CTCN Technical Assistance

“Developing a power to gas masterplan in Lao PDR”

POWER-TO-GAS (P2G) TECHNOLOGY STATE OF THE ART

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内容

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Abbreviations

BECS	Bio Energy with Carbon Capture and Storage
DACCS	Direct Air Carbon Capture and Storage
EU	the European Union
PEM	polymer electrolyte membrane
P2G	power-to-gas
R&D	research and development
SOEC	solid oxide electrolysis

1. Overview

This paper introduces a P2G technical and projects overview, which gives the examples of the ways to produce green hydrogen and/or synthetic methane gas and look at international codes and regulatory framework to be referenced when developing plans to introduce P2G technology to Lao PDR.

In the first part, technical outlines is provided for the three main technologies, including (i) alkaline water electrolysis, (ii) polymer electrolyte membrane (PEM) and (iii) solid oxide electrolysis (SOEC). No technology can be all-round and therefore it is important to recognize the advantages and disadvantages of each technology and the research and development progress status and select the most suitable technology while taking into consideration the electricity capacity to be supplied to electrolyzer, the electricity frequency, hydrogen production volume and so on.

In the second part, the outline of CO_2 separation is presented with the five main methods: (i) physical adsorption, (ii) physical absorption, (iii) chemical absorption, (iv) membrane separation and (v) cryogenic separation. In addition, the basics of methanation is presented in this part.

In the third part, P2G projects overview is provided, including the projects and its statuses in Europe, which is one of the forerunners for carbon neutral or zero carbon emission society. In addition, three important considerations for encouraging the P2G project are pointed out, such as, (i) predictability of funding, (ii) minimizing the adverse effects of the transition to carbon free/neutrality and (iii) strengthening and improving the competitiveness of the industries.

2. Power-to-Gas - Technical Overview

2.1 Scheme of a Power-to-Gas (P2G) Plant

The scheme of a typical P2G process is as shown below figure.

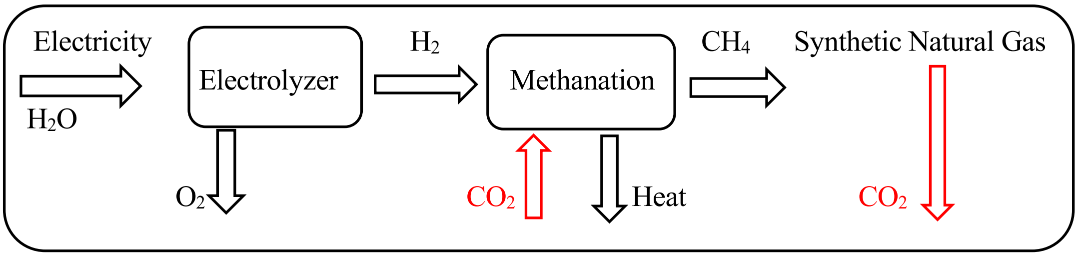

Figure 1: Scheme of a typical P2G process

The scheme shown above was first proposed by Dr. Koji Hashimoto, then a professor at Tohoku University in Japan.[1] The combination of electrolyzer and Sabatier reaction, which is $CO_2 + 4H_2 = CH_4 + 2H_2O$, allows methane synthesis. Furthermore, as CO_2 is recycled (especially in the case that the system is installed adjacent to industrial plants) in the process of producing methane gas, it can contribute to offsetting CO_2 emissions and therefore achieving carbon neutrality.

The function of the hydrogen/methane production system, as shown above, can be broken down to two phases, including (i) production of green hydrogen by a water electrolysis device using the carbon-free electricity from renewable energy source (hydropower stations in case of Lao PDR); and (ii) production of green methane by reacting green hydrogen with concentrated CO_2 from exhaust gas from the industrial plants.

This brings great merits to Lao PDR in terms of setting the country in the path of achieving carbon neutrality, as green electrical power from hydropower plants can be used as a feed to the electrolyzer, and CO_2 from industrial plants can be recycled from industrial plants. Generated synthetic methane gas can be distributed to its domestic households, among other ways to utilize as substitute of natural gas, which contributes to decreasing the amount of oil and gas imports, improving energy independency for Lao PDR.

