

Abstract

Industries in Nepal are heavy consumers of thermal energy, predominantly reliant on imported fossil fuels. This heavy dependence on fossil fuels not only impacts the country's economy but also contributes to greenhouse gas emissions, affecting Nepal's atmospheric conditions. In response to the challenge of reducing emissions, the Government of Nepal has devised the Nepal's Long-Term Strategy for Net Zero Emissions (LTS), which includes an estimated greenhouse gas (GHG) inventory for the year 2019. According to the LTS, the industrial sector's emissions amounted to approximately 4.49 million metric tons of CO₂ equivalent in 2019.

To address this issue and decrease emissions, hydrogen has emerged as a promising clean fuel alternative for the thermal applications in industries. This assignment aims to study the viability of hydrogen fuel for these applications and develop a roadmap for implementing green hydrogen-based alternative fuels. By incorporating hydrogen in major thermal applications like boilers and furnaces, the assignment seeks to determine the required hydrogen quantities in the coming years to replace emission-intensive fuels.

Many countries, including India, USA, Australia, and Japan, have already formulated strategies and roadmaps for adopting green hydrogen in various economic sectors. Nepal, too, has shown interest in this innovative technology by setting targets and implementing supportive policies. Notably, the Centre for Pollution Studies, in collaboration with Western Michigan University, developed the National Hydrogen Energy Roadmap of Nepal in 2007. Moreover, the Second Nationally Determined Contribution for 2020 proposed targets for clean energy generation in 2030 and 2045. The government has also taken action by including green hydrogen and green ammonia technology in a chemical fertilizer factory during the fiscal year 2022/23. Various research institutions, such as the Green Hydrogen Lab in Kathmandu University, are actively investigating hydrogen technology, while collaborative efforts, such as the memorandum of understanding between Nepal Electricity Authority and Kathmandu University, aim to commercialize ammonia production from hydrogen. Furthermore, Nepal Oil Corporation has initiated research into alternative fuels, including hydrogen.

For the assignment, numerous secondary data sources were collected and analyzed to estimate the energy status in industries for the base year 2022. According to reports from the Water and Energy Commission Secretariat, the energy consumption in industries for major thermal applications has been estimated to be around 92.90 petajoules (PJ) in 2022. Coal emerged as the primary fuel source (34.02%), followed by fuelwood (19.65%), agriculture residue (17.37%), furnace oil (13.04%), diesel (11.65%), and electricity (2.87%). The majority of the energy was consumed by furnaces used in process heat applications (61.74 PJ), with the remainder used in boilers. The emission in the base year has been calculated to be approximately 6.98 million metric tons of CO₂ equivalent. Among industries, cement, bricks, concrete, and clay product-based industries were found to be the most energy-intensive (39.67 PJ) and GHG-emissive (3.71 million metric tons of CO₂ equivalent).

The assignment delineates the immediate application cases of hydrogen. The applicability of hydrogen shows that the hydrogen is best suited for high grade heat applications. However, blending with other fuels, hydrogen can be useful in medium grade heat applications as well.

Depending on the temperature ranges the industries operate on during the production, hydrogen can be mainly useful in cement, bricks, concrete and clay product-based industries and glass, rubber, chemical products-based industries. In other industries, electricity is the amenable option in future. Thus, for these target industries, immediate applicability and challenges associated with using hydrogen has been presented in this assignment. The distinct combustion characteristics like high flame speed, high NO_x emissions and other factors of hydrogen necessitate certain modifications to the existing systems.

Furthermore, the assignment extrapolates future energy demands based on three economic growth scenarios: low, medium, and high. In the low economic growth scenario, thermal energy consumption is projected to reach 119.58 PJ by 2030 and escalate to 257.82 PJ by 2050, with CAGR of 3.71%. This would necessitate the import of 169.61 PJ of fossil fuels by 2050, representing almost twofold increase from the base year's requirement. The target industries namely cement and chemical industries, would need energies totalling up to about 144.56 PJ and 14.61 PJ respectively, by the year 2050. Hydrogen would provide about 72.88 PJ of energy to the cement industries while 13.87 PJ to the chemical ones. During the period 2036-2040, hydrogen demand would be about 1,248 thousand tons which will grow up to 3,110 thousand tons by the period 2046-2050. The electricity consumption in the latter period would be about 177 TWh which would require dedicated hydropower facilities. Hydrogen production dedicated hydropower capacities by the years 2040 and 2050, therefore, would be around 3,075 MW and 7,266 MW respectively. The GHG emission caused by the industries, without hydrogen penetration, has been estimated to be around 14.25 MMT and 20.91 MMT of $\text{CO}_{2\text{eq}}$ by the year 2040 and 2050. After the hydrogen penetration, the emission will be highly controlled and will go in downward trend after the year 2045 and reach the level below that of 2040 by the year 2050. The economic benefit of this carbon footprint savings, would amount to be around NRs 657 billion in the period, 2046-2050. The Marginal abatement cost by the period 2046-2050 would be around NRs 36,446 per tonne of $\text{CO}_{2\text{eq}}$.

In a scenario of medium economic growth, the need for thermal energy is expected to be roughly 144.40 PJ and 567.49 PJ by the years 2030 and 2050, signifying an average yearly growth rate of 6.68%. Such a scenario would mandate the import of approximately 373.33 PJ of fossil fuels by 2050, a quantity that surpasses the base year's total thermal energy demand by more than four times. The focal industries, such as those of cement and chemicals, would require energy total of nearly 318.19 PJ and 32.17 PJ respectively, by 2050. Hydrogen could supply about 160.41 PJ of energy to the cement sector and 30.54 PJ to the chemical sector. In the decade spanning 2036-2040, the demand for hydrogen is expected to be around 1,931 thousand tons, escalating to 6,511 thousand tons in the 2046-2050 period. Electrical consumption during the latter period would be about 370 TWh, demanding dedicated hydroelectric power facilities. Hydrogen production facilities powered by hydropower would require capacities of approximately 5,037 MW by 2040 and 15,993 MW by 2050. The greenhouse gas (GHG) emissions from industries without hydrogen integration, are estimated to be around 23.34 million metric tons (MMT) and 46.03 MMT of $\text{CO}_{2\text{eq}}$ by the years 2040 and 2050, respectively. Upon the adoption of hydrogen, these emissions will be significantly curtailed, and the compound annual growth rate (CAGR) would be capped at roughly 3.78%. The economic value derived from this reduction in carbon emissions could total about NRs 1,374 billion in the 2046-2050 period. The marginal abatement

cost in this scenario is expected to reach about NRs 33,930 per ton of CO_{2eq} by the period 2046-2050, from NRs 43,297 per ton of CO_{2eq} in 2036-2040.

Finally, in high economic growth scenario, the thermal-intensive applications are forecasted to demand energy levels around 173.61 PJ and 1,189.41 PJ by 2030 and 2050 respectively, yielding an average annual growth rate of 9.53%. Such a situation would compel the import of a significant 782.46 PJ of fossil fuels by 2050. The target industries, specifically cement and chemical industries, would necessitate energy amounts of roughly 666.90 PJ and 67.42 PJ respectively, by 2050. Hydrogen could deliver approximately 336.21 PJ of energy to the cement sector and 64.00 PJ to the chemical sector. In the 2036-2040 period, the demand for hydrogen could reach about 3,052 thousand tons, which would then rise to 13,117 thousand tons in the decade from 2046-2050. Electrical consumption during this latter period is expected to be around 746 TWh. The hydroelectric capacities dedicated to hydrogen production would have to be about 8,324 MW by 2040 and 33,520 MW by 2050. GHG emissions from industries, in the absence of hydrogen use, are projected to be around 38.57 MMT and 96.47 MMT of CO₂ equivalent by the years 2040 and 2050 respectively. After integrating hydrogen into these industries, these emissions will be lessened and the CAGR would be restrained to approximately 6.56%. The economic advantage gained from these carbon savings could be as high as NRs 2,767 billion in the 2046-2050 period. The marginal abatement cost in this scenario is largest at about NRs 46,712 per ton of CO_{2eq} in the period 2046-2050.

These scenarios indicate that 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 assignment includes possibilities for using hydrogen in various industries based on their thermal heat requirements, with a focus on ammonia production from hydrogen as well. It identifies several barriers and obstacles, such as economic viability, value recognition, and inadequate infrastructure for hydrogen production, storage, transport, and consumption. The theory of change for this new technology has also been included in the assignment. According to this, a roadmap is proposed, in order to achieve the vision, the assignment also proposes an implementation plan for different phases of hydrogen technology up to 2050. The case studies done in different industries have been referenced during the assignment preparation which has provided with great insights on the industries status and their opinions on this transition on the fuel use.

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Acronyms and Abbreviations

AEPC	Alternative Energy Promotion Centre
CAGR	Compound Annual Growth Rate
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 ₂ O	Nitrous Oxide
NAP	National Adaptation Plan
NDC	Nationally Determined Contribution
NESC	Nepal Energy Sector Vision
NOC	Nepal Oil Corporation
NPC	National Planning Commission
PJ	Peta Joule
RD & D	Research Development and Demonstration
RDI	Research Development and Innovation
SDG	Sustainable Development Goals
TJ	Tera 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

Water and Energy Commission Secretariat is a governmental agency with the primary responsibility to assist Government of Nepal and different ministries relating to Water Resources and Energy in the formulation of policies and planning of projects in the water and energy resources sector. It has previously published different documents highlighting the energy consumption and supply status of different along with forecasting the energy demand in different scenarios. Some of these documents are Nepal's Energy Sector Vision 2050 A.D., Electricity Demand Forecast Report (2014-2040), Energy Consumption and Supply Situation in Federal System of Nepal (Koshi, Madhesh Province and Bagmati Province) etc. All these reports highlight the necessity for the increase in the share of renewable energy in the overall energy mix of the country.

Global warming has become more severe than ever before in history. Carbon dioxide emissions are responsible for about 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. The emissions from industrial sector alone amounted to 9.2 Gt (IEA, 2023). The industrial sector is highly thermal intensive sector. The most convenient and cost-effective method is combustion of fuels in the system. Industries are heavily reliant on fossil fuels like coal, diesel, furnace oil, etc. for thermal heat. The combustion of these fuels has made the sector extremely emission intensive. The convenience of this method and prominent use of the fossil fuels has made this sector as one of the hard-to-abate sectors. Therefore, there is urgent need of alternative fuels to decarbonize the industrial sector whilst sustaining the energy demand. Hydrogen is one of the alternative fuels that promises to reduce the current emissions and decarbonize the sector.

Nepalese industries have relied on fossil fuels for industrial heating applications. Coal is the primary energy source for the Nepalese industry. 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 NPR 665 per cylinder on LPG, NPRs 16.28 per liter on petrol, and NPRs 11.78 liter on diesel (NOC, 2022). There are potential alternative clean fuels, but the subsidies on fossil fuels have made them difficult to compete in the marketplace.

Green Hydrogen can be an alternative fuel for clean energy in a world struggling to limit global warming. In the present context, hydrogen produced from renewable electricity through an electrolysis process is considered green as it has very low carbon footprints as emits no greenhouse gasses. With the increasing trend to shift towards renewable energy technology, the research and development towards green hydrogen as a fuel is accelerating at a rapid speed. Even in case of Nepal, the Government of Nepal has explicitly planned to increase the share of renewable energy (15%) in the overall energy mix in its second Nationally Determined Contribution. In addition, the Government of Nepal has targeted to achieve Net Zero Emission by 2045 in its Long-Term Strategy for Net-zero Emission.

Keeping up with the necessity for the promotion of renewable energy in Nepal, WECS has developed a term of reference for *“Study of hydrogen fuel for thermal applications in Industries”* with the aim to look at the current scenario in different industries and propose a solution on green hydrogen based alternative fuels for the industrial heating process in order to help drive a green hydrogen-based economy in Nepal and to facilitate the decarbonization process in industrial sector.

1.2 Objectives

The main objective of the study is to carry out the study on hydrogen fuel for thermal applications. The specific objectives are as follows:

- To collect data and analyze the present scenario of the energy mix in different industrial thermal applications.
- To investigate the possibility of hydrogen fuel as a suitable option for decarbonizing the industrial thermal sectors to reduce the consumption of traditional and fossil fuels.
- To develop a road map for intervention of green hydrogen-based alternative fuels in the industrial sector.

1.3 Scope of work

The assignment will be carried out systematically using appropriate methods and methodology. The scope of work in order to fulfill the consulting assignment as indicated in request for proposal (RFP) includes

- To identify the existing database and information system of individual energy resources and energy consumption of industrial heating sector
- To collect primary and secondary data and analyze the present energy mix scenario in different industrial thermal applications in Nepal
- To study and identify the potential green hydrogen-based fuel that can help effectively replace the existing traditional source of fuel being used in different industrial heating application of Nepal
- To investigate the potential for the replacement of fossil fuel with green hydrogen-based fuel for the decarbonization of industrial heating sector
- To analyze the economic aspect for the application of green hydrogen-based fuel in industrial heating applications in the context of Nepal
- To establish the need and opportunity for green hydrogen as means of energy balance in the industrial sector for low carbon emission in Nepal
- To develop a roadmap for intervention of green hydrogen-based fuels in the industrial heating sector

Chapter Two: Overview of Thermal Heat in Industries

2.1 Energy consumption in Nepal

Nepal has experienced a constant rise in energy consumption, reaching 626 PJ in 2021 at a CAGR of 10.60%. The majority of energy usage in the country is attributed to the use of traditional fuels, accounting for 66.26% of total energy consumption, while commercial fuels constitute 31.34%, and renewable fuels only make up 2.40% of the energy mix. Glancing at the economic sectors, the residential sector consumes 63.2% of the total energy consumption, followed by the industrial sector at 18.3%.

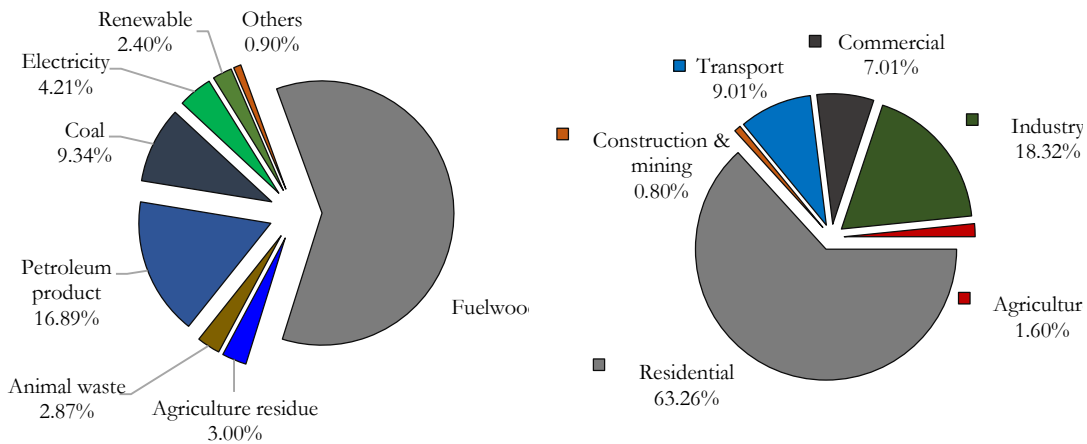


Figure 2-1: Energy consumption status of Nepal in 2021 (by fuels and economic sectors)

The industrial sector relies heavily on traditional fuels, especially biomass, dung cake, and agricultural residue, as they are commonly burned in boilers and furnaces for various purposes. This has resulted in use of traditional fuels such as biomass, dung cake, and agricultural residue contributing to 84.87% and 52.48% of energy consumption in boilers and furnace in the industrial sector.

2.2 Industries distribution

There are 3,280 manufacturing industries out of the total industries registered by the fiscal year 2022. The share of the manufacturing industries by category type in 2022 is as shown in Figure 2-2. Statistics shows that textiles, readymade garment & leather products-based industries are highest in number, followed by industries based on food, beverage and tobacco products. Number of chemical products, rubber, glass & plastics-based industries rank the third whereas cement, bricks, concrete & clay products-based industries are the fourth-most registered industries.

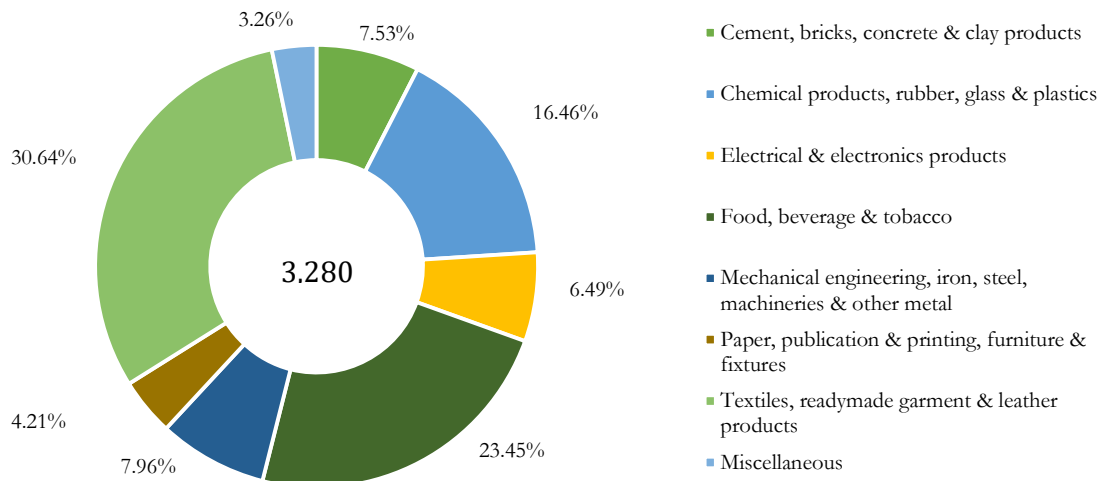


Figure 2-2: Industries in Nepal by category type (2022)

The distribution of industries for each province is shown in Figure 2-3. Most of the industries are in Bagmati province (1,718), followed by Madhesh (518) and Lumbini (474). In all provinces except Karnali, food, beverage & tobacco industries are the most registered ones followed by chemical products, rubber, glass & plastics. Province wise, the number of cement, bricks, concrete & clay products-based industries is highest in Bagmati province (91), followed by Lumbini (73) and Koshi and Madhesh. Karnali province has only eight industries situated in it, with three being cement, bricks, concrete & clay products-based, another three being chemical products, rubber, glass & plastics-based and last two being food, beverage & tobacco-based ones.

