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A PRELIMINARY TECHNO-ECONOMIC ANALYSIS OF POWER TO AMMNONIA PROCESSES USING ALKALINE ELECTROLYSIS AND AIR SEPARATION UNIT

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ABSTRACT

Considerable attention has been given to utilize the redundant renewable energy with its increasing penetration in the overall energy system. The corresponding concept of "power to gas" is actively investigated by changing the power into hydrogen for using it later. Because of its benefit of efficiency and environmentally friendliness, hydrogen is obviously a promising energy source. On the other hand, it costs a lot to store and transport it in practice. It is necessary to transform it into hydrogen-containing materials that is cheap to store and deliver. Alternatively, this paper investigates the case of using ammonia. While the ammonia production processes have been already developed, using it as an energy carrier is a different issue. It should be evaluated in terms of various measures such as economic feasibility, safety, etc. Particularly, this paper investigates the techno-economic feasibility of power to ammonia technology. The overall ammonia production cost is estimated based on the process simulation by using the surplus electricity price. There is much to be done in addition to the current work for the implementation of P2G in practice. The insight obtained in this paper can be a good indicator for the implementation.

Keywords: Power-to-Gas, Renewable energy, Process simulation, Electrolysis, Air separation unit, Ammonia synthesis

NONMENCLATURE

Abbreviations	
ASU	Air Separation Unit
CAPEX	Capital Expenditures
EOS	Equation of State
OPEX	Operational Expenditures
O&M	Operation & Maintenance
P2G	Power to Gas
TPC	Total production cost
Symbols	
G	Gas
K	Kelvin; absolute temperature
K	Kilo(10^3)
l	Liquid
M	Mega(10^6)
W	Watt

1. INTRODUCTION

The climate change has become a global threat that needs to be addressed in the entire economic and social environments. The most obvious change is the replacement of already matured and high efficient fossil fuel based energy systems into renewable sources. However, the renewable energies are not fully competitive. Current technologies are not enough to minimize their side effect. One of the most important ones is that their output is intermittent and subject to variation. Additional solutions such as energy storage system and power to gas should be incorporated to address this.

That is to say, the amount of redundant energy from renewable sources will be increased. It has been generally curtailed and wasted. In order to take advantage of the potential of the redundant energy, the concept of Power to Gas (P2G) has been receiving an increasing attention.

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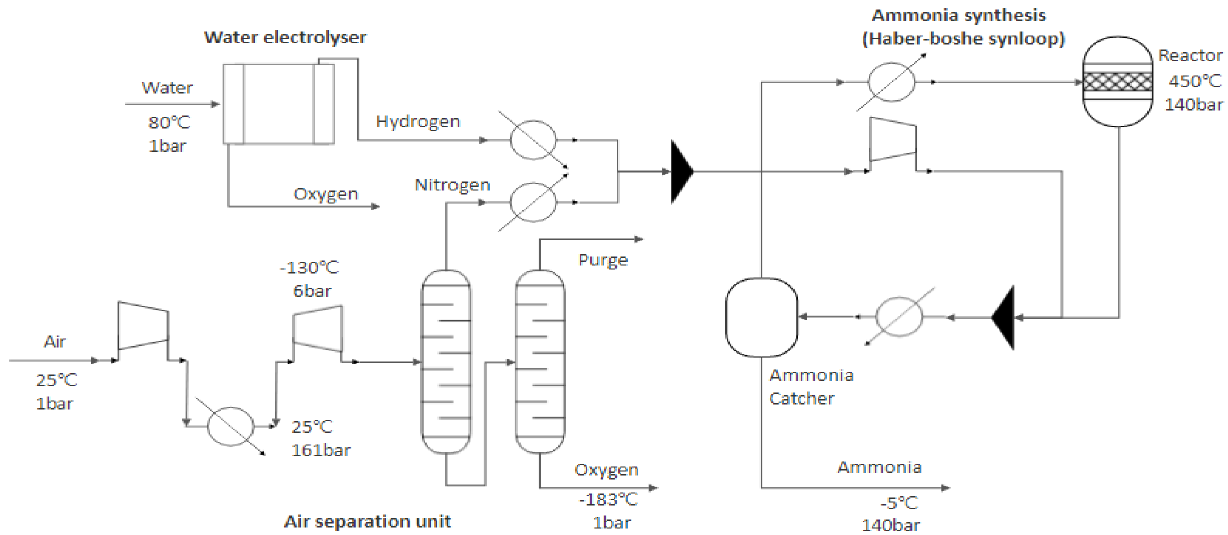

Fig 1. An Illustration of power to ammonia process diagram

It is an option to store energy in a long term by converting electric energy into chemical energy that can be used whenever necessary without much less restriction than energy storage system such as battery.

P2G produces hydrogen mostly through water electrolysis and converts hydrogen into other compounds because it is generally agreed that hydrogen storage for the general energy supply is not desirable at the moment. It mainly converts to hydrocarbon such as methane and formic acid. After being converted, it has the advantage of easy storage and transportation. However, the hydrocarbon has the disadvantage when it is used as an energy source because the carbon dioxide that is the greenhouse gas is discharged.