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[1] Hitachi Zosen, *カーボンリサイクル技術（CCR）に関する取組み (Regarding the activities on carbon recycling)*, 2. https://www.jstra.jp/conference/docs/GHG 戦略 19-2-2-3 カーボンリサイクル技術（CCR）に関する取組み.pdf

2.2 Electrolyzer (H_2 Production)

The water electrolysis technology is broadly classified by the type of electrolyte used. As shown the below table (Table 1), currently three types – alkaline water electrolysis, polymer electrolyte membrane (PEM) type and solid oxide electrolysis (SOEC) type – are available, while SOEC type is still at the research and development stage. In this paper, technical comparison is made only for the commercialized technologies, alkaline water electrolysis and PEM.

	Alkaline	**PEM**	**SOEC**
Stage/Phase	commercialized	commercialized	R&D
Electrolysis temp.	80~90^{O}C	90~120^{O}C	600~900^{O}C
Electrode area	more than 3 m^2	more than 0.2 m^2	unclear
Current design	2~10 kA/m^2	10~30 kA/m^2	2~6 kA/m^2
Electrolysis voltage	1.75~2.10 V	1.72~2.20 V	Up to 1.50 V
Electricity consumption	4.2~5.0 kWh/Nm^3	4.1~5.2 kWh/Nm^3	Up to 3.6 kWh/m^3
Equipment cost	low	high	unclear

Table 1: Types of electrolysis

Alkaline water electrolysis technology is the most mature electrolysis technology with commercial machines in use since the 1920's. Potassium hydroxide or sodium hydroxide solution is used for the electrolyte, commonly nickel, nickel alloy, iron or nickel cobalt oxide for anode (positive electrode) and iron, iron-nickel alloy or iron-rare for cathode (negative electrode). The advantages and disadvantage of the system are as follows (Table 2).

Advantage	Disadvantage
Good response for change in load	Compared to PEM, the range of operation load is limited, minimum load usually falls within 10~40% range, the electrolyzer to be switched off under the lower input condition
Consistently and stable operation and can operate for long period	Additional device is required when pressure is required for output gas
Large scale system is possible; therefore, scale of megawatt can be implemented	Additional purification equipment is required to make high purity gas
Suitable to store large scale of energy more than 200 Nm^3/h of hydrogen production	Compared to PEM, size of electrolyzer becomes bigger with current density becomes lower
Compared to PEM, the raw materials of device configuration are moderately priced	High safety standard measures and disposal control are required as high temperature and highly concentrated alkaline solution is used as an electrolyzer solution
	Long restarting time after shutdown

Table 2: Advantages and disadvantages of alkaline water electrolysis technology

Although **PEM electrolysis technology** has been commercialized, initially it did not have a sufficient capacity to generate a large amount of hydrogen. However, in the recent years, many companies have been developing the technology to enhance its capacity of PEM type electrolysis. The advantages and disadvantages of the system are as follows (Table 3).

Advantages	Disadvantages
Fast response and compatibility with various power sources such as solar and wind power	Compared to Alkaline Water Electrolysis, the raw material cost of electrode and polymeric is higher
Adaptable to changes in output fluctuation in the range of 0~100% and capable of DSS (daily start-up and shutdown) operation	Large scale compatibility and applicability remains as a risk as large size of the membrane is under development and the proven size is limited to 10 MW, while Alkaline Water Electrolysis is capable for more than 100 MW
Capable of high purity hydrogen gas production	Shorter lifetime compared to alkaline water technology and falls within 5~20 years range
Operation with diverse compression is possible	
No electrolysis solution is required	

Table 3: Advantages and disadvantages of PEM electrolysis

2.3 CO_2 Separation, Production, Utilizing and Storage

The main CO_2 sources are (i) CO_2 from carbon capture technologies, (ii) CO_2 from biomass, obtained by means of fermentation, gasification, and/or combustion, (iii) CO_2 from industrial processes obtained as a by-product and (iv) CO_2 from air.

The major CO_2 separation and recovery technologies are (i) physical adsorption method, (ii) chemical absorption method, (iii) membrane separation method and (iv) cryogenic separation method.