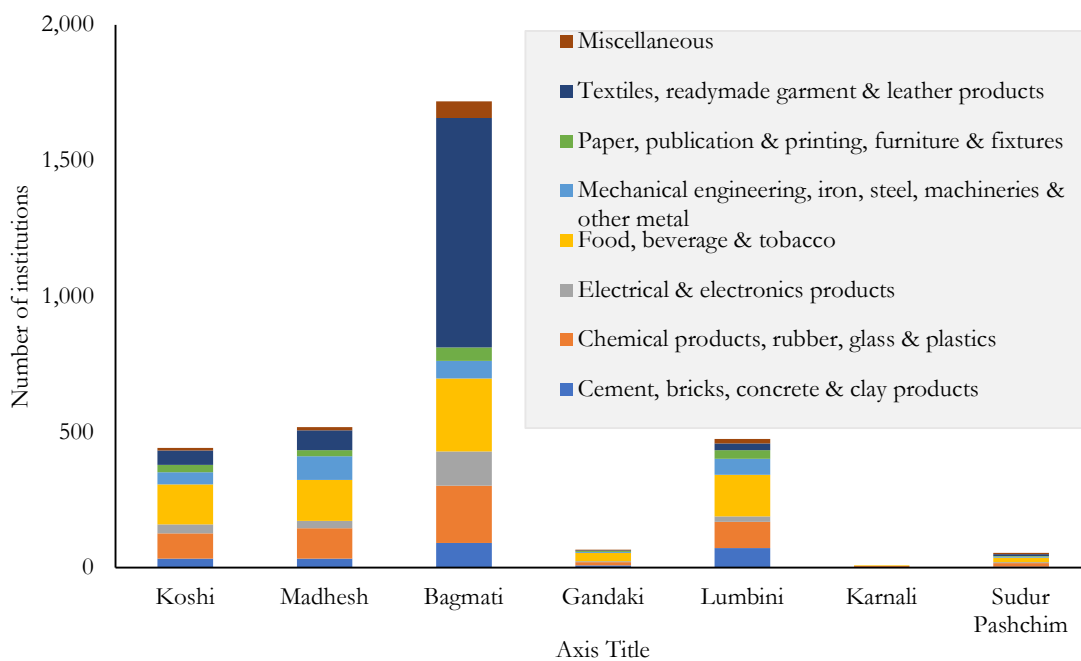


Figure 2-3: Industries distribution in provinces

2.3 Thermal energy consumption

Total thermal energy consumption by manufacturing industries has been estimated to be around 92.90 PJ. The thermal energy mix scenario in the industrial sector is shown in Figure 2-4. The primary fuel for thermal applications in industries is coal, at 31.61 PJ, followed by fuelwood (18.26PJ). Agriculture residue ranks third in fuel consumption, followed by furnace oil which amounts to about 16.14 PJ. Briquette use is not found in industries while share of LPG and Petrol uses is under 1%. Electricity consumption on the other hand, is found to be about 2.66 PJ.

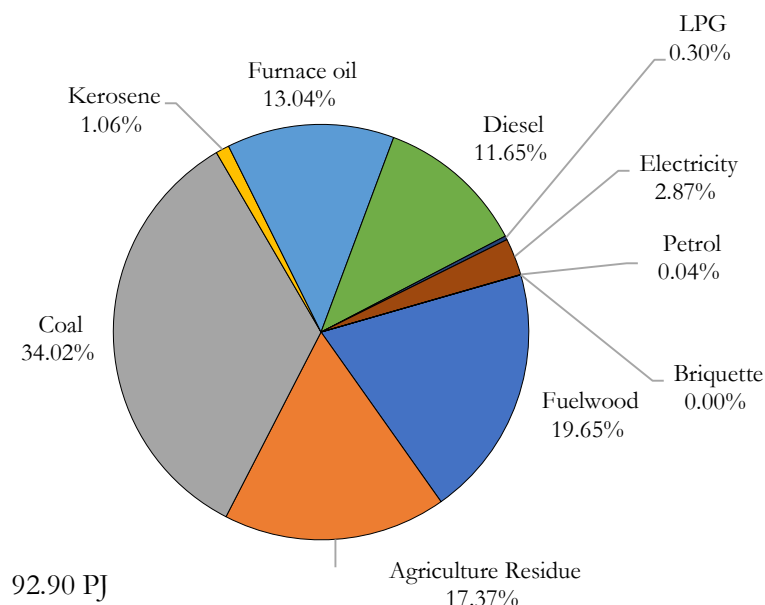


Figure 2-4: Thermal energy mix scenario in industries in 2022

Therefore, the industries are highly reliant on fossil fuels and traditional fuels which are GHG emission intensive fuels. Electricity, the only cleanest fuel currently in these applications, has minor share, meaning the current industries are highly carbon intensive due to the need of high thermal energy.

2.4 Consumption by category type

The thermal energy consumption in industrial sub-categories is different depending on the processes they incorporate and the products they make. Cement, bricks, concrete & clay products heavily use furnaces to burn and dry the products, therefore, they use coal and furnace in large amounts. The energy demand in the industries by fuel-types is as shown in Table 2-1. The traditional fuels category incorporates fuelwood and agriculture residue whereas briquette is taken as modern biomass. Fossil based fuels, namely petrol, diesel, coal, furnace oil, LPG and kerosene are grouped together in Non-renewable category. The industries in Nepal consume Non-renewable energy in largest quantity, at around 63%, followed by traditional fuels. Modern biomass is not used generally in industries for thermal energy. Electricity use is still under 3%, which indicated that overall industries in Nepal are emission intensive

Table 2-1: Total thermal energy demand of industries by fuel types in 2022

(Tera Joule)

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

2.5 Consumption by end-uses

In regard to the end-use applications, the boiler and process heats have different energy mixes. The energy consumption in the industries by end-use applications is shown in Table 2-2. Boilers are heavily used in food, beverage & tobacco industries whereas industries based on cement, bricks, concrete & clay products use mostly thermal energy in furnaces for process heat applications. Mechanical engineering, iron, steel, machineries & other metal-based industries only use furnaces. In overall, process heat applications make the most amount of thermal energy consumption in industries, at 66.45%.

Table 2-2: Thermal energy consumption in industries by end-use applications

(Tera Joule)

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

In case of energy mix scenario of each thermal applications, boilers in industries are heavily dependent on agriculture residue while furnaces (process heat) are on coal which is shown in Figure 2-5. Fuelwood ranks second for thermal use in boiler, followed by diesel which shows that traditional fuels are the primary source of thermal energy in boilers. In case of furnaces, Coal is the primary fuel, at 31.46 PJ, followed by furnace oil (11.83 PJ) and diesel (7.11 PJ). This shows that furnaces in industries of Nepal, are heavily reliant on fossil-based fuels. Share of electricity consumption in the both applications are more or less same.

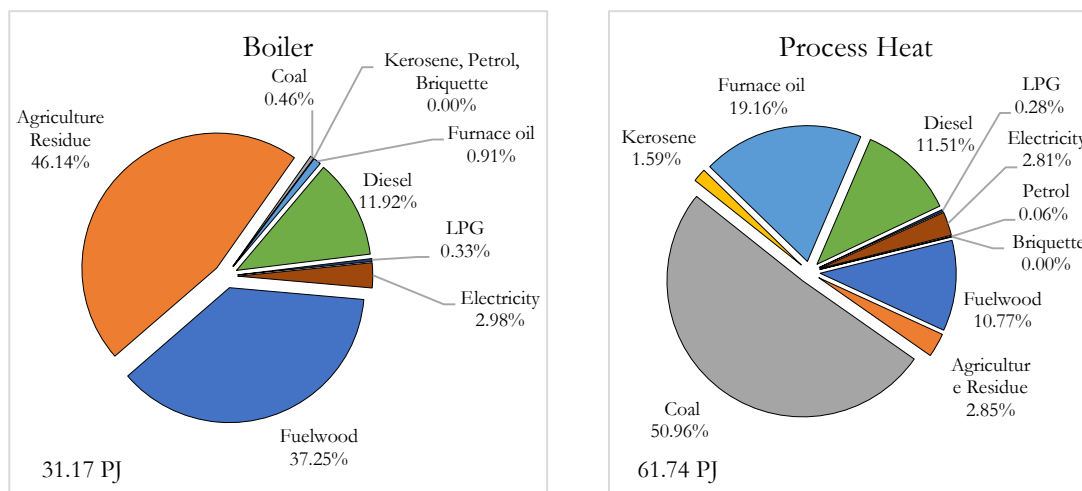


Figure 2-5: Energy mix scenario in boilers and process heat applications

2.6 Emission by industries

In case of the emissions, three GHGs have been considered, namely methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). 1 kg of N_2O emission is equivalent to introducing 298 kg of CO_2 into the atmosphere, whereas 1 kg of CH_4 is equivalent to 84 kg of CO_2 . The total emission in the base year has been estimated to be around 7.4 MMT of $\text{CO}_{2\text{eq}}$ of which the contribution by the different industrial categories is as shown in Figure 2-6. The main contributor to the emission is the cement, bricks, concrete & clay products, owing to the fact that they are the main consumer of the thermal energy. The primary fuel consumption in these industries is also coal, therefore, replacement of coal with clean energy sources such as electricity and green hydrogen itself is the immediate need manifested by emission status in base year. The second most emission intensive industries are the industries that are based on food, beverage & tobacco products, followed by mechanical engineering, iron, steel, machineries & other metal-based industries and chemical products, rubber, glass & plastics-based industries. Electrical & electronics products-based industries (not shown in Figure 2-6) are the clean industries with no contribution to the emission whereas rest of the industries emit GHGs in some way or another in respective quantities.

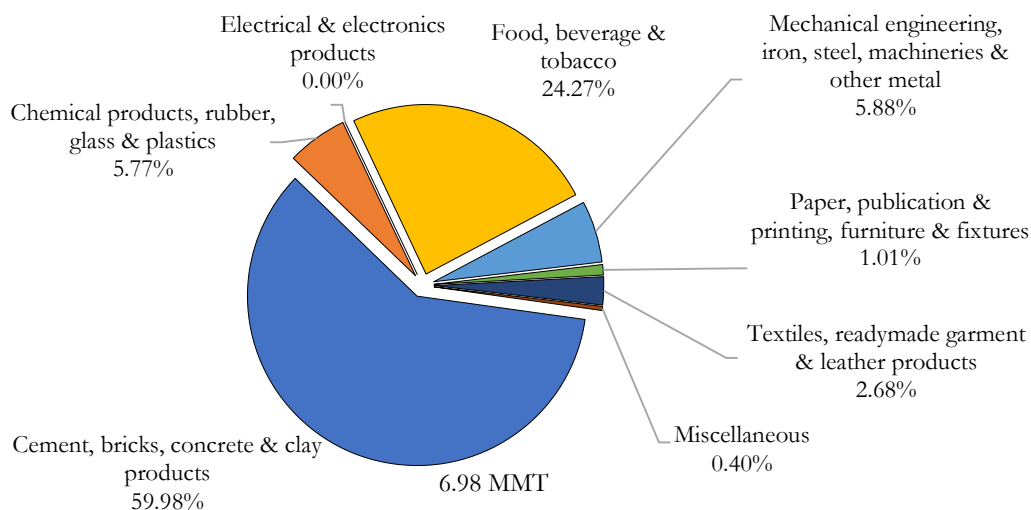


Figure 2-6: Emission mix status by different industrial types (CO_{2eq})

The emission by industries as per the GHGs, is as shown in Table 2-3. Carbon dioxide is the most emitted GHG, largely produced by cement, bricks, concrete & clay products-based industries, followed by food, beverage & tobacco industries and mechanical engineering, iron, steel, machineries & other metal-based industries.

Table 2-3: Emission in base year by GHG types

Category	GHGs emission			Total CO _{2eq} emission
	N ₂ O	CO ₂	CH ₄	
Cement, bricks, concrete & clay products	0.00	3.64	0.00	3.71
Chemical products, rubber, glass & plastics	0.00	0.38	0.00	0.39
Electrical & electronics products	-	-	-	-
Food, beverage & tobacco	0.00	2.13	0.00	2.19
Mechanical engineering, iron, steel, machineries & other metal	0.00	0.38	0.00	0.38
Paper, publication & printing, furniture & fixtures	0.00	0.12	0.00	0.14
Textiles, readymade garment & leather products	0.00	0.09	0.00	0.11
Miscellaneous	0.00	0.05	0.00	0.06
Grand Total	0.00	6.80	0.00	6.98

(Million tons)

Chapter Three: Hydrogen for Nepal

3.1 Hydrogen Fundamentals

Hydrogen, the most abundant chemical substance in the universe, can be used as an energy carrier as it has the highest energy density i.e., 120 MJ/kg which is more than thrice the energy density of other fossil fuels. Hydrogen can be produced from several resources such as natural gas, nuclear power, biomass, and renewable power like solar and wind. The hydrogen thus, obtained can be stored by pressurization and liquefaction which can be used to generate energy with little or no carbon emissions. It can be directly combusted or used as reducing agent in chemical processes. Moreover, it can be used to produce electricity using fuel cells. The versatility in both production and combustion and low emission when using, has made hydrogen an attractive fuel with promising future.

Based on the production pathways, hydrogen has been colour-coded by industries as “hydrogen rainbow”. Three of the most common hydrogen types are green, grey and blue. The hydrogen produced with steam reforming of natural gas or coal, is termed as grey hydrogen. It is the most carbon-intensive method. If the carbon released during this process is captured and stored, then it is called blue hydrogen. This is less emission intensive method than the grey. Green hydrogen is the cleanest fuel with no emission during the production as it is obtained from the electrolysis process utilizing the renewable energy. The only by-product in this process is oxygen which can be stored for other purposes.

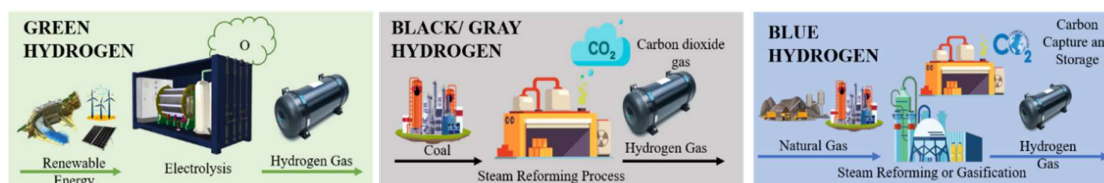


Figure 3-1: Type of Hydrogen fuels

The consumption of hydrogen is clean however the current production of hydrogen is still emission intensive. In 2021, about 94 Mt of hydrogen was produced which was 5% increase from the previous year (IEA, 2022). About 96% of hydrogen was produced with natural gas and fossil fuels and only 4% of hydrogen was produced with electrolysis process. Moreover, only 33% of electricity used in this process comes from renewable energy, this makes the share of green hydrogen to be mere 1% (IRENA, 2022).

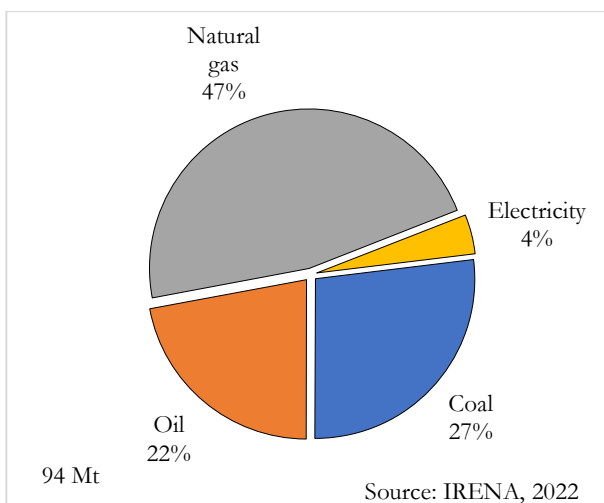


Figure 3-2: Source of energy for global Hydrogen production in 2021

Many countries are striving for an energy transition from grey and blue hydrogen to Green because of the clean production. Therefore, green hydrogen has emerged as a key element to achieve net-zero emissions from heavy industry and transport. Along with the net-zero commitments by growing numbers of governments, green hydrogen has started gaining momentum because of low-cost renewable electricity, ongoing technological improvements and the benefits of greater power-system flexibility. Nepal has ample potential for renewable resources including hydropower and solar. The resources can produce green hydrogen sustainably and cost-effectively. Green Hydrogen can channel renewable energy sources to decarbonize the high heat energy applications in the industrial and transportation sectors. The energy cost for hydrogen production varies from US\$ 5.91 to US\$ 12.75 depending upon the production period and tariff rates. In contrast, Nepal has a competitive advantage over other nations as excess energy with the risk of being spilled, can be utilized for green hydrogen production thus reducing the energy cost. If the excess electricity is provided at a discounted rate, the cost of production for 1 kg of hydrogen would come down significantly to US\$ 1.17- US\$ 2.55 for different time-of-day tariff rates (Biraj Singh Thapa, 2021). The policy-based interventions to promote renewables as the primary supply of energy can push green hydrogen to overtake fossil fuels both technically and economically in Nepal. The green hydrogen technology can help decrease the load during the peak time and help in flattening of the load curve by acting as an energy storage from hydroelectricity during off periods and utilizing that energy during peak time.

