ERIA Research Report FY2025, No. 11

Policy Study of Hydrogen Utilisation in Mongolia

Mongolian Energy Economics Institute

with the Support of the

Economic Research Institute for ASEAN and East Asia

Policy Study of Hydrogen Utilisation in Mongolia

ERIA Research Project Report FY2025 No. 11

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Preface

Mongolia possesses vast coal reserves and currently meets over 67% of its electricity and heating needs through coal consumption. However, aligning Mongolia's energy sector development with global energy trends, regional energy advancements, and the energy strategies of neighboring countries is crucial to facilitate an environmentally friendly transition toward green energy.

In response, the State Great Khural (Parliament) of Mongolia adopted the "Vision-2050" long-term development policy in 2020 and the "New Recovery Policy" in 2021, defining key energy sector development directions. These policies emphasize renewable energy expansion, reduction of greenhouse gas emissions, and increased efficiency. One of the key objectives outlined is conducting a feasibility study on utilizing solar and wind energy resources in Ömnögovi province to generate renewable energy for integration into the Northeast Asian power grid.

As part of this policy implementation, Mongolian Energy Economics Insitute (MEEI) proposed a research project titled "Policy Study on Hydrogen Energy Utilization in Mongolia" to the Economic Research Institute for ASEAN and East Asia (ERIA). Additionally, a request was made to train Mongolian researchers in Japan, which was positively received by your institute, leading to the successful completion of the research.

Southern Mongolia has abundant solar energy resources but limited water resources. Your research has highlighted the potential of transmitting electricity generated in the Gobi region to central Mongolia for hydrogen production, which could not only meet domestic heating demands using green energy but also export hydrogen energy to neighboring Northeast Asian countries where demand is high. This is a highly significant finding.

The export of green hydrogen could play a key role in enhancing energy security in Northeast Asia. Additionally, it presents an opportunity to combine the advanced technology and financial resources of developed countries in the region with Mongolia's rich energy reserves, fostering mutually beneficial, long-term economic cooperation that could evolve into a sustainable energy system.

On this occasion, I would like to express my sincere gratitude to the Economic Research Institute for ASEAN and East Asia (ERIA) for successfully conducting this hydrogen research project in collaboration with the Energy Economics Institute of Mongolia. I also believe this study has significantly enhanced the understanding of hydrogen energy among researchers at your institute and will contribute to the development of a hydrogen policy tailored to Mongolia's specific conditions.

Choijilsuren Battogtokh

Member of the State Great Khural (Parliament) of Mongolia,
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List of Abbreviations and Acronyms

ADB	Asian Development Bank
ALK	alkaline electrolyser
BAU	business-as-usual scenario
CHP	combined heat and power
EBT	Energy Balance Table
GDP	gross domestic product
GW	gigawatt
GWh	gigawatt-hour
HOB	heat only boiler
IEA	International Energy Agency
km	kilometre
km2	square kilometre
kV	kilovolt
kWh	kilowatt-hour
LOHC	liquid organic hydrogen carrier
LPG	liquefied petroleum gas
m2	square metre
MCH	methylcyclohexane C7H14
METI	Ministry of Economy, Trade and Industry of Japan
MEEI	Mongolian Energy Economic Institute
MW	megawatt
O&M	operation and maintenance
OCCTO	Organisation for Cross-regional Coordination of Transmission Operators, Japan
PEM	proton exchange membrane
PV	photovoltaic
RE	renewable energy
SOEC	solid oxide
TFEC	Energy Balance Table
TOL	toluene
TPES	total primary energy supply
TRL	Technology Readiness Level

Executive Summary

Mongolia's total primary energy supply (TPES) remains heavily dependent on indigenous coal, which accounted for 67% of TPES in 2020, followed by oil at 23% and biomass at 7%. Approximately 91% of coal is consumed in the transformation sector, with the remainder used in the railway and residential sectors. Within the transformation sector, around 1,000 kilotonnes of oil equivalent (ktoe) of coal is used in heat plants and approximately 3,400 ktoe in combined heat and power (CHP) plants, which produce both electricity and heat. Due to Mongolia's high heat demand, CHP output for heat is 1.6 times greater than for electricity.

To reduce coal dependency and carbon dioxide (CO_2) emissions while enhancing energy security, Mongolia aims to harness renewable electricity – particularly solar photovoltaic (PV) and wind power – to produce green hydrogen. This hydrogen will primarily serve heat demand, while green electricity, supported by battery energy storage systems, pumped hydro storage, or cross-border interconnections, will meet electricity needs. The deployment of green hydrogen and renewable electricity will significantly reduce coal use and contribute to the country's energy transition.

In the final energy consumption sectors, coal and petroleum products still play a notable role. The roadmap to decarbonisation involves:

- Replacing diesel oil in the industrial sector with hydrogen-based systems (e.g., hydrogen boilers and furnaces),
- Replacing coal and diesel in the rail sector with hydrogen-powered trains,
- Substituting gasoline and diesel in the road transport sector with electricity and hydrogen,
- Replacing coal in the residential sector with hydrogen heating solutions.
- Thus, green electricity and hydrogen will be central to Mongolia's ambition to achieve carbon neutrality by 2050.

While coal has traditionally been a strategic export for Mongolia, global decarbonisation efforts will curtail future demand. As an alternative, Mongolia can explore exporting blue hydrogen – produced from coal via gasification with carbon capture, utilisation, and storage (CCUS). This transition offers Mongolia the opportunity to remain a key energy exporter in a carbon-constrained world.

Hydrogen represents a strategic solution for Mongolia to:

- Continue utilising its indigenous energy resources,
- Meet its carbon neutrality goals,

- Develop a new export-oriented energy sector.

To realise this potential, Mongolia must develop a comprehensive Hydrogen Strategic Plan, similar to Japan's, while drawing insights from other hydrogen leaders such as Australia, the Republic of Korea, New Zealand, and the United States. The strategy should evaluate both the supply and demand sides of hydrogen, address supply chain development, and estimate future hydrogen production and distribution costs.

The Mongolian Energy Economic Institute (MEEI), which compiles Mongolia's energy balance tables (latest available for 2020), plays a critical role. These tables form the foundation for modelling future hydrogen demand and supply scenarios. For effective hydrogen planning, Mongolia will require:

- High-quality, historical energy data,
- Accurate energy balance tables,
- Robust energy outlook models.

These components are essential for assessing hydrogen's contribution to carbon neutrality and for establishing an actionable, evidence-based hydrogen strategy.

Chapter 1
Introduction

This research study, titled 'Policy Study on Hydrogen Utilisation in Mongolia', aims to identify a pathway for achieving carbon neutrality in the country by utilising hydrogen to produce green electricity from sources such as solar PV and wind power systems. Because Mongolia has significant potential for green hydrogen, particularly in the southern part known as the Govi Desert, according to a 2020 report of the Asian Development Bank (ADB).

Firstly, by referring to existing publications prepared by regional and international organisations such as ADB, we forecast the available capacity (gigawatt [GW]) and power generation (gigawatt-hour [GWh]) of solar and wind power systems in 2040. If we produce hydrogen using electrolysis equipment, we need water. However, the southern part of Mongolia lacks water due to its desert environment. Therefore, this study also analysed the necessary number of transmission lines to connect the south and the north.

Secondly, based on the forecast green power generation amount (GWh), we forecast annual hydrogen production amount (kilo tonne). There are several types of electrolysis facility, however we assumed proton exchange membrane (PEM) electrolysis system due to its high productivity and economic reason.

Thirdly, we analysed the impact of hydrogen on the energy and environmental situation in Mongolia. According to the country's 2020 energy balance table (EBT) updated by the MEEI, Mongolia fully depends on coal in terms of power and heat generation, and heat demand was much bigger than electricity demand. So, we assumed hydrogen could be used as heating fuel basically. If hydrogen production is much bigger than its heating demand, we will reduce hydrogen production and allocate green power generation for electricity demand.

Fourthly, based on the study results mentioned above, we extracted policy implications for Mongolia to set up policies of hydrogen utilisation.

In addition, the Economic Research Institute for ASEAN and East Asia (ERIA) invited two MEEI researchers to Japan and arranged following site visits:

1) Participation to the Hydrogen EXPO in Tokyo
2) One-day lecture of hydrogen provided by Chiyoda Corporation
3) Site visit to Macromolecule Laboratory at Yamanashi University and Komekurayama Hydrogen Center in Yamanashi prefecture
4) Site visit to Chiyoda Hydrogen Park in Yokohama City

We also organised a workshop to present the major outcomes of this study to MEEI and stakeholders in Ulaanbaatar, Mongolia, in order to gather comments and suggestions from Mongolian hydrogen experts.

Chapter 2
Renewable Energy Potential and Use for Hydrogen Production

2.1 Solar and wind power potential in Mongolia

This subsection 2.1 describes the solar and wind power potential in Mongolia, based on literature review. The potential for solar and wind power in Mongolia is well mentioned in the technical assistance consultant's report published by ADB in 2020 (ADB, 2020).

The following four scenarios are provided in the report:

Scenario 0: 'min gigawatt (GW)' capacity in 2020, connected to Mongolia's 220 kilovolt (kV) power grid, only for the country's electricity consumption. 'Min GW' capacity refers to the available connection capacity to current 220 kV substations.

- Scenario 1: + 5 GW in 2026, mainly for export to neighbouring countries
- Scenario 2: + 10 GW in 2036 (therefore + 5 GW between 2026 and 2036) for export to neighbouring countries also
- Scenario 3: +100 GW in the long term.

The important difference between the scenarios in the context of calculating the renewable energy (RE) potential is whether the distance to existing substations is considered. Scenario 0 assumes a maximum distance of 200 kilometre (km) from the existing substation, as it is assumed to be connected to domestic transmission lines, whereas Scenarios 1 to 3 have no such restriction. For this reason, the following introduces the content with focus on Scenarios 1 to 3.

Table 2.1 also shows ranking indicators for RE location. The report provides five scores for evaluating RE locations, such as wind speed, solar irradiation, proximity to roads, and others. Each criterion is weighed according to its importance and, after a comprehensive review, each RE location is discriminated into five scores. In summary, the higher the score figure, the more suitable for RE location.

Table Error! No text of specified style in document..1 Ranking Indicators for RE Location

Criteria		Scores					Weight in % Wind	Weight in % Solar
		1	2	3	4	5		
A	Wind speed in m/s	6.5–7	7–7.5	7.5–8	8–9	9–10	90	–
A	Solar irradiation GHI in kWh/m2	1500–1600	1600–1650	1650–1700	1700–1750	> 1750	–	80
B	Proximity to roads in km	> 100	100–80	80–50	50–20	< 20	5	5
C	Proximity to railway or railway station in km (only PV)	> 100	100–80	80–50	50–20	< 20	0	5
D	Slope (only for PV)	15–20	10–15	6–10	1–6	1	–	5
E	Distance to city or village in km (criteria for O&M)	> 200	200–150	150–100	100–50	< 50	5	5

GHI = Global Horizontal Irradiance, kWh = kilowatt-hour, m2 = square metre, km = kilometre, PV = photovoltaic, O&M = operation and maintenance.
Source: ADB (2020).

Table 2.2 shows the solar potential capacity in Scenarios 1 to 3, including the area and the number of areas by score. The total capacity of all scores reaches 29,931 GW, with an area of 748,278 km2 and a total of 8,431 locations.

Table Error! No text of specified style in document..2 Solar Potential Capacity in Scenarios 1 to 3

	Score 1	Score 2	Score 3	Score 4	Score 5	All Scores Total
Capacity (GW)	11,764.0	4,165.8	12,835.6	1,165.7	0	29,931.0
Area (km2)	294,100	104,144	320,891	29,142	0	748,278
Number of areas	3,399	1,509	949	2,574	0	8,431

GW = gigawatt, km2 = square kilometre.
Source: ADB (2020).

Focusing on Score 4, Table 2.3 shows the solar potential capacity per prefecture. This shows that Umnu-govi has the highest potential, followed by Dundgovi and Dornogovi. It means that locations with high potential for solar PV are concentrated in the south of the country.

Table Error! No text of specified style in document..3 Solar Potential Capacity per Prefecture at Score 4

Prefecture	Capacity (GW)	Total Area (km2)	Number of Areas
Umnu-govi	1,032.77	25,819	574
Dundgovi	100.21	2,505	1,526
Dornogovi	16.16	404	41
Ovorhangai	14.69	367	358
Bayanhongor	1.77	44	68
Govi-Altai	0.12	3	8
Total	1,165.72	29,142	2,574

GW = gigawatt, km2 = square kilometre.
Source: ADB (2020), modified by the authors.

Table 2.4 shows the wind potential capacity in Scenarios 1 to 3, including the area and the number of areas by score. The total capacity of all scores reaches 2,326.7 GW, with an area of 465,367 km2 and a total of 3,438 locations.

Table Error! No text of specified style in document..4 Wind Potential Capacity in Scenarios 1 to 3

	Score 1	Score 2	Score 3	Score 4	Score 5	All Scores Total
Capacity GW	881.9	791.5	458.8	191.6	2.9	2,326.70
Area (km2)	176,390	158,310	91,766	38,324	577	465,367
Number of areas	1,484	1,086	630	223	15	3,438

GW = gigawatt, km2 = square kilometre.
Source: ADB (2020).