Physical adsorption is suitable for small- to medium-scale projects, and multiple adsorption towers are required for a large-scale facility. CO_2 is adsorbed on adsorbents like activated carbon, then the same is separated and recovered by decompressing the adsorbent.

Physical absorption is suitable for CO_2 separation from the gas in a high-pressure environment. CO_2 is absorbed by absorption solvent under high pressure, then the same is separated and recovered by decompression of the absorbent.

Chemical absorption is suitable for low pressure gas, and heat is required. CO_2 is absorbed chemically by amine solutions, then the CO_2 is separated and recovered by heating solutions.

For a largescale facility, the improvement in penetration speed and selection is under development for **membrane separation**. CO_2 is separated and recovered by selective filter using membrane.

Cryogenic separation is suitable for achieving CO_2 purity of more than 98%. CO_2 is liquified under low temperature, then separated and recovered making use of different boiling point.

2.4 Methanation

Hydrogen (H_2) obtained from the electrolyzer and carbon dioxide (CO_2) obtained from CO_2 separator are preheated to $180^{O}C$ and then fed into a reactor. H_2 and CO_2 fed into the reactor react in the presence of a catalyst in the reactor to produce steam and methane, by Sabatier reaction ($CO_2 + 4H_2 = CH_4 + 2H_2O$).

The post-reacted gas is cooled to 60°C in the gas condenser, and most of the steam is condensed to water. The gas and water are separated in the process tank and the gas flows into process cooler.

After the gas is cooled to 38°C in the gas cooler, the cooled gas flows into mist separation tank, wherein the water mist is separated, and the product gas of methane (CH_4) is obtained.

