NEPAL HYDROGEN INITIATIVE

GREEN HYDROGEN HANDBOOK
FOR NEPAL

GREEN HYDROGEN LAB

Foreword

Green hydrogen is a supple energy carrier and chemical feedstock that has the potential to decarbonize the energy and industrial sector. Globally, the green hydrogen industry is underpinned by a series of mature technology and relevant marketplace that need transit to clean energy. The development of the hydrogen industry requires investment in infrastructure and reduction of cost in hydrogen technology through a series of strategic plans and policies to attract investment from the public and private sectors.

Countries around the world have already made progressive steps to use green hydrogen as the dominant source of energy. Many countries including Australia, China, Chile, France, India, Norway, South Korea, and the USA have already formulated either a roadmap or a strategy. Even fossil fuel exporting countries like Saudi Arabia and Oman have developed green hydrogen plans and policies. Nepal's neighboring country India has already updated its "National Hydrogen Energy Roadmap 2006" in 2021 among other programs to make it self-reliant in the energy sector.

Nepal has the required resources and skills to build economical sustainability through the national hydrogen value chain, which can help contribute to the commitment to the Paris agreement and address the concerns of energy security. Nepal can have a competitive advantage over the cost of hydrogen production to US$ 1.17- US$ 2.55 per kg in contrast to US$ 5.91 to US$ 12.75 per kg globally with proper management of surplus energy from hydropower and solar. The appropriate research and development backed by the country's policies can establish green hydrogen in the energy stream of Nepal to overtake fossil fuels both technically and economically. Green hydrogen can be a clean fuel for a more secure and sustainable low-carbon economy in Nepal.

The Green Hydrogen Handbook is prepared by Green Hydrogen Lab, Kathmandu University, Nepal as a deliverable of the project "Incubation of Nepal Hydrogen Initiative Program" funded by Energize Nepal. The objective of the handbook is to help understand Green Hydrogen, its potential as a clean fuel, and to help act each individual for a green economy. The lab has made every effort for the accuracy of the information. However, the lab doesn't represent the accuracy, completeness, or purpose of the content. The information can further be used for research and teaching purposes with appropriate citations but the accuracy of the content should be independently verified. Green Hydrogen Lab takes no responsibility for the liabilities caused in connection with the use of the content.

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Abbreviations

GDP	Gross domestic product
LPG	Liquefied petroleum gas
AEPC	Alternative Energy Promotion Centre
NHI	Nepal Hydrogen Initiative
GHG	Green House Gases
SDG	Sustainable Development Goals
UNFCCC	United Nations Framework Convention on Climate Change
IEA	International Energy Agency
CEM H2I	Clean Energy Ministerial Hydrogen Initiative
IRENA	International Renewable Energy Agency
UNIDO	United Nations Industrial Development Organization
IPHE	International Partnership for Hydrogen in industries
WEC	World Energy Council
WECS	Water and Energy Commission Secretariat
HP	Hydrogen production
GON	Government of Nepal
PPP	Public Private Partnership
GHLab	Green Hydrogen Lab
NOC	Nepal Oil Corporation
KU	Kathmandu University
GGGI	Global Green Growth Institute
NREP	Nepal Renewable Energy Programme
NEA	Nepal Electricity Authority
ISO	International Standards Organization
ICE	International Electrotechnical Commission
EIGA	European Industrial Gases Association
MOICS	Ministry of Industry, Commerce and Supplies
CCS	Carbon Capture and Storage

Introduction to Hydrogen

What is Hydrogen?

Hydrogen (H_2) is the first element in the periodic table and has atomic number 1. It is the first and most basic among all the elements in the universe. Almost 90% of all the atoms in the universe are hydrogen atoms, hence it is the most abundant chemical substance in the universe. On earth, it's rarely found in pure form. Instead, it is found in combinations such as water, methane, and biomass. At standard temperature and pressure, hydrogen is a gas that human senses can't detect. It is odorless, tasteless, colorless, nontoxic, noncorrosive and stable gas. Hydrogen is also the lightest gas. Because it's 14 times lighter than air, it rises and disperses rapidly- at speeds of almost 20 m/s.

Hydrogen is a flammable gas, so it must be stored properly away from heat, flames, and sparks. When hydrogen burns in air, it doesn't produce smoke. Its pale blue flame is difficult to see; in fact, in daylight, the human eye can barely detect it. Although a hydrogen flame burns just as hot as those of other common fuels, it radiates less heat and is less likely to start secondary fires.

Hydrogen isn't a primary energy source. Instead, it's an energy carrier (like electricity), meaning it can store and deliver energy in an easily usable form. Hydrogen can be used as an energy storage system as it has the advantage of having the highest energy density i.e., 120 MJ/kg which is almost more than thrice the energy density of other fossil fuels. The stored hydrogen can be used to generate energy with little to no carbon emissions.

Table 1 Properties of Hydrogen

Property	Hydrogen	Comparison
Density (gaseous)	0.089 kg/m3 (0°C, 1 bar)	1/10 of natural gas
Density (liquid)	70.79 kg/m3 (-253°C, 1 bar)	1/6 of natural gas
Boiling point	-252.76°C (1 bar)	90°C below LNG
Energy per unit of mass (LHV)	120.1 MJ/kg	3x that of gasoline
Energy density (ambient cond., LHV)	0.01 MJ/L	1/3 of natural gas
Specific energy (liquefied, LHV)	8.5 MJ/L	1/3 of LNG
Flame velocity	346 cm/s	8x methane
Ignition range	4–77% in air by volume	6x wider than methane
Auto-ignition temperature	585°C	220°C for gasoline
Ignition energy	0.02 MJ	1/10 of methane

(Source: IEA)

Production of Hydrogen

Hydrogen is found in a compound state, typically in the form of water and hydrocarbons, and must be synthesized from raw materials with the help of an external source. Since Hydrogen is a flexible vector, it can be produced from several energy sources including petroleum products, renewables, and nuclear using a wide range of technologies like steam reforming, gasification, electrolysis, pyrolysis, water splitting, and others.

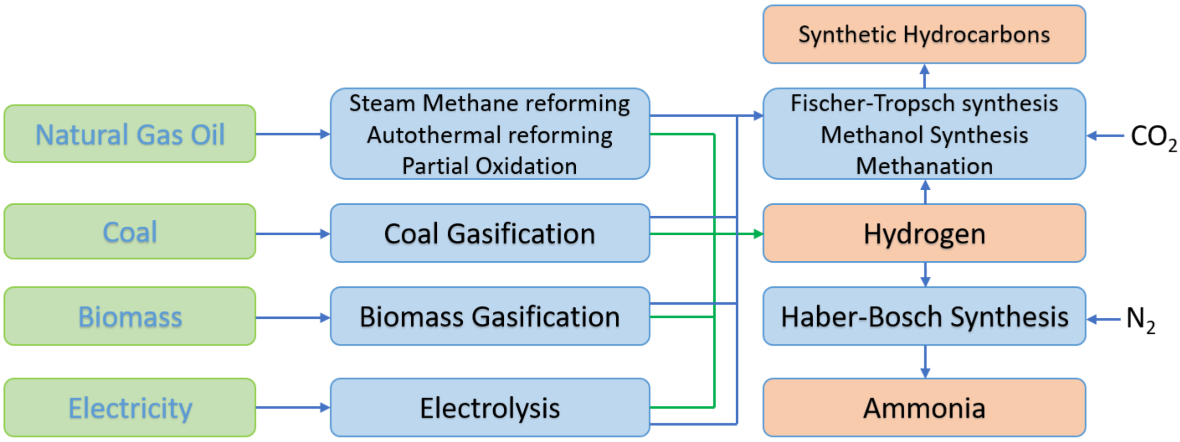


Figure 1: Production of hydrogen and hydrogen-based products
(Source: The Future of Hydrogen, IEA)

Global hydrogen production today is dominated by the use of fossil fuels. Electrolytic hydrogen – that is, hydrogen produced from water and electricity – plays only a minor role. With declining costs for renewable power (in particular solar PV and wind), interest is now growing in water electrolysis for hydrogen production and in the scope for further conversion of that hydrogen into hydrogen-based fuels or feedstocks, such as synthetic hydrocarbons and ammonia, which are more compatible than hydrogen with existing infrastructure.

Types of Hydrogen

Depending on the feedstock and production process, hydrogen is mainly divided into three categories. Grey hydrogen, blue hydrogen, and green hydrogen are the dominant types of hydrogen that are widely produced and used. The hydrogen produced with steam reforming of natural gas is termed grey hydrogen. It is the most carbon-intensive method of hydrogen production that is commercially used today. 10 kg of carbon dioxide is released into the atmosphere for every 1 kg of gray hydrogen produced. The production method of blue hydrogen is similar to gray hydrogen but additionally, it captures and stores the carbon emitted during the process with carbon capture and storage technology. It has a significantly lower CO2 impact on the environment than gray hydrogen.

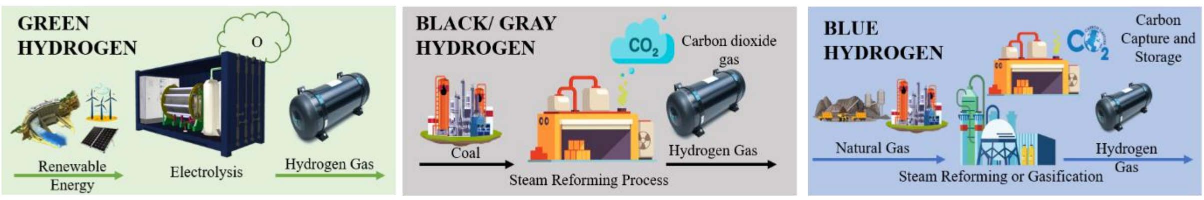


Figure 2 Color indicator of hydrogen

The most sustainable type of hydrogen is green hydrogen which is the hydrogen produced by using renewable energy through the process of electrolysis of water. It is produced without any emission of greenhouse gasses. Among total hydrogen produced in 2018, 48 % of hydrogen was grey hydrogen, 48 % was blue hydrogen and the remaining 4% was green hydrogen.

Why Green Hydrogen?

Today, more than 95% of the world's hydrogen production is based on fossil fuels, with GHG emissions. Many countries are striving for an energy transition from grey and blue hydrogen to Green. Nepal has a competitive advantage for adopting green hydrogen technology without deploying grey and blue hydrogen technology. Green Hydrogen produced from renewable energy through the thermochemical process is considered a prerequisite for the global energy transition as it produces no greenhouse emissions. In this process, an electrical current from a renewable source is used to dissociate water into hydrogen and oxygen using an electrolyzer. The split hydrogen is stored, and the other by-product oxygen can be released directly into the atmosphere or stored to be supplied for secondary use.

Transition to Green Hydrogen: Why now?

Climate change is one of the most pressing issues that threaten the lives and livelihoods of billions of people. Presently, there is a broad international scientific consensus that greenhouse emissions from human activity such as fossil fuel use and deforestation, are the key element of climate change. At the end of 2015, the Paris agreement was signed with a pledge to curb greenhouse gas (GHG) emissions to minimize the rise in the temperature and strengthen the capability to deal with climate risk. The energy sector is a major contributor to GHGs emissions, which accounts for two-thirds of the global emission. For the reasonable likelihood to stay below 1.5°C of global warming, the net anthropogenic GHG emission should decline by around 45% by 2030, from 2010, reaching carbon neutrality by 2050. As a result, several countries have published their plan and policies to reduce GHGs emissions and achieve net-zero emissions.

Nepal is one of the minimal contributors, about 0.027 percent of the global GHG emission but is most vulnerable to the consequence of GHG. Due to climate change, the country has experienced a change in precipitation, shrinking of ice, and increment in the frequency of extreme weather conditions such as floods, landslides, droughts, and other water-induced disasters resulting in loss of life and damage to socio-economic aspects.

Nineteen of the warmest year have occurred since 2000 A.D. and the year 2020 tied with 2016 for the hottest year in record-keeping began in 1880.[1]

[1] Global Climate Change, Official Website, available at, https://climate.nasa.gov/vital-signs (accessed on March 15, 2022)

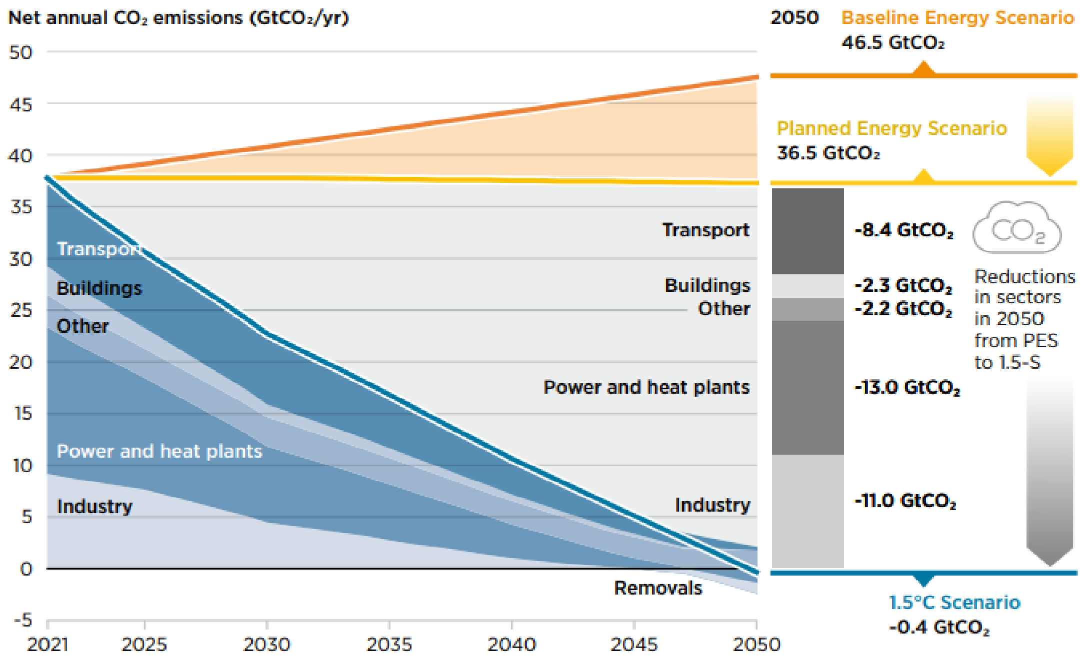


Figure 3 Projected trends in global CO_2 emission under three scenarios, 2020-2050[2]

The transition to a green hydrogen-energy economy would represent the ultimate step on the path away from carbon-based fossil energy. Presently, the industrial use of hydrogen (pure hydrogen and hydrogen-based fuel) is already a major global business with a global demand of around 115 million metric tons in 2018. For the past few decades, industrial application of hydrogen is dominated by the use of hydrogen as a chemical feedstock in the chemical industries, oil refineries, and steel industries. Today, governments around the world are committed to net-zero emissions by 2050. Since green hydrogen can generate zero-emission at the point of end-use and can be produced from renewable energy, it has the potential to be used as fuel for power and transportation.

