Final Public Report

Project Partners

CHIYODA CORPORATION

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Business Development Renewable Energy

Executive Summary

ITM Power, Chiyoda Corporation, Mitsui & Co. Ltd and G&S Budd Consulting Ltd conducted a techno-economic analysis of hydrogen production in British Columbia (BC).

With the worldwide growth of hydrogen as a new clean energy medium, British Columbia has great potential. A combination of low cost, low carbon electricity generation, numerous deep sea harbour locations and good road/rail networks makes BC an ideal location for large scale hydrogen production and export worldwide to areas such as Japan and California.

Hydrogen generation using ITM Power's state of the art PEM electrolyser technology is paired with a means for the storage and transportation of hydrogen in the form of a liquid organic hydrogen carrier (LOHC) developed by Chiyoda Corporation called SPERA Hydrogen.

The objectives behind the study where to examine the technical and economic feasibility of building centralized renewable hydrogen production plants in British Columbia for three plant sizes. These included 10 megawatt (MW), 100 MW and 300 MW plants.

The feasibility study involved two phases. Phase 1 covered the collection of the necessary data associated with potential installation sites, economic benefits and environmental assessment requirements. Phase 2 included the economic evaluation of hydrogen produced in BC and its demand both locally and internationally.

The main results and recommendations for next steps are below:

- A number of attractive opportunities exist for hydrogen deployment in BC.
- The location of BC presents many benefits for hydrogen production and export.
- The most economic plant size is 300+MW however this must be balanced against the timing of demand for hydrogen and its market price.
- As the technology develops costs continue to decline however the combination of current pricing and demand uncertainty mean that monetary and regulatory incentives are critical for first of kind deployments.
- A good initial project may be the development of a 10 MW pilot plant to satisfy the local demand for renewable hydrogen and fuel vehicles designed to help BC meet its new Zero Emission Vehicle and renewable gas goals.
- An alternative option is to start with a small-scale hydrogen gas plant (larger than 10 MW to benefit from economies of scale) and combine the hydrogen supply for fuel cell electric vehicles with other short- and medium-term demand opportunities such as the direct injection of hydrogen into the natural gas grid, power to gas, and/or synfuel production in BC.

Table of Contents

Figures

Objectives

The objectives of this study were to examine the technical and economic feasibility of building centralised renewable hydrogen production plants in British Columbia (BC) in order to produce and export hydrogen. This process would include using ITM Power's state of the art electrolysis powered by BC Hydro's low carbon electricity. The objectives included evaluating the supply of renewable hydrogen for two target export markets, California and Japan. The method of storage and transportation would be in the form of a LOHC for foreign markets, and then as a compressed gas for use in BC. A major component of the study was evaluating of the potential demand for hydrogen in BC as well the target export markets.

Introduction

The Ministry of Energy, Mines and Petroleum Resources (MEMPR) and the Ministry of Jobs, Trade and Technology (MJTT) provided support and funding in the amount of C$230,000 for this study. ITM Power Inc., Chiyoda Corporation, and Mitsui & Co. Ltd., (the "Partners") provided resource support in the form in-kind labour and travel costs. The project was kicked-off in Vancouver, BC in April 2018 and was formally completed at the end of March 2019.

The feasibility study was split into two phases. Phase 1 included the collection of the necessary input information for the study. Phase 2 included the economic evaluation of large scale hydrogen production in BC, as well as analysis of the potential demand for renewable hydrogen for both local and export markets by 2030 and 2050.

Given the availability of BC's clean, low-cost electricity, the province is strongly positioned as a potential producer and exporter of renewable hydrogen generated via water electrolysis. BC's coastal harbour infrastructure offer ocean vessel transportation access for the demand markets of Japan and California and potentially cost effective supply of renewable hydrogen to these markets. This project evaluated the feasibility to produce hydrogen in BC and its use in the province. The two export markets decided upon for evaluation in this study were chosen as both are world leaders in the adoption of hydrogen for fuel cell electric vehicle (FCEV) deployment as well as for industrial applications, such as power generation.

The California zero-emission vehicle (ZEV) mandate has been instrumental in supporting the global growth of both FCEV and battery electric vehicle (BEV) deployment over the past two decades. The development of a hydrogen infrastructure in California has attracted vehicle test fleets from several major automotive OEMs and provides a real market for the commercialization of FCEVs.

The most recent Japanese government plan, depicted as the *Basic Hydrogen Strategy*, was announced in December 2017 with a future vision up to the year 2050. A target for 2030 of 800,000 FCEVs and 1,200 fuel cell electric buses (FCEB) are planned to be deployed.

Concurrent with the execution of this feasibility study on November 20, 2018 the Government of British Columbia announced the BC Zero Emissions Vehicle (ZEV) Standard. This legislation will set out to target 10% ZEV sales by 2025, 30% by 2030 and 100% by 2040. These ZEVs will include both FCEVs and BEVs; a positive announcement for the objectives of this feasibility study. The ZEV Standard incorporates three elements: expanding the size of the province's electric vehicle fleet, increasing the provincial ZEV adoption incentive program, and other long-term incentive programs with the objective of making ZEVs more affordable for British Columbians. In addition to the ZEV Standard, the Government of BC in December 2018, released *CleanBC*, the Province's climate strategy. It incorporates as one of its major themes the development of the hydrogen economy that can play a major role in BC's low carbon energy system objectives.

DESCRIPTION OF THE LIQUID ORGANIC HYDROGEN CARRIER TECHNOLOGY

Chiyoda Corporation, one of the Partners in this study, has developed a liquid form and system for the storage and long distant transportation of hydrogen in large quantities. This is called SPERA Hydrogen technology. Unlike conventional hydrogen storage and transportation systems, this LOHC technology is able to use the same infrastructure as is currently used for the storage and delivery of large quantities of chemical liquids.

The following is a brief description of the process. Using the technology that Chiyoda Corporation has developed, hydrogen is reacted with toluene to form methylcyclohexane (MCH). Both of these chemicals can be stored at ambient temperatures and pressures. These chemicals are also commonly used for numerous industrial applications and can be transported in large quantities over the oceans. Once the MCH arrives as a hydrogen rich liquid to the destination market, the process of dehydrogenation takes place using Chiyoda Corporation's specially developed catalyst technology, to extract the hydrogen as a gas for use in the market place. Figure 1 provides a schematic summary of how the SPERA Hydrogen process works.

