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Optimization of Green Ammonia Production Facility Configuration in Australia for Import into Korea

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〈Abstract〉

Many countries across the world are making efforts beyond reducing CO_2 levels and declaring ‘net zero,’ which aims to cut greenhouse gas emissions to zero by not emitting any carbon or capturing carbon, by 2050. Hydrogen is considered a key energy source to achieve carbon neutrality goals. Korean companies are also interested in building overseas green ammonia production plants and importing hydrogen into Korea in the form of ammonia. Green hydrogen production uses renewable energy sources such as solar and wind power, but the variability of power production poses challenges in plant design. Therefore, optimization of the configuration of a green ammonia production plant using renewable energy is expected to contribute as basic information for securing the economic feasibility of green ammonia production.

Keywords : Green Hydrogen, Green Ammonia Production, Renewable Energy, Ammonia Synthesis, Plant Concept Optimization

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1. Introduction

The government of the Republic of Korea announced the first statutory basic plan for the hydrogen economy through the 1st Hydrogen Economy Implementation Basic Plan in November 2021. Following the global trend, “hydrogen” was selected as a key means to achieve carbon neutrality, and the goal was to become a leading country in terms of the entire cycle of hydrogen production, distribution, and utilization[1].

The Korean government announced a plan to increase hydrogen supply from 220,000 tonnes in 2020 to 3.9 million tonnes in 2030 and 27.9 million tonnes in 2050. Among them, hydrogen imported from overseas is 1.96 million tonnes in 2030 and 22.9 million tonnes in 2050, and dependence on hydrogen imports is continuously increasing from 50.3% in 2030 to 82.1% in 2050 (Table 1). As the amount of overseas hydrogen imported rapidly increases, it is essential for domestic companies and governments to establish overseas hydrogen supply chains in terms of energy security.

Table 1. Korea’s hydrogen economy implementation basic plan

Year	2020	2030	2050
Hydrogen supply capacity (Mt)	0.22	3.9	27.9
Import of overseas hydrogen (Mt)	-	1.96	22.9
Share of hydrogen imports (%)	-	50.3	82.1

Accordingly, Korean companies are showing great interest in building overseas green hydrogen production complexes. Australia and the Middle East are attracting attention as major target countries for the construction of production complexes[2].

This study was conducted as part of a feasibility study to optimize the configuration of green hydrogen production facilities for importing green hydrogen from Western Australia to Korea.

2. Green Ammonia Production Facility Configuration Analysis

Because it is difficult to transport hydrogen over long distances with current technology, converting the produced hydrogen into ammonia and transporting it is accepted as an economical alternative[3]. Therefore, in this study, ammonia was set as the final product.

The configuration of the major facilities for producing green ammonia is as follows.

- Renewable energy generation complex
- Renewable energy configuration
- Hydrogen production facility (HPF)
- Ammonia production facility (APF)

The facility configuration was optimized based on producing 150,000 tonnes of green ammonia per year for 25 years and transporting it to Korea.

2.1 Determination of Minimum Capacity of Each Facility

As the world's leading independent energy advisor, DNV's SHARE model simulation tool that is a techno-economic modelling tool which is typically implemented on green ammonia projects using variable renewable energy is used to determine the optimal design capacity of renewable energy, hydrogen and ammonia production, and the related utilities and infrastructure necessary to export the ammonia by vessel.

The benefit of this model is the ability to optimise the mixture of Wind, Solar, BESS (Battery Energy Storage System), H2 storage, Electrolysis and Ammonia equipment capacity. Each unit operation has certain technical constraints, such as ramp rates, limiting min/max capacities.

Degradation and augmentation of equipment is also considered for example for solar PV panels and BESS degradation. The model can produce hourly simulation results across the entire life of a project.

2.2 Renewable Energy Generation Complex and Configuration

Fig. 1 shows photovoltaic power output of Australia. Because solar energy intensity is directly related to electricity production, an analysis of solar energy intensity across Australia found that the West of Australia was a relatively good location.

Analysis of the average wind speed around Australia at 100 m above sea level, as shown in Fig. 2, shows that wind speed in western Australia is generally characterized by daily wind speed variation, i.e., slower wind speeds during the day and higher wind speeds at night.