3.2 Production possibility of Hydrogen in Nepal

Nepal has significant potential for green hydrogen production using its electricity resources. Out of technically feasible hydropower capacity of 72.54 GW, the techno-economic capacity of Nepal is about 32.68 GW (WECS, 2019). However, as of fiscal year 2021/22, harnessed hydropower capacity is only about 2,082 MW which is around only 5% of total economic capacity (NEA, 2022). The number of hydropower plants is growing rapidly in recent years and the hydroelectricity export to India is also increasing during the wet season. Therefore, the future holds a great potential of hydroelectricity for Nepal. In near future, there will be surge of electricity in Nepal which cannot be consumed domestically with current rate of the electricity demand growth. Therefore, it is often forecasted that the large amount of electricity will go unused and only the export will be the option.

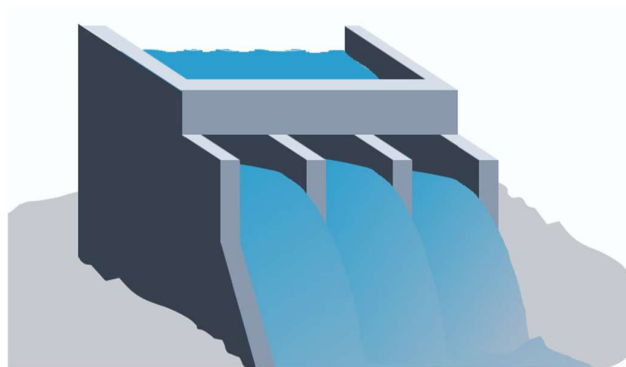


Figure 3-3: Hydroelectricity in Nepal

Hydrogen can play vital role in this scenario. Since green hydrogen is the cleanest fuel from production to consumption, the excess electricity can be used to produce green hydrogen in order to consume in industries for thermal applications. The international levelized cost of green hydrogen is about \$4 to \$6, of which electricity cost is the primary factor (IEA, 2022). Producing green hydrogen from the electricity at cheaper rates will provide a great pathway into the utilization of the hydroelectricity and decarbonization of the industries of Nepal. In regards to this potential use of hydroelectricity, several studies have been conducted. Biraj Singh Thapa in his paper, has shown that hydrogen production potential for Nepal using surplus electricity ranges from 63,072 tonnes to 3,153,360 tons by 2030 utilizing the 20% and 100% of contemporary surplus electricity respectively (Thapa et al., 2021). Therefore, there is huge possibility of production of hydrogen in Nepal which can replace current import of fossil fuels and move the nation into decarbonization phase. Another study has proposed that the levelized cost of hydrogen if produced in Nepal ranges from 3.8€/kg to 4.5€/kg (Bhandari et al., 2023). The electricity tariff rate in this study was considered to the average of power purchase agreement (PPA) between NEA and IPPs. With reduction in electricity tariff rate for hydrogen production by the government, the LCOH can be further reduced which will make the application in industrial sector feasible and economic. NEA Managing Director Ghising has advocated for the utilization of electricity from hydropower projects for hydrogen and ammonia production, along with the establishment of a fertilizer factory, as a promising option.

3.3 Hydrogen Value chain

In order to decarbonize the industries in Nepal, a hydrogen value chain need to incorporated. It is a series of consecutive steps that goes from production site to the actual end-use in the target industries. Embracing a hydrogen value chain presents a transformative opportunity for Nepal's industries to embrace decarbonization and pave the way for a greener and more sustainable future. By establishing a well-coordinated series of steps from hydrogen production to its utilization, Nepal can harness its renewable energy potential, reduce carbon emissions, and enhance its industrial competitiveness on the global stage. The hydrogen value chain for thermal heat applications in industries is as shown in Figure 3-4.

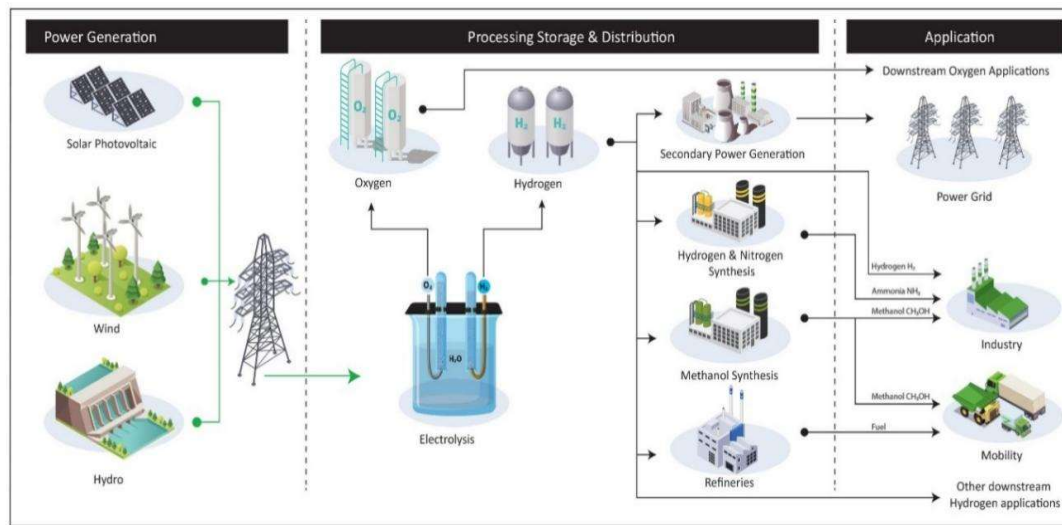


Figure 3-4: Green Hydrogen value chain

The path to achieve emission reduction in industries through hydrogen utilization in Nepal is outlined below:

- **Hydropower Generation**

The process begins with the generation of electricity from abundant hydropower sources in Nepal. Hydropower plants harness the energy from flowing water to produce clean and renewable electricity, contributing to Nepal's commitment to sustainable energy production.

- **Electricity Transmission**

The generated electricity is transmitted through robust and efficient transmission lines to ensure its smooth and reliable distribution across different regions of the country. The establishment of a well-developed electricity transmission infrastructure is crucial to effectively supply power to the subsequent stages of the hydrogen value chain.

- **Hydrogen Production in electrolysis plant**

At the heart of the hydrogen value chain, an electrolysis plant comes into play. Here, electricity from the hydropower grid is directed to an electrolyser, where water (H_2O) undergoes a process called electrolysis. During this process, water molecules are split into hydrogen gas (H_2) and oxygen gas (O_2). Sufficient water supply is provided to ensure the production of one kilogram of hydrogen with 50 kilowatt-hours (kWh) of electricity and 9 litres of water.

- **Hydrogen Compression and Liquefaction**

The produced hydrogen is then compressed and liquefied to enhance its storage and transport capabilities. This ensures that large quantities of hydrogen can be efficiently stored and moved to different locations or industries as required. Additionally, the by-product oxygen generated during electrolysis finds use in various applications, further maximizing the overall benefits of the hydrogen production process.

- **Storage and Transportation**

Once compressed and liquefied, the liquid hydrogen is either stored in specialized storage facilities or transported to target industries using heavy vehicles. Adequate safety measures are employed to handle and transport hydrogen, considering its unique properties as a cryogenic and flammable gas.

- **Utilization in industries for thermal heat**

The final stage of the hydrogen value chain involves the utilization of hydrogen in industries for thermal heat applications. Industries such as cement, steel, and chemical production, which require high-temperature processes, can effectively replace conventional fossil fuels with hydrogen. By doing so, these industries significantly reduce their carbon emissions, contributing to Nepal's broader efforts in combatting climate change and achieving sustainability goals.

This comprehensive hydrogen value chain represents a holistic approach to emission reduction in industries, leveraging Nepal's renewable energy resources to produce clean hydrogen for high-temperature industrial processes. The integration of hydropower and hydrogen technologies presents a compelling opportunity for Nepal to transition towards a low-carbon and environmentally conscious industrial sector. The successful implementation of this roadmap requires strong collaboration between the government, private sector, and research institutions, along with supportive policies and investments to realize the full potential of hydrogen as a clean and sustainable energy carrier in Nepal.

3.4 Hydrogen for thermal heat

Hydrogen being the emission clean fuel has the potential to power the industrial sector with high thermal heat demand. Industrial heats are divided into three grades depending on the temperature; low grade heat being below 100°C, medium grade heat 100°C to 400°C, high grade heat above 400°C (IRENA, 2020). Hydrogen combustion produces high-grade heat at around 2,045°C in the air (Helmenstine, 2019)¹. More than 85% of the industrial heat is consumed in iron and steel, chemicals and cement industries with around 95% of high-temperature heat provided by fossil fuels and combustible by-products (IEA, 2019). While electrical heating offers benefits like accurate temperature control and reduced maintenance expenses, its implementation necessitates the overhaul of industrial equipment and significant capital investment. As a result, industrial operators might favour less disruptive alternatives, such as hydrogen, which requires minimal redesigning.

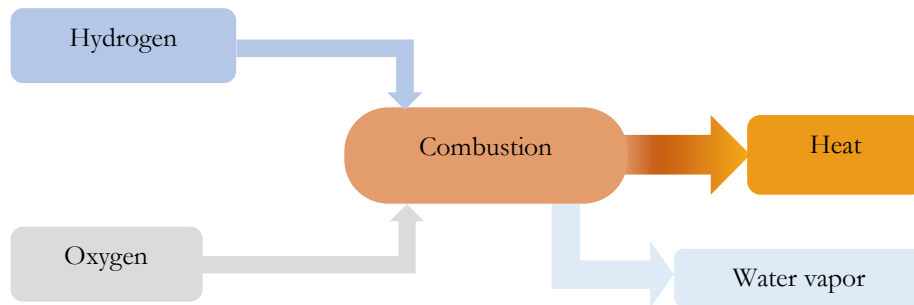


Figure 3-5: Combustion of hydrogen for thermal purposes

Critical challenges to using hydrogen for high-temperature heat:

- **Changes in heat transfer characteristics**

Direct replacement of current fuels in existing furnaces is not feasible. As its flame velocity and combustion temperature are different in contrast to the current fuels. For example, flame speed of Hydrogen fuel reaches about 1.7 meters per second while that of natural gas is about only 0.4 meters per second². This makes the controlling of the hydrogen flame in the combustion chamber very difficult vis-à-vis other commercial fuels. Furthermore, it causes flashback effect which is a phenomenon when flame speed overcomes the gas-air mixture flow velocity exiting the burner making the flame rush

¹ <https://www.thoughtco.com/flame-temperatures-table-607307>

² <https://cea.org.uk/practical-considerations-for-firing-hydrogen-versus-natural-gas/>

back into the gas orifice and make explosive sound. This will induce high thermal and structural stress into the burner. Also, the walls of the burner will need redesign because of the high flame temperature.

- **Higher NO_x emissions**

Air when heated to high temperature produces NO_x. Though hydrogen does not produce any emissions apart from water vapor, the high flame temperature produced during burning of hydrogen does cause the generation of NO_x. Therefore, in order to reduce the emissions, the burner has to be designed or the hydrogen has to be blended in some form or another, so that the flame temperature and rate of hydrogen and air mixing slow down.

- **Changes in flue gas composition**

When switching from existing fuels into hydrogen, the flow rate of the flue gas reduces. A study has shown that replacing natural gas with hydrogen, may cause reduction of as much as about 11% in flue gas flow³. Since the only by product is water vapor, this will change the flue gas composition as well. This will affect the radiation flux in the chamber.

- **Colour of the flame**

The hydrogen burns with a pale blue flame that is almost invisible during the daylight. Therefore, the hydrogen flame is almost impossible to see with the naked eye. This makes the visual inspection of the hydrogen fuel very difficult. Blending with ammonia, can make the flame visible.

3.5 Applicability in Industries

In industries, major thermal uses encompass several end-uses, including boilers, process heat, and space heating. Space heating typically necessitates the utilization of low-grade heat, whereas boilers demand medium to high-grade heat. Similarly, furnaces employed in process heat applications operate with high-grade heat. Various research has indicated that low-grade heat applications in industry are more effectively served through direct electric utilization, while the demand for high-grade heat restricts the feasibility of widespread electrical implementation. Consequently, the combustion of hydrogen emerges as a more suitable alternative.

³ <https://www.industriadefuturo.pt/wp-content/uploads/2023/03/Sander-Gersen-DNV.pdf>

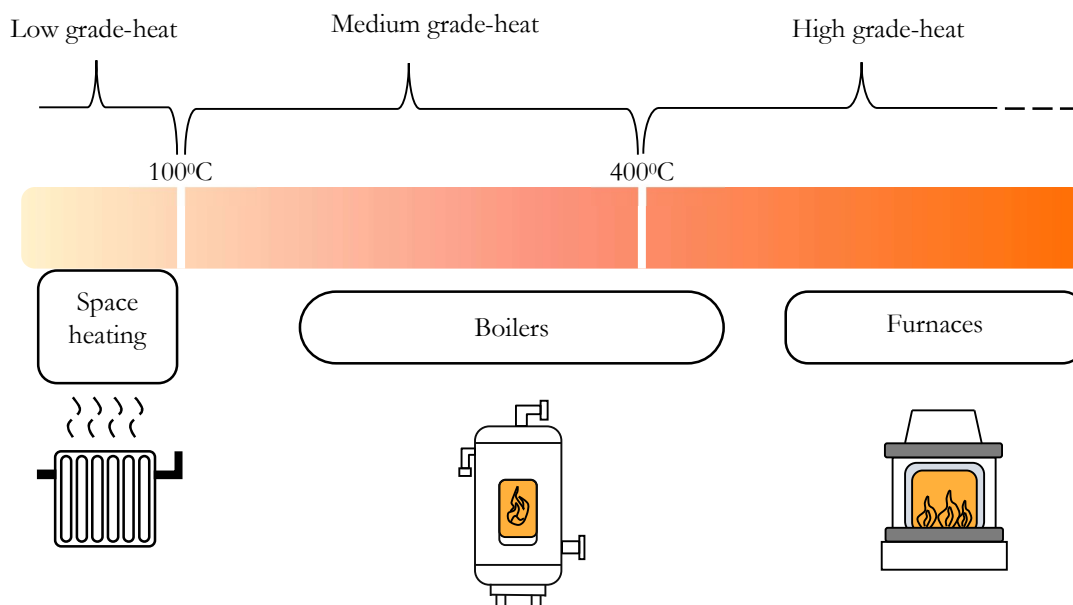


Figure 3-6: Different thermal technologies used in industries

Certain industries, such as cement, bricks, concrete, clay products, chemical products, rubber, glass, and plastics, require high-grade heat for their processes. These industries present excellent opportunities for hydrogen adoption due to their specific technology and combustion needs. However, electrification may be feasible in other industrial sectors, but for these particular industries, implementing electrification would necessitate a complete overhaul and redesign of their existing systems.

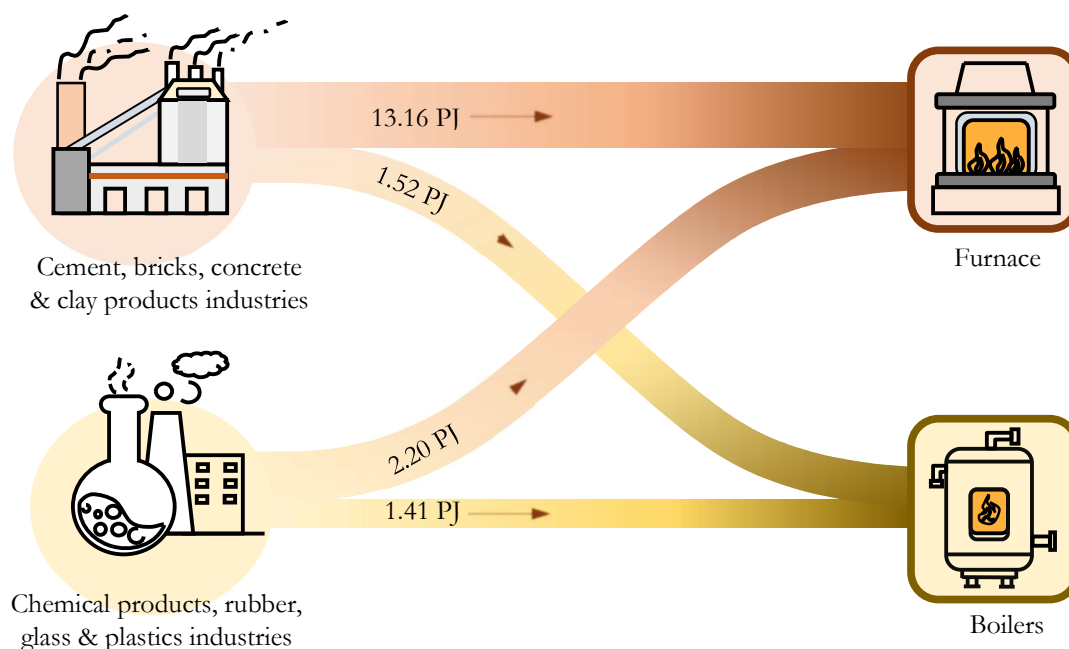


Figure 3-7: Target industries and current thermal technologies

3.6 Immediate application of hydrogen

Immediate application of hydrogen in the base year would need complete replacement of the fuels other than electricity. The amount of hydrogen needed in targeted industries by the end-uses is shown in Figure 3-8. Cement, bricks, concrete & clay products-based industries will need almost five times more hydrogen than chemical products, rubber, glass & plastics industries. The demands of hydrogen in boilers alone in both the target industries are more or less same.