Focusing on Score 4, Table 2.5 shows the wind potential capacity per prefecture. The table shows that the prefectures highlighted in red – the southern prefectures – have high potential. This is the same trend as for solar. In other words, RE potential is very high in the south of Mongolia.

Table Error! No text of specified style in document..5 Wind Potential Capacity per Prefecture at Score 4

Prefecture	Capacity (GW)	Total Area (km2)	Number of Areas
Zawkhan	0.15	29	1
Uvs	0.23	47	1
Khuwsgul	0.43	87	2
Arkhangai	1.00	199	4
Dornod	1.52	305	5
Govisumber	2.57	513	1
Khowd	2.81	561	14
Töv	3.00	599	7
Bayan-Olgii	4.65	929	21
Khentii	6.89	1,377	11
Sükhbaatar	6.92	1,384	12
Ovorhangai	10.20	2,039	17
Bayankhongor	15.46	3,091	40
Govi-Altai	21.37	4,275	30
Dundgovi	32.52	6,505	36
Umnu-govi	37.00	7,399	20
Dornogovi	44.92	8,983	22
Total	191.62	38,324	223

GW = gigawatt, km2 = square kilometre.
Source: ADB (2020), modified by the authors.

2.2 Estimation of RE installation and transmission costs for hydrogen production from RE

This subsection mentions the estimation of RE installation and transmission costs for hydrogen production from RE. As mentioned in the previous subsection, most RE potential areas are in the southern part of Mongolia. Table 2.6 shows the solar and wind potential capacity and RE power available in each prefecture in the south. The RE power available shown in Table 2.6 was calculated by multiplying the RE potential capacity by the solar and wind capacity factor in the ADB report (solar: 17.8%, wind: 45.6%).

Table Error! No text of specified style in document..6 RE Potential Capacity and Power Available in Each Prefecture

Prefecture	RE Capacity (GW)	RE Power Available (GWh/year)
Umnu-Govi	1,070	1,758,176
Dundgovi	133	286,159
Dornogovi	61	204,634
Ovorhangai	25	63,650
Bayanhogor	17	64,516
Govi-Altai	21	85,551
Total	1,327	2,462,685

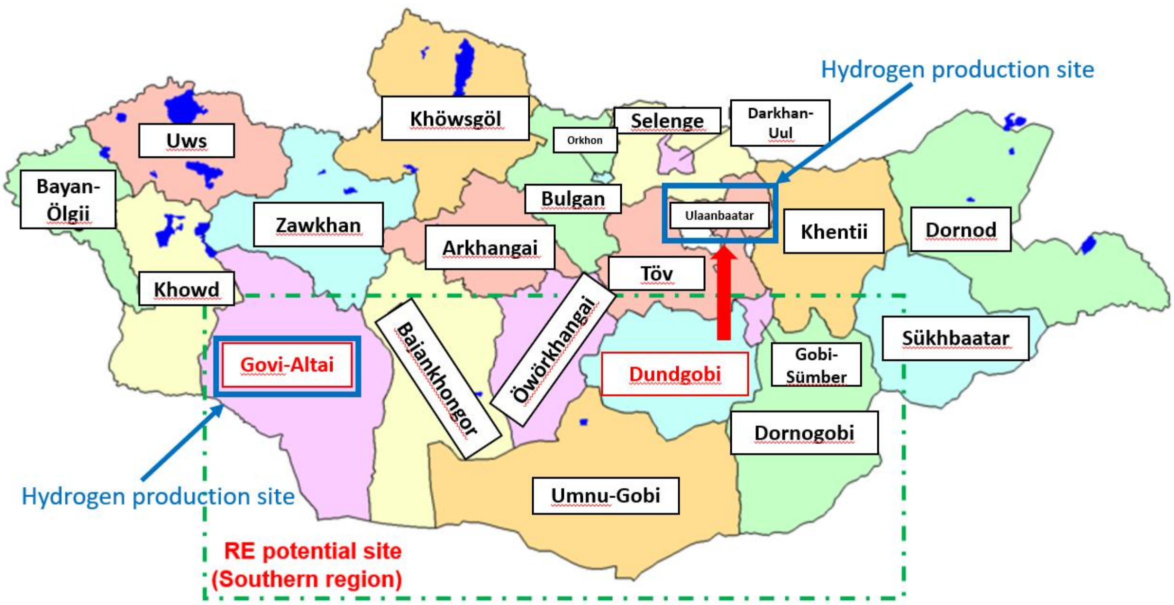
GW = gigawatt, GWh = gigawatt hour.
Source: ADB (2020), modified by the authors.

On the other hand, we know from Mongolian experts that most of these areas have almost no or low demand for electricity and the water needed to produce hydrogen. In this case, RE electricity should be transmitted to areas where water is available and where there is some electricity demand. However, the RE potential capacity is so large that it is not practical to transmit all of it to the area of demand. For example, if Mongolia will construct transmission lines to send all of it to Ulaanbaatar, which is most demanding area in the country, Mongolia needs over 200 transmission lines. We think this is unrealistic.

From this thought, we made the assumption shown in Figure 2.1. We selected Govi-Altai and Dundgovi as priority development areas for RE. In Govi-Altai, there is water to meet the hydrogen and electricity demand of the industrial sector. So, we assumed that in this prefecture, RE development and hydrogen production using RE-derived electricity would be carried out, and that hydrogen produced would be consumed by the industrial sector in this prefecture. The electricity produced was assumed to be 85,551 GWh/year due to the RE potential in this prefecture.

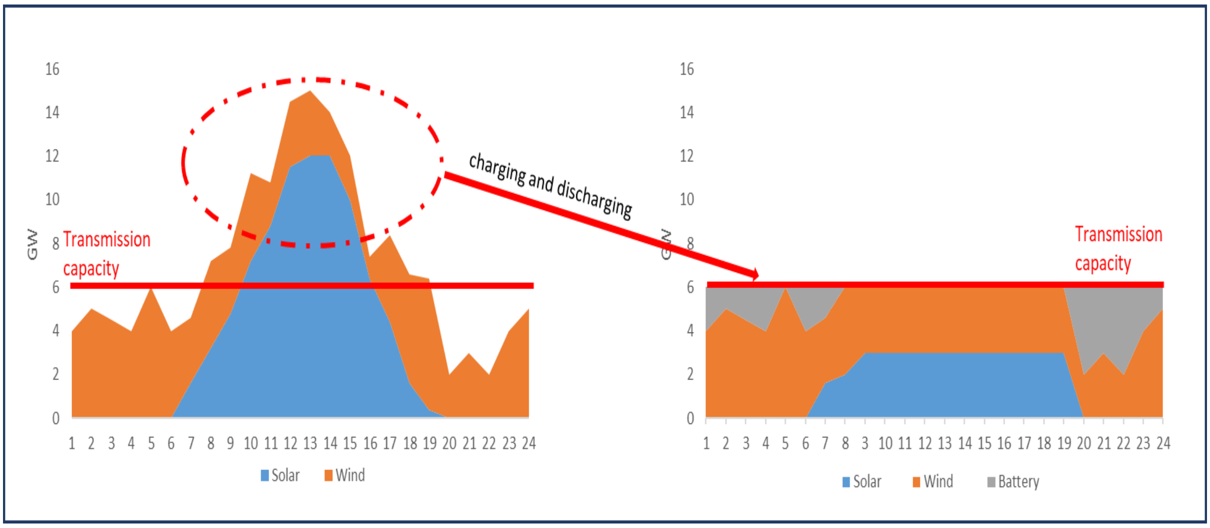
Dundgovi does not have enough water to produce hydrogen, and the electricity demand is still low. However, the distance to Ulaanbaatar is relatively close, about 300 km, compared to other southern prefectures with high RE potential. Therefore, we assumed that RE would be developed in Dundgovi but the electricity generated would be transmitted to Ulaanbaatar where hydrogen could be produced and consumed. The transmission line connecting Dundgovi and Ulaanbaatar is assumed to be 500 kV class, 2 circuits, and 2 lines. In this case, transmission capacity per line is about 6 GW, then total capacity is 12 GW. Given the RE potential of the prefecture, more RE and transmission lines could be installed; however, it is not realistic to build three or four transmission lines from one prefecture in terms of social and economic aspects. Therefore, two transmission lines were chosen. Also, it is assumed that each transmission line connects directly to a hydrogen production unit, meaning there is no connection to the existing power grid. Several transmission lines already exist in the south; however, they are already connected to various power stations, making it impossible to assess the available capacity. To simplify matters, we assumed that there would be no connection to the existing power grid at this time. It was also assumed that storage batteries were installed on the RE side to maintain the RE's unstable output at a constant level. In this case, the amount of electricity generated and transmitted is 101,966 GWh/year, based on the assumption that the output on the RE side is kept constant by installing storage batteries and the utilisation ratio of the transmission line is 100% (Figure 2.2).

Figure Error! No text of specified style in document..1 Overview of the Study Concept



Source: Authors.

Figure Error! No text of specified style in document..2 Battery Utilisation



GW = gigawatt.
Source: Authors.

Table 2.7 shows the unit cost of solar PV installation and Table 2.8 shows the unit cost of wind farm installation, based on actual Japanese performance in 2023 obtained from the Ministry of Economy, Trade and Industry (METI) of Japan (METI, 2024). These unit costs include not only each equipment cost but also construction, design, connection costs, and so on. As in Table 2.7 and Table 2.8, we assumed that the unit costs of solar PV and wind farm installation are set at 1,900 $/kW and 2,234 $/kW, respectively.

Table Error! No text of specified style in document..7 Unit Cost of Solar PV Installation

	Unit Cost ($/kW)
Panel	660
PCS	193
Frame	260
Other equipment	107
Construction	520
Design	20
Land reform	100
Connection	120
Other / Discounts	-80
Total	1,900

kW = kilowatt.
Source: METI (2024).

Table Error! No text of specified style in document..8 Unit Cost of Wind Farm Installation

	Unit Cost ($/kW)
Design	67
Wind turbine	773
Tower	127
Other equipment	153
Foundation works	287
Installation work	200
Electrical work	120
Connection	127
Other construction	327
Other	53
Total	2,234

kW = kilowatt.
Source: METI (2024).

Table 2.9 shows the assumed unit cost of a transmission line, which refers to Japan's standard unit price obtained from the Organisation for Cross-regional Coordination of Transmission Operators (OCCTO), Japan (OCTTO, 2016). It is generally difficult to calculate a uniform unit cost for a transmission line because it depends not only on the thickness of the wire and the number of conductors, but also on the route, the shape of the foundation, the method of transporting materials, and other location conditions. Therefore, the values in Table 2.9 are simplified to some extent. Also, as for the substation cost, the unit cost was assumed to be $17,000/MW, which refers to the report of the International Energy Agency (IEA) that mentions substation costs vary between $10,700–$24,000 /MW (IEA, 2014).

Table Error! No text of specified style in document..9 Unit Costs of a Transmission Line

Voltage (kV)	500
Line type	ACSR 410m2 × 4
Circuit number	2
Capacity (GW)	6
Unit cost per km (million $/km)	3.4

kV = kilovolt, ACSR = aluminium conductors steel reinforced, GW = gigawatt, km = kilometre.
Source: OCCTO (2016), modified by the authors.

Based on the abovementioned assumptions, the results of the estimation of RE installation and transmission costs for hydrogen production from RE are shown in Table 2.10 for RE installation costs and in Table 2.11 for transmission costs. In Table 2.10, the RE power available is as shown in the assumptions. In total, Dundgovi and Govi-Altai together total 187,517 GWh/year. In this case, the solar and wind power available was distributed according to the percentage of solar and wind potential in each region. Next, the required RE installed capacity was calculated based on this RE power available. But for Dundgovi, a transmission loss of 3% was considered since transmission lines are used. Then, RE installation costs were calculated with the required RE installed capacity and each unit cost. The total installation cost was estimated at $145.1 billion, of which $70.5 billion is for solar power and $74.6 billion is for wind power. Table 4.11 estimates the transmission costs from Dundgovi to Ulaanbaatar at $1.2 billion, of which $1.0 billion is for transmission lines and $0.2 billion is for substations.

Table Error! No text of specified style in document..10 RE Installation Costs

Prefecture	RE Power Available (GWh/year)			RE Installation (GW)			RE Installation Costs (billion $)		
	Solar	Wind	Total	Solar	Wind	Total	Solar	Wind	Total
Dundgovi	55,673	46,293	101,966	36.9	12.0	48.9	70.1	26.8	96.9
Govi-Altai	187	85,364	85,551	0.2	21.4	21.6	0.4	47.8	48.2
Total	55,860	131,657	187,517	37.1	33.4	70.5	70.5	74.6	145.1

GWh = gigawatt hour, GW = gigawatt.
Source: Authors.

Table Error! No text of specified style in document..11 Transmission Costs

Prefecture	Transmission Capacity (GW)	Distance to Northern Area (km)	Transmission Line Cost (billion $)	Substation Cost (billion $)	Total Cost (billion $)
Dundgovi to Ulaanbaatar	12	300	1.0	0.2	1.2

GW = gigawatt, km = kilometre.
Source: Authors.