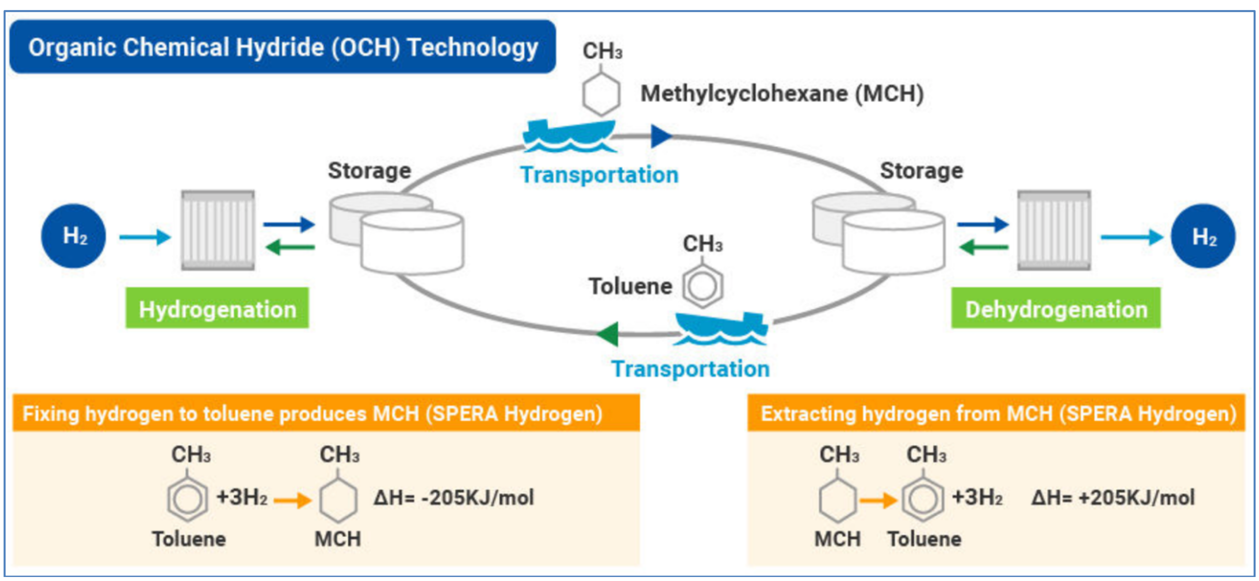

FIGURE 1 SPERA HYDROGEN SYSTEM

Description of the PEM electrolyser

ITM Power is a world-leading Polymer Electrolyte Membrane (PEM) electrolyser manufacturer headquartered in the United Kingdom (UK). PEM electrolysis is a method of creating hydrogen by splitting water using electricity, if the electricity is from renewable sources the resulting hydrogen is truly zero carbon. ITM Power's electrolyser design is based upon state of the art PEM electrolyser stack and system technology that is designed to offer high power density, rapid response for electricity grid load management and ease of maintenance. In April 2017, the company unveiled its designs for a 100 MW electrolyser plant. This was in response to utilities and the oil and gas industry demand for larger-scale industrial installations. Shortly thereafter, in September 2017, ITM Power was awarded a contract to install a 10 MW electrolyser at the Shell Wesseling refinery site in Rhineland, Germany. This electrolyser would be the largest system of its kind using PEM technology.

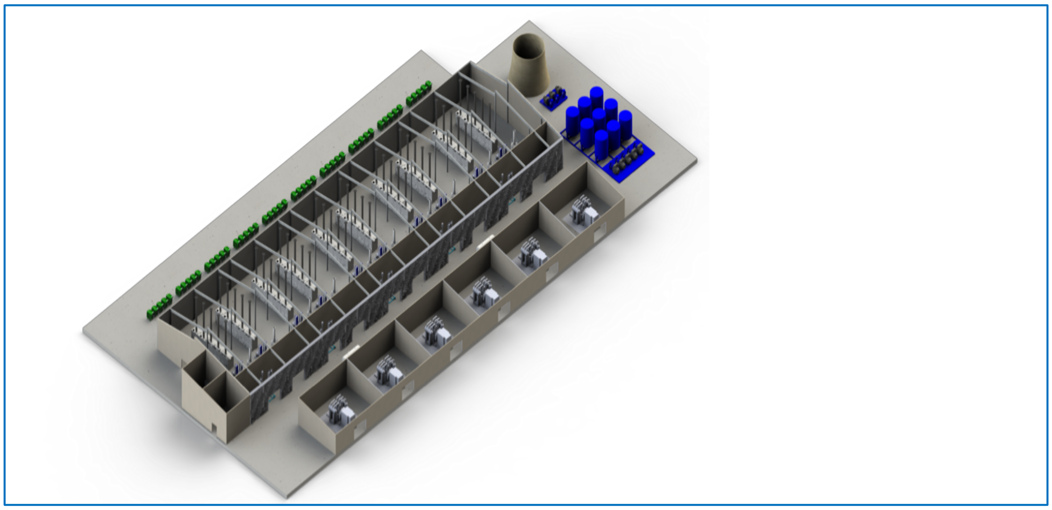

FIGURE 2 RENDERING OF A 100 MW ITM POWER PEM ELECTROLYSER PLANT

Reporting and internal project management processes

The regular project progress and financial reporting took place with the issuance of quarterly reports to the MEMPR that included an accounting of the use of funds together with a project Gantt chart summarizing developments for each work package. These reports incorporated budget and expenditure summaries that identified the use of the government funds together with details of in-kind financial project support provided by the Partners.

Project planning and progress reports on an ongoing basis took place monthly via internal Partner conference call communications. In-person meetings in BC and the USA were held on four occasions. MEMPR and MJTT were invited to and participated in all of the face-to-face meetings that took place in BC.

Phase 1 - Develop inputs for the techno-economic feasibility assessment

1. Plant capital and operational inputs – three sizes 10 MW, 100 MW, 300 MW

1.1. Capital investment to build plants

Chiyoda Corporation and ITM Power provided all of the relevant capital cost estimations for three plant sizes: 10 MW (pilot plant), 100 MW (commercial plant) and 300 MW (large commercial plant). The compilation of these costs (Capex) included the equipment capital, construction, installation and plant commissioning cost components. The list of Capex estimates included the major cost items for electrolysis and hydrogenation plants in BC, as well as for the dehydrogenation plants in the demand markets of Japan and California.

