Fueling the Future with Clean Hydrogen

An Analysis of the Low-Carbon Hydrogen Market, Regulation, and Origin Certification in the US and Canada

An Interactive Qualifying Project Proposal
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements
for the degree of Bachelor of Science

By:
Sameer Desai
Belisha Genin
Tera Keang
Neena Xiang

Date: April 28th, 2023

Project Sponsor:
Dr. Yenhwa Chen and Jean Hsien
Taiwan Institute of Economic Research

Advisors:
Professor Grant Burrier and Professor Alex Sphar
Worcester Polytechnic Institute

Authorship Page

Section	Primary Authors
Abstract	T.K., N.X.
Acknowledgements	T.K., N.X.
Executive Summary	All
Introduction	B.G.
Background	B.G.
Methodology	B.G.
Results	N.X.
Discussion	N.X.
Conclusion	T.K.
1.0 Introduction	All
2.0 Literature Review	All
2.1 Low-Carbon Hydrogen	N.X.
2.1.1 Green Hydrogen Production and Life Cycle	N.X.
2.2 Policy on Low-Carbon Hydrogen	T.K.
2.2.1 Policy and Roadmaps in the US	T.K.
2.2.2 Policy and Roadmaps in Canada	T.K.
2.2.3 Certificate System and Offsets	T.K.
2.3 Market on Low-Carbon Hydrogen	B.G.
2.3.1 Low-Carbon Hydrogen in the US and Canada	B.G.

2.4 Barriers of Low-Carbon Hydrogen	N.X.
2.5 Taiwan's Current Energy Overview	S.D
2.5.1 Taiwan's Energy Usage and Production	S.D
2.5.2 Promoting Renewable Energy in Taiwan	S.D
3.0 Methodology	All
3.1 Archival Research	S.D., B.G.
3.1.1 Scholarly Papers	B.G.
3.1.2 Government Publications	S.D.
3.1.3 Press Reports	S.D., B.G.
3.1.4 Roadmaps in the US and Canada	S.D.
3.1.5 Limitations of Archival Research	B.G.
3.2 Interviews	N.X.
3.2.1 Data Collection for Interviews	N.X.
3.2.2 Data Analysis for Interviews	T.K., N.X.
3.2.3 Limitations for Interviews	T.K.
3.3 Final Deliverables	T.K.
4.0 Results	T.K.
4.1 Archival Results	B.G.
4.1.1 United States Results	B.G.
California	B.G.
Colorado	S.D.
Hawaii	B.G.
Texas	T.K.
4.1.2 Canada Results	N.X.
Alberta	S.D.
British Columbia	N.X.

Ontario	N.X.
Québec	T.K.
4.2 Interview Results	S.D.
4.3 Report Results	T.K.
5.0 Discussion	B.G., T.K., N.X.
5.1 ZEVs and FCEVs	B.G.
5.2 State Province Comparison	N.X.
5.3 Exports and Imports	T.K.
5.4 Renewable Portfolio Standards and Certificates	B.G.
5.5 Hydrogen Hubs	T.K.
6.0 Conclusion	T.K., N.X.
6.1 Limitations	T.K.
6.2 Moving Forward	N.X.
Appendices	T.K., N.X.
Appendix A: Email Template for Interviews	T.K.
Appendix A.1: Initial Email for Interview Request Template	All
Appendix A.2: Accepted Interview Email Response Template	All
Appendix A.3: Follow-Up Email Response Template	All
Appendix B: LinkedIn Template for Interviewees	All
Appendix C: List of Interviewees	All
Appendix D: Informed Consent Agreement for Participation in a Research Study	T.K., N.X.
Appendix E: Sample Interview Questions for Government Officials	T.K.
Appendix F: Sample Interview Questions for Industry Leaders	T.K.
Appendix G: Sample Interview Questions for Scholars	T.K.
Appendix H: Questions for Interviewees	All

Appendix H.1: Yu Zhong	All
Appendix H.2: Mark Ruth	All
Appendix H.3: Amgad Elgowainy	All
Appendix H.4: Shih Yu (Elsie) Hung	All
Appendix I: Gantt Chart	All
Appendix J: Report Deliverables	All
Appendix J.1: United States General Report	B.G.
Appendix J.2: California, United States Report	B.G.
Appendix J.3: Colorado, United States Report	S.D.
Appendix J.4: Hawaii, United States Report	B.G.
Appendix J.5: Texas, United States Report	T.K.
Appendix J.6: Canada General Report	N.X.
Appendix J.7: Alberta, Canada Report	S.D.
Appendix J.8: British Columbia, Canada Report	N.X.
Appendix J.9: Ontario, Canada Report	N.X.
Appendix J.10: Québec, Canada Report	T.K.

Abstract

The Taiwan Institute of Economic Research (TIER) is interested in creating a green hydrogen Guarantee of Origin (GO) scheme to ensure all hydrogen energy imported into Taiwan is made with zero carbon emissions. Our project goal was to investigate the United States' and Canada's policies, market, and strategies on hydrogen to recommend strategies on the implementation of a GO scheme to TIER. To explore the policy and market of the clean hydrogen in the US and Canada, we conducted archival research examining press reports, government-official documents, and policy roadmaps. We interviewed individuals from the government and academia to learn more about the influence of public policy on the hydrogen market. We also experienced limitations in data collection due to time constraints including low response rates for interview requests, particularly from private industry and Canadian sources.

The findings of this project revealed that Taiwan should consider adopting policies similar to Hawaii due to similar geographical characteristics and Hawaii's successful implementation of pro-green hydrogen initiatives and policies such as the Renewable Portfolio Standard and their Hydrogen Investment Capital Special Fund that are seen to be successful in reducing carbon emissions. Taiwan could also consider implementing a hydrogen tax credit system that has been passed in the US and Canada to incentivize the adoption of clean hydrogen in addition to beginning their hydrogen transition through the construction of a small scale hydrogen hub that Taiwan already has the infrastructure for. Based on this research, TIER has proposed to the government the implementation of green hydrogen hubs in Taiwan. However, TIER will ultimately have the last decision on which policies are suitable for the country to adopt.

Acknowledgements

Our team would like to thank the following individuals and contributors who helped us complete our project:

- Project collaborators at the Taiwan Institute of Economic Research in the Taiwan Renewable Energy Certificate sector: Dr. Yenhwa Chen, Jean Hsien, and Chia Wen (Lilliane) Hsu.
- Project advisors from Worcester Polytechnic Institute, Dr. Grant Burrier and Dr. Jefferson Sphar.
- Project directors Dr. Wen-Hua Du and Dr. Jennifer Rudolph.
- Interviewees Dr. Yu Zhong from Worcester Polytechnic Institute, Shih Yu (Elsie) Hung from Rice University's Baker's Institute for Public Policy, Mark Ruth from the National Renewable Energy Laboratory, and Dr. Amgad Elgowainy from Argonne National Laboratory.

Executive Summary

Introduction

The industrial revolution has led to the release of over 2,500 billion metric tons of carbon dioxide emissions, resulting in global warming of 1°C above pre-industrial levels. Without changes to the way we consume natural resources, global temperatures could rise by 3°C by the turn of the 22nd century, leading to detrimental consequences for human life such as an increase in intense weather phenomena, rising sea levels, food and water insecurity, and mass displacement. To minimize the impacts of climate change, the Intergovernmental Panel on Climate Change (IPCC) has recommended limiting global warming to a maximum of 1.5°C above pre-industrial levels, requiring a massive shift in the energy sector of the economy towards renewable energy sources.

One of the renewable energy sources being explored is hydrogen, which can be produced using fossil fuels (gray hydrogen), with emissions offset by carbon capture storage (blue hydrogen), or using renewable electricity (green hydrogen). The focus of the project sponsored by the Taiwan Institute of Economic Research (TIER) is to aid in the development of a low-carbon hydrogen certification system in Taiwan. To achieve this goal, our project aims to analyze, summarize, and visualize information on low-carbon hydrogen policies, market forecasts, and regulations in the United States and Canada, to provide TIER with data to support the creation of policy to certify low-carbon hydrogen and stimulate the low-carbon hydrogen industry in Taiwan.

Background

Hydrogen comes in three varieties distinguished by their production process and carbon emissions. Gray hydrogen is the most commonly produced but emits significant amounts of carbon. Blue hydrogen is produced in the same way but uses carbon capture and storage to reduce emissions. Green hydrogen is made through electrolysis using low- or zero-carbon electricity and is seen as a leading fuel source to reach net-zero carbon emission targets, despite obstacles like limited infrastructure and higher costs compared to other fuels. The project focuses on the certification of low-carbon hydrogen, including blue hydrogen with a 70% reduction in carbon emissions and green hydrogen.

The US defines clean hydrogen, its equivalent to low-carbon hydrogen, as having a maximum of 4.0 kg CO_2e per kg of hydrogen produced and has implemented policies and funding to support the development of a clean hydrogen economy. The Bipartisan Infrastructure Law (BIL) allocated $9.5 billion to decarbonizing hydrogen and establishing regional hydrogen hubs, while the Inflation Reduction Act (IRA) provides a tax credit for clean hydrogen production. Canada aims to be a leading exporter of clean hydrogen and has published the Hydrogen Strategy for Canada, which includes building a domestic hydrogen supply chain, stimulating the end-use market, and implementing policies and regulations to support the market. Both countries have made efforts to decarbonize hydrogen and have a vision for rapid expansion in the years 2030-2050.

Defining and regulating low-carbon hydrogen is challenging due to varying definitions and regulations across regions. The lack of a united federal definition has led to inconsistent policies and regulations, making it challenging to import and export energy between states and provinces. The certification of green hydrogen depends on the carbon intensity of the electricity used to produce it, which can be difficult to quantify based on how that electricity was produced. Regions with significant renewable energy and natural gas infrastructure are best suited to build a low-carbon hydrogen industry. Although there is no federal regulation certifying renewable hydrogen fuel, state and provincial laws can provide useful information for the project.

Meeting the net-zero emissions goals requires a significant increase in low-carbon manufacturing facilities, particularly for green hydrogen, with an estimated 48-720 GW of electrolysis capacity required by 2030. While blue hydrogen can serve as a transition from gray to green hydrogen, the cost of green hydrogen is rapidly decreasing. The viability of low-carbon hydrogen in end-use cases will determine its industry's growth. In the US and Canada, the market for hydrogen is expected to expand as the technology develops. The use of low-carbon hydrogen as an alternative fuel source in commercial transportation, particularly in the maritime shipping sector, is promising, but innovative bunkering infrastructure is necessary. The US government is investing in carbon projects and research and development to decarbonize hydrogen.

Low-carbon hydrogen technology faces multiple barriers, including regulatory, economic, technological, and infrastructural hurdles, such as inconsistent international policies, high production costs, and inadequate infrastructure. Another challenge is the short-term warming effect that hydrogen can have if not managed properly. While green hydrogen can be less expensive, significant incentives are required to make it a viable option. Countries and companies must invest in dedicated infrastructure and innovation to realize the full potential of green hydrogen.

Taiwan currently heavily relies on imported fossil fuels to meet their energy needs, with only 2% of energy produced domestically while industrial products are the largest part of their economy. However, the country is making efforts to increase its renewable energy production and has set a target to achieve net-zero emissions by 2050. Taiwan's Bureau of Energy has implemented policies to encourage investment in renewable energy projects, including tax incentives, subsidies, and the Feed-in Tariff Program. The country's Phased Goals and Actions Toward Net-Zero Transition roadmap outlines 12 key strategies, including a Hydrogen Strategy that aims to generate 9-12% of power from hydrogen by 2050 and promote hydrogen-based industry manufacturing processes and regulations for hydrogen vehicles. Private industrial companies, such as TSMC, have also invested in renewable energies. The potential of low-carbon hydrogen technology is also being explored as a sustainable energy source to help Taiwan decarbonize its economy and play a role in reducing global greenhouse gas emissions.

Methodology

The goal of our project was to investigate low-carbon hydrogen policies in the U.S. and Canada in order to provide TIER with sufficient data and case-studies to develop policies to define low-carbon hydrogen and develop its industry in Taiwan. To meet this goal two objectives were set:

(1) Understand the US and Canada's current low-carbon policies and what certification systems exist for tracing the origin of low-carbon hydrogen

(2) Analyze the potential applications for low-carbon hydrogen based on policy goals in the US and Canada.

In order to achieve these objectives, the team utilized archival research and conducted semi-standardized interviews to investigate the certification process for low-carbon hydrogen in the U.S. and Canada to use as reference for Taiwan. The team read scholarly papers on low-carbon hydrogen, analyzing its synthesis, efficiency, and potential market demand, as well as government publications to understand the regulatory framework surrounding hydrogen energy. We also studied press reports to stay informed of current events and identify trends in the low-carbon hydrogen market, and we analyzed roadmaps from the US and Canada to inform Taiwanese policymakers about low-hydrogen policies.

The team conducted semi-standardized interviews with experts from governmental agencies, industry leaders, and academics, using a combination of website searches, networking websites, and emails to contact potential interviewees. All interviews were conducted virtually, and the data collected was analyzed using content analysis and triangulated with information from archival research. This study provided valuable insight into the perspectives of different groups involved in the low-carbon hydrogen industry and filled knowledge gaps left by archival research.

Results

In the United States, most policies that aimed at promoting clean hydrogen are still in development or were recently passed. California has focused on alternative fuel vehicles and zero-emission vehicles, offering incentives and rebates, while adopting the Low Carbon Fuel Standard (LCFS) as a comprehensive program for clean hydrogen production. Colorado is focused on developing hydrogen for transportation, while Hawaii began investing in clean hydrogen as part of a comprehensive plan spanning from 2010-2020, focusing on improving the renewable electricity grid and hydrogen infrastructure. Texas has the goal to reach 50% renewable energy generation by 2030, supported by federal Renewable Portfolio Standard (RPS) and the Texas Emission Reduction Plan (TERP).

Canada aims to become a leader in exporting clean hydrogen to create jobs and expand market influence. The regulations in Canada focus on limiting the emissions of hydrogen production due to the variety of resources available to them. The country has adopted the EU's CertifHy emission standard as their definition of low-carbon hydrogen. Several funds and tax credits support the research and infrastructure investment of hydrogen projects. Alberta is adapting their natural gas infrastructure to contain hydrogen and slowly converting their natural gas to hydrogen. British Columbia contains most of the hydrogen projects and companies in Canada, and their goal is to lower overall emissions by 40% by 2030. Ontario aims to create green hydrogen to provide to its local communities, with global exports in the future. Québec is investing in developing hydrogen-based technologies and an overall green hydrogen ecosystem in the province.

Our study contacted 75 potential interviewees, but only 13 responded, resulting in a response rate of 17.3%. The interview response acceptance rate was 5.33%, with four individuals accepting the interview, five rejecting, and four who remained tentative. The interviewees came from those in government and academia who shared their knowledge on the potential uses of reversible hydrogen fuel cells, the role of Hydrogen Hubs, the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET Model), and establishing a sustainable hydrogen market in the United States. Overall, the interviewees provided valuable insights in directing the research efforts of the study.

Discussion

In the US, state-level policies have been implemented to reduce emissions from motor vehicles, focusing on both light-, medium-, and heavy-duty vehicles through various measures.

Hawaii has been successful in introducing hydrogen through ZEVs, while Canada is pushing to reduce GHG emissions from fuel and vehicles. FCEVs have niche applications in medium- and heavy-duty vehicles like trucks and buses. In Taiwan, FCEVs could be used for the transportation of goods, but the lack of a large automotive industry and clean hydrogen may make the transition too expensive and early.

The US and Canada have similar policies and plans for the implementation of green hydrogen, with both countries having regions that have the potential to be great hubs for green hydrogen. They can independently produce their own hydrogen, which means they do not need to depend on other countries for green hydrogen. Taiwan can be influenced by Hawaii's procedures, but it is important to note that the highly-developed US and Canada are not comparable to smaller countries like Taiwan with limited natural resources.

Establishing a Renewable Portfolio Standard (RPS) has proven to be effective in increasing the generation of renewable energy in multiple US states, with Hawaii's RPS helping the region achieve a renewable energy generation of 29% in 2022. Taiwan could create its own RPS and Renewable Energy Certificate program, and can look to Hawaii's successful strategies to achieve their net-zero goals. To facilitate Taiwan's transition to clean hydrogen, a set standard for clean hydrogen must be created and included in the RPS program.

The US and Canada are interested in developing green hydrogen hubs in Texas, Hawaii, and Québec, which offer proximity to resources and energy independence but require significant investment. TIER has expressed interest in developing a green hydrogen hub in Taiwan, and a project proposal is currently in the works.

Conclusion

Throughout our research study, we faced several challenges in methodology and data collection, which ultimately impacted the scope of our results. One major challenge encountered was limited access to certain government documents, which restricted the information we could gather and share with TIER. Furthermore, given the dynamic nature of policy, the information contained in our reports may become outdated by the time TIER reviews it.

Due to time constraints, we were also unable to research every state and province, as it would have required a significant amount of time to analyze and summarize the official documents. Language barriers also posed a challenge when researching Taiwan's current market stance on green hydrogen, which affected our ability to collect accurate data.

In terms of interviews, contacting professionals through LinkedIn and email proved to be challenging, and some interviewees were unable to answer questions due to non-disclosure agreements. Moreover, our sample population was limited to two government and two academic interviewees from the US, preventing us from gathering insights from industry professionals. The overall data collection for Canada was also limited, as we were unable to connect with professionals in Canada for interviews, and had to rely on archival research.

From our findings, we suggest that Taiwan could adopt policies similar to Hawaii since there are geographical similarities and Hawaii's successful renewable energy regulations such as the Renewable Portfolio Standard that is helping Hawaii reach their NZE goals. Taiwan should also consider implementing tax credit systems and creating hydrogen hubs to initiate their transition to green hydrogen. However, with TIER's expertise in green hydrogen, TIER should carefully evaluate each policy's applicability to Taiwan's economy and status before proposing new projects.

Table of Contents

1.0 Introduction

The industrial revolution that spurred the rapid modernization of many countries around the world between the late 18th century and mid 19th century has led to the release of over 2,500 billion metric tons of carbon dioxide ($GtCO_2$) emissions (OWID, 2022). As of 2017, these emissions, trapped in the atmosphere, have resulted in a global warming effect of 1°C above pre-industrial levels and are predicted to continue to increase by 0.2°C per decade (IPCC, 2018). Without changes to the way we consume natural resources, global temperatures could rise by 2°C above pre-industrial levels by the turn of the century, the consequences of which would be detrimental to human life. Under a 2°C warming scenario we will see an increase in frequency of intense weather phenomena, such as droughts, wildfires, and heavy precipitation; sea levels will rise and we will witness a mass-extinction event. With an unstable climate, food and water insecurity will increase leading to a predicted displacement of 216 million people around the world by 2050 (World Bank, 2021).

To minimize the severe impacts of climate change the Panel on Climate Change (IPCC) has recommended limiting global warming to a maximum of 1.5°C above pre-industrial levels as a way to minimize the severe impacts of climate change. In order to accomplish this goal, there must be a massive shift in the energy sector of the economy. Countries must reduce fossil fuel consumption, electrify on a mass scale, improve energy efficiency and shift to alternative fuel sources to stop climate change.

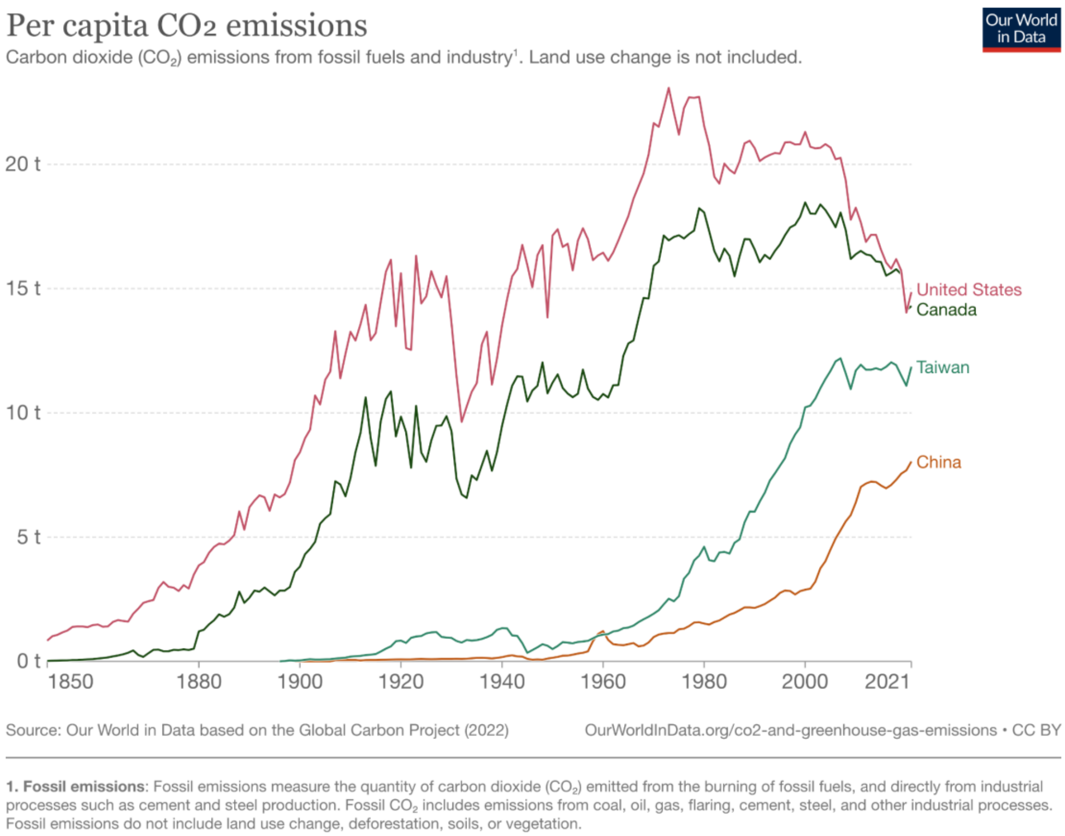


Figure 1.1: Carbon dioxide emissions per capita in the United States, Canada, China, and Taiwan.

With continued consumption of unsustainable energy, total carbon dioxide emissions will continue to rise contributing to global warming. In the past decade, there has been significant progress in transitioning away from traditional fossil fuels to renewable energy and it is anticipated that this trend will continue to grow in the next decade. The International Energy Agency (IEA) predicted that by 2026 global renewable electricity capacity is “forecast to rise more than 60% from 2020 levels to over 4,800 GW,” and “renewables [are] set to account for almost 95% of the increase in global power capacity through 2026”. Governments have been key to instigating this transition through the incentivization of the production and usage of renewable energy. In 2021, the United Nations developed the COP26, a climate initiative team formed to tackle the growing emergency surrounding global warming by accelerating the adoption of renewable energy. Figure 1.2 outlines the types of renewable energy available, some of which break down into further categories that will be key components in the energy transition.

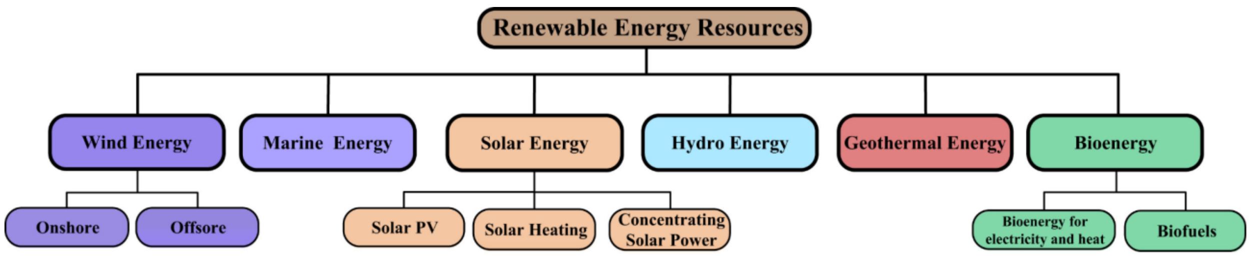


Figure 1.2: Sources of Renewable Energy (Ellabban et al., 2014).

In an effort to reduce carbon emissions, some countries have turned to hydrogen as an alternative fuel source. Currently, the majority of hydrogen produced is processed using fossil fuels, a nonrenewable source. Hydrogen produced using fossil fuels is called gray hydrogen. As technology continues to improve, efforts are being made on both the government and market level to shift to producing hydrogen using electricity generated from renewable resources.

The types of hydrogen that are considered to be low-carbon are blue and green hydrogen. Blue hydrogen is produced under similar conditions to gray hydrogen, but implements carbon capture storage (CCS) to offset greenhouse gas emissions. In the best case scenario, emissions can be reduced by 85-95% (Bianco and Blanc, 2020). On the other hand, green hydrogen is synthesized using renewable electricity and emits close to zero green-house-gas emissions. The set quantity of emissions that is permitted for green hydrogen to be considered green varies country by country, however, hydrogen produced from renewable electricity may also be referred to as renewable hydrogen. Low-carbon hydrogen has the capacity to lower global emissions and is the focus of our project.

Located in Taipei City, the Taiwan Institute of Economic Research (TIER) is a think tank with the goal “to promote both domestic and international economic research and advance exchanges and co-operations with other international institutions" to “promote Taiwan’s economic development” (Taiwan Institute of Economic Research, 2007). TIER is partnered with the Taiwan Renewable Energy Certificate (T-REC), a governmental agency that specializes in coordinating, issuance, and management of renewable energy certificates (Taiwan Institute of Economic Research, 2023). Due to the rising demand for renewable energy, T-REC promotes the research and market development of Taiwan’s clean energy sector, with the goal to power 20% of total energy consumption through renewable energy by 2025 (National Renewable Energy Certification Center). T-REC has issued over 1.5 million certificates, and traded 1.4 million certificates in an effort to meet this goal. As part of our sponsorship with TIER, we hope to aide in the development of a low-carbon hydrogen certification system by answering the following research questions:

(1) How can Taiwan learn from the United States’ and Canada’s regulation of low-carbon hydrogen?

(2) How does the US' and Canada’s plan to incentivize the development of the low-carbon hydrogen market?

To meet answer our research questions, the following objectives were identified:

(1) Understand the US and Canada’s current clean hydrogen policies and what certification systems exist for tracing the origin of clean hydrogen.

(2) Analyze the potential applications for clean hydrogen based on policy goals in the US and Canada.

This project aims to analyze, summarize, and visualize information on low-carbon hydrogen policies, market forecasts, and regulations in the United States and Canada. Our objective is to provide TIER with data to support the creation of policy to certify low-carbon hydrogen and to stimulate the low-carbon hydrogen industry in Taiwan.

2.0 Literature Review

The purpose of this literature review is to evaluate the current research on low-carbon hydrogen policies and the state of low-carbon hydrogen in the United States and Canada. This evaluation is intended to assist the Taiwan Institute of Economic Research (TIER) and the Taiwan Renewable Energy Certificate (T-REC) division of TIER in the creation of a low-carbon hydrogen certification system and in promoting the growth of the low-carbon hydrogen industry in Taiwan.

The literature review will discuss low-carbon hydrogen, including its production, life cycle, and significance. To understand each government's position on low-carbon hydrogen, we will review the policies in the United States and Canada that pertain to the adoption and usage of low-carbon hydrogen. The current and forecasted international low-carbon hydrogen market, with emphasis on the US' and Canada's involvement, will be examined alongside suggested measures to accelerate production capacity and expand end case usage. Following market analysis, the barriers that the implementation of low-carbon hydrogen, specifically green hydrogen, faces in terms of policy, cost, and infrastructure will be detailed. Lastly, the literature review will conclude by evaluating the current state of renewable energy and low-carbon hydrogen in Taiwan.

2.1 Low-Carbon Hydrogen

Standard hydrogen and low-carbon hydrogen are terms for the different colors of hydrogen: gray, blue, and green. The differences can be seen in Figure 2.1. Gray hydrogen is produced using fossil fuel sources such as methane and coal through the process of steam methane reforming and coal gasification, respectively. Due to its status as a cheap and accessible fuel source, gray hydrogen is the most common type of hydrogen produced; however, it produces a substantial amount of carbon emissions and cannot support plans for net-zero carbon emission (NZE). Blue hydrogen is hydrogen made under the same conditions as gray, but utilizes carbon capture and storage (CCS) to reduce emissions. On the other hand, green hydrogen is synthesized through the process of electrolysis (the process of breaking down water molecules into hydrogen and oxygen) using low- or zero-carbon electricity.

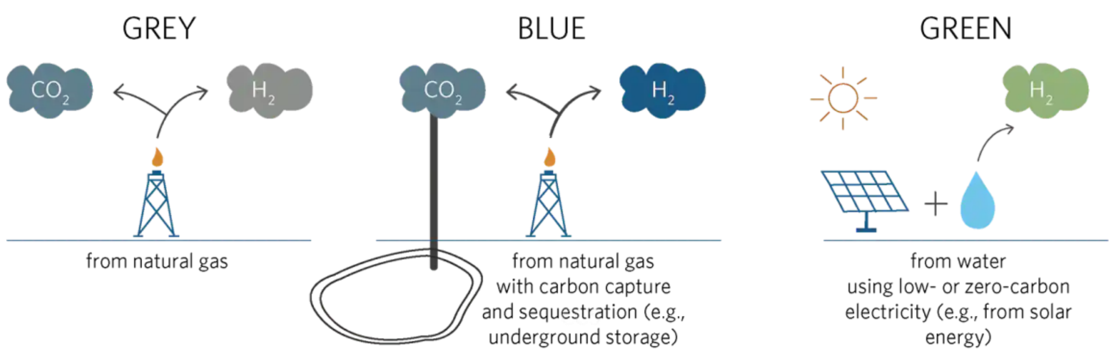


Figure 2.1: Difference between gray, blue, and green hydrogen (Merida, 2021).

Although the US and other countries are making an effort to switch to low-carbon hydrogen as an alternative fuel source, the hydrogen industry is still dominated by gray hydrogen. Low-carbon hydrogen made up "less than 1% of the total [global] hydrogen production" in the years between 2018 and 2021 (International Energy Agency, 2022). In a report released by the International Renewable Energy Agency (IREA) in 2020, the IREA stated that the carbon emission reduction process had barely begun with only 8.8% carbon reduction seen in the first half of 2020 (Bianco & Blanco, 2020). This reduction is similar in size to the reduction seen during the same period in 2019, so in order to reach the 2050 NZE goal a more significant effort must be made by countries to reduce emissions. Producing green hydrogen via electrolysis is a relatively new technology and remains costly in comparison to gray or blue hydrogen, however, there have been pushes to accelerate the adoption of green hydrogen industry for the sake of meeting the 2050 NZE goal. This project's focus will be on the certification of low-carbon hydrogen which includes blue hydrogen with a reduction of at least 70% in carbon emissions and green hydrogen.

2.1.1 Green Hydrogen Production and Life Cycle

The life cycle of green hydrogen begins with the production and transformation, followed by the transportation, and finishes when it is used by the consumer. Starting with production, green hydrogen uses a process called electrolysis: an electrical current is used to split water molecules into oxygen and hydrogen (Office of Energy Efficiency, 2023). The most common types of electrolysis are alkaline and Proton Exchange Membrane (PEM). Though the high cost of materials is a large drawback, these conventional processes of electrolysis are flexible and can operate at higher electrical currents which makes hydrogen production more energy efficient (Falcão, 2023).

Despite the challenges with current forms of electrolysis, researchers, including Falcão, are making improvements to the process to reduce the cost of materials. New methods of electrolysis, such as Anion Exchange Membrane Water Electrolysis (AEMWE), were created to reduce the drawbacks of the traditional methods while retaining performance at a low cost (Falcão, 2023). However, these methods are still in their early stages of development and still require additional time and resources before they can be used in industrial settings. Regardless, given more time and the reducing costs of renewable electricity, the production of green hydrogen can become more accessible and economically viable.

