Green Hydrogen as a Future Multi-disciplinary Research at Kathmandu University

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Abstract. Over 100 million tons of hydrogen are produced every year for a range of industrial purposes. The vast majority of this industrial hydrogen is produced from coal gasification or steam methane reforming, both of which need a lot of energy and generate significant carbon dioxide emissions. A much smaller proportion of hydrogen is produced from the electrolysis of water, which can be a far more sustainable and clean method if the electricity is produced from renewable sources. While the urgency of greenhouse gas emission mitigation has increased, many countries have begun to take action to decarbonize their economies. Nepal is expected to have about a 3000 MW electricity surplus by the Year 2030. It is a time to explore alternative use of electricity to make hydropower projects financially feasible. Hence it is also high time to investigate Hydropower-to-Hydrogen (H2H) technology and transfer the relevant knowledge in the region. Kathmandu University (KU) has been leading to initiate and institutionalize the new academic programs and research avenues to address the future need for this country. KU has played a role model to introduce and establish innovative and unique programs in engineering education in Nepal since it was established in 1994. Since the establishment period, KU carried the vision to establish itself as a research-based university. KU has carried the objective to design its academic programs, courses, and curricula to directly contribute to the research problem the industry or society has been facing. The intuitional realization that Green Hydrogen (GH) is the future academic and research need of this country will be the far-slightness of KU.

Keywords: Fossil Fuels, Climate Change, Hydropower, Hydrogen Energy, Research Centre

1. Introduction

Energy-related CO_2 emissions account for two-thirds of global greenhouse gas emissions. For a reasonable likelihood to stay below 2 °C of warming by 2100, global net anthropogenic CO_2 emissions should decline by around 25% by 2030, from 2010 levels, reaching net-zero by 2070 [1]. Figure 1 shows projections of the greenhouse emission and its effects on the average change in atmospheric temperature for different scenarios. With the business as a usual reference case, the rise in average global temperature will cross 3.5°C by 2100. However, with the strong determination to bring the global emissions to net-zero by 2060 the temperature rise can be brought back within the limits of 1.5°C by 2100.

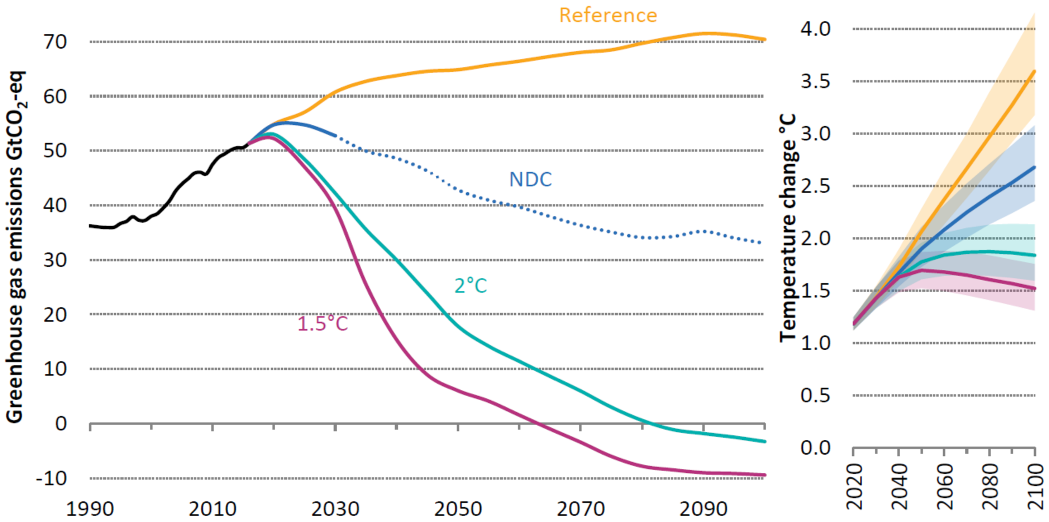

Figure 1. Greenhouse gas emissions and temperature rise [1]