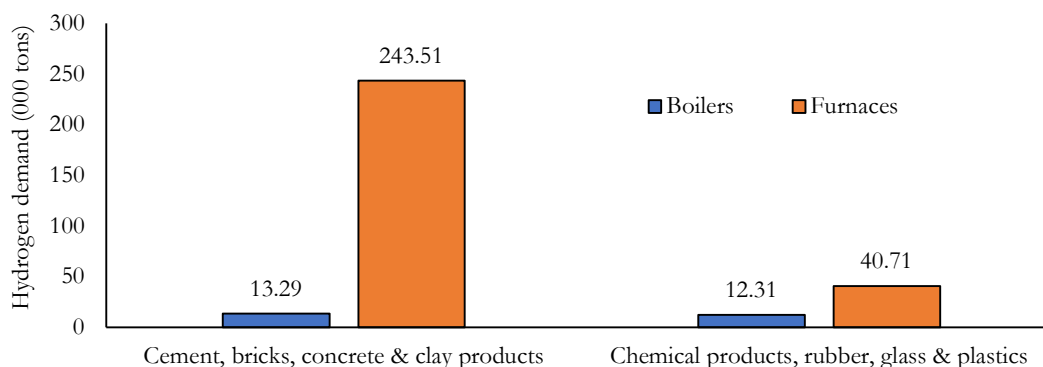


Figure 3-8: Immediate application of hydrogen in industries

Furnaces are the most energy intensive end applications in industries requiring more than ten-fold the hydrogen for boilers. The electricity consumption for hydrogen production in electrolysis plant is presented in Table 3-1, along with the dedicated hydropower capacity. Notably, the sheer electricity demand for hydrogen production alone would almost exhaust the entire installed hydropower plant capacity in the base year if immediate hydrogen implementation were to occur. This emphasizes the need for careful planning and efficient use of resources to scale up hydrogen production without compromising the stability of the energy grid and other essential industries relying on hydropower. Balancing hydrogen integration with sustainable growth strategies becomes crucial to harness its potential while ensuring the long-term viability and stability of Nepal's energy landscape.

Table 3-1: 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

3.7 Consideration for cost analysis

Currently hydrogen is relatively expensive to other fuels. The cost is the main barrier pertinent in the scenario. However, Nepal being rich in hydroelectricity can reduce the cost of producing green hydrogen by subsidizing the electricity cost. The Levelized cost of hydrogen has to be made affordable for industries to transition into this clean energy. For the succeeding analysis sections, the levelized cost of hydrogen has been kept constant at NRs 600 per kg of hydrogen.

3.8 Global policies review

Country	Reports	Targets
India	Harnessing Green Hydrogen, 2022 National Green Hydrogen Mission, 2023	<ul style="list-style-type: none"> • Minimum of 5 MMT of green hydrogen annually by 2030 • Reach 10 MMT per year and develop export markets • Reducing 50 MMT per year of CO₂ emissions • Hydrogen demand to be 10% of global hydrogen demand by 2050 • Achieve cost parity of hydrogen with grey hydrogen by 2030 • Hydrogen share of 16% by 2030 to almost 94% by 2050 • Cumulative CO₂ emission reduction of about 3.6 Gt between 2020 and 2050
Australia	National Hydrogen Strategy, 2019 DOE National Clean Hydrogen Strategy and Roadmap, 2022	<ul style="list-style-type: none"> • Annual production of 10 MMT by 2030, 20 MMT by 2040 and 50MMT by 2050 • Reduce the cost of 1 kg hydrogen to USD 1 within one decade • Establishment of hydrogen hubs and promotion of hydrogen use in transport, mining and energy production
China	National Hydrogen Development Plan, 2021-2035, 2022	<ul style="list-style-type: none"> • Hydrogen production capacity of over 1 million tons by 2025 and over 6 million tons by 2030 • Power generation using hydrogen with capacity of 1 GW by 2025 and 10 GW by 2030
Europe	Hydrogen Roadmap, 2019, European Hydrogen Strategy, 2020	<ul style="list-style-type: none"> • Reduce about 560 million tonnes of CO₂ emissions by 2050 • Limit emission to about 770 million tonnes by 2050 • Share of hydrogen to about 24% of total energy demand (~2,250 TWh of energy) • About 160 TWh of hydrogen to produce high-grade heat and another 140 TWh to replace coal in steelmaking processes in the form of direct reduced iron in industrial sector by 2050
United States of America	Roadmap to a US Hydrogen Economy, 2021	<ul style="list-style-type: none"> • Meet 14% of US final energy demand by 2050 (2,468 TWh annually) • Generate as estimated \$140 billion per year in revenue and support 700,000 total jobs across the hydrogen value chain by 2030

Country	Reports	Targets
		<ul style="list-style-type: none"> • By 2050, generate about \$750 billion per year in revenue and a cumulative 3.4 million jobs • Share of hydrogen as fuel for industry (5%) by 2050
Republic of Korea	Hydrogen Economy Roadmap, 2019 Outlook on Hydrogen Economy & Roadmap, 2022	<ul style="list-style-type: none"> • Hydrogen supply up to 5.26 million tonnes annually by 2050 • Reduction of cost of hydrogen to KRW 3,000/kg by 2050
Japan	Hydrogen and Fuel Cell Roadmap, 2020 Japan's Vision and Actions toward Hydrogen Economy, 2022 Hydrogen Basic Strategy, 2023	<ul style="list-style-type: none"> • Reduction of water electrolysis equipment • Increase supply of hydrogen and ammonia to 3 million tons by 2030, to 12 million tons by 2040 and to 20 million tons by 2050 • Reduce cost of hydrogen to JPY 30 per Nm³ by 2030 and to JPY 20 per Nm³ by 2050 • Expand the number of water electrolysis equipment with Japan-made parts in them (15 GW globally by 2050)
Germany	A Hydrogen roadmap for Germany, 2019	<ul style="list-style-type: none"> • Hydrogen to provide 4-20 TWh of energy by 2030 and 250-800 TWh by 2050 • 6 million tonnes of crude steel from Direct Reduction of Iron (DRI) using hydrogen by 2030 and 20-30 million tonnes by 2050 • Production capacity between 1 to 5 GW by 2030 and 50 to 80 GW by 2050 • 1 million cars and 5 thousand trucks by 2030 and 10 million cars and 200 thousand trucks by 2050 (FCEVs)
France	A road-map for an ambitious hydrogen strategy by 2030, 2022	<ul style="list-style-type: none"> • Annual production of 1,090 thousand tons ("Ambition+ 2030" scenario) by 2030 • Build 6.5 GW electrolyser capacity and reduce CO₂ emissions by 6 million tonnes each year
Norway	The Norwegian Government's hydrogen strategy, 2020	<ul style="list-style-type: none"> • Zero emission cars and light vans by 2025 • Zero emission large vans, 75% of new long-distance buses and 50% of new trucks by 2030 • Virtually transport to be zero emission or climate neutral by 2050
United Arab Emirates	UAE Hydrogen Leadership Roadmap	<ul style="list-style-type: none"> • 25% market share of low carbon hydrogen and derivatives in key import markets by 2030 • Demand of 4-10 million tonnes H₂ annually by 2050

Country	Reports	Targets
United Kingdom	Hydrogen net zero investment roadmap, 2023	<ul style="list-style-type: none"> • Low carbon Hydrogen production capacity up to 10 GW by 2030 • Support over 12,000 jobs in hydrogen value chain by 2030
Spain	Hydrogen Roadmap: A Commitment to Renewable Hydrogen, 2020 Green hydrogen roadmap, 2020	<ul style="list-style-type: none"> • 4 GW installed electrolyser capacity by 2030 • 24% consumption of hydrogen in industry • 150-200 FCEV buses by 2030 • 5,000-7,500 FCEV road vehicles by 2030 • 500,000 tonnes hydrogen consumption annually by 2030 • Reduction by 4.6 million tonnes of CO₂ equivalent emissions by 2030
Russia	Russian hydrogen energy industry, 2019 Roadmap for Development of Hydrogen Energy for 2020-2024, 2021	<ul style="list-style-type: none"> • Export 2 million tonnes of hydrogen by 2030 and 15 million tonnes by 2050 (Baseline scenario) • Export 12 million tonnes of hydrogen by 2030 and 50 million tonnes by 2050 (Optimistic scenario) • Support the research and testing of hydrogen projects • Promotion of use of hydrogen or hydrogen-methane mixed fuels for power generation and transportation • Develop legislation for hydrogen generation, storage, transport and use

3.9 National Policies, Organizations and Institutions to drive Green Hydrogen use

National Hydrogen Energy Roadmap of Nepal, 2007	<p>Centre for Pollution Studies, advocating for Western Michigan industry, created the National Hydrogen Energy Roadmap of Nepal, 2007.</p> <ul style="list-style-type: none"> • The roadmap aimed to introduce hydrogen fuel in the transport sector • Hydrogen fuel could be used in modified combustion engines or fuel cells • Hydrogen production estimates were based on using 40% of excess electricity • The study also predicted the need to replace petrol and diesel in the transport sector by 2020
Industrial Policy 2011	The industrial policy 2011, was developed with the vision to make remarkable contribution in national economy through sustainable and broad-based industrial development in an effective, coordinated and collaborative partnership of public, private and cooperative sectors

	<p>thereby to support poverty alleviation. The policy identifies and prioritizes the use of energy efficient technologies in industries. The points highlighted in the document regarding the energy are</p> <ul style="list-style-type: none"> • Technical and financial assistance shall be made available to the industries that use environment-friendly and energy saving technology on their own costs; • Special measures shall be taken to promote green industries and to make the established industries pollution free and zero to carbon emission; • The expenses made by any industry in the machine or instrument that help decrease consumption of energy, the capital expenses and technology and process for installation of a system for pollution control and less impact in environment may be deducted for the purpose of income tax
Second Nationally Determined Contribution, 2020	<p>As mandated by the Paris agreement, the Government of Nepal has prepared the Nationally Determined Contribution (NDC) in 2016 and submitted to the United Nations Framework Convention on Climate Change (UNFCCC). It further updated the targets of the NDC and submitted the Second NDC to UNFCCC in 2020. Nepal's SNDC outlines actions to implement adaptation and mitigation actions to protect and improve the livelihoods of climate vulnerable communities and approaching towards low carbon economic development. The Second NDC includes policy targets in each section that are well aligned with Government of Nepal's 15th five-year plan, relevant sectoral policies and strategies, climate change policy, and other national documents. The goals of NDC under the energy generation are</p> <ul style="list-style-type: none"> • By 2030, expand clean energy generation from approximately 1400 MW to 15000 MW of which 5-10% will be generated from mini and micro hydropower, solar, wind and bioenergy. Of this, 5,000 MW is an unconditional target. The remainder is dependent upon the provision of funding by the international community • By 2030, ensure 15% of the total energy demand is supplied from clean energy sources.
Long term strategy for net zero emission, 2021	<p>Long term strategy for Net zero emission has been prepared with the ambitious target to achieve the net zero carbon emissions by 2045. It further projects the emissions in different scenario and develops the emission reduction that can be achieved through various strategic action. The various strategic actions in residential sector includes</p> <ul style="list-style-type: none"> • Strategic action: (1) Expansion of efficient and clean production technologies; (2) Electrification in process heat, boilers, and in motive power in all industries ; (3) Replacement of traditional brick kilns (FCBTK) with modern improved brick kilns (zigzag kilns, and electric tunnel kilns) ; (4) The intervention of CCUS

	<p>in the cement industry; (5) The intervention of green fuels (electricity, waste , and hydrogen) for thermal processes in the industries; (6) Introduction of electric technology for process heat in heavy industries (metals, cement, and brick)</p> <ul style="list-style-type: none"> • Emission reduction: This strategic action has the potential to reduce 3 MMT CO₂e emissions in 2030 and 14 MMT CO₂e in 2050 in 2030 and 2050 respectively in with existing measures scenario and 3.3 MMT CO₂e emission reduction in 2030 and 19.8 MMT CO₂e in 2050 in with additional measures scenario compared to the REF scenario
Budget speech of Fiscal Year 2022/23	<p>Recently Nepal government, for the first time, has included the programs for Green Hydrogen in its National policy and budget for the year 2079/80 in two clauses, clause 36 and clause 257.</p> <ul style="list-style-type: none"> • Clause 36: An initiative will be taken to establish a chemical fertilizer factory using green hydrogen and green ammonia technology • Clause 257: Necessary work will be commenced for the commercial use of hydrogen energy for the overall development of Nepal energy sector
Green Hydrogen Lab – Kathmandu University (KU)	<p>The Green Hydrogen Lab (GHLab) conducts research on hydrogen production, use, and feasibility.</p> <ul style="list-style-type: none"> • GHLab has aligned industries, academia, and government to foster technology transfer and local adaptation of hydrogen in Nepal • Multiple national and international entities are collaborating with GHLab to develop infrastructure and facilities • Notable publications include "Green Hydrogen Handbook for Nepal" and "Green Hydrogen for Development in Nepal," providing foundational knowledge on hydrogen • Many journal articles have been published detailing technical aspects of hydrogen • GHLab carries out extensive research on hydrogen applications in cooking, ammonia production, transportation, power backup, and other fields • The institution regularly engages with government bodies and stakeholders through meetings, training, seminars, and workshops, spreading knowledge on hydrogen
Nepal Electricity Authority (NEA)	<p>The Nepal Electricity Authority (NEA) has undertaken various initiatives to foster the use of hydrogen technology and to enable local electricity-generated ammonia production for industrial usage and fertilization within Nepal.</p> <ul style="list-style-type: none"> • An agreement has been formalized between the NEA and Kathmandu University (KU) via a Memorandum of

		<p>Understanding (MOU) to collaboratively work in the field of ammonia production</p> <ul style="list-style-type: none"> • Additionally, NEA has established a partnership with the Global Green Growth Institute (GGGI) through a MOU to execute technical activities focused on Green Hydrogen, Ammonia, and fertilizer production • This partnership also seeks to facilitate investment in the emerging sector of hydrogen applications
Nepal Corporation (NOC)	Oil	<p>Nepal Oil Corporation (NOC) is responsible for importing and distributing fossil fuels in Nepal. Currently, it is exploring and investing in potential alternative fuel sectors.</p> <ul style="list-style-type: none"> • NOC has entered into a Memorandum of Understanding (MOU) with Kathmandu University (KU) to enhance collaboration between academic institutions and government entities in the realm of energy and fuel. This is particularly focused on alternative energy sources such as hydrogen • Furthering its partnership with KU, NOC has agreed to develop pilot projects for the production of green hydrogen fuel, test its commercial viability in the transport sector, and explore other business opportunities • NOC provides policy guidelines to the Government of Nepal, advocating for the production, storage, and end-use of green Hydrogen as a future fuel source

Chapter Four: Prospects of Hydrogen

4.1 Scenario development

Scenario development is a crucial step in forecasting energy demand and analysing 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 transportation 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. 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). 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, Energy Sector Vision 2050 etc. The GDP growth rate for different years considered in these scenarios is shown in Table 4-1.

Table 4-1: 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%

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.

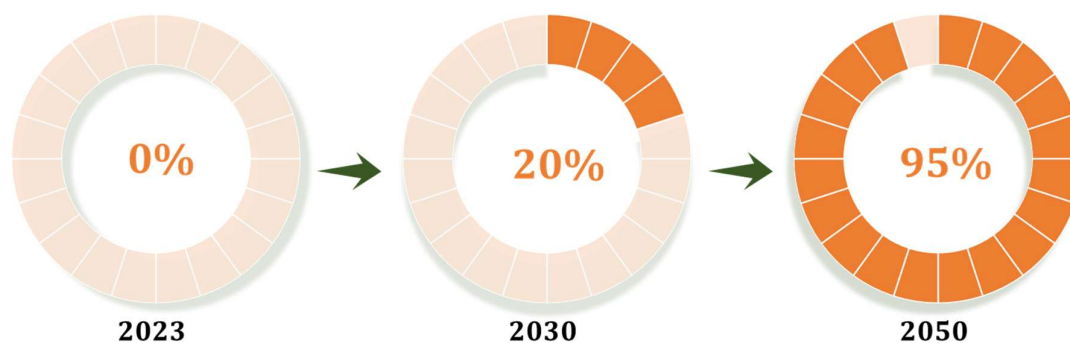


Figure 4-1: Hydrogen penetration in target industries

4.2 Scenario analysis

The energy demands for the scenarios up to 2050 have been estimated using the software MAED. Thermal energy mix scenario for the thermal applications in industries in the future for different scenarios has been presented.

4.3 Low growth scenario

The total energy demand in the base year amounted to 92.90 PJ and is projected to increase to 119.58 PJ by the year 2030, and further escalate to 257.82 PJ by 2050 under the low growth scenario. Extensive analysis has revealed that the annual growth rate will experience an upsurge, reaching 3.92% between 2026 and 2030, peaking at 3.94% between 2036 and 2040, and ultimately stabilizing at approximately 3.88% during the period spanning from 2046 to 2050.

Figure 4-2 illustrates the progression of fuel consumption until 2050. Traditional fuel use comprises fuelwood and agriculture residue, while briquette is categorized as a modern biofuel. Notably, the most substantial surge in energy demand is attributed to electricity. Nevertheless, it is anticipated that fossil fuels will remain the primary energy source in the foreseeable future according to the scenario. By 2030, the demand for fossil fuel will reach approximately 74.98 PJ, whereas traditional fuels will account for about 40.72 PJ. Fossil fuels alone are projected to surpass the total energy consumption observed in the base year by 2035. Looking further ahead to 2050, the demand for fossil fuels is estimated to reach 169.61 PJ, with traditional fuels following at around 76.64 PJ. As a consequence, there will be a substantial requirement for importing considerable quantities of fossil fuels to meet thermal end-use needs. It is important to note that the demand for electricity is relatively minor, projected at around 3.89 PJ in 2030 and 11.57 PJ in 2050. Thus, the pressing necessity to replace fossil fuels with hydrogen in Nepal's industries becomes evident.