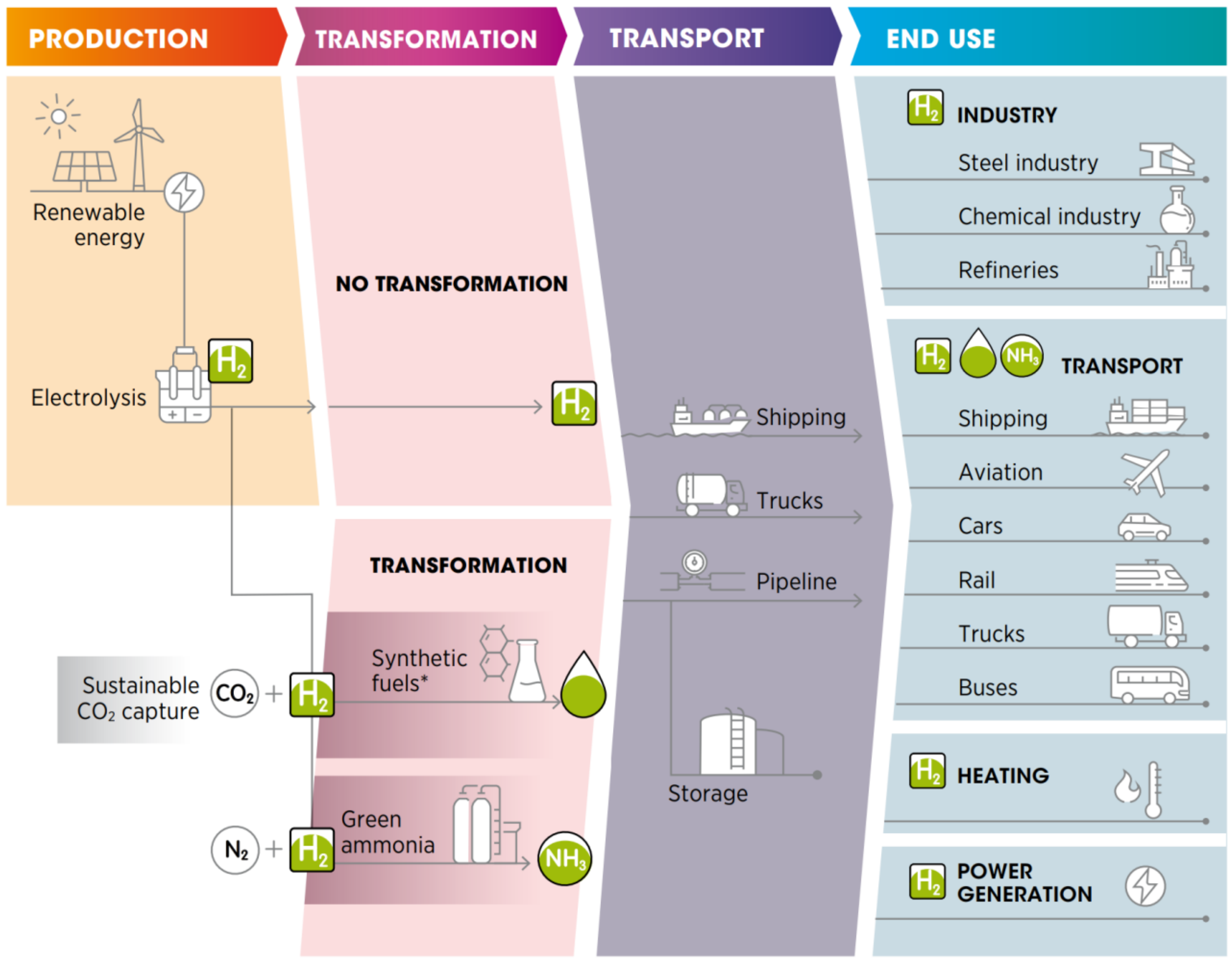


Figure 2.2: The life cycle of green hydrogen, starting from the production to its end uses (Bianco & Blanco, 2020).

As seen in Figure 2.2, the next step in the hydrogen life cycle is transformation, which is not a required step since hydrogen fuel can be used as is, but depending on the end-use case it may be transformed into ammonia or synthetic fuels. After the transformation step, the hydrogen is stored before being used. The functions of hydrogen include, but are not limited to industry, transportation, heating, and power generation. Despite limited infrastructure for transportation, ongoing development of end-use technology, and higher costs compared to other fuels, green hydrogen remains as a leading fuel-source for reaching NZE goals internationally. For further information on end-use cases refer to section 2.3.1 Low-Carbon Hydrogen Market in the US and Canada.

In summary, gray hydrogen, which is produced using fossil fuel sources, is the most common type of hydrogen produced but produces a substantial amount of carbon emissions. Blue hydrogen is similar to gray hydrogen, but utilizes carbon capture and storage to reduce emissions. Green hydrogen is synthesized through the process of electrolysis using low- or zero-carbon electricity. There is a push to innovate renewable hydrogen to meet the net-zero carbon emission goal by 2050. Due to limited infrastructure and higher costs, green hydrogen remains a leading fuel source for reaching net-zero carbon emission goals internationally.

2.2 Policy on Low-Carbon Hydrogen

The low-carbon hydrogen market is only in the beginning stages of development, so country-by-country, the potential low-carbon hydrogen demand depends largely upon the existence of a sustainable hydrogen roadmap and its scope (Wappler et al., 2022). The regions that are capable of producing cheap and low-carbon hydrogen are those with existing large-scale wind and solar renewables and natural gas infrastructure. A few notable regions include North America, China, and Europe (Sadik-Zada, 2021).

The European Union (EU) has many regions with the capacity to become self-reliant on renewable energy from wind, solar, hydro and geothermal resources, which can be used to produce low-carbon hydrogen. Transitioning the total EU hydrogen production to low-carbon hydrogen could be feasible given the expanding network of renewable energy in the region (Kakoulaki et al., 2021). The EU published the REPowerEU plan in May 2022 that reflects the adoption of the EU strategy on hydrogen in 2020 that created a vision for the European hydrogen ecosystem. This strategy explores the production and utilization of renewable energy while also minimizing carbon emissions and supporting the EU economy (European Union, 2022). The EU Hydrogen Strategy proposed 20 action points to hold themselves accountable that includes the investment agenda, the boost in demand for the scale up production, design for a supportive framework, and implementing an international dimension. The EU strategies and standards have been used to model plans for the transition to renewable energy by other nations looking to become more sustainable.

With the reduction in cost of sustainable energy in the past decade, green hydrogen has become a more viable alternative energy source. Figure 2.3 showcases how the price of renewable electricity has dropped since 2010 with some forms of renewable energy such as solar photovoltaic and offshore wind becoming cheaper than fossil fuels in 2017. To reach NZE goals, countries are beginning to incorporate green hydrogen into their plans for a sustainable future. The International Renewable Energy Agency (IRENA) has called for the promotion of green hydrogen through domestic policies. The policy proposals consider each country’s ambition for hydrogen usage, the fair-value for hydrogen, the emissions released during the product's life cycle, and the pre-existing policies that support or limit hydrogens uses (IRENA, 2020).

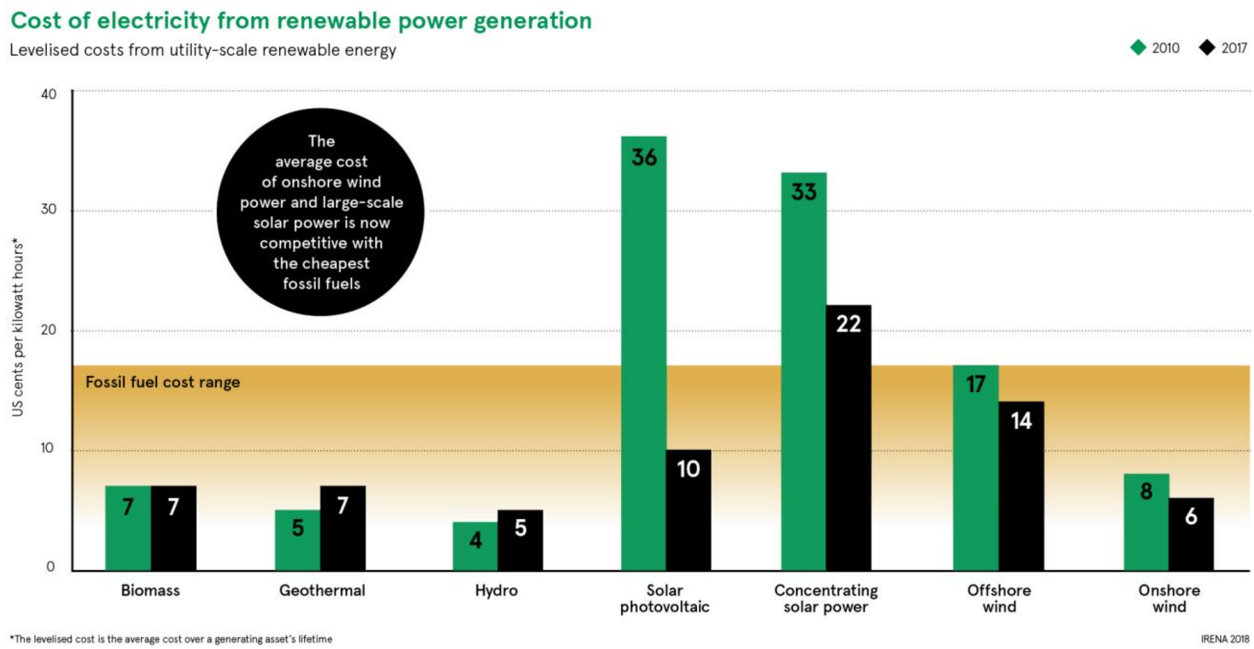


Figure 2.3: Cost of Electricity Generated from Renewable Energy (IRENA, 2019).

2.2.1 Policy and Roadmaps in the US

In the US, low-carbon hydrogen is known as clean hydrogen and is defined as having a total life cycle emissions equal to or less than 4.0 kg of CO_2e per kg of hydrogen produced. The federal government in recent years passed two policies and published a roadmap targeting the decarbonization of hydrogen and the stimulation of the clean hydrogen economy. The first bill to be passed was Infrastructure Investment and Jobs, or the Bipartisan Infrastructure Law (BIL), in 2021. It granted $62 billion to the US Department of Energy to use for the development of renewable energy, with $9.5 billion allocated specifically to decarbonizing hydrogen. Additionally, the BIL also laid the groundwork for the development of regional hydrogen hubs which produce, consume and transport hydrogen. In early 2022, the Inflation Reduction Act (IRA) was passed with provisions for a clean hydrogen production tax credit to stimulate the economy. The latest document that has been released by the federal government is the draft of the Department of Energy's *National Clean Hydrogen Strategy and Roadmap*. This roadmap calls for more government funding for research projects, regional hubs for clean hydrogen production, and to lower the cost per kg of hydrogen produced to $1. Although there have been important steps made by the U.S. towards developing clean hydrogen, there is still no certification system in place to guarantee that the origin of any hydrogen fuel is renewable.

2.2.2 Policy and Roadmaps in Canada

While Canada's low-carbon hydrogen market has been growing in the past years, policy and regulation are still loosely defined and based on standards from the EU and the US, hence, Canada uses both the terms "low-carbon" and "clean" hydrogen. In 2020, the Canadian government published the Hydrogen Strategy for Canada: a plan developed together by groups from the government, industry, and academia that would place hydrogen at the forefront of the country's plans to reach net-zero by 2050. Canada sees the potential of the hydrogen market and plans to be a large exporter of clean hydrogen in the upcoming decades. By developing hydrogen technology earlier, Canada can use their feedstock variety to generate jobs and income. Québec has one of the world's largest green hydrogen production facilities in the world and Canada plans to maintain the momentum by building more production plans as hydrogen becomes a larger part in the global NZE effort (Hydrogen Strategy for Canada, 2020). The scope of the plan includes the building of a domestic hydrogen supply chain, stimulating the end-use market of hydrogen, and creating policies and regulations to support the emerging market.

Although much of the current hydrogen policy remains underdeveloped, Canada has made an effort to decarbonize hydrogen with the Clean Fuel Standard and the $1.5 billion dollar Low-carbon and Zero-emissions Fuels Fund. These plans provide support for near term investments into the hydrogen market and Canada will continue to push for more standardized, long-term policies that will be vital for the proliferation of the hydrogen market. The federal government has yet to create a standard for what clean hydrogen is, but regions have already started to create policies to regulate and standardize their hydrogen. Additionally, regional hydrogen hubs serve as a starting point for pilot projects and will be the grounds for the foundation of Canada's hydrogen technology in the near future.

Canada foresees the rapid expansion of hydrogen as a fuel source in the years 2030-2050 as the number of uses grows. They want to be prepared with a backbone of production and distribution infrastructure which will allow for easier and quicker adoption in the far future. Dedicated hydrogen pipelines will be more prevalent and clean hydrogen will become more accessible as a fuel source.

2.2.3 Certificate System and Offsets

As the term low-carbon hydrogen is relatively new, its definition varies by region and so does its regulation. The United States' standards for clean (low-carbon) hydrogen are defined by the DOE. While the guarantee of origin and the carbon intensity standards have not been defined at the federal level in Canada, there is support to follow the EU CertifHy standard. Provinces have developed their own regulation of low-carbon hydrogen which has created a "patchwork of policies and regulations across jurisdictions" that will make importing and exporting energy difficult without a united federal definition (Hydrogen Strategy for Canada, 2020). In Figure 2.4, the International Organization for Standards outlined steps for creating a certification system.

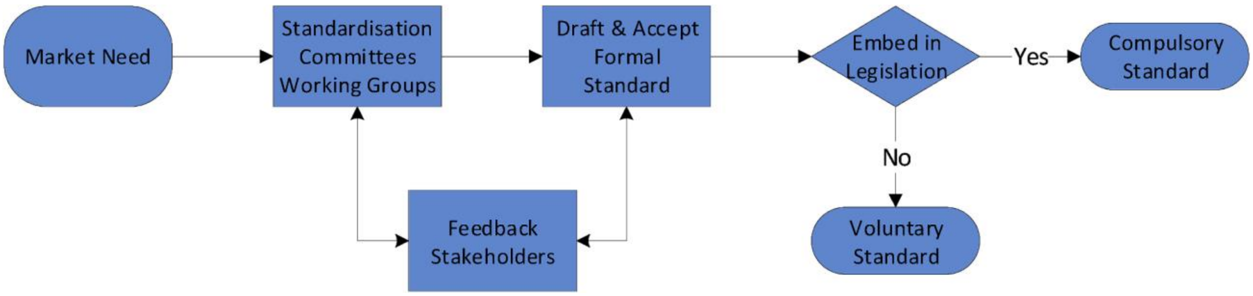


Figure 2.4: Guidelines for creating standards based on international standards (Velazquez Abad & Dodds, 2020).

The certification of green hydrogen depends upon how the electricity used to create it was generated and certifying electricity as renewable brings its own unique challenges. Renewable energy comes in two forms: gas and electric and regulation of both types of energy is necessary but difficult as the physical characteristics of electricity and gas differ from each other. Velazquez Abad and Dodds (2020) organized the physical flow of hydrogen which places both producers and consumers in the chain. Therefore, "renewable electricity GOs can only operate in a book and claim approach, as it is not possible to ensure that a particular batch of electricity correspond to a particular source, as electrons cannot be tracked back to their origin once they are fed into the grid" (Velazquez Abad & Dodds, 2020). Figure 2.5 offers different chain approaches to guarantee the origin of hydrogen.

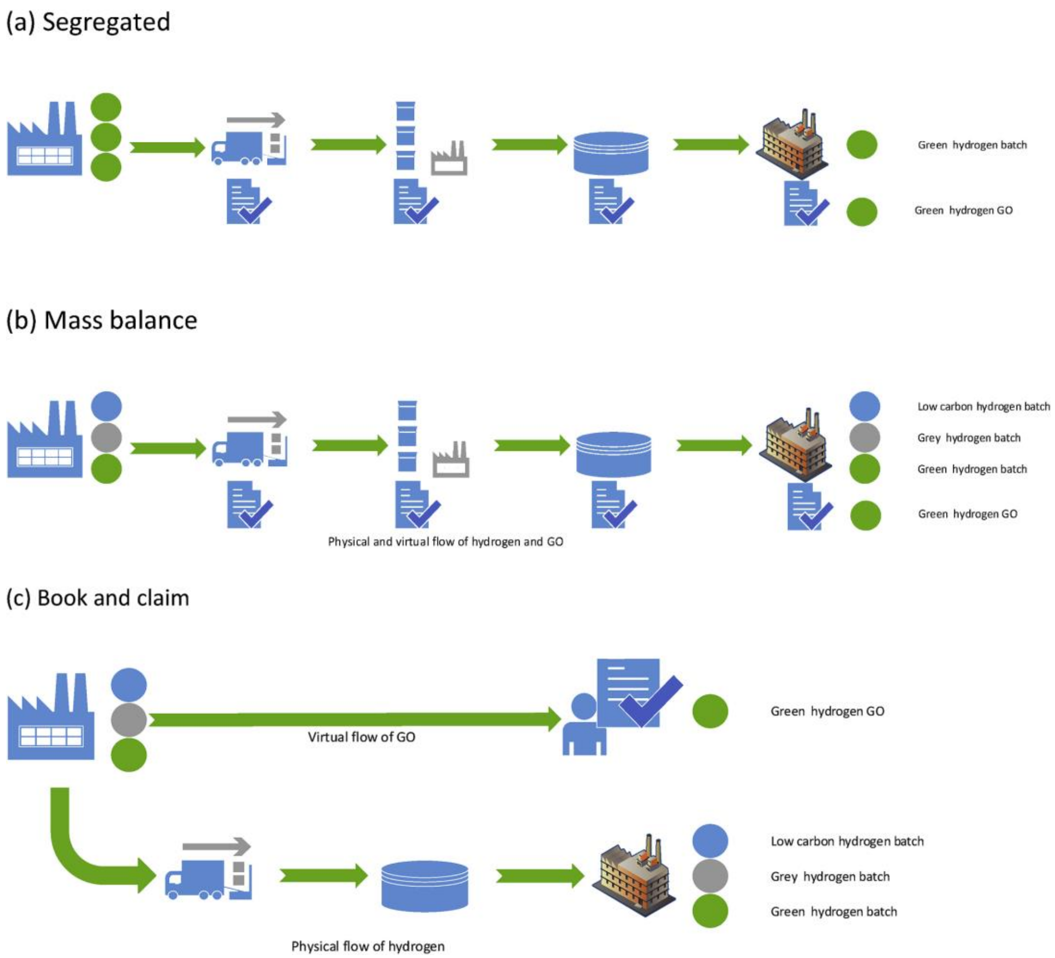


Figure 2.5: Chain of custody approaches for green hydrogen guarantees of origin (Velazquez Abad & Dodds, 2020).

The biggest challenge for the development of a green hydrogen standard is the regulation of its carbon intensity. Carbon intensity is a way to quantify how clean the electricity used is; the grams of CO_2 released to produce a kilowatt (kWH) of electricity (National Grid, 2023). Although the primary goal of implementing renewable energy certificates is to monitor the carbon-footprint of hydrogen during production and transportation, byproduct emissions that are released during hydrogen consumption are difficult to quantify. Oftentimes these emissions are not accounted for, but they may contribute significantly to total CO_2 emissions (IRENA, 2020).

Across the world countries have begun to incorporate low-carbon hydrogen into their plans to reach net-zero. The regions that are best suited for building a low-carbon hydrogen industry are those with large-sale renewable energy and existing natural gas infrastructure which leave us with the regions identified as the EU, China and North America. In North America, Canada and the United States have started to pass policies to incentivize the industry and create plans to further the adoption of clean hydrogen. Although on a federal level in both Canada and the United States, there is no regulation that certifies whether the hydrogen fuel sold is renewable or not and clean hydrogen does not have a set regulatory definition in either the U.S. or Canada. However, state and provincial laws may be further developed in specific states and provide useful information to the project.

2.3 Market on Low-Carbon Hydrogen

In order to meet the NZE demands, there must be an increase in low-carbon manufacturing facilities, specifically for green hydrogen. To produce the forecasted demand of green hydrogen based on announced projects and roadmaps globally, an estimated 48-720 gigawatts (GW) of electrolysis capacity is needed by 2030 depending on operating strategies and hours. Based on current existing and planned plants, meeting this goal would require an average manufacturing growth rate of 200% annually from 2026 to 2030 (Wappler et al., 2022).

A current alternative would be to switch to blue hydrogen during the transition period from gray to green hydrogen. There have been investments into blue hydrogen production plants; for example, Shell Quest and Carbon Trunk Link have financed plants in Alberta, Canada. However, as the cost of renewable energy continues to go down as electrolyzer capacity upscales, green hydrogen is becoming increasingly cheaper. Figure 2.6 shows that the predicted costs of green hydrogen decrease with the cost of electricity and as time passes. In order for blue hydrogen to remain competitive with green hydrogen in the future there needs to be investment into the advancement of CCS technology to improve carbon-capture efficiency and reduce total cost (Tetteh and Salehi, 2022).

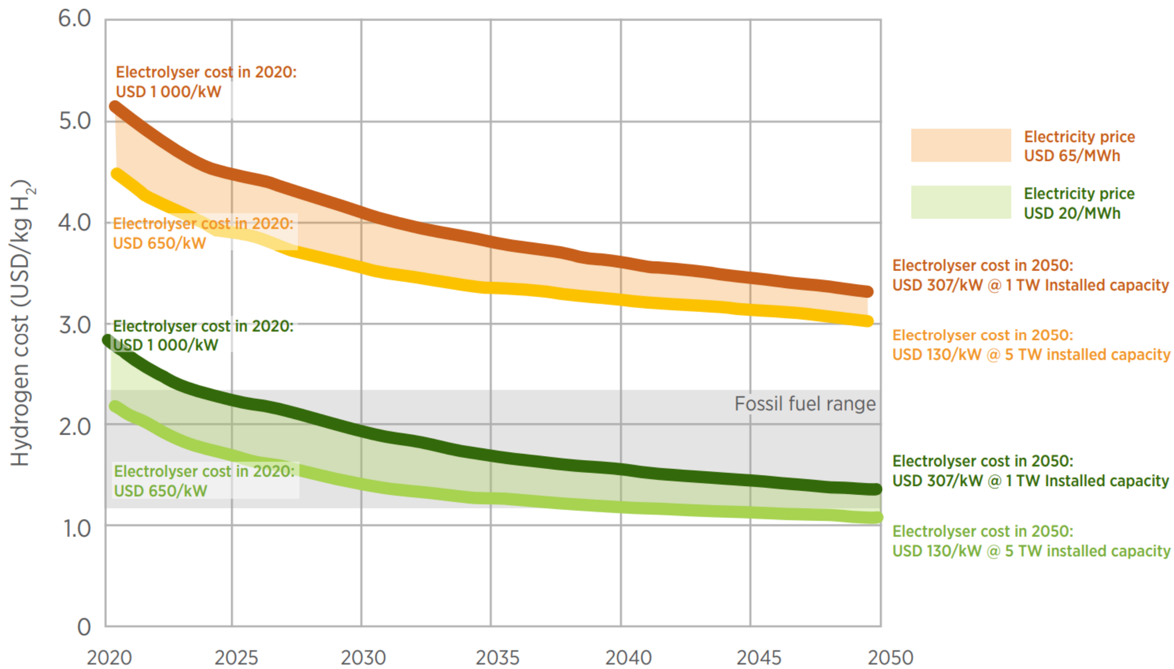


Figure 2.6: Predicted Hydrogen Cost from 2020 to 2050 (IRENA, 2020).

Growth in demand for low-carbon hydrogen depends on the viability of hydrogen fuel in end-use case scenarios. Low-carbon hydrogen may be an optimal fuel source in industries with no clear path to decarbonization, including steel and cement industries (Jovan and Dolanc, 2020). Low-carbon hydrogen fuel application in other industries, such as the maritime shipping industry, rely on the development of supporting technology for its end use (Atilhan et al., 2021). Given the prohibitive costs and the additional technology that is necessary to develop for its use, opinion is divided upon whether or not to create incentives for the low-carbon hydrogen market. Considering the cost of green hydrogen is tied to the cost of renewable energy, there exists support to focus on the rollout of renewable energy first and to stimulate the low-carbon hydrogen market at a later date (Sadik-Zada, 2021). However, given the limited time to meet the goal of NZE by 2050, there is reason to accelerate the development of the green hydrogen industry on both the production and usage end through incentives (Dong et al., 2022).

2.3.1 Low-Carbon Hydrogen Market in the US and Canada

Current demand for hydrogen in the US and Canada comes from the refining and heavy industry sector with an emphasis on its use as fertilizer and for chemical production, however, as the technology around hydrogen develops so will the scope of its market. This hydrogen by large is captive: produced and consumed on site. Recognizing that the growing demand for low-carbon hydrogen is set to increase from 91 metric tons (mt) in 2021 (IEA, 2022) to between 150 to 500 million metric tons (MMT) by 2050 (PwC, 2023), the US Steel and Shell signed a Cooperation Agreement to invest in the development of clean hydrogen hubs in multiple areas of the country (United States Steel, 2022). As governments begin initiating sustainable energy goals and policy using low-carbon hydrogen, countries that are industrialized but lack the natural resources to produce low-carbon hydrogen would need to import it to meet demands (Wakim, 2022). According to IRENA's projections, by 2050 approximately 25% of the world's green hydrogen will be exchanged between countries, a figure comparable to the current level of international trade in natural gas, which stands at 33% (IRENA, 2022)

In order for hydrogen to be a competitive fuel source, its cost must be reduced to $1 per 1 kilogram in line with the DOE's Hydrogen Energy Earthshot plan to make clean hydrogen affordable (The Electrochemical Society, 2021). To reduce the cost of clean hydrogen and reach the DOE’s goal of producing 50 MMT of clean hydrogen by 2050 (DOE, 2022) the US government has begun to stimulate the industry by investing in 15 carbon projects and allocating

$15 billion towards innovations in research and development to decarbonize hydrogen (Department of Energy, 2021).

Multiple sectors of the economy are testing applications for low-carbon hydrogen, with one of the most important sectors being commercial transportation. In the US, heavy and medium duty vehicles account for approximately 28% of GHG emissions in transportation. With commercial trucks anticipated to increase travel mileage by 60%, the US is motivated to shift to clean hydrogen and electric fuel cells to reduce petroleum consumption and emissions. Studies show that shifting to electric fuel cell trucks with onboard hydrogen storage would not significantly compromise performance as most vehicles can meet 90% of their daily route requirements in the US after switching (Kast et al., 2017).

The decarbonization of commercial shipping methods is a crucial aspect of achieving NZE goals, and while electrification may not be a viable solution, the use of low-carbon hydrogen as an alternative fuel source is emerging as a promising option, according to recent studies. Commercial shipping methods, such as maritime freight and air freight are not quick to electrify and will require the use of alternative fuels to meet NZE goals (Feldmann et al., 2023). Maritime shipping, which accounts for a quarter of all emissions from the global transportation sector, will rely heavily upon low-carbon hydrogen to decarbonize in the upcoming decades. Due to the relative ease of retrofitting ships with hydrogen fuel cells, approximately 99% of voyages between the United States and China could switch to hydrogen fuel soon (O'Neil and Reinsch, 2021). Barriers remain when using hydrogen as fuel source for commercial shipping; one of which being the need for innovative bunkering infrastructure for maritime shipping (Hoecke et al., 2021). Despite its drawbacks, low-carbon hydrogen is one of the leading alternative fuels for the shipping industry and will remain important to it and other sectors to decarbonize by the 2050 deadline.

The use of low-carbon hydrogen as an alternative fuel source is emerging as a promising option to achieve net-zero emissions (NZE) goals. US Steel and Shell have invested in the creation of clean hydrogen hubs across various regions in the United States. Furthermore, the US government has taken steps to promote the industry by investing in 15 decarbonizing hydrogen projects and committing $15 billion to research and development initiatives aimed at decarbonizing hydrogen. The use of low-carbon hydrogen as an alternative fuel source in the commercial transportation industry is emerging as a promising option, particularly in the maritime shipping sector. However, there are barriers to using hydrogen as a fuel source, one of which being the need for innovative bunkering infrastructure for maritime shipping.

2.4 Barriers of Low-Carbon Hydrogen

As low-carbon hydrogen is a new technology, its adoption faces many challenges. Regulatory, economic, technological, and infrastructural barriers hinder further adoption of low-carbon hydrogen technology. As previously mentioned, each country has their own set of policies surrounding the production, usage, and regulation of low-carbon hydrogen. As a result, to comply with a specific country’s regulations, low-carbon hydrogen producers may find themselves locked into selling to only certain regions.

The lack of a harmonized international standard for production and sustainability of green hydrogen leads to difficulties in selling across borders. Specific regions could only buy from producers who meet their carbon intensity standards, which could result in artificially higher prices (Sailer et al., 2022). IRENA’s 2020 *Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the* 1.5^{0}*C Climate Goal* report points out the difficulty of ensuring the entire process of green hydrogen is completely sustainable. For example, if the electricity used to produce hydrogen is sourced from fossil fuels, countries will categorize hydrogen differently (Bianco and Blanco, 2020). In extreme cases, many companies, such as Fusion-Fuel who want to ensure that their hydrogen is completely green, are pushed towards producing their own electricity through on-site solar power (Fusion-Fuel, 2021).

Beyond the lack of consistent international policies surrounding green hydrogen and the challenge that creating a universal standard would entail, the adoption of green hydrogen struggles to compete with fossil fuels. IRENA outlines a few additional obstacles in their *2020 Guide to Policy Making Report*, one of which is the high production cost. Bianco and Blanco (2020) found that hydrogen fuel cells can be 1.5 to 2 times more expensive than their fossil fuel counterparts and the production of synthetic fuel with hydrogen is 8 times higher than fossil jet fuels. This expense may be a strong deterrent to nations who lack financial resources to dedicate to a technology that is still in development regardless of the long-term benefits. Without the policy support and the current cost, low-carbon hydrogen is barely an economically viable fuel source. In Jovan and Dolanc's (2020) analysis of green hydrogen's economic viability, they found that green hydrogen struggles to compete with the cost of fossil fuels in many sectors, which include the industries in heat generation and heat stock.

However, there is a growing niche for green hydrogen in the transportation market. Within the Solvanian market, Jovan and Dolanc (2020) found that if green hydrogen fuel were excluded from taxes, it could be a cheaper alternative for transportation than Euro-super 95 and diesel. Although low-carbon hydrogen was cheaper than the mentioned fuels, that price was only possible by excluding the value-added tax, meaning that significant incentives are needed for low-carbon hydrogen to be viable. Efforts can be made to convert natural gas infrastructure to be functioning hydrogen-based ones, but inadequate changes can lead to leakage and losses of yield.

Hydrogen has a short-term warming effect of a few decades that could contribute to climate change if the small particles are handled improperly and allowed to escape (Ocko and Hamburg, 2022). This leakage leads to the release of unintended emissions into the atmosphere which reduces the overall impact of switching from fossil fuels to low-carbon hydrogen to cutting CO_2 emissions by half. Therefore, Ocko and Hamburg have proposed that the best plan of action for hydrogen consumption offsets is to build infrastructure with anti-leakage measures and start tracking the warming effect of gases that also have a short and medium term impact. To realize the full benefits of green hydrogen, countries and companies must invest into dedicated infrastructure and innovation.

Low-carbon hydrogen technology faces various challenges in terms of regulatory, economic, technological, and infrastructural barriers. Each country's policies for the production, usage, and regulation of low-carbon hydrogen make it difficult for energy producers to sell across borders, and the lack of consistent international policies and a universal standard for production or sustainability poses difficulty in ensuring the entire process of green hydrogen is sustainable. Moreover, high production costs and lack of infrastructure make it harder for green hydrogen to compete with other fuel sources. Despite green hydrogen being cheaper in some cases, it requires significant incentives to be viable. Furthermore, hydrogen has a short-term warming effect that could contribute to climate change if not handled properly. Thus, investing in dedicated infrastructure and innovation is necessary to realize the full benefits of green hydrogen.

2.5 Taiwan's Current Energy Overview

2.5.1 Taiwan's Energy Usage and Production

Taiwan's demand for energy continues to grow while its domestic resources remain limited. Around 98% of its energy is imported and the remaining 2% is produced domestically (Bureau of Energy, 2022). Taiwan heavily relies on imported crude oil, coal, and natural gas to meet their energy needs, with their main trading partners being Saudi Arabia and Australia for oil and natural gas and coal respectively (Bureau of Energy, 2022). Industrial products are the main focus of their economy with around 51% of their exports being integrated circuits and other electronics (Observatory of Economic Complexity, 2020). Figure 2.7, exhibits Taiwan's industrial sector, in which they consume 62.3% of their total energy (Bureau of Energy, 2022).