1.2. Electricity costs - pricing and tariff structure

During the course of Phase 1, numerous meetings with BC Hydro were held. Productive support was provided in terms of listing and evaluating potential production sites in BC where electrical loads of up to 300 MW could be geographically supported. BC Hydro also supplied details of the industrial electricity tariffs under Rate Schedule 1823. For this study the 2019 electricity price provided in the referenced rate schedule was used and adopted for the economic evaluations. Specifically, the total average unit electricity cost including PST used was C$0.064/kWh. This value has been used in all of the applicable economic scenarios including the sensitivity analyses for the production of hydrogen and the hydrogenation reactor step in BC.

1.3. GHG Reductions / Carbon valuation

Two greenhouse gas (GHG) evaluation models were developed for this study. The primary variables adopted for the modeling were derived from a number of carbon intensity databases. Further details can be found in the reference section of this report. In summary the main data bases used included GHGenius 5.0a and the latest version of CA-GREET dated February 28, 2019. Carbon intensity data and information with regards to Japan were supplied by Chiyoda Corporation.

- The first evaluation model was to assess the carbon footprint of supplying renewable hydrogen to fuelling stations in Vancouver, BC and the surrounding cities for FCEVs. The evaluation compared renewable hydrogen and gasoline used for internal combustion engine vehicles.

  The results of the BC GHG evaluation are presented in figure 4. The model considered a range of hydrogen production plant sizes of 10 MW, 100 MW and 300 MW and included factors associated with hydrogen production, compression, delivery to the Lower Mainland and the compression, storage and dispensing functions at fuelling station sites. The evaluation includes the inputs to support the fuelling established for 700 bar FCEV applications described in SAE J2601[1] and the fuelling protocol for light-duty FCEVs. Figure 3 provides the results of the number of estimated FCEVs that each plant size would support. In addition, the approximate annual amount of hydrogen produced by the three plant sizes is provided.