Studies show that by 2050 the number of vehicles used for transportation will double by exceeding 2.5 billion globally [2]. An energy transition is needed to break the link between economic growth and increased CO_2 emissions. In order to achieve the emission control targets, there is a need for a paradigm shift in the production and use of clean energy. Green Hydrogen (GH) energy is coming up as a competitive solution to fossil fuels and battery-based transportation systems [3]. Further research and innovation in this technology are necessary to make hydrogen energy technically and financially feasible to aim for a carbon-neutral society. The development of hydropower systems to produce GH energy for commercial applications can change the future of hydropower development in the Himalayan region by becoming an exporter of green fuel worldwide.

Hydrogen is the simplest form of all molecules; it has the lowest energy content by volume, but it has the highest energy content of any fuel by weight. Due to the high energy content of hydrogen, it is employed as a fuel in applications such as Fuel Cells and rockets. Hydrogen produced from electrolysis of water with the electricity is produced from renewable sources is often called as the GH energy. GH energy creates zero harmful emissions, which is one of the most significant limitations of fossil fuels, and the heating value of hydrogen is three times higher than that of petroleum. Figure 2 shows the current and future demand for hydrogen for different applications. The demand for hydrogen is projected to increase 10 times by 2050 compared to that for 2015. Most of the increased demand would be for the new sector as transportation and industrial energy, which consumes a negligible amount of hydrogen energy at present. If future demand for hydrogen is supplied as GH this would significantly contribute to meet the global emission targets. Electrolyzers are scaling up quickly, from megawatt (MW)- to gigawatt (GW)-scale, as technology continues to evolve. Electrolyzer costs are projected to halve by 2040 to 2050, from USD840 per kilowatt (kW) today, while renewable electricity costs will continue to fall as well. Renewable hydrogen will soon become the cheapest clean hydrogen supply option for many greenfield applications [4]. However, this needs much technological advancement for reducing the production cost of GH and increasing the efficiency of the over the system. The current research trends in GH is towards the innovations for better fuel cells, which is considered as the heart of the GH systems.

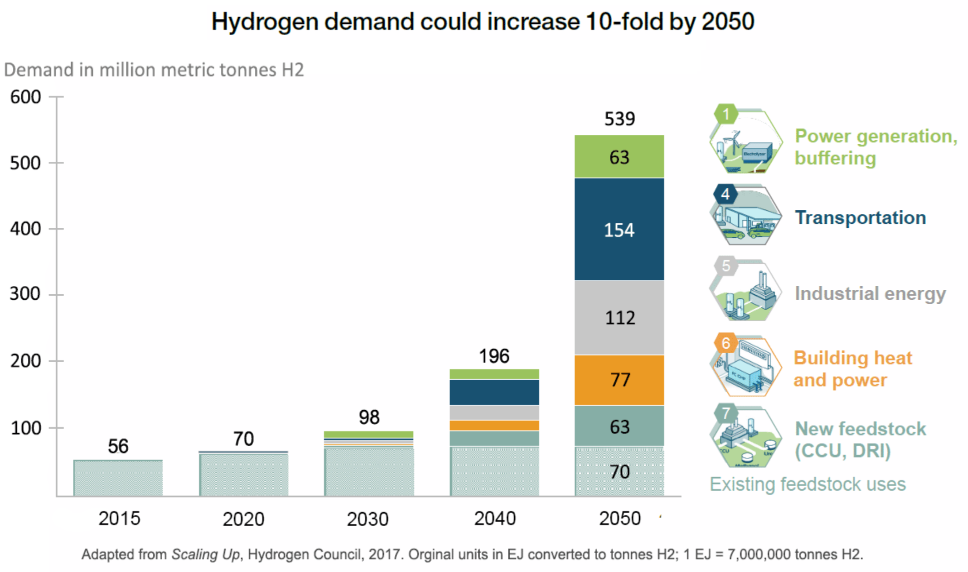

Figure 2. The stake of Hydrogen Energy in Future [5]