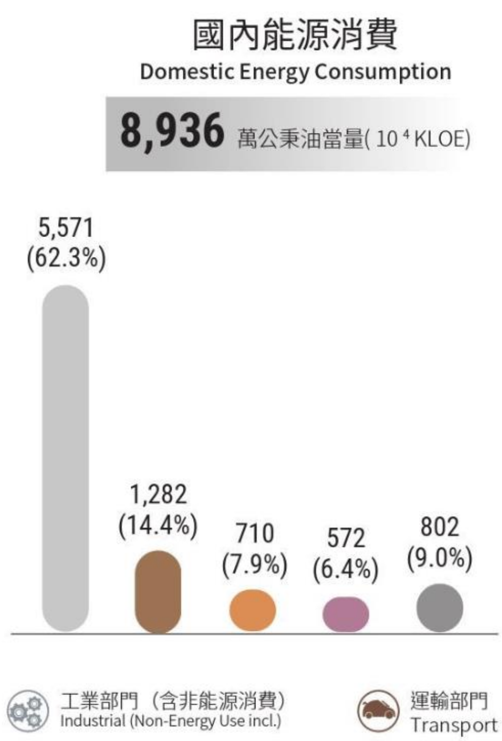


Figure 2.7: Domestic Energy Consumption by Sector (Bureau of Energy, 2022).

Also seen in Figure 2.8, growing from 4.8% in 2016, only 6% of Taiwan's electricity came from renewable energy sources in 2021. Although there has been a slight increase in the use of renewable energy, the majority of their electricity is still generated from coal and natural gas, which contributes to GHG emissions. Taiwan is currently highly dependent on imported, unsustainable energy, but it has implemented policies to encourage the importation and domestic production of more renewable energies in an effort to reach NZE by 2050.

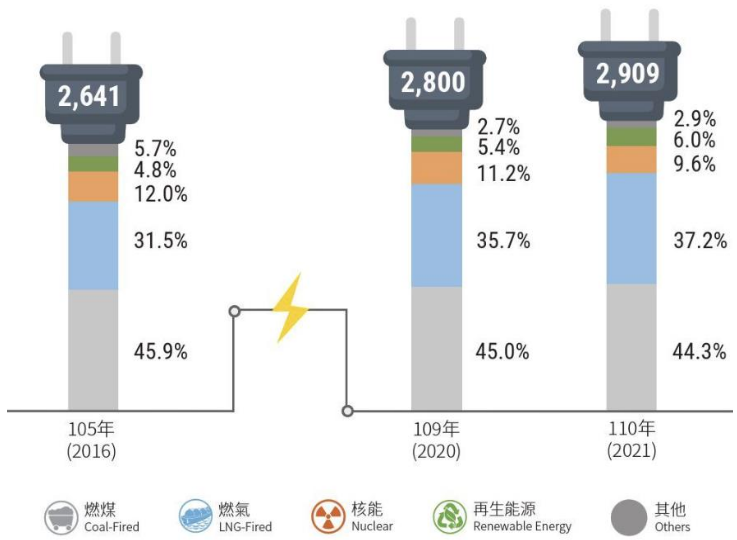


Figure 2.8: Total Electricity Generation by Type (Bureau of Energy, 2021).

2.5.2 Promoting Renewable Energy in Taiwan

In Taiwan, there are several key government agencies, private companies, and research institutions that are actively promoting the use and development of renewable energy. The Bureau of Energy (BOE), a subsection of the Ministry of Economic Affairs, has set a goal to reach NZE by 2050 with renewable energies comprising 60-70% of electricity generation (Bureau of Energy, 2023). The BOE is responsible for implementing policies and regulations to encourage investment in renewable energy projects. For example, they have created tax incentives for companies to invest in renewable energy, subsidies for equipment purchases for renewable energy projects, and the Feed-in Tariff (FiT) Program which provides a fixed payment to renewable energy producers for every unit of electricity they generate (Bureau of Energy, March 2022).

Multiple organizations under the Taiwanese government have collaborated to develop a roadmap called the Phased Goals and Actions Toward Net-Zero Transition, current as of Dec 28, 2022, which outlines 12 Key Strategies for achieving net-zero emissions in Taiwan by 2050. At the Net-Zero City Conference held on March 29, 2023, our team obtained a draft document from the Bureau of Energy detailing Key Strategy #2, the Hydrogen Strategy. This document discusses the short-term plans from 2023 to 2030 for using hydrogen in various sectors such as power generation, steelmaking, and hydrogen vehicle demonstrations. Spanning the years from 2031 to 2050, Taiwan plans to generate 9-12% of power from hydrogen, to create more H_2 based industry manufacturing processes, and pass regulations for hydrogen vehicles. Additionally, the Bureau of Energy plans to collaborate with other countries to create a hydrogen supply chain and evaluate details of hydrogen importation, such as the safety evaluation of liquefied H2 infrastructures, tanks, and pipelines. To oversee these developments, the Ministry of Economic Affairs (MOEA) has established the Hydrogen Energy Promotion Taskforce consisting of 7 government entities with different focuses on developing hydrogen energy. The plan aims to enhance R&D capabilities, establish regulations, collaborate with foreign countries for hydrogen supply, and strengthen technical expertise. It emphasizes using hydrogen-blending co-combustion for power generation and low-carbonization in industrial manufacturing. The plan includes short-term, medium-term, and long-term goals for hydrogen supply, such as domestic gray hydrogen production, hydrogen importation, and gradually transitioning to domestically produced hydrogen. Infrastructure construction will be evaluated in alignment with the hydrogen supply and application field.

Many private industrial companies have also invested in renewable energies to take advantage of financial benefits from the BOE. One of the key research institutions paving the way for technical advancements in renewable energy is the Industrial Technology Research Institute (ITRI), a non-profit research institute which has developed technologies for solar power, wind power, and energy management systems. They also work closely with the government to plan policies encouraging renewable energy in the industrial sector (ITRI, 2022). The Taiwan Semiconductor Manufacturing Company (TSMC) has committed to using 100% renewable energy by the end of 2050 and has purchased many long-term renewable energy purchase contracts, renewable energy certificates, and carbon credits to help prompt renewable energy in Taiwan's industrial sector (Line and Sun, 2020). The Taiwan Renewable Energy Certification Center (T-REC) is the government entity responsible for issuing renewable energy certificates for companies that use wind, solar, geothermal, biomass and hydro power. They are currently developing a certification system for sourcing low-carbon hydrogen energy, which is where our research with TIER will be applied. Another one of Taiwan's main policies involving low-carbon hydrogen energy is The Energy Transition Promotion Scheme by the Ministry of Economic Affairs which outlines goals to set a target of 20% renewable energy generation by 2025, increase natural gas usage, reduce coal generated electricity, and stop the use of nuclear energy (Ministry of Economic Affairs, 2023). Taiwan has also developed many key international partnerships with Japan, South Korea, the US, and Australia to share knowledge and expertise in the development of low carbon hydrogen energy technologies.

Low-carbon hydrogen technology faces various challenges such as regulatory, economic, and technological barriers. The lack of consistent international policies and the high production cost are some of the major obstacles to the adoption of green hydrogen. Without policy support and cost efficiency, low-carbon hydrogen is not an economically viable fuel source. Taiwan's energy demand heavily relies on imported crude oil, coal, and natural gas, with renewable energy sources contributing only 6% of their total electricity generation in 2021. The country has implemented policies to reach NZE by 2050 and various agencies, private companies, and research institutions are promoting the use and development of renewable energy. Renewable hydrogen is still an emerging technology, but its potential as a low-carbon and sustainable energy source is rapidly gaining attention worldwide. Taiwan is making significant progress in developing strategies to use hydrogen as a low-carbon and sustainable energy source. By investing early on in the development of renewable hydrogen technology, Taiwan has the potential to decarbonize its economy in the future and play a significant role in global efforts to reduce greenhouse gas emissions.

3.0 Methodology

The goal of this project was to analyze policy on the certification of low-carbon hydrogen production in the United States and Canada to assist the Taiwan Institute of Economic Research (TIER) in creating policy to certify the low-carbon hydrogen production and to stimulate the low-carbon industry. To achieve this goal, the following objectives were set:

(1) Understand the US and Canada's current clean hydrogen policies and what certification systems exist for tracing the origin of clean hydrogen.

(2) Analyze the potential applications for clean hydrogen based on policy goals in the US and Canada.

To achieve our goal, we met these two objectives by conducting archival research from sources such as governmental agencies and peer-reviewed journals, reviews of current press reports, and conducting semi-standardized interviews with government officials, leaders in industry, and academic scholars. By gathering data from different sources, we triangulated, or confirmed the validity of our data, to increase the confidence of our conclusions and reduce possible error (Berg & Lune, 2017, Ch. 8.1). The gathered data gave high credibility to the motivations, roadmaps, and market demands of clean hydrogen in the US and Canada.

Although we considered conducting surveys as they are a common and quick method to obtain data, they are not reliable. Oftentimes surveys are voluntary and require a strategic set of questions that ensure participants answer each question to the fullest extent (Berg & Lune, 2017, Ch. 4.5). A benefit of questionnaire surveys is that they are easy to distribute and far-reaching, but the response rate is relatively low as participation is entirely optional. Moreover, subjects may not have time or see any benefit to participating in our study. The previous team sponsored by TIER organized and conducted surveys; Gong et al. (2022) received a low response rate of 8.18% out of the 98 individuals contacted for their investigation into stakeholders of the US Carbon Offset Market. They were not able to collect enough data to perform any substantial analysis. Considering the limitations of surveys, our team believed that in order to collect a larger quantity of data our time and efforts were better allocated elsewhere. Thus, we focused on creating well-detailed questions to be asked during our semi-standardized interviews.

3.1 Archival Research

Our team investigated the existing research surrounding low-carbon hydrogen, including its production, efficiency, possible uses, and the current policies and roadmaps created by governmental bodies. We used the method of archival research to gain an understanding of the different stances on clean hydrogen in the US and Canada and the forecasted development of the market to guide Taiwan in the creation of a certification process for low-carbon hydrogen.

3.1.1 Scholarly Papers

As the process of synthesizing low-carbon hydrogen becomes more efficient, multiple applications have been proposed. One of our primary methods to learn more about low-carbon hydrogen was to read peer-reviewed research papers on three of the following topics: the synthesis, efficiency, and potential market demand of low-carbon hydrogen.

To be effective in our research, we read and summarized multiple sources for each of the topics above to produce a more accurate view on the topic. As the research that discusses the applications of low-carbon hydrogen as a fuel source and by extension its efficiency is relatively novel, we found multiple peer-reviewed papers on the same topic to confirm credibility. It was important that we triangulated our sources to reduce selection bias in our research. For the data we collected, we categorized and summarized it, through the use of diagrams and tables, to draw our own conclusions.

Although research papers helped us understand low-carbon hydrogen from a technical perspective, they could not help us in every avenue. There was the possibility that the research we needed had not been conducted and reviewed yet, so we needed to pivot from the discussion of certain end-applications of low-carbon hydrogen. We proceeded to investigate the political state of low-carbon hydrogen to learn about the developing incentives for market adoption and the certifications passed to verify its quality of origin.

3.1.2 Government Publications

Reading existing policy through the United States' and Canada's government publications provided an understanding of the current regulatory framework surrounding hydrogen energy. In addition to reviewing the documents, the team took notes to be used for reference. Our policy research concentrated on two primary areas; first, the methods used by the US and Canada to verify the origin of renewable hydrogen and second, the policies that encourage companies to establish infrastructure for the production of and technology for the use of hydrogen. These policies are public records that contain official primary information from knowledgeable organizations that "often convey important and useful information that a researcher can effectively use as data" (Berg & Lune, 2017, Ch. 8.1).

By reviewing US and Canadian public policy, we gained insight into the approaches that have worked well and what has not. This research was used to inform TIER about policies regarding low-carbon hydrogen in the US and Canada to identify potential best practices for the production and importation of low-carbon hydrogen in Taiwan. Additionally, reading existing policies from other countries provided insight into the broader global trends and developments in low-carbon hydrogen energy which can help shape more comprehensive and forward-looking policy in Taiwan.

Our team was invited to attend the 2023 Net Zero City Exposition at the Taipei Nangang Exhibition Center on March 29, 2023 to understand Taiwan's current projects and progress on transitioning to sustainable energy. The booths that were visited were Taiwan's Green Trade, Bureau of Energy, Ministry of Economic Affairs, and the Taiwan External Trade Development. At these booths, governmental official documents were gathered on the strategies, roadmaps, and developing policies on the transition to low-carbon hydrogen. The information was then used to aid in background research for the literature review, as well as to help our group understand the current situation of low-carbon hydrogen in Taiwan so we can identify the most relevant findings from the US and Canada to share with TIER.

3.1.3 Press Reports

As low-carbon hydrogen is part of an emerging market, it is important to stay up to date with current events to gain a better understanding of the sector as a whole. To achieve this goal, our research process involved reading and analyzing newspaper articles, publications in energy industry journals, and websites specializing in news on energy. Using press reports, we collected data on recently announced policy proposals, progressing projects, and opinion pieces published by key business stakeholders. Press reports were used to identify patterns and trends in the low-carbon hydrogen market. By looking at multiple sources, we were able to fill any knowledge gaps in coverage and find inconsistencies in our archival research. Current reporting also has the advantage of being up to date. Examples of our sources were well-trusted news organizations such as the New York Times, Wall-Street Journal, and Bloomberg, as well as more energy-focused publications such as the Clean Energy Wire (CLEW) and the Hydrogen Fuel News website. The information from these press reports were cross-referenced with our archival research to raise the credibility of our work and strengthen our conclusions.

Since press reports were a secondary source of gathered information, they were less reliable than other methods of research. They were written by "people [or corporations] with obvious and unreliable prejudices" who were "... 'cleaning' the record against future examination" (Berg and Lune, 2017, Ch. 8.4). The reliability of reports was limited because press reports generally tend to be broad and vague. They are at high risk for bias as a consequence of personal or corporate interest and lack scrutiny due to absence of peer-review in the publication process. While reviewing reports, the team considered how and in what way the author was trying to influence the reader and remained cautious not to use unverified arguments as a basis for our research.

3.1.4 Roadmaps in the US and Canada

Roadmaps provided a clear and concise overview of the goals, timelines, and steps required to achieve a specific objective. They are often created through collaboration with a wide range of stakeholders from various industries working towards a common goal. By analyzing roadmaps on hydrogen energy from the US and Canada, we gained insight into market developments and future policy proposals, as well as any barriers that needed to be addressed. The potential challenges that low-carbon hydrogen energy may face are technical, economic, regulatory, or societal in nature, and roadmaps took many of these possibilities into consideration. Furthermore, roadmaps track the progress and implementation of renewable hydrogen energy policy over time, which provides valuable data for comparative analysis and evaluating the effectiveness of policy implementation.

Roadmaps are also public archives that were easy for our team to access and provided "large quantities of inexpensive data" with the benefit that "archival material is virtually nonreactive to the presence of investigators" (Berg & Lune, 2017, Ch. 8.1). Another benefit of utilizing this type of archival data was that this information is meant to be shared and widely spread by the public to increase the awareness of renewable hydrogen energy.

3.1.5 Limitations of Archival Research

One major drawback to archival research was limited information, as existing documents may not always provide a complete explanation of the current state of clean hydrogen in the US and Canada. Furthermore, when examining how policy from the US and Canada can be applied to Taiwan, we acknowledged that some policies and systems were not directly applicable due to differences in geography, culture, and economic and political structures.

It was understood that some existing documents were outdated, particularly in newly or rapidly developing sectors like the low-carbon hydrogen landscape. Furthermore, reading the preexisting journals was a time-consuming process, especially when considering policies that tend to be lengthy or complex.

Archival research is subject to selection bias, "occurring when the nonrandom selection of cases results in inferences, based on the resulting sample, which are not statistically representative of the population" (Lustick, 1996). To combat selection bias, we triangulated our research by finding multiple sources from archival research, press reports, and interviews, to gather varying perspectives on each topic that increased the credibility of our conclusions. There was a possibility that "archives may be the wrong source of data for some other questions" (Berg & Lune, 2017, Ch. 8), for we could not ask our own questions to experts using archival research like we did during interviews or stay up-to-date on developing projects as we can with press reports. The sources we required to answer our questions were not published yet, so we used additional methods outside of archival research to collect data.

3.2 Interviews

To gain first-hand accounts from experts on low-carbon hydrogen, our team aimed to conduct semi-standardized interviews with subjects from three groups of interest: governmental agencies, industry leaders, and academics. Government agencies provided insight on what industry sectors the government wants to incentivize low-carbon energy usage in and to what extent policy accelerated its adoption. Industry leaders provided feedback on how policy affects business operations and their perspective on the future of the low-carbon hydrogen industry. From academics, we derived information on their specific field of expertise and obtained more technical knowledge on low-carbon hydrogen developments.

The following is a list of key players from each group identified: governmental agencies including the DOE and Natural Resources Canada (NRCan); industrial leaders from Fuel Cell Energy, Bakken Energy, Air Liquide, etc.; and academics sourced from the articles we reviewed and from professors at Worcester Polytechnic Institute and other accredited universities. The three groups identified play a significant role in the low-carbon hydrogen industry and by gathering these differing perspectives, we gained a more balanced and nuanced view on the low-carbon hydrogen sector.

Interviews filled knowledge gaps left by archival research and reinforced our findings. Although they may have come from the same area of expertise and held similar opinions, these individuals performed differently during interviews and provided different narratives, thereby giving us greater insights. Semi-standardized interviews also allowed us to gather richer data about each group working with low-carbon hydrogen, as we asked specific questions based on their specialty. Berg and Lune (2017, Ch. 4.3) specifically mentioned that interviews give us a glimpse into how people think.

3.2.1 Data Collection for Interviews

In order to find and interview subjects from the groups identified above, we used a combination of searching through websites from governmental agencies, databases of ongoing low-carbon hydrogen projects, online networking websites such as LinkedIn and contacting authors of relevant papers. The targeted interviewees were contacted via email utilizing the email template in Appendix A.1, and if they chose to participate in our study, then they were responded with an email outlined in Appendix A.2. If the interviewee was only able to be contacted on LinkedIn, Appendix B outlined the message template that was sent. Once the interviewees were contacted and accepted the interview request, we coordinated a time with the interviewee to meet. Potential interviewees were contacted from week one to week four, and two follow up emails were sent, Appendix A.3, one week after the previous email if no response was received. Seventy-five individuals were contacted, and Appendix C lists all of the individuals who accepted our interview requests.

Since we were in Taiwan, we were unable to hold any in-person interviews. As a result, all communication was set in the interviewees' time zones for their convenience and the interviews themselves were conducted virtually via Zoom. Before we began the interview, the interviewee reviewed the consent form, seen in Appendix D, which permitted us to use their words as data for the study.

Appendix E, F, and G outlined sample guided interview questions that were directed to the three different types of individuals we wished to interview. Since our interviews were semi-standardized, not all of the questions were always asked. As more information was understood, more valuable questions were spontaneously asked amidst the interview, and questions may be revised in between interviews. Appendix H outlines the specific questions that were asked to each interviewee.

Interviewees were able to end the interview at any time for any reason. While conducting interviews, we recorded the whole session, via video and audio recording and took notes on any comments we found particularly intriguing or insightful. We also used external webcams and microphones to ensure our interviews were of a high transmission quality. At the conclusion of the project, all videos were deleted to protect the privacy of our interviewees.

While conducting all our interviews, we followed Berg and Lune's (2017, Ch. 4.5) suggestions on interviewing to ensure that the interviewee was respected. We set an environment for the interview by asking a non-topic specific question before the interview began. In Berg and Lune's (2017, Ch. 4.5) *Qualitative Research Methods for the Social Sciences*, "this [setting the environment for a conducive interview] can be accomplished by reducing many of the responses to either affirmative (yes), negative (no), no clear response (unclear), or a very brief excerpt (no more than one sentence)". In other words, the interview was structured with open-ended questions throughout, allowing for extensive elaboration from the interviewee for each question.

Diving into the purpose of the interview, the interviewees were asked specific questions based on their current position, prior qualifications, and assumed knowledge through background research that was conducted on each interview subject prior to the interview date. As we were planning to interview subjects from government agencies, industry, and academia, we asked them questions in regard to the promotion of sustainable energy, market barriers under current and developing legislation, the advancement of low-carbon hydrogen technology, and in what ways sustainable forms of energy were being used. At the end of the interview, we asked for any suggestions for additional sources and interview subjects whom they could connect us with.

3.2.2 Data Analysis for Interviews

The data collected from interviews was triangulated with information from archival research. Berg and Lune (2017, Ch. 4.16) have identified that "answers like these will not offer much information during analysis," "these" referring to monosyllabic responses such as *yes* or *no*. Therefore, the responses collected will allow for the collection of more in-depth data since we asked open-ended questions. The data that was analyzed were the video recordings and real-time notes from the interviews.

With the data gathered from different governmental agencies, industry leaders, and academics, we conducted a content analysis: one of the most useful methods of qualitative data analysis, suggested by Berg and Lune (2017, Ch. 4.16). Firstly, the collected data was tagged to generalize the type of information we received. Second, this information was categorized into generalized groups to allow for the sorting of information in an organized manner. The data was inputted into a spreadsheet program, such as Microsoft Excel or Google Sheets. We further analyzed the data by identifying patterns in the opinions on sustainable energy policies, production, and uses. Ultimately, we represented the data through tables and graphs comparing different subjects' opinions on low-carbon hydrogen. As there was no clear international definition on the type of hydrogen that is classified under "clean", we created a table on how each region defined "clean hydrogen". We also visualized the market sectors that are best suited for making the transition to low-carbon hydrogen using diagrams and maps.

3.2.3 Limitations of Interviews

Multiple limitations arose during the gathering of data through interviewing. The interview process required significant time and effort and due to added difficulty in connecting with high officials from government agencies and companies or with academics with limited time, this challenge was exacerbated. In addition to the time constraints of our project, the typical response rate for interviews was predicted to be low. Industry leaders were especially hard to connect with, due to some hesitancy with breaching their company's non-disclosure agreements. As seen with the previous IQP group's project sponsored by TIER, they received a response rate of 16% from a contact pool of 56 interviewees (Gong et al., 2022). Thus, we anticipated that the response rate for our interviews would not be high, and it was important that the interviews we conducted were thorough and productive.

In general, interviews do not provide an objective view of the subject; it only gave a single perspective that the interviewee themselves shared on low-carbon hydrogen. Consequently, responses were biased as interviewees could only provide us with information that they were privy to and that suited their best interests (Berg & Lune, 2017, Ch. 4.18). The challenge was to effectively incorporate interviewees' opinions on low-carbon hydrogen despite their potential bias towards a particular position as their opinions may lean heavily in favor of one position or another without supporting evidence.

Another significant challenge we encountered was the inability to gather all the pertinent information from interviewees due to their reluctance to disclose certain details. Especially since we planned to record our interviews, some individuals did not feel comfortable enough to share specific information that could have been beneficial to our research (Berg & Lune, 2017, Ch.

4.18). As interviewers, we tried our best to foster an environment in which the subject could feel comfortable enough to divulge sensitive information on low-carbon hydrogen.

3.3 Final Deliverables

We were able to meet the goals of this project in its limited time span through an organized Gantt Chart, seen in Appendix I. It outlined the timeline and length of each task to complete during our stay in Taiwan. The necessary tasks were identified into five categories: Archival Research, Interviews, Data Analysis, Check-Ins, and Report. Weekly meetings with TIER's liaison, Jean Yi-Chun Hsieh, and her team were scheduled to give updates on reports and progress on our findings, and bi-weekly meetings with Dr. Yenhwa Chen were scheduled for formal presentations. All meetings with TIER were collaborative and conversational, where feedback was given to the team to improve our work for the next week. The schedule of the Gantt Chart was thoroughly followed, as it was the best method for our group to be sure that tasks were completed on time.

Our final deliverable to TIER was a series of reports that entailed the statuses of clean hydrogen progress in the US and Canada, in which the information was gathered through archival research of scholarly papers, governmental documents, press reports, and interviews. A general report of the US and Canada was made, followed by four regions in each country: California, Texas, Hawaii, and Colorado in the US, and Alberta, Ontario, British Columbia, and Quebec in Canada. These regions were selected based on their demonstrated commitment to low-carbon hydrogen development, as evidenced by their public policies, roadmaps, and current demonstration projects for low-carbon hydrogen. These reports included the market trends, regulations, policies, and projects for low-carbon and green hydrogen in each region and were given during each weekly sponsor meeting and were summarized in a final presentation. Any external resources were cited throughout each report. The following final regional reports can be found in Appendix J. All the reports and their additional resources were compiled in a Google Drive folder.

4.0 Results

The team observed the policies and market demands in the United States and Canada and selected four regions in each country to conduct research and construct detailed reports: California, Colorado, Hawaii, and Texas in the US, and Alberta, British Columbia, Ontario, and Québec in Canada. The following section contains the findings from our research for each country and region in addition to our interviews that were conducted.

4.1 Archival Results

Most of the archival results came from government roadmaps with some policies found on the government's websites. Most policies found were published recently, being passed within the last 3 years, with the exception of Hawaii and California who started their hydrogen investment early, so the effectiveness of most policies is still unknown. Many regions still lack hydrogen specific policies but have clean energy policies that may apply to hydrogen. Some regions have highlighted policies around renewable electricity that can contribute to the production of green hydrogen. Any relevant information pertaining to hydrogen or renewable electricity that could be used to produce hydrogen were recorded in reports that are found in Appendix J.

4.1.1 United States Results

In the United States, most policies at the federal level targeting clean hydrogen are still in development or were only passed in the last two years. The push to speed-up the adoption of clean hydrogen began in November 2021 with the passing of the Bipartisan Infrastructure Law that created the initiative for the regional hubs. Following the BIL, the Inflation Reduction Act was passed which created a production tax credit for clean hydrogen which gives tax credit per kg of hydrogen produced back to companies depending on the quantity CO_2e produced. Lastly, was the US DOE National Clean Hydrogen Strategy and Roadmap which established three goals in the US: funding clean hydrogen projects, HydrogenShot (reducing cost of hydrogen to $1 per kg) and the development of hydrogen hubs.

The clean hydrogen definition was set by the US DOE in past policies and in the proposed Clean Hydrogen Production Standard (CHPS) draft. It is defined as hydrogen produced with an amount equal to or under 4.0 CO_2e life cycle emissions as counted by the US GREET model produced by the Argonne Lab. CHPS is an emissions-based regulation that acts as a guideline for the DOE's when choosing hydrogen projects to fund and is subject to change. Currently, there is no guarantee of origin (GO) scheme in the United States, however, it is possible that the US will adopt CertifHy, a scheme used by the European Union to certify renewable hydrogen. Recently, the federal government's action towards decarbonizing hydrogen has been significant, with the DOE allocating over $7 billion dollars in funding for hydrogen hubs alone, in addition to other hydrogen decarbonization projects. This investment provides a crucial foundation for supporting the implementation of new policies at the state level, as well as reinforcing existing ones, in order to facilitate the transition towards clean hydrogen.

Table 4.1: A comparison of US federal and state policy.

	FEDERAL U.S.	CALIFORNIA	COLORADO	HAWAII	TEXAS
GUARANTEE OF ORIGIN	No GO scheme	Low Carbon Fuel Standard (LCFS)	No GO scheme	No GO scheme	No GO scheme
EMISSION STANDARDS	Clean Hydrogen Production Standard (CHPS) draft	Follows CHPS		Follows CHPS	
HYDROGEN FUEL		Hydrogen Strategy Act of 2021		Hawaii Renewable Hydrogen Program 2006	
HYDROGEN FUEL CELL VEHICLES		Requirement, Rebate, Grant, Program	Grant, Loans, Rebates	License Tax, Fee, Rebate, Requirement, Program	Incentives. Grant,
INDUSTRY		Scoping Plan 2022			Alternative Fueling Facilities Program,
INFRASTRUCTURE		The Energy and Climate Change Budget Bill			
RESEARCH & INVESTING	National Clean Hydrogen Strategy and Roadmap	The Energy and Climate Change Budget Bill	Colorado Hydrogen Plan Roadmap	Hydrogen Investment Capital Special Fund 2006	
TAX CREDITS	Production Tax Credit (IRA) 2022		Zero Emission Vehicle Tax Credits		
ELECTRICITY				Renewable Portfolio Standard	Renewable Portfolio Standard, Renewable Energy Credit
HYDROGEN HUB	DOE Funds Hydrogen Hubs	Applied	Applied	Applied	Applied

California

In California, early efforts to accelerate the adoption of hydrogen fuel have been focused primarily on alternative fuel vehicles (AFV) and zero-emission vehicles (ZEV) which includes fuel cell electric vehicles (FCEV) that are powered by hydrogen. To incentivize the adoption of FCEVs, California has passed multiple policies and created programs. Included in these policies are rebates for ZEV parts, requirements for states to acquire ZEVs, grants to build fueling and parking infrastructure. These efforts have helped California become the state with the leading number of ZEVs and FCEVs.

In terms of a guarantee of origin scheme, California has the Low Carbon Fuel Standard (LCFS). LCFS is a comprehensive program that includes a certification process for the production of clean hydrogen, a requirement for transportation producers and importers to reduce carbon intensity of their fuels, and a tradable certificate system. The tradable certificate system allows clean hydrogen producers to apply for credits equivalent to a reduction of 1 metric ton of CO_2e. Tradable certificates can then be sold to companies obligated to meet carbon intensity reduction goals. This approach allows the market to set the cost of renewable energy while simultaneously creating a baseline demand for it.

In addition to the LCFS, California has also been stimulating the industry for clean hydrogen through the Energy and Climate Change Budget bill and Scoping Plan of 2022. The Energy and Climate Change Budget bill creates the fund for projects that focus on the production, transportation, storage, and use of clean hydrogen. Combining funding for projects with the Scoping Plan of 2022, which sets clean hydrogen usage requirements by industry, and the Hydrogen Hub they plan to build, California has set itself up to adopting hydrogen into its net-zero goals. Refer to Appendix J.2 for the full report.

Colorado

Colorado is focused on developing hydrogen for transportation, with a plan to reduce greenhouse gas emissions by 26% by 2025, 50% by 2030, and 90% by 2050. The state's energy office has released a low-carbon hydrogen roadmap, identifying hydrogen as a key fuel for reducing emissions in hard-to-electrify sectors beyond 2030. The Colorado Hydrogen Network is a non-profit, membership-based hydrogen advocacy organization that promotes the environmental and economic benefits of hydrogen and fuel cell technology. The Colorado Department of Revenue provides forms for registering motor vehicles with spaces for reporting the use of alternative fuels, while the Colorado Department of Public Health and Environment can issue grants, loans, and rebates through the Clean Fleet Enterprise to help businesses and government entities replace their fleet vehicles with clean vehicles. NREL's Hydrogen Infrastructure Testing and Research Facility in Golden, Colorado, develops, quantifies performance of, and improves renewable hydrogen production methods. Refer to Appendix J.3 for the full report.

Hawaii

Hawaii is a state heavily reliant on importing fossil fuel to power itself. To reduce reliance on fossil fuels to reduce cost of energy in the long term and meet net–zero goals, Hawaii has invested in clean hydrogen. *Hawaii began investing in clean hydrogen in 2006* with the creation of the Hawaii Renewable Hydrogen Program and the Hydrogen Investment Capital Special Fund. The Hawaii Renewable Hydrogen Program was a comprehensive plan spanning from 2010-2020 that had two priorities: building up the renewable energy grid and hydrogen infrastructure. Focusing on improving the renewable electricity grid allows Hawaii to reduce the cost of clean hydrogen in the future. The second goal is to support infrastructure so hydrogen can be produced, transported and stored. In addition, the fund provided seed funding to start-ups and venture capital to companies researching and developing clean hydrogen.

Like California, Hawaii has invested in AFVs and ZEVs, including funding fueling infrastructure and adding vehicle acquisition requirements for governmental agencies. Hawaii is also a part of the multi-state medium- and heavy-duty ZEV action plan. Although Hawaii has invested into AFVs and ZEVs, it is not as extensive as California's plan.