[2] World Energy Transitions Outlook 2021, IRENA

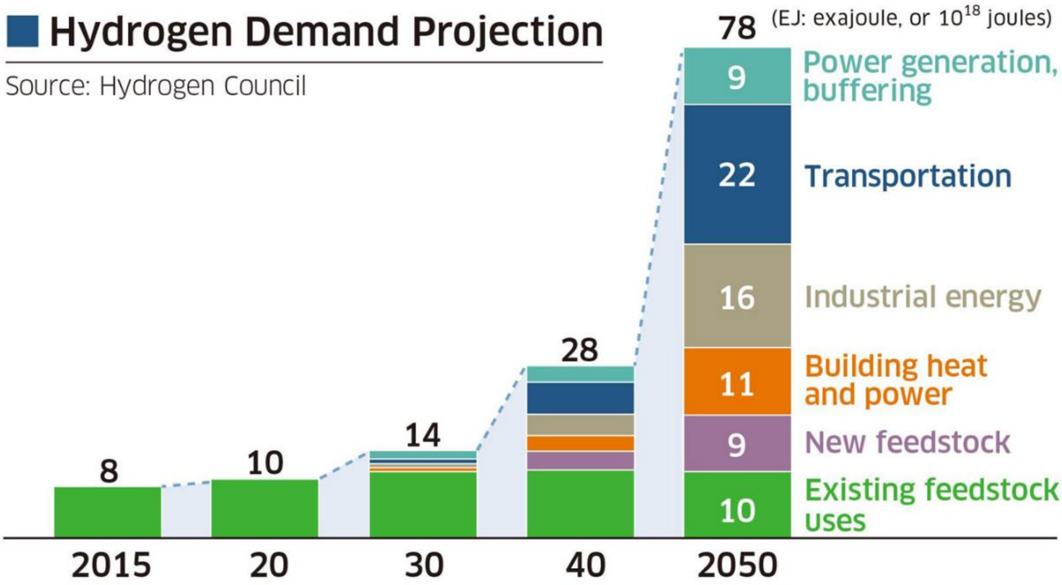


Figure 4 Forecast of Hydrogen Demand for 2050
(Source: Hydrogen Council)

The annual demand for hydrogen is 8 Exajoule (EJ) in 2015 and is expected to rise by 10-fold in 2050. The transportation sector is anticipated to be the highest consumer of hydrogen. By 2030, it is expected that 1 in 12 cars could be powered by hydrogen in California, Germany, Japan, and South Korea, and more than 350,000 hydrogen buses and thousands of passenger trains and ships could be operating without carbon emission. After the transport sector, industries could be the highest consumer of hydrogen as it could be a more feasible route for decarbonization than electrification.

The government's commitment to decarbonizing the economy has resulted in increased investment in clean energy technology, as well as increased R&D and demonstration spending by the private sector, all of which have accelerated industrial growth. The possibility of zero-emission production and application of hydrogen has attracted global interest in hydrogen as an alternative, and clean fuel.

Hydrogen value chain: Production to end-use

Hydrogen produced from the electrolysis process utilizing renewable energy sources is used to split water into hydrogen and oxygen using an electrolyzer. An electrolyzer consists of two electrodes- a negatively charged cathode and a positively charged anode separated by an electrolyte membrane surrounded by water. There are currently three leading electrolysis technologies- alkaline water electrolyzer, proton exchange membrane electrolyzer, and solid oxide electrolyzer. The alkaline water electrolyzer is the most mature technology for commercial application compared to other electrochemical processes.

Hydrogen produced from the electrolyzer is in the gaseous state but can be physically stored in the gas or liquid states. Due to low energy density at ambient temperature, hydrogen must be compressed before distribution. Generally, it is stored below 100 bar for stationary applications but requires higher pressure of around 200-720 bar for mobile applications. Liquid hydrogen is stored in especially cryogenic tanks under pressure which has provision for cooling and venting. For the same tank size, liquid hydrogen has high energy content than compressed hydrogen storage but requires higher energy for the refrigeration process.

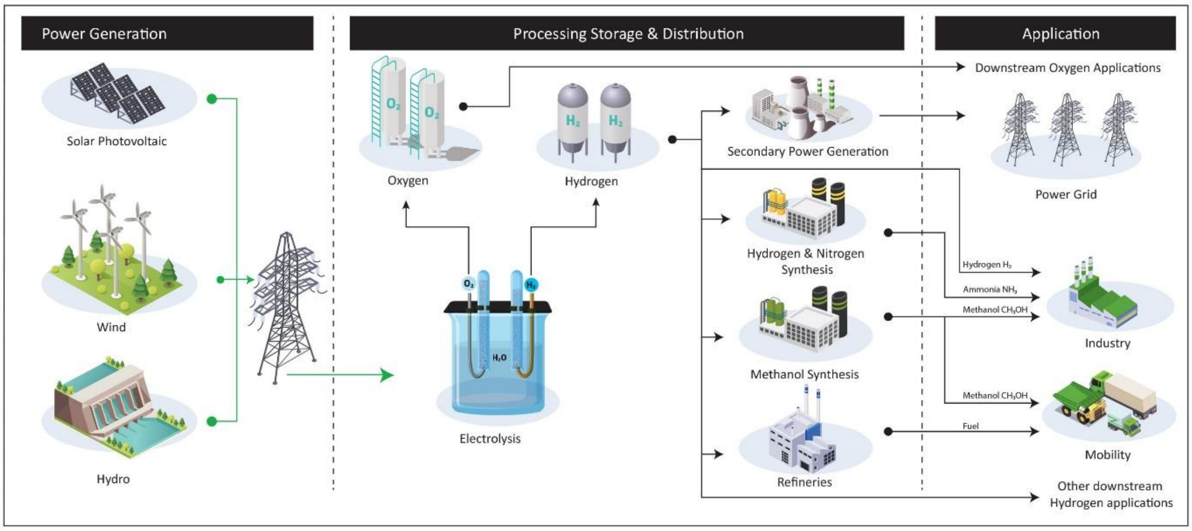


Figure 5 Different phases in the hydrogen ecosystem
(Source: Momentous Energy)

The hydrogen delivery process is divided into two parts. First, from the production site to the city gate or other transfer location, and then distribute the hydrogen from the transfer location to the end-user location. The possible modes for distribution and transportation of hydrogen are pipelines, tube trailers, and shipping depending upon quantities and distances. Hydrogen can be transported in gaseous, liquid, or other forms like ammonia and synthetic methane. Since hydrogen is one of the flexible elements, it can be used as an energy carrier and industrial feed.

Prospective of green hydrogen in Nepal

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. 1 Kg of hydrogen can produce about three times more energy than the same of petrol without carbon emission as long as it is produced from renewable energy. 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 surplus energy, having the risk of being spilled, can be utilized for green hydrogen thus reducing the energy cost. If the surplus 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. 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.

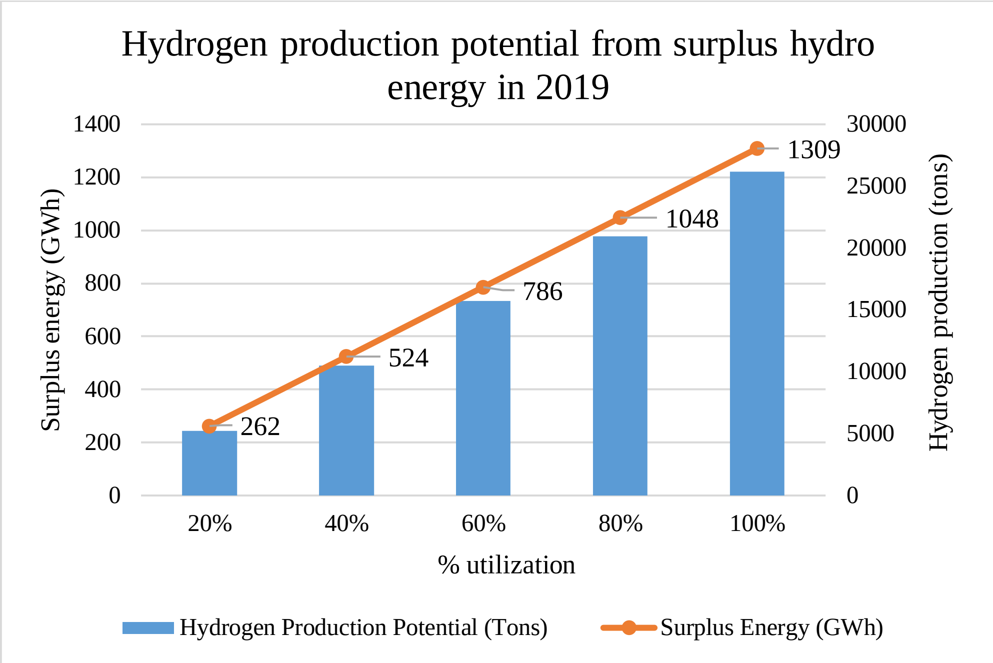


Figure 6 Potential hydrogen production from excess hydro energy in Nepal in 2019

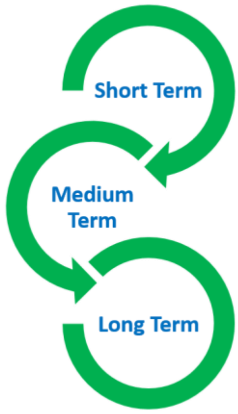
Nepal relies on imports for all fossil fuels, consuming up to 10% of the country's GDP, and is one of the strong contributors to the trade deficit of around 13%. The production and use of green hydrogen to replace fossil fuels will enhance energy security and sustain the domestic energy sector. Nepal has huge hydropower potential, with over 20,000 MW in various stages of development. If proper planning is not done now, it is expected that 3,500 MW of production capacity will be unused during production peak periods over the next decade. It is evaluated that in 2028, 20% utilization of overflow power will create 8410 tons of green hydrogen and 336,384 tons if 100% of overflow power is utilized. To put it in Nepal's vitality setting, 336,384 tons of hydrogen will be sufficient to supplant 25% of the fossil fuel request for 2028. Additionally, 82,475 tons of hydrogen is sufficient to supply feedstock to the generation plant to meet the current request of 800,000 tons of urea. Moreover, it is critical to evaluate the potential application of hydrogen in other segments as well, which can contribute to a more secure and sustainable low-carbon economy. Substitution of coal and heater oils within the mechanical division, LPG and strong fills within the private segment, fossil fuel-based control reinforcement frameworks, and clean fuel for future businesses like mining, re-electrification, etc. are a few of the regions that require advanced investigation.

Legal and Strategic Barrier

Nepal has no legal regulation for green hydrogen. Several policies and programs are supporting renewable and alternative energy sources but none of them has specific provisions for the production and utilization of green hydrogen. However, under pollution prevention, control, and minimization, clause 8.1 of the National Environment Policy 2076 (2019) calls for the promotion of hydrogen as a clean transportation fuel. There is a need for policy intervention and regulatory action to establish a green hydrogen economy in Nepal. This cross-sectoral coordination among different bodies of government can establish the commercial application of green hydrogen in Nepal.

It is important to note that the improper handling and negligence in the transportation and end-use of hydrogen can cause harm to the environment, individuals, and property. Thus, a safety regulatory body is required to control and monitor the hydrogen value chain through careful planning and specifying standards of hydrogen technologies.

Potential Action Plan



Nepal must take swift action to prepare a legal framework for green hydrogen technology to be in parity with other nations making legitimate advances and benefiting from its use. The studies recommend two stages for the development of a legal framework. Initial, Adaptive stages where particular policy/strategy/roadmap is defined and necessary changes are made to the existing relevant legislation. Finally, the mature stage in which specific legislation on hydrogen is actualized.

In the case of Nepal, few conceivable revisions can be made to Industrial Enterprises Act & Rules (2020 & 2021), Fiscal Act and Tax Laws, Electricity Act and Rules (1992 & 2016), and Public-Private Partnership Investment Act & Rules (2017 & 2018). Different agencies and organizations should work on developing short-term, medium-term, and long-term plans to present green hydrogen in Nepal. The Nepal Hydrogen Initiative (NHI), established by Kathmandu University, which is conceived to be owned by Nepal Government in the future can be a research and knowledge hub for establishing policy foundations, hydrogen energy value chain, and developing action plans. A separate authority body is recommended to be chartered by the act of parliament as a long-term institution for better mobilization of the fund allocated in the national budget and for the overall governance and regulation of commercial initiatives taken by private sectors. The initiatives taken by academic institutions, research organizations, and private sectors should be supported by the government through their annual plans and budgeted activities.

Global Green Hydrogen Economy- A Move to Net Zero Emission

The current global interest in the advancement of green hydrogen technologies is majorly driven by

- Reducing the dependency on foreign oil and gas
- Pursuit of the alternative energy technology for net-zero carbon emission
- Abundance of hydrogen and its availability
- Global effort to fight with the climate action

This chapter elaborates on the global and national perspective on green hydrogen technology with international commitment and collaboration of developed, developing, and neighboring countries, and provides an overview of the development of the green hydrogen technology.

The global hydrogen economy is likely to be driven by the demand for cleaner fuel and assurance of energy security. Its sustainability and eco-friendly development have caught the attention of numerous nations. The ultimate outcome of changes relevant to green hydrogen technology is directly linked to the commitment of the states under the following conventions and treaties:

Sustainable Development Goals (SDG), 2030

Sustainable Development Goals, also known as the 2030 Agenda for Sustainable Development, are the collection of the 17 different goals set up and adopted by the United Nations Resolution. Among these 13 distinctive goals, two of them are directly linked to having zero carbon footprint with energy access for all.

Table 2 SDG relevant and linked to energy

Goals	Targets
7 AFFORDABLE AND CLEAN ENERGY — Ensure access to affordable, reliable, sustainable and modern energy for all	• Universal access to renewable energy sources. • Increase in the global percentage of green energy. • Advancements towards research and investment in green energy. • Expanding and upgrading energy services for developing countries.
13 CLIMATE ACTION — Take urgent action to combat climate change and its impacts	• Limiting global average temperature below 1.5°C. • Reaching net-zero carbon dioxide emission globally by 2050.

United Nations Framework Convention on Climate Change (UNFCCC)

The United Nations Framework Convention on Climate Change sets out the basic legal framework and principles for international climate change cooperation to stabilize the atmospheric concentration of GHGs. The treaty was signed by 154 nations to maintain an ecosystem to adapt to the adverse effect of climate change and mitigate the risk of human-induced interference with the climate system. The Framework cover two articles relevant to the discussion of green hydrogen technology.