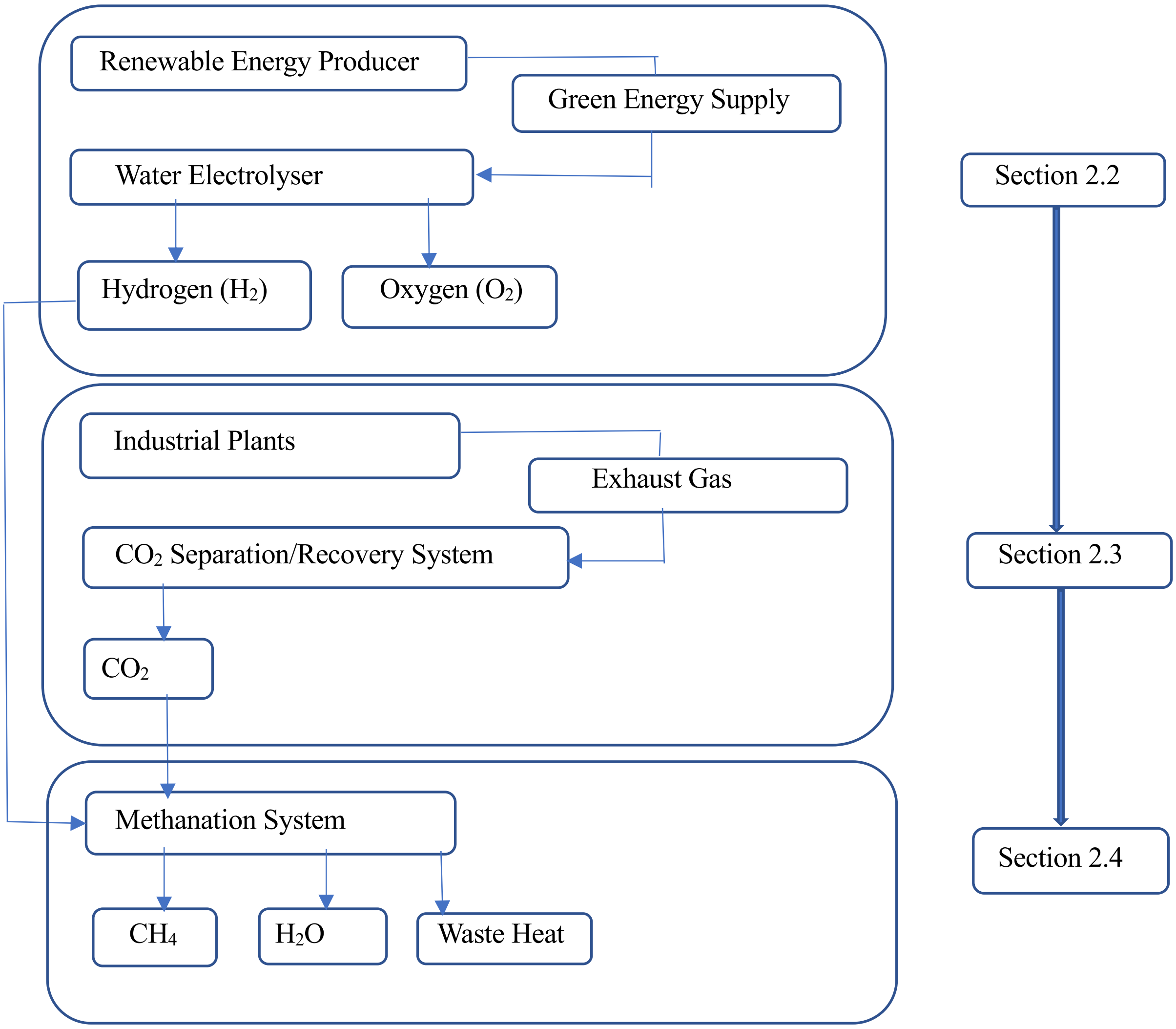

Figure 2: Water electrolyzing process

2.5 Hydrogen Production Value Chain

Hydrogen (produced either by electrolysis or other methods), is generally stored in either gaseous or liquid forms. For storing hydrogen in gaseous form, hydrogen is compressed at a high pressure and stored in storage compartments, such as naturally formed underground locations such as salt cavities, aquifers, or depleted oil or gas fields, or manmade vessels such as metal containers. For commercial use, metal tanks are considered more suitable since it offers stability and purity of stored hydrogen, in addition to its portability which becomes particularly advantageous especially when there is a distance between the location of hydrogen production and location of use. However, further development and demonstration to make the pressurizing technology and containers are required in order to lower the cost so that more users can adopt the technology in the future.[2]

Hydrogen can also be stored in liquid form by cooling it down to -253℃. When turned into liquid, the mass of hydrogen becomes 800 times smaller than it is in the gaseous form, which is naturally more cost-effective in storage and transportation. Liquid hydrogen can be transported stored in containers or through pipelines. The latter is effective in providing a large amount of liquid hydrogen at a time at a stable speed, since it is essentially the same method that natural gas is provided to commercial and industrial buildings and households in most developed countries. However, production of liquid hydrogen, as well as to transportation via pipelines required significant investment in the infrastructure, therefore, for Laos, it is unlikely the first option when developing hydrogen storage and transportation strategies.

Lastly, as mentioned above, methane can be produced using hydrogen and carbon dioxide via chemical reaction. Methane, unlike hydrogen, can be handled and used in a similar way to natural gas, which may require less investment especially if a country has infrastructure to store and distribute natural gas in the first place.

2.6 End-uses and applications

Although it is still in the early stage of conducting feasibility studies, hydrogen and to some extent methane can be used as fuels in electricity generation and industrial settings. For instance, it has been proven that hydrogen mixed with natural gas can be used to fuel large-scale gas turbines to generate electricity when the equipment are modified adequately to allow stable combustion of hydrogen and natural gas. Because natural gas and hydrogen have different combustion properties where make hydrogen burn faster, a phenomenon called a flashback which can potentially damage the turbines and

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[2] Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry. "水素の製造、輸送・貯蔵について" ("Hydrogen production, transportation, and storage"). https://www.meti.go.jp/committee/kenkyukai/energy/suiso_nenryodenchi/suiso_nenryodenchi_wg/pdf/005_02_00.pdf

surrounding facility, can occur.[3] However, hydrogen-fueled turbines have been installed in some thermal powerplants around the world, including Japan[4] and Australia.[5]

In industrial settings, fuel cell generators that use hydrogen as fuel are also in the feasibility studies and demonstration stage. For instance, Tokuyama (chemicals manufacturer) and Panasonic in Japan have recently installed a fuel cell generator that use by-product hydrogen to provide heat and electricity to be consumed in the same factory and office rooms.[6] Likewise, Panasonic and Toshiba of Japan have made fuel cell generators commercially available for businesses and municipalities, with plans to also make it available for households in the future.[7] If and when fuel cell generators become more affordable, it can replace boilers and co-generations systems at factories that currently use fossil fuel, which in turn will lead to considerable GHG emission reduction when adopted at a large scale.