Finally, we analysed the cost per kWh (Table 2.12). This is the total cost, consisting of the RE cost and the transmission cost, divided by the amount of electricity generated. In the calculation, the operation period of RE was assumed to be 20 years. As a result, the cost per kWh was estimated at 4.8 cents/kWh for Dundgovi, 2.8 cents/kWh for Govi-Altai, and 3.9 cents/kWh overall.

This calculation is a simplified estimation method. In practice, the installation of the control centre, battery and related equipment will add further costs, and these maintenance costs will also be higher than usual due to the lack of water in the south. Therefore, further analysis will be needed for the details in the implementation phase.

Table Error! No text of specified style in document..12 Cost per kWh

Prefecture	RE Power Available			Cost			
	Per year (GWh/year)	Operation Period (Year)	Total (GWh)	RE Installation (billion $)	Transmission (billion $)	Total (billion $)	Cost per kWh (cents/ kWh)
Dundgovi	101,966	20	2,039,320	96.9	1.2	98.1	4.8
Govi-Altai	85,551	20	1,711,020	48.2	-	48.2	2.8
Total	187,517	-	3,750,340	145.1	1.2	146.3	3.9

GWh = gigawatt hour, GW = gigawatt.

Source: Authors.

Chapter 3

Hydrogen Production Potential and its Transportation in Mongolia

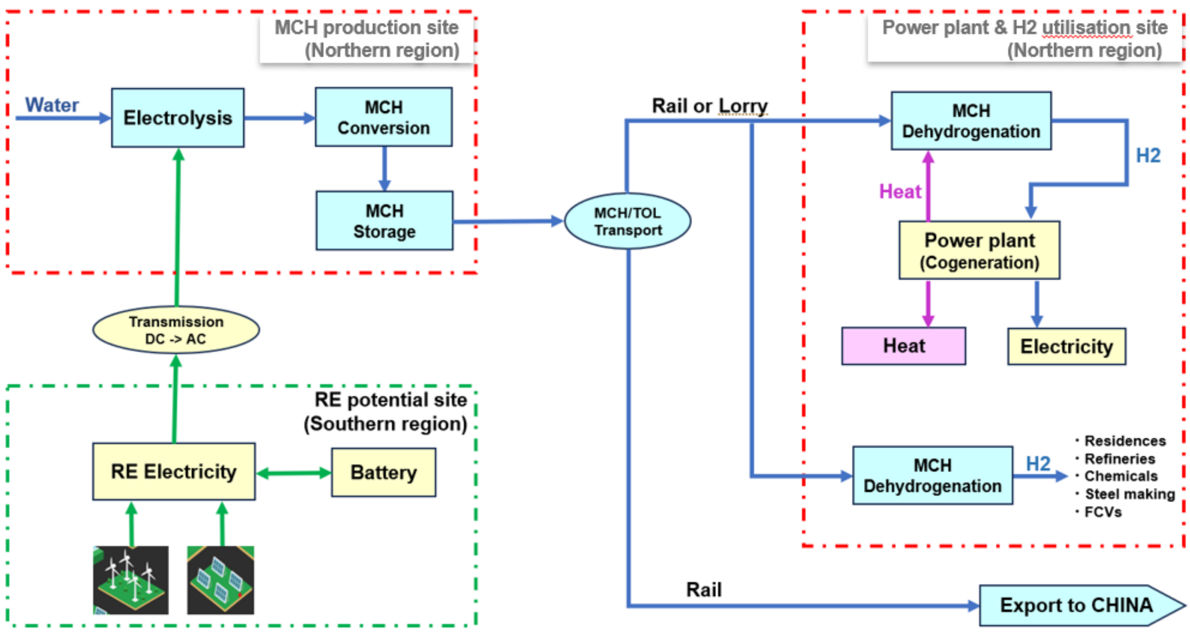
3.1 Concept of hydrogen energy system in Mongolia

3.1.1 Concept of hydrogen energy system

A concept of hydrogen energy system using the liquid organic hydrogen carrier (LOHC) method is illustrated in Figure 3.1. Chiyoda's LOHC-methylcyclohexane C7H14 (MCH) (SPERA Hydrogen) technology is used as the hydrogen carrier that enables the safe, efficient, and commercially viable storage and transportation of hydrogen on a global scale.

As for the hydrogen energy system in Mongolia, the hydrogen carrier transportation is limited to rail and lorry transportation, and LOHC-MCH excels over other carriers in terms of safety and use of existing infrastructure. Additionally, the freezing points of MCH and toluene (TOL) are -127℃ and -95℃, respectively, allowing them to remain in a liquid state through all seasons.

Figure Error! No text of specified style in document..1 Concept of the Hydrogen Energy System in Mongolia



AC = alternating current, DC = direct current, FCV = fuel cell vehicle, H2 = hydrogen, MCH/TOL = methylcyclohexane/toluene, RE = renewable energy.

Source: Author.

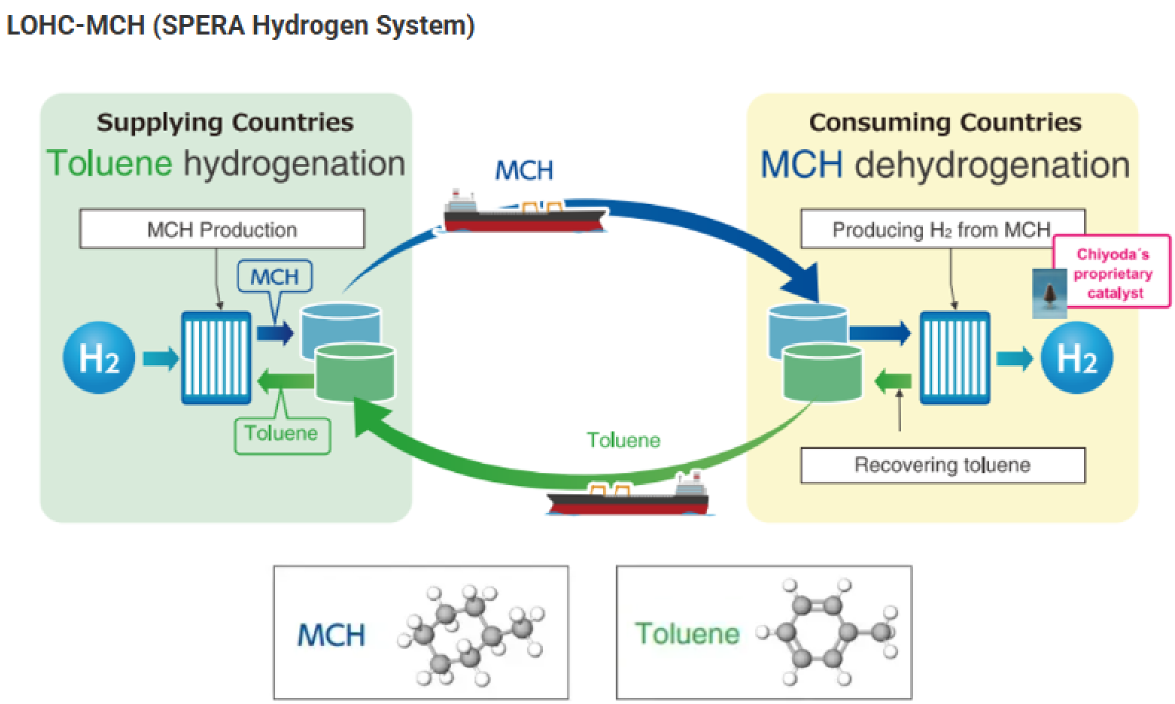
SPERA Hydrogen system

Figure 3.2 shows the SPERA Hydrogen system. For MCH conversion, H2 is sourced from H2 production, while toluene (TOL) is recovered and transported from dehydrogenation to the destinated market. MCH conversion is performed through the hydrogenation reaction of TOL, which is an exothermic reaction.

MCH, transported and received in a destinated market, is dehydrogenated to produce H2 and recover TOL using external heat supply for the endothermic dehydrogenation reaction.

H2 is delivered to the destinated market, while recovered TOL is returned for MCH conversion.

Figure Error! No text of specified style in document..2 LOHC Method Using MCH-TOL



Source: Chiyoda (n.d.) Available at: https://www.chiyodacorp.com/en/purposestory/co-creation/spera-hydrogen/

LOHC-MCH, liquid hydrogen and ammonia are all promising hydrogen carriers, each with their own set of advantages and challenges. Table 3.1 compares the three types of carriers.

Table Error! No text of specified style in document..1 Key Characteristics of Each Carrier

Blue : Pros Red : Cons

	LOHC - MCH	NH3	LH2
H2 Compaction	1/500	1/1300	1/800
Liquid Phase @	Ambient	- 33 deg-C	- 253 deg-C
Leakage Risk (Fire)	Moderate	Moderate	High
Leakage Risk (Toxic)	Moderate	High	Low
Technology Readiness	Ready (Large scale)	Ready (Direct Use) *) Around 2030 (Cracking)	2030 - 35 (Large scale)
H2 Purity	Above 99.8%-H_2 (FCV grade after PSA)	75%-H_2 + 25%-N_2 (FCV grade after PSA)	99.999%-H_2 (FCV grade)
Reaction Condition	(To MCH) below 250 deg-C below 1MPa (To H2) 350 - 400 deg-C below 1 MPa	(To NH3) 400 - 500 deg-C 10-30 MPa (To H2) 700 - 950 deg-C below 1 MPa or above	(To LH2) -253 deg-C above 1 MPa (To H2) -253 to Ambient 1 MPa to high pressure
Infrastructure	Abundant existing petroleum infra.	Limited existing LPG/NH3 infra.	New dedicated LH2 infra.

*) Ammonia has two uses, direct use as fuel and cracking for H2 use.

Source: Chiyoda Corporation, https://www.chiyodacorp.com/en/.

■ LOHC-MCH (SPERA Hydrogen)

- LOHC is a type of hydrogen carrier that stores hydrogen in the form of a liquid organic compound.
- It has a high hydrogen storage capacity, typically around 6%–8% by weight.
- LOHC is stable and non-toxic, making it safe to handle and transport at ambient conditions and can use existing petroleum-related facilities.
- It can release hydrogen on demand through a catalytic process, allowing for efficient and controlled hydrogen release.
- LOHC is recyclable, meaning the liquid organic compound can be reused multiple times without significant degradation.
- It has a lower energy density compared to liquid hydrogen but provides a more practical and safer method of hydrogen storage and transportation.
- MCH (Methylcyclohexane C7H14) is one of the representatives of LOHC. The practical applications of the hydrogen supply chain by MCH are being actively pursued by Chiyoda Corporation.

■NH3 (Ammonia)

- Ammonia can be stored and transported as a liquid at moderate pressures and temperature, having a lower energy content per unit volume compared to liquid hydrogen.
- It has a high hydrogen content, with approximately 17.6% hydrogen by weight.
- It has a relatively low energy density compared to liquid hydrogen but is still higher than LOHC.
- The storage and handling of ammonia requires certain safety precautions due to its toxicity and flammability.
- Large-scale ammonia cracking, necessary for the use as H2, is not yet well-established and needs further development.

■LH2 (Liquid Hydrogen)

- Liquid hydrogen is stored at an extremely low temperature of -253℃) to maintain its liquid state. This process requires specialised cryogenic equipment, which can be costly and challenging.
- The purity of product hydrogen through gasification is shown to be the highest amongst the three carriers.
- It has a very high energy density, allowing for a larger amount of hydrogen compared to other hydrogen carriers.
- It is highly flammable and requires careful handling and safety precautions.
- Liquid hydrogen requires additional processing such as liquefaction, due to the generation of boil-off-gas during storage which can lead to hydrogen losses.
- The production and transportation of liquid hydrogen can be energy-intensive and expensive.

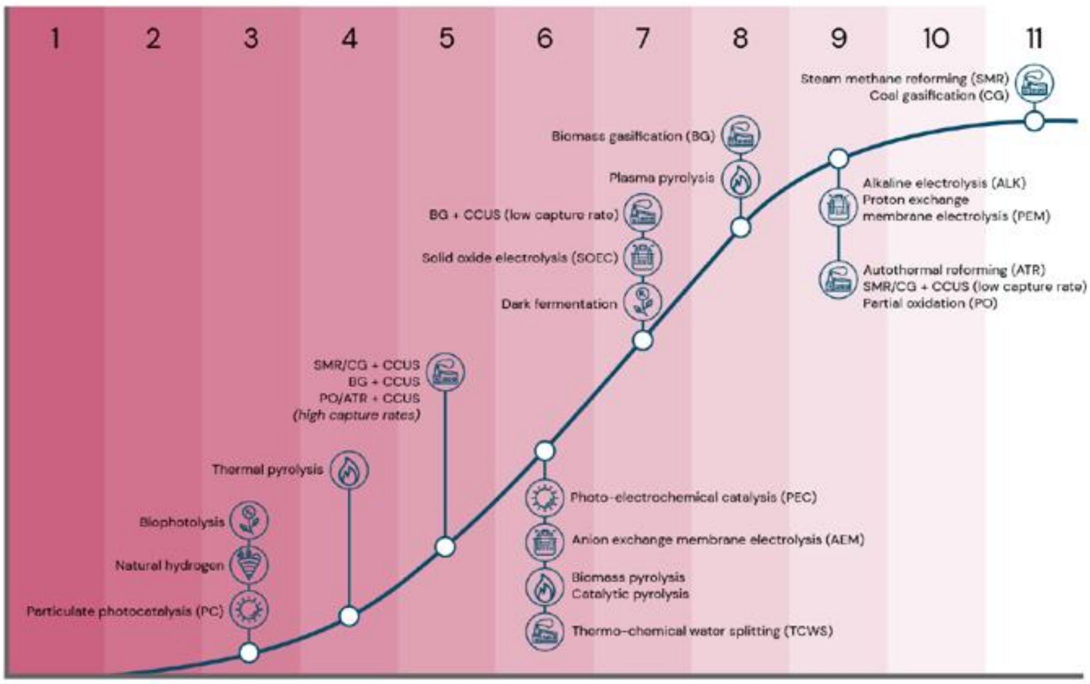
3.2. Hydrogen production potential in the northern region

3.2.1 Hydrogen production technology

There are five production routes for hydrogen: thermochemical, electrolytic, pyrolytic, biological, and photolytic. Each of these routes include multiple technologies at different levels of maturity.