- *Article 3: Principle*

The state parties are obliged to define the approaches to require preparatory measures to except, anticipate, or minimize the cause of climate alteration and moderate its unfavorable impacts. Furthermore, the articles moreover clarify the state must not make any delay or any arrangements to anticipate climate dangers or irreversible harm due to a need for full logical certainty.

- *Articles 4: Commitment*

State parties shall take into account enforcement mechanisms based on their national and regional development, objective, and circumstances that convey the responsibilities as below:

  - Review and Policy Compliance.
  - Implementation Efforts.

The Kyoto Protocol and the Paris agreement were adopted in 1997 and 2015 respectively to boost the effectiveness of the 1992 UNFCCC.

Table 3 Climate Agreement

Climate Agreement	Description
Kyoto Protocol	The country-specific target is to limit and reduce greenhouse emissions.
Paris Agreement	The specific goal of this agreement is to reduce GHGs emissions so that the global average temperature would not rise more than 1.5˚C compared to the pre-industrial era.

International Institutions and Collaboration for green hydrogen

Recently, there has been formidable cooperation and support to promote the use of hydrogen on a national and international level. Countries have formed coalitions and mutual efforts to maintain a standard regulatory regime to promote green hydrogen in the energy sector. There are several international institutions working to promote green hydrogen some of them are enlisted below:

1. International Energy Agency (IEA)

The International Energy Agency is an international intergovernmental organization that mainly focuses on establishing a secure and sustainable energy future for all. It has partnered with several programs, researching a range of hydrogen-related thematic areas. The partnership agreements are signed by the authorities and are under their control, while the research and technology communities participate in the various work packages within the programs.

Figure 7 Net-Zero Tracker
(Source: Clean Energy Ministerial Hydrogen Initiative (CEM H2I))

The CEM H2I (Clean Energy Ministerial Hydrogen Initiative) is a voluntary multi-government initiative, launched on May 22, 2019. It has been developed under the CEM framework. The objective of CEM H2I is to advance policies, programs, and projects which intend to accelerate the commercialization and deployment of hydrogen and fuel cell technologies.[1]

2. International Renewable Energy Agency (IRENA)

The International Renewable Energy Agency (IRENA), Collaborative Framework on Green Hydrogen, is a platform that serves as dialogue, cooperation, and coordinated action required for accelerated development and deployment of green hydrogen as a universal energy carrier. Participation in the collaborative framework on Green Hydrogen is available to the private sector and other international institutions as well. Furthermore, it has been acting as a global voice for renewables, a network hub, and a source of advice and support for various countries, willing to promote green energy.

3. Hydrogen Council

Hydrogen Council is an initiative that is a global CEO-led initiative of leading companies with a united version and long-term ambition. The institution focuses to foster the use of hydrogen as a clean energy transition for a better and more resilient future. The main focus of the council is to shift the momentum in the energy sector from the use of the fossil fuel-driven energy sector into a hydrogen-based energy transition.

4. UNIDO's Global Programme for Green Hydrogen in Industries

United Nations Industrial Development Organization (UNIDO) under the Vienna Energy Forum (VEF), 2021 launched the Global Partnership for Hydrogen Application in Industry. The UNIDO's green hydrogen initiative has been undertaken to decarbonize the industry as well as promote the application of green hydrogen.

5. International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)

In 2003, the United States Department of Energy and the United States Department of Transportation facilitated the formation of "The International Partnership for the Hydrogen Economy." The rationale behind the establishment of IPHE was to nurture international cooperation on hydrogen and fuel cell research and development, common codes and standards, and information sharing on infrastructure development.

Currently, Nepal is one of the members of institutions that are working in the energy sector like IRENA and WEC but not on institutions that are directly working on hydrogen-like hydrogen council, IPHE.

Table 4: Nepal in International Energy Institution

Institutions	Nepal's Affiliation
International Energy Agency (IEA)	None
International Renewable Energy Agency (IRENA)	Member
Hydrogen Council	None
International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)	None
UNIDO's Global Program for Green Hydrogen in Industry	Member (of UNIDO)
World Energy Council (WEC)	Member

Country-specific activities, policies, and plans for Hydrogen

Globally, several countries have begun to address hydrogen development strategically to provide clear long-term investment in green hydrogen.

The Russian Government approved a series of Russia's strategic development initiatives until 2030 including the "Clean energy (renewables and hydrogen") in a "Technical Breakthrough" section of this initiative on 6 October 2021[4].

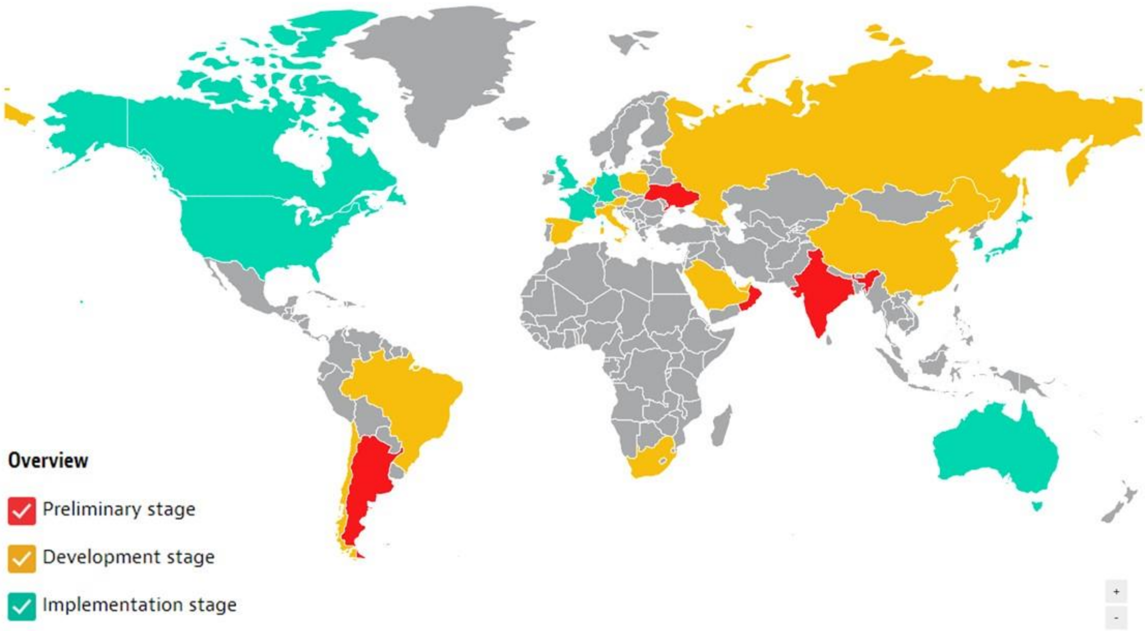


Figure 8 Hydrogen Heat Map[3]

***Hydrogen Heat Map shows glimpses of hydrogen initiatives undertaken globally to support the growth of low-carbon hydrogen in the form of legal, regulatory, and policy developments.*

Australia	Announced more than AUD 100 million to support hydrogen research and pilot projects. Published a technical roadmap for hydrogen in Australia produced by the Commonwealth Scientific and Industrial Research Organization (CSIRO). Developed a national hydrogen strategy in 2019.
Austria	Hydrogen strategy based on renewable electricity has been developed in 2022 as part of the Austrian Climate and Energy Strategy for 2030.
Belgium	Published a government-approved hydrogen roadmap in 2018, with specific targets set for 2030 and 2050 and an associated EUR 50 million regional investment plan for power-to-gas.

[3], Hydrogen Heat Map, Official Website, available at, https://resourcehub.bakermckenzie.com/en/resources/hydrogen-heat-map/heat-map (accessed on March 15, 2022)

Brazil	Included hydrogen in the Science, Technology and Innovation Plan for Renewables and Biofuels. Hosted and supported the 22nd World Hydrogen Energy Conference in 2018.
Canada	Canada has released Hydrogen Strategy for Canada in 2020 with the aim to position Canada as a world-leading producer, user and exporter of clean hydrogen, and associated technologies.
China	Released the country's first-ever long-term plan for hydrogen, covering the period of 2021–2035. Announced that the Ten Cities programme that launched battery electric vehicles in the People's Republic of China ("China") would be replicated for hydrogen transport in Beijing, Shanghai and Chengdu, among others. Announced that Wuhan will become the first Chinese Hydrogen City, with up to 100 fuel cell automakers and related enterprises and up to 300 filling stations by 2025. Announced targets of 1 million FCEVs by 2030, plus 1000 refueling stations. Exempted FCEVs (and battery electric vehicles) from vehicle and vessel tax.
European Union	Adopted "A hydrogen strategy for a climate-neutral Europe" in 2020 with a vision for the creation of a European hydrogen ecosystem from research and innovation to scale up production and infrastructure to an international dimension. The European Commission published a long-term decarbonisation strategy that included hydrogen pathways for achieving carbon neutrality; recast the directive on the promotion of the use of energy from renewable sources, enabling hydrogen produced from renewable sources with guarantees of origin to be counted against 2030 renewables targets; and set up a "Hydrogen Energy Network" as a platform for discussion of hydrogen among EU member states. Twenty-eight European countries signed the Linz Declaration "Hydrogen Initiative" promoting co-operation on sustainable hydrogen technology, alongside around 100 businesses, organizations and institutions.
France	Unveiled a Hydrogen Deployment Plan and EUR 100 million funding and 2023 and 2028 targets for low-carbon hydrogen in industry, transport and for renewable energy storage, including for islands in 2018 and released the National Strategy for Decarbonised Hydrogen Development in 2020.
Germany	Approved the National Innovation Programme for Hydrogen and Fuel Cell Technologies for another ten years with EUR 1.4 billion of funding, including subsidies for publicly accessible hydrogen refueling stations, fuel cell vehicles and micro co-generation purchases, to be complemented by EUR 2 billion of private investment. Supported the first commercial operation of a hydrogen-powered train, and the largest annual increase in refueling stations in the country, though the H2mobility programme. Released a National Hydrogen Strategy in 2020 with the focus on achieving its climate goals and with the awareness of the economic chances of a growing hydrogen market and seeks to become a leading provider of green hydrogen technologies.
India	The government announced that, from 2023/24, 10% of refinery hydrogen demand (increasing to 25% in the following five years) and 5% of hydrogen demand for fertilizer production (increasing to 20% in the following five years) should be met with renewable hydrogen. India announced National Hydrogen Energy Mission (NHM) which will draw up a roadmap for using hydrogen as an energy source. The NHM, according to a draft paper prepared by the Ministry of New and Renewable Energy (MNRE), has identified pilot projects, infrastructure and supply chain, research and development, regulations and public outreach as broad activities for investment with a proposed financial outlay of Rs 800 crores for the next three years.

Italy	Issued regulations to overcome barriers to the deployment of hydrogen refueling stations by raising the allowable pressure for hydrogen distribution and enhancing safety, economic and social aspects. Italy released "Italian Hydrogen Strategy: preliminary guidelines" in 2020. This document sets a medium and long-term objective, according to which the national energy consumption is expected to consist of 2% hydrogen by 2030 and 20% by 2050.
Japan	Hosted the first Hydrogen Energy Ministerial Meeting of representatives from 21 countries, plus companies, resulting in a joint Tokyo Statement on international co-ordination. Updated its Strategic Roadmap to implement the Basic Hydrogen Strategy, including new targets for hydrogen and fuel cell costs and deployment, and firing hydrogen carriers in power plants. The Development Bank of Japan joined a consortium of companies to launch Japan H2 Mobility with a target to build 80 hydrogen refueling stations by 2021 under the guidance of the Japanese central government's Ministerial Council on Renewable Energy, Hydrogen and Related Issues. The Cross-Ministerial Strategic Innovation Promotion Program (SIP) Energy Carriers initiative concluded its 2014–18 work programme and a Green Ammonia Consortium was launched to help support the next phase. Released the Green Growth Strategy in 2020 which was then revised in 2021 puts emphasis on measures to strengthen hydrogen supply including transportation and storage. Through these steps, the strategy aims to bring down the price of hydrogen and to expand the volume of domestic introduction up to 3 million tons in 2030 and 20 million tons in 2050.
Korea	Published a hydrogen economy roadmap with 2022 and 2040 targets for buses, FCEVs and refueling stations, and expressed a vision to shift all commercial vehicles to hydrogen by 2025. Provided financial support for refueling stations and eased permitting. Announced that it would work on a technological roadmap for the hydrogen economy.
The Netherlands	Published a hydrogen roadmap and included a chapter on hydrogen in the Dutch Climate Agreement. Spearheaded the first meetings of the Pentalateral Energy Forum of Belgium, the Netherlands, Luxembourg, France, Germany and Austria in support of cooperation on hydrogen in north-west Europe. The Netherlands issued its national hydrogen strategy in 2020.
New Zealand	Signed a memorandum of co-operation with Japan to work on joint hydrogen projects. Set up a Green Investment Fund to invest in businesses, including those commercialising hydrogen. Developed Hydrogen Green Paper 'A vision for hydrogen in New Zealand' in 2019 and later released New Zealand Hydrogen Scenarios in July 2022.
Norway	Awarded funding for development of a hydrogen-powered ferry and a coastal route vessel. Published The Norwegian Government's hydrogen strategy in 2020 which is thought to be a contribution to the process of developing new low-emission technologies and solutions. Later in 2021, the Norwegian government released its hydrogen roadmap, outlining key policy plans up to 2030 that will support the country's ambition to have an established hydrogen market by 2050.
Portugal	Portugal has developed a 7 billion EUR National Hydrogen Strategy, aiming at increasing the share of hydrogen in the final energy consumption to 5% by 2030. Specific targets include: the gradual increase of hydrogen consumption in the road transport sector up to 20% by 2050, reaching up to 100 HRS in the country by 2030, and the installation of 2 GW electrolyzers by 2030 and 5 GW by 2050. An industrial hub will be developed in Sines, with 1GW electrolyzers based on seawater and clean water, including synergies of nearby water port, sun and land availability.