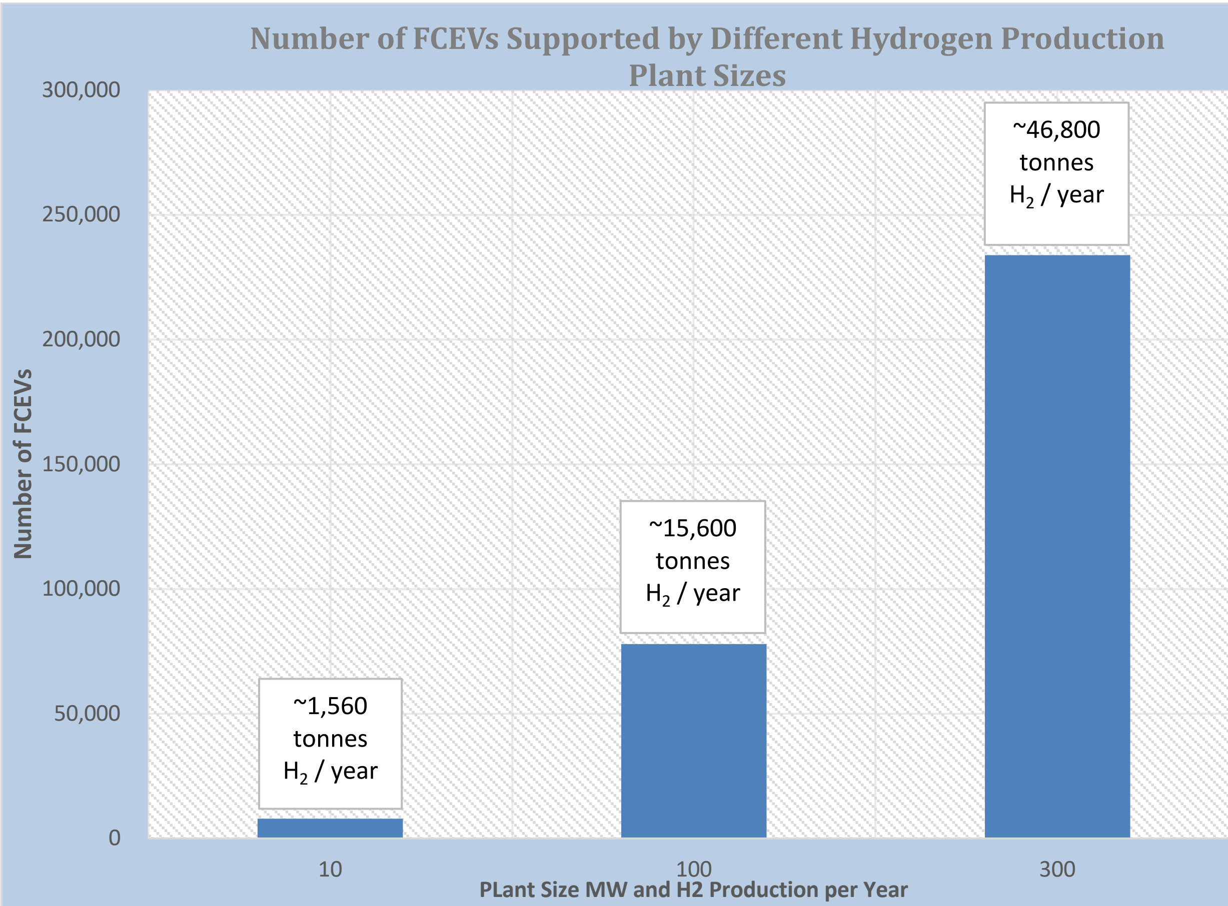

FIGURE 3 HYDROGEN PLANT SIZE ANNUAL PRODUCTION AND NUMBER OF FECVS

[1] https://www.sae.org/standards/content/j2601_201003/

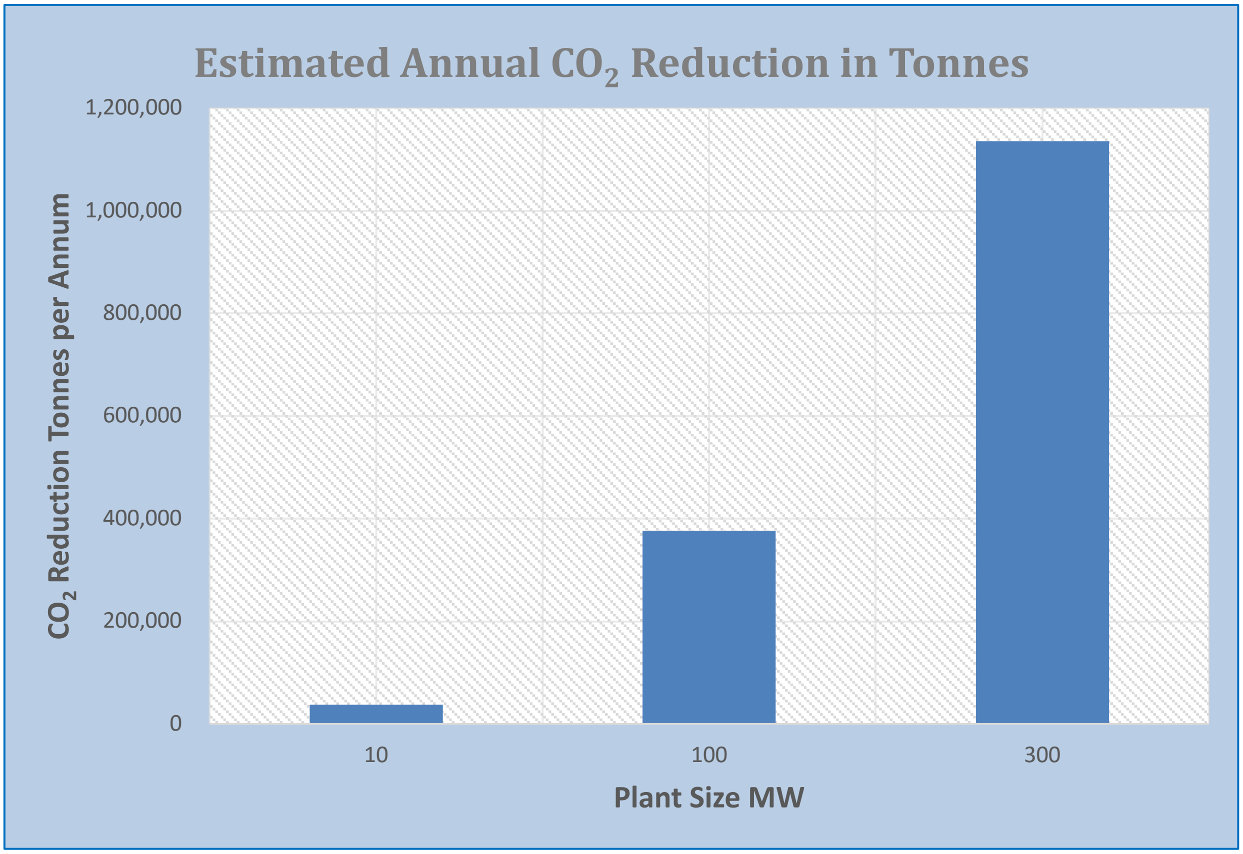

FIGURE 4 CARBON DIOXIDE REDUCTION SUMMARY

- The second model was developed to determine the carbon intensity reductions of renewable hydrogen produced in BC and delivered to the export markets of Japan and California. The case in Japan was to evaluate the carbon reduction results when the LOHC hydrogen is used for industry or mobility applications in comparison to the steam methane reformation (SMR) case. For California the comparison was between the LOHC hydrogen for fuel cell electric vehicles and gasoline for internal combustion engines was undertaken.

Estimated net CI reduction for hydrogen supplied from a 300 MW plant in BC to Japan. Compared to hydrogen generated from SMR	Estimated net CI reduction of hydrogen supplied from a 300 MW plant in BC to Los Angeles California. Compared with gasoline.
Tonnes CO_2e/year	Tonnes CO_2e/year
>170,000	>800,000

FIGURE 5 CARBON INTENSITY REDUCTIONS FOR THE LOHC LOS ANGELES CALIFORNIA AND JAPAN SCENARIOS

In figure 5, the BC-California LOHC case and BC-Japan LOHC case provide compelling CO_2 reduction estimates.

The Japanese market scenario showed a significant carbon intensity reduction for the industry use such as refineries or mobility. Further evaluations continue to be undertaken in terms of which market segments, by way of example such as industry, mobility or power sectors would offer the greatest benefits in terms of GHG reductions. It can be expected that the FCEV sector for the future market in Japan will offer greater benefits in this regard as is the case for California.

The California CA-GREET model does not have registered biogas pathways at the time of writing this report, but it is conceivable to assume that a pathway could be registered that would add to the carbon saving potential presented in figure 5.

1.4. Evaluation of revenue generated from by-product oxygen and waste heat

The opportunities to sell either by-product oxygen from the electrolyser and or waste heat from the hydrogenation reactor is site specific. None of the sites considered at the time of this feasibility study offered these by-product revenue opportunities.

2. Siting selection and installation cost inputs - BC production facility

The objective was to establish a process to select hydrogen production sites in BC that best met the criteria for economically viable hydrogen production, hydrogenation and transportation to both domestic and export markets. The approach adopted was to use the 300 MW electrolyser plant size for this evaluation and selection process. The assumption being that smaller plants such as a 10 MW pilot plant would be feasible at these sites as well but less competitive due to the reduction of the economies of scale.

This portion of the report was subcontracted. A summary of the deliverable is as follows.

2.1. Methodology

The site selection process included a number of specific steps, the first of which was to develop a list of “required criteria” that incorporated “must have” elements in order inform a site “select” or “no-select” decision.

Required Criteria	Threshold
Proximity to ≥ 230 kV transmission line	Must be within 50 km
Power capacity at substation	Must have capacity at local substation to provide up to 300+ MW power
Fresh water supply	Must have local freshwater source, able to provide up to 3.2 million litres/day
Proximity to natural gas network	Must be within 10 km for small diameter connection
Proximity to port	Must be within 10 km for pipe connection

Proximity to rail	Must be within 2-5 km for rail spur line, but rail must connect to major tank terminal
Proximity to highway	Must be within 10 km
Industrial land available	Must have industrial zoning / available crown land to support max plant size footprint (170,000 m2)

FIGURE 6 REQUIRED CRITERIA SELECTION LIST

The next step was to develop a list of "relative criteria" categories with sub-criteria that were linked to a number of subjective attributes. Weightings for each category were developed and agreed to in consultation with the Partners and MJTT. The range was from 1 to 10 (1 = lowest priority, 10 = highest priority). It is to be noted that the use of the BC Economic Atlas and the training provided by the MJTT was of great value.

2.2. Identify potential site locations – for small and full scale plant sizes

Twenty sites in BC were identified and evaluated during this study with BC Hydro and MJTT providing a number of site opportunities. However, it should be noted that the list of sites provided by BC Hydro were for substations that would meet the transmission line requirements of greater-than-or-equal to 230kV and support a site load requirement of more than 300 MW. The list of sites is provided in figure 7.