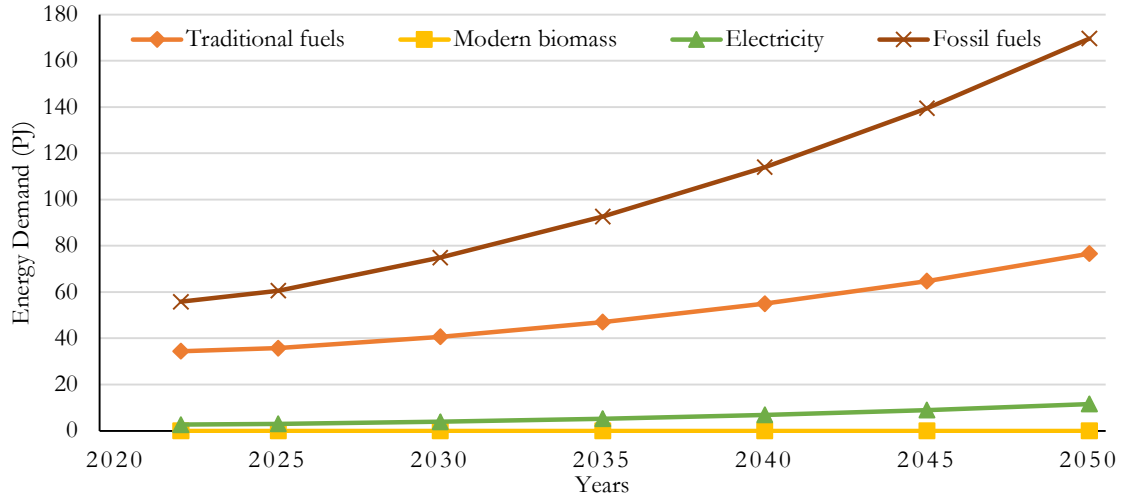


Figure 4-2: Energy demand growth trend of different fuels for low growth scenario

The thermal energy demand for various industries in the future after the hydrogen penetration has been presented in Table 4-2. By the year 2030, the consumption in industries related to cement, bricks, concrete, and clay products is expected to significantly rise to 55.68 PJ out of which about 14% will be contributed by Hydrogen. By the year 2050, more than 50% of the energy will be provided by the Hydrogen. Conversely, the demand for thermal energy in chemical products, rubber, glass, and plastics-based industries is forecasted to increase up to 23.77 PJ by the year 2050 where about 58% of the energy will be supplied by Hydrogen.

Table 4-2: Energy demand in different industries for low growth scenario

		(Peta Joule)						
Category	Energy	2022	2025	2030	2035	2040	2045	2050
Cement, bricks, concrete & clay products	Total energy	39.67	44.51	57.31	73.15	92.56	116.14	144.56
	Hydrogen energy	-	-	7.70	17.39	30.73	48.75	72.88
Chemical products, rubber, glass & plastics	Total energy	6.43	6.64	7.53	8.70	10.25	12.20	14.61
	Hydrogen energy	-	-	1.54	3.43	5.99	9.39	13.87

Hydrogen is the cleanest form of energy that can be implemented in chemical and cement industries. Figure 4-3 illustrates the required hydrogen amounts based on penetration rates in different years. The cement industry emerges as the largest consumer, needing substantial hydrogen volumes. Between 2026 and 2030, approximately 0.23 MMT of green hydrogen is anticipated. Looking ahead to 2046-2050, this demand will skyrocket to 3.11 MMT. Remarkably, in each period, the cement sector's hydrogen demand outstrips that of the chemical industry by roughly five times. For hydrogen production during 2026-2030, an estimated 12.96 TWh of

electricity will be utilized. Moreover, as we progress, cumulative electricity consumption for hydrogen production will continue to grow.

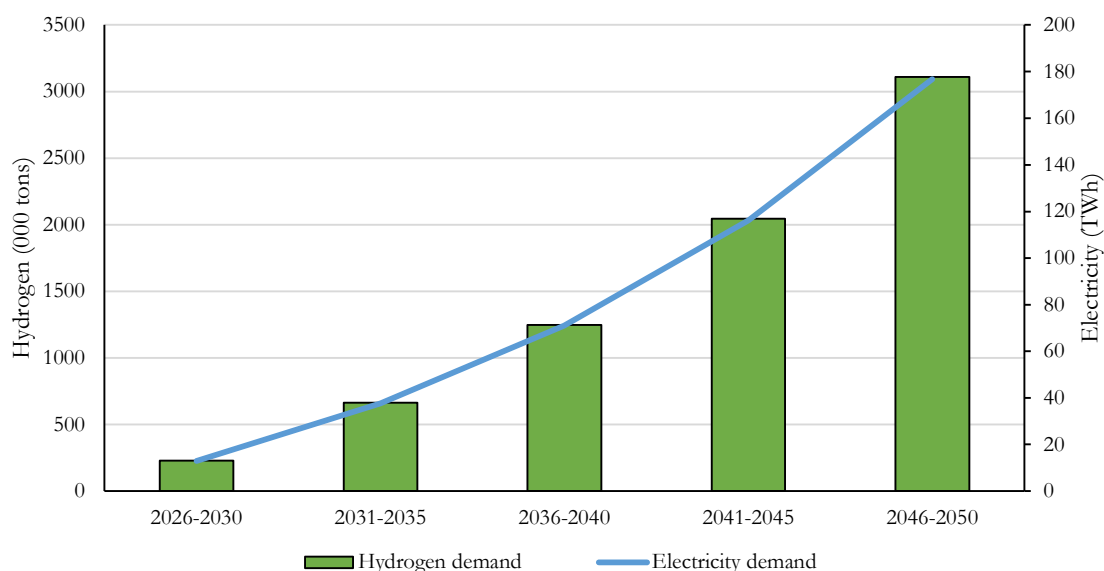


Figure 4-3: Hydrogen and electricity demand in low growth scenario

The share of electricity demand for hydrogen production out of the total generation will grow as the penetration gets higher. The share of electricity in the period 2026-2030 will be around 5.04%, growing up to about 11.74% and finally 19.94% during the periods 2031-2040 and 2041-2050 respectively. The hydropower capacity needed in different years for hydrogen production has been presented in

Table 4-3. For hydrogen production alone, the hydropower plant capacity needed by the year 2040 will be around 3.08 GW which will grow up to 7.27 GW by 2050.

Table 4-3: Hydropower capacity needed in low growth scenario

(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

Based on the low economic growth scenario, estimated emissions by industrial sector for various years with and without hydrogen adaption are shown in Figure 4-4. Emissions are expected to increase significantly, reaching 9.43 MMT by 2030 and approximately 20.91 MMT by 2050. Cement, bricks, concrete, and clay products-based industries alone are set to amount the total base year emissions by 2035. Conversely, chemical products, rubber, glass, and plastics-based industries are projected to emit less than one MMT even by 2050. After hydrogen penetration,

the emission reduces by as much as 5.23 MMT by 2030 and 11.94 MMT by 2050, making the emission by 2050 less than that by 2040.

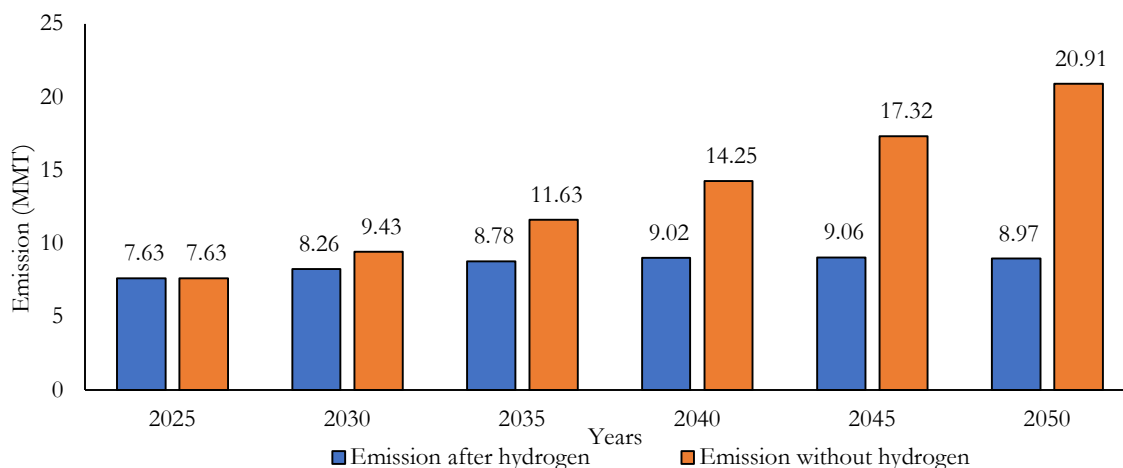


Figure 4-4: Emission by industries in low growth scenario

The emission reduction due to hydrogen penetration between 2036-2040 has been estimated to be 21.12 MMT of CO_{2eq} which will grow up to 52.11 MMT by the period 2046-2050. The marginal abatement cost (MAC) with hydrogen implementation is calculated as shown in Table 4-4. The cost of producing hydrogen in Nepal for industrial use has been estimated to be about NRs 275,698 million in the initial period (2026-2030) which will increase up to about NRs 894,191 million by the period 2036-2040 and by the end period 2046-2050 the investment would require about NRs 1,899,212 million. MAC in the first period would be around as high as NRs 74,294 per unit ton of CO_{2eq}. In the following periods, the MAC would go in continuous declining phase at the CAGR of negative 3.50%, reaching about NRs 36,446 per ton of CO_{2eq}.

Table 4-4: Marginal abatement cost in low growth scenario

Period	2026-2030	2031-2035	2036-2040	2041-2045	2046-2050
Emission reduction (MMT)	3.71	10.62	21.12	35.01	52.11
Carbon saving (NRs million)	46,757	133,764	266,172	441,095	656,592
Investment on electrolyser plant (NRs million)	47,509	90,454	122,060	165,989	221,829
Electricity cost (NRs million)	108,880	316,182	595,918	976,330	1,484,715
Total cost of producing hydrogen (NRs million)	275,698	590,901	894,191	1,321,171	1,899,212
Marginal Abatement Cost (NRs/ton of CO _{2eq})	74,294	55,660	42,329	37,740	36,446

4.4 Medium growth scenario

In this scenario, the total energy consumption will go up to about 144.40 PJ by 2030, reaching up to about 567.49 PJ by 2050. Fossil fuels consumption will rise by massive rate at 9.29%

between 2035 and 2040, amounting to about 186.71 PJ by 2040 and 373.33 PJ by 2050. Similarly, demand for traditional fuels will increase at 6.60% between 2035 and 2040, reaching up to 90.01 PJ by 2040 and finally will peak to about 168.70 PJ by 2050. Electricity consumption will reach up to about 25.66 PJ by 2050. In this way, if the current trend of growth and share of fuels continue, the energy demand for different fuels will go on increasing as shown in Figure 4-5. Demand for modern biomass, on the other hand will not be present as per the scenario.

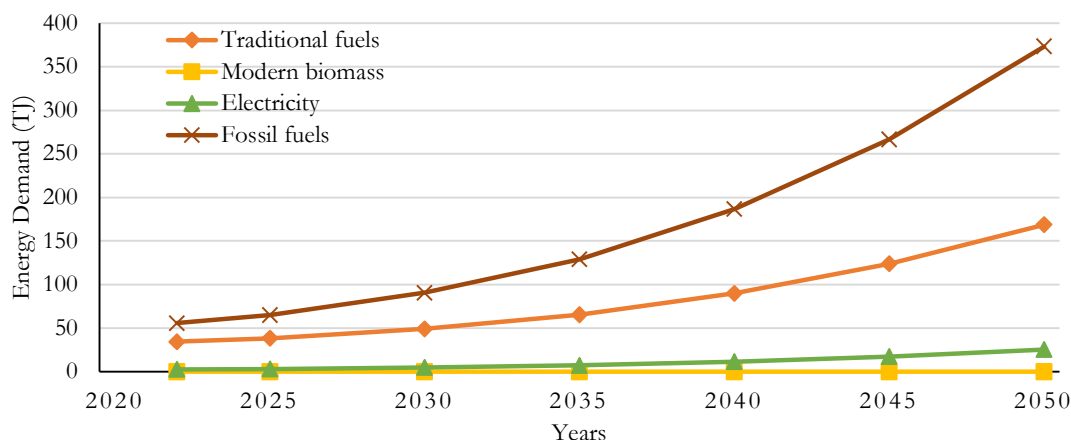


Figure 4-5: Energy demand growth trend of fuels for medium growth scenario

Energy consumption by different industries in different years as per the medium growth scenario, is shown in Table 4-5. Cement, bricks, concrete & clay products-based industries are the most growing industries on the energy demand context. The energy demand in this sector alone will expand by more than the total base year energy by 2035. The highest growth rate will also reach at its peak (7.74%) in the period 2035-2040. By the year 2050, about 160.41 PJ of energy will be supplied by Hydrogen. Chemical products, rubber, glass & plastics-based industries will need about more than eight-fold of the base year demand by the year 2050.

Table 4-5: 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	39.67	47.78	69.21	101.69	151.60	222.05	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

After penetration of hydrogen in cement and chemical industries, the demand of hydrogen in future will grow every year. The cumulative hydrogen demand during the period 2026-2030 will be about 271 thousand tons and will increase to about 1.93 MMT and 6.51 MMT by the period 2036-2040 and 2046-2050 respectively. This will make the electricity demand also grow in the sector. The hydrogen demand in different periods and corresponding electricity demand for

production alone is presented in Figure 4-6. The electricity demand in the period 2026-2030 will be about 15.40 TWh. This value will surge to about 109.76 TWh and 370.11 TWh by the periods 2036-2040 and 2046-2050 respectively.

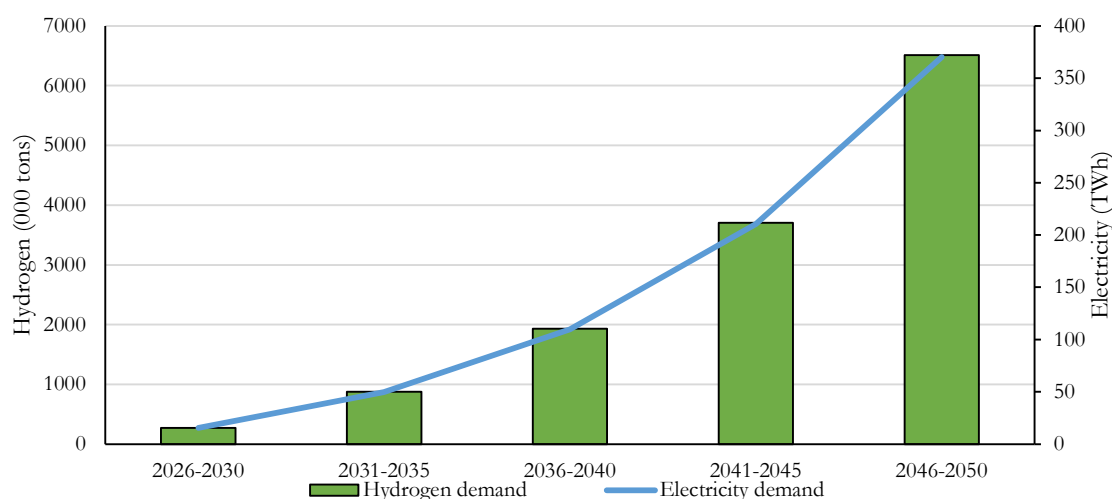


Figure 4-6: Hydrogen and electricity demand in medium growth scenario

In order to sustain the hydrogen production from electricity, the dedicated hydropower capacity for the industries in different years is shown in Table 4-6. The overall hydrogen capacity for hydrogen production alone in the year 2035, will be more or less the total installed hydropower capacity in the base year 2022. The electricity demand in the year 2050 will need the hydropower capacity of about 16 GW. This is only for production of hydrogen, for storage and other auxiliary operations, the electricity demand will be even more.

Table 4-6: Hydropower capacity needed in medium growth scenario

(Mega Watt)					
Category/Year	2030	2035	2040	2045	2050
Cement, bricks, concrete & clay products	778.71	2,024.20	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	2,423.72	5,036.68	9,311.04	15,992.80

Without the intervention of hydrogen in the industries and continued trend of fuel consumption, the emission in the industries because of thermal consumption of fuels will grow significantly and reach about massive 46.02 MMT by the year 2050. As the hydrogen penetration succeeds, the emission will be prevented greatly. The emission in the industrial sector will be limited to 19.74 MMT by 2050 which is less than half of the possible emission without green hydrogen transition. The trend of the emission reduction is shown in Figure 4-7. The cost saved due to emission reduction, will be about NRs 423 billion by the period 2036-2040. This will ramp up to about NRs 1,413 billion by the period 2046-2050.