Hawaii has no guarantee of the origin scheme for hydrogen. Its definition of clean hydrogen is hydrogen produced renewable electricity and biomass. Set emission standards are not clear, but it is likely that Hawaii will follow the CHPS set by the US DOE as Hawaii has sought funding from the federal government for both research projects and hydrogen hub. Although they have no formal GO scheme, Hawaii has made significant efforts to increase its production and usage of renewable energy. The Renewable Portfolio Standard (RPS) of 2008 set minimum sale percentages an energy producer must sell of renewable energy every year. This minimum percentage increases every five years and ends in 2045 when 100% of energy sold will be renewable. By reducing the cost of renewable electricity and increasing funding for clean hydrogen, Hawaii is setting itself up to reduce both costs and environmental impact in the upcoming decades. Refer to Appendix J.4 for the full report.

Texas

Texas has been projected to contain one of the world's largest green hydrogen hubs as they have goals to reach 50% of renewable energy generation by 2030 which includes green hydrogen production through the federal Renewable Portfolio Standard (RPS). Similar to other regions in the US, Texas is starting their energy transition to renewables with hydrogen fuel cell vehicles and this effort is also supported by the Texas Emission Reduction Plan (TERP) that provides incentives to push for more clean technology. The Center for Houston's Future's report, "Houston as the epicenter of a global clean hydrogen hub", has projected that Texas may have the ability to meet the Department of Energy's goal of $1 per kilogram of hydrogen with its potential for carbon capture storage (CCS) which forecasts strong possibility for Texas to own a hydrogen hub in the near future. Several projects have already been announced to develop a green hydrogen hub in Brownsville, Texas and a green hydrogen production facility in Wilbarger County, Texas. Texas' programs such as the Renewable Energy Credit (REC) program and Alternative Fueling Facilities Program (AFFP) set goals and to drive motivation for the transition to renewable energy, however, there exists no certification system or guarantee of origin scheme for the import of hydrogen. Refer to Appendix J.5 for the full report.

4.1.2 Canada Results

Canada has its sights set on becoming a leader in exporting clean hydrogen, as a means to create jobs and expand their market influence. Due to the amount of and variety of resources available to them, Canada has many means of hydrogen production which results in their regulations focusing on limiting the emissions of hydrogen production instead of making all green hydrogen. They are dedicated to making their energy system cleaner through the production of clean hydrogen. Canada has been looking at Europe and California as inspiration for their own strategy, adopting the EU's CertifHy emission standard as their definition of low-carbon hydrogen which is set to 36.4 gCO_2e/MJ as of 2020, but there has yet to be a guarantee of origin scheme.

Although Canada has started to create a hydrogen strategy, policies are still limited, and technology is still developing. To encourage the energy transition, Canada has created multiple funds, such as the Clean Energy Fund and the Net Zero Accelerator fund, to support the research and infrastructure investment of hydrogen projects. Inspired by the US' inflation reduction act, Canada has also created a tax credit system to support the adoption of low-carbon hydrogen with the goal to phase out the credits by 2030. As a starting point to focus on, Canada looks to eliminate much of the emissions from transportation through the use of hydrogen. Many of the medium and heavy-duty vehicles that cannot easily be electrified will be replaced with vehicles made with hydrogen fuel cells. More details about funds and regulations can be found in the full report in Appendix J.6.

Table 4.2 A comparison of the Canada federal and provinces policy.

	FEDERAL CANADA	**ALBERTA**	**BRITISH COLUMBIA**	**ONTARIO**	**QUÉBEC**
GUARANTEE OF ORIGIN	No GO scheme	No GO scheme	No GO scheme	No GO scheme	Green Hydrogen and Bioenergy Strategy
EMISSION STANDARDS	CertifHy				
HYDROGEN FUEL	Clean Fuel Standard		Low Carbon Fuel Source Regulations (LCFS)	Clean Energy Credits (CECs)	
HYDROGEN FUEL CELL VEHICLES			Zero Emission Vehicles Act, Greenhouse Gas Reduction Regulation (GGRR)		
INDUSTRY	Clean Energy Fund		Clean Industry and Innovation Rate		
INFRASTRUCTURE	Net Zero Accelerator Fund	Alberta Energy Regulator			Recyclage Carbone Varennes Project
RESEARCH & INVESTING	Hydrogen Roadmap	Alberta Hydrogen Roadmap	British Columbia Hydrogen Road Map	Ontario Hydrogen Road Map	Hydro-Québec Strategic Plan
TAX CREDITS	Hydrogen Tax Credit				
ELECTRICITY			Clean Grid	Clean Grid	

Alberta

Alberta has gained recognition for its vast reserves of oil sands, natural gas, and conventional oil, positioning it as a significant contributor to the nation's energy sector. The province also stands out as the largest hydrogen producer in Canada, with hydrogen playing a crucial role in the oil, gas, and chemical industries. In 2021, Alberta produced 2.5 million tons of hydrogen, of which 81% was gray hydrogen and 19% was blue hydrogen, according to the Alberta Energy Regulator. Additionally, several potential sites for Carbon Capture, Utilization and Storage (CCUS) could be developed to capture carbon emissions from the hydrogen production process. With its abundant natural gas reserves and existing pipeline infrastructure, Alberta has the potential to become a renewable hydrogen production and export leader. The cities of Edmonton and Calgary have been identified as the most suitable locations in Alberta to establish Hydrogen Hubs that would leverage the existing natural gas pipeline infrastructure and renewable energy sources to produce and transport low-carbon hydrogen. Alberta's strategy involves initially focusing on blue hydrogen, which entails blending hydrogen into the existing natural gas pipeline to reduce overall carbon emissions, followed by gradually transitioning to green hydrogen. Refer to Appendix J.7 for the full report.

British Columbia (BC)

British Columbia (BC) contains most of the hydrogen projects and companies in Canada and was the first province/territory to come out with a hydrogen strategy. They have the goal of lowering their overall emissions by 40% by 2030. As a leading province, BC stands to export the most hydrogen. BC's current focus is replacing medium and heavy-duty transportation with hydrogen fuel cell vehicles, lowering emissions in industry and refining, displacing natural gas, and displacing diesel used electricity generation in remote communities. BC's electricity grid is 98% renewable and makes green hydrogen as their target hydrogen to produce.

BC has created general policies that focus on clean energy as a whole, many of which are more focused on making renewable electricity cheaper and more accessible. The Clean Energy and Innovation Rate offers cheaper electricity to companies looking to switch from fossil fuels, and the Clean Energy Act encourages the production and use of energy sources that reduce emissions. These policies seem to encourage the production of hydrogen through electrolysis. Similarly, the Zero-Emissions Vehicles act serves as a more general policy on all forms of energy relation of vehicles. Electrified vehicles are more likely to replace the current fossil fuel counterparts for light duty vehicles, but medium and heavy vehicles will most likely rely on hydrogen-based fuels. Additionally, BC created the Low-Carbon Fuel Source Regulations to ensure that current fuels emissions will decrease with each passing year. This regulation will ensure that hydrogen will start to be incorporated into current fuels and hopefully overtake fossil fuels. More details on all these policies can be found in Appendix J.8: the full report.

Ontario

Ontario's immediate goals are to create hydrogen to provide to its local communities, with global exports in the far future. They plan to focus on green hydrogen using their clean energy grid that is 90% renewable. About 75% of Ontario's GHG emissions come from transportation and industry, so they have created policies tackling these sectors. They have passed the Red Tape and Burden Reduction Act to ease the bureaucratic cost of hydrogen projects. There have yet to be many policies specific to hydrogen, but there have been some on clean electricity. They have created Clean Energy Credits (CECs) for companies to show their commitment to sustainability. CEC was created for sustainable electricity, but the application would extend to the production of green hydrogen. Refer to Appendix J.9 for the full report.

Québec

Québec has set the goal to reach 37.5% of emission reduction and have 10% of the province's energy consumption be from renewable sources by 2030, where they are currently investing in developing hydrogen-based technologies and an overall green hydrogen ecosystem in the province. However, the province is still in the beginning stages of developing and transitioning to hydrogen technology. In terms of the regulations, strategies, and policies pertaining to renewable energy, Québec has implemented the Respecting the Quality of the Environment (RQE) and Environment Quality Act to ensure that the province remains clean and sustainable. Similar to Canada's federal policies, Québec has no official guarantee of origin scheme yet, but it is in the works and is being developed by the Ministry of Energy and Natural Resources of Québec. Refer to Appendix J.10 for the full report.

4.2 Interview Results

A total of 75 potential interviewees were contacted and 13 responded to our request, thus giving a response rate of 17.3%. Twenty-nine individuals were from governmental agencies, twenty were from related industries, twenty-four were from academia, and two were from other related areas. Out of the potential interviewees who responded to our requests, four individuals accepted an interview, five rejected, and four were tentative as they did not follow up on a time to meet. Our interview response rate was 5.33%. Two of the accepted interviewees were from governmental agencies, and two were from academia. Appendix C listed all individuals who were interviewed with their affiliation, position, and what sector they are classified in. Mark Ruth, Amgad Elgowainy, Yu Zhong, and Elsie Hung were interviewed, and they were affiliated with the National Renewable Energy Laboratory, Argonne National Laboratory, Worcester Polytechnic Institute, and Rice University, respectively.

Appendix H lists all the questions each interviewee was asked; each list of questions was created through extensive background research of the individual to generate specific questions. Since interviews were conducted, only qualitative information was gathered, so it was difficult to objectively quantify the success of the interviews. However, the insights shared by the interviewees proved to be quite valuable in directing our research efforts.

During our first academic interview with a professor conducting materials research for hydrogen fuel cells, our team learned about reversible hydrogen fuel cells and their two modes of operation. We learned that these fuel cells can convert electricity into hydrogen or use hydrogen to produce electricity. Additionally, we learned that fuel cells produce less pollution and less noise than traditional internal combustion engine (ICE) gasoline engines. One potential application of reversible fuel cells is to store excess electricity from renewable sources in hydrogen form. This stored hydrogen can then be used to generate electricity during periods when there is no electricity from solar or wind. This usage is particularly useful for wind turbines, which often generate excess electricity that cannot be stored efficiently. By converting this excess electricity to hydrogen fuel, it can be transported to areas further away from the source to be used as a clean energy source. Overall, our team gained valuable insights into the potential uses of reversible hydrogen fuel cells and their ability to store and transport excess renewable energy.

In our second interview with a government program manager from the US National Renewable Energy Laboratory (NREL), our team learned about the potential of Hydrogen Hubs as a means to produce and transport hydrogen for use in various industrial sectors. We also discovered that the most critical incentives should be aimed at assisting industrial processes such as ammonia, steel, and concrete production. Interestingly, we learned that these incentives should be tied to emissions measurements rather than mandating that states produce a specific amount of hydrogen. This approach would enable industries to work toward reducing emissions while also providing them with flexibility in how they reach their targets. Overall, our interview provided us with valuable insights into the role of Hydrogen Hubs and the importance of implementing tailored incentives to drive the adoption of clean hydrogen in different industrial sectors.

During our third interview with a government program manager from the US Argonne National Laboratory who specializes in hydrogen and electrification infrastructure, we learned about the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET Model) and transporting hydrogen in the form of ammonia. The GREET model is a valuable tool for evaluating the energy and environmental effects of vehicle technologies, fuels, products, and energy systems. With GREET, researchers, energy and vehicle producers, and regulators can calculate the total energy consumption and emissions for any given energy and vehicle system. Moreover, companies can use the GREET model to measure their emissions and apply for tax credits from the government. Additionally, we learned that ammonia is a promising option for transporting hydrogen due to its high hydrogen content by weight, easy liquefaction, and the existing infrastructure for ammonia transportation. Furthermore, ammonia is less expensive to transport than hydrogen, thanks to its higher boiling point and lower cost of production. Overall, this interview provided valuable insights into the GREET model which is an important tool to encourage the use of renewable hydrogen in industry as well as the potential of using ammonia to transport hydrogen.

From our fourth interview with a research manager from Rice University's Baker Institute Center for Energy Studies, we gained valuable insights into the potential for establishing a sustainable hydrogen market in the United States. We learned that to establish a sustainable hydrogen market, it is crucial to increase the involvement of multiple companies in both hydrogen production and usage while reducing reliance on subsidies. The market must have robust supply and demand dynamics, allowing it to develop without the need for any subsidies in the future. This idea underscores the need for collaboration and cooperation between stakeholders to establish a viable and sustainable hydrogen economy.

4.3 Report Results

The deliverables to TIER from the team were regional reports followed by a final presentation. The regional reports, seen in Appendix J, were constructed to be easily read and understood by TIER in which it contained an overview of the region, regulations, strategies, policies, market trends, and projects in relevance to green hydrogen and what the team believed was useful information for TIER. All information was gathered from press reports, governmental official documents, and the conducted interviews where the sources were cited in the sections where they were mentioned.

These reports were delivered at the weekly meetings the team held with TIER, where a brief summary of the findings was presented to the TIER team alongside a brief discussion for questions and clarifications. The policies and strategies in the US and Canada were compared to distinguish the similarities and differences between the two regions to TIER.

5.0 Discussion

5.1 ZEVs and FCEVs

In the United States, early efforts to use low-carbon or renewable hydrogen at the state level targeted reducing emissions from motor vehicles. Across states, policy has focused on both light-, medium- and heavy-duty vehicles. Policy varies from building hydrogen fueling stations and preferred parking to rebates for car parts to grants and requirements for state agencies to expand zero-emission vehicles (ZEV) fleets. Specifically in Hawaii, the use of these ZEVs is seen to be successful in introducing hydrogen in their energy market as these policies are still active. Similarly, Canada has called for the transition to more electric vehicles with hydrogen-based vehicles still in development. Vehicle and fuel policies specific to hydrogen have yet to be created across all of Canada, but they are pushing to ensure their fuel and vehicles emit less GHG as a whole. Over the past decade, the popularity of electric vehicles has risen, especially when considering light-duty passenger vehicles. Considering this trend, incentivizing hydrogen fuel cell light-duty vehicles may not be necessary given that the alternative option, plug-in electric vehicles, are proven to work and have succeeded. From our interviews with researchers working on ZEVs, there is an application that is niche for FCEVS in medium- and heavy-duty vehicles like trucks and buses as hydrogen fuel can be stored on the vehicle which is efficient for long-distance haul and has fast refueling time.

In Taiwan, FCEVs may be applicable for moving supplies within the country. In 2020 86% of good transportation used road travel (Directorate General of Budget, Accounting and Statistics of Taiwan, 2020). To reduce emissions and increase efficiency in the long run, Taiwan could incentivize the adoption of FCEVs trucks into their transportation chain, similar to Hawaii's approach for introducing hydrogen in their market. However, in order to meet the demand for hydrogen fuel Taiwan would have to build up fueling infrastructure and import or produce enough low-carbon hydrogen. For Taiwan, which does not currently produce low-carbon hydrogen, incentivizing the transition to FCEVs may be too expensive and too early considering the limitations of their low-carbon hydrogen network. Additionally, Taiwan does not have any large automotive manufacturers which means that investing in FCEVs would not stimulate their industry which may deter the government from currently investing.

5.2 State Province Comparison

Looking at Table 4.1 of the comparison of US state and federal law, across the board there is a general trend to provide incentives. In a country where fossil fuels are cheap, it makes sense that there would be a greater government push to switch to clean (low carbon) hydrogen. The monetary cost would be harder to bear when there are cheaper fossil fuels around. Canada similarly has funds to encourage the development of expensive hydrogen projects. To start the transition, many states and provinces are placing a large emphasis on cleaning up their transportation sectors. Along with the rise in electric vehicle sales and use, governments are encouraging the transition to hydrogen fuel cell vehicles too. The US and Canada both see the potential in emission reduction if fossil fuel vehicles were removed from the roads. There is a trend that many countries and provinces require a percentage of emissions from energy production and fuel usage to be reduced in multiple states/provinces. Therefore, these types of policy may be some of the most effective when it comes to overall GHG reduction, giving companies more time and incentives to go green earlier so both the US and Canada can achieve NZE by 2050.

5.3 Exports and Imports

Based on our research on the United States and Canada’s import and export regulations and strategies, both countries have similar policies and developing plans for the implementation of green hydrogen. Both countries as a whole contain regions that have the potential of being great hubs of green hydrogen for the world—Texas and Hawaii for the United States and Québec for Canada—however, the development of these hubs are still in the early stages of development. Since each country can independently produce their own hydrogen, the US and Canada do not need to depend on other countries to obtain green hydrogen and therefore do not necessarily seek guarantee of origin schemes to import hydrogen energy. In terms of imports and exports of green hydrogen, Taiwan can be influenced by Hawaii’s procedures: Taiwan may have the infrastructure capabilities to have a green hydrogen hub, and therefore need to import all hydrogen. Researching the US and Canada, a highly developed country with a great abundance of natural resources, for this type of scheme to eventually provide recommendations for Taiwan, a much smaller country with limited natural resources, makes these suggestions incomparable.

5.4 Renewable Portfolio Standard and Certificates

Establishing standards for renewables through the creation of a renewable portfolio standard proven to work in multiple states. Hawaii has been able to increase its generation of renewable energy from below 10% in 2010 to 29% in 2022, allowing the region to get closer to their NZE goal by 2050 (U.S. Energy Information Administration, 2023). A RPS allows the government to set deadlines for renewable energy generation but gives the market enough control to develop the industry without adding incentives or tax credits that it could become reliant upon. To reach net-zero goals, Taiwan has created their own renewable portfolio standard and Taiwan Renewable Energy Certificate program and should continue to look at Hawaii's strategies on these regulations as Hawaii's RPS is successfully progressing to their NZE goal. Currently, low-carbon hydrogen does not have a certificate scheme or set standard in Taiwan. To facilitate the transition to low-carbon hydrogen, Taiwan must create a set standard for low-carbon hydrogen in the country and include it under the RPS program.

5.5 Hydrogen Hubs

The United States and Canada have shown strong interest in developing green hydrogen hubs throughout both countries, specifically in Texas, Hawaii, and Québec. Through conducting archival research, it has seen that there are both benefits and limitations to having hydrogen hubs. The benefits to having hydrogen hubs include the close proximity to resources as the hubs contain caverns for storage of excess energy and there is quick access to energy. Additionally, the nation can achieve energy independence as they do not need to import energy from neighboring facilities. However, cost is the largest barrier to green hydrogen hubs where great investment is needed to sustain a green hydrogen hub. Having a hydrogen hub would most likely come with the need to export hydrogen to other nations and ensuring the production and transportation is regulated through industrial practice and policies. Since Taiwan is a relatively small country with limited resources, having an on-site green hydrogen hub will be a challenge to develop, but it is not impossible. Hawaii is in the works of developing a hydrogen hub, and since its geographical components are similar to that of Taiwan, Taiwan can further look into Hawaii's hydrogen hub strategies when trying to implement hydrogen hubs of their own. During our Week Five meeting with TIER, they claimed to show interest in developing a green hydrogen hub in Taiwan, with the project proposal currently in the works.

6.0 Conclusion

6.1 Limitations

This research study encountered many challenges to the methodology and data collection in which it limited the results of the study. While collecting data through archival research, oftentimes we experienced restricted access to governmental official documents due to some developing policies and market demands that were unable to be disclosed. Due to this, some of the reports we constructed did not contain all of the information that was relevant to each regional report, and so TIER could not be fully informed of all existing projects and policies. Moreover, the policies that are currently in place can frequently change, in addition to the sources that were cited throughout our report. Our reports were dated to include when the report was last updated, however after this project, the reports will not be constantly updated and if the information in the reports were to be used, the policies need to be confirmed if they are still in effect or if they are updated.

A large limitation to gathering data through archival research is time; it takes a lot of time to read, understand, and analyze documents on projects and policies, and even a lot of time was spent reading these papers, sometimes it did not provide any useful information that we can provide to TIER. The large amount of time it took to analyze these documents was another reason why we decided to only analyze four regions per country; if more time were given, more regions could be looked into in more depth. Lastly, information pertaining to Taiwan's policies on green hydrogen were researched to help the team understand the policies that are currently being developed and implemented in Taiwan. Though, there exists a language barrier to research and understand these policies as they were typically written in Mandarin, and translating to English does not always explain the policies well.

There also existed challenges and limitations when gathering information from interviews. We encountered challenges when trying to initially contact interviewees as we cold-contacted them via LinkedIn and their emails if they were publicized. We noticed that connecting and messaging with interested individuals was challenging due to some of the individuals no longer using LinkedIn, so they do not check their account anymore, or if they were considered valuable members on LinkedIn, so they would not be interested in connecting and messaging our team who was not of high status on the social media platform. Moreover, LinkedIn only allows their general members to message a limited number of new individuals before they connect, which limits the number of individuals we were able to contact in general. Thus, email was deemed to be the most efficient method of contacting our interested individuals as it did not limit the number of individuals we could contact as long as we were able to obtain their emails.

When the individuals were contacted and responded, we experienced the challenge in that some individuals were unable to answer specific questions as the information is protected under their non-disclosure agreement (NDA), which limited us from gathering some information that may have been helpful in our project. Additionally, we interviewed a total of four individuals, two from government and two from academia. Therefore, our population sample was not representative of those who work in the green or clean (low carbon) hydrogen field as we were unable to interview individuals from industry. However, we have completed further research to triangulate the data received from our interviewees to ensure that there was no bias present in our findings. Furthermore, all the interviewees were from the United States, where they could only speak on behalf of the hydrogen progress in the US. We were unable to contact any individuals from Canada as they did not respond to our messages and emails, so all information pertaining to Canada was gathered via archival research.

6.2 Moving Forward

Based on geography, Taiwan could adopt similar policies to Hawaii. As a state of islands in the Pacific Ocean, Hawaii's high energy cost has forced them to transition to green and low-carbon hydrogen early which might be similar for Taiwan. Their policies would have the closest application to Taiwan during Taiwan's early hydrogen development stages. Providing similar funds and creating a policy similar to the Renewable Portfolio Standard may be an effective way for Taiwan to achieve their NZE goals. California's guarantee of origin (GO) scheme could also be a source of inspiration for Taiwan. As they are currently still making their certification system for green hydrogen, edits can be made with California's GO scheme as a base.

Taiwan may also want to use a tax credit system that both the US and Canada have started implementing with the caveat that they phase it out within 10 years to avoid an over reliance on it. Tax credits provide a good incentive to start investment into hydrogen and also ease some of the burden of cost. Thus, this system would translate very well to Taiwan's systems. TIER may want to avoid these types of incentives all together to avoid any external reliance the market may have, so it is up to TIER's judgment to determine if a credit system would translate well into their economy.

As with many of the states and provinces, Taiwan could also create hydrogen hubs as a start to their energy transition. With their current technology, implementing a hub on a microgrid level or in an industrial area is feasible. The infrastructure for these small-scale hubs is already present, but the policy and standards must be set and created before any projects can begin. Taiwan could also create larger scale hubs to store their offshore wind energy when there is excess electricity being generated. Green hydrogen would provide a way to ensure they do not waste all of the excess renewable electricity. Those large-scale hubs will require better technology and further investment in the future, that the government may be reluctant to provide the budget for at the current time. However, before starting working on any hydrogen hub, Taiwan must first establish their GO scheme and set a standard green hydrogen and infrastructure.

With our reports and our team's suggestions, TIER is educated about the benefits of hydrogen hubs that aid in the transition to green hydrogen. Dr. Chen and the Taiwan Renewable Energy Certification (T-REC) team have proposed to the Taiwanese government on the implementation of four different cases of hydrogen hubs throughout Taiwan depending on the available infrastructure. They have also gathered more information on hydrogen regulations in which they have developed a Low Carbon Hydrogen GO Concept Model in which it defines the mechanisms of regulations for on-site, centralized, and imported hydrogen.

Ultimately, TIER will know Taiwan's current status the best and use these reports to generate ideas. There are many differences between the North American countries and Taiwan. As a result, many of the researched approaches might not be able to be applied to Taiwan, but more to be used as a model for TIER. The US and Canada are more focused on emissions of any shade of hydrogen, while TIER is more specifically interested in green hydrogen. Policy is always changing so there may be new amendments in the near future. In this developing market. Taiwan's hydrogen journey will be in development for many years to come and this research will provide a basis for them to generate more projects and ideas.

Bibliography

Atilhan, S., Park, S., El-Halwagi, M. M., Atilhan, M., Moore, M., & Nielsen, R. B. (2021). Green hydrogen as an alternative fuel for the shipping industry. *Current Opinion in Chemical Engineering*, *31*, 100668. https://doi.org/10.1016/j.coche.2020.100668

Berg, B. L., & Lune, H. (2017). *Qualitative Research Methods for the Social Sciences* (9th ed.).

Pearson.

Bianco, E., & Blanco, H. (2020). *Green Hydrogen: A Guide to Policy Making*. https://www.h2knowledgecentre.com/content/researchpaper1616

Bureau of Energy. (2022a, March 1). *Official Announcement of the 2022 Feed-in Tariffs (FIT) Rates for Renewable Energy Electric Power* [Text]. Bureau of Energy, Ministry of Economic Affairs, R.O.C. https://www.moeaboe.gov.tw/ECW/English/news/News.aspx?kind=6&menu_id=958&news_id=25032

Bureau of Energy. (2022b). *Energy Statistics Handbook 2021*. Ministry of Economic Affairs. https://www.moeaboe.gov.tw/ECW_WEBPAGE/FlipBook/2021EnergyStaHandBook/index.html#p=

Bureau of Energy. (2023, February 10). *Public Communication Launched for the 2050 Net-Zero*

Goal: Decarbonization of Energy System [Text]. Bureau of Energy, Ministry of Economic Affairs, R.O.C. https://www.moeaboe.gov.tw/ECW/English/news/News.aspx?kind=6&menu_id=958&news_id=30312

Bureau of Energy, M. of E. A. (2012, March 21). *What's New* [Text]. Bureau of Energy, Ministry

of Economic Affairs, R.O.C. https://www.moeaboe.gov.tw/ECW/English/news/News.aspx?kind=6&menu_id=958&news_id=30312

Chinese Taipei (XXB) Exports, Imports, and Trade Partners | OEC. (n.d.). OEC - The

Observatory of Economic Complexity. Retrieved February 18, 2023, from https://oec.world/en/profile/country/twn?depthSelector1=HS4Depth&yearlyTradeFlowSelector=flow0

Department of Energy. (2021, April 20). *How the American Jobs Plan Will Advance America's*

Energy and Competitiveness Priorities. Energy.Gov. https://www.energy.gov/articles/how-american-jobs-plan-will-advance-americas-energy-and-competitiveness-priorities

DOE National Clean Hydrogen Strategy and Roadmap (Draft) : DOE Hydrogen Program. (2022). https://www.hydrogen.energy.gov/clean-hydrogen-strategy-roadmap.html

Dong, Z. Y., Yang, J., Yu, L., Daiyan, R., & Amal, R. (2022). A green hydrogen credit framework for international green hydrogen trading towards a carbon neutral future. *International Journal of Hydrogen Energy*, *47*(2), 728–734. https://doi.org/10.1016/j.ijhydene.2021.10.084

Ellabban, O., Abu-Rub, H., & Blaabjerg, F. (2014). Renewable energy resources: Current status,

future prospects and their enabling technology. *Renewable and Sustainable Energy Reviews*, *39*, 748–764. https://doi.org/10.1016/j.rser.2014.07.113

European Union. (2022). *Hydrogen*. European Union: Energy Systems Integration. Retrieved February 1, 2023, from https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen_en

Falcão, D. S. (2023). Green Hydrogen Production by Anion Exchange Membrane Water Electrolysis: Status and Future Perspectives. *Energies*, *16*(2), 943. https://doi.org/10.3390/en16020943

Feldmann, J., Byrum, Z., & Cyrs, T. (2023). Clean Hydrogen: Outlook for Freight Transport in the United States. *World Resources Institute*. https://doi.org/10.46830/wriwp.21.00155

Fusion-Fuel. (2021). Fusion Fuel. https://www.fusion-fuel.eu/about-us/

Gong, J., Harrison, C., Patel, T., & Stilin, K. (2022). *A Stakeholder Study of the US Carbon Offset Market*. Worcester Polytechnic Institute.

Industrial Technology Research Institute. (2022). *Innovations & Applications - Green Energy &*

Environment. https://www.itri.org.tw/english/ListStyle.aspx?DisplayStyle=01&SiteID=1&MmmID=1037333532467607737

International Energy Agency. (2022a). *Executive summary – Global Hydrogen Review 2022 – Analysis*. IEA. https://www.iea.org/reports/global-hydrogen-review-2022/executive-summary

International Energy Agency. (2022b). *Hydrogen*. IEA. https://www.iea.org/reports/hydrogen

International Energy Agency. (2023). *Renewable electricity growth is accelerating faster than ever worldwide, supporting the emergence of the new global energy economy - News*. IEA. https://www.iea.org/news/renewable-electricity-growth-is-accelerating-faster-than-ever-worldwide-supporting-the-emergence-of-the-new-global-energy-economy

IPCC. (2022). *Global Warming of 1.5°C: IPCC Special Report on Impacts of Global Warming of*

1.5°C above Pre-industrial Levels in Context of Strengthening Response to Climate Change, Sustainable Development, and Efforts to Eradicate Poverty. Cambridge University Press. https://doi.org/10.1017/9781009157940

IRENA. (2019). *Renewable power generation costs in 2018* (p. 86). International Renewable Energy Agency.

IRENA. (2020). *Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5^{0}C Climate Goal*. International Renewable Energy Agency.

Jovan, D. J., & Dolanc, G. (2020). Can Green Hydrogen Production Be Economically Viable under Current Market Conditions. *Energies*, *13*(24), 6599. https://doi.org/10.3390/en13246599

Kakoulaki, G., Kougias, I., Taylor, N., Dolci, F., Moya, J., & Jäger-Waldau, A. (2021). Green hydrogen in Europe – A regional assessment: Substituting existing production with electrolysis powered by renewables. *Energy Conversion and Management*, *228*, 113649. https://doi.org/10.1016/j.enconman.2020.113649

Kartal, M. T., Kılıç Depren, S., Ayhan, F., & Depren, Ö. (2022). Impact of renewable and fossil fuel energy consumption on environmental degradation: evidence from USA by nonlinear approaches. *International Journal of Sustainable Development & World Ecology*, *29*(8), 738–755. https://doi.org/10.1080/13504509.2022.2087115

Kast, J., Vijayagopal, R., Gangloff, J. J., & Marcinkoski, J. (2017). Clean commercial transportation: Medium and heavy duty fuel cell electric trucks. *International Journal of Hydrogen Energy*, *42*(7), 4508–4517. https://doi.org/10.1016/j.ijhydene.2016.12.129

Khan, I., Hou, F., & Le, H. P. (2021). The impact of natural resources, energy consumption, and

population growth on environmental quality: Fresh evidence from the United States of America. *Science of The Total Environment*, *754*, 142222. https://doi.org/10.1016/j.scitotenv.2020.142222

Line, P., & Sun, L. (2020, July 27). *TSMC Becomes the World's First Semiconductor Company to*

Join RE100, Committed to 100% Renewable Energy Usage. TSMC ESG. https://esg.tsmc.com/en/update/greenManufacturing/caseStudy/37/

Lustick, I. S. (1996). History, Historiography, and Political Science: Multiple Historical Records

and the Problem of Selection Bias. *The American Political Science Review*, *90*(3), 605–618. http://www.jstor.org/stable/2082612

Marques, A. C., Fuinhas, J. A., & Pires Manso, J. R. (2010). Motivations driving renewable energy in European countries: A panel data approach. *Energy Policy*, *38*(11), 6877–6885. https://doi.org/10.1016/j.enpol.2010.07.003

Merida, W. (2021, July 28). *OPINION: Why green hydrogen — but not grey — could help solve*

climate change. BayToday.Ca. https://www.baytoday.ca/around-ontario/opinion-why-green-hydrogen-but-not-grey-could-help-solve-climate-change-3979968

Ministry of Economic Affairs. (2023, February 16). *Energy Transition Promotion Scheme*. MOEA,R.O.C. https://www.moea.gov.tw/MNS/english/Policy/Policy.aspx?menu_id=32904&policy_id=19

National Grid. (2023). *What is carbon intensity?* https://www.nationalgrid.com/stories/energy-explained/what-is-carbon-intensity

Ocko, I. B., & Hamburg, S. P. (2022). Climate consequences of hydrogen emissions. *Atmospheric Chemistry and Physics*, *22*(14), 9349–9368. https://doi.org/10.5194/acp-22-9349-2022

Office of Energy Efficiency. (2023). *Hydrogen Production: Electrolysis*. Energy.Gov. https://www.energy.gov/eere/fuelcells/hydrogen-production-electrolysis

PricewaterhouseCoopers. (2023). *Green hydrogen economy - predicted development of tomorrow*. PwC. https://www.pwc.com/gx/en/industries/energy-utilities-resources/future-energy/green-hydrogen-cost.html

Reinsch, W. A., & O'Neil, W. (2021). *Hydrogen: The Key to Decarbonizing the Global Shipping Industry?* https://www.csis.org/analysis/hydrogen-key-decarbonizing-global-shipping-industry

Ritchie, H., Roser, M., & Rosado, P. (2020). Taiwan: CO_2 Country Profile. *Our World in Data*. https://ourworldindata.org/co2/country/taiwan

Sadik-Zada, E. R. (2021). Political Economy of Green Hydrogen Rollout: A Global Perspective. *Sustainability*, *13*(23), 13464. https://doi.org/10.3390/su132313464

Sailer, K., Reinholz, T., Malin, K., & Crone, K. (2022). *Global Harmonisation of Hydrogen Certification*. World Energy Council.