Lastly, hydrogen, as well as methane produced with green hydrogen, can be used as fuel for automobiles as well. Fuel cell vehicles (FCVs) have begun to become commercially available around mid-2010s, notably with Toyota’s Mirai[8] and Hyundai’s Nexo[9] which are currently in production. Like electric vehicles, FCVs use electricity to run an electric motor, except in the case of FCVs, electricity is generated using a fuel cell stack, which is an assembly of membrane electrodes, via chemical reaction of hydrogen in an onboard fuel tank and oxygen in the air. As for driving range of FCVs per refuel, it is around 380 to 400 miles.[8-9] In addition, engines of the vehicles that run on natural gas as fuel can be modified retroactively to use methane instead since natural gas and methane are similar in nature.

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[3] Syed, N., et al. “The effect of hydrogen containing fuel blends upon flashback in swirl burners”. Applied Energy. 89, 1. 106-110.

[4] Mitsubishi Heavy Industrial. “大型高効率ガスタービンで水素 30%混焼試験に成功 発電時の CO2 排出削減に貢献” (“Contributing to CO2 emission reduction through completing study on mixing 30% of hydrogen to fuel a large-scale gas turbine”). https://power.mhi.com/jp/news/20180119.html

[5] General Electric. “GE innovates Australia's first hydrogen-blend power plant”. https://www.ge.com/gas-power/resources/case-studies/australias-first-dual-fuel-hydrogen-plant

[6] Tokuyama. Tokuyama and Panasonic Start the Demonstration of Pure Hydrogen Fuel Cell Generators That Use By-product Hydrogen. https://www.tokuyama.co.jp/eng/news/2021/2021091401.html

[7] Panasonic. “純水素型燃料電池 5 kW タイプを発売” (“Launch of 5 kW hydrogen fuel cell generators”). https://news.panasonic.com/jp/press/data/2021/10/jn211001-3/jn211001-3.html

[8] Toyota. 2021 Mirai. https://www.toyota.com/mirai/.

[9] Hyundai. 2021 NEXO Fuel Cell. https://www.hyundaiusa.com/us/en/vehicles/nexo.

3. P2G Projects Overview

3.1 Background

As it is mentioned previously in this paper, the basic technical concept of P2G is originated in Japan in 1990's, by Dr. Hashimoto, the Professor of Tohoku University of Japan. Afterword, the R&D activities have been booming in Europe, especially in Germany.

In response to the enactment of the Paris Climate Agreement in December 2015, the European Union (EU) published its own climate change plan named "A European Green Deal" in December 2019. In the Europe Green Deal and Europe Climate Laws, it is stipulated that EU will be carbon neutral by 2050 and settles its interim target that GHG emission to be reduced by 55% by 2030 compared to the level in 1990. EU designated that GHG emission shall be the first priority issue and decided to inject a third of EU budget and Europe Recovery Fund (in total EUR 1.8 trillion) into the related projects and R&D activities.[10]

In Japan, the government has announced its green growth strategy in December 2020 which aims for carbon neutrality by 2050, setting its interim target of 26% decrease GHG emission by 2030 against the level of 2013, and the target was amended to 46% in the climate summit held in April 2021. In response to this, the Japanese government has arranged US$ 20 billion for green innovation fund, which aims to fund.

Likewise, in the United States, there are various federal funding for hydrogen production projects and research activities, including a $64 million funding by the Department of Energy for the H2@Scale initiative which included 18 hydrogen production, transport, and storage projects for the fiscal year 2020.[11]

3.2 Status of P2G Projects in Europe

The GHG emission activities started its initial journey in Europe. Most of the projects are

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[10] The European Commission, "*Recovery plan for Europe*". https://ec.europa.eu/info/strategy/recovery-plan-europe_en

[11] Office of Energy Efficiency and Renewable Energy, *"H2@Scale"*. https://www.energy.gov/eere/fuelcells/h2scale

located in Germany. In Europe, the industrial foundation has started its significant change as green fuel will be the fuel instead of fossil fuels.