Russia	The Russian Federation released its Energy Strategy to 2035 in 2020 which includes a broad overview of its plan for hydrogen: to export 0.2 million metric tons of hydrogen by 2024 and 2 million by 2035 and then later released a roadmap for Hydrogen Development in the same year. The Russian government's most recent and most detailed release, the Concept for the Development of Hydrogen Energy in Russia (August 2021), is the first step in the lengthy action plan outlined in the roadmap.
Spain	The Spanish government has developed the country's "Hydrogen Roadmap: A Commitment to Renewable Hydrogen" plan to contribute to achieving climate neutrality and a 100% renewable electricity system with objectives for 2030 and a vision for 2050 to ensure that renewable hydrogen contributes to the country's climate neutrality by 2050.
Saudi Arabia	Saudi Aramco and Air Products announced they are going to build Saudi Arabia's first hydrogen refueling station. Saudi Arabia hopes to attract more than $36 billion of investment by 2030 under its National Hydrogen Strategy, which is being finalized. On the northwestern shores of Saudi Arabia, plans are underway for a multibillion-dollar hydrogen plant with a daily production target of 650 tonnes of green hydrogen.
South Africa	Included fuel cell vehicles as part of Green Transport Strategy to promote the use of fuel cell public buses in metropolitan and peri-urban areas of the country. South Africa aims to deploy 10 gigawatts (GW) of electrolysis capacity in Northern Cap by 2030 and produce about 500 kilotons of hydrogen annually by 2030.
United Kingdom	Set up two GBP 20 million funds for innovation in low-carbon hydrogen supply and innovation in storage at scale including Power-to-X. Is testing blending of up to 20% hydrogen in part of the UK natural gas network. Released UK Hydrogen Strategy in 2021 which sets out the approach to developing a thriving low carbon hydrogen sector in the UK to meet the increased ambition for 10GW of low carbon hydrogen production capacity by 2030. The United Kingdom is vying to become a "global leader on hydrogen by 2030," the second goal in its Ten Point Plan for a Green Industrial Revolution.
United States	In June 2021, The DOE announced Hydrogen Energy Earthshot, an ambitious initiative to slash the cost of clean hydrogen by 80% by 2030. The DOE has launched H2USA which is a public-private partnership to promote the commercial introduction and widespread adoption of hydrogen-fueled fuel cell electric vehicles across America. Extended and enhanced the 45Q tax credit that rewards the storage of CO2 in geological storage sites, and added provisions to reward the conversion of CO2 to other products, including through combination with hydrogen. California Fuel Cell Partnership outlined targets for 1000 hydrogen refueling stations and 1000000 FCEVs by 2030, matching China's targets. A plant in Texas that is under development is expected to produce over 2.5 billion kilograms of green hydrogen per year.

Global context: Policy Perspectives

The past two years have seen a new wave of policy interest and support for clean hydrogen across the globe, reflected through a rapid increase in national hydrogen strategies and roadmaps. The following chart delineates that the journey of hydrogen recently initiates in most of the country. Nepal has an opportunity for following the trend and is not far behind to take benefits of hydrogen technology.

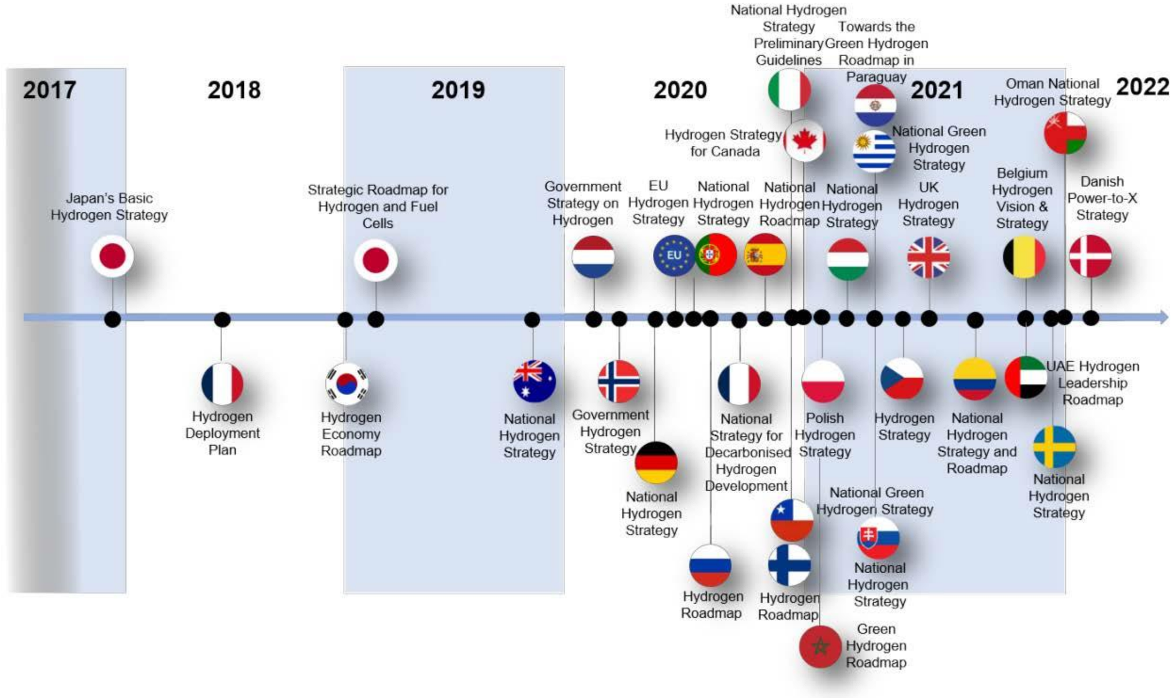
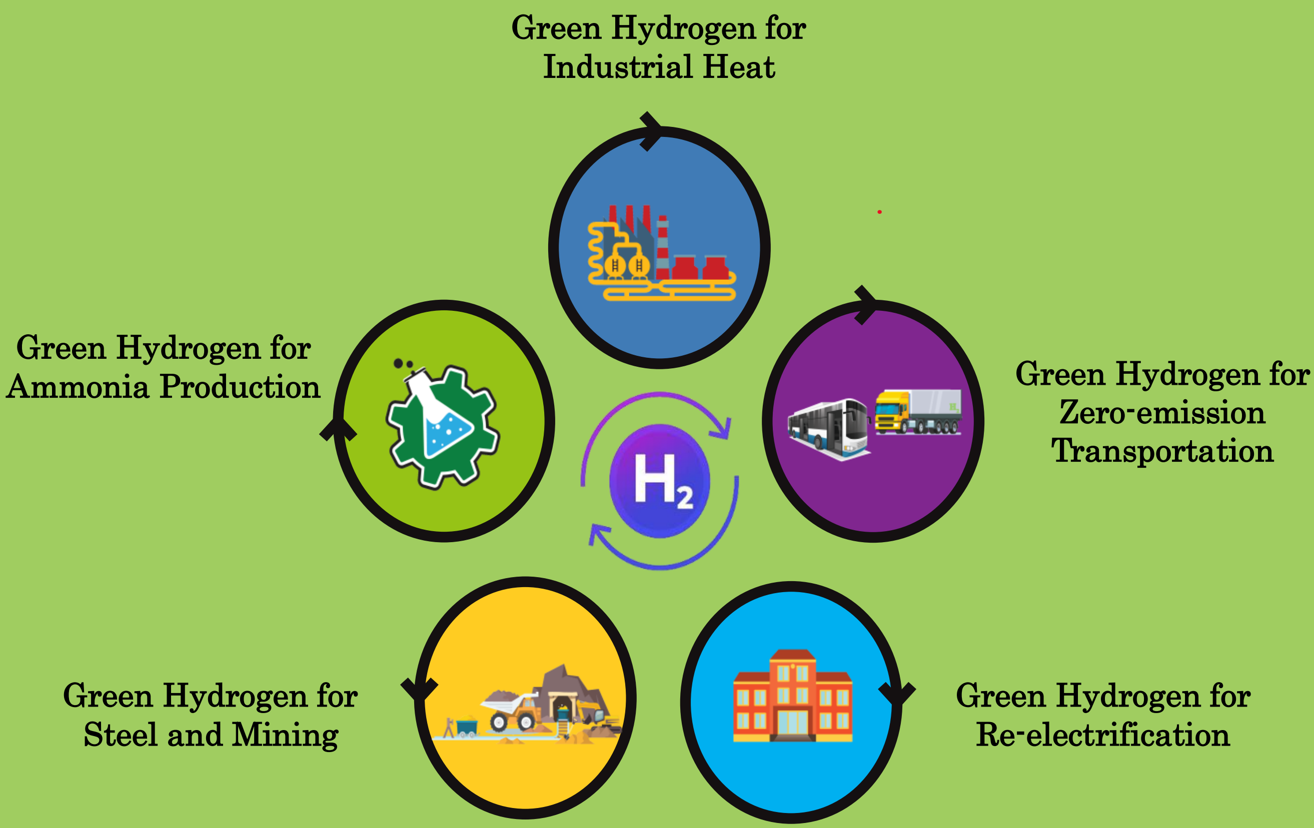


Figure 8 Hydrogen roadmap strategies across the globe[4]

The observation of the country-specific regime on hydrogen indicates that the movement to incorporate a legal framework for the promotion and regulation of green hydrogen has taken momentum after 2015. The countries like Nepal that have not started the initiative of legal action to support green hydrogen are not far behind if they start to formulate provisions from this specific point. Most countries have started their initiative to support and develop legal regulations for green hydrogen through hydrogen-specific roadmaps and strategies. For regulatory framework, countries have focused to amend and revise the regulatory framework relevant for facilitating the operation of green hydrogen in the commercial sector.

[4], Goldman Sachs Investment Research, Official Website, available at, https://www.goldmansachs.com/insights/pages/gs-research/carbonomics-the-clean-hydrogen-revolution/carbonomics-the-clean-hydrogen-revolution.pdf

Hydrogen Economy in Nepal



It is right time for the clean energy transition in Nepal with proper use of its immense hydropower and abundant solar energy sources to strategically replace fossil fuels in both commercial and residential sectors.

Green hydrogen can play a vital role in the economy as an energy carrier and could be one of the promising links in the clean energy transition for Nepal. This will have a significant impact on the energy mix of the country and energy export alternatives.

The total energy consumption of Nepal in 2019 was around 586 PJ, with an annual average growth rate of around 4%. The energy mix of Nepal is composed of biomass, petroleum products, coal, hydroelectricity, and renewable energy. While biomass consumption decreased from 82% in 2009 to 69% in 2019 (WECS, 2021), the consumption of petroleum products has been increasing. At present, almost 200 million USD is needed annually to procure fossil fuels, which is about 10% of the national GDP.

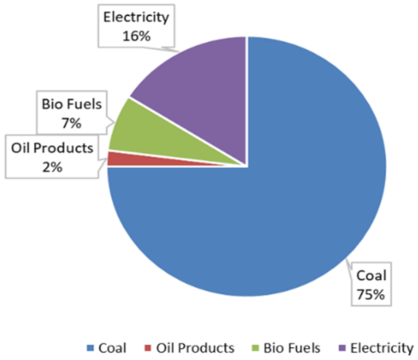


Figure 1 Energy mix of Nepalese Industries (IEA, 2018)

Green hydrogen is emerging as an impressive clean energy carrier with the ability to offer flexibility to renewable energy. In the present context, hydrogen produced from renewable electricity through an electrolysis process is considered green as it has incredibly low carbon footprints since it emits no greenhouse gasses.

Hydrogen production and end-use in Nepal

Nepal has the potential to produce green hydrogen as the country has an abundant supply of fresh water, and the recent monsoon season has generated about 450 MW of excess power. The energy consumption of hydrogen production varies greatly depending on the size and type of systems and equipment used but is estimated at around 5055 kWh per kg of H_2 (excluding gas processing and compression aids). Hydrogen production through electrolysis is not as competitive as other fossil fuel production, mainly because of the high cost of electricity. The energy cost for hydrogen production varies from US$ 5.91 to US$ 12.75 depending upon the production period and tariff rates[5]. In contrast, Nepal has a competitive advantage over other nations as surplus energy from hydropower and other renewable energy can be utilized for green hydrogen production at a reduced cost. If the surplus electricity is provided at a subsidized rate, the cost of production for 1 kg of hydrogen would come down significantly to US$ 1.17 to US$ 2.55 for different time of day tariff rates. A kg of hydrogen can produce about three times more energy than the same amount of petrol without carbon emission as long as it is produced from renewable power. Applications of green hydrogen in Nepal have been identified and illustrated in Figure 7 and further discussed in the Showcase Project Section.

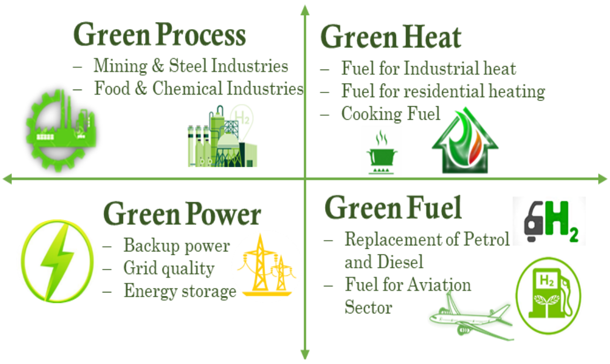


Figure 2 Application areas of green hydrogen in Nepal

[5] B. S. Thapa and B. Thapa, "Green Hydrogen as a Future Multi-disciplinary Research at Kathmandu University," *Journal of Physics: Conference Series*, vol. 1608, no. 1, p. 012020, Aug. 2020, doi: 10.1088/1742-6596/1608/1/012020

Nepal has abundant water resources and adequate geography for hydroelectricity generation with a potential of around 32,680 MW[6]. More than 20,000 MW of hydropower projects are in various developmental stages, and it is projected that around 3500 MW of electricity is going to be surplus within the next decade[7]. The spillage of this surplus energy will result in a huge loss of the capital invested in them. Increased capacity utilization of hydropower and producing hydrogen from the hydropower surplus electricity is one of the possible options for addressing the energy utilization problem in Nepal[8]. Encouraging hydropower plant owners to produce green hydrogen at the point of generation or point of interconnection can be a feasible solution for maximum utilization of the available resources. A study done in 2008 projected that Nepal has the potential to produce hydrogen from existing hydropower plants during the off-peak load by utilizing

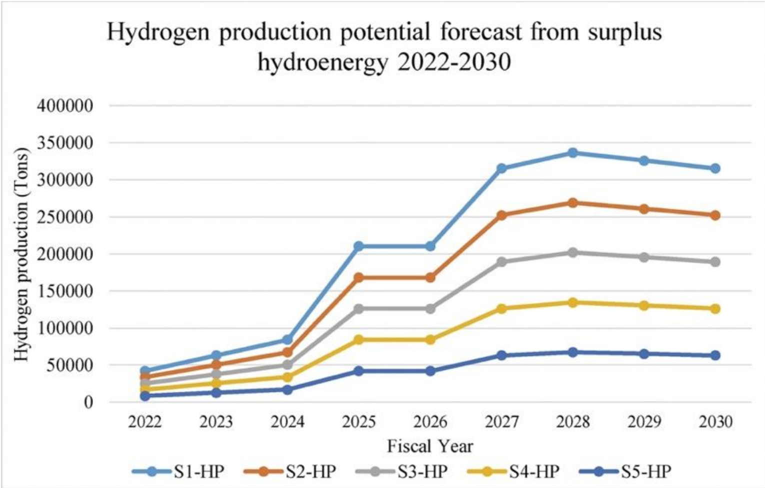


Figure 3: Potential Hydrogen production (HP) forecast at different scenarios using Surplus Energy for 2022–2030[8].