Shang, Y., Han, D., Gozgor, G., Mahalik, M. K., & Sahoo, B. K. (2022). The impact of climate policy uncertainty on renewable and non-renewable energy demand in the United States. *Renewable Energy*, *197*, 654–667. https://doi.org/10.1016/j.renene.2022.07.159

Taiwan Institute of Economic Research. (2007). *Welcome to TIER - Taiwan Institute of Economic Research*. https://english.tier.org.tw/eng_about/background.aspx

Taiwan Institute of Economic Research. (2022). *Taiwan Institute of Economic Research*. http://www.thfcp.org.tw/en/xccompany/cont?xsmsid=0L330540834918638148&sid=0L351585135337843499

Taiwan Renewable Energy Certification (T-REC) Center. (2017). *Our Missions and Visions T-REC*. https://www.trec.org.tw/en/page/en-our-missions-and-visions

Tetteh, D. A., & Salehi, S. (2022). The Blue Hydrogen Economy: A Promising Option for the Near-to-Mid-Term Energy Transition. *Journal of Energy Resources Technology*, *145*(4), 042701. https://doi.org/10.1115/1.4055205

The Observatory of Economic Complexity. (2020). *Chinese Taipei (XXB) Exports, Imports, and Trade Partners | OEC*. https://oec.world/en/profile/country/twn?depthSelector1=HS4Depth&yearlyTradeFlowSelector=flow0

United Nations. (2021). *COP26: Together for our planet*. United Nations. https://www.un.org/en/climatechange/cop26

United States Steel. (2022, August 16). *U. S. Steel, Equinor and Shell to Explore Regional Clean Energy Opportunities*. https://investors.ussteel.com/news/news-details/2022/U.-S.-Steel-Equinor-and-Shell-to-Explore-Regional-Clean-Energy-Opportunities/default.aspx

Van Hoecke, L., Laffineur, L., Campe, R., Perreault, P., Verbruggen, S. W., & Lenaerts, S. (2021). Challenges in the use of hydrogen for maritime applications. *Energy & Environmental Science*, *14*(2), 815–843. https://doi.org/10.1039/D0EE01545H

Velazquez Abad, A., & Dodds, P. E. (2020). Green hydrogen characterisation initiatives: Definitions, standards, guarantees of origin, and challenges. *Energy Policy*, *138*, 111300. https://doi.org/10.1016/j.enpol.2020.111300

Wakim, G. (2022, October 13). *Potential pricing regimes for a global low-carbon hydrogen market*. Clean Air Task Force. https://www.catf.us/2022/10/potential-pricing-regimes-global-low-carbon-hydrogen-market/

Wappler, M., Unguder, D., Lu, X., Ohlmeyer, H., Teschke, H., & Lueke, W. (2022). Building the green hydrogen market – Current state and outlook on green hydrogen demand and electrolyzer manufacturing. *International Journal of Hydrogen Energy*, *47*(79), 33551–33570. https://doi.org/10.1016/j.ijhydene.2022.07.253

World Bank. (2021). *Groundswell Report*.

https://www.worldbank.org/en/news/press-release/2021/09/13/climate-change-could-force-216-million-people-to-migrate-within-their-own-countries-by-2050

Zafar, M. W., Zaidi, S. A. H., Khan, N. R., Mirza, F. M., Hou, F., & Kirmani, S. A. A. (2019). The impact of natural resources, human capital, and foreign direct investment on the ecological footprint: The case of the United States. *Resources Policy*, *63*, 101428. https://doi.org/10.1016/j.resourpol.2019.101428

Appendices

Appendix A: Email Template for Interviewees

Purpose: The purpose of this Appendix A is to contact targeted individuals to potentially interview to gather information to analyze the low-carbon hydrogen market, regulation, and origin certification in the United States and Canada.

Appendix A.1: Initial Email for Interview Request Template

Subject: Renewable Hydrogen Research Interview - Taiwan Institute of Economic Research

Dear [*POTENTIAL INTERVIEWEE*],

We are Worcester Polytechnic Institute (WPI) undergraduate students from Massachusetts, USA working in sponsorship with the Taiwan Institute of Economic Research (TIER) to analyze the policies, market demands, and regulation methods of low-carbon or green hydrogen in the United States and Canada.

Your expertises relating to clean hydrogen [*INSERT SPECIFICS BY SUBJECT*] and your affiliation with [*AFFILIATION*] will be helpful in answering questions on [specific topic]. Your participation in the research will help the team and TIER understand low-carbon hydrogen regulation and market potential in the US and Canada. Would you be able to participate in a 30-60 minute virtual interview to speak to the team?

If you have any questions please feel free to reach out at gr-wpi-tier-2023@wpi.edu. We appreciate your time and consideration and hope to hear back from you soon.

Best regards,
Sameer Desai, Belisha Genin, Tera Keang, and Neena Xiang

Taiwan Institute of Economic Research

Appendix A.2: Accepted Interview Email Response Template

Purpose: The purpose of this appendix is to follow up with our targeted individuals who accepted to interview with the team to schedule a time to meet.

Subject: Renewable Hydrogen Research Interview - Taiwan Institute of Economic Research

Dear [*INTERVIEWEE*],

Thank you for getting back to us. We are currently working out of Taiwan, we will be working in the Taiwan time zone. We have listed our availability for the next two weeks **(EDT)**:

- [*TIMES*]

Though if none of these times work for you, we would be happy to accommodate your schedule.

To prepare we have attached the interview consent form, we will ask for verbal consent prior to the start of our interview. We look forward to meeting with you soon!

Best regards,
Sameer Desai, Belisha Genin, Tera Keang, and Neena Xiang

Taiwan Institute of Economic Research

Appendix A.3: Follow-Up Email Response Template

Purpose: The purpose of this appendix is to follow up with our targeted individuals whom we contacted to potentially interview to ensure they did not miss our initial email or message.

Subject: Renewable Hydrogen Research Interview - Taiwan Institute of Economic Research

Dear [*POTENTIAL INTERVIEWEE*],

I hope this email finds you well. I wanted to follow up on the email I sent a few days ago regarding the research project my team and I are working on with the Taiwan Institute of Economic Research (TIER).

We are interviewing experts to gather information on clean hydrogen policies and market demands in the US and Canada from March 22nd to April 14th. Would you be available for a 15-30 minute virtual interview to speak to the team? Your participation will help our team and TIER gain a better understanding of low-carbon hydrogen regulation and market potential in the US and Canada.

If you have any questions or concerns about the interview or the project, please do not hesitate to reach out to us at gr-wpi-tier-2023@wpi.edu. Thank you for your time and consideration, and we look forward to hearing back from you soon.

Best regards,
Sameer Desai, Belisha Genin, Tera Keang, and Neena Xiang

Taiwan Institute of Economic Research

Appendix B: LinkedIn Template for Interviewees

Purpose: The purpose of this Appendix B is to contact targeted individuals to potentially interview to gather information to analyze the low-carbon hydrogen market, regulation, and origin certification in the United States and Canada.

Subject: [*NONE*]

Dear [*POTENTIAL INTERVIEWEE*],

I am an undergraduate student from Worcester Polytechnic Institute (WPI) in Massachusetts, USA working on a project in sponsorship with the Taiwan Institute of Economic Research (TIER) to analyze low-carbon/green hydrogen in the United States.

My team is interested in your work in [*FILL IN*] and want to hear more about it. Would you be interested in participating in a 30-60 minute virtual interview to speak to our team?

If you have any questions please feel free to reach out at gr-wpi-tier-2023@wpi.edu. I appreciate your time and consideration and hope to hear back from you soon.

Best regards,
Sameer Desai, Belisha Genin, Tera Keang, and Neena Xiang

Taiwan Institute of Economic Research

Appendix C: List of Interviewees

Sector	Name	Position	Association
SCHOLARS	Yu Zhong	PhD Materials Science	Worcester Polytechnic Institute
SCHOLARS	Shih Yu (Elsie) Hung	Research Manager	Center for Energy Studies at Rice University's Baker's Institute for Public Policy
GOVERNMENT	Mark Ruth	Laboratory Program Manager II-Policy Analysis	National Renewable Energy Laboratory
GOVERNMENT	Amgad Elgowainy	Senior Scientist and Group Manager	Argonne National Laboratory

Appendix D: Informed Consent Agreement for Participation in a Research Study

Informed Consent Agreement for Participation in a Research Study

Investigator:	S. Desai, B. Genin, T. Keang, & N. Xiang
Contact Information:	Email: gr-wpi-tier-2023@wpi.edu
Title of Research Study:	An Analysis of the Low-carbon Hydrogen market, Regulation, and Origin Certification in the US and Canada
Sponsor:	Taiwan Institute of Economic Research

Introduction

You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

The study is conducted by undergraduate students from Worcester Polytechnic Institute in Worcester, Massachusetts, USA sponsored by the Taiwan Institute of Economic Research (TIER) in completion of the Interactive Qualifying Project (IQP) graduation requirement.

Purpose of the Study

The purpose of the study is to gather information regarding the policies, market demands, and use of clean hydrogen in the United States in Canada to present to the Taiwan Institute of Economic Research to aid in the establishment of a certification of clean hydrogen in Taiwan.

Procedures to be followed

(Here describe the research procedures to be followed, including duration of the subject's participation. Experimental procedures must be identified. This section is required.)

1. You will receive an email from *gr-wpi-tier-2023@wpi.edu* with a consent form and Zoom link for a virtual meeting.
2. You should review the consent form prior to the interview time. If agreed, you will be asked to provide your verbal consent during the interview.
3. When it is the time of your interview, please enter the Zoom link attached in the email.
4. You will be asked if you agree to the terms and conditions of the study, and if you agree to allowing the interviewers to record the interview.
5. The interview will be 30 to 60 minutes.
    a. It is expected that you are being truthful answering all questions. At any time you wish to not answer a question truthfully, you may inform the interviewees that you abstain from answering the question.
6. Once the interview has concluded, you will be asked to leave.
    a. You will receive a follow-up email within a few days after the interview was conducted.

Benefits to research participants and others

The benefit of participating in this research project is to help the Taiwan Institute of Economic Research and undergraduate students of Worcester Polytechnic Institute to understand the current policies and stances of, but not limited to, clean hydrogen. Participating in this interview will give you credit in the project's final report.

Record keeping and confidentiality

The interview will be transcribed, video recorded, or voice recorded (depending on the comfort of the interviewee) by the interviewers and kept on a flash drive for easy access by the interviewers. If the interviewee(s) wish to have a copy of the recording, the interviewee can request the recording from the interviewees via email. Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or its designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB), will be able to inspect and have access to confidential data that identify you by name. For any publication or presentation of the data will not identify you, all videos will be deleted at the end of the project.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact:

Investigator Contact Information:	Email: gr-wpi-tier-2023@wpi.edu
Worcester Polytechnic Institute	
IRB Manager:	Ruth McKeogh Tel: 508 831-6699 Email: irb@wpi.edu
Human Protection Administrator:	Gabriel Johnson Tel: 508-831-4989 Email: gjohnson@wpi.edu

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

Additional costs to the subject that may result from participation in this research include:

- Significant new findings or information, developed during the course of the research, may alter the subject's willingness to participate in the study. Any such findings will be promptly communicated to all research participants.
- Should a participant wish to withdraw from the study after it has begun, the following procedures should be followed:
    1. Please inform your interviewer(s), via verbal or direct message confirmation, that you wish to terminate your participation in this study.
    2. You will be asked to leave the Zoom meeting.
    3. No additional action will be needed from the interviewee. A follow-up email will be sent from the interviewers thanking you for your participation.
    4. Withdrawing from the study early will not result in any further consequences for the subject.

Appendix E: Sample Interview Questions for Government Officials

1. Clean hydrogen encompasses the usage of hydrogen as a source of energy, with low emissions of carbon dioxide. This includes green hydrogen. How does [your company] associate with green hydrogen?
2. What do you consider to be clean hydrogen?
3. How has the current progressing development of clean hydrogen influenced and helped [your affiliation]?
4. What role does your agency see clean hydrogen playing within the next 5 to 10 years? What is the ideal scenario?
5. Are there any future policies pertaining to clean hydrogen that are being worked on right now? If so, what are they?
6. What factors play a role in which environmentally-motivated policies are proposed and passed?
7. How do you believe the transition to using clean hydrogen will effect:
    a. The economic sectors?
    b. The legal sectors?
    c. The US's environmental goals?
    d. [Your affiliation]'s public reputation?
8. Have there been consideration on managing the imports and exports of clean hydrogen into the United States? What have you and [your organization] seen with these proposals?
    a. What certifications are currently in place/in development to verify the origin and quality of clean hydrogen?
9. What sections of the market should be incentivized to switch to clean hydrogen now/ within the next decade?
10. On a scale of 1 to 10, 1 being least influential and 10 being most influential, how much do you believe that [your affiliation] is positively and negatively influencing the transition of energy use to clean hydrogen?
11. Are there any more contacts you believe would be useful for us to have participated in our study?

Appendix F: Sample Interview Questions for Industry Leaders

1. Clean hydrogen encompasses the usage of hydrogen as a source of energy, with low emissions of carbon dioxide. This includes green hydrogen. How does [your company] associate with green hydrogen?
2. How has the current progressing development of clean hydrogen influenced and helped [your affiliation]?
3. What technological developments are necessary for clean hydrogen to be competitive in [your affiliation]?
4. How do you see the transition of energy use to hydrogen to benefit [your company]?
5. What do you believe the challenges are for low-carbon hydrogen compared to the gray kind?
6. What kind of policy would you create to help boost the usage and production of green/blue hydrogen?
7. Should incentives be passed to encourage the market to transition to clean/low-carbon hydrogen? If yes, what incentives would be most useful to your operations?
    a. Should incentives be on the producer side or consumer side of the industry?
8. How do you believe the transition to using clean hydrogen will effect:
    a. The economic sectors?
    b. The legal sectors?
    c. The US's environmental goals?
    d. [Your affiliation]'s public reputation?
9. On a scale of 1 to 10, 1 being least influential and 10 being most influential, how much do you believe that [your affiliation] is positively and negatively influencing the transition of energy use to clean hydrogen?
10. Are there any more contacts you believe would be useful for us to have participated in our study?

Appendix G: Sample Interview Questions for Scholars

1. Clean hydrogen is hydrogen that results in the low emissions of carbon dioxide and reduced use of fossil fuels which includes green hydrogen. In what ways does [your company/organization/research] associate with green or clean hydrogen?
2. From your research in [research topic], where do you see the future of green hydrogen progressing? What are the benefits and drawbacks? Please elaborate if possible.
3. What changes have you made so far for your research supporting clean hydrogen?
4. How has the current progressing development of clean hydrogen influenced and helped [your affiliation]?
5. What is your opinion on utilizing hydrogen as a fuel source compared to alternative energy sources such as electricity and fossil fuels?
6. How fast do you believe hydrogen technology is developing? What is the greatest progressor? Greatest barrier?
7. How do you believe the consumption of clean hydrogen can be regulated during the transition to renewable energy?
8. On a scale of 1 to 10, 1 being least influential and 10 being most influential, how much do you believe that [your affiliation] is positively and negatively influencing the transition of energy use to clean hydrogen?
9. Are there any more contacts you believe would be useful for us to have in our study?

Appendix H: Questions for Interviewees

The following appendices include the questions that were asked to each interviewee.

Appendix H.1: Yu Zhong

1. Based on your work with hydrogen fuel cells, what technology needs to improve for the cost of hydrogen fuel cells to go down?
2. Emphasize what technology needs to improve to decrease the cost of usage
3. With that being said, where do you see the future of green hydrogen progressing?
4. What are the benefits and drawbacks?
5. What changes have you made so far for your research supporting clean hydrogen?
6. What is your relationship with the DOE? How did you come to be funded by the DOE?
7. How has the current progressing development of clean hydrogen influenced and helped DOE?
8. Are there any more contacts you believe would be useful for us to have in our study and would you be able to connect us with them?

Appendix H.2: Mark Ruth

1. What are the most important policies that the US government has implemented to promote renewable hydrogen energy?
    a. In addition, which policies that might be created in the future will make a large impact
2. What, if any, incentives should be passed to encourage the market to transition to clean/low-carbon hydrogen?
    a. And what incentives have you seen to be the most useful?
3. In California, we see a credit based system for renewables, where certain organizations are required to meet renewable energy quotas and purchase credits generated by clean energy producers. Do you see this type of market-incentive program as positive for the development of the industry?
4. So moving forward, what are some of the most successful case studies of renewable hydrogen energy implementation that you have seen?
5. How can policymakers incentivize investment in clean hydrogen research and development, and what role can the government play in promoting the use of clean hydrogen in industry and transportation?
6. Have there been consideration on managing the imports and exports of clean hydrogen into the United States? What have you and the NREL seen with these proposals?

7. What advice would you give to policy-makers in Taiwan who are interested in promoting renewable hydrogen energy, based on your experience?

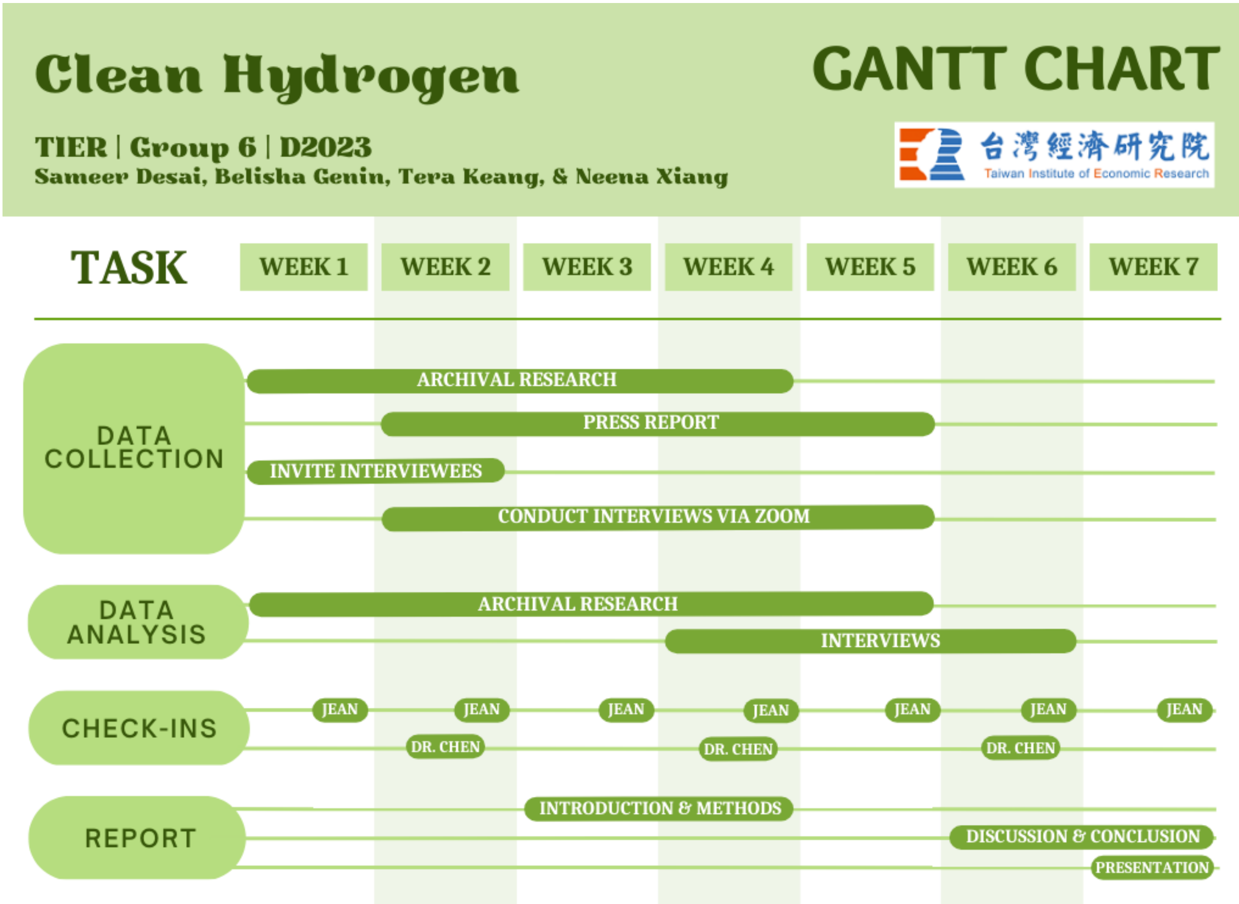
Appendix H.3: Amgad Elgowainy

1. How fast is hydrogen technology developing? What is the greatest barrier right now?
2. There has been a lot of investment into Alternative Fuel Vehicles and Zero Emission Vehicles with hydrogen fuel cell technology, why are different states focusing on this application of hydrogen over other?
3. Is the GREET model comparable to a guarantee of origin scheme?
4. Do you see the U.S. developing a guarantee of origin scheme in the future?
5. TIER is currently developing a roadmap for green hydrogen, and they are interested in starting their own small hydrogen hubs around the country. TIER is very interested in meeting with Argonne Lab to learn more, do you have a contact that you could refer us to?

Appendix H.4: Shih Yu (Elsie) Hung

1. Based on your work analyzing China's Energy Map, how does the plan to adopt clean/green hydrogen as a fuel source differ and how is it similar between the US and China?
2. Focusing more specifically on your current work, what specific policies are in the works or are currently implemented to help Texas transition to clean/green hydrogen?
3. What, if any, incentives should be passed to encourage the market to transition to clean/low-carbon hydrogen?
4. What additional policies would you like to see passed at the federal level to help facilitate the transition to clean hydrogen?
5. Based on your experiences, what advice would you give to policy-makers in Taiwan who are interested in promoting renewable hydrogen energy?

Appendix I: Gantt Chart



Appendix J: Report Deliverables

The following appendixes include the final report deliverables given to TIER. The reports cover the US with the regions of California, Texas, Colorado, and Hawaii, whereas Canada included regions of Alberta, Ontario, British Columbia, and Québec.

Taiwan Institute of Economic Research

Renewable Hydrogen: U.S.

LAST UPDATED: 6th April 2023

OVERVIEW

In the United States, low-carbon hydrogen is referred to as "clean hydrogen," a term which includes blue hydrogen and green hydrogen. The **Clean Hydrogen Production Standard** in the U.S. is proposed by the U.S. Congress. It is meant to guide the funding of future hydrogen projects but is not a set regulatory standard.

Clean Hydrogen Production Standard (CHPS): Hydrogen with lifecycle GHG emissions target of 4 kg CO_2e per kilogram of hydrogen.

ORGANIZATIONS

1. **Department of Energy –** One of the functions of the Department of Energy (DOE) is to develop innovations in science and technology, including working towards ending pollution and reaching NZE.
2. **Office of Energy Efficiency and Renewable Energy (EERE) –** EERE is an office under the department of energy. The objective of EERE is to lead the advancement, experimentation, and introduction of pioneering technologies, systems, and methodologies that: (1) facilitate the transition of Americans to a 100% clean energy-based economy by 2050 at the latest and (2) ensure that the advantages of the clean energy economy are accessible to all Americans.
3. **Hydrogen and Fuel Cell Technologies Office –** Under the EERE, this office is in charge of the advancement of hydrogen technologies and fuel cells.

REGULATION & POLICIES:

DOE National Clean Hydrogen Strategy and Roadmap (September 2022)

The Department of Energy created the National Clean Hydrogen Strategy and Roadmap to accelerate research into clean hydrogen technology and advance the hydrogen market.

Targets:

1. **Funding Projects:** Provide funding for "target strategic, high-impact uses for clean hydrogen to ensure that clean hydrogen will be used in the highest value applications and achieve 10 million metric tons per year of clean hydrogen by 2030".
2. **Energy Earthshot–Hydrogen Shot: "**Reduce the cost of clean hydrogen and enable $2 per kilogram of electrolysis by 2026 and $1 per kilogram by 2031."
3. **Hydrogen Hubs:** "Focus on regional networks, including deploying four or more regional hydrogen hubs to enable large clean hydrogen production and end-use in close proximity to each other and ramp up scale."

The plan is required to be updated every three years under the Bipartisan Infrastructure Law (BIL).

Clean Hydrogen Production Standard (CHPS)

Published as draft in September 2022, the Clean Hydrogen Production Standard creates a standard for clean hydrogen defining it a hydrogen with life cycle GHG emissions target of 4 kg CO_2e per kilogram of hydrogen. This is not a regulatory standard, but is used to guide policymakers in the future when deciding which projects to fund.

Inflation Reduction Act (January 2022)

Production Tax Credit: Proposed a clean hydrogen production credit for any taxable year that is within the 10-year period beginning on the date such facility was originally placed in service.

The credit is equivalent to (a) multiplied by (b):

(a) The kg of **qualified clean hydrogen** produced.

(b) The **applicable amount** defined below:

The **applicable amount** is a **applicable percentage** of $0.60 USD.

The **applicable percentage** is defined based on the life cycle greenhouse emissions per kg of hydrogen produced:

Applicable Percentage Ranges:

- 2.5 kg of $CO_2e \leq x < 4.0$ kg of CO_2e per kg hydrogen produced
  - *Applicable Percentage* = 20%
- 1.5 kg of $CO_2e \leq x < 2.5$ kg of CO_2e per kg hydrogen produced
  - *Applicable Percentage* = 25%
- 0.45 kg of $CO_2e \leq x < 1.5$ kg of CO_2e per kg hydrogen produced
  - *Applicable Percentage* = 33.4%
- $<$ 0.45 kg of CO_2e per kg hydrogen produced
  - *Applicable Percentage* = 100%

Qualified Clean Hydrogen:

Qualified clean hydrogen is hydrogen produced with a lifecycle greenhouse gas emissions process rate of not greater than **4 kg of CO_2e per kg of hydrogen**.

Life Cycle Greenhouse Gas Emissions:

(1) Defined "lifecycle greenhouse gas emissions" as the same under subparagraph (H) of section 211(o)(1) of the Clean Air Act (42 U.S.C. 7545 (o)(1))
(2) GREET model as developed by Argonne National Laboratory

Bipartisan Infrastructure Law (BIL) (November 2021)

**Infrastructure Investment and Jobs Act of 2021*

Regional Clean Hydrogen Hubs: Established funding of $7 billion USD for 6 to 10 Regional Clean Hydrogen Hubs (H2Hubs). A hub creates "networks of hydrogen producers, consumers, and local connective infrastructure to accelerate the use of hydrogen as a clean energy carrier that can deliver or store tremendous amounts of energy"

Requirements:

(1) Provides a minimum of 50% non-federal cost share (50% of the total project cost including both DOE share and recipient cost share, for a total project cost of at least $800 million to $2.5 billion) to be executed over approximately 8-12 years (or sooner) depending on the size and complexity of the H2Hub
(2) The award period will include the planning, development, and construction of the H2Hub as well as 2-4 years of operations.

Deadlines: Concept papers were due by November 7, 2022 and applications must be filed by April 2023.

Taiwan Institute of Economic Research

Renewable Hydrogen: California

LAST UPDATED: 27th March 2023

OVERVIEW

California has been leading the country in the development of a clean hydrogen industry and deployment of hydrogen fuel-cell vehicle technology and infrastructure. In the past couple of years, large energy producers have announced and begun development of renewable hydrogen projects in the state.

The California Air Resources Board is tasked with setting standards for air quality and is also responsible for drafting and monitoring legislation targeted towards reducing emissions and reaching net-zero. The Low Carbon Fuel Standard program, regulated by the California Air Resources Board, is the guarantee of origin program for hydrogen in California.

Many policies in California are directed towards increasing the use of Zero-Emission Vehicles, including hydrogen fuel cell light-, medium- and heavy-duty vehicles, by providing incentives and rebates and building up supporting infrastructure.

ORGANIZATIONS

1. **California Air Resources Board (CARB):** Responsible for the creation, monitoring, and evaluation of policies targeted towards NZE goals.
2. **ARCHES:** The Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES) is a consortium of government agencies, research labs, and private companies allied to develop clean hydrogen hubs in California. Including Go-Biz and CARB, different research labs and city governments, and important companies such as Air Products and Chevron.
3. **GO-Biz:** A state agency in California that supports economic development and job creation efforts in the state.
4. **Public Utilities Commission:** The commision sets the standards and definitions of clean hydrogen in California.

REGULATION & POLICIES

Guarantee of Origin (GO) in California:

Low Carbon Fuel Standard Program:

Regulated by the California Air Resource Board (CARB), the Low-Carbon Fuel Standard Program (LCFS) provides GO certification to verify the source and production of renewable hydrogen. It requires transportation producers and importers to reduce the carbon intensity of multiple fuels, including hydrogen. The goal of the program is to reduce emissions to below 2010 standards by 10% by the year 2022.

Under the LCFS market-incentive program, renewable hydrogen producers can apply for LCFS credits. These tradable certificates equate to a emissions reduction of **1 metric ton of CO_2e**.

These certificates are sold on the open market to parties obligated to meet annual carbon intensity requirements set by LCFS and voluntary buyers who support clean energy:

Those required to meet LCFS CI standards are:

1. Refiners and importers of gasoline and diesel fuel
2. Producers and importers of alternative fuels, such as renewable/clean hydrogen
3. Suppliers of transportation fuels to California consumers, including fuel distributors and retailers

These standards can be met through:

1. Producing clean energy
2. Purchasing LCFS credits

Standards: For each type of eligible hydrogen fuel the CI standard that must be met to qualify for LCFS program is listed in the referred table: (CA-GREET3.0 Lookup Table**)**

Public Utilities Commision:

The standards for the clean hydrogen in California are set by the California Public Utilities Commission.

Standards: Hydrogen produced with a carbon intensity up to 4 kg of CO_2e. This includes hydrogen produced by breaking down methane from biomass and biomethane.

Hydrogen Strategy Act of 2021: Senate Bill 1505

Defines regulation standards for hydrogen as:

1. Renewable resources: 33.3% of H2 produced must be made from renewables
2. NOx reduction: 50% reduction of NOx emissions relative to gasoline
3. GHG reduction: 30% reduction of GHG emissions relative to gasoline
4. Toxic Air Contaminants: No increase in toxic air contaminants

Application: Applies to state funded/co-funded hydrogen stations immediately and all hydrogen stations once 3,500 metric tons/year statewide throughput is reached.

The Energy and Climate Change Budget Bill: Assembly Bill 209

Provides funding for the Clean Hydrogen Program which supports projects that produce, process, deliver, store or use hydrogen that is produced from eligible renewable sources.

Eligible Projects: Reduce sector-wide emissions, benefit geographically diverse areas of the state, and/or maximize air quality, equity, health, and workforce benefits.

Hydrogen Fuel Standard: CA Code and Regulations Title 4, Section 4180-4181

Standard: Hydrogen fuel used in internal combustion engines and fuel cell vehicles must meet the standards set by the Society of Automotive Engineers (SAE) J2719 code.

Scoping Plan of 2022

Summary: The Scoping Plan of 2022 is the plan created by the California Air Resource Board to "reduce anthropogenic greenhouse gas (GHG) emissions by 85 percent below 1990 levels no later than 2045" (California Air Resources Board, 2022). It calls for the deployment of clean energy and sustainable development, with renewable hydrogen requirements set by industry.