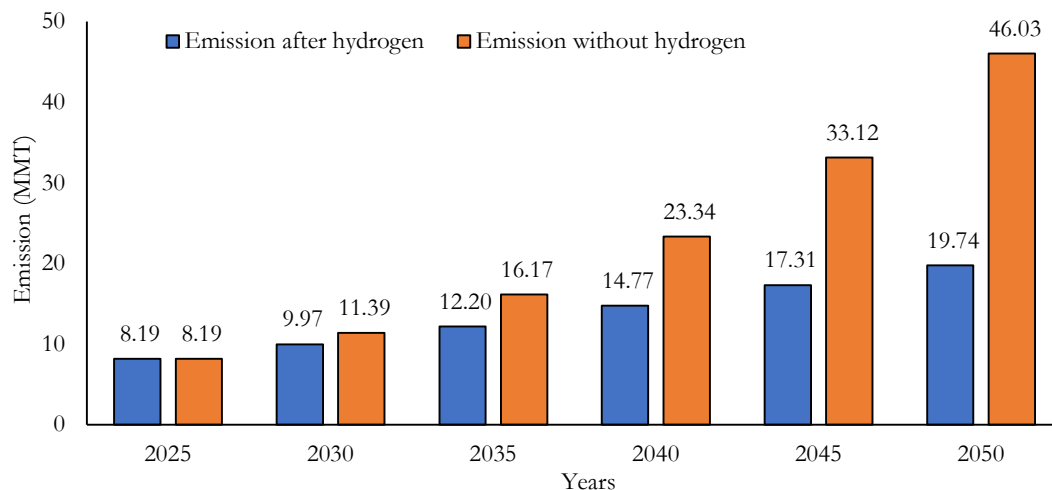


Figure 4-7: Emission by different industries for medium growth scenario

The emission reduction due to hydrogen penetration between 2036-2040 has been estimated to be 32.68 MMT of CO_{2eq} which will grow up to 109.03 MMT by the period 2046-2050. The marginal abatement cost (MAC) with hydrogen implementation is calculated as shown in Table 4-7. The cost of producing hydrogen in Nepal for industrial use has been estimated to be about NRs 331,133 million in the initial period (2026-2030) which will increase up to about NRs 1,414,867 million by the period 2036-2040 and by the end period 2046-2050 the investment would require about NRs 3,699,295 million. MAC in the first period would be around as high as NRs 81,546 per unit ton of CO_{2eq}. In the following periods, the MAC would go in continuous declining phase at the CAGR of negative 4.29%, reaching about NRs 33,930 per ton of CO_{2eq}.

Table 4-7: Marginal abatement cost in medium growth scenario

Period	2026-2030	2031-2035	2036-2040	2041-2045	2046-2050
Emission reduction (MMT)	4.06	14.06	32.68	63.39	109.03
Carbon saving (NRs million)	51,165	177,123	411,741	798,776	1,373,724
Investment on electrolyser plant (NRs million)	56,450	125,858	220,008	369,179	585,044
Electricity cost (NRs million)	129,371	417,811	922,022	1,768,101	3,108,896
Total cost of producing hydrogen (NRs million)	331,133	747,789	1,414,867	2,317,865	3,699,295
Marginal Abatement Cost (NRs/ton of CO _{2eq})	81,546	53,196	43,297	36,562	33,930

4.5 High growth scenario

Considering high economic growth rate, the total thermal energy consumption will increase to about 173.61 PJ in 2030 and 475.93 PJ in 2040, finally reaching up to 1,189.41 PJ in 2050. The fuel wise demand of thermal energy in future for industries is shown in Figure 4-8. Fossil fuels consumption would amount to about 108.86 PJ in 2030, 308.59 PJ in 2040 and 782.46 PJ in 2050. The growth rate of fossil fuels will be at peak (12.98%) during the period 2030-2035. Demand

of traditional fuels on the other hand, will grow to about 59.11 PJ by 2030. The energy demand for traditional fuels alone will surpass the total base year demand by 2035. By 2050, the demand of traditional fuels will be around 353.58 PJ. The electricity demand in the similar manner will increase to about 53.37 PJ by the year 2050. There will still be no use of modern biomass in future.

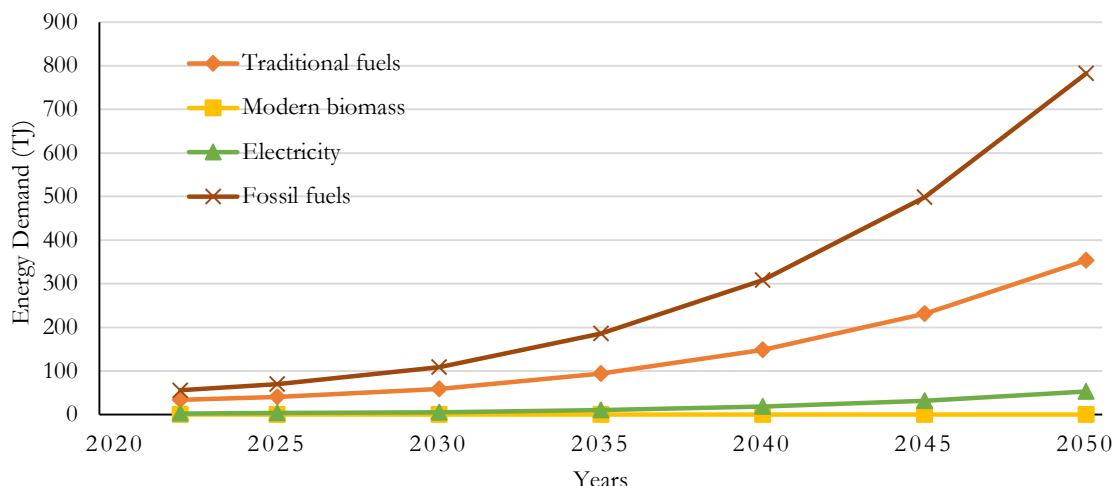


Figure 4-8: Energy demand growth trend of different fuels for high growth scenario

Energy consumption by different industries in different years as per the high growth scenario, is shown in Table 4-8. Cement, bricks, concrete & clay products-based industries are the most growing industries on the energy demand context. The highest growth rate will also reach at its peak (11.40 %) in the period 2030-2035. By 2040, hydrogen fuel will have fair share of about 36% to the total energy in these industries. Chemical products, rubber, glass & plastics-based industries will need more than base year demand by 2050 out of which about 55% of the energy will be supplied by 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	39.67	51.21	83.21	146.64	250.56	415.08	666.90
	Hydrogen energy	-	-	11.18	34.85	83.17	174.25	336.21
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

After penetration of hydrogen in cement and chemical industries, the demand of hydrogen in future will grow every year. The cumulative hydrogen demand during the period 2026-2030 will be about 306 thousand tons and will increase to about 3.05 MMT and 13.12 MMT by the period 2036-2040 and 2046-2050 respectively. This will make the electricity demand also grow in the sector. The hydrogen demand in different periods and corresponding electricity demand for

production alone is presented in Figure 4-9. The electricity demand in the period 2026-2030 will be about 17.37 TWh. This value will surge to about 173.49 TWh and 745.59 TWh by the periods 2036-2040 and 2046-2050 respectively.

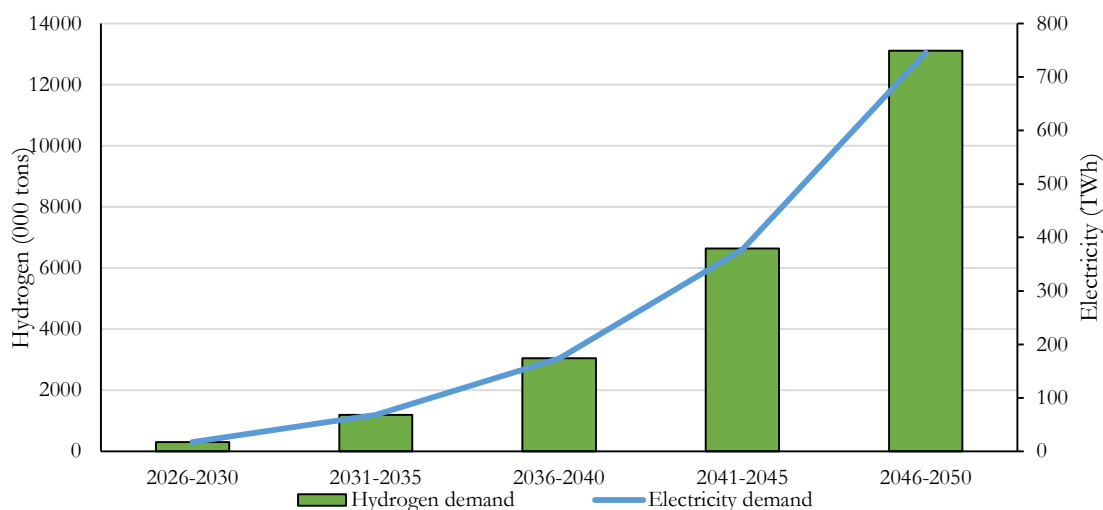


Figure 4-9: Hydrogen and electricity demand in high growth scenario

The hydropower capacity needed for the production of hydrogen alone, is presented in Table 4-9. By the year 2035, cement industries alone would need more than the total base year's installed hydropower capacity. In this way, in high growth scenario, the dedicated hydropower capacity in the year 2050 would be about 33 GW to sustain the hydropower production alone.

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	14,593.76	28,159.13
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	17,405.24	33,519.61

The emission due to industrial thermal applications would amount to 13.70 MMT by 2030, 38.57 MMT by 2040 and 96.47 MMT by 2050. As the penetration starts and accelerates after the year 2025, the emission will be reduced greatly. The emission reduction due to hydrogen application will be about 14.16 MMT by 2040 and 55.09 MMT by 2050. In this way, the emission from the industries will be limited to about 41.38 MMT by 2050. The emission reduction and the remaining emission are shown in Figure 4-10. Due to this massive reduction of emission, the cost saved during the period 2046-2050 would amount to about NRs 2,846 billion.

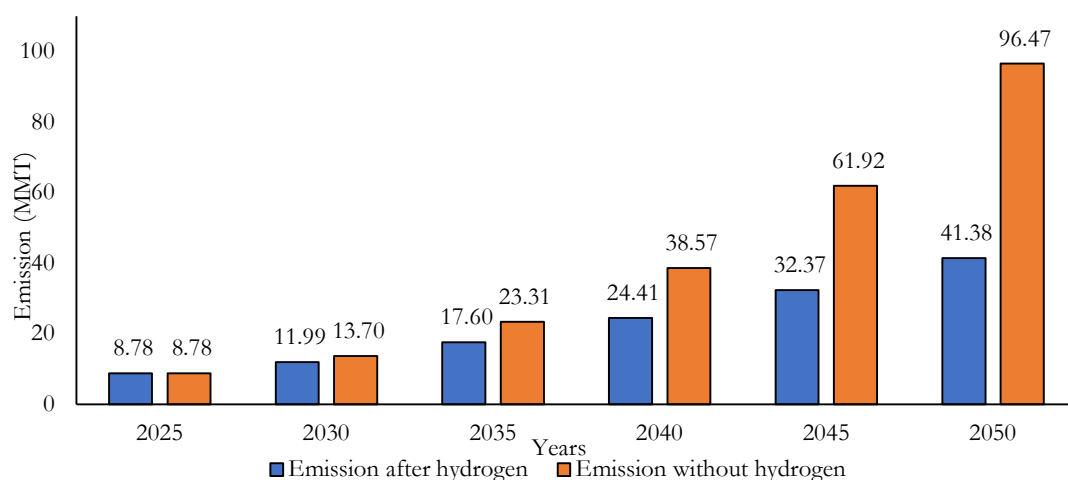


Figure 4-10: Emission by different industries for high growth scenario

The emission reduction due to hydrogen penetration between 2036-2040 has been estimated to be 51.67 MMT of CO_{2eq} which will grow up to 219.57 MMT by the period 2046-2050. The marginal abatement cost (MAC) with hydrogen implementation is calculated as shown in Table 4-10. The cost of producing hydrogen in Nepal for industrial use has been estimated to be about NRs 369,495 million in the initial period (2026-2030) which will increase up to about NRs 2,663,599 million by the period 2036-2040 and by the end period 2046-2050 the investment would require about NRs 10,256,508 million. MAC in the first period would be around as high as NRs 81,546 per unit ton of CO_{2eq}. In the following periods, the MAC would go in continuous declining phase at the CAGR of negative 2.69%, reaching about NRs 46,712 per ton of CO_{2eq}.

Table 4-10: Marginal abatement cost in high growth scenario

Period	2026-2030	2031- 2035	2036-2040	2041-2045	2046- 2050
Emission reduction (MMT)	4.59	19.24	51.67	113.61	219.57
Carbon saving (NRs million)	57,807	242,402	651,105	1,431,454	2,766,551
Investment on electrolyser plant (NRs million)	63,672	185,404	386,798	746,556	1,350,337
Electricity cost (NRs million)	145,922	570,828	1,457,287	3,168,234	6,262,917
Total cost of producing hydrogen (NRs million)	369,495	1,185,379	2,663,599	5,410,880	10,256,508
Marginal Abatement Cost (NRs/ton of CO _{2eq})	80,538	61,616	51,545	47,628	46,712

4.6 Comparison of scenarios

The total thermal energy demand forecasts without hydrogen intervention, on the basis of the above three scenarios are shown in Figure 4-11. The thermal energy demand in 2030, is estimated to be 119.58 PJ, 144.40 PJ and 173.61 PJ for low, medium and high growth scenarios respectively. Similarly in year 2050, thermal energy is estimated to be around 257.82 PJ, 567.49 PJ and 1,189.41 PJ in demand for three scenarios respectively. The highest growth rates for low and medium

growth scenarios, occur during the period 2035-2040 which will be around 3.94% and 7.41% respectively. On the other hand, for high growth scenario, the growth rate peaks at 10.84% during the period 2030-2035.

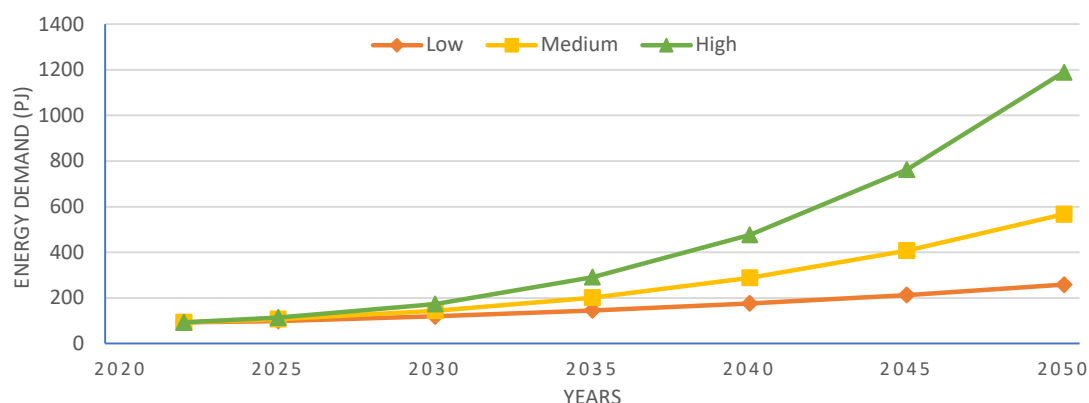


Figure 4-11: Total thermal energy demand in industrial sector

The share of fuels for thermal applications in industries has been forecasted, for different years based on the past. The electricity is the prevailing cleanest energy of all in Nepal. The share of electricity is 2.87% in the base year, and is expected to grow to 4.27% by 2030 and all the way up to 7.92% by 2050. In this context, the electricity in sectors other than cement and chemical industries has been considered to be amenable to decarbonize them. In these two sectors, hydrogen has the potential to replace the rest of the emission intensive fuels. The Figure 4-12 shows the amount of hydrogen needed in different periods, in different scenarios.

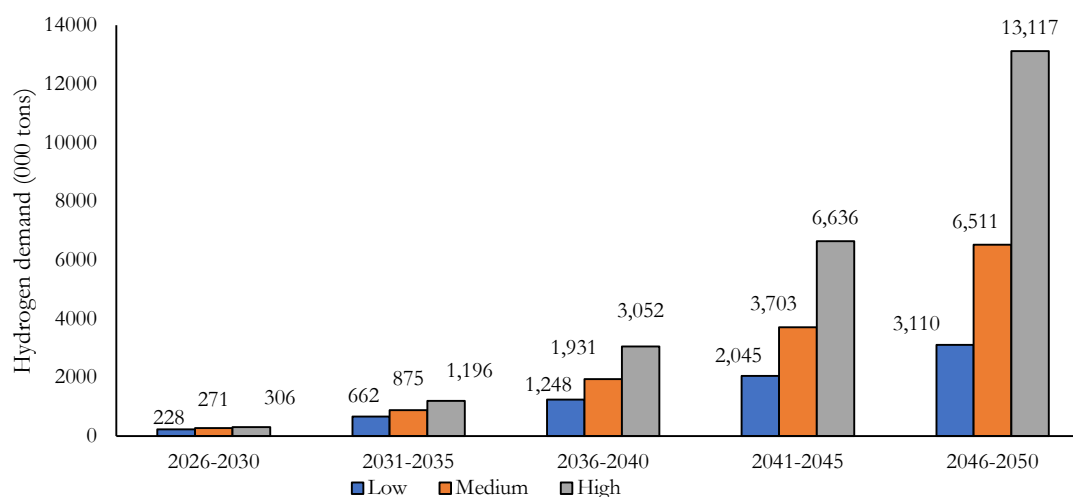


Figure 4-12: Hydrogen demand in different scenarios

Replacement of fuels other than electricity, with hydrogen can reduce emission in the industries in future. The remaining emission for three scenarios in different years after the application of hydrogen in industries is shown in Figure 4-13. The emission in the low growth scenario looks under control. Therefore, the emission can be limited in the low growth scenario due to hydrogen application alone. However, emission in other scenarios seem to need other clean energy

transition (electrification) or much broader (other industries than cement and chemical) and aggressive application of hydrogen.