SITE #	DESCRIPTION
1	Brownfield; industrial park
2	Brownfield;
3	Brownfield;
4	Brownfield;
5	Greenfield; area targeted for industrial development
6	Greenfield; area targeted for industrial development
7	Brownfield;
8	Substation only; no identified land parcel
9	Substation only; no identified land parcel
10	Substation only; no identified land parcel
11	Substation only; no identified land parcel
12	Substation only; no identified land parcel
13	Substation only; no identified land parcel
14	Substation only; no identified land parcel
15	Substation only; no identified land parcel
16	Substation only; no identified land parcel
17	Substation only; no identified land parcel
18	Substation only; no identified land parcel

19	Substation only; no identified land parcel
20	Site identified near BC Hydro substation

FIGURE 7 SITE LIST

3. Environmental assessment and permitting requirements

The overview of the environmental assessment and permitting requirements for this feasibility study was subcontracted, a summary of the report follows.

The scope of the report included a description of a roadmap for the environmental regulatory approvals and compliance required at all levels of international, Federal, provincial, regional governance to build and operate both pilot along with commercial projects. The report reviewed the main Federal and provincial regulatory requirements for an environmental assessment (EA) and other required permitting, the associated time frames and estimated costs. It also described the implications of potential spills of toluene and MCH on land and in the marine environment. Furthermore, an overview of legislative and regulatory requirements associated with spill prevention and contingency planning were provided.

Summary of implications and responsibilities provided in the main report:

- If the project is located on a brown field site, residential site contamination is likely and will need to be managed in accordance with the contaminated sites regulation of the Environmental Management Act.
- If spills were to occur, the transporting vessel as well as the facility storing the products would likely be responsible for reporting, responding and undertaking recovery activities.
- In a spill scenario the sub-contractor recommends ongoing monitoring of natural attenuation (i.e. visual observations and physical sampling), since the products would likely begin to attenuate with wind and wave action.

Phase 2 Techno-economic feasibility assessment

4. Assess Future Export Market Potential

The potential annual demand of hydrogen up to 2050 for the two markets of California and Japan were analyzed. Both markets have advanced plans and activities in place for the adoption of hydrogen in large quantities as a future energy vector The two markets that were selected as export opportunities due to their relatively close proximity to BC and stated commitments for renewable hydrogen.

4.1. Supply to California

The writing of a California hydrogen market report for this study was subcontracted.

This report presents several scenarios for the evolution of renewable hydrogen demand in California.   The scenarios for transportation demand are derived as variants of state's Vision for

Clean Air and Mobile Source Strategy documents (California Air Resources Board 2012, 2016) wherein hydrogen fuel cell vehicles and other hydrogen market segments that are assumed to achieve varying levels of penetration for the spectrum of transportation applications. The demand splits for the optimistic scenario are shown in figures 8 and 9. The aggregate demand under low, mid and high cases are presented in figure 10.

Whether the actual demand growth tracks more closely with the conservative (low) or optimistic (high) scenario depends upon the cost and performance progress of renewable hydrogen and fuel cell drive technology in relation to renewable diesel, compressed renewable natural gas and electric drive technologies. Refining and fertilizer production require hydrogen, and in these cases, renewable hydrogen demand will be determined by the presence or absence of decarbonisation policies for those applications and the pace at which decarbonisation is required. The power generation, storage and end-use demand scenarios assume varying levels of penetration of renewable hydrogen for electricity storage needs, as forecast in the California Public Utility Commission RESOLVE resource planning model[2]. Should renewable hydrogen production cost reach levels below US$2 - US$3/kg, which is within the scenario range for costs in the 2030 time frame, significant adoption is likely irrespective of climate policy and subsidies.