In 2028, 336,384 tons of hydrogen can replace one-fourth of the total demand for fossil fuel. If only 20% of the surplus electricity from hydropower from 2028 is used to produce hydrogen, it can be used for re-electrification to generate 1346 GWh. The hydrogen produced from the renewable electricity can potentially be applied as feedstock in the urea and ammonia industry. For example, the hydrogen produced from 20% to 80% surplus energy utilization scenarios for the year 2022 when used to produce urea, the amount of urea-produced ranges from a minimum of 33,638 tons to a maximum of 326,292 tons of urea. This possible maximum amount of urea production in the year 2022 from green hydrogen surpass the annual import of around 300,000 tons of Urea in Nepal. The annual total demand for Urea fertilizer in Nepal is around 800,000 tons. To meet the demand production of urea through green hydrogen route would require 82,475 tons of hydrogen. This can be achieved utilizing 40% of the projected surplus hydroelectricity. This implies that the green hydrogen has the potential to meet the feedstock requirement to produce Urea in Nepal[8].

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[6] "Water and Energy Commission Secretariat, Assessment of Hydropower potential of Nepal," 2019.

[7] B. S. Thapa and B. Thapa, "Green Hydrogen as a Future Multi-disciplinary Research at Kathmandu University," *Journal of Physics: Conference Series*, vol. 1608, no. 1, p. 012020, Aug. 2020, doi: 10.1088/1742-6596/1608/1/012020

[8] A. Zhou, W. Zhou, and P. Manandhar, "A Study on the Prospect of Hydropower to Hydrogen in Nepal," Manila, Philippines, Aug. 2020. doi: 10.22617/WPS200218-2.

surplus electricity. The result indicated the potential of producing 8370 tons of hydrogen when 20% of surplus energy in 2005 was utilized, and the produced hydrogen has the potential to replace 31,680 kL of gasoline[9]. According to a recent study conducted by Thapa et.al, the minimum amount of hydrogen produced for the year 2028 is 8410 tons and 335,385 tons for 20% and 100% surplus energy utilization respectively.

The Driver of the Green Hydrogen Economy in Nepal

Green hydrogen has been regarded as a clean energy vector that can play a huge role in increasing the consumption of renewable energy for low-carbon energy. In Nepal, the need for green hydrogen is driven by the following factors:

1. Availability of renewable electricity

One of the major drivers of green hydrogen in Nepal is the availability of clean electricity. The country has abundant renewable electricity in the form of hydropower. According to the Department of Electricity Development, there are around 7900 MW hydropower projects under construction in the country. Some of this energy can be utilized for green hydrogen production that has various applications such as mobility, heating, and energy production. The techno-economical study and incentives from the government are required for the commercialization of the hydrogen production plant.

2. The seasonal disparity in energy supply

Most of the hydropower in Nepal are run-of-the-river hydropower plants resulting in surplus electricity in the wet season and acute shortage during the dry season. Green hydrogen produced from the electrolyzer can be stored for long periods and can be used to re-electrify the power system using fuel cells. This will prevent the over-installation of hydropower to meet demand during the dry season. Additionally, this can also prevent the imports of electricity from neighboring countries.

3. Nepal's Commitment

Despite being a signatory to the Kyoto Protocol, Nepal has not set any binding goals. Similarly, the country did not ratify the Doha Amendment made to the Kyoto Protocol. Nepal signed the Paris agreement on April 22, 2016. Subsequently, Nepal ratified the Paris agreement on October 5, 2016. As a contracting state of the Paris Agreement, Nepal is bound by the obligation under Article 2 Sub-Article 1 (a) of the Paris Agreement i.e., to uphold the commitments to limit the rise of temperature to 1.5°C. Nepal has submitted the first and second NDC prepared by the GON to implement the commitment envisaged by the Paris Agreement.

Green hydrogen can play a crucial role in the reduction of Greenhouses Gases (GHG) in transportation, industrial, mining, and specifically in those areas where

[9] B. B. Ale and S. O. Bade Shrestha, "Hydrogen energy potential of Nepal," *International Journal of Hydrogen Energy*, vol. 33, no. 15, pp. 4030–4039, 2008, DOI: 10.1016/j.ijhydene.2008.04.056.

fossil fuel is consumed as a fuel. Green hydrogen as an energy carrier can contribute to meeting the commitment published by the Government of Nepal.

4. Diversification of application

Due to its supple nature, hydrogen produced using renewable energy from the electrolysis process can be utilized as an energy carrier as well as feedstocks for different industries.

5. Unlimited availability of good quality water

Green hydrogen production requires pure water as feedstock and electricity in the form of energy. Nepal has abundant snow-fed pure water flowing in the rivers. 1 kg of H_2 production requires 18-24 kg of pure water as an input. The annual production of 336,384 tons of H_2 requires 6.7 billion liters of water. This figure is just 0.003% of Nepal's annual runoff (225 billion m^3) from its river system.[10]

Challenge for Green Hydrogen economy in Nepal

A few challenges are hindering the development of commercial-scale hydrogen production and end-use system in Nepal. They are listed below:

1. High investment costs

A major challenge to the proliferation of green hydrogen is the investment cost for establishing the hydrogen value chain in Nepal. Since the cost associated with green hydrogen depends on the cost of the technology and energy, reduced cost of technology can be achieved through economies of scale, and advancement in production processes. Furthermore, the reduced cost of electricity will make green hydrogen a viable alternative for Nepal.

2. Lack of infrastructure for Hydrogen

Infrastructure is a major barrier to promoting green hydrogen technology in countries like Nepal as there are no facilities for production, storage, transportation, distribution, and end-use. Initially, there is a need for establishing infrastructure dedicated to hydrogen that requires investment and human manpower. Hence, the lack of necessary infrastructures can impede the growth of the hydrogen economy in Nepal.

3. Lack of value recognition

There is a lack of recognition of hydrogen technology, even after its numerous advantages. The current production and use of sustainable materials and plans 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. 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. While interest

[10] WECS, "National Water Plan",2005, https://moewri.gov.np/storage/listies/May2020/national-water-plan.pdf

in the idea of green materials and goods is growing, little to no actual demand exists.

4. Institutional barrier

Adoption of hydrogen is not only limited to technical and financial factors but economics, politics, and social factors also play an equally important role. Those countries who have heavily invested in the innovation of this technology would want to regulate to take advantage of this technology. Any large-scale hydrogen project needs government assistance, and the political structure of the nation influences this decision. Additionally, society must play a part in embracing hydrogen as a component of the economy.

5. Legal Barrier

The closest legal regulation that facilitates the promotion of hydrogen in Nepal is under policy 8.1 of the National Environment Policy 2019 (2075). There are many policies and regulations which support renewable and alternative energy technology but do not explicitly use the term "hydrogen" anywhere.

Law and Policy for Green Hydrogen in Nepal

The constitution of Nepal (2015) under the chapter of Fundamental Rights ensures that every citizen of Nepal has the right to live in a clean and healthy environment.[11] The policies of the constitution of Nepal emphasize the supply of reliable and affordable renewable energy to fulfill the energy requirement of the country.[12] In addition, the constitution states that the GON requires to adopt appropriate measures to abolish or mitigate existing or possible adverse environmental impacts on nature, environment, and biological diversity.[13]

Globally, green hydrogen is recognized as the clean alternative energy carrier for valorizing renewable energy supplies which could ensure the fundamental right to a clean environment. Taking reference to the national policies and plans of countries like Norway, Australia, Japan, France, and many others, the use of green hydrogen has been derived from the national objectives of the countries to protect and promote the environment and reduce the effects of the climate change. Although Nepal has been slow to take initiatives for such measures, priority over green hydrogen should be the next initiative to derive action consistent with the constitutional provision.

I. Review the existing law and policy for green hydrogen

Nepal does not have any legal provision which monitors and controls the production, distribution, and various aspects of the commercial application of green hydrogen.s

Table 5: Review of legislation relevant to hydrogen.

Legislations	Relevancy to hydrogen

[11] Constitution of Nepal (2015), Article 30, pg. 13.
[12] Ibid, Article 51 (g) (3).
[13] Ibid, Article 51 (g) (7).

Nepal Petroleum Act, 1983(2040) and Nepal Petroleum Rules, 2017 (2074)	Regulation of green hydrogen as it is fuel for hydrogen fuel vehicles.
Electricity Act, 2049 (1992) & Electricity Rules, 2073 (2016)	Identify hydrogen as a carrier of electricity.
Public-Private Partnership Investment Act, 2017 (2074) & Public-Private Partnership Investment Rules, 2018 (2075)	Open doors for PPP investments in green hydrogen infrastructure through renewable project
Industrial Enterprises Act, 2020 (2076) & Industrial Enterprises Rules, 2021 (2077).	Provide recognition to hydrogen production plants as industries
Fiscal Act & Tax laws (Customs, Excise, Vat, et al.)	Incentives and benefits to hydrogen-based technologies
Fiscal Budget	Allocation of budget specific to green hydrogen and green ammonia.

II. Regulatory Authority

The regulatory authorities are required to observe and look upon the application of hydrogen and commercial usage and production of green hydrogen. Hydrogen is volatile in nature which means mismanagement and negligible handling of hydrogen during production, storage, transportation, and end-use could cause severe impact on the surrounding, human, and infrastructure of an enterprise. For this purpose, the regulatory body should be formed for a careful plan of action, monitor, specify standards, and facilitate the market for the usage of green hydrogen. Following are the responsibility of regulators for the hydrogen industry:

- Provide exclusive rights to carry out exclusive commercial operations for green hydrogen.
- Formulate standards, and criteria for providing licensing and approval for a person to conduct an operation related to green hydrogen.
- Approve assessment, feasibility, and compliance test under precautionary and protection measures for commercial operation of green hydrogen.
- Guarantee of origin of Green hydrogen production to ensure that there are no carbon emissions during the process.
- Authorize individual, official, or authority to make inspection and investigation to ensure compliance with the standards and criteria maintained in the laws and regulations.
- Provide specific plans, policies, budgets, and strategies for promotion in investment, usage, and research development of technology related to green hydrogen.

Table 6: Framework for hydrogen regulatory authority

Framework	Description
Supervisory and planning authority	The ministry related to the energy and water commission can play a supervisory role to plan and advise on the standards, guidelines of safety, operational procedures, and governing of the licensing regime.
Regulatory and compliance authority	The regulatory and compliance authority need to be assigned for internal operation, and general administrative regulation for the hydrogen value chain. Inspection and regular monitoring should be conducted by the government staff of the concerned institutions to check compliance with standards set by the government.

Green hydrogen institutional body in Nepal

There are few institutions and organizations currently working directly or indirectly in the field of green hydrogen. These institutions and organizations are listed below

1. Kathmandu University (KU)

KU has been working on a mission to minimize fossil fuel consumption and promote renewable technology to contribute to the low carbon economy in the country. The university has been promoting green hydrogen technology to contribute to a green economy in Nepal through Green Hydrogen Lab (GHLab). Nepal has abundant solar energy and surplus energy that can profitably be converted as green hydrogen for local utilization and export to the international market. The green hydrogen value chain has the potential for business innovation in Nepal. However, strong political and social commitment, high-level knowledge transfer from universities to industries and communities, and willingness from the commercial and business sectors to invest in green hydrogen are needed. Kathmandu University has set forth the 'Nepal Hydrogen Initiative' (NHI) on 5 June 2021. NHI is a consolidated program of the Government of Nepal to establish the policy foundation, develop an implementation action plan, and incubate a value chain for green hydrogen business innovation as the driver to address present and upcoming environmental, social and economic challenges in Nepal.

2. Alternative Energy Promotion Centre (AEPC)

AEPC is an organization set up to support and promote the use of alternative/ renewable energy as a medium for energy balance in Nepal. The organization is supporting academic and research work to promote green hydrogen in Nepal. AEPC aided in laboratory equipment at GHLab, KU in the initial phase. AEPC is also interested in supporting further activities related to green hydrogen with support from the associated development partners and programs such as NREP.

3. Nepal Oil Cooperation (NOC)

NOC is a governmental organization with the aim to import, store and distribute petroleum products within Nepal. The organization has envisaged itself as an exporter of energy with hydrogen-based fuels in the future. NOC has provided financial assistance to KU in converting an internal combustion engine car to a hydrogen fuel cell electric car. NOC has also provided support to a master's student at KU in their research project for green hydrogen-based transportation in Nepal.

4. Global Green Growth Institute (GGGI)

GGGI has also started working in green hydrogen in Nepal. It has shown interest to make arrangements for the funds for initiating green hydrogen-based pilot-scale projects in Nepal to open up commercial projects in the future.

5. Investment Board Nepal (IBN)

IBN has also shown interest in the introduction of green hydrogen in Nepal. A preliminary discussion was held through KU and they are currently working on project ideation related to green hydrogen in Nepal.

6. Nepal Electricity Authority (NEA)

NEA is a parent organization for electricity generation and distribution under the supervision of the government of Nepal. The organization has started to consider green hydrogen as the means to establish the energy load in Nepal. Currently, NEA and the green hydrogen lab are working together on a project for the production of green ammonia at a pilot scale to meet the demand in the local market. The project also aims to establish the need and prospect of green hydrogen as the means for energy balance, low carbon economy, and industrial development in Nepal and also establish the foundation for the professional linkage with potential investors and business sectors to create a value chain in both local and global markets.