This diurnal wind behaviour is beneficial since it complements solar PV, where energy production only occurs during the daylight hours. Therefore, an optimum mix of solar and wind energy can be found which, when combined, provides a more stable energy

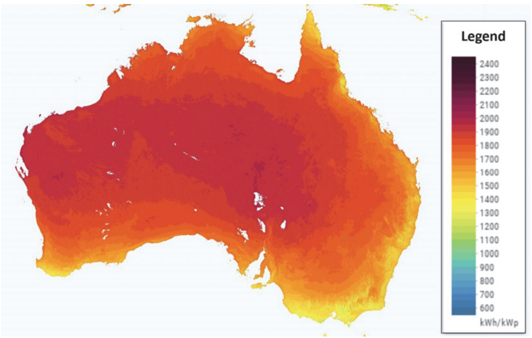

Fig. 1 General illustration for solar energy intensity across Australia[4]

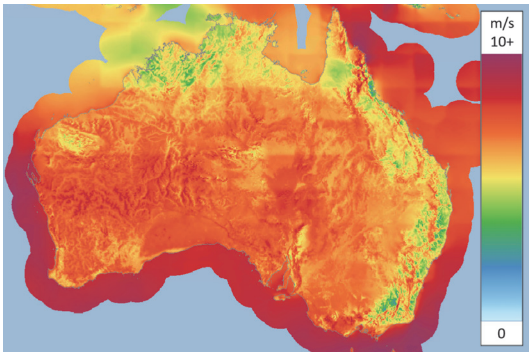

Fig. 2 Mean wind speeds across Australia at 100 m elevation[5]

resource for hydrogen and ammonia production, while minimizing over-investment in renewable energy capacity and losses due to curtailment (in the context of an off-grid energy island).

According to the results of the analysis of solar resources and wind resources, the requirements for the renewable energy generation complex site were established and the site area according to capacity was determined.

Through SHARE model simulation, the configuration of new renewable energy was determined as follows.

- 400 MWp solar PV plant
- 217 MW wind farm (utilizing 35 x 6.2 MW turbines)
- 100 MW / 4-hour (400 MWh) lithium-ion BESS
- HV power transmission

The low tolerance for changes in production rates by an ammonia synthesis plant drive much of the optimization effort.

The NREC (New and Renewable Energy Complex) requires BESS facilities that can accommodate the variability of renewable energy generation. The operating philosophy of the BESS system is to store any excess energy production from the solar PV and wind farm when excess power is being generated. This will then the utilized overnight to maintain power supply to the HPF/APF for continuous ammonia production. Furthermore, the BESS will also provide dampening of short-term energy production changes, particularly from the solar PV facility.

2.3 Hydrogen Production Facility (HPF)

Water electrolysis utilizes electricity to convert water into hydrogen and oxygen. It is seen as a key technology in enabling a net-zero energy system. Water electrolysis can take place over wide range of operating temperatures, from room temperature up to 800 ° C and using different electrolytes.

Several technologies, described in Table 2, have been developed, each with specific advantages and challenges.

Among the technologies mentioned in the Table 2, Alkaline water electrolysis could be classified as a "mature and well established" technology since it was successfully demonstrated on industrial scale as early as the beginning of the 20th century[6].

Therefore, in this study, alkaline water electrolysis was proposed considering the maturity of the current technology and production stability.

After the hydrogen is produced it can be

Table 2. Comparison of main electrolyzer technologies

	Alkaline	PEM	AEM	HTSE
Operating temperature [°C]	70-90	50-80	40-60	700-850
Operating pressure [bar]	1-30	30-70	~30	1
Efficiency [kWh/Nm3]	4.7	4.8	4.8 (stack only)	3.6
Stack lifetime [h]	~80,000	~50,000	<5,000	~20,000
Commercial status	Available	Available	Under development	Available 2022-2024

used as a raw material for ammonia production in the Haber-Bosch ammonia synthesis process. Intermediary storage of hydrogen will be required in case hydrogen production and hydrogen usage are out of phase.