Technology Readiness Level (TRL) (Figure 3.3) is used to give information about the stage of development of a technology. In TRL 9, technologies are commercially ready.

Figure Error! No text of specified style in document..3 TRL of Hydrogen Production Technologies



Source: HAL Open Science (2023).

Based on the TRL curve, the existing technologies that are commercially available or ready for commercial production include thermochemical, electrolytic, and pyrolytic routes. Amongst the three routes, electrolytic route is selected for hydrogen production.

Four types of electrolysers are under focus: alkaline electrolyser (ALK), proton exchange membrane (PEM), solid oxide (SOEC), and anion exchange membrane (AEM).

Among the four types, SOEC and AEM are still at the pre-commercial stage, but SOEC could become cost-competitive in the near future due to its high efficiency.

From the view of cost and availability, ALK is much superior to PEM. On the contrary, from the view of flexibility to the intermittent renewable energy, PEM is above ALK. Table 3.2 compares the key characteristics of electrolysers.

Table Error! No text of specified style in document..2 Comparison of the Key Characteristics of Electrolysers

	ALK	PEM	SOEC
Characteristics	Utilisation of alkaline solution (KOH)	Comapct electrolysis device using noble metal catalyst	High temperature electrolysis using high temperature steam
Efficiency (steady state)	Stack: ~4.8 kWh/Nm^3-H2 System: ~6.5 kWh/Nm^3-H2	Stack: ~4.8 kWh/Nm^3-H2 System: ~6.5 kWh/Nm^3-H2	Stack: ~3.2 kWh/Nm^3-H2 System: ~4.0 kWh/Nm^3-H2
Operation temperature	Rt~80°C	Rt~80°C	Approximately 700°C
pros	Most mature technology Upscaling achieved	Space-saving Flexible to intermittent RE	High energy efficiency (Further efficincy through waste heat utilisation)
Cons	Concentration control of alkaline solution and post processing	Limited noble metal supply	Still at technological development

Source: Toshiba (2023).

Hydrogen production potential

The aimags with a potential capacity of over 20 GW in RE total of wind and solar energy are listed in Table 3.3. The figures are based on Chapter 2. Maximum electricity potentials are estimated using the load factors of 45.6% of wind and 17.8% of solar, respectively.

Among the six aimags, Dundgovi was chosen as a suitable site for RE electricity utilisation for hydrogen production due to its proximity to Ulaanbaatar, and Govi-Altai as a suitable site for hydrogen production because water is available.

The electricity potential for electrolysis is calculated based on the electric transmission capacity of 6 GW per each line with 3% of transmission loss.

Electricity potential for electrolysis (GWh/y) = 6 GW/line x 2 lines x 365 d/y x 24 hr/d x (1 - 0.03)

The H2 production potential and demineralised water consumption are calculated using the efficiency of 4.75 kWh/Nm3-H2 (53.2 kWh/kg-H2) and 10 L/kg-H2, respectively.

H2 production potential (ktonne/y) = Electricity potential for electrolysis GWh/y / 53.2 kWh/kg

H2 production potential using RE power from Dundgovi is 1,917 ktonne/y, and the potential in Dovi-Altay is 1,608 ktonne/y, respectively.

Table 3.3 shows the calculation results for the two aimings.

Table Error! No text of specified style in document..3 H2 Production Potential in Dundgovi and Govi-Altai

Province (*Aimag*)	RE Capacity			Maximum Electricity Potential	Transmission Capacity exclusively H2 Production	Electricity Potential for Electrolysis	H2 Production	Water Consumption
	GW (Wind)	GW (Solar)	GW (Total)	GWh/y	GW	GWh/y	ktonne/y	ktonne/y
Omnogovi	37	1,033	1,070	1,758,176		0	0	0
Dundgovi	33	100	132.7	286,159	12	101,966	1,917	19,167
Dornogovi	45	16	61.1	204,634		0	0	0
Ovorhangay	10	15	24.9	63,650		0	0	0
Bayanhongor	15	2	17.2	64,516		0	0	0
Govi-Altay	21	0	21.5	85,551	Local use	85,551	1,608	16,081
Total	161	1,166	1,327	2,462,685	12	187,517	3,525	35,248

Source: Author.

1) Green hydrogen production cost

Green hydrogen production costs are calculated as shown in Table 3.4, using the electricity cost of 4.8 cents/kWh from Dundgovi and 2.8 cents/kWh in Govi-Altai, referring to Table 2.12.

The green hydrogen cost depends mainly on the cost of RE electricity; however, it is also influenced by the capital expenditures (CAPEX) of electrolyser and operational expenses.

The formula for estimating hydrogen cost is as follows.

H2 cost ($/kg-H2) = [CAPEX/(Depreciation years) + EC + Fixed OPEX]/(H2 production kg/y)

EC (Electricity cost/y) = Electricity unit cost $/kWh x Electricity consumption kWh/y

Fixed operating expenses (OPEX): Personnel cost, maintenance cost, etc.

The values used for the estimation have been calculated using in-house data.

Table Error! No text of specified style in document..4 Green Hydrogen Production Costs, Dundgovi and Govi-Altai

	Unit	Dundgovi	Govi-Altay
Electricity cost	Cents/kWh	4.8	2.8
Green Hydrogen Cost	USD/kg-H2	3.0~3.6	2.0~2.6

Source: Author

3.3. Transportation of hydrogen using the MCH-TOL system

3.3.1 Global Hydrogen Supply Chain Project

In December 2020, AHEAD successfully completed the world's first Global Hydrogen Supply Chain Demonstration Project, a milestone for the construction of an international hydrogen supply chain towards realising a decarbonised society.

The project overview and supply chain route are illustrated in Figure 3.4.

Figure Error! No text of specified style in document..4 The World's First Global Hydrogen Supply Chain Demonstration Project

Facility Scale	Maximum 210 tons/year
Hydrogen Supply	Brunei Darussalam (Hydrogen production)
Hydrogen Uses	Kawasaki City, Japan (Fuel for gas turbine power generation facilities)
Transportation	ISO tank container (container vessels and trailers)
Scheme	- Funded by the New Energy and Industrial Technology Development Organization (NEDO) - Conducted by the Advanced Hydrogen Energy chain Association for technology Development (AHEAD)

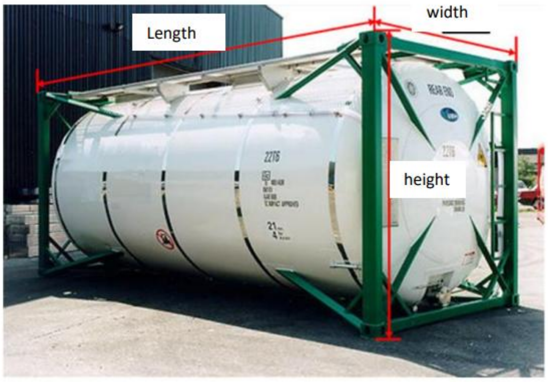
Source: Chiyoda (n.d), available at: https://www.chiyodacorp.com/en.service/lowcarbon/hydrogen/demonstration/

3.3.2 ISO tank container

ISO tank containers have different types with varying the dimensions. ISO tank containers can be towed by trailers or transported by railway bogies. ISO tank containers can be used for transportation and storage containers.

The big difference between a tank lorry and an ISO tank container is that a tank lorry is divided into multiple compartments, while an ISO tank container has a single compartment, which makes loading and unloading easier and more popular.

Figure Error! No text of specified style in document..5 Dimensions of ISO Tank Container



Capacity (kL)	14	21	24	26
Length (mm)	6,058	6,058	6,058	6,058
Width (mm)	2,438	2,438	2,438	2,438
Height (mm)	1,980	2,591	2,591	2,591
Tare weight (kg)	2,980	3,420	3,540	3,890
MCH Loading (tonne)(*)	10.2	15.4	17.6	19.0
H2 Contained in MCH (tonne/Nm3)	0.63 / 7,022	0.94 / 10,534	1.07 / 12,038	1.16 / 13,042
Toluene Loading (tonne)(*)	11.6	17.4	19.8	21.5

* Filling Rate ：95% of Tank Capacity, Specific Gravity：0.77 (MCH), 0.88 (Toluene)

Source: NYK Trading Corporation, https://www.nyk-trading.com

3.3.3 Handling of ISO tank containers

Reach stackers are special vehicles used for loading and unloading large transport containers, lifting them and moving or stacking them, and loading and unloading them onto container transport vehicles.

Figure Error! No text of specified style in document..6 Handling of ISO Tank Containers

Towing by trailer

Source：NRS Corporation HP, https://www.nrsgr.com

3.3.4 Rail transportation in Mongolia

The Trans-Mongolian Railway branched off from the Trans-Siberian Railway at Ulan-Ude Station in Russia and entered Mongolia, passing through Mongolian military and economic areas such as Sukhbaatar, Darkhan, Zunhara, Ulaanbaatar, Choyil, Sainshand, and Zamin-Ud (Figure 3.7). The route passes through several important cities.

Figure Error! No text of specified style in document..7 Existing Railway Transportation in Mongolia

Source: Rogers (2025), available at: https://www.globalconstructionreview.com/mongolia-and-china-agree-plan-to-connect-rail-networks/

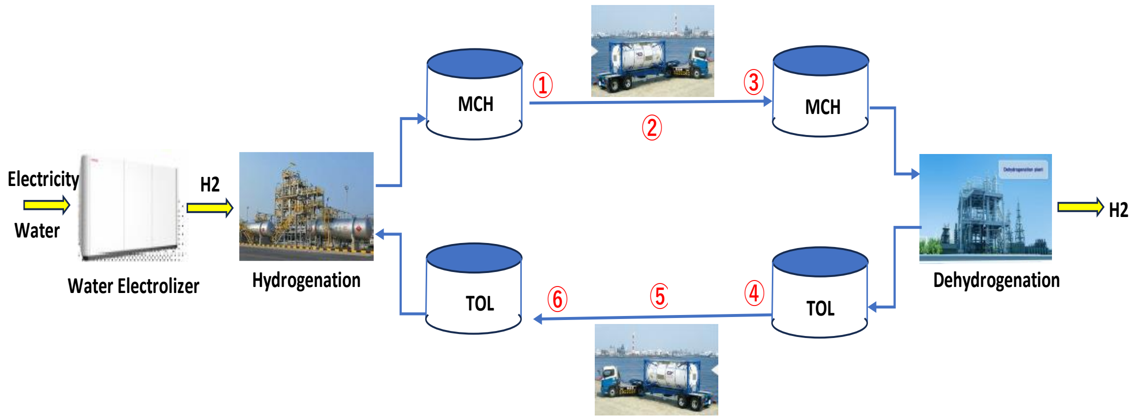
3.4. Transport between hydrogenation and dehydrogenation sites

3.4.1 Study conditions

- Capacity of dehydrogenation plant: 200,000 tonnes-H2/y
- (equivalent to power plant of 350 MW)
- Distance between hydrogenation plant and dehydrogenation plant: ～100 km
- Use of 26 kL-type ISO tank containers
- Sequence of operation (Figure 3.8)
- MCH shipping to ISO container at hydrogenation site
- Transportation
- MCH unloading to storage tank at dehydrogenation site

- TOL shipping to ISO container
- Transportation
- TOL unloading to storage tank at hydrogenation site

Figure Error! No text of specified style in document..8 Transportation of MCH and Toluene between Hydrogenation and Dehydrogenation Sites



Source: Author.