A fuel cell is a device that converts chemical potential energy (energy stored in molecular bonds) into electrical energy. A PEM (Proton Exchange Membrane) cell uses hydrogen gas (H_2) and oxygen gas (O_2) as fuel. The products of the reaction in the cell are water, electricity, and heat. Hydrogen driven fuel cells can serve as the alternative means to generate electrical power to drive all sorts of electrical appliances. The first fuel cells were invented by Sir William Grove in 1838 [6]. The first commercial use of fuel cells came more than a century later following the invention of the hydrogen-oxygen fuel cell by Francis Thomas Bacon in 1932. The alkaline fuel cell, also known as the Bacon fuel cell after its inventor, has been used in NASA space programs since the mid-1960s to generate power for satellites and space capsules [7]. Since then, fuel cells have been used in many other applications. Fuel cells are used for primary and backup power for commercial, industrial and residential buildings and in remote or inaccessible areas. The first commercially produced hydrogen fuel cell automobile was introduced in 2013. It is projected that by 2030 more than 15 million such cars will be sold [8]. The aviation sector is another prominent area where GH is being researched as a future commercial fuel. It is expected that by 2040 large commercial aircraft will be powered by fuel cells with GH as the fuel.

As the rest of the word is making the transition towards the hydrogen-based economy, the developing country like Nepal cannot alone remain behind. There is a need to initiate scientific exploration and research on this technology at the Nepalese academic institutions. Since the technology has achieved a much higher development stage at a global level, for Nepal the start would be knowledge transfer and local adaptation. If the initiation is taken earlier, the transition period of the technology transfer will be much shorter.

2. Hydropower based Green Hydrogen Energy from Nepal

The Himalaya, Hindu-Kush, and Karakoram Mountain range from the greatest band of mountains on the planet binging huge prospects of hydropower development opportunities. This is especially true in Nepal, one of the poorer nations of the world, where more than 20000 MW of hydropower projects are under some stage of development. However, the forecasted domestic demand for electricity falls much lower than its production within this decade. Exports of excess hydroelectricity by inter-boarder grid connection among the South Asian Countries is one of the major discussions in Nepal. The results of a study [9] show that Nepal can generate revenue of up to USD 3 billion per year in 2030 and as high as USD 10 billion per year in 2045 if the country is able to sell electricity by harnessing its hydropower potential. Figure 3 shows the projections of the increase in installed capacity build-up of 34.4 GW in 2045 in the trade scenario as compared to only 8.9 GW in the base scenario. This trade can also be in the form of the export of GH energy if the country prepares for this new dimension of business.

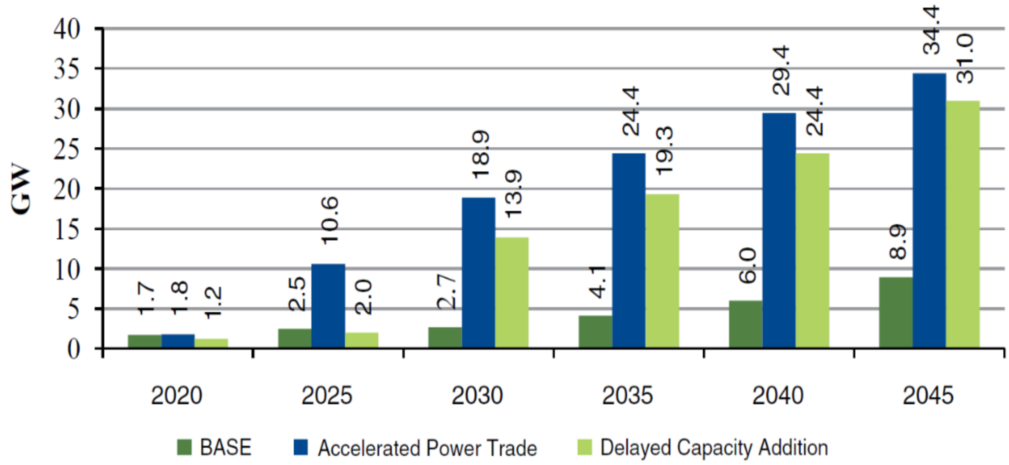

Figure 3. Build-up of Power Generation Capacity in Nepal [9]