Initiation Taken by Nepal Government

The Government of Nepal started to make necessary policies by prioritizing green hydrogen-based industrial/commercial projects in Nepal. Recently the Ministry of Energy has formed a Coordination Committee under the secretariat of the Water and Energy Commission to conduct a study on the role of Green hydrogen in balancing the demand and supply of hydropower electricity with low carbon and sustainable energy mix in Nepal. The Green Hydrogen Coordination committee submitted its report to the Energy Minister. Based on the recommendation given by the coordination committee, 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 as follows:

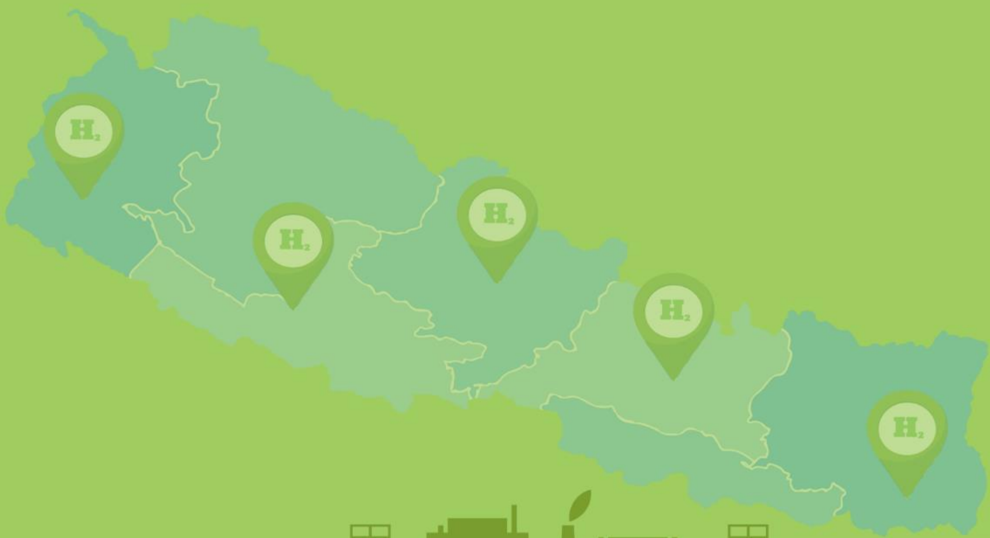
Clause 36:

Work will be taken forward for the establishment of chemical fertilizers factories using Green hydrogen and green ammonia technology in collaboration with the Nepal Investment Board.

Clause 157:

The necessary actions will be taken for the commercial use of hydrogen energy contributing to Nepal's fuel and energy consumption in the transportation and industrial sector.

NEXT STEP: The Way Forward



Recommendation

In line with recent legal development around the globe, Nepal should develop a regulatory framework to better mobilize the fund allocated in the fiscal year budget 2079/80 and to support and promote green hydrogen in two stages:

i. Initial stage

In this stage, Nepal may formulate short-term, medium-term, and long-term plans and strategies for green hydrogen and necessary changes in the relevant legislation. These legal reforms aim to regulate the hydrogen business, promote green hydrogen as an alternative energy source, and attract investment.

ii. Mature stage

In a mature stage, Nepal should formulate specific legislation and legal framework for green hydrogen. After achieving a dedicated policy plan, the country requires to form necessary regulations and authority to control the extensive use of green hydrogen in various commercial applications.

Amendments in Legislation for green hydrogen in Nepal

Regardless of the introduction of hydrogen-specific law, existing legislation must be amended, as detailed below:

S.N.	Legislation	Required Amendments	Impact
A.	*Energy Sector Laws*		
1.	Electricity Act, 2049 (1992) and Electricity Rules 2073 (2016)	Include hydrogen specifically as a carrier of renewable electricity and Provide exemption of Tax, royalty, and concession for green hydrogen produced from electricity.	Electricity generated from hydropower will be utilized for the commercial application contributing to a low carbon economy in Nepal.
2.	Nepal Petroleum Act, 1983(2040) and Nepal Petroleum Rules, 2017 (2074)	Consider other alternative energy fuels including hydrogen under petroleum products and provides an exemption of royalty and custom duty for hydrogen technology.	Facilitation for incorporation of hydrogen as fuel under petroleum products.
B.	*Industry and Foreign Investment Laws*		
1.	Industrial Enterprises Act,	• Recognition and incorporation of	The attraction of national and foreign investments

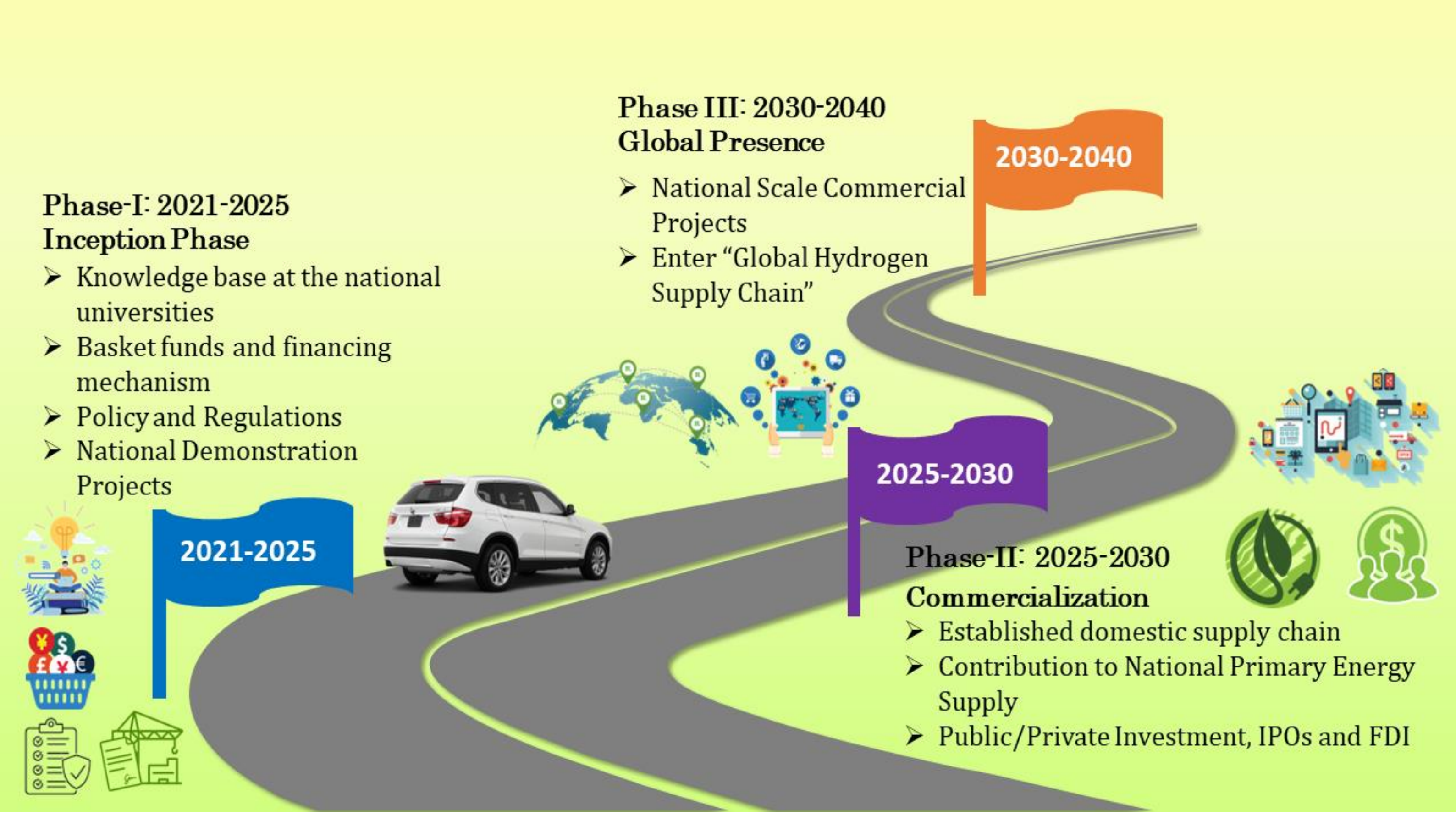
	2020 (2076) & Industrial Enterprises Rules, 2021 (2077):	hydrogen-based industries as a type of energy industry. • Provide fiscal and non-fiscal incentives to such industries.	from private and public sectors.
2.	Fiscal Act & Tax laws	• Incentives, tariffs, and subsidies for green hydrogen technologies and systems. • Amendments based on the fiscal act every year.	Encourage and support business personnel and relevant stakeholders to make the required investment for a hydrogen-based economy by utilizing tax benefits in the form of incentives and tariffs and subsidies.
3.	Public-Private Partnership Investment Act, 2017 (2074) & Public-Private Partnership Investment Rules, 2018 (2075)	Include the green hydrogen industry as an 'infrastructure' project.	Support for the private investment and PPP in the development of required infrastructure for hydrogen business and its commercial operation.

Roadmaps and Strategies

This section explains the steps Nepal must take in order to introduce green hydrogen into the country. Nepal will require short-, medium-, and long-term strategies with specified goals and deadlines. In short term, an existing government body must lay the ground for promoting green hydrogen in Nepal. For the mid-term, the establishment of a separate entity should be able to launch the next phase of green hydrogen in Nepal.

The Nepal Hydrogen Initiative (NHI) has been conceived as a consolidated program to establish the policy foundations, develop an implementation action plan, and incubate a value chain for business development with Green Hydrogen as the driving force to address the existing and upcoming challenges of the environment, fuel, energy, economy, and industrial development in Nepal. At present, NHI is an entity of Kathmandu University and is conceived to be owned by Nepal Government in the future. An independent authority body chartered by the Act of Parliament is versioned for the long-term institutional arrangement. Other organizations such as GGGI, which has shown interest to work in Nepal's green hydrogen initiatives should also be included in the efforts.

The following could be roadmaps and strategies for Nepal:



The following are the outlines of the action that could be undertaken to introduce a green hydrogen economy in Nepal:

Timeline	*Action Point*	*Achievement*
Short Term Plan *(Duration: 1 year)*	▪ Assign the roles to MOICS, WECS, AEPC, NHI, etc. in the hydrogen-based economy. ▪ Involve stakeholders from the relevant sector to invest and use green hydrogen. ▪ Prioritize green hydrogen production as a low-carbon energy carrier in the Government's budget and programs. ▪ Frame Strategy, Policy, and/or Roadmaps regarding green hydrogen ▪ Launch the hydrogen-specific programs.	▪ Responsible institutions will be mobilized rightfully to operate import, export, use, and promotion of hydrogen. ▪ The promotion of green hydrogen will be an official agenda of the Government of Nepal and will open the way for the Government to come up with different promotional schemes such as tax benefits. ▪ This will provide a policy framework for the further development of legal and institutional set-ups.
Medium Term Plan *(Duration: 1 - 5 years)*	▪ Incorporate amendments in relevant existing laws to include green hydrogen as a carrier of energy and industrial activity & provide fiscal/non-fiscal incentives. ▪ Designate the existing institution (s) as the competent agency.	▪ Support in the commercialization of the green hydrogen industry. ▪ Facilitate the research and development, and startup of green hydrogen.
Long Term Plan *(Duration: More than 5 years)*	▪ Draft and enactment of Green Hydrogen-specific legislation. ▪ Build institutional arrangements specifically for the green hydrogen value chain.	▪ Enactment of the Green Hydrogen Act encompasses the institutional setup, its regime, safety, and standards. ▪ If designated existing institutional structures and their current capacity are inadequate and inept, new and separate institutional arrangements can be established for the regulation of green hydrogen for its commercialization and regulation.

Financial Incentives and Tax Exempt

One of the major obstacles to promoting and deploying green hydrogen is its production cost. For this purpose, the government must provide proper incentives and tax exemptions on the equipment and accessories for the production of green hydrogen. For instance, South Korea has a provision of the Hydrogen Act that facilitates providing subsidies and loans on:

- Expenses for technological development and professional training to innovate the safety, economy, and eco-friendliness of the hydrogen business.

- Expenses for international cooperation and technology exchange with foreign countries.[14]

Furthermore, the current draft electricity bill of India provides facilities to exempt taxes over the use of green hydrogen to power electricity. To provide the facilities for the green hydrogen industrial sector with exemption and facilities, it is important to provide relief under tax laws as well as sector-specific laws.

The three possible ways to provide financial incentives in Nepal are as follows

1. By enlisting the financial incentives or exemption facility under sector-specific laws which govern and regulate the use of hydrogen.
2. By providing relief and financial incentives under general laws of the energy sector which may not be specific to Hydrogen.
3. By enlisting the financial incentives or exemption facility under the tax law which is then brought revised and updated every year under the Fiscal Act.

For the stable clause in the financial incentives and tax exemption, it is important to incorporate the provision in both sector-specific laws which govern and regulate the Hydrogen and Fiscal Act under tax law. This is because, if the relief clauses are only provided under the sector law, then the amendment in the fiscal year can amend the provision and repeal the facilities. So, it is important to maintain consistent clauses to facilitate the green hydrogen industry with financial incentives and exemption of taxes.

Safety Measures

The handling and usage of hydrogen is safer than that of the fuels commonly used today due to a number of its characteristics. For instance, Hydrogen is non-toxic and non-corrosive. In addition, because hydrogen is much lighter than air, it dissipates rapidly when it is released, allowing for relatively rapid dispersal of the fuel in case of a leak. Some of hydrogen's properties require additional engineering controls to enable its safe use. Specifically, hydrogen has a wide range of flammable concentrations in air and lower ignition energy than gasoline or natural gas, which means it can ignite more easily. Consequently, adequate ventilation and leak detection are important elements in the design of safe hydrogen systems. Because hydrogen burns with a nearly invisible flame, special flame detectors are required. Furthermore, some metals can become brittle when exposed to hydrogen, so selecting appropriate materials is important to the design of safe hydrogen systems. In addition to designing safety features into hydrogen systems, training in safe hydrogen handling practices is a key element for ensuring the safe use of hydrogen.

[14] Hydrogen Economy Promotion and Hydrogen Safety Management Act, Article 10

Table 7 Potential hazard and related safety measures for hydrogen

Hydrogen Characteristics	Potential Hazard	Safety Measures
Colorless, odorless, and tasteless	Undetectable to human senses	Detection sensors
Low viscosity and small atoms that can be absorbed into materials	Stores at high pressure	Leak-detection systems, ventilation, and material selection
Low volumetric energy density	Stored at high pressure	Storage container design and pressure-relief devices
Not breathable	Can accumulate in confined spaces and act as an asphyxiant like any other gas that displaces oxygen	Ventilation and leak detection systems
Wide flammability range of 4% to 75%	Leaks of all sizes are a concern	Ventilation and leak detection systems
Low ignition energy	Ignition by even a small spark is possible under some conditions	Ventilation, grounding, and removal of possible ignition sources
Burns with a pale blue flame that is nearly invisible in daylight, produces no smoke, emits little heat	Potential for undetected flames	Flame detectors and leak-detection systems
Low liquefying temperature (-252.9°C) for cryogenic storage	Cryogenic burns and lung damage	System design, leak-detection systems, and personal protective equipment
Rapid phase change from liquid to gas during cryogenic storage	Pressure explosions	System design, pressure relief devices, and ventilation

(Source: US Department of Energy, Hydrogen Program)

For the efficient and accurate operation of hydrogen technologies, the government and countries' legal authorities must acknowledge the essential safety and operational standards and law.