Results

・MCH transportation: 11,600 kL/d470 ISO containers/d

・TOL transportation： 9,500 kL/d385 ISO containers/d

・Required containers： ～1,000 containers (assuming 2 days for round trip)

Chapter 4

Hydrogen Demand Potential and its Impact on the Energy Situation of Mongolia

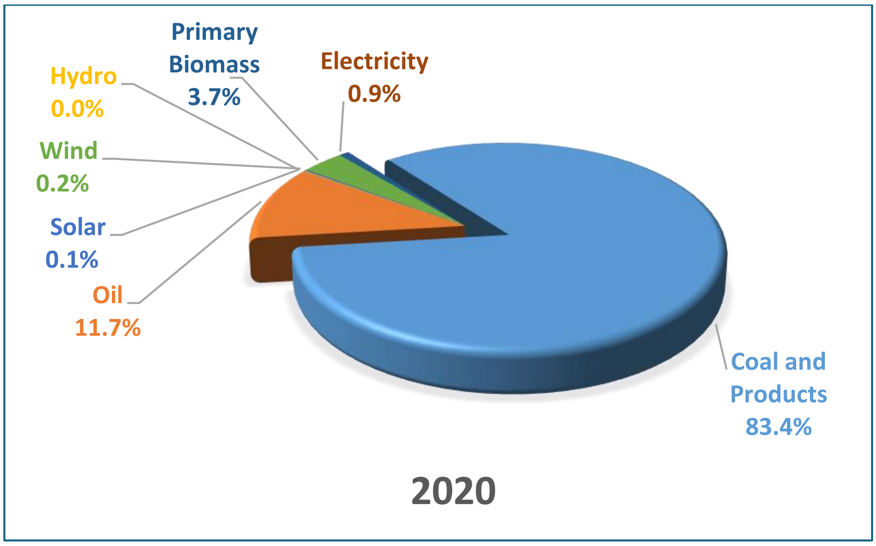
This chapter reviews the current energy situation of Mongolia and estimates the potential hydrogen demand and its impact on the country's future energy situation. The transport and power generation sectors are expected to become the end-use sectors of hydrogen The potential use of hydrogen as heat demand in industry, residential, and commercial sectors are not covered by this study.

4.1. Mongolia's energy situation, 2020

The Mongolian Energy Economics Institute (MEEI) provides the Energy Balance Table (EBT) from 2000 to 2020. These energy data is the basis for producing the simplified EBT 2020 of Mongolia (Table 4.1).

Mongolia's TPES was 16 Mtoe in 2020 and has been increasing at an average rate of 7.5% per year over the 2000–2020 period. Coal dominates the TPES (83.4%) while oil share in the TPES is almost 12%. Primary biomass share is around 4% (Figure 4.1). Mongolia imports electricity mainly from China and Russia. Mongolia also exports electricity to Russia. The share of electricity trade is almost 1% of the TPES. Renewable energy sources of Mongolia consist of hydro, solar, and wind, amounting to around 0.3% of the TPES.

Figure Error! No text of specified style in document..3 Total Primary Energy Supply of Mongolia, 2020



Source: Author's calculation based on MEEI working file on EBT in 2020.

Table Error! No text of specified style in document..13 Simplified Energy Balance Table of Mongolia, 2020 (in Ktoe)

		1.	2.	3.	4.	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	4.10	5.	6.	7.	8.	9.	10.	11.	12.	13	14
SECTOR / ENERGY SOURCES		Coal	Coal Products	Crude Oil	**Petroleum Products**	Motor Gasoline	Aviation Gasoline	Jet Fuel	Kerosene	Gas/Diesel Oil	Fuel Oil	LPG	Lubricants	Bitumen, Asphalt and Petroleum Jelly	Other Petroleum Products	Natural Gas	Renewable Energy	Water Energy (Hydro)	Solar Energy	Wind Energy	Nuclear Energy	Electricity	Heat	Primary Biomass	**Total**
1.	Indigenous Production	37,283	1	556	0	0	0	0	0	0	0	0	0	0	0	0	61	7	15	39	0	0	0	597	38,498
2.	Imports	5	1	0	1,842	615	21	47	0	1,042	3	47	22	44	0	0	0	0	0	0	0	147	0	0	1,994
3.	Exports	-34,639	-8	-554	-2	0	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-4	0	0	-27,074
4.	International Marine/Aviation Bunkers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.	Stock Changes	2,828	0	-2	58	13	2	0	0	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,892
6.	**Total Primary Energy Supply**	**5,478**	**-6**	**0**	**1,898**	**628**	**21**	**47**	**0**	**1,086**	**2**	**47**	**22**	**44**	**0**	**0**	**61**	**7**	**15**	**39**	**0**	**143**	**0**	**597**	**16,311**
8.	Total Transformation Sector	-4,997	420	0	-2	0	0	0	0	0	-2	0	0	0	0	0	-61	-7	-15	-39	0	609	1,412	0	-2,608
8.1	Electrcity Plant	-82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-61	-7	-15	-39	0	71	0	0	-72
8.2	Heat Plants	-1,070	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-12	537	0	-534
8.3	CHP	-3,421	0	0	-2	0	0	0	0	0	-2	0	0	0	0	0	0	0	0	0	0	549	876	0	-1,998
8.4	Other Transformation	-424	420	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-4
9.	Loss & Own Use	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-163	-193	0	-357
10.	Discrepancy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.	**Total Final Energy Consumption**	**482**	**414**	**0**	**1,895**	**628**	**21**	**47**	**0**	**1,086**	**0**	**47**	**22**	**44**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**588**	**1,219**	**597**	**5,195**
12.	Industry Sector	0	0	0	385	0	0	0	0	385	0	0	0	0	0	0	0	0	0	0	0	317	323	0	1,025
13.	Transport Sector	24	2	0	1,420	628	21	47	0	701	0	0	22	0	0	0	0	0	0	0	0	25	38	0	1,510
13.2	Rail	24	2	0	104	0	0	0	0	104	0	0	0	0	0	0	0	0	0	0	0	5	38	0	174
13.3	Road	0	0	0	1,295	628	0	47	0	597	0	0	22	0	0	0	0	0	0	0	0	20	0	0	1,315
13.4	Aviation	0	0	0	21	0	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21
14.	Other Sector	458	412	0	46	0	0	0	0	0	0	46	0	0	0	0	0	0	0	0	0	247	857	596	2,615
14.1	Residential	456	412	0	46	0	0	0	0	0	0	46	0	0	0	0	0	0	0	0	0	141	527	596	2,177
14.2	Commercial, Public Service & Others	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	106	331	0	438
14.3	Commercial & Public Service	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	203	0	263
14.4	Others	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	46	127	0	175
15.	Non-energy Use	0	0	0	44	0	0	0	0	0	0	0	0	44	0	0	0	0	0	0	0	0	0	1	45

Source: Author, based on data from MEEI on EBT in 2020.

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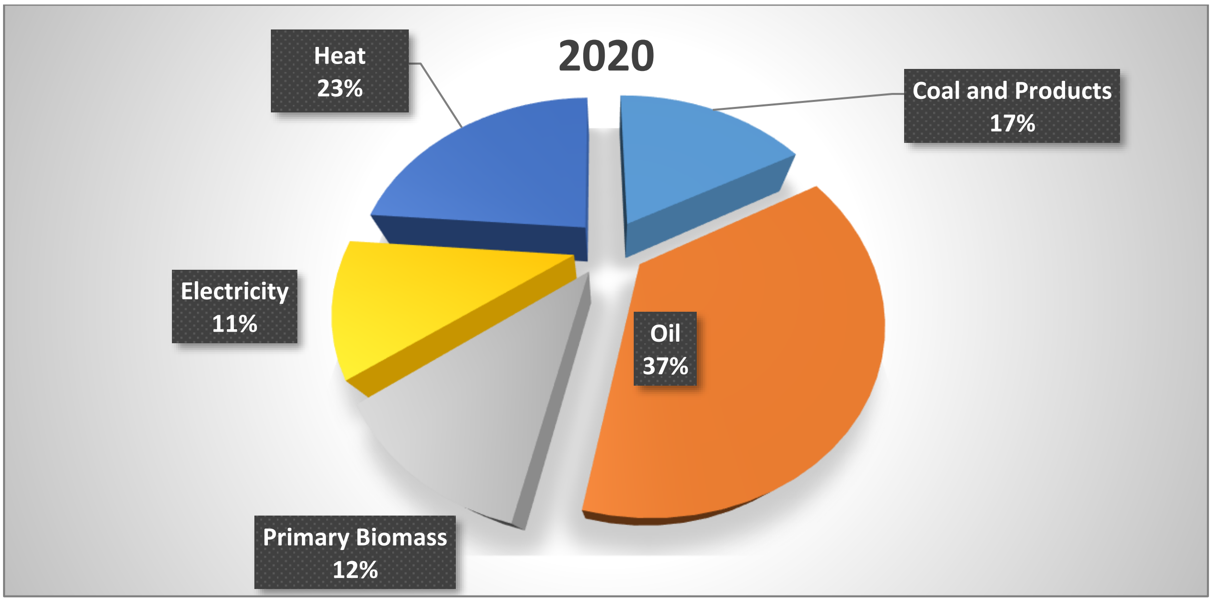
In the final sector, coal share in the total final energy consumption (TFEC) was only 17%, indicating that coal is mainly consumed in the transformation sector (electricity and heat generation, and others such as coal briquette plants).

Oil share was the highest at 37% and heat consumption share was 23%. The remaining share comprises primary biomass at 12% and electricity at 11%. Majority of the oil was consumed in the road transport sector. Diesel consumption was the highest compared to gasoline.

Biomass is mainly consumed by the residential sector. Mongolia's TFEC was around 5.2 Mtoe in 2020 and has been increasing from 2000 at an average rate of 7% per year. This rate is faster than the economic growth of 6.5%.

Figure Error! No text of specified style in document..4 Total Final Energy Consumption of Mongolia, 2020



Source: Author's calculation based on MEEI working file on EBT in 2020.

Mongolia has three types of plant to generate power and heat:

- Electricity: coal, oil, renewable (solar and wind)
- Heat: coal
- CHP (combine heat and power): coal

CHP plants dominate the electricity and heat generation in the country. In general, CHP plants are more efficient than electricity and heat plants. Based on the EBT 2020, CHP plants' output was 1,425 ktoe, of which 549 ktoe electricity and 876 ktoe heat. The coal input of CHP plants was 3,421 ktoe, resulting in an overall efficiency around 42%

Considering coal is the main source of energy in Mongolia, the CO_2 emissions increase rapidly at an average rate 8% per year, from around 14 mt-CO_2 in 2000 to 60 mt-CO_2 in 2020 (Table 4.2)

Table Error! No text of specified style in document..14 Total CO_2 Emissions of Mongolia, 2020

Fuel Type	2000	2020
Coal	12.31	54.74
Oil	1.51	5.46
Natural Gas	-	-
Total	13.82	60.20

Source: Author's calculation based on MEEI working file on EBT in 2020.

4.2.Mongolia's energy situation, 2040

The country's growth outlook remains favourable, with economic growth expected to average 6% over 2020–2040. The basis of this assumption is the World Bank Development Indicator (WDI) and Mongolia Economic Update. The WDI provides the gross domestic product (GDP) of Mongolia and its real growth from 1982 to 2023. Based on this data, Mongolia experienced real GDP growth of 6.5% per year over the 2000–2020 period. Real GDP of 2020 contracted to -4.56% due to the COVID pandemic but it started to recover to 1.64% in 2021, 5.03% in 2022, and 7.02% in 2023. World Bank forecast of Mongolia's real GDP growth will be 6.2% in 2024, 6.4% in 2025, and 6.1% in 2026.

Analysing the elasticity for TPES and TFEC over the 2000–2020 period, the study assumes improvement in the future elasticity of both TPES and TFEC. This includes the TFEC of the final sector. Based on these elasticities and if the share of fuels in each sector remains constant, the resulting EBT of 2040 for Mongolia is shown in Table 4.3. This is considered as the EBT 2040 business-as-usual scenario (BAU).

Under BAU, Mongolia's TPES will reach 34.6 Mtoe in 2040, around twice that of 2020. The TFEC will be growing at a slower rate over the 2020–2040 period (3.9%) compared to that of 2000–2020 (5.2%). Since the fuel share assumption under BAU in 2040 is similar to that in 2030, coal will still be the main fuel source of Mongolia, with share around 82%. Oil share in the TPES is around 14% while renewable share is around 1%. The remaining shares are that of primary biomass and electricity (net trade).

As in 2020, majority of the coal in 2040 will be consumed in the transformation sector (96%). In the final sector, the residential sector will be the main user of coal in 2040 for heating purposes. Oil will continue to be the main fuel for road transport.

The total CO_2 emission in 2040 is projected to reach 127 Mt-CO_2. This is an increased by almost twice that of 2020.