A high economic growth scenario in Nepal induced by the benefits of electricity trade is expected to change the living standard and energy consumption pattern quite drastically. Figure 4 shows the energy consumption pattern in Nepal until 2050. It indicates that the consumption of petroleum products will exponentially rise to meet the energy demand in the country's rise in the transportation sector due to high access to roads and purchasing capacity to own private cars.

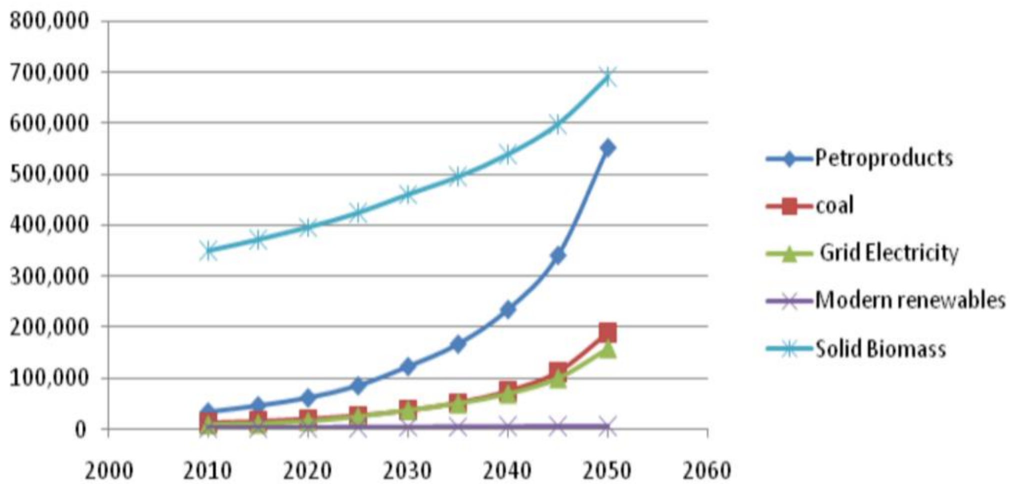

Figure 4. Consumption of energy in Nepal at high economic growth scenario [10]

The government of Nepal has recently announced a 100% tax exemption in the electric vehicles as an attempt to interfere with the energy mix scenarios. However, Nepal needs to make a huge investment in infrastructure and vehicle replacement to make a sustainable transition to the electric-based transportation sector. Furthermore, battery-based electric vehicles inherit several limitations including lower energy density in the battery, short driving range, and speed, longer recharge time, shorter battery life. Hydrogen driven Fuel Cell-based electric vehicles are emerging as an alternative means to overcome these limitations. The studies [11] show that this technology would dominate the transportation sector including aviation by 2050s. Figure 5 shows that the demand for GH will increase exponentially by 2050, with the production cost coming below the gasoline.