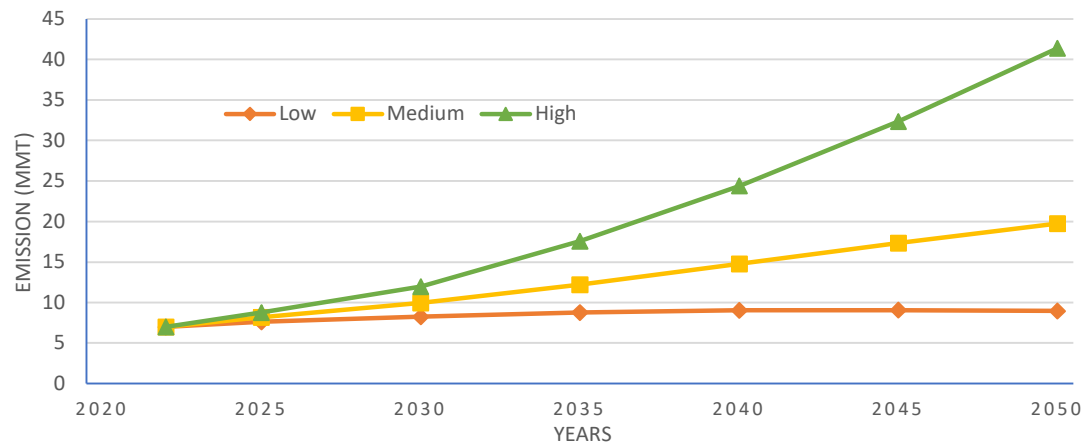


Figure 4-13: Estimated GHG emission forecasts from industries for different scenarios

The scenarios have given the estimates of investment needed in future for hydrogen application. For low growth scenario, by the period 2046-2050, about NRs 1,899 billion will be required for installing electrolyser plant and other accessories along with using electricity from the grid. Similarly, about NRs 3,699 billion and 10,257 billion of investments would be required in the same period in medium and high growth scenarios.

Chapter Five: Roadmap for hydrogen penetration

5.1 Theory of Change

Achieving decarbonization in energy-intensive industries necessitates the development of a comprehensive theory of change a conceptual framework that elucidates how specific actions and policies within a roadmap will lead to a series of desired outcomes. This theory of change will serve as a strategic blueprint, outlining the cause-and-effect relationships between interventions and their anticipated impacts.

5.1.1 Vision

The Vision of the Roadmap is “Penetration of Hydrogen in Industries”. This can be rephrased as “Decarbonisation of Industries of Nepal through Hydrogen Penetration”. This vision aligns with Nepal’s commitment towards achieving “Net-zero emissions by 2050”.

5.1.2 Levers of change

The levers of change comprise of the activities or policies that will drive and actualize this change. As shown in Figure 5-1, theory of change has identified following levers of change:

- Policy framework to facilitate hydrogen introduction
- Regulatory framework to monitor and deploy the clean energy pathway
- Commitment of industries to green energy transition
- Attractive investment environment
- Research and development to equip with skills and knowledge
- International policies
- Infrastructure development and policy supports

5.1.3 Partners

The proper realisation of the vision can be only obtained with the collaboration of different stakeholders. The potential field of stakeholders that will be directly engaged in this chain of actions are:

- Government agencies and policymakers
- Private sector companies and industries
- Research institution and universities
- Non-governmental organizations (NGOs) and environmental groups
- Energy expert consultants
- Local communities
- Cutting-edge technology providers and suppliers
- Financial institutions and investors

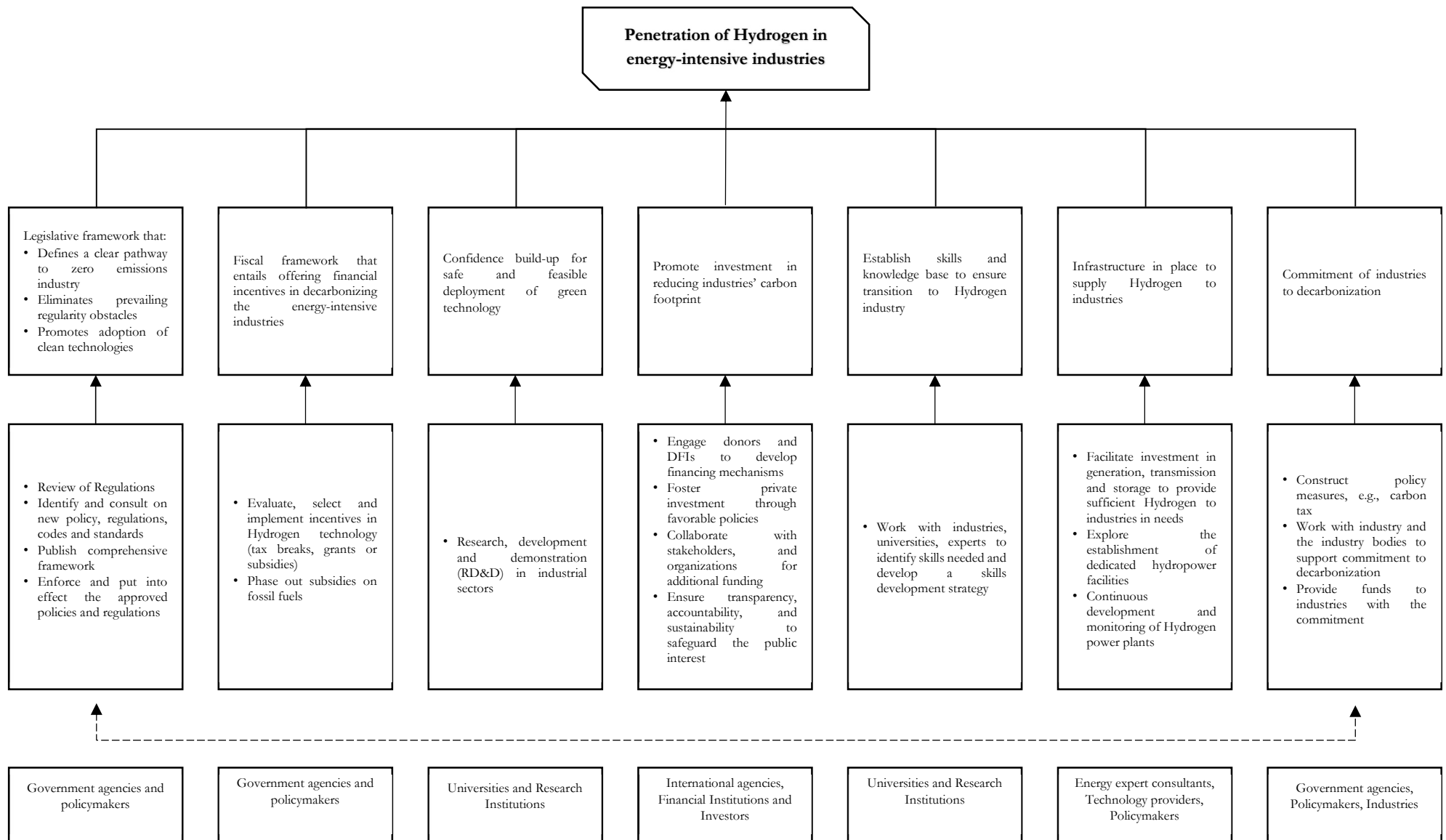


Figure 5-1: Theory of change for Hydrogen penetration in industries

5.2 Roadmap for hydrogen penetration

A comprehensive and coordinated response across government is required for creating the environment that could support creating hydrogen economy across all sectors to promote Nepal's move towards creating Net-zero emission. Nepal Hydrogen Summit (NGHS) which was held in Nepal in from October 10 to 11, 2022 where various renowned international experts, leaders and global companies that are working in Green Hydrogen technology came together to work for the production of green ammonia and green fertilizer to meet net zero targets. A major focus was given to bring down the cost of green hydrogen while increasing the revenue of existing hydropower. 6 major aims were presented to bring green energy wave in Nepal's economy to develop a competitive edge and globally valuable. In transitioning towards a hydrogen-centric energy landscape, Nepal can leverage a strategic and multifaceted roadmap. This approach not only addresses the immediate challenges but also encompasses broader, strategic objectives that will secure the nation's energy future.

A cornerstone of this roadmap is the mitigation of investment risks. Recognizing the substantial capital required for extensive hydrogen production and utilization, the government needs to devise and execute financial measures that could share or distribute the intrinsic risks associated with such pioneering technologies. This approach could encompass risk-sharing mechanisms, public-private partnerships, and safeguards for early adopters.

Another fundamental part of the roadmap is the harmonization of standards and policies. A unified and consistent regulatory framework can ease industries' transition, diminish uncertainty, and cultivate an environment favorable to innovation and investment. Harmonization should consider safety standards, industry regulations, and policy incentives that cater to diverse sectors and stages of the hydrogen value chain. Demand creation is crucial to ensure a sustainable market for hydrogen. Initiatives such as public procurement of hydrogen technologies, quota systems, and tax incentives could stimulate initial demand. Additionally, public awareness campaigns can underscore the advantages of hydrogen, fostering its broader acceptance and utilization.

Promoting research, development, and innovation is another fundamental tenet of the roadmap. Joint efforts between academic institutions, research organizations, and industries could spur technological advancements, enhancing the affordability, efficiency, and accessibility of hydrogen technologies. Government grants and funding could further incentivize innovation in this field. Strategic demonstration and deployment projects constitute a key part of the roadmap. Such projects, especially in hard-to-abate sectors, serve as practical testbeds for hydrogen technologies. These demonstrations not only validate the practical applicability of hydrogen but also offer valuable insights to refine strategies and policies.

Furthermore, it's essential to undertake feasibility assessments of hydrogen production, storage, and distribution in Nepal. This endeavor should emphasize areas like policy and target development, standard creation, barrier removal, and research and development. To facilitate the development of hydrogen technology, substantial investment is needed, necessitating support from international, government, and private sectors.

Ultimately, this roadmap represents a comprehensive, concerted approach to establish a hydrogen-centric energy future for Nepal. By addressing investment risks, harmonizing standards and policies, stimulating demand, promoting research and innovation, and executing strategic

demonstration projects, Nepal can genuinely harness the potential of hydrogen, transitioning towards a cleaner, more sustainable energy future. The feasibility of hydrogen production, storage and distribution in Nepal is to be assessed where various areas like policies and target development, creating standards and removing barriers and working in the field of research and development should be emphasized. The information about cost, technologies and global trends regarding green hydrogen should be conveyed to all related bodies. For the development of hydrogen technology, large scale investment is needed for which the help from international level, government and private sectors is crucial. A roadmap is necessary that could prioritize the sectors of chemicals and fertilizers, energy and power. In addition, industrial sector is another sector where the decarbonization could help to achieve the sustainable development goals. The motive of Nepal government to reduce the GHG to restrict climate change without hindering the attempts to attain the developing country status can be economically challenging as well as sluggish effort. The key actions that are to be considered are summarized in Figure 5-2.

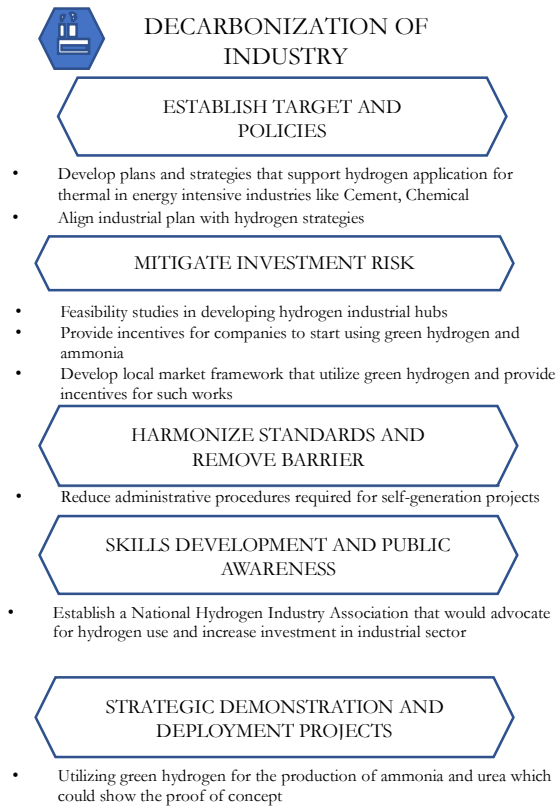


Figure 5-2: Summary of Hydrogen Roadmap

5.3 Implementation plan

The roadmap necessitates a detailed implementation plan to clearly demarcate an all-encompassing pathway for the strategic integration of hydrogen within the current industrial landscape. As outlined in Table 5-1, the plan concisely aggregates the critical actions that are required to be incorporated across diverse timeframes. The key stakeholders, or 'champions,' who will be actively involved in these transformative actions are to receive assistance and guidance from the Government and various regulatory and oversight bodies.

To ensure the effective progression of this plan, robust criteria will be established, forming a comprehensive monitoring and evaluation mechanism. This will facilitate regular assessment and adjustment of the strategic actions, maintaining alignment with our objectives and ensuring that the path towards hydrogen integration remains effective and responsive to evolving industrial needs.

The plan aims not just to outline the steps, but also to clearly define the outcomes to be achieved during the respective timeframes. These expected outcomes serve to clearly articulate the specific goals that will be pursued, setting clear benchmarks for success, and ensuring alignment of efforts towards the overarching vision of industrial decarbonisation through hydrogen integration. This implementation plan thus represents a pivotal instrument for managing the evolution of our industries towards a more sustainable and environmentally responsible future.

Table 5-1: Action plan for hydrogen penetration in industries

Actions	Role player	Expected outcomes	Monitoring criteria	Time frame
<ul style="list-style-type: none"> Undertake comprehensive assessments of practicality for hydrogen production and utilization Begin in-depth Research and Development initiatives to facilitate the introduction of hydrogen in existing industrial domains Formulate extensive and robust policies for the application of hydrogen within industrial contexts Develop detailed proposals and strategic plans for pilot projects to test the viability of hydrogen integration 	Government of Nepal, WECS	<ul style="list-style-type: none"> Ensure the formulation of a proper policy for hydrogen production. Establish the necessary infrastructure to facilitate a secure and seamless shift towards hydrogen. 	<ul style="list-style-type: none"> National and International Policies reviewed Policies revised and framework constructed 	2023-2025
<ul style="list-style-type: none"> Initiate production of hydrogen on industrial-scale, thereby promoting its technological and economic feasibility for broader use Launch pilot projects in hard-to-abate sectors, such as cement, concrete, brick, and clay manufacturing, to exhibit hydrogen's transformative potential Champion the use of hydrogen-blended fuels, balancing immediate emission reduction with long-term transition goals Develop a quota system for hydrogen utilisation across different industries, providing direction and encouraging a shift towards hydrogen-based systems Grant financial incentives and fiscal support to industries ready to shift towards hydrogen, minimising financial obstacles and stimulating quicker uptake Emphasise on Research, Development, and Deployment (RD&D) initiatives, specifically targeting enhancements in affordability and accessibility of hydrogen technologies 	Government of Nepal, WECS	<ul style="list-style-type: none"> Ensure the formulation of a proper policy for hydrogen production. Establish the necessary infrastructure to facilitate a secure and seamless shift towards hydrogen. 	<ul style="list-style-type: none"> National and International Policies reviewed Policies revised and framework constructed 	2023-2025

Actions	Role player	Expected outcomes	Monitoring criteria	Time frame
<ul style="list-style-type: none"> • Execute regular reviews and monitoring processes to verify the efficacy of strategies and adapt to technological progress, economic shifts, or new scientific insights. 				
<ul style="list-style-type: none"> • Boost hydrogen production using excess electricity to generate green hydrogen • Mobilize investment for green material production via hydrogen use • Maintain solid support for industries using hydrogen • Extend subsidies to industries keen on transitioning to hydrogen • Widen pilot project scope to include more manufacturing sectors • Prioritize RD & D to improve hydrogen technologies' affordability and reliability • Implement a routine review and monitoring system for strategy effectiveness • Advocate for the 'hydrogen valley' concept, positioning geographic hubs for hydrogen advancement. • Carry out initial and feasibility studies to identify ideal locations and plans for hydrogen valleys. • Develop policies to phase out industrial fossil fuel use, promoting cleaner energy alternatives. • Create a fund and solicit investments for resource accumulation in developing hydrogen valleys. 	Cement Industries, Brick industries, Government of Nepal, National and International financial institutions	<ul style="list-style-type: none"> • Enhance the scale of hydrogen production and consumption. • Advance the development of hydrogen-centric technologies. • Work towards making green hydrogen economically accessible. • Guarantee the dependability of hydrogen as an energy source. • Establish specialized 'hydrogen valleys' in designated locations. • Discourage the usage of fossil fuels in favour of cleaner energy sources 	<ul style="list-style-type: none"> • Tons of Hydrogen Used • GWh of electricity utilized • Cost of hydrogen reduced • Decline in usage of fossil fuels 	2031-2035
<ul style="list-style-type: none"> • Augment the development and expansion of existing hydrogen valleys, enhancing the regional deployment of this energy carrier. • Accelerate the transition of current industries towards green operations, endorsing the principles of sustainability and emission reduction. 	National and International investors, Government of Nepal, All industries	<ul style="list-style-type: none"> • Achieve complete industrial decarbonization within Nepal. • Optimize the use of surplus electricity for the production of hydrogen. 	<ul style="list-style-type: none"> • Tons of Hydrogen Used • GWh of electricity used 	2026-2030

Actions	Role player	Expected outcomes	Monitoring criteria	Time frame
<ul style="list-style-type: none"> • Draw out subsidies strategically from relevant industries, reinforcing the financial feasibility of the hydrogen transition. • Initiate pilot projects to stimulate further demand for hydrogen use, testing its applicability in new sectors. • Prioritize Research, Development, and Deployment (RD&D), fostering innovation in hydrogen technologies. • Embed systematic review and monitoring processes, ensuring ongoing effectiveness and adaptability of our strategies. • Drive technological advancement to facilitate the complete greening of industries, upholding the ultimate goal of carbon neutrality. • Transform compatible industries towards green operations and phase out those persisting with fossil fuel usage, to ensure alignment with our climate commitments. • Maximize hydrogen production from surplus electricity, enhancing the efficiency of our energy systems. • Undertake RD&D initiatives focused on broadening the scope of hydrogen applications, further integrating this versatile energy carrier into our energy systems. • Implement consistent review and monitoring mechanisms, maintaining oversight and enabling swift adjustments in response to emerging trends and findings. 		<ul style="list-style-type: none"> • Explore and introduce the utilization of hydrogen in diverse applications. • Expand the establishment of 'hydrogen valleys' across larger scales. • Diminish the prevalence of industries reliant on fossil fuels. 	<ul style="list-style-type: none"> • Use of hydrogen in Industries in maturity phase • Policies regulated • Hydrogen valley established • Use of Hydrogen in ammonia production 	

5.4 Barriers and willingness to switch

As hydrogen technology is in the developing phase there are various hurdles and obstacles from the regulatory level to their production, storage, and in their application. Some of them are:

- **Inadequate Specific Infrastructures**

Hydrogen production requires specialized facilities in locations with access to water and renewable electricity. Additionally, hydrogen storage accounts for the need of high-powered compressors and storage containers. In the context of Nepal, hydrogen storage and distribution infrastructure are underdeveloped. Further, most of the industries have technology and system which are not compatible for hydrogen combustion. Thus, transitioning to green hydrogen requires building new infrastructures for production, storage, as well as modifications in technology and system in existing industries which makes this process expensive and time-consuming.