Renewable Hydrogen: Requirements by Industry

TARGET	OVERVIEW
OCEAN-GOING VESSELS	Requires that 25% of Ocean-going vessels utilize hydrogen fuel cell electric technology by 2045.
AVIATION	Requires that 25% of aviation fuel demand be met by electricity (batteries) or hydrogen (fuel cells) by 2045.
FREIGHT AND PASSENGER RAIL	Requires that haul and passenger rail rely primarily on hydrogen fuel cell technology, and others use electricity.
CHEMICALS AND ALLIED PRODUCTS PULP AND PAPER	Requires that hydrogen is used for 25% of process heat by 2035, and 100% by 2045.
LOW-CARBON FUELS FOR TRANSPORTATION	Requires that biomass supply is used to produce hydrogen.
LOW-CARBON FUELS FOR BUILDING AND INDUSTRY	Requires that hydrogen blended in fossil gas pipelines at 7% energy (~20% by volume) to increase between 2030 and 2040. In 2030, dedicated hydrogen pipelines are to be constructed.

Zero Emissions Vehicles (ZEV)

*FCEVS are included under ZEV policies as they meet the requirements of Alternative Fuel Vehicles

NAME	CATEGORY	OVERVIEW	CITATION
Zero-or Near-Zero Emission Vehicles Component Rebates	Rebate	Establishes the Zero-Emission Project (ZAP) which provides applicants with a rebate to replace a battery, fuel cell, or other vehicle component. Rebates are available through July 31, 2025.	CA HS C 44274.9
Alternative Fuel Vehicle Parking Incentives	Incentive	Orders public parking spaces owned by the Department of General Services (DGS) and park-and-ride lots owned by the Department of Transportation (Caltrans) with 50 spaces or more to create preferred parking benefits for ZEVs. This includes fueling infrastructure, preferential spaces, and reduced fees.	CA PR C 25722.9
Alternative Fuel Vehicle and Fueling Infrastructure Grant	Grant	Provides funding via fees collected from the Motor Vehicle Registration Fee Program to reduce air CA HS C 44220 (b)pollution from on-and off-road vehicles. This includes the purchase of AFVs and fueling infrastructure.	CA HS C 44220 (b)
The California Clean Truck, Bus, and Off-Road Vehicle and Equipment Technology Program	Program	Usings funds allocated to the program, funds development and implementation for zero and near-zero emission trucks, buses, off-road vehicles and equipment. Included is greater motor vehicle and equipment freight efficiency and GHG reductions.	CA HS C 39719.2
Light-Duty Zero Emissions Vehicle Sales Requirement	Requirement	By 2035, all sales of light-duty passenger vehicles in California must be ZEVs. To be achieved through the deployment of the ZEV Market Development Strategy	Executive Order N-79-20)
Medium- and Heavy-Duty Zero Emission Vehicle (ZEV) Requirement	Requirement	By 2045, all sales of medium- and heavy-duty vehicles in California must be ZEVs. Annual sale percentages quotas by vehicle class are set by the Advanced Clean Truck Program.	CA Code of Regulations Title 13, 1963-1963.5 and 2012-2012.2

MARKET

Listed below are a couple of the new projects in development for clean hydrogen in California, both private and public ventures.

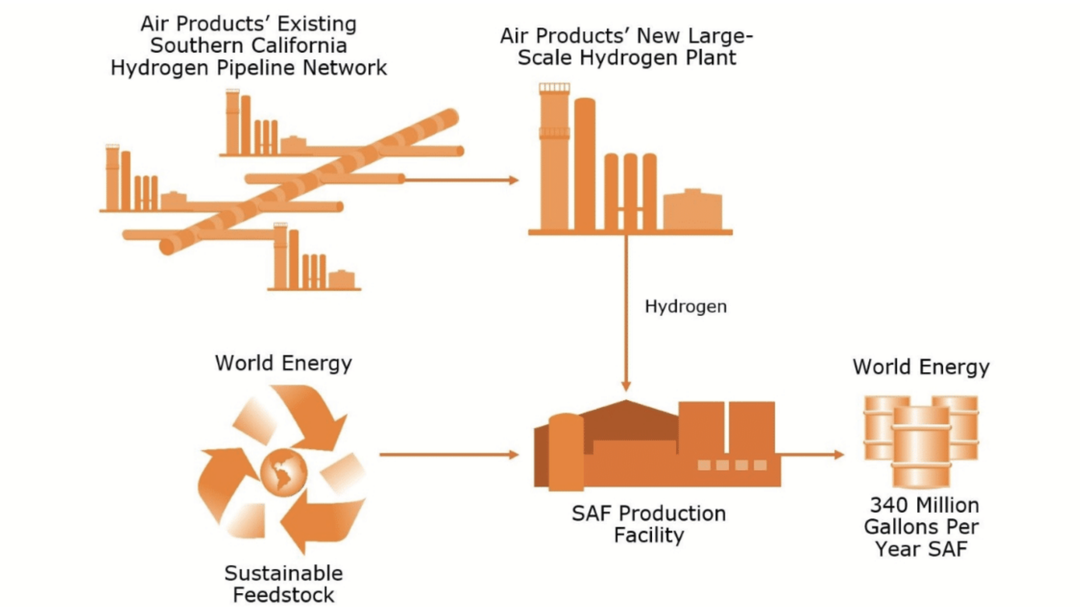
Air Products: Sustainable Aviation Fuel (SAF) – Paramount, CA

Type: Project

Status: Announced

Air Products together with World Energy announced a new $2 billion USD expansion project for a sustainable aviation fuel production and distribution hub in Paramount, CA (April 2022).

- Expands Air Products' South California Hydrogen pipeline
- Funds a new large-scale hydrogen plant
- Targeted goal of producing 340 million gallons of SAF per year
- Targeted opening year is 2025.



Air Products, *Sustainable Aviation Fuel Project,* 2022, https://www.airproducts.com/campaigns/casaf

SGH2: Green Hydrogen Plant – Lancaster, CA

Type: Project

Status: Announced

SGH2 is building a green hydrogen plant in Lancaster, CA that uses recycled mixed paper waste to produce green hydrogen (February 2023)

- Reduces emissions 2 to 3 times more than methods using electrolysis and renewable energy
- Cost is 5 to 7 times cheaper than gray hydrogen (SMR)
- The plant will be co-owned by the City of Lancaster
- Production Capabilities:
    - Daily: 11,000 kg
    - Yearly: 3.8 million kg
    - Yearly: 42,000 tons waste processed

Hydrogen Fuel Hub: Federally Funded Grants – California

Type: Project

Status: Ongoing bidding for grants

Under the Infrastructure Investment and Jobs Act (IIJA), $8 billion USD was made available to develop at least 4 regional clean hydrogen hubs. In May 2022, California announced it will intend to seek funding to develop a regional hub in California.

Taiwan Institute of Economic Research

Renewable Hydrogen: Colorado

LAST UPDATED: 12nd April 2023

OVERVIEW

Colorado is mainly focused on developing hydrogen for the transportation sector with fuel cell vehicles. The state has wind and solar resources for renewable electricity as well as existing natural gas infrastructure. The most promising market in the short term is medium to heavy duty fuel cell vehicles such as buses and trucks. The medium term outlook is for hydrogen to be used in the electricity sector as a way to store excess electricity.

ORGANIZATIONS

Colorado Energy Office

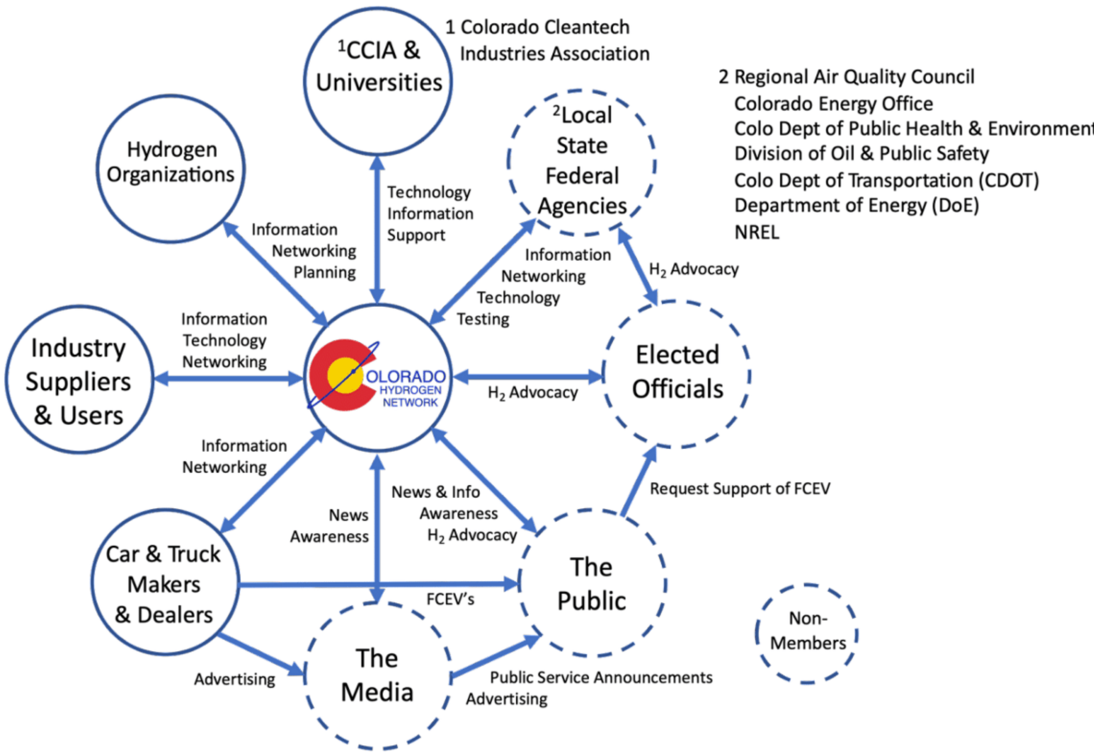
Colorado State Government organization

The Colorado Energy Office (CEO) is primarily focused on supporting the development of a robust hydrogen infrastructure, promoting the adoption of hydrogen fuel cell vehicles, and facilitating the use of hydrogen in other applications, such as power generation and heating.

Source: https://energyoffice.colorado.gov/

Colorado Hydrogen Network

The Colorado Hydrogen Network is a non-profit, membership-based hydrogen advocacy organization. Its primary goal is to promote the environmental and economic benefits of hydrogen and fuel cell technology, especially for transportation.



Source: https://www.colorado-hydrogen.org/members

ROADMAPS

Colorado Hydrogen Plan Roadmap (Oct 2021)

Created by Colorado Energy Office

Source: https://drive.google.com/file/d/1wV2Xq1COF0BY77X_OSvkNSMKgPNeMfcU/view

Colorado aims to reduce greenhouse gas emissions by 26% by 2025, 50% by 2030, and 90% by 2050. To achieve this, the state's energy office released a low-carbon hydrogen roadmap, identifying hydrogen as a key fuel for reducing emissions in hard-to-electrify sectors beyond 2030. Hydrogen could replace natural gas for electric peaking generation and provide load-following services to the electric grid. E3 recommends developing a hydrogen plan and mid-term targets related to hydrogen deployment in Colorado. Short-term applications for hydrogen consumption include medium and heavy-duty vehicles, while high-temperature industrial processes offer potential in the long term. Hydrogen delivery via pipeline and a large-scale central hub of storage are cost-effective opportunities for transport and storage.

Colorado GHG Pollution Reduction Roadmap

Created by Colorado Energy Office

Source: https://drive.google.com/file/d/1jzLvFcrDryhhs9ZkT_UXkQM_0LiiYZfq/view

Hydrogen energy can play a significant role in reducing greenhouse gas (GHG) emissions and achieving Colorado's 2025 and 2030 GHG emissions targets. The state's largest sources of GHG pollution are transportation, electricity generation, oil and gas production, and fuel use in residential, commercial, and industrial spaces. The transition to renewable energy sources and deep reductions in methane pollution from the oil and gas industry are critical to achieving the 2030 goals. Changes in transportation planning and infrastructure can also help reduce driving, and electrification of end uses in buildings and transportation will play a vital role. By 2050, nearly 100% of all cars on the road will need to be electric. Additionally, reducing methane emissions from landfills, sewage plants, and other sources, and enhancing waste reduction efforts, is necessary. Protecting and enhancing the resilience of Colorado's natural and working lands is also critical for sequestering carbon.

POLICIES

Hydrogen Laws and Incentives in Colorado from US DOE's Alternative Fuels Data Center

SOURCE: https://afdc.energy.gov/fuels/laws/HY?state=co

Alternative Fuel Vehicle (AFV) Registration

1. When registering a vehicle in Colorado, the owner must report the type of alternative fuel used and whether the vehicle uses more than one fuel.
2. The Colorado Department of Revenue provides forms for registering motor vehicles with spaces for reporting the use of gasoline, diesel, propane, electricity, natural gas, methanol/M85, ethanol/E85, biodiesel, and other fuels.
3. Alternative fuels are important for reducing greenhouse gas emissions and improving air quality.

Zero Emission Vehicle Tax Credits

SOURCE:
https://energyoffice.colorado.gov/zero-emission-vehicles/zero-emission-vehicle-tax-credits

1. Colorado offers tax credits for the purchase or lease of electric vehicles and plug-in hybrid electric vehicles
2. Tax credits are also available for the purchase, lease, and conversion of alternative fueled vehicles, such as those running on CNG, LNG, LPG, or hydrogen.
3. No credit is allowed for the purchase or lease of a used vehicle made on or after Jan. 1, 2017, and inquiries about tax-related advice should be directed to the Colorado Department of Revenue.

Fleet Alternative Fuel Vehicle Incentive Authorization

1. The Colorado Department of Public Health and Environment (CDPHE) can issue grants, loans, and rebates through the Clean Fleet Enterprise to help businesses and government entities replace their fleet vehicles with clean vehicles.
2. The program applies to light-, medium-, and heavy-duty vehicles and includes electric, hydrogen, and renewable natural gas vehicles, as well as idle reduction technology.
3. The Enterprise may charge fees to finance these programs and promote the adoption of clean vehicles in the state.

PROJECTS

NREL's Hydrogen Infrastructure Testing and Research Facility (HITRF)

Source: https://www.nrel.gov/hydrogen/hitrf.html

1. Develop, quantify performance of, and improve renewable hydrogen production methods
2. Evaluate fuel cell electric vehicle technologies and system configurations
3. Validate hydrogen infrastructure components and fueling protocols
4. Assess and validate safety, codes, and standards.

The facility is the hydrogen energy research branch of NREL's Energy Systems Integration Facility (ESIF) in Golden, Colorado.

Taiwan Institute of Economic Research

Renewable Hydrogen: Hawaii

LAST UPDATED: 17th April 2023

OVERVIEW

Hawaii began investing in renewable hydrogen with the creation of the Renewable Hydrogen Program and Hydrogen Investment Capital Special Fund in 2006. The program and consequential policies are focused on reducing Hawaii's dependence on fossil fuels and transitioning to hydrogen fuel.

Currently in Hawaii there is no guarantee of origin (GO) scheme and the definition of renewable hydrogen relies on the source that is used to produce it. Hawaii has also partnered with the US DOE on multiple projects that to receive funding would have to follow the clean hydrogen standard of 4 CO_2e emission per kg of hydrogen.

Definition: Under the Hawaii Renewable Hydrogen Program, renewable hydrogen that qualifies is hydrogen produced from renewable electricity generated from geothermal and wind power and hydrogen produced from biomass.

ORGANIZATIONS:

1. **Hawaii State Energy Office** – Governmental agency with goal of reaching net-zero in Hawaii
2. **Public Utilities Commissions** – In Hawaii, the Public Utilities Commission is tasked with managing renewable hydrogen rebates for fueling stations. It also manages the Renewable Portfolio Standard for renewable electricity .
3. **Hawaii Pacific Hydrogen Hub** – A consortium of public and private stakeholders, including energy companies, from Hawaii working to establish the Pacific H2Hub

POLICIES

Hawaii Clean Energy Initiative (HCEI)

The Hawaii Clean Energy Initiative (HCEI) is a comprehensive plan that aims to achieve Hawaii's clean energy future. The initiative was launched in 2008 between the State of Hawaii and the US Department of Energy to reduce dependence on imported fossil fuels. HCEI is used as a reference point for policies to advance the initiative.

GOAL: The state estimated that local, clean, renewable energy sources, including energy efficiency, could fulfill 60% to 70% of future energy needs in 2008. In 2014, HCEI reaffirmed its commitment to bold clean energy goals, such as achieving the nation's first-ever 100% renewable portfolio standards (RPS) by 2045.

Hawaii Renewable Hydrogen Program

SOURCE: Hawaii Renewable Hydrogen Final Report, Renewable Hydrogen Program 2010-2020
The Hawaii Renewable Hydrogen Program is a plan outlined steps for Hawaii to take between the years 2010 and 2020 to accelerate the adoption of hydrogen technology.

The main steps to accelerating the transition to renewable hydrogen are:

(1) Build up a large scale renewable energy grid
(2) Build up hydrogen infrastructure including production and storage

OBJECTIVES:

(1) **Infrastructure:** appropriated $8.7 million to fund infrastructure projects in addition to the Hydrogen Fund.
    (a) Renewable Energy: projects that develop renewable energy sources that can produce hydrogen
    (b) Production: infrastructure that produced hydrogen and dispensing systems
    (c) Entrepreneurships: support entrepreneurship in the hydrogen industry
    (d) Federal Funded Projects: cost-share for hydrogen projects from the government
(2) **Hydrogen-Fueled Vehicles:** recommendation to set standards and codes for hydrogen fuel cell cars and hydrogen fuel

Renewable Portfolio Standard (RPS)

SOURCE: PUC 2019 Report on RPS, RPS Goals in Hawaii

Under the Renewable Portfolio Standard (RPS) established in 2008, electric utility companies in Hawaii must meet a percentage of "renewable electrical energy" sales for each year. Renewable energy includes energy generated by hydrogen. The Public Utilities Commission (PUC) establishes yearly goals for sales, but they can't conflict with those set by legislation.

GOAL:

- 10% of its net electricity sales by December 31, 2010
- 15% of its net electricity sales by December 31, 2015
- 30% of its net electricity sales by December 31, 2020
- 40% of its net electricity generation by December 31, 2030
- 70% of its net electricity generation by December 31, 2040
- 100% of its net electricity generation by December 31, 2045

Hydrogen Investment Capital Special Fund

SOURCE: Hydrogen Investment Capital Special Fund, 2008-2009,

Passed as part of the 2006 Act 240, Session Laws of Hawaii 2006, The Hydrogen Investment Capital Special fund, formerly managed by Hawaii Strategic Development Corporation (now Hawaii Technology Development Corporation)

GOAL: It provided both seed (target start-ups) and venture (companies able to match funds) capital investments to hydrogen initiatives with the goal of creating public-private partnerships with companies focused on hydrogen technology. It prioritized projects first working on research, development, testing and implementation of renewable hydrogen technology, and general renewable technology second.

Alternative Fuels and Electric Vehicles

Name	**Type**	**Specifications**
Alternative Fuel Standard Development	Standard	Requires the state of Hawaii to develop a standard for alternative fuels (including hydrogen fuel). Under this standard, highway fuel demand should be composed of 20% by alternative fuel and 30% by 2030.
Alternative Fuel Tax Rate	License Tax	Requires distributors that use or sell alternative fuel to pay a license tax of $0.0025 per gallon. In addition, an extra tax (depending on energy content of fuel)
Alternative Fuel Vehicle Registration	Fee	Owners of electric plug-in vehicles (including hydrogen) are required to pay a registration of $50 to fund the State Highway Fund.
Alternative Fuel and Advanced Vehicle Acquisition and Rental Requirement	Requirement	State agencies must acquire 100% ZEV fleets of light-duty vehicles by 2035. During transition period, states and counties may buy
Hydrogen Fuel Station Rebate Authorization	Rebate	Offers up to $200,000 for the installation or upgrading of hydrogen fueling stations. Prioritizes public projects, projects that service fuel cell electric vehicles, and projects that serve multiple customers
Medium- and Heavy-Duty (MHD) Zero Emission Vehicle (ZEV) Deployment Support	Program	Hawaii has joined the multi-state medium- and heavy-duty ZEV action plan. The plan in partnership with the US DOE is to reduce emissions from trucks and buses in the US. Published in 2022, details for implementation can be found under the Medium- and Heavy-Duty ZEVs: Action Plan Development Process

MARKET

Hawaii Hydrogen Hub

SOURCE: Announcement

Hawaii Pacific Hydrogen Hub consortium composed of stakeholders like Hawaiian Electric Co, 174 Power Global and other companies announced a plan to bring a Hydrogen Hub to Hawaii. The idea is to raise $500 million in funds to match the federal government's $500 million to build the Hawaii Pacific Hydrogen Hub.

The building of the hub would reduce emissions and dependency on fossil fuels and increase fuel efficiency. Fuel could be sold to high consumers like the military which has a heavy presence in Hawaii. This would create more jobs in Hawaii as well. The final proposal was submitted to the U.S. Congress in April with the final decision set to be released in September 2023.

Waste-to-Energy: DOE Funds Hawaiian Research Company

SOURCE: Funding from DOE

Simonpietri Enterprises received $1.6 million in funding from the DOE to fund its waste-to-energy research project. This project focuses on taking construction and demolition debris out of landfills and making hydrogen fuel out of it. This project is one of the new projects the DOE has funded as part of its plan to reduce the cost of clean hydrogen and increase availability.

Taiwan Institute of Economic Research

Renewable Hydrogen: Texas

LAST UPDATED: 6th April 2023

OVERVIEW

In recent years, there has been a growing interest in developing renewable hydrogen production facilities and infrastructure in Texas. Texas is rapidly becoming a hub for hydrogen production through the establishment of large-scale projects.

In Texas, there are several policies and regulations in place to support and incentivize the development of renewable hydrogen. These policies include the Renewable Portfolio Standard (RPS), Texas Emissions Reduction Plan (TERP), and Alternative Fueling Facilities Program (AFFP). Texas has also initiated regulatory frameworks to ensure the safe production, transport, and storage of hydrogen through the Renewable Energy Credit (REC) Program, Texas Railroad Commission, and Texas Commission on Environmental Quality (TCEQ).

The market for renewable hydrogen in Texas is still in its early stages, but there are several projects underway to develop hydrogen production facilities and infrastructure. For example, Air Liquide is building a renewable hydrogen production plant in Wilbarger County, Texas, while Brownsville, Texas is developing the world’s largest hydrogen hub with an on-site salt-cavern for storage.

REGULATION & POLICIES

Renewable Portfolio Standards (RPS)

SOURCES: United States Environmental Protection Agency, Institute for Local Self-Reliance

Goal: To reach 50% of renewable energy generation by 2030.

Guide to Action:
https://www.epa.gov/sites/default/files/2017-06/documents/guide_action_chapter5.pdf

Standards:

- For non-wind renewable energy (i.e. solar, geothermal, biomass, etc.), to generate 5000 MW of renewable energy by 2025.
- For wind renewable energy, to generate 18,000 MW by 2025.

Renewable Energy Credit (REC) Program

Established in 2009 that ensures customers have access to purchase energy produced by renewable energy resources.

SOURCE: Texas.gov

Summary of RECs: El Paso Electric

Standards:

- Each REC represents 1 MW-hr of renewable energy generation, and utilities can use these credits to meet their RPS goals.
- Certifiable way to buy and sell renewable energy in which each REC has a unique serial number to be easily tracked and recorded.
- Only facilities that meet the requirements of the PUC Substantive Rule 25.173(c) are capable of earning RECs.

Alternative Fueling Facilities Program (AFFP):

SOURCE: Texas Commission on Environmental Quality

A state-run grant program that provides funding for the construction or retrofitting of alternative fueling stations that is designed to increase the availability of alternative fuels, such as compressed natural gas (CNG), propane, hydrogen, and electric charging stations in Texas.

Funding: The AFFP is funded through the Texas Emissions Reduction Plan (TERP) that provides financial incentives to reduce emissions from mobile sources. Grants to public, private, and nonprofit entities for up to 50% of the total eligible project costs, with a maximum grant award of $600,000 per station.

Texas Commission on Environmental Quality (TCEQ)

As the environmental regulatory agency for Texas, they regulate the hydrogen value chain and provide grants to help the purchases of new equipment that uses alternative fuels. The TCEQ administers the Texas Emission Reduction Plan (TERP).

SOURCES: Developing a Robust Hydrogen Market in Texas (p. 48), US Department of Energy

Goal: To enforce environmental laws and regulations, and to provide guidance, education, and funding to individuals, businesses, and communities on how to protect and preserve the environment.

Texas Emission Reduction Plan (TERP)

The program provides incentives for businesses, governments, and individuals to upgrade or replace older, more polluting vehicles with newer, cleaner models that meet stricter emissions standards.

SOURCES: Texas Emissions Reduction Plan, Developing a Robust Hydrogen Market in Texas

Goal: To provide financial incentives to individuals and organizations that invest in clean technology for emissions-reducing equipment.

Incentives:

Table 7 — Hydrogen Incentives through TERP in Texas

Program	Description
Emissions Reduction Incentive Grants (ERIG) and Rebate Grants Programs, TERP – TCEQ	The ERIG Program provides grants to improve air quality in nonattainment areas and other affected counties. Eligible projects include those that replace, retrofit, repower, or lease/purchase new heavy-duty vehicles, develop alternative fuel dispensing infrastructure and electrification infrastructure, and involve alternative fuel use. The Rebate Grants Program provides grants to upgrade or replace diesel heavy-duty vehicles and non-road equipment.
Clean School Bus Grants, TERP – TCEQ	Any public school district or charter school may receive a grant through TCEQ to pay for incremental costs to replace school buses or install diesel oxidation catalysts, diesel particulate filters, emission-reducing add-on equipment, and other emissions reduction technologies in school buses.
Texas Clean Fleet Program (TCFP), TERP – TCEQ	The TCFP provides grants to fleets to replace existing fleet vehicles with alternative fuel vehicles (AFV) or hybrid electric vehicles (HEV) that reduce emissions of nitrogen oxides or other pollutants by at least 25%. Neighborhood electric vehicles do not qualify. The last grant round was awarded in 2020 to five applicants (three school districts and two transit authorities) with a total of approximately $7.5 million.
Light-Duty Motor Vehicle Purchase or Lease Incentive Program (LDPLIP), TERP – TCEQ	LDPLIP is for the purchase or lease of light-duty vehicles using compressed natural gas or propane (up to $5,000), and hydrogen or electricity (up to $2,500). As of mid-2022, 386 vehicles had been awarded.
Governmental Alternative Fuel Fleet Grant (GAFF) Program, TERP – TCEQ	GAFF covers the purchase or lease of vehicles powered by natural gas, propane, hydrogen, or electricity. Grants are available based on vehicle class, ranging from $15,000 for Class 1 vehicles up to $70,000 for Class 7-8 vehicles. Up to 10% of funds may be for purchase, lease, or installation of refueling infrastructure, or refueling services. $6 million was awarded to a school district in 2021.
New Technology Implementation Grant (NTIG) Program, TERP – TCEQ	The NTIG program provides grants to offset the cost of implementing existing technologies to reduce pollution from stationary sources, including energy storage projects. The program has provided grants for electricity storage, improvements in combustion efficiency, process efficiency, and CO_2 capture. It has attracted comments related to expansion for hydrogen applications.[80]

Sources: Alternative Fuels Data Center, (https://afdc.energy.gov/laws/), U.S. DOE Energy Efficiency and Renewable Energy. See also TCEQ-TERP (https://www.tceq.texas.gov/airquality/terp/programs), Texas Statutes (http://www.statutes.legis.state.tx.us/), Transportation Code, Health and Safety Code, Water Code, and Texas Administrative Code (http://www.sos.state.tx.us/tac/index.shtml).

Incentives provided by TERP (Developing a Robust Hydrogen Market in Texas, Page 49).

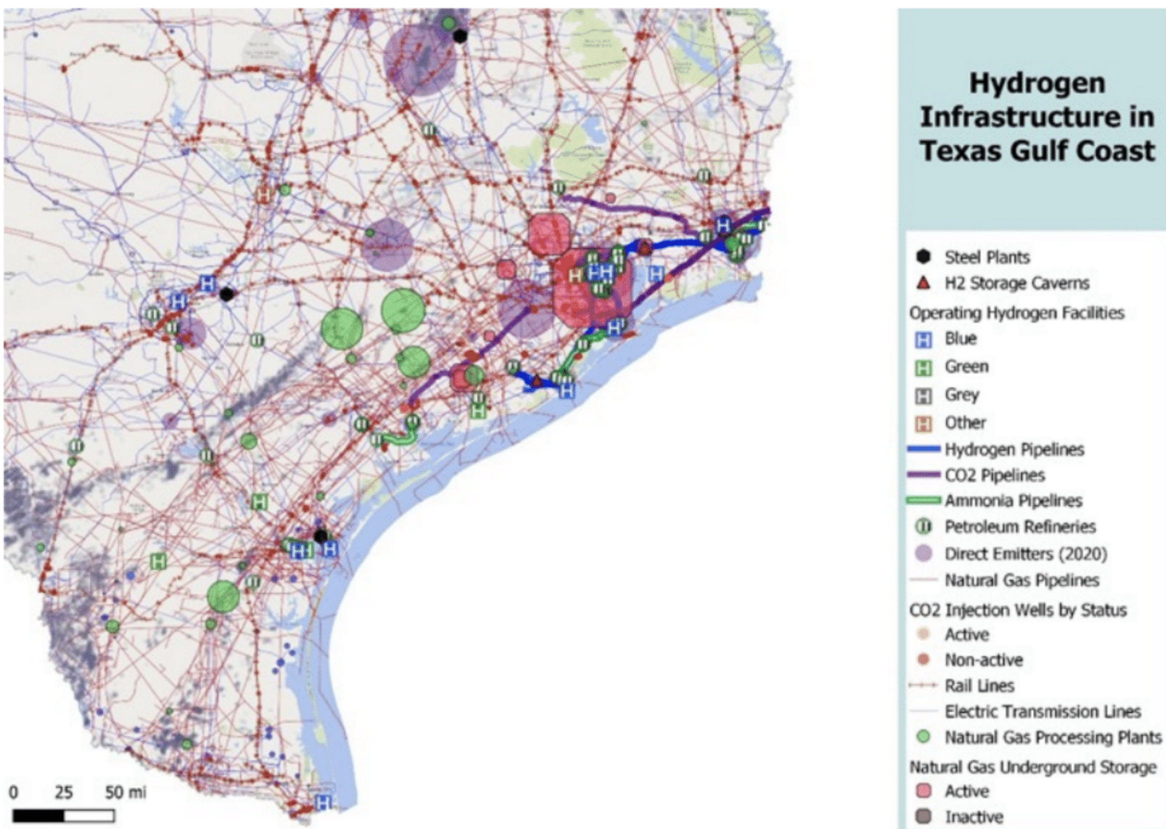
MARKET

Developing a Robust Hydrogen Market in Texas – Rice University

Rice University's Baker Institute for Public Policy has a working paper, "Developing a Robust Hydrogen Market in Texas", predicts a successful market potential of green hydrogen in Texas.

SOURCE: Developing a Robust Hydrogen Market in Texas

Figure 9 — Map of Existing Infrastructure in Texas Relevant to the Hydrogen Market



Sources: Data are taken from the Texas Railroad Commission, U.S. EIA, U.S. EPA, *Petroleum Economist*, Enverus, and authors' research. Mapping is done in QGIS.

Predicts strong potential for hydrogen in Texas Gulf Coast (SOURCE: Developing a Robust Hydrogen Market in Texas, Page 44).

Texas's Clean Hydrogen Hub – Houston, Texas

The Center for Houston's Future released a report, Houston as the epicenter of a global clean hydrogen hub, that discusses how Houston can utilize its strengths to establish itself as a central location for a worldwide clean hydrogen hub.

SOURCE: HyVelocity Hub in the Center for Houston's Future

Projections: With its carbon capture storage (CCS), they may be able to meet DOE's goal of $1/kg of hydrogen.