Table Error! No text of specified style in document..15 Simplified Energy Balance Table of Mongolia in 2040, BAU Scenario (in ktoe)

SECTOR / ENERGY SOURCES		1. Coal	2. Coal Products	3. Crude Oil	4. Petroleum Products	4.1 Motor Gasoline	4.2 Aviation Gasoline	4.3 Jet Fuel	4.4 Kerosene	4.5 Gas/Diesel Oil	4.6 Fuel Oil	4.7 LPG	4.8 Lubricants	4.9 Bitumen, Asphalt and Petroleum Jelly	4.10 Other Petroleum Products	5. Natural Gas	6. Renewable Energy	7. Water Energy (Hydro)	8. Solar Energy	9. Wind Energy	10. Nuclear Energy	11. Electricity	12. Heat	13 Primary Biomass	14 Total
1.	Indigenous Production	79,703		556	0												204	23	50	131				1,318	81,781
2.	Imports	0		0	4,839	2,033	26	58	0	2,514	0	103	61	44			0								4,839
3.	Exports	-67,953	-15	-556	0												0								-68,525
4.	International Marine/Aviation Bunkers				0												0								0
5.	Stock Changes	0		0	0												0								0
6.	**Total Primary Energy Supply**	**11,749**	**-15**	**0**	**4,839**	**2,033**	**26**	**58**	**0**	**2,514**	**0**	**103**	**61**	**44**	**0**	**0**	**204**	**23**	**50**	**131**	**0**	**0**	**0**	**1,318**	18,095
7.	Total Transformation Sector	-10,740	926	0	0	0	0	0	0	0	0	0	0	0	0	0	-204	-23	-50	-131	0	1,397	2,589	0	-6,032
7.1	Electrcity Plant	-1,845			0												-204	-23	-50	-131		572	0		-1,477
7.2	Heat Plants	-2,057			0																	-272	812		-1,517
7.3	CHP	-5,903			0																	1,096	1,778		-3,029
7.4	Other Transformation	-934	926		0																				-9
8.	Loss & Own Use	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-260	-347	0	-608
9.	Discrepancy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.	**Total Final Energy Consumption**	**1,010**	**911**	**0**	**4,839**	**2,033**	**26**	**58**	**0**	**2,514**	**0**	**103**	**61**	**44**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1,136**	**2,242**	**1,318**	**11,455**
11.	**Industry Sector**	0	0	0	784	0	0	0	0	784	0	0	0	0	0	0	0	0	0	0	0	645	659	0	2,088
12.	**Transport Sector**	0	0	0	3,909	2,033	26	58	0	1,729	0	1	61	0	0	0	0	0	0	0	0	60	39	0	4,008
12.1	Rail	0	0	0	146	0	0	0	0	146	0	0	0	0	0	0	0	0	0	0	0	5	38	0	189
12.2	Road	0	0	0	3,679	2,033	0	0	0	1,584	0	1	61	0	0	0	0	0	0	0	0	55	1	0	3,735
12.3	Aviation	0	0	0	84	0	26	58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	84
13.	Other Sector	1,010	911	0	102	0	0	0	0	0	0	102	0	0	0	0	0	0	0	0	0	431	1,544	1,317	5,315
13.1	Residential	1,008	911	0	102	0	0	0	0	0	0	102	0	0	0	0	0	0	0	0	0	311	1,164	1,317	4,812
13.2	Commercial, Public Service & Others	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	120	380	0	503
13.3	Commercial & Public Service	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	253	0	327
13.4	Others	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	46	127	0	176
14.	Non-energy Use	0	0	0	44	0	0	0	0	0	0	0	0	44	0	0	0	0	0	0	0	0	0	1	45

Source: Author's calculation.

4.3. Potential hydrogen demand, 2040

Considering Mongolia's heavy reliance on fossil fuels, decarbonising its energy-intensive sectors, such as space heating and heavy freight transport, faces significant challenges. Hydrogen has been a feasible option to Mongolia decarbonisation.

Estimating the hydrogen demand potential will focus on replacing coal use for heating and diesel oil consumption in the industry and transport sectors. There are two hydrogen cases to be analysed. Case 1 will be the green energy case where coal consumption for heat purposes will be replaced by hydrogen. Case 2 is the clean energy case where not only is coal for heat purposes to be replaced by hydrogen, but also diesel consumed in industries and the transport sector will be replaced by hydrogen. In addition, electricity will replace gasoline consumption in the transport sector to electricity and coal consumption for electricity generation only will also be replaced by renewable energy. For all cases, the hydrogen demand calculation uses the assumptions:

- 1 ktoe = 10^10 kcal
- 1 MJ = 238.846 kcal
- Heating value of hydrogen = 142 MJ/kg = 30,834 kcal/kg

4.3.1. Case 1: Green energy case

The green energy case analysed the energy situation of Mongolia in 2040 under the following conditions:

1. Coal consumption in the transformation sector for heat plants only and CHP plants will be replaced by hydrogen.
2. Coal consumption in the residential sector that are also assumed for heating purposes will be replaced by hydrogen.
3. Coal consumption for producing coke will be retained, and the coke is exported.
4. Coal consumption in other sectors is also being retained.

4.3.1.1. Heat only boilers

Under BAU, coal input for heat only boilers (HOBs) are 2,057 ktoe in 2040 while electricity input is 272 ktoe. Heat production is 812 ktoe. This indicates that the efficiency of the plant is 35%.

Under Case 1, hydrogen will replace coal input, and plant efficiency will improve to 70%.

The HOBs' output under Case 1 will be the same as in BAU.

Output : 812 ktoe
Efficiency: 70%
Total input = output/efficiency= 1,159 ktoe

The input share will be similar to BAU:

Input hydrogen: 1,006 ktoe
Input electricity: 153 ktoe

The hydrogen requirement in ktonne will be calculated by first converting ktoe to kcal. Then, using the heating value of hydrogen, the amount of hydrogen can then be converted to ktonnes

Hydrogen requirement = (1,006 *(10^10)/30,834)/1,000,000 = 332 ktonnes

4.3.1.2.Combined heat and power

Under BAU, coal input for CHP plant is 2,057 ktoe in 2040 and the outputs are 1,096 ktoe electricity and 1,778 ktoe heat. The efficiency of the plant is 35%. Under Case 1, hydrogen will replace coal input and plant efficiency will improve to 70%.

The CHP under Case 1 will be:

Total output : (1,096 + 1,778) = 2,874 ktoe.
Efficiency : 70%
Total input : 4,106 ktoe

The input is 100% hydrogen as replacement to coal. Applying the same approach as in the HOBs above, the hydrogen requirement will be= (4,106 *(10^10)/ 30,834)/1,000,000 = 1,332 ktonnes.

4.3.1.3. Residential sector

Under BAU, coal consumption (including coal products) in the residential sector will be 1,918 ktoe in 2040. If all the coal will be replaced by hydrogen, the amount of hydrogen will also be 1,918 ktoe. This requirement in ktonnes will be:

(1,918 *(10^10) /30,834)/1,000,000 = 622 ktonnes

4.3.1.4. Energy balance table Case 1

Table 4.4 shows the EBT of Mongolia under Case 1. The table consists of an additional row for hydrogen production and an additional column for hydrogen fuel. In Case 1, hydrogen production is through electrolysis with efficiency of 67%. The electricity requirement to produce hydrogen will be generated by renewable sources. The assumption is 90% solar and 10% wind. This is additional to the solar and wind requirement in electricity plant only as in BAU.

4.3.2.Case 2: Clean energy case

Case 2 is a cleaner energy condition for Mongolia. Under Case 2, the additional assumptions are:

1. Coal consumption for electricity generation (power plant only) will be replaced by renewable energy (solar and wind).
2. Gasoline consumption in road transport is being replaced by electricity. Thus, by 2040, all gasoline vehicles will be electric vehicles).
3. There will be no more lubricants because of the use of electric motor.
4. There will be no more liquefied petroleum gas (LPG) also in the road sector.
5. Diesel consumption in industry for heating will be replaced by hydrogen.
6. Diesel for rail will also be replaced by hydrogen
7. Coal will be difficult to export in 2040 because of decreasing coal use by countries to achieve non-zero emissions. In this regard, the intended coal export in Mongolia can be replaced by hydrogen through coal gasification technology. Thus, Mongolia can still earn revenues from the export of hydrogen.

Table Error! No text of specified style in document..16 Energy Balance Table 2040 – Case 1 (in ktoe)

SECTOR / ENERGY SOURCES		1A. Hydrogen	1. Coal	2. Coal Products	3. Crude Oil	4. Petroleum Products	4.1 Motor Gasoline	4.2 Aviation Gasoline	4.3 Jet Fuel	4.4 Kerosene	4.5 Gas/Diesel Oil	4.6 Fuel Oil	4.7 LPG	4.8 Lubricants	4.9 Bitumen, Asphalt and Petroleum Jelly	4.10 Other Petroleum Products	5. Natural Gas	6. Renewable Energy	7. Water Energy (Hydro)	8. Solar Energy	9. Wind Energy	10. Nuclear Energy	11. Electricity	12. Heat	13 Primary Biomass	14 Total
1.	Indigenous Production		69,818		556	0												16,332	23	14,565	1,744				1,318	88,024
2.	Imports		0		0	4,839	2,033	26	58	0	2,514	0	103	61	44			0								4,839
3.	Exports	-3821	-67,953	-15	-556	0												0								-72,345
4.	International Marine/Aviation Bunkers					0												0								0
5.	Stock Changes					0												0								0
6.	**Total Primary Energy Supply**	**-3,821**	**1,865**	**-15**	**0**	**4,839**	**2,033**	**26**	**58**	**0**	**2,514**	**0**	**103**	**61**	**44**	**0**	**0**	**16,332**	**23**	**14,565**	**1,744**	**0**	**0**	**0**	**1,318**	24,338
7.	Total Transformation Sector	5,739	-1,863	15	0	0	0	0	0	0	0	0	0	0	0	0	0	-16,332	-23	-14,565	-1,744	0	1,533	2,589	0	-3,060
7.1	Electrcity Plant		-1,845			0												-16,332	-23	-14,565	-1,744		16,700			-1,477
7.2	Heat Plants	-1024	0			0												0					-135	812		-348
7.3	CHP	-4106	0			0												0					1,096	1,778		-1,232
7.4	Other Transformation		-18	15		0												0								-3
7.5	**Hydrogen Production**	10869				0												0					-16,128			-5,259
8.	Loss & Own Use	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-379	-347	0	-727
9.	Discrepancy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	17
10.	**Total Final Energy Consumption**	**1,918**	**2**	**0**	**0**	**4,839**	**2,033**	**26**	**58**	**0**	**2,514**	**0**	**103**	**61**	**44**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1,136**	**2,242**	**1,318**	**9,537**
11.	**Industry Sector**		0	0	0	784	0	0	0	0	784	0	0	0	0	0	0	0	0	0	0	0	645	659	0	2,088
12.	**Transport Sector**	0	0	0	0	3,909	2,033	26	58	0	1,729	0	1	61	0	0	0	0	0	0	0	0	60	39	0	4,008
12.1	Rail		0	0	0	146	0	0	0	0	146	0	0	0	0	0	0	0	0	0	0	0	5	38	0	189
12.2	Road		0	0	0	3,679	2,033	0	0	0	1,584	0	1	61	0	0	0	0	0	0	0	0	55	1	0	3,735
12.3	Aviation		0	0	0	84	0	26	58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	84
13.	Other Sector	1,918	2	0	0	102	0	0	0	0	0	0	102	0	0	0	0	0	0	0	0	0	431	1,544	1,317	3,396
13.1	Residential	1,918	0	0	0	102	0	0	0	0	0	0	102	0	0	0	0	0	0	0	0	0	311	1,164	1,317	4,812
13.2	Commercial, Public Service & Others		2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	120	380	0	502
13.3	Commercial & Public Service		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	253	0	327
13.4	Others		2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	46	127	0	175
14.	Non-energy Use	0	0	0	0	44	0	0	0	0	0	0	0	0	44	0	0	0	0	0	0	0	0	0	1	45

Source: Author's calculation.

4.3.2.1. Electricity plant

Under BAU and Case1, coal is still used to generate power in electricity plants only (1,845 ktoe). The amount generated from these coal plants amounted to 368 ktoe or 4,283 GWh. Under Case 2, no more coal plants will operate; these will be replaced with solar and wind. Since the efficiency of these plants is 100%, then the amount of solar and wind requirement (input) will be 331 ktoe for solar and 37 ktoe for wind. This is assuming that the renewable input replacing coal will be 90% solar and 10% wind.

4.3.2.2. Road transport

Gasoline consumed in transport will all be replaced by electricity under Case 2. Gasoline is all consumed in the road transport sector. Under BAU, gasoline consumption is 2,033 ktoe. Replaced by electricity, the amount consumed will be lower since electric vehicles consume 30% less energy than internal combustion engine vehicles. In this regard, electricity consumption in road transport will be:

0.3* 2,033 = 610 ktoe

This increase in electricity demand in the road transport sector will increase electricity production. The assumption, as in Case 1, is that renewable energy will be the only input for electricity production in Mongolia. Thus, the renewable energy supply under Case 2 will increase, covered by solar (90%) and wind (10%).

Similar to gasoline, diesel consumption in road transport will also be replaced with hydrogen. Under BAU and Case 1, the diesel consumption in road transport is 1,584 ktoe. The amount of hydrogen requirement is estimated to be:

(1,584 *(10^10) /30,834)/1000000 = 467 ktonnes

LPG consumption in transport is assumed to be zero under Case 2. Lubricant consumption for road transport will also be zero under Case 2 since electric motors will not need lubricant anymore.