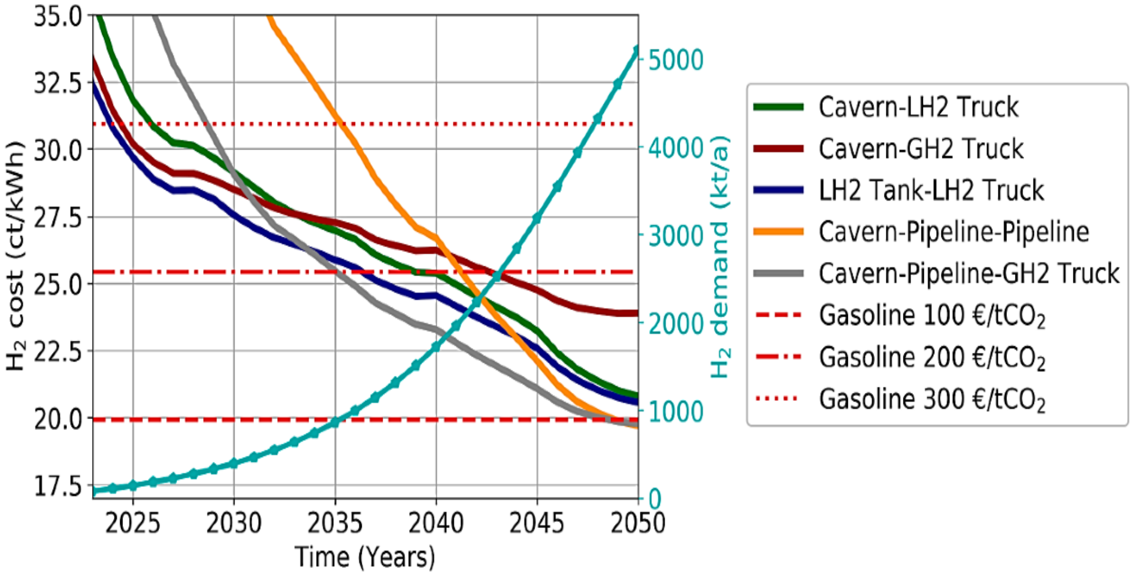

Figure 5. Electrolytic hydrogen supply chain production cost. [11]

These evidence indicates that GH energy will be at the center of the global economy by 2050. The surplus hydroelectric power in Nepal produced by then can profitability be converted as the hydrogen fuel, utilized, and exported. Hence the production and supply of GH energy from hydropower could be one of the innovative businesses for Nepal in the future. This will have a significant impact on the energy mix scenarios in the country and the energy export alternatives. Intervention made by the universities, government, and hydropower industry at present can change the paradigm of hydropower development in Nepal and the region.

3. Kathmandu University and Engineering Education

Nepal is a developing country with a literacy rate of 64.7% in 2015, which is a significant rise from 20.6% in 1981. About 10 % of the population have access to university education in Nepal. Among the total population receiving a university education, those getting engineering education is below 2% [12]. A formal university education system in Nepal started in 1959 with the establishment of Tribhuvan University. Nepalese education system during that period was dominated by the Indian system as the higher education in Nepal started with the affiliations from Indian Universities and more dependent on Indian faculties in the early days of development. Indian system was also basically influenced by the British system since the time of the British regime in India [13].

Kathmandu University (KU) was established to complement the role of the Government of Nepal in higher education after the major political change in the country in 1990. By then, the education programs in Nepal were more teacher-student focused on classrooms and textbook oriented. Very limited practical, laboratory, or project-based self-learning flexibility were available. Before KU was established, less than 10% of students were enrolled in the technical education sector including Engineering, Agriculture, Forestry, and Medicine. The challenge of KU, as the complementary institute was to get established as a new Nepalese university, providing an opportunity to study courses of global attraction, especially in technical areas, and offer unique pedagogical techniques to make teaching-learning more effective and interesting for students.

KU has played a role model to introduce and establish innovative and unique programs in engineering education in Nepal. Developing the programs in Mechanical Engineering, Electrical and Electronics Engineering, Biotechnology, Pharmacy, Hydropower Engineering, Geomatics Engineering, and Chemical Engineering for the first time in Nepal are some of its leadership examples. Since the establishment period, KU carried the vision to establish itself as a research-based university. KU has attempted to design its courses and curricula to directly contribute to the research problem the industry or society has been facing. All the faculties are expected to work in some research projects funded by the industry or external agency. Students are invited to work under the supervision of the relevant faculties to contribute to the progressive stage of the research projects. The successful integration of academic research with the community and industry is the purpose of the research-based engineering education at KU and has received international recognition [14].