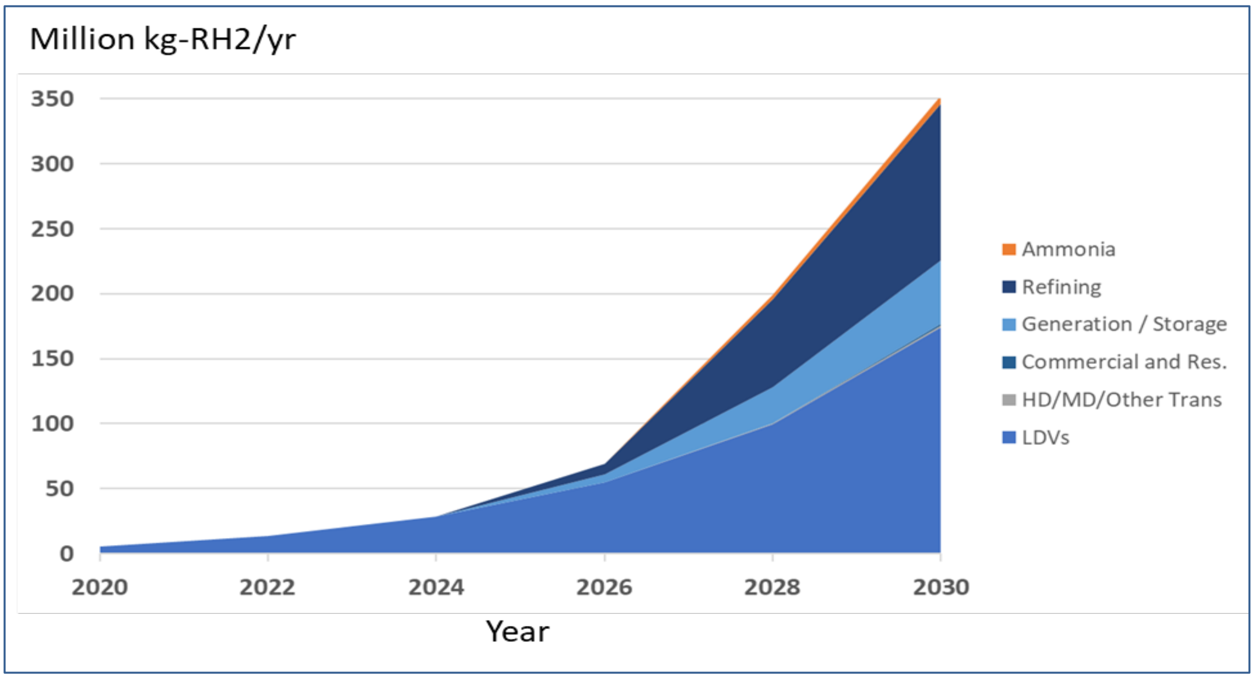

FIGURE 8 HIGH CASE RENEWABLE HYDROGEN DEMAND SCENARIO BREAKDOWN THROUGH 2030

[2] https://www.cpuc.ca.gov/General.aspx?id=6442457210

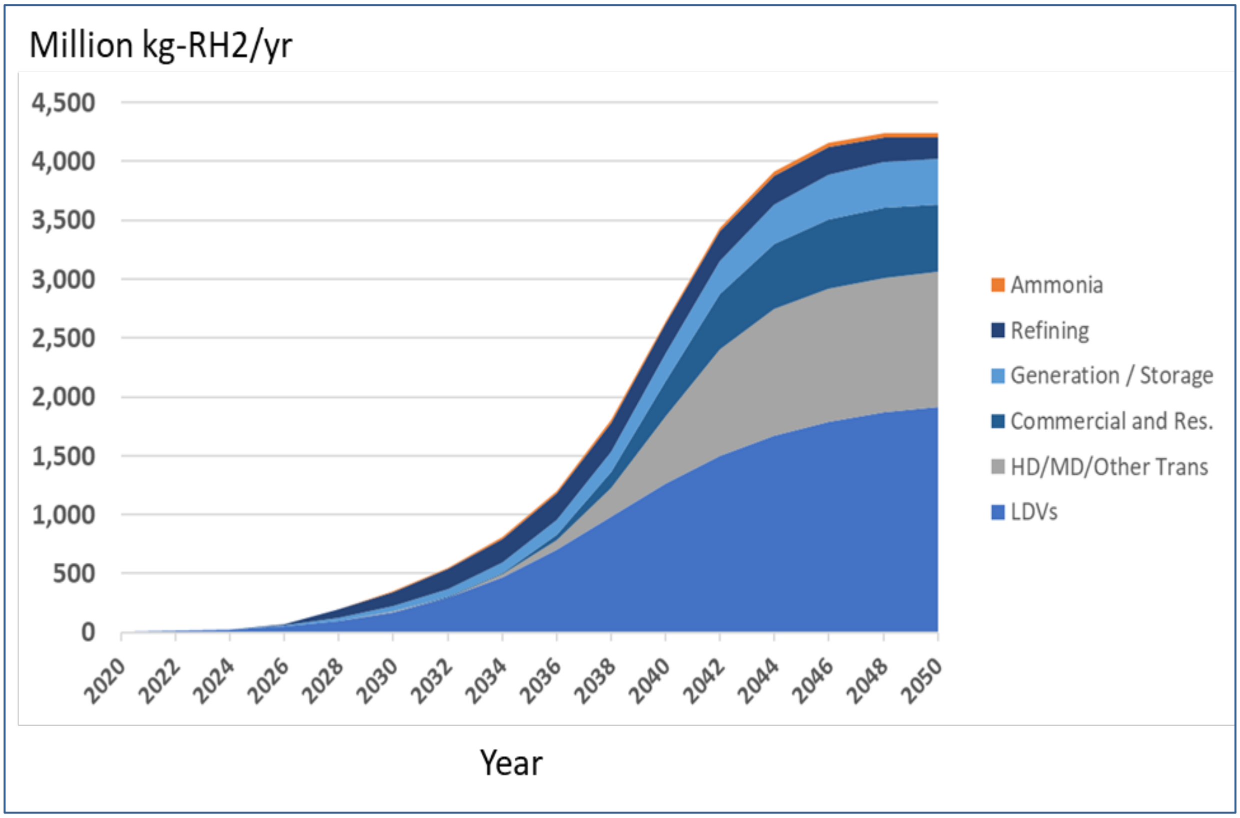

FIGURE 9 HIGH CASE RENEWABLE HYDROGEN DEMAND SCENARIO BREAKDOWN THROUGH 2050

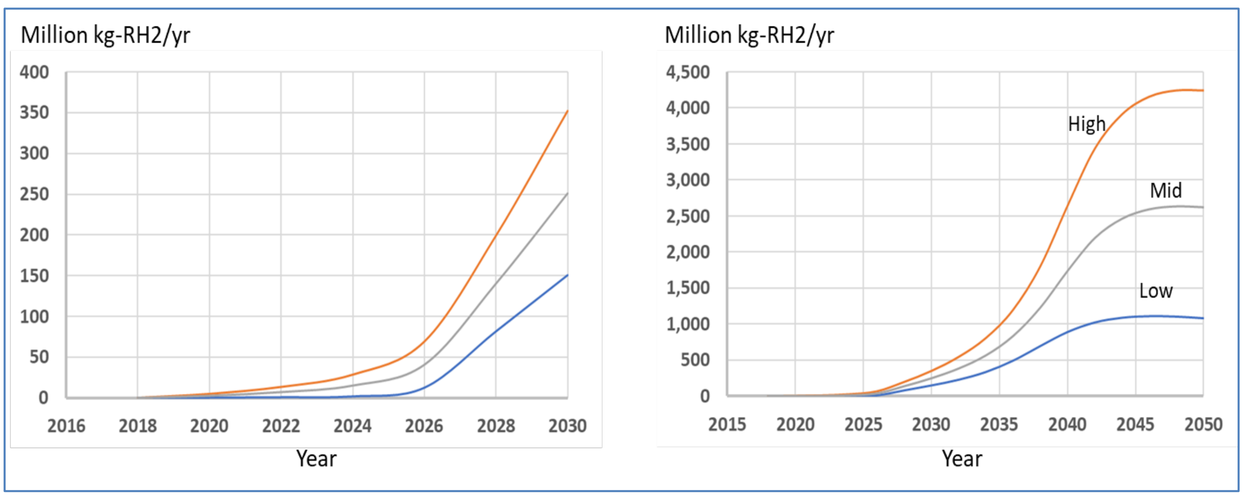

FIGURE 10 CALIFORNIA RENEWABLE HYDROGEN DEMAND SCENARIOS

4.2. Supply to Japan

A Japan hydrogen market report for this study was led and written by Chiyoda Corporation with support from Mitsui and ITM Power. A summary of the report follows.

Japan's response to energy and climate related issues has resulted in an ambitious strategy that will require cooperation between industry and the governmental sector in order to overcome the significant cost and technical challenges that lie ahead. Success of this program can only be declared when large volumes of zero-carbon hydrogen are produced, transported and consumed at a cost roughly equivalent to that of conventional fuels. Success of pilot and demonstration programs now underway will set the stage for larger scale-up and broader-based application by 2030 and beyond.