The regulation and rules for hydrogen application are not a new concept. There exist a range of international standard which may apply to hydrogen including those developed by:

- The International Standards Organization (ISO)
- The International Electrotechnical Commission (ICE)
- The European Industrial Gases Association (EIGA)

ISO standards are widely approved and incorporated under national legislation. The technical committees 197 ['TC'] at ISO in 1990 developed an international standard for hydrogen technologies[15]. The developed standard covers the areas for the production, storage, transport, measurement, and end-use systems and devices of hydrogen. To date, TC has published seventeen ISO standards relevant to hydrogen, with a further four under development. For the global market acceptance of hydrogen technologies, the hydrogen industrial sector must implement a set of standards to ensure the safety of its production and system which TC 197 has a major role in achieving.

The ICE is another body that is working to prepare the international standards and regulations for hydrogen. Currently, the organization has produced standards for fuel cell technologies associated with the application as given below:

- Standards for Fuel Cell Power System,
- Standards for fuel cells used in transportation,
- Standards for equipment and tools to use hydrogen for electricity,
- General electrochemical flow systems and processes.[16]

The European Industrial Gases Association (EIGA) has also published similar standards and guidelines focusing on the hydrogen technologies which are incorporated by the European countries including Norway, Denmark, and Sweden. The safety measures for hydrogen are necessary for essential safety and operational standards in the commercial operation of Hydrogen.

The possible safety standard that may be required are as follows:

- Guidelines for means of transportation using hydrogen as an alternative fuel
- Safety considerations associated with handling hydrogen
- Enable safety and encourage the safe commercialization of hydrogen uses
- Testing of hydrogen systems—tank leak tests, garage leak simulations, and hydrogen tank drop tests
- Prepare manual for safe handling of hydrogen

It is important to note that the legislation specified for hydrogen should provide the general layout for the scope and responsibility of authority to formulate safety measures.

[15] Eaun Starchen, 'The Emerging Hydrogen Economy: Regulation, Policy and Industry Update' *Akin Gump,* October 29, 2020.

[16] TC 105 Fuel cell technologies, available at, https://www.iec.ch/dyn/www/f?p=103:7:0::::FSP_ORG_ID,FSP_LANG_ID:1309,25 (accessed on October 6, 2021)

Potential Green Hydrogen Uses in Industry

1. Green Hydrogen for Ammonia Production

Ammonia is the second-largest chemical commodity produced globally. It is anticipated that the production of ammonia is increasing with the population growth, as it is one of the main ingredients of the fertilizer that enhance soil productivity. Moreover, ammonia has three times the energy density of compressed hydrogen and is emerging as a carbon-free energy carrier. Realizing the global demand and market, visionary nations like Norway, Denmark, and many more nations have initiated green ammonia production from renewable energy. Nepal has no facilities for ammonia plants and should develop pilot-scale production to contribute to the local market and attract an investor for large-scale production.

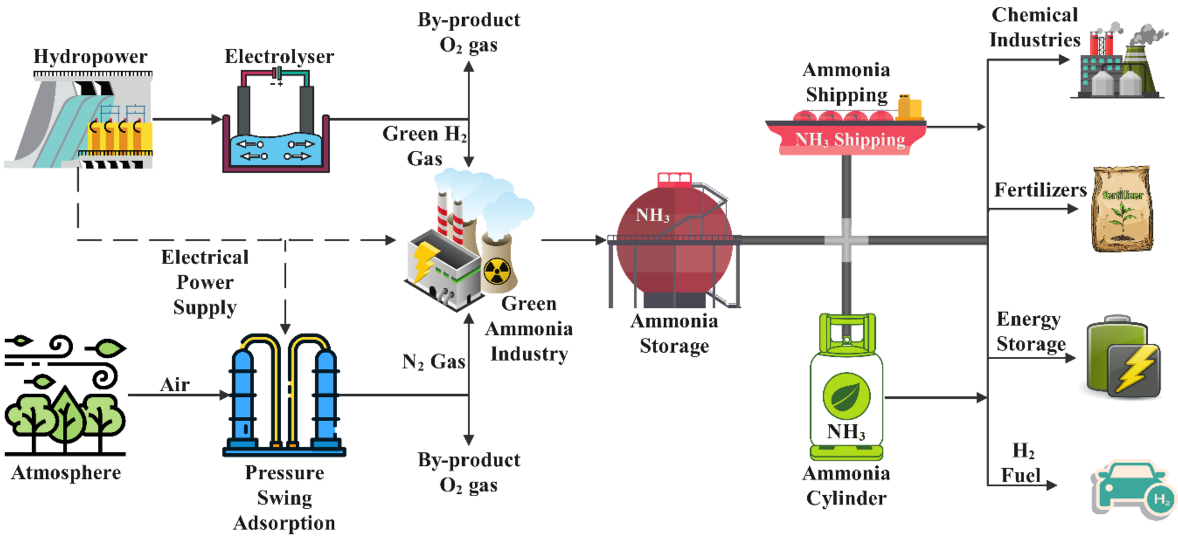


Figure 4: Schematic of Green Ammonia value chain

The most common method for ammonia production is the Haber-Bosch process. In the conventional Haber-Bosch, around 2% of fossil fuel is consumed worldwide and liberates over 420 million tonnes of CO_2 annually. In contrast to the carbon-based Haber-Bosch, Haber -Bosch process coupled with water electrolysis will make the process completely free of carbon. The production and application of green ammonia are shown in Figure 4. The main elements of this carbon-free Haber-Bosch process are air, water, and surplus hydroelectricity.

2. Green Hydrogen for Industrial Heat and Clean Cooking

Globally, the emission from the industrial sector is increasing due to coal being a primary source for heating applications. In 2020, the emission from the industrial sector is 34.07 billion metric tons up from 25.012 billion metric tons in 2000. The global commitment to Paris agreement has developed a need for alternative fuels for the world industrial sector towards an alternative fuel like green hydrogen. In the context of Nepal, the primary consumption of coal was 746 tons in 2019 which was an 8.23% increment from 2000. Nepal Rastra Bank reports that the country imported coal worth Nrs. 27.19 billion in the fiscal year 2020-2021. The country is dependent on 100% import of all kinds of fossil fuels and is providing subsidies on LPG despite inherent environmental and socio-economic issues. Despite the availability of clean electricity, there has been low attraction towards the adoption of electricity for cooking due to technical and social issues. There is a need for a holistic approach to address the social, economic, and environmental challenges of decarbonizing the industrial area for heating applications.

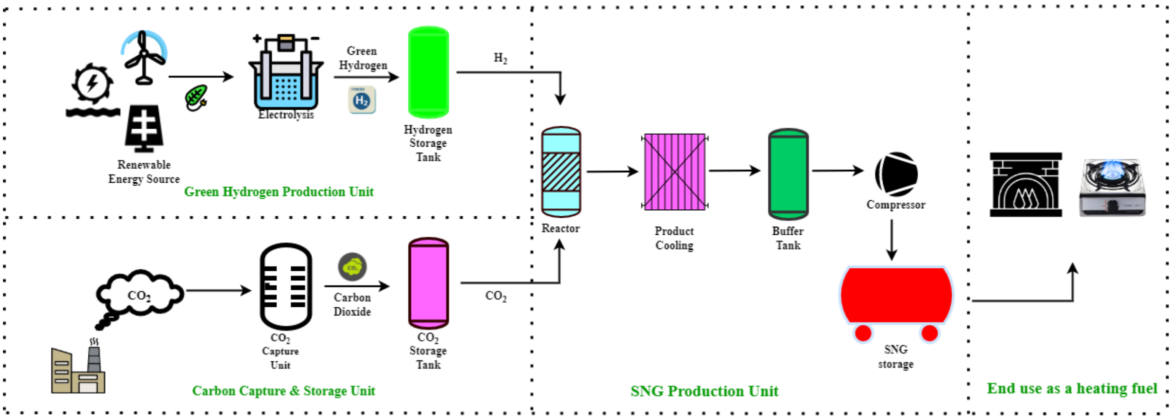


Figure 5: Process Flow Diagram of Sabatier process

Synthetic Natural Gas (SNG), also called green methane, produced by utilizing hydrogen obtained from electrolysis, and CO_2 from carbon capture and storage (CCS) via the Sabatier process, is developing as an alternative to Natural gas for cooking and industrial supplies. This can also increase the use of surplus renewable energy in an effective way. It has attracted the attention of developed nations such as Australia, Germany, and Japan. Several projects like the STORE&GO project have been demonstrated all around the world for proof of concept of the Sabatier process. The proposed project aims to design and produce green hydrogen-based SNG as an alternative to LPG and other fossil fuel-based industrial heat in Nepal. The facilities will be developed to validate the concept at the pilot scale, establishing the foundations for commercial applications in the future. The project focuses on technology development by adapting local resources and knowledge transfer from the university to the community.

3. Green Hydrogen for Re-electrification

Electricity backup systems are needed to address the temporary grid failure, short-term electricity supply at the locations without grids, power surges, and massive blackouts. The search for alternative solutions based on renewable energy has been sparked by the current power backup methods', which include batteries and fossil fuel-based generators, susceptibility to noise, and high carbon emissions. Hydrogen technology is emerging as an effective and efficient alternative to stored energy from variable renewable energy due to high energy density, unlimited production sources, and easy storage and transportation. Hydrogen produced from electrolysis using renewable electricity has a minimal carbon footprint among other alternatives and produced green hydrogen can be passed through a fuel cell to produce electricity in the required vicinity.

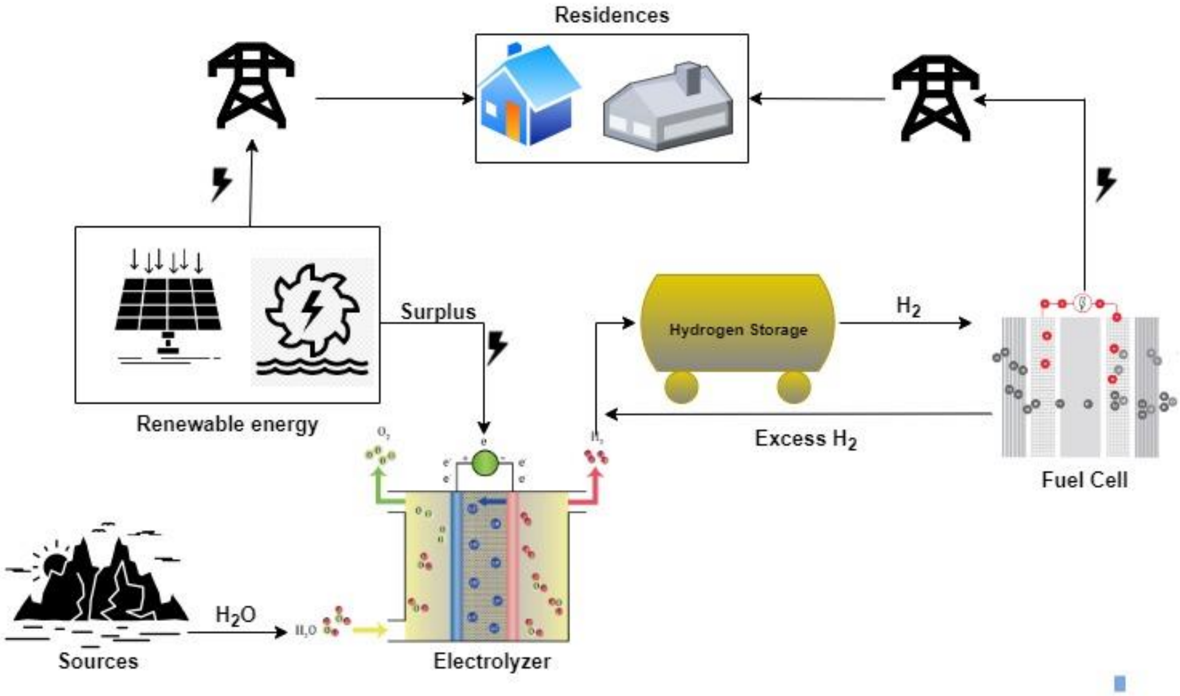


Figure 6: Pilot-scale Setup for re-electrification from the fuel cell

A fuel cell is a novel technology for harnessing hydrogen energy by electrochemically oxidizing hydrogen. Simply, a fuel cell combines hydrogen and oxygen to produce electricity. Like a hydrogen combustion engine, the by-product of the fuel is water vapor condensed to form pure water. Unlike a hydrogen combustion engine, the fuel cell is efficient and operates quietly without noise pollution. The pilot-scale setup for electricity production from the fuel cell is in Figure 6.

4. **Green Hydrogen for Steel and Mining**

Currently, the iron and steel industry is responsible for 8% of global total energy demand and 7% of the total CO_2 emission. In Nepal, the steel demand is rapidly growing due to the resumption of the halted projects from the earthquake in 2015 and investment in infrastructure from the government and private sector. To date, almost all the raw steel materials are imported from India and processed in the country. The prospect of local iron and steel products is anticipated as iron ores deposit is identified in the country. According to the Department of Mines and Geology, at least 100 million iron ores are located in four different places in Nawalparasi, Nepal. The feasibility studies, environmental impact assessment, and other preparatory works are in progress for excavation and mining work.

Steel and iron industries are energy-intensive sectors and have high CO_2 emissions due to fossil fuels being used as fuel and feedstock in the conventional mining process. In the carbon-intensive traditional process, fossil fuels are used for the iron ores pellets production, and coal is used as a fuel and reducing agent forming carbon monoxide when burned and reacting with iron oxide to produce carbon dioxide. In contrast, green hydrogen can replace fossil fuel for steel making, and the by-product is only water vapor.