The demand to transition to renewable energy is high in Texas, as they have the potential to reach 21 MT by 2050. The following are the driving forces of this transition:

DRIVING FORCE	PRODUCTS	CONTRIBUTION TO DEMAND
Hydrogen-based force	--	10 MT
Industrial Applications	Feedstock, heating	6 MT
Mobility	Commercial Vehicles	2.3 MT
	Marine Aviation	1.5 MT
Utility Power Generation	--	1.6 MT

The report also highlighted a roadmap of the 2050 vision that constitutes of multiple phases:

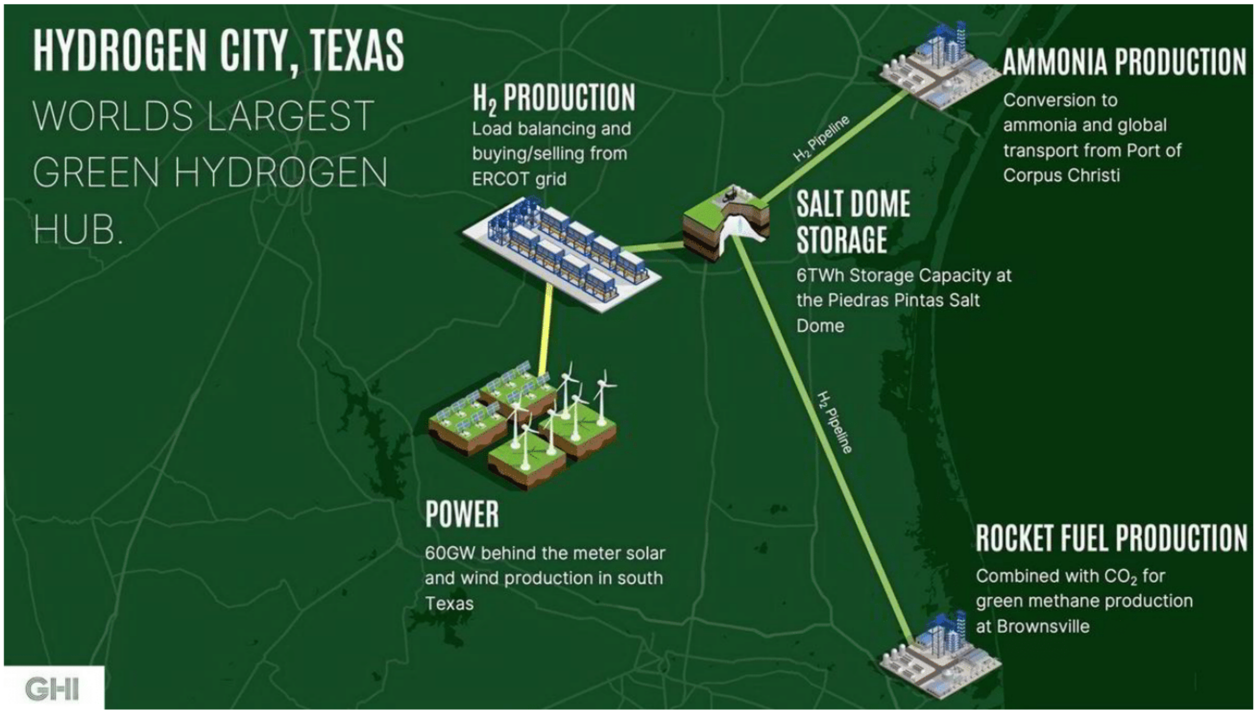
PHASE	YEAR	ACTION
Phase 1	2022-2025	Advocating for regulatory and policy incentives.
Phase 2	2025-2030	Decarbonize existing applications and explore new applications of energy.
Phase 3	2030-2035	Achieve the target of $1/kg of clean hydrogen.
Phase 4	2035-2050	Urge for local demand and export.

PROJECTS

60GW Hydrogen City – Brownsville, Texas

Type: Project

Status: Announced



Summary: Green Hydrogen International (GHI) announced a 60 GW renewable hydrogen project with an on-site salt cavern for hydrogen storage.

Plans:

1. Lowers the cost for renewable energy.
2. Production hydrogen from water with no emission of greenhouse gasses or pollutants.
3. Buffers of production through storage in salt caverns.
4. Production of green fuels to be shipped worldwide.

""Access to salt storage is critical to the scaling-up of green hydrogen production as it allows for maximum utilization of electrolysers and serves as a buffer between variable wind and solar production and final delivery of green hydrogen to customers," said GHI." (SOURCE: Recharge News)

Largest Green Hydrogen Facility in Texas – Air Products

Type: Project

Status: Announced

SOURCE: S&P Global

Summary: Air Products and AES are partnering to invest $4 billion to build the largest green hydrogen production facility in the US in Wilbarger County, Texas, using 1.4 GW of wind and solar assets, in which it is predicted to begin construction in 2027.

Plans: The Center for Houston's Future is the biggest drive for the project. Its goal is to produce 200 mt/day of green hydrogen, using wind and sun as energy sources.

Taiwan Institute of Economic Research

Renewable Hydrogen: Canada

LAST UPDATED: 5th April 2023

SOURCE: Hydrogen Strategy for Canada - https://natural-resources.canada.ca/sites/nrcan/files/environment/hydrogen/NRCan_Hydrogen%20Strategy%20for%20Canada%20Dec%2015%202200%20clean_low_accessible.pdf

OVERVIEW

Canada is one of the top countries invested in renewable hydrogen energy as it has an abundance of renewable energy sources, including hydroelectric, wind, and solar power, which provides a competitive advantage in developing renewable hydrogen technologies.

The main organizations developing policies surrounding hydrogen energy in Canada are:

1. **Natural Resources Canada (NRCan):** NRCan is a federal government agency responsible for promoting sustainable energy development in Canada, including hydrogen energy
2. **Canadian Hydrogen and Fuel Cell Association (CHFCA):** CHFCA is a non-profit organization that represents the Canadian hydrogen and fuel cell sector.
3. **Canadian Energy Strategy:** The Canadian Energy Strategy is a collaborative effort between the federal, provincial, and territorial governments of Canada to develop a long-term energy strategy for the country.

Target Export markets

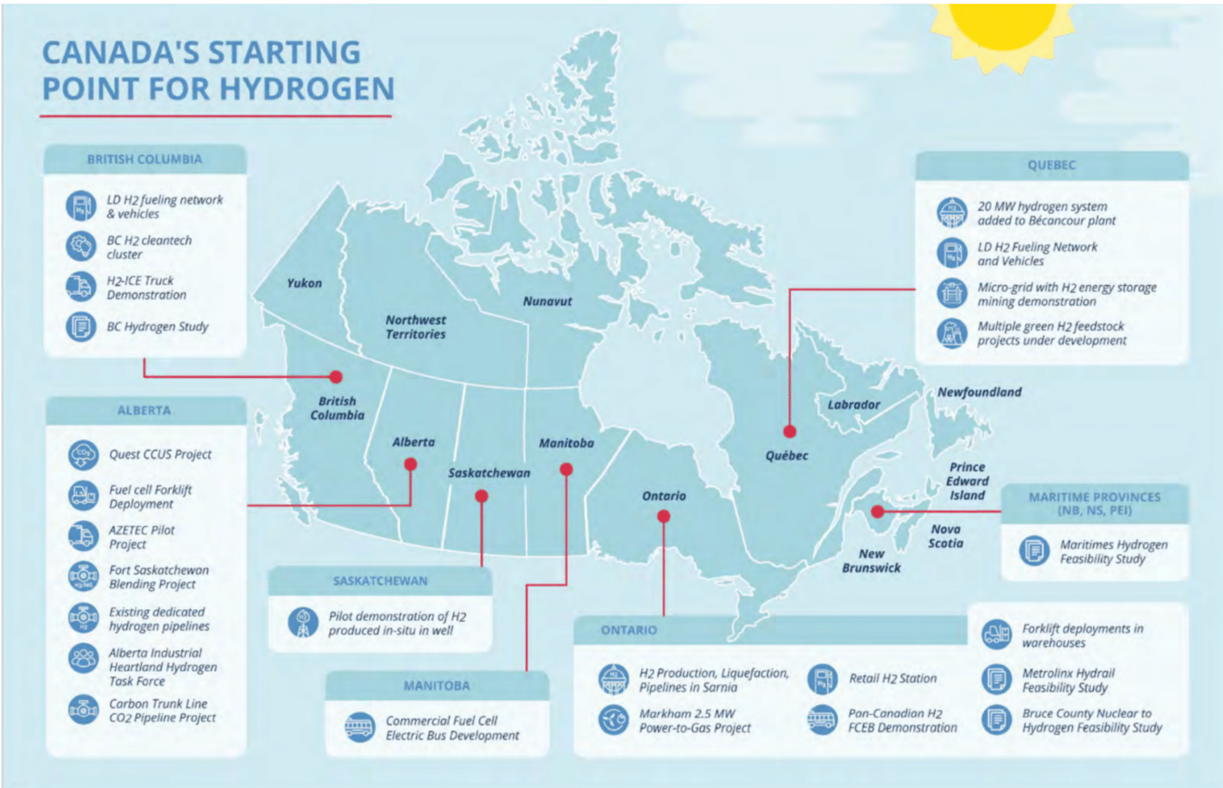
- USA (particularly California and the Eastern US)
- Japan,
- South Korea
- China
- European Union

*In the future if the market evolves, South America will also be a target

Emerged Cross-Cutting Themes

THEME	PURPOSE
MOMENTUM	The interest in hydrogen is growing throughout the world. Canada needs to act now to ensure we are not left behind.
ACTION	There are specific things we can focus on.
SIGNATURE PROJECTS	Increased focus can be brought to the creation and implementation of large-scale projects that could be highlighted and promoted internationally.
DOMESTIC DEPLOYMENT	Canada needs a strong domestic hydrogen market to ensure it can take advantage of and seize opportunities internationally.
LOW-CARBON INTENSITY	As the market grows, so should our focus on ensuring that hydrogen is produced using methods that have the lowest environmental impact.
HEAD START	Canada has a burgeoning hydrogen industry that gives us a significant competitive advantage.

Areas of Importance



Leading provinces in H2 initiatives in Canada (Hydrogen Strategy for Canada, 2020)

Due to the graph above, we chose to research the following four provinces of Canada:

- Alberta
- British Columbia
- Ontario
- Quebec

The European Commission

CertifHy, a pilot program created by the European Commission to develop an EU-wide Guarantee of Origin (GO) scheme for green and low carbon hydrogen that considers both the origin of the hydrogen and its greenhouse gas (GHG) intensity.

Recommendation: Threshold for GHG intensity is set at a 60% below the intensity of hydrogen produced from natural gas, currently set at 36.4 gCO_2e/MJ.

Relation to Canada: Canada seems to be following this definition of clean hydrogen as a guideline, but there is no clear definition as of now. They are first trying to define how to implement tax credits.

Low Carbon Hydrogen Standard

Canada does not currently follow the low-carbon hydrogen international standard because there is still no current standard for clean hydrogen.

Tax Credits: Canada will be implementing a hydrogen tax credit in 2023 that will be based on the US Inflation Reduction Act (IRA):

- Support emissions of 4.0kg of CO_2e or less per kg of hydrogen
- Highest support for levels of 0.45kg of CO_2e or less per kg of hydrogen

Canada will be changing the carbon intensity numbers and the amount of support based on what Canada needs and the different production methods. The credit will be made for the 2023 budget with the goal to phase out the credit system by 2030.

Source: Canada Fall Economic Statement 2022 - https://www.budget.canada.ca/fes-eea/2022/home-accueil-en.html

SPECIFICATIONS

The Canadian government listed the following barriers to their adoption of clean hydrogen.

Barriers of Hydrogen Adoption

BARRIERS	**DESCRIPTION**
ECONOMIC	A large upfront cost is needed for the investment into clean hydrogen technology.
INNOVATION	There has not been enough sustained investment to continuously improve the technology.
POLICIES	No long term policy that highlights hydrogen's importance in Canada's future.
CODES AND STANDARDS	Gap in existing codes and standards, reliant on EU standards.
AVAILABILITY	Limited domestic supply of low-carbon intensity hydrogen.
AWARENESS	Lack of general awareness in the general public, as well as tz industry and government.

Methods of Storage

STORAGE METHOD	DESCRIPTION
SALT CAVERNS	For underground storage of gaseous hydrogen.
HIGH-PRESSURE TANKS	Compressed gas stored as cryogenic liquid in specialty-insulated tanks.

REGULATIONS, STRATEGIES & POLICIES

"In September 2019, Canada was the first nation to endorse a pledge through the Global Commercial Vehicle Drive to Zero initiative to speed adoption of zero-emission and near-zero emission medium- and heavy-duty vehicles in urban communities by 2025 and achieve full market penetration by 2040." (Hydrogen Strategy for Canada, 2020)

Federal Hydrogen Strategy

Summary: In December 2020, the federal government of Canada announced its Hydrogen Strategy, which aims to position Canada as a global leader in hydrogen production and export. Canada's Federal Hydrogen Strategy is a plan to position Canada as a global hydrogen leader and build a competitive and sustainable hydrogen industry in Canada.

Sets a vision for their three pillars:

1. Building a domestic hydrogen supply chain
2. Creating end-use markets for hydrogen
3. Developing enabling policies and regulations

Goals: To establish Canada as a top-five producer of hydrogen and hydrogen products in the world by 2030, and to create 350,000 new jobs in the hydrogen sector by 2050.

Funding: $1.5 billion in funding over the next 10 years to support the development and deployment of low-emission and zero-emission hydrogen technologies and infrastructure.

Applications: Collaboration between government, industry, and other stakeholders to advance the hydrogen industry in Canada, and highlights the potential for hydrogen to play a key role in Canada's transition to a low-carbon economy.

Clean Fuel Standard

Summary: Canada's Clean Fuel Standard (CFS) is a regulation designed to reduce greenhouse gas emissions by increasing the use of cleaner fuels.

Parameters:

- The CFS sets a national benchmark for the carbon intensity of fuels and requires fuel suppliers to gradually reduce the carbon intensity of the fuels they produce and import.
- Fuel suppliers are assigned a carbon intensity score for each type of fuel they supply, and can meet their obligations by reducing the carbon intensity of the fuels they supply, using credits, or purchasing credits from other suppliers.

Goals: The CFS is expected to reduce Canada's greenhouse gas emissions by 30 million tonnes per year by 2030, and promote investment in clean technologies and a low-carbon economy.

Applications: The CFS applies to liquid, gaseous, and solid fuels, including gasoline, diesel, natural gas, propane, and biofuels, and is being phased in over several years.

Relationship to Hydrogen: This standard emphasizes a need to reduce emissions of hydrogen in all forms of production, as opposed to shifting to completely renewable production methods. Canada's abundance of feedstock makes tracking emissions a more effective way to use their many resources.

Canada’s Energy Future 2021

Summary: Canada's Energy Future 2021 report by the Canada Energy Regulator provides a projection of the country's energy supply and demand trends to 2050.

The report highlights:

- Canada's total energy use will increase by 1.3% annually until 2050, with renewable energy sources experiencing the fastest growth rate.
- Renewable energy sources will account for more than 60% of total electricity generation by 2050.
- Energy-related greenhouse gas emissions will decline by around 36% from 2019 to 2050, with the largest reductions coming from the electricity sector and increased adoption of low-carbon technologies.

Goals: To provide a robust and evidence-based analysis of Canada's energy system that can support informed decision-making and contribute to a sustainable and prosperous energy future for the country.

Net Zero Accelerator Fund

Summary: The Net Zero Accelerator Fund is a $8 billion fund established by the federal government to support the development and deployment of technologies that will help Canada achieve its net-zero emissions target by 2050.

The Net Zero Accelerator Fund:

- Includes investments in renewable hydrogen technologies and infrastructure, recognizing the potential of hydrogen to help decarbonize key sectors such as transportation, industry, and buildings.
- Provides money for research, development, demonstration, and commercialization of clean technologies across various sectors, including energy, transportation, and industry.

Goals: To reduce greenhouse gas emissions, supporting innovative projects, promoting clean energy, and meeting Canada’s climate change commitments.

Clean Energy Fund

Summary: The Clean Energy Fund is a $1.4 billion fund that supports the development and demonstration of innovative clean energy technologies, including renewable hydrogen.

Timeframe: 2009 to 2018

The fund is managed by Natural Resources Canada and provides funding for research, development, and demonstration projects aimed at advancing clean energy technologies and reducing greenhouse gas emissions.

The Clean Energy Fund supports:

- A range of clean energy technologies, including renewable energy, energy efficiency, and clean transportation.
- The development of clean energy infrastructure and the adoption of clean energy technologies in key sectors such as industry, buildings, and transportation.

Renewable Energy Certificate System

Summary: Canada uses a domestic REC system that is specific to certain provinces and territories.

In 2021, Canada's budget allocated money to purchasing renewable energy certificates for all its government buildings through the Federal Clean Electricity Fund.

- Starting at $14.9 million over 4 years
- Plan to spend $77.9 million in future years

All the REC go towards energy that is produced energy that is made domestically.

Appendix J.7: Alberta, Canada Report

Taiwan Institute of Economic Research

Renewable Hydrogen: Alberta

LAST EDITED: 10th April 2023

Alberta

OVERVIEW

Alberta, a province located in western Canada, is known for its reserves of oil sands, natural gas, and conventional oil, which have made it a significant contributor to the country's energy industry. The region is also the largest producer of hydrogen in Canada, with hydrogen being used in the oil, gas, and chemical industries. Of the 2.5 million tons of hydrogen produced in Alberta during 2021, 81% is gray hydrogen and 19% is blue hydrogen (Alberta Energy Regulator). There are also many potential sites for CCUS (Carbon Capture, Utilization and Storage) to be created for capturing carbon emissions from the hydrogen production process.

Alberta, with its abundant natural gas reserves and existing pipeline infrastructure, has the opportunity to become a leader in renewable hydrogen production and export. The cities of Edmonton and Calgary have been identified as the best-positioned in Alberta to create Hydrogen Hubs where these hubs would leverage the existing natural gas pipeline infrastructure and renewable energy sources to produce and transport low-carbon hydrogen. Alberta plans to start with blue hydrogen focusing on mixing hydrogen into the existing natural gas pipeline to bring down total carbon emissions and then slowly transfer to using green hydrogen.

POLICIES

Alberta Hydrogen Roadmap (Nov 2021)

Roadmap Overview (https://www.alberta.ca/hydrogen-roadmap.aspx)

They plan to first produce low-carbon blue hydrogen using natural gas reserves with carbon capture, utilization and storage (CCUS) to scale during initial stages and then transition to renewable electricity to produce green hydrogen.

Five Major Markets for Hydrogen

1. Residential + commercial heating
   - Heating appliances (furnace, boiler, stove, laundry dryer, etc.)
   - Can blend H_2 with natural gas to be burned for heating (slowly transition to higher blends of hydrogen to reduce carbon emissions of natural gas)

2. Transportation
   - Hydrogen fuel cells for cars, buses, trucks, trains, and aviation equipment
   - Hydrogen combustion engine for heavy duty applications

3. Industrial processes
   - Industrial uses for hydrogen: fossil fuel refining, bitumen upgrading, ammonia and fertilizers, chemicals, and liquid synthetic fuels.
   - 55% of Alberta's hydrogen production is used for heavy oil upgrading, 38% for chemical sector and industry by-products, and 7% for oil refining.

4. Power generation and energy storage
   - Produce electricity with hydrogen turbines + fuel cell generators
   - Produce hydrogen with electrolysis from renewable electricity. Excess electricity can be converted to hydrogen for storage.

5. Export market
   - Alberta has the energy resources to produce significant volumes of clean, cost competitive hydrogen for global markets.

Seven Policy Pillars

1. Build new market demand
    - Establish new demand for hydrogen outside of typical use as industrial feedstock
    - Focus on markets that can quickly deploy hydrogen into the provincial economy
2. De-risk investment
    - Long term investment certainty and funding is crucial
    - Create partnerships with industry and other governments to enable new hydrogen production, improve access to capital, de-risk hydrogen use in transportation, and consider establishing a hydrogen trading hub
3. Ensure regulations
    - Public safety is priority for hydrogen standards and regulatory requirements
    - Focus on performance to move hydrogen markets forward while reducing risk
4. Hydrogen exports
    - No current global supply chain for infrastructure, transportation, liquefaction, and storage
    - Alberta needs to have its own domestic export supply chain first before being doing international exports
5. Enable CCUS (Carbon Capture, Utilization and Storage)
    - To create clean hydrogen economy, CCUS need to be put in place to facilitate cost-effective, large-scale production
    - Expand initial CCUS infrastructure to more industries in the province
6. Innovation
    - Promote demonstration projects, research, and innovation to prove and scale up emerging hydrogen technologies
    - Work with Alberta's universities and technical to train the labor force to support the clean hydrogen economy
7. Alliances
    - Create partnerships with governments to advance the hydrogen economy, send coordinated signals to investors, and build public awareness and understanding
    - Developing global carbon intensity benchmarks and GO scheme
    - An emerging narrative against natural gas-based hydrogen can disrupt development

Alberta’s Natural Gas Strategy and Vision

The Natural Gas Strategy and Vision is focused on promoting the sustainable development of Alberta's natural gas industry and reducing GHG emissions. Eventually, the strategy aims to promote the development of a hydrogen industry in Alberta, which would use natural gas as a feedstock to produce blue hydrogen.

SOURCE:
https://open.alberta.ca/dataset/988ed6c1-1f17-40b4-ac15-ce5460ba19e2/resource/a7846ac0-a43b-465a-99a5-a5db172286ae/download/energy-getting-alberta-back-to-work-natural-gas-vision-and-strategy-2020.pdf

So far there is no Guarantee of Origin scheme for hydrogen or any renewable energy in Alberta.

ORGANIZATIONS

The Transition Accelerator

The Transition Accelerator (The Accelerator) is a pan-Canadian charity that creates positive, transformational system changes that solve societal challenges while moving Canada down viable pathways to reach net-zero greenhouse gas emissions by 2050.
SOURCE: https://transitionaccelerator.ca/about-us/

Alberta's Industrial Heartland Hydrogen Task Force

An independent working group created to develop a framework to implement a hydrogen economy in the region. The Task Force includes government, business, energy, academic, and sustainability leaders and will produce a public report detailing the approach and steps needed to advance a zero-emission fuel economy.
SOURCE: https://industrialheartland.com/association/#who

Edmonton Hydrogen Hub

The Edmonton Hydrogen Hub started development on April 15, 2023 and is projected to be functional by 2025. The Edmonton region is well suited to be Canada's first hydrogen HUB because of its existing experience in hydrogen production and carbon capture and storage, vast network of pipeline infrastructure, large talent pool of engineers and tradespeople, and engaged industry, government, Indigenous and academic leaders. It is also home to suitable and existing sites for carbon capture, storage and utilization and the world's largest CO_2 pipeline.
Source:https://erh2.ca/who-we-are/

REFERENCES

Alberta Hydrogen Roadmap:
https://open.alberta.ca/dataset/d7749512-25dc-43a5-86f1-e8b5aaec7db4/resource/538a7827-9d13-4b06-9d1d-d52b851c8a2a/download/energy-alberta-hydrogen-roadmap-2021.pdf

Alberta Natural Gas Strategy
https://open.alberta.ca/dataset/988ed6c1-1f17-40b4-ac15-ce5460ba19e2/resource/a7846ac0-a43b-465a-99a5-a5db172286ae/download/energy-getting-alberta-back-to-work-natural-gas-vision-and-strategy-2020.pdf

ERA Investments Corporation
https://www.eralberta.ca/wp-content/uploads/2022/08/ERA-TechnologyRoadmap2022.pdf
https://www.eralberta.ca/funding-technology/
https://www.eralberta.ca/about-era/

Canadian Hydrogen Convention April 2023
https://www.hydrogenexpo.com/

Edmonton Region Hydrogen Summit Feb 2023
https://erh2.ca/summit/

The Transition Accelerator
https://transitionaccelerator.ca/about-us/

News Article for Hydrogen Community to be built in 2023 Alberta
https://edmonton.ctvnews.ca/a-100-hydrogen-fuelled-community-is-being-built-in-alberta-this-is-what-it-will-look-like-1.6282942#:~:text=Canada's%20first%20fully%20hydrogen%20powered,the%20project%20announced%20on%20Feb.

Alberta Energy Regulator (Has good image) May 2022
https://www.aer.ca/providing-information/data-and-reports/statistical-reports/st98/emerging-resources/hydrogen#:~:text=In%202021%2C%20total%20hydrogen%20production,also%20increased%20slightly%20in%202021.

Taiwan Institute of Economic Research

Renewable Hydrogen: British Columbia (BC)

LAST UPDATED: 13th April 2023

OVERVIEW

British Columbia (BC) has a focus on hydrogen production, distribution, storage, end-uses, and export, as well as the setting of policy, regulatory, and other enabling frameworks. They have a focus on using hydrogen for the following:

- Medium and heavy-duty transportation
- Industry and refining
- Displacing natural gas
- Displacing diesel used for electricity generation in remote communities

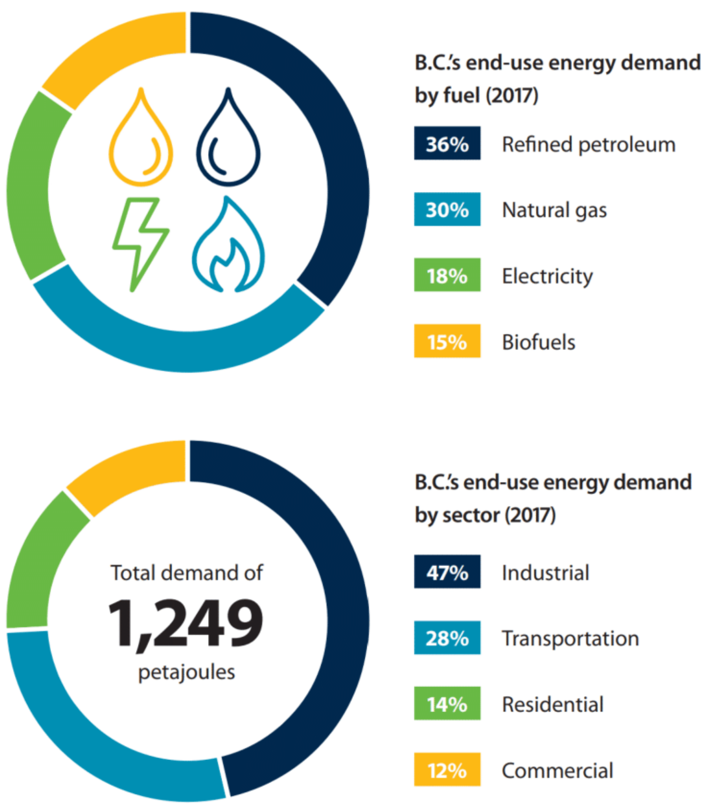
Similar to the Federal Canada government strategy, BC plans to produce enough hydrogen to satisfy local demands, as well as enough to export globally.

There has yet to be any guarantees of origin.

SOURCE: British Columbia Website - BC Hydrogen Office - Province of British Columbia (gov.bc.ca)

Markets

Summary: More than half of Canada's companies active in the hydrogen and fuel cell sector are located in B.C, so they plan to be one of Canada's bigger producers. BC plans to capture a significant portion of the global hydrogen market estimated to be greater than $305 billion by 2050.



Energy Demands in BC by fuel type and sector (SOURCE: B.C. Hydrogen Strategy, pg. 8).

BC plans to replace a lot of the fossil fuel demands through hydrogen. Hydrogen will also help transition away high emission fuels; natural gas and refined petroleum products such as gasoline and diesel. BC will try to electricity as much of their energy needs as possible, but the sectors that depend on fossil fuels that don't directly electrify easily (such as heavy-duty transportation and high-grade industrial heating) will use hydrogen to replace fossil fuels.

Objectives

THEME	SUMMARY
GHG REDUCTION	Promote innovation and investment in the production and deployment of hydrogen to achieve the energy system transformation required to meet CleanBC greenhouse gas (GHG) reduction target.
ECONOMY	Create economic development opportunities across B.C. through increased and equitable employment in trades, cleantech and energy service.
ENVIRONMENT	Improve air quality and reduce contamination and noise pollution in urban and remote communities.
CONVENIENCE	Make clean energy solutions more diverse, convenient, available and affordable for British Columbian.
INDIGENOUS RIGHTS	Fulfill our commitments under the Declaration on the Rights of Indigenous Peoples Act.

Means of Production

Summary: More than 98% of its electricity is clean or renewable so it has a good base for making hydrogen through electrolysis. B.C. also has low-cost natural gas reserves, significant geological storage capacity and expertise in carbon capture and storage (CCS) technology.

Goal: Convert most of the hydrogen production to be green using clean, renewable hydrogen, and ensure any blue hydrogen has emissions similar to green hydrogen.

Application: BC needs to create more regulatory frameworks to ensure blue hydrogen emissions remain as low as green hydrogen.

Organizations of Importance

SOURCE: B.C. Hydrogen Strategy

Hydrogen BC (HyBC): The B.C. regional branch of the Canadian Hydrogen and Fuel Cell Association. Partnered with the provincial government, HyBC has an initial mandate to promote the rollout of fuel cell electric vehicles and hydrogen fuelling stations.

Institute for Integrated Energy Systems (IESVic): At the University of Victoria, IESVic trains the next generation of changemakers and develops hydrogen technologies.

SPECIFICATIONS

CleanBC

Summary: CleanBC is the BC government's strategy to fight climate change. They currently have their sights on lowering carbon emissions by 40% by 2030. CleanBC has created a strategy to help BC become more sustainable in their roadmap.

SOURCE: Home - CleanBC (gov.bc.ca)

Application: CleanBC's action plan includes support for low-carbon hydrogen. They believe there should be more investment into hydrogen for industry and transportation. They plan to use hydrogen for medium and heavy duty vehicles.

REGULATIONS, STRATEGIES & POLICIES

Zero-Emission Vehicles Act

Summary: The Act was passed in May 2019 to "to meet an escalating annual percentage of new light-duty ZEV sales and leases, reaching: 10% of light-duty vehicle sales by 2025, 30% by 2030 and 100% by 2040".

SOURCE: gov.bc.ca, ZEV Act & Regulation Guidance

ZEV Regulation: Claims that BC will transition to 100% of light-duty electric vehicle sales by 2040.

Standards:
Credits can be earned by automakers for each ZEV sold or leased in BC. The credit values are as follows:

- Battery electric vehicles (BEVs) and hydrogen fuel cell vehicles (FCVs) earn 10 credits per vehicle.
- Plug-in hybrid electric vehicles (PHEVs) with a minimum electric range of 30 km earn 5 credits per vehicle.
- PHEVs with an electric range of less than 30 km earn 2.5 credits per vehicle.

Automakers can use credits to meet up to 100% of their annual ZEV sales targets. Any unused credits can be carried forward to future model years or sold to other automakers who need them to meet their targets.

British Columbia Hydrogen Strategy

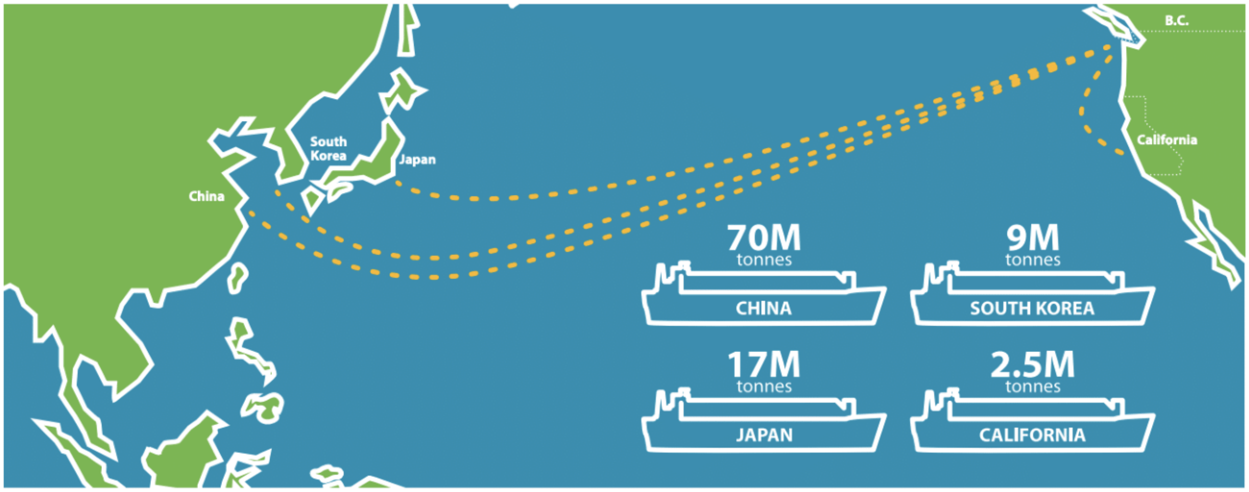
"By 2050, hydrogen has the potential to reduce the province's emissions by 7.2 megatonnes of carbon dioxide equivalent (CO_2e) per year, equal to 11% of B.C.'s 2018 emissions."