The oil and gas conglomerates, such as BP and Royal Dutch Shell, have announced that they will sell and release the current oil and gas assets to others and the revenue therefrom to be utilized to green energy development.

In addition, automobile manufacturers are also working on R&D for green-energy-fueled cars. For instance, a German car manufacturer Audi has built a methanation facility with CH_4 production of 6 MWh equivalence.[12]

The following map shows the locations and the current status of Power-to-Gas projects in Europe (Figure 3).[13]

Figure 3. Hydrogen projects in Europe

P2G projects in the map above are differentiated according to the target products hydrogen and methane as well as activity/inactivity.

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[12] McPhy "Audi E-Gas". https://mcphy.com/en/achievements/power-to-gas-en/audi/?cn-reloaded=1

[13] Thema, Bauer, and Sterner, *"Power-to-Gas: Electrolysis and methanation status review"*, 781.

- **Dark green:** PtG with biological CO2-methanation active.
- **Light green:** PtG with biological CO2-methanation inactive.
- **Red:** PtG with chemical CO2-methanation, active.
- **Orange:** PtG with chem. CO2-methanation, inactive.
- **Dark blue:** PtG without methanation, active.
- **Light blue:** PtG without methanation, inactive.

- **Yellow:** Power-to-X.

The following graph, which is introduced in the same report, shows the number of the Power-to-Gas Projects (left side) and total of installed electrical power in MW (right side) with regards to their product either hydrogen or methane from chemical or biological methanation. The figure includes active and inactive, complete and/or planned projects as of issuing the report. About 58% of all project have or had their focus on hydrogen production, storage, and use, while the rest have or had their focus on CO_2 methanation.

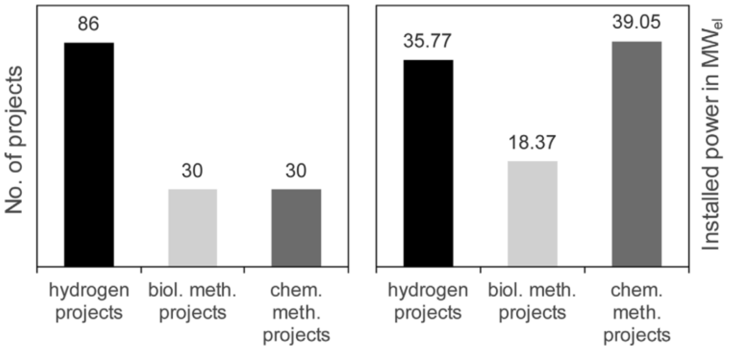

Figure 4. Number of power-to-gas projects and total of installed electrical power in MW_{el}

The Figure 3 shows that most of the projects are located in central Europe, especially in Germany, Denmark and Netherland. As for the installed capacity (electrical power or electrolyzer), Germany has a total 40 MW followed by Denmark with over 20 MW. The sources of CO_2 are (i) biogas or sewage gas from wastewater treatment plants, (ii) bioethanol/alcoholic fermentation plants, (iii) fossil power plants and (iv) capture from biomass combustion and direct capture from the air.

Considering that no significant number of waste treatment facilities (such as biogas plants and wastewater treatment facilities), fermentation plants are available in Lao PDR, it is still early for the country to adopt DACCS (Direct Air Carbon Capture and Storage/BECS (Bio Energy with

Carbon Capture and Storage) technology. As such, fossil power plants and industrial plants will most likely be the source of CO_2 for Power-to-Gas in Lao PDR.

In approximately 45% of the projects mentioned above, the product gas is injected into the gas network and about 35% of them is injected in the form of hydrogen, while the ratio of methane is 65%. Methane can be directly fed into the existing gas pipeline, while the special attention should be paid to the ratio of hydrogen fed into existing pipeline due to safety concerns.