Applications envisioned for Japan's proposed *hydrogen economy* revolve around three key areas: mobility, home and commercial energy and power generation. Hydrogen demand for the mobility sector considers the use of FCEVs for which there are currently about 2,500 in use in Japan. There is a goal of expanding the number of private FCEVs to ~ 800,000 by the year 2030. Eventually Japan aims to cut deeply into the 62 million passenger vehicles on the road through the implementation of infrastructure improvements, technology innovation in fuel cell stacks, and the reduction of the cost of ownership through subsidies. Up to 1,200 buses and 10,000 industrial forklifts powered by fuel cells are the target also for 2030 and heavy-duty gasoline or diesel powered commercial trucks would also be converted to fuel cells. The hydrogen demand for the mobility use in 2030 is assumed to be 75,920 tonnes/yr in total. This is based on the target of 800,000 FCEV's (86kg/unit/yr), 1,200 FC Buses (3,850kg/unit/yr), and 10,000 FC Forklifts (250kg/unit/yr).

4.3. Supply to BC

The BC hydrogen market analysis for this study was subcontracted. Two market segments were evaluated for what the potential future demand for renewable hydrogen could be. These included the use of hydrogen for FCEVs and the inclusion of Power to Gas (P2G) market opportunities.

Two methods were used to predict FCEV deployment in BC. The first approach, the "ZEV Standard Model" was based on estimated BC ZEV sales required to meet the expected ZEV Standard targets. FCEVs were then estimated as a percent of total ZEV sales. The second approach is the "OEM Credit Model" which assumes a credit system similar to that of Quebec. This approach will also consider the impact on OEMs. The models estimate the following FCEV deployment levels by 2030:

- OEM Credit model: ~19,000-26,000 FCEVs deployed on the road.
- ZEV Standard model: ~12,000-22,000 FCEVs deployed on the road.

The modelling results were used to estimate total hydrogen demand from FCEVs in BC based on the assumption that each FCEV consumes ~0.5 kg of hydrogen per day. In 2030, demand for hydrogen in BC is projected to be between 2.2 and 4.8 million kg.

P2G projects in Europe are being driven by the need to reduce curtailed electricity from renewable sources (primarily wind and solar) and store this energy. Accordingly, many small P2G electrolyser demonstration projects have been and are being established to evaluate the pathways that this technology has to offer. The recent publication of the province's renewable energy objectives (*CleanBC*) contain a renewable gas target of 15% in the natural gas distribution system by 2030. The injection of hydrogen offers one potential solution to support reaching this target.

As an estimate the P2G demand for renewable hydrogen is enormous. If renewable hydrogen is injected into the natural gas grid to support the renewable gas objective at levels of 2% to 15%, an annual demand of 10 to 80 million kg of hydrogen would potentially be required.

There are other market segments such as heavy duty truck (including harbour vehicles), transit buses and ferry applications that are being developed for the use of fuel cell power trains and hydrogen as a fuel. The culmination of these market segments may provide cause for a more comprehensive analysis of how a hydrogen economy can support BC climate objectives moving into 2050 and beyond.

5. TECHNO-ECONOMIC ASSESSMENT - MODEL SCENARIOS FOR 3 PLANT SIZES

5.1. DEFINE SCENARIOS TO MODEL

During the process of gathering plant equipment and operational costs, and related project attribute inputs, the initial economic evaluations indicated that four scenarios made the most economic sense to appraise. This was supported to a large extent by the site evaluation report conducted.

The scenario models chosen for economic evaluation include the following:

1. A 300+ MW plant and the production of hydrogen and MCH in BC, for the export to Japan to a dehydrogenation plant and for hydrogen use in the power generation industry.
2. A 300+ MW plant and the production of hydrogen and MCH in BC for the export to California to a dehydrogenation plant incorporating hydrogen purification and compression to supply hydrogen to refuelling stations for the FCEV market in California.
3. A 100 MW plant in BC to produce compressed hydrogen gas for use in the BC market and supply the FECVs and potentially other markets such as P2G opportunities.
4. A 10 MW plant in BC to produce compressed hydrogen gas for use in the BC market and supply the FECVs and potentially other markets such as P2G opportunities.

5.2. RUN THE ECONOMIC MODEL WITH THE SELECTED SCENARIOS

The respective Capex and Opex of each of the four scenarios were reviewed. For each of the LOHC scenarios the following approximate schedules would be applicable:

- Year 0: project launch.
- Year 0 – 1: completion of detailed cost and price analyses. Including the use of low carbon fuel standard (LCFS) credits and establishment of partners and customers.
- Year 1 – 3: full environment and permitting assessment and FEED analysis.
- Year 3 – 6: engineering, procurement and construction.
- Year 6: commissioning and operation.

The economic models were established to evaluate a business case over a twenty year period. Each of the models included an internal rate of return (IRR) of 10% to conduct sensitively evaluations. This IRR figure was chosen for each case as a fixed number that enabled the establishment of resultant unit prices for hydrogen. The variables that were changed in the sensitivity analyses included the cost of electricity and the Capex inputs. The IRR target will most likely be different and established by potential future investors in accordance with each organisations' business investment criteria.

- **Scenario 1: 300 MW BC-Japan for the export of hydrogen in the form of MCH.**
  The intended use for the hydrogen in this case is for power generation in Japan. The results of the analysis BC-Japan scenario indicate that even at low costs of electricity and a reduction of Capex, the price of hydrogen in Japan is still above the target of approximately C$4/kg. This target has been set by the Japanese Ministry of Economy Trade and Investment (METI) for the year of 2030.

- **Scenario 2: 300 MW BC-California for the export of hydrogen in the form of MCH.**
  The intended use for the hydrogen in this case is as a fuel for FCEVs in California. The results of the analysis for the BC California scenario indicates that even at low costs of electricity and a reduction of Capex, the landed price of hydrogen in California is still above the target. The DOE target range is from US$2.00/kg to US$4.00/kg for 2030.

- **Scenario 3: 100 MW BC production for the use in the BC Lower Mainland and to be delivered as a compressed gas.**
  The intended use for hydrogen in this case is as a fuel for FCEVs in BC and possibly for other applications such as P2G to support the reduction of carbon emissions in the natural gas distribution system. The results of the analysis for the 100 MW BC scenario indicate that at low costs of electricity and a reduction of Capex, the free on board (FOB) plant costs of hydrogen are close to the current price of the gasoline equivalent for internal combustion engine (ICE) powered vehicles.