4.3.2.3. Rail transport

Diesel consumed in rail transport will also be replaced with hydrogen under Case 2. Under BAU and Case 1, diesel consumption in rail transport is 146 ktoe. The amount of hydrogen requirement is estimated to be:

(146 *(10^10))/30,834)/1,000,000 = 43 ktonnes

4.3.2.4. Industry sector

Under Case 2, diesel consumption in industries will also be replaced by hydrogen as in the road transport sector. Under BAU and Case 1, industrial diesel consumption is 784 ktoe. Replacing this to hydrogen will amount to:

(784 *(10^10)/ 30,834)/1,000,000 = 231 ktonnes

4.3.2.5. Energy balance table, Case 2

Table 4.5 shows the EBT of Mongolia under Case 2. The table consists of additional rows for hydrogen production. In Case 1, hydrogen production is through electrolysis with an efficiency of 67%. Under Case 2, hydrogen will also be produced through coal gasification technology and the

Table Error! No text of specified style in document..17 Energy Balance Table, 2040 – Case 2 (in ktoe)

SECTORS/ ENERGY SOURCES	1A. Hydrogen	1. Coal	2. Coal Products	3. Crude Oil	4. Petroleum Products	4.1 Motor Gasoline	4.2 Aviation Gasoline	4.3 Jet Fuel	4.4 Kerosene	4.5 Gas/Diesel Oil	4.6 Fuel Oil	4.7 LPG	4.8 Lubricants	4.9 Bitumen, Asphalt and Petroleum Jelly	4.10 Other Petroleum Products	5. Natural Gas	6. Renewable Energy	7. Water Energy (Hydro)	8. Solar Energy	9. Wind Energy	10. Nuclear Energy	11. Electricity	12. Heat	13 Primary Biomass	14 Total
1. Indigenous Production		67,973		556	0												17,310	23	15,446	1,842				1,318	87,157
2. Imports		0		0	292	0	26	58	0	0	0	103	61	44	0		0								292
3. Exports	-42079	0	-15	-556	0												0								-42,650
4. International Marine/Aviation Bunkers					0																				0
5. Stock Changes		0		0	0												0								0
6. Total Primary Energy Supply	**-42,079**	**67,973**	**-15**	**0**	292	**0**	**26**	**58**	**0**	**0**	**0**	**103**	**61**	**44**	**0**	**0**	**17,310**	**23**	**15,446**	**1,842**	**0**	**0**	**0**	**1,318**	86,878
7. Total Transformation Sector	46,511	-67,971	15	0	0	0	0	0	0	0	0	0	0	0	0	0	-17,309	-23	-15,445	-1,841	0	2,143	2,589	0	-1,583
7.1 Electrcity Plant		0			0												-17,309	-23	-15,445	-1,841		17,309	0		0
7.2 Heat Plants	-1024	0			0																	-135	812		-348
7.3 CHP	-4106	0			0																	1,096	1,778		-1,232
7.4 Other Transformation		-18	15		0																				-3
7.5 Hydrogen Production	10869				0																	-16,128			-5,259
	40772	-67,953			0																				-27,181
8. Loss & Own Use		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-397	-347	0	-744
9. Discrepancy	0	0	0	0	62	0	0	0	0	0	0	1	61	0	0	0	0	0	0	0	0	0	0	0	62
10. Total Final Energy Consumption	**4,432**	**2**	**0**	**0**	230	**0**	**26**	**58**	**0**	**0**	**0**	**102**	**0**	**44**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1,746**	**2,242**	**1,318**	**7,268**
11. Industry Sector	784	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	645	659	0	1,304
12. Transport Sector	1,730	0	0	0	84	0	26	58	0	0	0	0	0	0	0	0	0	0	0	0	0	670	39	0	2,523
12.1 Rail	146	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	38	0	189
12.2 Road	1,584	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	665	1	0	2,250
12.3 Aviation		0	0	0	84	0	26	58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	84
13. Other Sector	1,918	2	0	0	102	0	0	0	0	0	0	102	0	0	0	0	0	0	0	0	0	431	1,544	1,317	3,396
13.1 Residential	1,918	0	0	0	102	0	0	0	0	0	0	102	0	0	0	0	0	0	0	0	0	311	1,164	1,317	4,812
13.2 Commercial, Public Service & Others		2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	120	380	0	502
13.3 Commercial & Public Service		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	253	0	327
13.4 Others		2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	46	127	0	175
14. Non-energy Use	0	0	0	0	44	0	0	0	0	0	0	0	0	44	0	0	0	0	0	0	0	0	0	1	45

Source: Author's calculations.

production ratio is assumed to be 60%. This assumes that there will be no more coal export from Mongolia since countries will reduce their coal use to obtain their non-zero emissions target by 2050 or 2060.

4.4. Analysis on the impact of hydrogen to the energy situation of Mongolia

This section will analyse the impact of introducing hydrogen to Mongolia's energy situation in 2040. This comparison is based on the EBT projected for 2040 based on Mongolia's EBT 2020 as provided by the MEEI. Three EBTs are formulated: EBT 2040 BAU, EBT 2040 Case 1, and EBT 2040 Case 2.

4.4.1.Reduction in coal use

Under BAU, coal is still the major fuel in the transformation sector. Total coal consumption in 2040 reached 10,173 ktoe. Majority of these consumptions (74%) are for CHP plants (5,903 ktoe) and for HOB's (2,057 ktoe). Under Case 1, the coal consumption of HOBs and CHPs have been replaced with hydrogen, which means a 7,961 ktoe reduction in the coal consumption for the transformation sector. Beside the transformation sector, coal and briquette in the residential sector will also be replaced by hydrogen. As a result, there will be no more coal being consumed in the transformation sector to produce this product. Overall, the total coal consumption in Case 1 will only be 1,865 ktoe compared to 11,749 ktoe under BAU. This is a reduction around 84%, which will also significantly reduce the CO2 emissions under Case 1.

Under Case 2, coal consumption will be further reduced by 1,845 ktoe as coal power plants will not be operating and will be replaced with renewable energy, which in this case is solar and wind energy. Thus, under Case 2, coal consumption will be reduced by almost 100% compared to BAU. The remaining will only be coal consumed to produce coal product (18 ktoe), which will be exported.

4.4.2.Reduction in oil use

Under Case 2, diesel consumption in the industry and transport sectors will be replaced by hydrogen. Under BAU, total diesel consumption is 2,514 ktoe where 784 ktoe is the consumption in industries and 1,730 ktoe is the consumption in both the rail and road transport sectors.

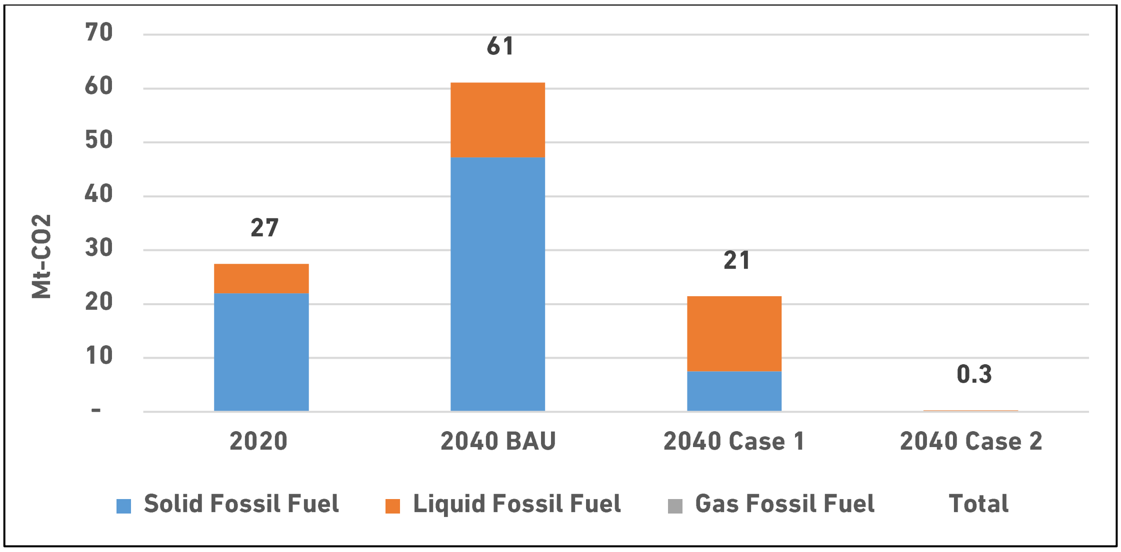
Beside replacing diesel, gasoline is also assumed to be replaced with electricity. Consequently, no lubricant will be consumed in road transport; LPG will also only be consumed by the residential sector for cooking.

4.4.3. Reduction in CO2 emission

Figure 4.3 shows the total CO2 emission by fuel type for 2020, 2040 BAU, 2040 Case 1, and 2040 Case 2. Solid fuel dominates the CO2 emission of Mongolia (80% in 2020 and 77% in BAU). Under Case 1, the share of coal will decrease, and liquid fossil fuel will dominate the total CO2 emissions (35% and 65%, respectively).

Total CO2 emitted was 27 Mt-CO2 in 2020 and increased to 61 Mt-CO2 in 2040 under BAU. Under Case 1, total emissions will decline to 21 Mt-CO2 while under Case 2, it will further decrease to around 300 kt-CO2. Coal is still being produced under Case 2 but only to produce hydrogen for export purposes through the gasification technology.

Table Error! No text of specified style in document..18 Total CO2 Emissions of Mongolia



Source: Author's calculations.

4.4.4. Hydrogen demand and supply

Under Case 1, total hydrogen demand will be 7,048 ktoe (2,286 ktonnes) while under Case 2, the demand will be 9,562 ktoe (3,101 ktonnes). Based on Chiyoda's estimation, total hydrogen production will be 3,525 ktonnes (10,869 ktoe). This will imply a surplus of hydrogen production, which can be exported. Under Case 1, hydrogen export can be 1,239 ktonnes (3,820 ktoe) while under Case 2, export will only be 424 ktonnes (1,307 ktoe).

Under Case 1, hydrogen export will add to the earnings from coal export. Case 2 assumes there will be no more coal export. This is because coal will not be an import commodity anymore as countries will significantly reduce coal use to reach their zero-emission target. In this condition, Mongolia can still produce coal but the amount for export will be replaced by hydrogen through coal gasification technology. So, under Case 2, total hydrogen export will increase to 42,079 ktoe (13,647 ktonnes).

4.4.5. Increasing renewable energy's role in power generation

Under BAU, electricity production from renewable energy is 204 ktoe in 2040 (2,373 GWh). Under Case 1, production from renewables will increase to meet the electricity requirement for hydrogen production using the electrolysis technology (green hydrogen). The amount of electricity for hydrogen production will be 16,128 ktoe, which will be produce by 90% solar and 10% wind sources. As a result, total renewable energy generation of electricity under Case 1 will increase to 16,332 ktoe.

Under Case 2, replacing gasoline with electricity and replacing coal power plants with renewables will further increase electricity generation from renewables. Total renewable generation under Case 2 will be 17,309 ktoe.

Chapter 5
Introduction of Japan's Hydrogen Strategy

5.1. Background

In 2017, Japan formulated the world's first national hydrogen strategy, the Basic Hydrogen Strategy. Spurred by this move, 26 countries and economies, including Japan, developed their hydrogen strategies by January 2022.

Subsequently, considering changes in global trends regarding hydrogen use and the 2050 Carbon Neutrality Declaration made in October 2020, the Government of Japan revised its Basic Hydrogen Strategy in June 2023.

This strategy positions nine technologies, including fuel cells and hydrogen electrolysis devices, as key areas, resulting in Japan's decision to invest more than 15 trillion yen (¥) over the next 15 years.

5.2. Overall policy, target amount, and cost of hydrogen

5.2.1. Overall policy

The introduction of hydrogen into Japan will be premised on S+3E, S means Safety and 3E means Energy security, Economic efficiency and Environment.

a) Safety

Hydrogen is the lightest of all gases, is colourless and odourless, and is prone to diffusion and leakage. Considering these characteristics, Japan will lead the formulation of international standards and establish appropriate safety standards.

b) Energy security

For a country like Japan that lacks readily available resources, hydrogen can be produced from renewable energy sources, can be produced and stored domestically, and can also be supplied overseas, helping to strengthen energy security.

c) Economic efficiency

The IEA's Energy Technology Perspectives 2020 projects the hydrogen produced through electrolysis (using electricity derived from renewable energy) to be cost competitive compared to existing fossil fuels as the costs related to renewable energy power sources continue to decrease. Furthermore, hydrogen produced using renewable energy has had relatively slight price fluctuations. When carbon pricing programs gain momentum in Japan as well in the future, and when, as a result, the environmental value of carbon is converted into specific product prices, hydrogen as a non-fossil fuel will become a commercially self-sustaining fuel. It will probably provide an economically stable and attractive energy source option.

d) Environment

Hydrogen and ammonia may not only be burned with or without fossil fuels to reduce or eliminate greenhouse gas emissions from thermal power generation but may also serve as a balancing energy and stability pathfinder, contributing to the widespread use of renewable energy.

Hydrogen, therefore, is an energy that can contribute to the decarbonisation for a wide range of industrial fields. In addition, we will prioritise low-carbon hydrogen production amongst many policy measures to increase the use of hydrogen to accelerate carbon neutrality.

5.2.2. Target amount of H2

Table Error! No text of specified style in document..19 Target Amount of H2

Year	2030	2040	2050
Target Amount of Hydrogen (Max million tonne-H2	3	12 (including NH3)	20

Source：Agency for Natural Resources and Energy (2023).