3.3 Status of P2G Projects in Japan and Elsewhere

There are several notable PtG projects in Japan, as shown below (Table 4).

Project Name	**Product**	**Power (MW)**	**Project Start**
Japan			
Hydrogen Production Feasibility Study[14]	H_2	2	2021-current
Fukushima Hydrogen Energy Research Field[15]	H_2	10	2018-current
Hokkaido Supply Chain Feasibility Study[7]	H_2	.22	2018-2020
Hydrogen Production Feasibility Study at Keihin Port[16]	H_2	1.98	2015-2020
Floating Offshore Wind Power Feasibility Study[17]	H_2	-	2014-2015
International Hydrogen Supply Chain Feasibility Study (Brunei-Kawasaki partnership) [18]	H_2	-	2012-2021
United States			
H2@Scale[19]	H_2	-	2019-
SGH2 Lancaster[20]	H_2	-	2020-

Table 4. List of hydrogen projects in Japan and United States

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[14] Tokyo Gas, “*メガワット級水電解装置を利用した水素実証実験の実施について” (Regarding the hydrogen feasibility study using a megawatt scale electrolysis)*. https://www.tokyo-gas.co.jp/news/press/20210707-02.html

[15] Toshiba, *“水素実証事業における当社の取り組み事例と自治体との連携について” (Hydrogen-related activities and collaborations with municipalities)*. https://www.env.go.jp/seisaku/list/ondanka_saisei/lowcarbon-h2-sc/events/PDF/shiryou07.pdf

[16] The Ministry of the Environment, Japan. *“京浜臨海部での燃料電池フォークリフト導入とクリーン水素活用モデル構築実証” (Fuel cell forklifts and green hydrogen feasibility study at Keihin port).* https://www.env.go.jp/seisaku/list/ondanka_saisei/lowcarbon-h2-sc/demonstration-business/PDF/demonstration_01_20210113.pdf

[17] Toda, *“浮体式洋上風力発電事業” (Floating wind power projects).* https://www.toda.co.jp/business/ecology/special/windmill_02.html

[18] Kawasaki City, *“水素サプライチェーン構築モデル” (Hydrogen supply chain model project).* https://www.city.kawasaki.jp/590/page/0000111043.html

[19] Institute for Energy Economics and Financial Analysis, *“Frontier Energy launches three year, $10.8 million green hydrogen pilot project in Texas”*. https://ieefa.org/frontier-energy-launches-three-year-10-8-million-green-hydrogen-pilot-project-in-texas/

[20] Fuel Cell Bulletin, *“SGH2 plant to produce green hydrogen from waste in California”*. https://www.sciencedirect.com/science/article/abs/pii/S1464285920302479

In addition to the projects listed above, there are some countries with a plan to produce hydrogen at a commercial basis in a near future. For instance, Chile's National Green Hydrogen Strategy envisions that the country will begin exporting green hydrogen in 2030.[21] Likewise, China's Sinopec expects to launch its first green hydrogen production project in the Inner Mongolia in 2022.[22]

3.4 Challenges

There are several challenges, for both developed and developing countries alike, that need to be overcome in order to develop a commercially viable hydrogen production project. First, there are some technical aspects of a project that need to be calibrated based on the circumstances of the project location, which incudes, but not limited to; 1) identification of most suitable pre-process method; 2) identification of most suitable and cost-effective CO2 separation method; 3) analysis of operation data, feedstock gas, and produced gas in order to achieve optimal reaction condition in gas production; 4) verification of life span and replacement frequency of the catalyst; 5) construction of a control system which can support the load and optimize CO2 separator and hydrogen production as necessary; 6) identification of most suitable and cost-effective methanation reactor. In addition, since green hydrogen production that relies on renewable energy is susceptible to fluctuations in the change in electricity supply level, which can occur especially in countries where hydrogen power is the dominant source of renewable energy due to water scarcity caused by climate change or dry seasons, a survey on rainfall and electricity supply fluctuations should be conducted to have a long-term prediction. Additionally, when a P2G project is taking place in a country with limited experience on gas production and handling, safety codes and regulations must be developed in order to ensure safe operation of hydrogen production and distribution. This is particularly applicable to the case of Laos, where there is no fossil fuel production within the country, including natural gas. Lastly, since producing green hydrogen requires renewable energy, it can be a challenge to some countries that still partially rely on thermal power generation using fossil fuel. As for Laos, however, this

