8%	5.1%	5.4%
28	Fabricated metal products	5.0%	7.1%	8.9%
29	Machinery and equipment	0.1%	0.3%	0.3%
31	Electrical machinery and apparatus	2.2%	1.1%	0.8%
32	Radio, television and communication equipment	0.3%	0.4%	0.5%
34	Motor vehicles, trailers, semi-trailers	0.0%	0.0%	0.1%
36	Furniture; manufacturing	1.3%	0.9%	1.3%

Share of GDPs in industries as per the classification defined in the report

Category	1996	2006	2011
Cement, bricks, concrete & clay products	7.2%	7.9%	14.1%
Chemical products, rubber, glass & plastics	9.2%	12.3%	12.4%
Electrical & electronics products	2.5%	1.5%	1.3%
Food, beverage & tobacco	34.8%	44.1%	47.1%
Mechanical engineering, iron, steel, machineries & other metal	6.9%	12.5%	14.6%
Paper, publication & printing, furniture & fixtures	5.8%	7.5%	4.9%
Textiles, readymade garment & leather products	33.5%	12.2%	5.1%
Miscellaneous	0.2%	2.0%	0.5%

Share of GDP in different economic sectors

Economic Sector	Share to GDP
Agriculture	29.23%
Construction	7.39%
Mining	0.74%
Manufacturing	5.80%
Service	54.12%
Energy	2.72%

Emission factors (kg/TJ)

Category	N_2O	CO_2	CH_4	CO_2 equivalent
Fuelwood	4	112,000	30	115,712
Agriculture Residue	4		30	3,712
Coal	2	92,600	10	93,887
Kerosene	1	71,900	3	72,331
Furnace oil	1	77,400	3	77,831

Diesel	1	74,100	3	74,531
LPG	0	63,100	1	63,214
Electricity				-
Petrol	1	74,100	3	74,531
Briquette	3	97,500	1	98,478

Assessment of The Potential Use of Hydrogen Fuel for Thermal Applications in Nepalese Industries

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Date: November 26, 2023

To Whom It May Concern:

This is to certify that the paper titled "***Hydrogen Production Assessment from Surplus Hydropower Potential In Nepal***" (Submission# **391**) submitted by **Birendra Bhandari** as the first author has been accepted after the peer-review process for presentation in the 14th IOE Graduate Conference being held during Nov 29 to Dec 1, 2023. Kindly note that the publication of the conference proceedings is still underway and hence inclusion of the accepted manuscript in the conference proceedings is contingent upon the author's presence for presentation during the conference and timely response to further edits during the publication process.

Bhim Kumar Dahal, PhD
Convener,
14th IOE Graduate Conference