During the day green power is produced using solar power, but at night the green power production rate will drop to zero. Also, green power produced with wind turbines will not always be available. The availability of green power greatly determines the green hydrogen production rates in case no back-up grid power will be available for filling the gaps in green power production. This will imply that hydrogen production rates will fluctuate considerably over a day.

Therefore, in this study, an additional hydrogen storage tank was introduced to reduce ammonia production variability.

2.4 Ammonia Production Facility (APF)

The currently most-used, and widely considered most-mature, production method for ammonia is the Haber-Bosch process[7].

For green ammonia production, the Haber-Bosch process can be combined with water electrolysis instead of methane reforming to produce hydrogen, as shown in Fig. 3.

The Haber-Bosch process is currently the main industrial process for the production of (non-renewable) ammonia[8]. The overall process converts nitrogen (N_2) to ammonia (NH_3) through a reaction with hydrogen (H_2) according to the stoichiometric equation below.

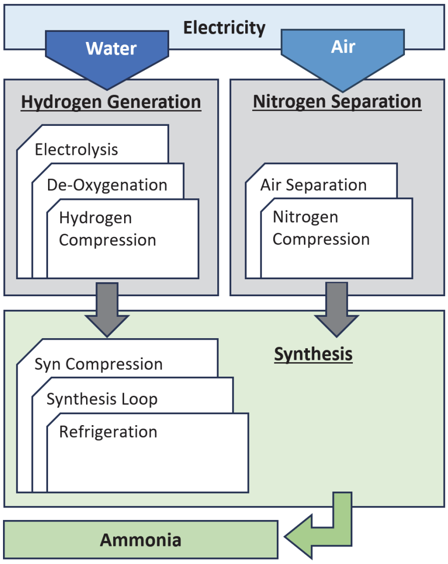

Fig. 3 Electricity-based ammonia production method with the Haber-Bosch process for ammonia synthesis

$$N_2\ (g) + 3H_2(g) \rightarrow 2NH_3\ (g)$$
$$\Delta_f H^\circ = -45.64\ kJ/mol_{NH3}$$

The process requires a catalyst in order to convert the very unreactive nitrogen gas and achieve a viable reaction rate. The catalyst accelerates the scission of the strong triple bond between the nitrogen atoms but requires elevated temperatures and pressures to do so. The second of the equation has fewer moles of gas, therefore an increase of pressure will shift the equilibrium towards conversion of nitrogen and hydrogen to ammonia.

Iron-based catalysts is industrially proven types of catalyst being the most studied and widely applied in ammonia synthesis. Iron-based catalysts include Fe_2O_3 (hematite), Fe_3O_4 (magnetite), and Fe1−xO (wüstite) and have to be promoted with minor quantities of promoter materials such as cobalt.

To obtain nitrogen feed gas for green ammonia production, an air separation device is required to separate the nitrogen from the air. Techniques for this purpose include fractional distillation, cryogenic air separation units (ASU), membrane separation, pressure swing adsorption and vacuum pressure swing adsorption. For the high purity nitrogen gas at the large project scale the cryogenic distillation technique is required, and the other techniques are not typically economic.

Heat integration is key for a cryogenic distillation unit in order to maintain an energy efficient process. The incoming compressed fresh air is pre-cooled with relatively cold gases from the distillation column. A rough estimation of the energy required in the cryogenic ASU is 0.2 kWh/Nm^3 N2 gas. Typical turndown ratio is 40% of design capacity. Due to the use of liquid nitrogen storage which provides a buffer of nitrogen, it is not necessary to operate the ASU at lower turndown rates.

Ammonia storage, either at the ammonia production plant and/or in the export terminal will be required for managing the irregular ammonia production and shipping schemes.

Ammonia can be kept in tanks at either:

- Low pressure (<10 barg) at ambient temperature in a gaseous state;
- High pressure at ambient temperature (30 barg at a maximum of 50° C) in a liquid state;
- Low pressure at low temperatures (atmospheric at -33.3° C) in a liquid state.

The location of the ammonia tanks and the length of the transport pipe can determine the type of the tanks.