Summary: B.C. has the resources to produce both green and blue hydrogen with low carbon intensity with short, medium, and long term actions.

SOURCE: B.C. Hydrogen Strategy

How we'll regulate hydrogen production
2020-2025
• Review provincial, federal and international codes, standards and regulations for hydrogen production and establish a compatible regulatory framework • Amend regulations to allow the BC Oil and Gas Commission to regulate hydrogen production, storage and transportation if produced from fossil fuels • Amend *Water Sustainability Act* related regulations to include hydrogen production as an authorized industrial water use purpose and set new water fees and rentals • Enable hydrogen as a pathway for natural gas utilities to reduce emissions • Ensure regulatory frameworks relating to hydrogen production and use are aligned to encourage continued reductions in carbon intensity over time • Establish carbon-intensity targets for hydrogen production pathways • Provide support only for renewable or low-carbon hydrogen pathways • Establish a working group made up of representatives from the hydrogen industry, regulatory agencies and government to implement B.C. Hydrogen Strategy actions
2025-2030
• Continue to implement the Low Carbon Fuel Standard Part 3 Agreements to advance hydrogen production, fuelling infrastructure, operation and maintenance projects • Review sectoral opportunities for hydrogen offtake • Develop carbon management frameworks to encourage at-scale production of low-carbon hydrogen and transition policy incentives from direct support to market-based mechanisms
2030-beyond
• Achieve a clear and supportive regulatory environment for hydrogen production in B.C. • Require a phased reduction in the carbon intensity of hydrogen produced and used in B.C. • Explore policy framework mechanisms for long-duration energy storage using hydrogen

Regulation plan for hydrogen in British Columbia (SOURCE: B.C. Hydrogen Strategy, pg. 18).



Demand projections by jurisdiction in 2050

Predicted export plans of hydrogen from British Columbia (SOURCE: B.C. Hydrogen Strategy, pg. 31).

Exports: As BC is planning to become a hydrogen hub, they also have plans to export their produced hydrogen in which it has the potential to generate significant revenue for the province.

- China, Japan, South Korea, and California are predicted to account for almost 50% of total global demand for hydrogen by 2050, with a combined market size of $305 billion.
    - British Columbia's proximity to these markets and their advanced plans for hydrogen adoption strengthen its export potential.
- The BC Hydrogen Study estimates British Columbia's potential production capacity for hydrogen to be over 2.2 million tonnes annually.

How we'll develop B.C.'s export market for hydrogen
2020-2025
• Collaborate with industry stakeholders and international partners regarding export opportunities • Promote B.C. internationally as an attractive jurisdiction for investment in hydrogen production for domestic supply and export • Continue to promote B.C.'s fuel cell technology abroad and promote the province as a supplier of low-carbon hydrogen to global markets
2025-2030
• Attract domestic and international investment for the development of supply chains to export hydrogen
2030-beyond
• Enable the construction of dedicated infrastructure for hydrogen export

Export plans of hydrogen from British Columbia (SOURCE: B.C. Hydrogen Strategy, pg. 32).

Clean Industry and Innovation Rate

Summary: This policy offers discounted electricity for hydrogen production. BC Hydro offers a 20% discount on their current electricity rate to those switching from fossil fuels to clean electricity.

Clean Energy Act

Summary: BC created the clean energy act to help their energy transition to cleaner energy. They hope to reduce greenhouse gas emissions and waste produced during energy production, as well as create more jobs and become an exporter of clean energy.

SOURCE: Clean Energy Act (gov.bc.ca)

Application: This act suggests and encourages the use of clean hydrogen to meet BC's emission reduction goals.

Greenhouse Gas Reduction Regulation (GGRR)

Summary: As a part of the clean energy act, GGRR suggests the undertaking for electric vehicle charging stations, allowing utilities to recover costs from ratepayers for public fast charging infrastructure meeting specified criteria. The measures came into force as of June 2020 and apply to stations installed before December 31, 2025.

Amendment: Utilities can produce or purchase hydrogen for displacing fossil fuels in the natural gas grid

Low Carbon Fuel Source Regulations (LCFS)

Summary: All imported and produced fuel sources must follow LCFS. Each year the allowed carbon intensity decreases, making the production more stringent each year. If companies don't comply with these regulations, they are fined $600 per tonne.

- Fuel suppliers generate credits for supplying fuels with a carbon intensity below the targets and receive debits for supplying fuels with a carbon intensity above the targets.
- The debits and credits are proportional to the emissions a fuel generates over its full life cycle.
- Credits can be traded between fuel suppliers or banked for future use.
- At the end of each compliance period, suppliers must have a balance of zero or more credits to avoid non-compliance penalties.

SOURCE: LCFS Requirements - Province of British Columbia (gov.bc.ca)

COLUMN 1 Compliance Period	COLUMN 2 Carbon Intensity Limit for Diesel Class Fuel	COLUMN 3 Carbon Intensity Limit for Gasoline Class Fuel
	(g CO_2e/MJ)	(g CO_2e/MJ)
2020	86.15	80.13
2021	85.11	79.17
2022	84.08	78.20
2023	83.04	77.24
2024	82.01	76.28
2025	80.98	75.32
2026	79.94	74.36
2027	78.91	73.40
2028	77.88	72.44
2029	76.84	71.47
2030 and subsequent compliance periods	75.81	70.51

The permitted carbon emission according to the year

Application: Hydrogen falls under these regulations since it can make synthetic fuel, so all carbon emission guidelines apply to it. Fuels made with hydrogen and hydrogen itself are more energy dense than other fuels. Therefore, more energy is stored in a smaller amount of space.

PROJECTS

General Projects

Summary: There are already 40 hydrogen projects proposed or under construction in B.C. with more on the way. These projects represent $4.8 billion in proposed investment in the province. Small and medium projects will focus on providing hydrogen to local communities while large projects will focus on exporting to the rest of the world.

Taiwan Institute of Economic Research

Renewable Hydrogen: Ontario

LAST UPDATED: 17th April 2023

MAIN SOURCE: Ontario's Low-Carbon Hydrogen Strategy | ontario.ca

OVERVIEW

Summary: Ontario is currently focusing on developing their low-carbon hydrogen from clean electricity. There has yet to be many policies created specifically for clean hydrogen, but Ontario is starting to take actions to encourage the energy transition. About 75% of Ontario's 2019 greenhouse gas emissions come from energy use for transportation, buildings and industry, so Ontario is interested in using low-carbon hydrogen in these sectors to replace fossil fuels, like diesel and gasoline, which are used to power cars, trucks, ships, and trains.

Currently there has yet to be a guarantee of origin scheme.

Advantages

THEME	SUMMARY
OPEN FOR BUSINESS	Ontario has a highly skilled workforce, global hydrogen technology manufacturers and many established industrial sectors that can support growth of the province's low-carbon hydrogen economy (e.g., cleantech, steel, auto manufacturing and chemicals).
CLEAN, RELIABLE, AND AFFORDABLE ELECTRICITY SYSTEM	Ontario's electricity system is among the world's cleanest with very low emissions. In addition, Ontario now has competitive electricity rates for large electricity consumers through a number of programs that could benefit hydrogen producers, particularly by using off-peak electricity.
EXISTING STORAGE AND PIPELINE INFRASTRUCTURE	Ontario has existing and planned pipeline and storage infrastructure that can be used to store hydrogen and deliver it to homes and businesses. This includes geological storage opportunities and an extensive natural gas distribution network.
ENABLING REGULATORY ENVIRONMENT	Ontario is prioritizing red-tape reduction to attract investment and create jobs. Ontario's regulatory framework for fuels has already enabled a pilot project to blend hydrogen into natural gas pipelines, as approved by the Ontario Energy Board (OEB) with support from the Technical Standards and Safety Authority (TSSA).
CLEAN BIOFUEL RESOURCES	Ontario's rich forest, agricultural and municipal biomass resources could be used to create low-carbon hydrogen or other renewable fuels. This includes using diverting waste streams from these sectors, as well as material from sustainably managed forests and purpose-grown crops.

Markets

Summary: At the current time Ontario is focusing on producing enough hydrogen for its local demand. There is not as much of a focus on exporting in this province. However, Onterario eventually hopes to meet global market demands and use it's location to trade with the US and overseas in Europe and Asia.

Objectives

THEME	SUMMARY
GENERATE ECONOMIC DEVELOPMENT AND JOBS	Capitalize on Ontario's competitive and regional advantages, including our talent, infrastructure and resources, to accelerate growth in Ontario's low-carbon hydrogen economy.
REDUCE GHG EMISSIONS	Support our Made-in-Ontario Environment Plan targets to reduce GHG emissions by encouraging the use of low-carbon hydrogen.
PROMOTE ENERGY DIVERSITY	Consider how low-carbon hydrogen can cost-effectively support Ontario's evolving energy system and build redundancies through electricity storage and clean fuel supply.
PROMOTE INNOVATION AND INVESTMENT	Enable opportunities for low-carbon hydrogen use and position Ontario as a leading destination for investment.
STRENGTHEN COLLABORATION	Work with the private sector, the federal government, municipalities, Indigenous communities, academic institutions and other stakeholders to grow and sustain a low-carbon hydrogen economy in Ontario.

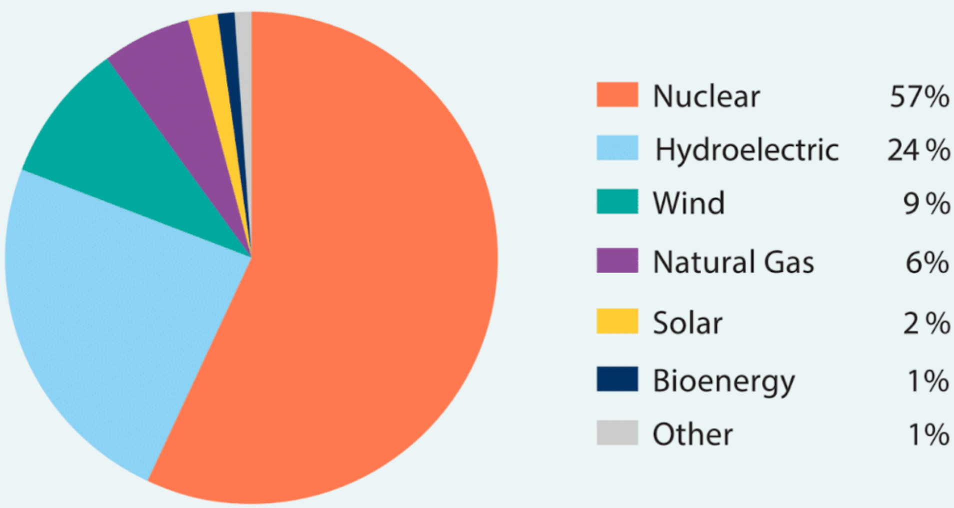
Means of Production

Summary: Ontario has some of the cleanest electricity in the world that is generated by a combination of nuclear, hydroelectric, other renewable electricity sources and natural gas. They plan to use excess electricity to make hydrogen and convert the hydrogen back to electricity if needed.

SOURCE: [Ontario's Low-Carbon Hydrogen Strategy | ontario.ca]

Ontario's Clean Electricity Generation

In 2020, about 94 per cent of Ontario's electricity came from non-emitting sources, including nuclear, hydroelectric, biomass, wind and solar. Natural gas generation is required to help meet temporary supply gaps due to the refurbishment of Ontario's nuclear fleet and provide back-up generation when the sun is not shining and the wind is not blowing.



Organizations of Importance

SOURCE: Low-carbon hydrogen | ontario.ca

Ontario has created the Hydrogen Strategy Working Group who have contributed to and helped create their hydrogen strategy. The members include:

- Atura Power
- Canadian Hydrogen and Fuel Cell Association (CHFCA)
- Canadian Steel Producers Association (CSPA)
- Cummins
- dynaCERT Inc.
- Emerald Energy from Waste
- Enbridge Gas
- EPCOR Utilities Inc.
- Evolugen
- GE Gas Power
- H2GO Canada
- Hydrogen Business Council of Canada
- Hydrogen Optimized
- Independent Electricity System Operator (IESO)
- Nuclear Innovation Institute
- Ontario Clean Technology Industry Association (OCTIA)
- Ontario Environment Industry Association (ONEIA)
- Ontario Power Generation (OPG)
- Ontario Public Transit Association
- Ontario Trucking Association
- Ryerson University
- Toyota
- Transition Accelerator
- TC Energy

SPECIFICATIONS

Push for Federal Collaboration

Ontario wants the federal government to support:

- Funding and risk-sharing opportunities
- Clear and efficient regulations that are harmonized across leading jurisdictions
- Support for innovation

They hope that the government will provide funding that will ensure future hydrogen technology.

REGULATIONS, STRATEGIES & POLICIES

Ontario Hydrogen Strategy

Summary: Ontario is poised to create a lot of green hydrogen for their local communities in the near future.

Immediate plans of action:

1. Launching the Niagara Falls Hydrogen Production Pilot
2. Identifying Ontario's Hydrogen Hub Communities
3. Assessing the Feasibility of Hydrogen Opportunities at Bruce Power
4. Developing an Interruptible Electricity Rate
5. Supporting Hydrogen Storage and Grid Integration Pilots
6. Transitioning Industry Through the Use of Low-carbon Hydrogen
7. Consulting on an Ontario Carbon Sequestration and Storage Regulatory Framework
8. Supporting Ongoing Hydrogen Research

Consultations: Ontario has held several public consultations to develop their hydrogen strategy

1. Clean Technology Sector Engagement: As part of the Ontario Jobs and Recovery Committee's work, the government consulted with the clean technology sector, including hydrogen stakeholders, in spring 2020. The purpose was to understand COVID-related disruptions and how the government could support the sector to continue to grow and prosper beyond the immediate recovery.
2. Low-Carbon Hydrogen Discussion Paper: The government posted a discussion paper to the Environmental Registry of Ontario for public consultation in fall 2020. The purpose of the discussion paper was to begin a dialogue and seek input to better understand the needs of the sector, the challenges of supporting a complex hydrogen market, and ways to enable the private sector to expand adoption of hydrogen and support regional growth.
3. Stakeholder Webinars: Ontario hosted two webinars in January 2021 to broaden the reach and obtain additional feedback from stakeholders, and shared information with Indigenous communities. Ontario received 145 comments from 140 organizations and individuals on the hydrogen discussion paper, including comments from industry, academia, environmental groups and the public.
4. Hydrogen Strategy Working Group: Ontario established the Hydrogen Strategy Working Group that met nine times from February to June in 2021 and was made up of 23 industry and academic experts who provided advice on how to use hydrogen across various sectors and help Ontario compete in the global hydrogen market

Clean Energy Credits (CEC)

Summary: CECs are electronic certificates used to demonstrate that clean energy from Ontario based generation has been acquired, to meet a voluntary target. The current fuel types supported by this program are Biofuel, Biogas, Biomass, Hydro, Nuclear, Solar, and Wind. These credits can be bought and sold.

SOURCE: Ontario Program (ieso.ca)

Goal: Offer businesses a new tool to show their commitment to environmental and sustainability goals. These credits prove a company has created fuels in a low-emission manner.

Application: The CEC for electricity means that hydrogen produced through electricity is incentivised as companies can meet hydrogen sustainability goals with clean electricity.

Red Tape and Burden Reduction

Summary: The Act will reduce the high cost of doing business in the province. This will make Ontario companies more competitive and attract new investments.

Goal: The goal is to make it easier to do business in the province and to create a more competitive and prosperous economy. The initiative involves a comprehensive review of regulations, policies, and processes to identify unnecessary or duplicative requirements and streamline the regulatory environment.

Application: This act creates easier job accessibility for the increased hydrogen demand and makes it easier for companies to invest into hydrogen technologies by reducing costs and bureaucratic hurdles.

PROJECTS

Hydrogen Investments

Summary: Ontario is a world leader in hydrogen developments. The world's first commercial hydrogen powered trains, North America's first hydrogen-blended natural gas project in Markham and the commercialization of large-scale hydrogen production systems all rely on hydrogen technologies developed by Ontariobased companies.

Niagara Falls Hydrogen Production Pilot

Summary: Atura Power's proposal for the province's largest low carbon hydrogen production facility. Ontario Power Generation (OPG) owns Altura Power as a subsidiary. They plan to make a 20 MW electrolyzer to produce electricity that can be used to make low-carbon hydrogen.

Ontario plans to make the Niagara Facility to be a hydrogen hub for heavy-duty trucking, municipal mobility and heavy industrial consumers in Ontario. Currently, the Markham Power-to-Gas facility has a capacity of 2.5 MW for hydrogen production. The addition of this new facility will increase Ontario's installed electrolyzer capacity to 22.5 MW.

Taiwan Institute of Economic Research

Renewable Hydrogen: Québec

LAST UPDATED: 18th April 2023

OVERVIEW

The Québec government has set a target of reducing greenhouse gas emissions by 37.5% below 1990 levels by 2030, and has identified hydrogen as a potential tool for achieving this goal.

Québec has set the following projected goals:

1. Production of 5 GW of hydrogen by 2030.
2. 10% of the province's energy consumption will come from green hydrogen by 2030.
3. Reduction of greenhouse gas emissions by 37.5% by 2030.
4. Development of a green hydrogen ecosystem that includes production, storage, transportation, and distribution.
5. Investment in research and development of new technologies and applications including supporting the development of fuel cells and other hydrogen-based technologies.

"By the 2050 horizon, according to the International Energy Agency, global hydrogen demand could be multiplied by five and bioenergy production could meet 20% of global energy needs, if global carbon neutrality is targeted." (SOURCE: Québec Government - Green Hydrogen and Bioenergy Strategy)

REGULATIONS, STRATEGIES & POLICIES

Québec Regulation Respecting the Quality of the Environment (RQE)

Summary: Adopted in 1986, the regulation sets limits for the release of hydrogen into the environment and requires permits for activities that involve handling or producing hazardous materials.

SOURCE: Publications Québec - Regulation

Standards: Standards set limits on the amount of pollutants that can be released into the environment, and help to ensure that the air and water in Québec remain clean and healthy.

Environment Quality Act

Summary: Promotes the reduction of greenhouse gasses and adaptation to climate change while ensuring compliance with sustainable development principles.

SOURCE: Publications Québec - Environment Quality Act

Standards:

1. *Environmental quality* - Sets out environmental quality standards for various substances, such as air pollutants and water contaminants, to protect human health and the environment.
2. *Waste management* - Establishes requirements for the management of various types of waste, including hazardous waste, electronic waste, and construction and demolition waste.
3. *Soil protection* - Contains provisions aimed at protecting soil quality and preventing soil contamination.
4. *Noise and vibration* - Sets out standards for noise and vibration levels to protect the health and well-being of Québecers.
5. *Environmental impact assessment* - Requires that certain projects undergo an environmental impact assessment to evaluate their potential environmental impacts and ensure that appropriate measures are taken to mitigate any adverse effects.

Hydro-Québec Strategic Plan

Summary: According to Hydro-Québec's estimate, achieving carbon neutrality in Québec by 2050 and decarbonizing its current energy mix will necessitate more than 100 terawatt-hours (TWh) of additional electricity, which represents over half of the province's present annual generating capacity.

Status: Announced on April 4, 2023

SOURCES: Hydro-Québec, News Wire, 2022-2026 Strategic Plan

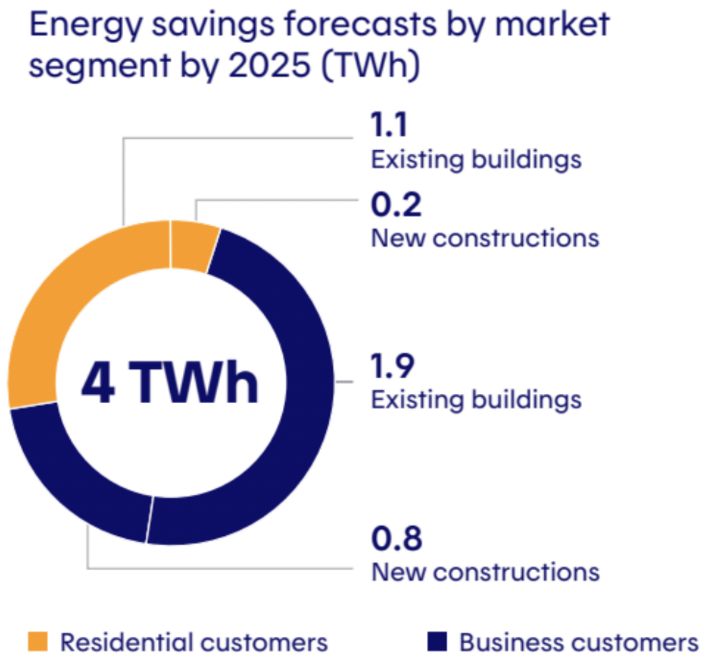
Initiatives: (SOURCE: News Wire)

1. *Increased energy efficiency targets* - Plans to boost energy efficiency efforts and exceed its estimated 25 TWh potential with help from experts and various organizations.
2. *Modernization of existing generating stations* - Adding 2,000 MW of capacity by 2035, including 128 MW from ongoing rehabilitation work in three generating stations.
3. *Wind power* - Six wind farm projects and called for a tender of 1,500 MW to increase their wind power capacity, aiming to double it soon.
4. *Preliminary study on the hydroelectric potential of Rivière Petit Mécatina* - Assessing sites with the greatest theoretical potential for new hydropower generation capacity and will soon engage in dialogue with nearby communities for the preliminary study phase in Rivière Petit Mécatina

PLAN:

Hydro-Québec faces paradigm shifts to implement this strategy: (SOURCE: 2022-2026 Strategic Plan, pg. 8-12)

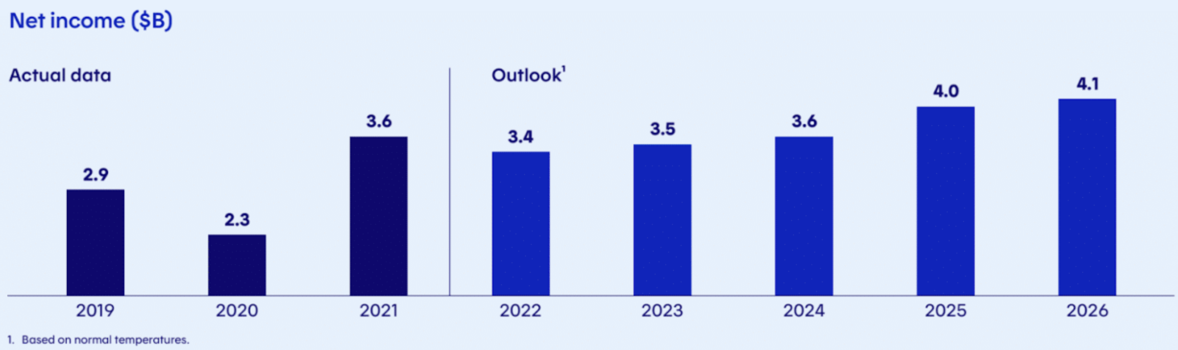
1. *Energy and capacity balances* - Maximizing energy expenditure and revenue.
2. *Supply costs* - To limit the increase on their supply costs.
3. *Grid's design and operation* - Optimize the processes and enhance benefits for customers.
4. *Infrastructure investments* - To pay attention to resource allocation to maximize investments.



Electricity distribution in Québec (SOURCE: 2022-2026 Strategic Plan, pg. 21).

Hydro-Québec has identified four objectives to complete the strategy: (SOURCE: 2022-2026 Strategic Plan, pg. 19)

1. Drive the efficient decarbonization of Québec.
2. Prepare our grid for tomorrow's energy and technology needs.
3. Increase Québec's collective prosperity.
4. Engage our customers, employees and partners in the achievement of our goals.



Main factors that can lead to variations in net income	Impact on net income for 2022 ($M)	Impact on net income for 2026 ($M)
Energy prices on export markets • Variation of US 1¢/kWh	±165	±250
Exchange rate (C$/US$1) • Variation of 10¢	±15	±250
Temperatures above or below normals (December–March) • Variance of 1°C	±95	±95

Projected financial outlook after implementation of strategic plan (SOURCE: 2022-2026 Strategic Plan, pg. 43).

Outcome: "Between 2015 and 2019, Hydro-Québec's annual exports averaged 33.2 TWh, representing an average revenue of $772 million." (SOURCE: Québec Government - 2030 Plan, pg. 67)

- The emission of greenhouse gas was reduced by 8 million tons during that time.

Guarantee of Origin

Summary: Québec's guarantee of origin (GO) for hydrogen is a certification system that verifies the production and distribution of green hydrogen that is produced from renewable energy sources, which includes the carbon footprint during the production process. This system is managed by the Ministry of Energy and Natural Resources of Québec.

SOURCES: Québec Government - Green Hydrogen and Bioenergy Strategy, Osler - Hydrogen Regulatory Framework

Québec has set the following objectives to focus on green hydrogen: (SOURCE: Québec Government - Green Hydrogen and Bioenergy Strategy)

1. Reduce its GHG emissions 37.5% below the 1990 level by 2030.
2. Reduce its consumption of petroleum products 40% below the 2013 level by 2030.
3. Achieve carbon neutrality by the 2050 horizon.

Overall, Québec is currently developing a regulatory framework which includes legislation. However, these plans are seen in Québec's Environment Quality Act and their roadmaps and strategies for green hydrogen.

MARKET

Recyclage Carbone Varennes Project

Type: Project

Status: Announced on March 27, 2023

Location: Varennes, Québec

SOURCE: Biofuels Digest - Québec Investment, Canada Infrastructure Bank, Varennes Carbon Recycling

The Ministry of Economy and Innovation is investing $277M in Recyclage Carbone Varennes (RCV) in which the project has merged the biofuel plant and the green hydrogen production plant. This project eventually will replace the green hydrogen production plant invested by Hydro-Québec.

Project Strategic Partners: Shell, Suncor, Proman
The project's strategic partners will serve as additional investors and undertake the responsibility of aiding in the setup of an 88 MW capacity electrolyzer and a clean fuel production plant in Varennes that will produce green hydrogen.

2026 Québec Energy Transition, Innovation and Efficiency Master Plan

Type: Roadmap

Status: Announced and in effect since June 10, 2022

SOURCE: Québec Government - Energy Transition Master Plan

Summary: Québec is committed to transitioning to a low-carbon economy with green hydrogen as a key component. The province recognizes energy efficiency as a priority and aims to reduce its dependence on petroleum products. Strong support for innovation in the energy sector has enabled Québec to develop the full potential of renewable energies, while strengthening governance and making the state accountable. This commitment to renewable energy and green hydrogen is driven not only by environmental considerations but also by the desire to support economic development and create jobs in the clean energy sector.

Targets:

- Improve the efficiency with which energy is used by 15%.
- Reduce the quantity of petroleum products consumed in Québec by 40%.
- Increase total renewable energy production by 25%.
- Increase bioenergy production by 50%.
- Eliminate the use of thermal coal in Québec.

2030 Plan for a Green Economy

Type: Guide

Status: Announced

SOURCE: Québec Government - 2030 Plan, Québec Green Hydrogen Strategy

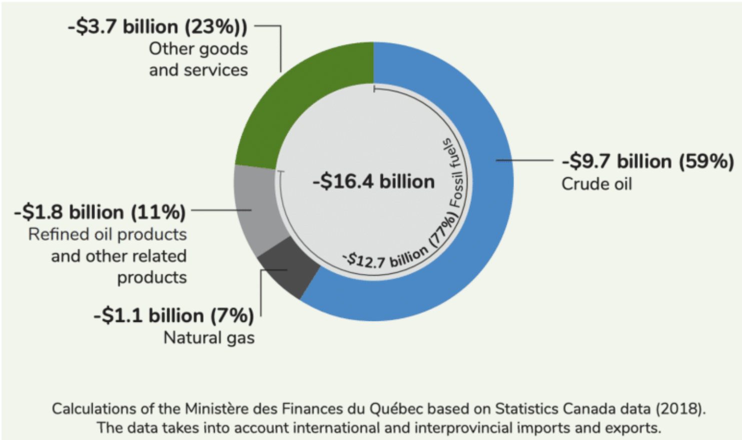
It is projected that Québec has the potential to become a world leader of hydrogen production due to its strong capability of supporting large-scale productions of renewable energy.

Policy Framework: (SOURCE: Québec Government - 2030 Plan, pg. 27)

- Electrification and the fight against climate change are major levers for economic development and the creation of wealth.
- Electrification and the fight against climate change must maximize the reduction of greenhouse gas emissions across Québec while taking advantage of the flexibility offered by the carbon market.
- Electrification and the fight against climate change are grounded in the efficient use of energy and resources.

Potential Energy Exports: (SOURCE: Québec Government - 2030 Plan, pg. 67)

- Can sell clean energy to 15 connections, including markets in Ontario, New Brunswick, New York, and New England.
- "Through the 2030 Plan for a Green Economy, the government will continue its progress, using the availability of clean electricity to attract companies looking to benefit from green, reliable energy at a predictable cost to lower their greenhouse gas emissions."

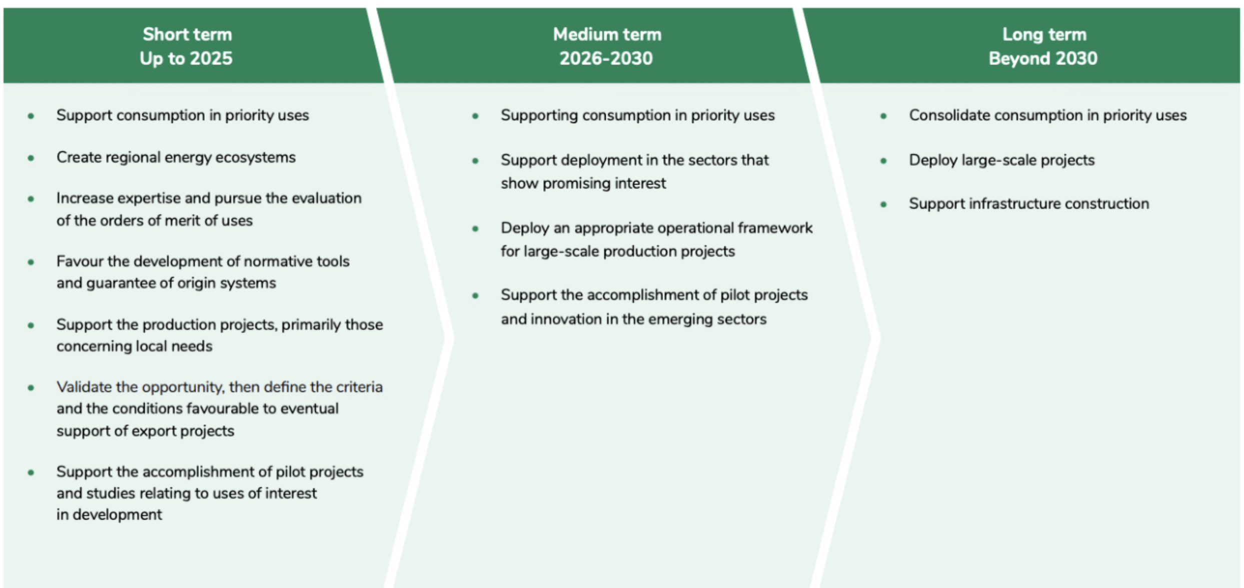


Export revenue in 2018 and its positive effect on Québec's economy (SOURCE: Québec Green Hydrogen Strategy, Slide 21).

Promising Applications of Green Hydrogen: (SOURCE: Québec Government - 2030 Plan, pg. 70)

- *Industrial processes* - To be replaced as a renewable raw material from fossil fuels.
- *Heavy and intensive transport* - To be used as an energy carrier that can be converted back into fuel-cell powered electric vehicles.
- *Green chemistry* - To make bioenergy production more efficient by using green hydrogen as a renewable raw material that can also be used to produce synthetic fuels for aviation sectors.
- *Massive energy storage* - Can power off-grid systems that can lower greenhouse gas emissions.
- *Heat production* - Can be injected into natural gas grids that can be easily distributed to consumers through existing infrastructures.

Phases of Deployment for Green Hydrogen:



Action priorities for the development of green hydrogen (SOURCE: Québec Green Hydrogen Strategy, Slide 33).