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[21] The Ministry of Energy, Government of Chile, *"National Green Hydrogen Strategy",* 18. https://energia.gob.cl/sites/default/files/national_green_hydrogen_strategy_-_chile.pdf

[22] Reuters, *"Sinopec to launch first green hydrogen project in 2022"*. https://www.reuters.com/business/sustainable-business/sinopec-launch-first-green-hydrogen-project-2022-2021-05-25/

should not be a problem since the country enjoys abundant renewable energy, as it will be discussed in the next chapters.

Hence, taking a P2G feasibility study to a commercially viable project faces a wide array of both technical and regulatory challenges that requires involvement of various experts in the respective fields, which will benefit from having comprehensive plans to which the stakeholders can refer as they make progress forward.

4. Codes, Regulations and Standards

As hydrogen and methane must be produced, transported, stored under a high pressure, safety is the foremost priority in each stage. In Japan, the Ministry of Economy and Trade and Industry has established the law “High Pressure Gas Safety Act” and appointed the High Pressure Gas Institute of Japan to supervise the high-pressure-gas-related industries and activities. In addition, relevant international codes and standards are listed in the table below (Table 5).

It is not necessary for Lao PDR to exactly follow the procedure of Japanese government; however, the following points can be a useful reference for the consideration for its future codes, regulations and standards, along with international codes that have been established for each stage.

	Japanese Codes	International Codes
■ Production	The gas with the pressure more than 1 MPa shall be subject to the High Pressure Gas Safety Act and prior to having the production facility, the company shall issue the application to the municipality office for its approval. In the application, the company shall stipulate the concept of the production facility and the technical specification of equipment and parts of the facility. The company shall perform the voluntary inspection of the equipment every year. The company shall nominate the exclusive officer(s) to monitor the safety of daily production activities.	ISO 22734
■ Storage	The High Pressure Gas Safety Act stipulates that high pressure gas must be stored in a location proved by the local municipality (Articles 15-16).	ISO/TR 15916 ISO 13985 (for land vehicle fuel tanks)
■ Transportation	Tanks, cylinders, pipelines and trucks for the transportation shall meet the safety requirements under the High Pressure Gas Safety Act and the company shall perform the safety training to the person/people engaging the transportation activities (Article 24).	ISO 16111 ISO 19880 ISO 14687 (for utilization in vehicular and stationary applications)
■ Equipment manufacturing	The manufacturer shall have the production facility meeting the requirements of the High Pressure Gas Safety Act and shall issue the application to the municipality office for its approval and issuing the fabrication license. The specification of the equipment and parts thereof shall be in line with the guideline of The High Pressure Gas Institute of Japan. The equipment can be delivered upon the inspection clearance of the institute and issuance of the certificate thereof. It is mandatory requirement for the manufacturer to nominate the exclusive safety officer. The fabrication license shall be renewed every five years (Article 39).	ISO 22734

Table 5. List of Japanese and international codes and standards

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1. Hitachi Zosen, “カーボンリサイクル技術（CCR）に関する取組み” (“Regarding the activities on carbon recycling), 2. https://www.jstra.jp/conference/docs/GHG 戦略 19-2-2-3 カーボンリサイクル技術（CCR）に関する取組み.pdf
2. The European Commission, “Recovery plan for Europe”. https://ec.europa.eu/info/strategy/recovery-plan-europe_en
3. Office of Energy Efficiency and Renewable Energy, “H2@Scale”. https://www.energy.gov/eere/fuelcells/h2scale
4. McPhy “Audi E-Gas”. https://mcphy.com/en/achievements/power-to-gas-en/audi/?cn-reloaded=1
5. Thema, Bauer, and Sterner, “Power-to-Gas: Electrolysis and methanation status review”, 781. https://www.sciencedirect.com/science/article/pii/S136403211930423X
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9. Toda, “浮体式洋上風力発電事業” (Floating wind power projects). https://www.toda.co.jp/business/ecology/special/windmill_02.html
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