- **High cost of production and use**

The cost of hydrogen production, especially from renewable sources, is currently higher compared to traditional fossil fuel sources. The high cost is mainly due to the energy-intensive processes involved in production. The technology related to electrolyser is still not mature and utilizes various metals (iridium, ruthenium, and platinum) which are expensive in technology. Further, the requirement of industries currently relying on traditional fuels to upgrade the infrastructure to rely on green hydrogen adds to the cost significantly. As evident during the case studies, the industries have to invest capital up to three to five times their current investment. This cost barrier acts as a major factor in restricting hydrogen penetration in industries in the context of Nepal. Its production and use in the present case are found to be quite expensive compared to the locally available resources that have been used since ages. The levelized cost of green hydrogen (LCOH) is around NRs 600 which may produce around 120MJ of energy whereas the locally available agricultural residue could easily produce that energy by utilizing 10 kg of it that could not cost more than NRs 100 if the conversion efficiencies are not taken into consideration. For any business where profit is the main goal, the shifting of technology towards hydrogen doesn't seem practically feasible unless the cost of hydrogen production and use is brought down to a considerable level. This cost barrier acts as a major factor in restricting hydrogen penetration in industries in the context of Nepal.

- **Distinct Policy**

There is no precise policy for the infrastructural development, financial incentives, and regulatory frameworks regarding green hydrogen application in Nepal. Moreover, the lack of specific guidelines for production facilities, storage systems, and distribution networks acts as a barrier to stakeholders and potential investors seeking to contribute to such advancements. Further, there is no proper provisions promoting cooperation between counties to allow exchange of expertise and experiences to foster innovation and accelerate the deployment of green hydrogen technologies in industries. As evident during the case studies, the owners of the industries have highlighted the lack of proper policy and incentives which has made the transition even more challenging.

- **Lack of value recognition**

In the context of Nepal, proper valuation is not done for the industries or any areas which utilize hydrogen. The prospect of energy sources and their emission is not valued in the application as long as the need for energy is fulfilled. Even though the application of green hydrogen in the industries limits GHG emission to a great extent, the government has not given any emphasis to such initiatives. No distinction is done in the global market between green and grey hydrogen that could promote renewable energy production sources.

- **Loss of energy**

The process of producing hydrogen through electrolysis or other methods requires substantial amounts of energy, resulting in efficiency losses at each stage. During electrolysis about 30-35 % of energy that is used to produce hydrogen is lost. These energy losses reduce the overall efficiency of hydrogen production and increase the costs associated with it. Additionally, hydrogen has a low energy density by volume, making it challenging to store and transport efficiently. Further, there is significant energy loss during the transfer of hydrogen into thermal applications in industries. Efficient technology regarding thermal conversion is lagging.

- **Economic viability**

The current production and use of sustainable materials and plan for green materials are driven mainly by climate ambition or speculation on their demand rather than immediate economic gain. While stakeholders may believe that economic gain will happen in the future, currently an established means of placing a monetary value on the benefits of green goods does not exist. Furthermore, the reluctance of industries to adopt green hydrogen becomes evident when they do not perceive clear economic advantages in comparison to traditional fossil fuel-based systems, as demonstrated by various case studies conducted. In the absence of compelling financial incentives or cost competitiveness, industries may be deterred from investing in green hydrogen technologies, impeding its broader application. Indeed, there is no widespread compensation for the higher costs that green goods entail, nor are there adequate economic barriers to non-climate-friendly solutions.

- **Demand creation**

The lack of demand is accompanied by a substantial lack of production and infrastructure (IRENA, 2020a), creating the so-called chicken and egg problem of green hydrogen. Though increasing, little to no actual demand exists. The lack of demand for green hydrogen can hinder its application in industries. When there is limited or insufficient market demand for green hydrogen, industries may be reluctant to invest in the necessary infrastructure and technologies for its production, storage, and utilization. Without a strong demand, there is a reduced incentive for industries to adopt green hydrogen solutions. This lack of demand can create a vicious cycle, as it discourages further investments and hinders the development of a robust hydrogen ecosystem.

- **Safety**

Safety concerns can impede the application of green hydrogen in industries. Due to its highly flammable nature and wide flammability range, safety considerations become crucial during the production, storage, and utilization of hydrogen. Industries may hesitate to adopt green hydrogen technologies if they perceive safety risks as unmanageable or if they lack the necessary knowledge and expertise to handle hydrogen safely.

Addressing these hurdles and promoting green hydrogen can significantly reduce carbon emissions associated with thermal applications, promote energy transition, and improve local air quality by replacing traditional combustion fuels. Further, it is essential to develop policies and mechanisms that provide financial incentives such as grants, subsidies, tax credits etc. to encourage industries to embrace green hydrogen technologies by offsetting the initial costs and providing long-term economic benefits. Also, rigorous safety protocols, training programs, and risk mitigation strategies can be implemented to address the safety concerns to ensure safe handling and use of green hydrogen. By addressing the potential barriers strategically, industry stakeholders can gain confidence in its application, paving the way for wider adoption and integration into industrial processes.

Chapter Six: Conclusions and Recommendations

6.1 Conclusions

In drawing this report to a close, it is pertinent to highlight the unique position of industries dealing with cement, bricks, concrete, clay, chemical products, rubber, glass, and plastics in Nepal. These industries are prime candidates for the integration of hydrogen. Moreover, the paths paved by countries such as India, the USA, Australia, and Japan, who have established strategic roadmaps for the assimilation of green hydrogen, can offer valuable lessons. Simultaneously, Nepal has embarked on its journey towards hydrogen integration, manifested in the development of a National Hydrogen Energy Roadmap and the adoption of green hydrogen and green ammonia technologies. Given its clean and renewable nature, hydrogen bears immense potential for industrial applications within Nepal, particularly in light of the expanding role of hydroelectricity. As a multi-purpose energy carrier and fuel source for industrial thermal applications, the strategic significance of hydrogen in shaping a sustainable industrial future cannot be overstated. The conclusions drawn from the reports are listed below:

- The analysis indicates a pressing need for hydrogen introduction in Nepal's industrial sector, which accounted for 18.32% of the total energy in 2021
- The industry is thermal energy-intensive, consuming approximately 92.90 PJ in the base year, primarily from coal (31.61 PJ) and fuelwood (18.26 PJ)
- The clean energy present, electricity, only contributes around 2.66 PJ
- 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
- Boilers heavily rely on traditional fuels (83.39%) and furnaces on fossil fuels (83.57%)
- These thermal applications generate about 6.98 MMT of emissions, with 53.17% from industries based on cement, bricks, concrete, and clay products
- Immediate implementation of hydrogen in these industries would demand about 310 thousand tonnes of hydrogen and 15 TWh of electrical energy, necessitating a hydroelectric power capacity of approximately 2,739 MW
- 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 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
- The production of this amount of hydrogen will consume about 138.19 TWh of electrical energy in the period 2046-2050 and require a dedicated hydropower capacity of approximately 7.27 GW by 2050
- This scenario would avoid about 87.12 MMT of CO₂eq emissions, resulting in a cost saving of around NRs 1,129 billion
- 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

- Hydrogen is expected to supply around 11.16 PJ of energy by 2030 in the medium growth scenario, and 13.41 PJ in the high growth scenario
- By 2050, hydrogen's energy contribution is anticipated to rise to approximately 190.95 PJ and 400.22 PJ under medium and high growth scenarios, respectively
- This energy supply will necessitate the production of around 6.51 MMT of hydrogen during 2046-2050 in the medium growth scenario, consuming at least 370 TWh of electricity
- In the high growth scenario, approximately 13.12 MMT of hydrogen will be required during the same period, demanding an estimated 746 TWh of electrical energy
- Fulfilling these energy needs will require about 16 GW and 33 GW of dedicated hydropower capacity by the year 2050 under medium and high growth scenarios, respectively
- The resultant CO₂eq emission levels will be capped at 19.74 MMT and 41.38 MMT under medium and high growth scenarios respectively in the same year
- The cost savings from carbon mitigation in these scenarios are projected to be around NRs 1,374 billion and NRs 2,767 billion for the period 2046-2050 under medium and high growth scenarios, respectively

The transition to hydrogen as a renewable energy source mandates an all-encompassing strategy that includes the examination of economic viability, the articulation of value, and the development of the necessary infrastructure. This policy document serves as a roadmap to facilitate this transition, providing a comprehensive theory of change, strategic blueprint, and actionable plan extending to the year 2050. The document delineates key milestones, risk management strategies, and actionable steps, ensuring the transition's progress is both trackable and responsible. Insights from industry-specific case studies offer a pragmatic perspective on the challenges encountered in the adoption of hydrogen technology, thus informing and refining the strategic trajectory. Collectively, these resources compose an integral toolkit to inform policy decisions and catalyse the transition to hydrogen, thus steering Nepal towards a future of resilient and sustainable energy.

6.2 Recommendations

To position Nepal at the forefront of hydrogen production and utilization, a dynamic and multi-faceted approach is essential. This pathway necessitates a concerted effort, encompassing a comprehensive array of strategic actions that cut across the spectrum of policy formulation, research and development, industry transformation, and infrastructure development. By synergistically combining these initiatives, Nepal can effectively transition towards a sustainable hydrogen economy, contributing significantly to its broader energy transition goals.

The following recommendations aim to facilitate this transition, each targeting a critical aspect of the hydrogen value chain - from production and storage to utilization across various industries. These recommendations, while ambitious, are rooted in the reality of technological progress and global best practices. Their successful implementation promises not only to transform Nepal's energy landscape but also to position the country as a leader in green hydrogen adoption. The proposed recommendations are as follows:

- It's vital to undertake comprehensive assessments of hydrogen production and utilization, paving the way for evidence-based policy-making
- Emphasizing comprehensive Research & Development initiatives and robust policy formulation can enable the seamless integration of hydrogen within existing industries
- Harnessing pilot projects in hard-to-abate sectors can showcase the transformative potential of hydrogen and foster confidence in its wider adoption
- Implementing a systematic quota system for hydrogen utilization and promoting hydrogen-blended fuels can provide a balanced approach to meeting sustainability goals
- Minimizing financial barriers by offering substantial incentives to industries transitioning to hydrogen can stimulate rapid uptake
- By prioritizing R&D initiatives that focus on the affordability and accessibility of hydrogen technologies, and implementing regular strategic reviews, we can ensure continual adaptability and innovation
- Enhancing green hydrogen production by harnessing surplus electricity can improve energy system efficiency and align with sustainability goals
- Mobilizing investments for green material production using hydrogen and ensuring sustained support for transitioning industries can affirm a long-term commitment to a greener future
- Broadening the impact of hydrogen integration through expanded pilot projects and extended subsidies can foster an inclusive and supportive environment for industries
- Advocating for the 'hydrogen valley' concept and conducting comprehensive feasibility studies can identify strategic locations and plans for regional hubs of hydrogen advancement
- Reforming policies to phase out industrial fossil fuel use and establishing a dedicated fund for the development of hydrogen valleys can accelerate the shift towards cleaner, more sustainable energy alternatives
- Accelerating the green transition of industries and driving technological advancements can achieve the overarching goal of carbon neutrality, demonstrating a strong commitment to sustainability
- Undertaking focused R&D initiatives to expand the scope of hydrogen applications can further integrate this versatile energy carrier into our energy systems, securing a resilient and sustainable energy future

References

- Ahman, M. (2020). Retrieved from Perspective: Unlocking the 'hard to abate' sectors: <https://www.wri.org/climate/expert-perspective/unlocking-hard-abate-sectors>
- Bataille, C. (2020). *Physical and policy pathways to net-zero emissions industry*. WIREs Climate Change. Retrieved from <https://doi.org/10.1002/wcc.633>.
- Bijen Mali, D. N. (2021). Green Hydrogen: Production Methodology, Applications and Challenges in Nepal. *IEEE*.
- Biraj Singh Thapa, B. N.-s.-H. (2021). Green Hydrogen Potentials from surplus hydro energy in Nepal. *International Journal of Hydrogen Energy*, 22256-22267.
- Bruce S, T. M. (2018). *National Hydrogen Roadmap*. Australia: CSIRO.
- CBS. (2014). *Development of manufacturing industries in Nepal*. CBS.
- CBS. (2019). *Nepal Labour Force Survey 2017/2018*. Kathmandu.
- Energy, M. o. (2023). *National Green Hydrogen Mission*. New Delhi, India.
- Energy, M. o. (2023). *National Green Hydrogen Mission*. New Delhi, India.
- Energy, U. D. (2022). *DOE National Clean Hydrogen Strategy and Roadmap*. Washington, DC.
- Energy, U. D. (2022). *Industrial Decarbonization Roadmap*. Washington, DC.
- FCHO. (2020). Retrieved from Clean Hydrogen Partnership: https://www.clean-hydrogen.europa.eu/knowledge-management/fuel-cells-and-hydrogen-observatory_en
- Gencer, E. (2021, June 23). *Climate Portal*. Retrieved from <https://climate.mit.edu/explainers/hydrogen>
- GoN. (2020). *Second Nationally Determined Contribution (NDC)*. Kathmandu.
- GoN. (2021). *Nepal's Long-term Strategy for Net-zero Emissions*. Kathmandu.
- Gupalo, O. (2023). Study of the efficiency of using renewable hydrogen in heating . *OP Conference Series: Earth and Environmental Science*.
- IAEA. (2006). *Model for Analysis of Energy Demand (MAED-2)*. Vienna, Austria.
- IEA. (2022). *Global Hydrogen Review 2022*. Paris, France.
- IEA. (2022). *World Energy Outlook*.
- IRENA. (2019). *Hydrogen: A Renewable Energy Perspective*. Abu Dhabi: International Renewable Energy Agency.
- IRENA. (2020b). *Reaching Zero With Renewables: Eliminating CO₂ Emissions From Industry and Transport in Line with the 1.5°C Climate Goal*. Abu Dhabi.
- IRENA. (2021a). *Green Hydrogen Supply: A guide to policy making*. Abu Dhabi.

- IRENA. (2021b). *World Energy Transitions Outlook 1.5C Pathway*. Abu Dhabi.
- IRENA. (2022). *Green Hydrogen for Industry: A guide to policy making*. Abu Dhabi: International Renewable Energy Agency.
- Jeffrey Rissman, C. B. (2020). Technologies and policies to decarbonize global industry: Review and assessment of mitigation drivers through 2070. *Applied Energy*.
- Ministry of Industry, C. a. (2022). *Industrial Statistics*. Department of Industry.
- MoF. (2023). *Economic Survey 2022/2023*. Kathmandu.
- NEA. (2022). *A year in review-fiscal year 2021/2022*. Kathmandu.
- NPC. (2020). *The Fifteenth Plan (Fiscal year 2019/20-2023/24)*. Kathmandu.
- R.Bhandari, S. (2023). *Renewable Energy* , 403-414.
- Ramchandra Bhandari, S. S. (2023). Evaluation of surplus hydroelectricity potential in Nepal until 2040 and its . *Renewable Energy* 212, 403-414.
- Shrestha, R. K. (2013). *Atmospheric Brown Clouds (ABC) Emission Inventory Manual*. Nairobi, Kenya: United Nations Environment Programme.
- WECS. (2013). *Nepal's Energy Sector Vision 2050*. Kathmandu.
- WECS. (2021). *Energy Consumption and Supply Situation in Federal System of Nepal (Province No. 1 and Province No. 2)*. Kathmandu.
- WECS. (2022). *Energy Consumption and Supply Situation in Federal System of Nepal (Bagmati Province)*. Kathmandu.
- WECS. (2023). *Energy Consumption and Supply Situation in Federal System of Nepal (Gandaki, Lumbini, Karnali, Sudurpaschim Provinces)*. Kathmandu: Unpublished reports.
- Worldbank. (2021). Retrieved from Carbon Pricing Dashboard: <https://worldsteel.org/steel-topics/statistics/world-steel-in-figures/>
- Zhiyuan Fan, S. J. (2021). Low-carbon production of iron and steel: Technology options, economic assessment, and policy. *Joule*.