- **Scenario 4: 10 MW BC production for the use in the BC Lower Mainland and to be delivered as a compressed gas.**
  The intended use for the hydrogen in this case is as a fuel for FCEVs in BC and possibly for other applications such as P2G to support the reduction of carbon emissions in the natural gas distribution system. The results of this analysis for a 10 MW BC scenario indicate that this smaller plant has economic disadvantages verses the larger 100 MW plant. Even at lower costs of electricity and a reduction of Capex, the FOB plant costs of hydrogen are above the current price of the gasoline equivalent for internal combustion engine (ICE) powered vehicles.

6. Conclusions

6.1. Key conclusions and opportunities

The most promising opportunity to establish a business producing and delivering clean hydrogen is for the Californian market**:** the **LOHC BC-California scenario**. This is driven by the potential LCFS credits that could be collected through the use of clean hydrogen in FCEVs. The pathway would need to be established by a fuel provider in California before a project could be launched. The value for example of a LCFS credit could range from US$3 to US$4 per kg of hydrogen, depending upon the unit price of carbon. At the time of writing this report a LCFS credit had a value of approximately US$190 per tonne in California, and is expected to increase over time.

However, irrespective of this benefit, in order to achieve California's target price for hydrogen, the cost of BC electricity would need to be reduced as well as the plants' Capex through support mechanisms like government incentives, grants, and more detailed FEED analysis to reduce the capital equipment costs.

The same logic can be applied to the scenario for a 100 MW plant in the lower mainland to produce compressed hydrogen gas. Again, this is dependent upon the future value of BC-LCFS credits and a reduced electricity cost. In addition, plant Capex needs to be reduced with the use of government incentives, grants and more detailed FEED analysis to reduce the capital equipment costs. A challenge for this scenario is the BC demand for hydrogen as a 100 MW plant would be capable of producing about 15,600 tonnes of hydrogen per annum.

6.2. General conclusions

The opportunities to establish a first-of-its-kind business entity to produce and export large quantities of renewable hydrogen via LOHC technology is positive in terms of the BC resource potential and proximity to export markets.

In summary BC has the following advantages to support the growth of the BC and export hydrogen economies:

- The province has ideal locations for the production and supply of large quantities of hydrogen to both local and export markets, such as the US west coast and Asia.
- BC currently has a surplus of clean, renewable electricity that can be utilized to produce hydrogen.
- Water as a feedstock for electrolysis is available in the requisite quantities with the addition of small investments in water purification installations.
- Investments in a BC hydrogen economy will grow employment in the province and provide numerous social and financial benefits.
- Investments in a BC hydrogen economy will support the province's and Canada's long-term climate objectives.
- The hydrogen economy growth potential in BC will provide a sound foundation to support the province's ZEV objectives and for the deployment of FCEVs.
- The investment in hydrogen will continue to support and help develop new innovative clean tech businesses in the province.
- Based on the optimistic projection of FCEVs deployed by 2030 in BC, the large scale hydrogen production facility would support the displacement up to 26,000 light duty

vehicles on the road, which is equivalent to a reduction of 160,000 metric tonnes equivalent of CO_2 emissions.

Organisations that have an interest in pursuing investment for the production of hydrogen in BC that target both export and local markets will need a wide range of monetary and regulatory support. The incentives and provisions that need to be considered include by way of example, but not limited to, the following options or combinations thereof:

Competitiveness of delivered hydrogen

- New or enhanced capital investment grants or tax incentives for large scale electrolyser, hydrogenation, and dehydrogenation equipment in both import and export jurisdictions; and
- The price of electricity.

Fostering demand growth

- The demand for renewable hydrogen in BC needs to be supported with the establishment of a ZEV mandate targets which includes FCEVs. Future iterations of the BC ZEV legislation should incorporate various types of fuel cell powered transportation opportunities, including, but not limited to, transit buses, drayage trucks, yard trucks, ferries and other specialty vehicles.
- Additional incentives could include ZEV purchase subsidies, lease rebates, tax exemptions, and vehicle insurance rate benefits could be considered.
- Other applications for hydrogen to encourage demand and foster growth for the wider use of hydrogen in BC could include injecting renewable hydrogen into existing natural gas distribution system, as well as promoting the use of clean hydrogen in oil refineries and petrochemical production.

7. Glossary

Abbreviation	Details
ARB	California Air Resources Board
Capex	Capital cost
CCME	Canadian Council of Ministers of the Environment
CEC	California Energy Agency
CI	Carbon intensity
DOE	Department of Energy
EA	Environmental assessment
ECHA	European Chemicals Agency
FCEB	Fuel cell electric bus
FCEV	Fuel cell electric vehicle
FOB	Free On Board
GHG	Greenhouse gas
ICE	Internal combustion engine
MCH	Methylcyclohexane
MEM&PR	Ministry of Energy Mines and Petroleum Resources
METI	Japanese Ministry of Economy Trade and Investment
MIR&R	Ministry of Indigenous Relations and Reconciliation
MJT&T	Ministry of Jobs Trade and Technology
MW	Megawatt
NEDO	Japanese New Energy and Industrial Technology Development
NG	Natural Gas
OEMs	Original equipment manufacturers
Opex	Operational cost
PEM	Polymer Electrolyte Membrane
PSA	Pressure swing adsorption
PST	Provincial sales tax
SMR	Steam methane reformation

FIGURE 11 ABBREVIATION LIST

8. Acknowledgments

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9. References

The key references provided below pertain to the supply of information primarily for plant Capex and Opex inputs, related information and carbon intensity variables.

- All cost related inputs for hydrogenation, marine transport and dehydrogenation plants and related carbon intensities for transportation and Japan carbon intensity variables were provided by Chiyoda Corporation.
- All costs related inputs for the electrolysis plants, the hydrogen compression and storage data and all applicable carbon intensities for the Los Angeles, California LA case were provided by ITM Power.
- Electricity prices. BC Hydro - https://app.bchydro.com/accounts-billing/rates-energy-use/electricity-rates/transmission_rate.html.
- Carbon intensities databases for the calculation of GHG assessments:
  - GHGenius 5.0a https://www.ghgenius.ca.
  - CA-GREET 2.0 https://www.arb.ca.gov/fuels/lcfs/fuelpathways/pathwaytable.htm.
- Greenhouse gas emissions from heavy-duty natural gas, hybrid, and conventional diesel on-road trucks during freight transport - https://reader.elsevier.com/reader/sd/pii/S1352231017305794?token=B5BCCA1CBFAEDDA3F081EDCC80FD2C0F574F0B6035CC8F88D0DC3CF455878579101FBAB03867F570F9D90F8CCF7F41E4.