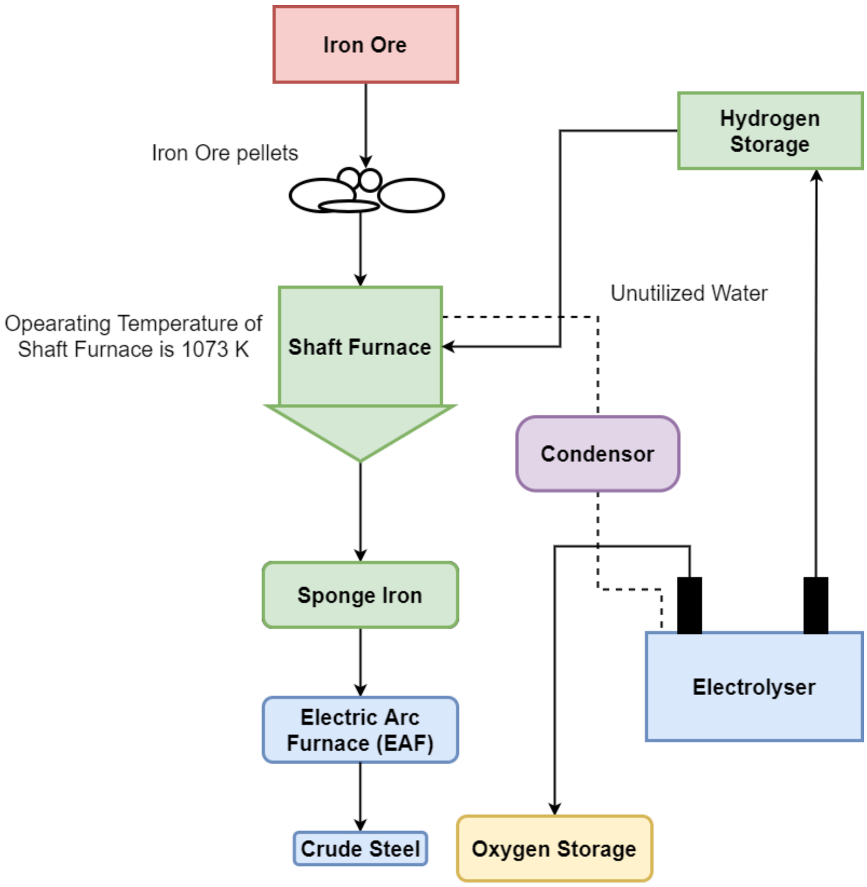


Figure 7: Schematic of a CO2 emission-free DRI production process

Nepal has realized the urgency to reduce fossil fuels in the transportation and industrial sector. Hydrogen is a viable alternative for replacing coal in the steel and iron sectors as the by-product is only water vapor. The direct reduced iron (DRI) process, shown in Figure 7, uses green hydrogen as a reducing agent for iron ores instead of coal and the process has been commercially demonstrated in different parts of the world. Hence, the future mining industry in Nepal should rely on state-of-art low-carbon technologies.

5. Green Hydrogen for Transportation

The transport sector of Nepal is 99.96% dependent on petroleum products for transportation fuel as of 2019. Diesel consumption has increased by 96% in 5 years from 2014. The major demand for fuels is diesel used by heavy-duty vehicles with high payloads. The emissions from transportation fleets are toxic, deadly pollutants and carcinogens, these emissions are more numerous in diesel-powered heavy-duty vehicles. In addition to this, a high level of dependency on fossil fuels and increasing consumption have created a big trade deficit. Electrification of the transport sector is a promising strategy to improve the security of the energy supply and reduce harmful emissions to the environment. Battery electric vehicles are better suited as an alternative for light-duty operations whereas Hydrogen fuel-cell electric vehicles are more effective for applications that require long ranges and demand duty cycles with minimum downtime.

Green Hydrogen from renewable energy can power the transportation sector, especially for the heavy-duty vehicle fleet. In order to establish a network of hydrogen heavy-duty fleet, a value chain of hydrogen supply and distribution channels have to be designed, tested for feasibility/safety, and implemented. The hydrogen value chain for transportation applications is shown in the figure below.

Figure 8: Green Hydrogen Value Chain for Transportation Application

6. Green Hydrogen for Biogas Upgradation

In Nepal, about 10 percent of the population lack access to electricity, and about 69 percent of the total energy demand is met by biomass energy. Despite the enormous renewable energy potential, only 3.2 percent of the total energy consumption in Nepal is covered by renewable energy. Extending the national grid, especially in remote rural areas, is complex and costly due to rugged terrain and high costs. Given these challenges and its reliance on biomass energy, the Government of Nepal has adopted a policy to encourage alternative energy sources. Biogas technology has been identified and promoted as a viable alternative renewable energy source along with several others, such as solar and wind energy. With growing concern about organic waste management and increasing demand for clean energy, large-scale biogas technology has recently gained traction. But the high CO_2 concentration of about 40-60% in produced biogas and the necessary purification system to remove the CO_2 is making the large-scale biogas technology less profitable. Currently, AEPC has been subsidizing and supporting the large biogas installations in Nepal. To make the technology more appealing, a holistic approach is needed.

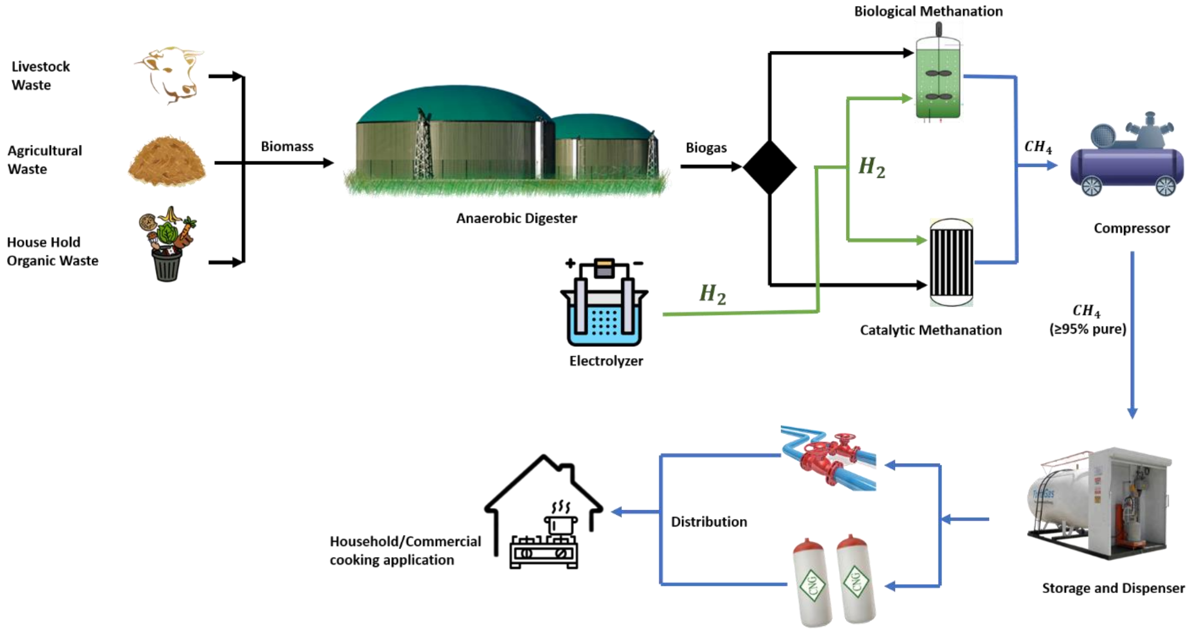


Figure 9: Schematic of biogas upgradation using Green Hydrogen

Methanation technology is emerging as a possible solution to this challenge. It can solve the challenges through enrichment of biogas by utilizing the unused carbon-dioxide and contribute to making overall value chain more carbon-neutral. In methanation process the biogas produced from anaerobic digestion process using different biomass sources is fed into a separate reactor. In that reactor, green hydrogen is also injected and the methanation reaction takes place. There are mainly two types of methanation processes, biological methanation and catalytic methanation. In the biological methanation process, microorganisms are used as catalysts, and the reactor contains a water phase, which serves both as a habitat for the microorganisms and as the solvent for the nutrients necessary for the growth of the microorganisms, such as Na_2S and NH_3. The microorganisms metabolize the CO_2 and the H_2; CH_4 is released as a by-product. In the catalytic methanation process, active metal catalysts, such as nickel, ruthenium, etc., convert the CO_2 in the biogas to CH_4 by reacting it with Hydrogen. Since the reaction is exothermic in nature, the catalytic methanation proceeds at temperatures above 300–400°C. The high-temperature range leads to a high reaction rate. But the challenge in catalytic methanation reactors is to remove the significant heat of reaction from the reactor to avoid catalyst sintering and conversion limitations due to the thermodynamic equilibrium. The produced gas usually has methane concentration greater than 95% which can be compressed and distributed for the use in household and commercial cooking applications.

Glossary

Green House Gases (GHG): Gases such as Carbon Dioxide, Methane, and Nitrous Oxide that traps heat in the atmosphere

Kyoto Protocol: The protocol that puts the United Nations Framework Convention on Climate Change into action by committing developed and developing countries to restrict and reduce greenhouse gas (GHG) emissions in line with agreed-upon individual targets.

Paris Agreement: The Paris Agreement is a legally binding international climate change pact that was adopted by 196 Parties at COP 21 in Paris on December 12, 2015, and went into effect on November 4, 2016.

Surplus Energy: The energy that is in excess supply and in greater quantities than required.

Feedstock: The raw material used to feed or power a machine or industrial operation.

Haber - Bosch process: It is a method discovered by the German physical scientist Fritz Haber for directly generating ammonia from hydrogen and nitrogen.

Clean Electricity: The electricity produced using clean renewable energy with very low carbon emission

Carbon Capture and Storage: The process of capturing and storing carbon dioxide (CO2) produced by power plants and industrial activities so that it is not released directly into the atmosphere

STORE&GO Project: It is a project to integrate Power-to-Gas technology into the future European energy system with the collaboration of 27 partner organizations and companies from all over Europe with a project life span of 48 months, starting from March 2016 to the end of February 2020. It was funded by the European Union's "Horizon 2020 research and Innovation program".

Carbon Footprint: The amount of carbon dioxide (CO2) emissions associated with all of a person's or other entity's activities (e.g., manufacturing, heating, transportation, etc.) includes direct emissions from fossil-fuel combustion in manufacturing, heating, and transportation, as well as emissions required to produce the electricity associated with goods and services consumed.

Fuel Cell: A fuel cell is a device that uses the chemical energy of hydrogen or other fuels to generate electricity.

Direct Reduced Iron (DRI) Process: Direct reduction of iron is the removal of oxygen from iron ore or other iron-bearing materials in a solid state, i.e., without melting, by using reducing agents such as carbon monoxide and hydrogen, which can be obtained from reformed natural gas, syngas, or coal.

Trade Deficit: A trade deficit is an amount by which the cost of a country's imports exceeds its exports of both physical goods and services.

The **Nepal Hydrogen Initiative (NHI)** is a consolidated program to establish the policy foundations, develop an implementation action plan, and incubate a value chain for the business development with Green Hydrogen as the driving force to address the existing and upcoming challenges of the environment, fuel, energy, economy, and industrial development in Nepal. At present, NHI is an entity of Kathmandu University and is conceived to be owned by Nepal Government in future.

Contributing to '**Carbon Neutral and Energy Independent Nepal**'.

Showcase Projects

- Green Hydrogen for Ammonia Production.
- Green Hydrogen for Industrial Heat.
- Green Hydrogen for zero-emission Transportation.
- Green Hydrogen for Re-electrification.
- Green Hydrogen for Steel and Mining.

Mission

Reduction in fossil based fuel consumption and green-house gas emissions, and contribute to more secure and efficient industrial processes by enabling the commercialization of green hydrogen technologies in Nepal.

Vision

Transformation of Nepalese Economy and Society by enabling the sustainable and affordable Green Hydrogen Technologies from the available renewable energy resources.

H2

2021

NEPAL HYDROGEN INITIATIVE

Targets

Phase-I: 2021-2025: Inception phase

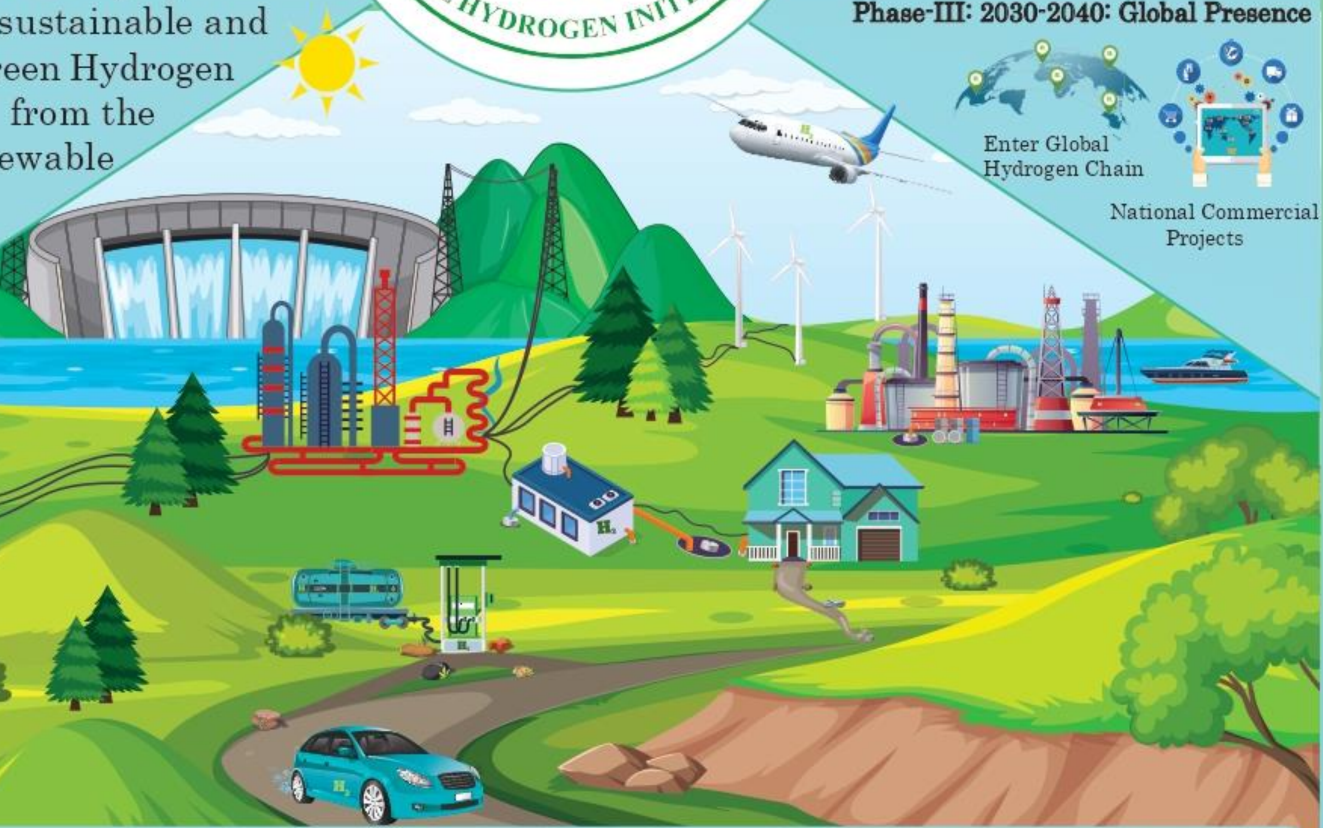
Knowledge base · Basket Funds · Policy & Regulation · National Projects

Phase-II: 2025-2030: Commercialization

Domestic Supply Chain · National Energy Supply · Public/Private Investments

Phase-III: 2030-2040: Global Presence

Enter Global Hydrogen Chain · National Commercial Projects



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