3. Integrated Renewable Power-to-Ammonia Facility Configuration

Variations in power, hydrogen, and ammonia production were analyzed as shown in Fig. 4. The electrolyzer plant capacity calculation is driven by an optimization of the mix of renewable energy, BESS, hydrogen storage and ammonia synthesis plant size. The SHARE model implemented takes all of these factors into account for a given plant life, factoring in degradation of key equipment,

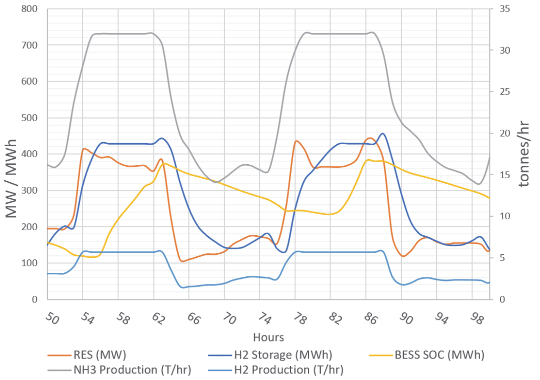

Fig. 4 Hourly time series of the green ammonia production profile

to derive optimal sizing capacity. The SHARE model therefore seeks to optimize the levelized cost of ammonia (LCOA) to the lowest level, for a required production throughput across a project life.

Based on the preliminary modelling, the following key capacities are noted for the HPF and APF:

- 330 MW of electrolysis plant (pressurized alkaline water electrolysis)
- Hydrogen gas buffer storage capacity of 35,000 kg.
- For a nominal annual throughput of 150,000 tonnes per annum of anhydrous ammonia, the design capacity of the ammonia synthesis plant should be approximately 310,000 tonnes per annum (max rate of 850 tonnes/day NH_3).
- Ammonia storage as refrigerated liquid in 2 x 60,000 m^3 storage tanks, considered the minimum to provide redundancy and ensure export ship loading can be completed typically with a single storage tank.

The overall conceptual configuration of an integrated NREC including hydrogen and ammonia production facilities developed in this study can be illustrated by a high-level block flow diagram on the back, as shown in Fig. 5. Different parts of the facility have been segregated in the flowchart for clarity, however in reality, there is significant optionality as to the best location for each facility, but where possible, combining the facilities together as much as possible will yield cost and scale benefits due to shared utilities and reduced operational costs.

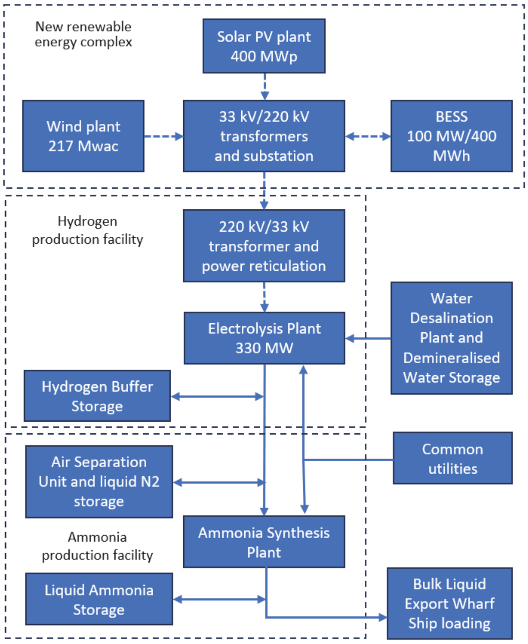

Fig. 5 Block Flow Diagram - Integrated Renewable Power-to-Ammonia Facility Concept

4. Conclusion

In this study, the configuration optimization of a plant to produce 150,000 tonnes of green ammonia per year was performed.

The optimal capacity of each facility was calculated as the minimum capacity of the facility that can maximize the operation rate, considering the volatility of renewable energy. In the optimization, BESS, hydrogen tank, and ammonia tank were considered as buffers to minimize the impact of renewable energy volatility on production, and the optimal storage capacity was calculated through sensitivity analysis.

Selection of a production site is important to ensure economic feasibility for future imports of green ammonia into Korea. The distance between the renewable energy complex and the ammonia production plant should be considered, and further analysis of the distance from the ammonia production plant to the port and pipelines is required.

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