5.2.3 Hydrogen supply cost (CIF)

Table Error! No text of specified style in document..20 Target Hydrogen Supply Cost (CIF)

Year	2030	2040	2050
Hydrogen Supply Cost (CIF)	30(*1)	NH3 (CIF) Upper 10 yen range/Nm3 (H2 equivalent)	20

Note：¥30/Nm3 corresponds to 2.2 $/kg-H2 (@¥150/$)

Source：Agency for Natural Resources and Energy (2023).

5.3 Hydrogen industrial strategy

5.3.1 Supply side

Water electrolysis equipment introduction targets for Japanese companies both domestic and overseas by 2030： 15 GW (Note *2)

Supporting the development and social implementation of carbon capture and utilisation technology (Note *3), which is essential for low-carbon H2.

Note *2：The global installed capacity of water electrolysers is estimated to reach 134 GW.

In 2030, Japan expects to account for about 10% of this figure.

Note *3： Japan aims to secure an annual CO2 storage capacity of 6–12 million tonnes by 2030.

5.3.2 Demand side (Note *4, See Table 5.3)

- Power Generation： Achieving a wide range of hydrogen (Note *5)/ammonia (Note *6) co-firing ratios by 2030
- Fuel cell technology： Establishing a position as a platform provider
- Heat and raw material utilisation
- Technological development and demonstration of hydrogen and ammonia : burners and boilers
- Introduction and spread of cogeneration systems using hydrogen gas : turbines
- Promoting hydrogen use in the steel and petrochemical industries

Japan has begun demonstrating hydrogen reduction steelmaking using an actual large blast furnace, with the aim of commercialising the technology by 2030.

Note *4 :

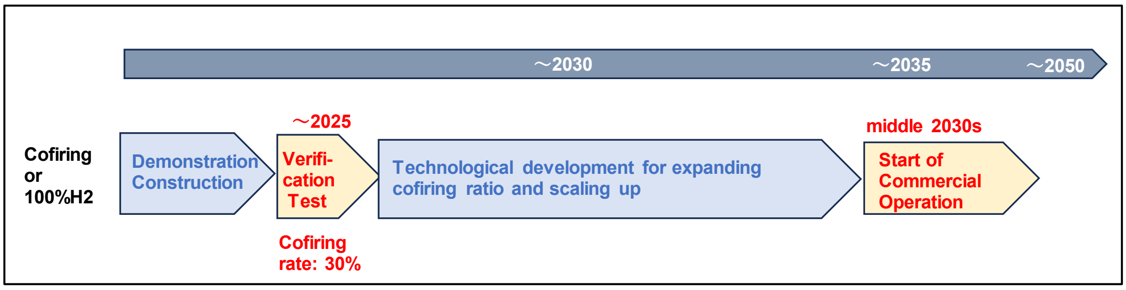
Table Error! No text of specified style in document..21 Potential Applications for Hydrogen and Ammonia (Direct Use)

Applications (major classification)	Applications (medium classification)	Hydrogen	Ammonia
Electricity	Mixed combustion/exclusive combustion for coal-fired power generation		○
	Mixed combustion/exclusive combustion for gas-fired power	○	
Non-power (Fuel)	Heat utilisation (industrial furnaces, etc.)	○	○
	Engines for ships, etc.	○ (Short to medium distance)	○ (Long distance)
	Fuel cells for mobility/stationary use, etc.	○	
Non-power (Raw material)	Hydrogen reduction iron manufacturing	○	
	Total basic chemicals	○	

Source : Author.

Note*5 :

Figure Error! No text of specified style in document..5 Hydrogen Utilisation Plan for Power Generation Towards 2050



Source : Author

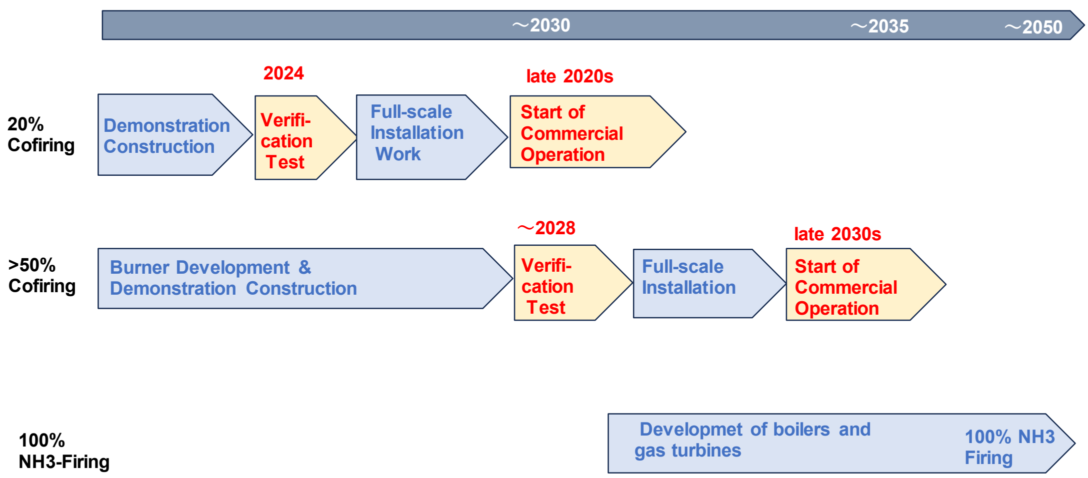
Table 5.4 An Example of H2 Cofiring Project in Japan

Site	Place	Participating Companies	Summary of Plans and Results
Niigata Thermal Power Station	Niigata Pref.	Tohoku Elec.Co., Ltd	**Hydrogen cofiring** demonstration at Niigata Thermal Power Plant Group 5 (109,000 KW) began in October 2023, and was the first hydrogen cofiring test in Japan for a commercial gas combined cycle thermal power plant. Hydrogen cofiring rate: 1% by volume

Source: https:///www.tohoku-epco.co.jp/news/normal/1237143_2558.html (in Japanese)

Note *6

Figure Error! No text of specified style in document..6 Ammonia Utilisation Plan for Coal Power Plant Towards 2050



Source：Author

Demonstration project of NH3 co-firing at Hekinan Power Plant in Aich Prefecture

- Demonstration plant： Hekinan #4 coal fired; 1,000 MW; Thermal efficiency: 44% (LHV)
- NH3 cofiring ratio：20% (calorie basis)
- Schedule: 2024 April～June
- Objective: Nitrogen oxide (NOx) emissions, Impacts on boilers and surrounding equipment and operability

5.4. Hydrogen safety strategy

5.4.1 Objectives

- Clarification and organisation of the overall relationship of applicable laws and regulations
- Rationalisation and optimisation of safety regulations and rules
- Public–private action guidelines for establishing a safety regulation system with a view to 2050
- Strategic acquisition of scientific data to contribute to the formulation of safety standards
- Improving the hydrogen utilisation environment

5.4.2. Interim report

On 23 March 2023, METI compiled an interim report on the Hydrogen Safety Strategy based on discussions at the Study Group on the Formulation of the Hydrogen Safety Strategy (chaired by Atsumi Miyake, Director and Vice President of Yokohama National University).

In the interim report, three action plans and nine specific measures were presented to build a rational safety regulation system.

【Action Plan and Specific Measures】

Action Plan 1 Initiatives based on scientific data and evidence through technological development, etc.

Method 1: Strategic acquisition of scientific data and sharing of data on shared areas

Method 2: Creating a smooth experiment and demonstration environment

Action Plan 2 Rationalisation and optimisation of rules for the gradual implementation of a hydrogen society

Method 3: Priority areas for supply chain

Method 4: Clarifying the way forward

Method 5 : Development and training of third-party certification and inspection organisations

Method 6: Cooperation with local governments

Action Plan 3 Improving the hydrogen utilisation environment

Method 7: Risk communication

Method 8 : Human resource development

Method 9 : Understanding trends in each country, and working towards regulatory harmonisation and the formulation of international standards

【Technology Map】

Also in the interim report, a technology map and process chart for hydrogen safety were compiled.

The international standards in the hydrogen field based on the official website of the International Organisation of Standardisation/International Electrotechnical Commission was organised. For ISO, the number of standards is 77, and for IEC 30.

The standards were organised into the following eight categories: (i) general; (ii) manufacturing; (iii) storage and transportation; (iv) transportation sector; (v) power generation sector; (vi) industrial sector; (vii) civil sector, and (viii) others.

Chapter 6

Conclusions and Policy Recommendations

6.1 Conclusions

Chapter 2 forecasts the renewable energy (RE) power generation potential of solar PV and wind power systems, with Umnu-Govi identified as a province with substantial RE potential (ADB, 2020). This chapter focuses on provinces scoring 4 in solar PV and wind potential capacity (GW) in southern Mongolia: Umnu-Govi, Dundgovi, Dornogovi, Ovorhangai, Bayanhongor, and Govi-Altai. The estimated solar PV capacity is 1,165.7 GW, while wind power capacity is 191.6 GW. As electricity will be used for both hydrogen production and human consumption, it must be transported from the south – where Umnu-Govi lacks water – to the north. Additionally, the southern provinces have lower population densities. To minimise transmission costs, RE electricity from Dundgovi (requiring two 300 km transmission lines to Ulaanbaatar) and Govi-Altai (which requires no additional transmission line) was selected. The total investment cost for solar and wind RE is estimated at $145.1 billion, with an additional $1.2 billion for transmission infrastructure. Assuming a 20-year operational lifespan for both RE and transmission lines, the estimated power supply cost is 3.9 cents per kWh.

Chapter 3 forecasts hydrogen production in the northern region. Amongst available electrolysis technologies – alkaline (ALK), proton exchange membrane (PEM), and solid oxide electrolysis cell (SOEC) – PEM is selected based on its efficiency and cost advantages. Assuming an average efficiency of 4.75 kWh/Nm^3-H_2, the RE electricity generates approximately 3,525 kilotonnes of hydrogen (equivalent to 10,869 ktoe). The estimated hydrogen production cost is $2.5–3.1 per kg-$H_2$. In Mongolia, hydrogen is primarily intended for use as a heating fuel to replace coal. Therefore, it must be transported from electrolysis sites to end-use locations such as commercial buildings, factories, and residential areas. To address safety and logistical concerns, the use of methylcyclohexane (MCH) as a hydrogen carrier, transported by tank truck or freight train, is recommended due to its stability at ambient temperature and pressure.

Chapter 4 analyses Mongolia's Energy Balance Table (EBT), which shows coal as the dominant fuel for combined heat and power (CHP) and heat generation. In 2020, Mongolia consumed 5,478 ktoe of coal in the transformation sector (1,070 ktoe for heat generation and 3,421 ktoe for CHP) and 482 ktoe in the final energy consumption sector. Based on GDP growth projections, coal consumption in 2040 is forecasted to rise to 10,173 ktoe (2,057 ktoe for heat generation and 5,903 ktoe for CHP). Replacing this with hydrogen, the projected hydrogen demand is 326 ktoe for heat generation and 4,106 ktoe for CHP, assuming higher energy efficiency. The remaining hydrogen (8,861 – 326 – 4,106 = 4,429 ktoe) would be allocated to heating in residential and industrial sectors, transport fuels for the road sector, and exports.

Chapter 5 introduces Japan's Hydrogen Strategic Plan, which outlines a comprehensive hydrogen supply chain involving hydrogen imports and identifies demand sectors such as power, transport, industry, residential, and commercial uses. The plan targets a hydrogen supply cost of $1–2 per kg by 2040–2050.

6.2 Policy Recommendations

Based on the conclusions outlined above, this report recommends the following:

a. In Mongolia, heat demand is substantial and currently met primarily by coal through heat-only plants and combined heat and power (CHP) systems. Therefore, hydrogen use should be prioritised for meeting this heat demand.

b. According to the 2020 ADB report, Mongolia possesses significant renewable energy (RE) potential – particularly solar PV and wind – in the southern region, including Umnu-Govi. Mongolia should develop these RE resources to meet electricity and hydrogen production needs. However, developing RE in the Gobi Desert would require constructing long transmission lines due to limited water availability and low population density. To minimise transmission distance and cost, it is recommended that Mongolia focus RE development efforts in the northern and central grassland areas.

c. Solar and wind energy, along with hydrogen derived from these RE sources, are critical for Mongolia to achieve carbon neutrality by 2050 or later. Electricity and hydrogen can replace fossil fuel demand such as coal and petroleum products. If RE power becomes the dominant energy source, energy security should be supported through:
(i) the installation of battery storage systems,
(ii) interconnection with neighbouring countries, and
(iii) the development of stable power sources, such as hydrogen-fuelled power plants.

d. Coal has long been a key export commodity for Mongolia. However, due to the global shift towards carbon neutrality, future coal exports to neighbouring countries are likely to decline. In response, Mongolia could utilise its coal reserves to produce hydrogen through coal gasification. To do this sustainably, Mongolia must capture the CO_2 emissions from gasification and store them in underground saline aquifers. Alternatively, it can use captured CO_2 in the production of synthetic fuels, gases, plastics, and construction materials – an approach known as carbon capture, utilisation, and storage (CCUS).

e. If Mongolia intends to utilise hydrogen across both supply and demand sides to realise a carbon-neutral society, it must develop a national hydrogen strategy, similar to Japan's. Additionally, a comprehensive RE development plan should be formulated, incorporating solar PV and wind power not only in the southern Gobi Desert but also in the northern and central grassland regions.

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