Some of the successful good practices of teaching-learning methods and pedagogy at practiced and developed by KU are as follows:

- ***Performance-Based Learning*:** Traditional approach – formative and summative assessments where each student is evaluated based on performance and progress on a continuous assessment basis.
- ***Participatory-Based Learning:*** A new form of learning approach started in the Nepalese higher education system with a combination of presentations, case study & report writing.
- ***Project-Based Learning:*** Make student and teacher more interactive to identify the need or problem identification. Prepare group work for solving problems, acquire skills and knowledge to solve the problem, develop and test the solution, present, and report to the stakeholders for dissemination.
- ***Passion-Based Learning:*** Driven by the passion and the dedication of the candidate to find answers to the research problem. The research activities are conducted under the supervision of expert faculties and international journal publications are often expected.
- ***Evidence-Based Learning*:** Includes Empirical methods, Experiments, Observational studies, Case studies, Quantitative and qualitative analyses of data, Argumentation analysis, and Evidence-based research outcomes.
- ***Profession-Based Learning:*** Preparing specialized graduates at a professional engineering level itself instead of providing broader engineering knowledge. Graduates are well versed in solving specific technical problems and research issues in a narrow spectrum of their profession.
- ***Community-Based Learning:*** Integrate student projects with rural communities through the University's outreach program. Use the knowledge and research skills to solve the problem or challenge a specific community is facing.
- ***Digital-Based Learning:*** A virtual library is created with the videos of professional teachings in specialized courses and linked with e-learning and open online courses through Moodle systems.

This is a high-time for KU to expand its teaching-learning methods to implement international practices and address the educational response to the global problem. ***Multi-disciplinary Research-Based Learning*** is the future of the progressive academic institution like KU. Solving a complex problem by the joint effort of inter-departmental, or inter-school research groups by dividing the problem into a research theme for the respective groups and integrating the specific research outcomes as a single product or service is the basis of the proposed multi-disciplinary research-based learning at KU.

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Initiation of multi-disciplinary research in the discipline of GH energy with the focus on H2H technology in the context of Nepal and prepare the country to enter the GH energy could be a good start. The development of hydropower systems to produce GH energy for commercial applications can change the future of hydropower development in the entire Himalayan region. KU has sufficient background and resources to lead this multi-disciplinary research at the regional level.

4. Green Hydrogen Energy as multi-disciplinary research at KU

Conducting research and education activities in the theme of GH needs a multi-disciplinary research team with a specialization in Environmental Science and Engineering, Chemical Engineering, Electrical Engineering, and Mechanical Engineering. In the context of Nepal, the vision of multi-disciplinary research in GH could be "Nepalese industries specialized to produce, store, transport, and use Green Hydrogen at a commercial level". The specific research methods for KU in this area could be "technology transfer, innovation, and local adaptation of Green Hydrogen systems through continuous research and development activities." The outcomes of this multi-disciplinary research would be "technically, financially, and environmentally feasible production, transmission, and utilization of Green Hydrogen energy in Nepal and the Himalayan region". Excess hydropower and other renewable energy sources as solar and wind energy can be the parallel activities are some of the means in Nepal and region for the production of the GH energy.

The Department of Mechanical Engineering under the School of Engineering at KU offers four different specializations for its undergraduate (UG) program. The UG students are separately enrolled for specialization in Energy Technology, Hydropower, Design and Manufacturing, and Automobile domain of Mechanical Engineering. The School of Engineering also runs programs in Electrical and Electronics Engineering and Chemical Engineering. School of Science offers programs in Environmental Science and Engineering. All these departments and specialization units have their research groups and research projects. There is a strong possibility and opportunity to develop a GH research team in each of these research groups and integrate it as the multi-disciplinary research unit for GH. The multi-disciplinary research unit for GH has a possibility to be developed as a Centre for Green Hydrogen (CGH) as state-of-art research facilities. Table 1 shows the research roles and contributions from the respective departments and sub-divisions under the School of Science and School of Engineering at KU for the CGH. As Nepal and Himalaya region has very high hydropower potential the specifics research focus of CGH could be Hydropower-to-Hydrogen (H2H) technology for the region. There is a need to identify the prospect of H2H technology in the Nepalese context and transfer the relevant knowledge in the Himalayan region. The fundamental and applied research conducted at CGH can lay the foundation for the commercial application of H2H technology in Nepal and the region. The engagements in academic and research degrees will produce capable and competent human resources necessary for project development in the future. Followings are the proposed objectives for the multi-disciplinary research for the CGH:

- Assessment of technical, financial, environmental, and market aspects of green hydrogen from hydropower and other renewable energy sources in the Himalayan region.
- Capacity and competence development for hydropower-to-hydrogen energy technology through research and innovations.
- Produce future generations of young professionals for hydrogen technology by integrating research and innovation with academic programs in the university.
- Provide professional services and technology transfer to the industrial sector for business development and commercial initiatives.

Table 1 shows the proposed roles of the different departments and sub-divisions under the school and Science and School of Engineering at KU. The research groups and resources in each unit have the capacity to contribute to the intended roles at CGH.

Table 1. Prospective units at KU for multi-disciplinary research at CGH

Department/ Sub-division	**Roles at CGH**	**Resource Assessments**
Environmental Science and Engineering	Correlation between energy, environment, and technologies	Strengthening the existing resources and expertise is needed
Chemical Engineering	Improvements in electrolyzer and Fuel Cells for commercial applications	A new research facility and equipment are necessary for the existing expertise
Energy Technology (Mechanical Engineering)	Integration of electrolyzer and Fuel Cells with GH systems	Some additional research facilities are required
Hydropower (Mechanical Engineering)	Adaption and optimization of existing and new hydropower projects for the production of GH	A new research facility and equipment are necessary for the existing expertise
Design and Manufacturing (Mechanical Engineering)	Development of equipment and safety standards for storage and transmission of GH	Strengthening the existing resources and expertise is needed
Automobiles (Mechanical Engineering)	Optimization of existing and new vehicles for end-use of GH in the transportation sector	Strengthening the existing resources and expertise is needed
Electrical and Electronics Engineering	Design of process control and associated electrical systems	Strengthening the existing resources and expertise is needed

KU can be a leader in Nepal and region for initiating the research on GH energy. The proposed CGH at KU can be a facilitator to all universities/research institutes in Nepal to engage in H2H for the overall development of Nepal. The existing partnership with leading institutions in hydrogen research, including, Norwegian University of Science and Technology, Norway, Korea Maritime and Ocean University, Korea, SINTEF, Norway can play a pivoting role for knowledge and resources sharing for capacity and competence at KU.

5. Conclusions

The environmental and health challenges induced by emissions are forcing the effects of Nature to lift-off the carbon footprints from the energy and economy ecosystem. The Green Hydrogen based economy is the future of the sustainable solution to balance the economy and environment. There is a need for research and innovation to make the GH systems technically and financially feasible as the replacement of fossil fuel.

In the context of Nepal and the Himalaya region, it is a high time to investigate the Hydropower-to-Hydrogen (H2H) technology and prepare the region to enter the Green Hydrogen era. The development of hydropower systems to produce GH for commercial applications can change the value chain of hydropower development in the entire Himalayan region. Nepal can generate revenue of up to USD 3 billion per year in 2030 by using an excess of 3000 MW of hydroelectricity for H2H by producing Green Hydrogen. There is a need to prepare the academic institutions in Nepal to develop knowledge and resources in the field of Green Hydrogen studies.

To initiate the production, transmission, and utilization of Green Hydrogen from hydropower projects, Kathmandu University (KU) aims to develop a Centre for Green Hydrogen (CGH) as an exemplary

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multi-disciplinary research unit with state-of-art research facilities. There is a need to identify the prospects of Hydropower-to-Hydrogen (H2H) technology in the Nepalese context and transfer the relevant knowledge in the region. The fundamental and applied research conducted at CGH will lay the foundation for the commercial application of H2H technology in Nepal in the near future. The engagements in academic and research degrees will produce capable and competent human resources necessary for project development in the future.

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