Therefore, in this study, ammonia is considered as an alternative material instead of hydrocarbons. It has advantage of easy storage and low transportation cost. Also It can be used raw material for fertilizer or it can be used energy source[1]. Compared to other chemicals, the ammonia doesn't discharge carbon in the air when it used for any form. However, the ammonia is hard to synthesis compared to other hydrocarbons. Therefore, the production cost of ammonia will be higher than others.

In the literature, there is little work that explicitly addressed the economic feasibility of the power to ammonia process in the context of energy carrier. In recent, the power to ammonia studies are conducted[2]. However, their studies are focus on the future not a present. It is necessary to evaluate whether power to ammonia process is feasible in present.

To evaluate the feasibility of power to ammonia process, this study aims to present an overall energy supply system consisting of 100MW Electrolyzer, air separation unit(ASU) as summarized in Fig 1. The overall process is evaluated using commercial process simulator, Aspen Plus V10. All of required electricity used for Electrolyzer. is assumed to utilize surplus electricity that is assumed to be generated from renewable energy sources. Finally, the ammonia price according to the surplus electricity change is analyzed through the economical evaluation of whole process.

2. METHODOLOGY

2.1 Process description

In this study, the entire process consists of three parts: water electrolysis, ASU and ammonia synthesis. The first part is hydrogen generation by way of alkaline electrolysis with KOH. In Electrolyzer, water is separated into hydrogen and oxygen. The oxygen is sold as a product and hydrogen is sent to the ammonia synthesis part after cooling process. The second part is ASU to prepare the raw materials for ammonia, nitrogen. The cryogenic distillation is used for producing nitrogen. There are two columns in ASU. The nitrogen is separated from first column and the oxygen is separated from second column. There is no column for separating argon in air. The argon is discharged through the purge stream. The nitrogen is sent to the ammonia synthesis part after heating process. The last part is ammonia synthesis. The most commonly used and well known Haber-Bosch synloop is chosen for ammonia production. In ammonia synthesis part, the product stream returned to reactor after ammonia catcher which separates the ammonia from surplus of reactant. The overall process of power to ammonia (P2A) is shown in Fig. 1.

2.2 *Simulation*

The entire process is simulated by Aspen Plus V10. The thermodynamic method is Peng-Robinson EOS. The mass balance of the entire process is shown in Table 1.

Table 1. Mass balance summary of the presented process

	value
Input	
Air(kg/hr)	*11,586*
Water(kg/hr)	*16,010*
Surplus electricity(kWh)	*100,000*
Output	
Oxygen(kg/hr)	*16,800*
Ammonia(kg/hr)	*7,898*

2.3 *Model*

2.3.1 Alkaline electrolysis

The alkaline electrolysis is suitable for large scale Electrolyzer. The reaction in Electrolyzer is denoted in equation (1). The electrolysis efficiency is assumed to be 70% [3][4]. It consumes 55.8 kW per kilogram hydrogen. The generation amount of hydrogen per hour is about 1,781 kg. The product is assumed to have no impurities in this model. Therefore there is no additional process at the end of electrolysis.

$$H_2O_{(l)} \;\rightarrow\; H_{2(g)} + \frac{1}{2}O_{2(l)} \qquad (1)$$

2.3.2 Air Separation Unit (ASU)

The ASU is used for generating nitrogen. The air price is assumed to be free. The purity and recovery of product nitrogen and oxygen is 99% and 95% respectively. The first column of ASU has 26 stages and 1.33 reflux ratio. The second column of ASU has 40 stages and 6 reflux ratio. Both column are calculated in equilibrium.

2.3.3 Ammonia synthesis

The ammonia is synthesized in Haber-Bosch synloop [5]. The reaction temperature is 723K and the reaction pressure 140bar [5]. The whole reaction in ammonia synthesis reactor is shown in equation (2). The recycle system is selected to prevent waste of raw materials because the ammonia reaction has low conversion. In this model, 3% of product stream is purged. In this process, the ammonia production rate is 189.5ton/day.

$$N_{2(g)} + 3H_{2(g)} \;\rightarrow\; 2NH_{3(g)} \qquad (2)$$

2.4 *Economic analysis*

The economic condition is defined for the power to ammonia plant in Table 2. The O&M cost of electrolysis and ammonia synthesis is CAPEX 2% and CAPEX 4% respectively. The O&M cost in ASU is calculated by Aspen Plus 10.

The CAPEX of the entire process is calculated separately for each process. First, the CAPEX of Electrolyzer is 1,320 $/kW [6]. The scale of water electrolysis in this study is 100MW, therefore the total CAPEX is 132 M$. Second, the CAPEX of ASU is calculated by Aspen plus analyzer is 39M$. Third, the CAPEX of ammonia synthesis is calculated by using economy of scale sizing exponent of 0.65 [5]. Therefore, the CAPEX of ammonia synthesis is 49.9 M$.

Table 2. Economic parameter assumption

Parameter		***value***
Construction period		3 years
O&M cost	Electrolysis	CAPEX of 2%[4]
	ASU	3.3M$
	Ammonia synthesis	CAPEX of 4%[5]
Operation time		8000 hr/year
Depreciation		20 years MACRS
Tax		40%
Plant life		30 years
General inflation		2%

2.5 Results

The ammonia production price according to surplus electricity price have been studied. There are three ammonia cost. The first is OPEX cost of ammonia based on TPC. The second is CAPEX cost of ammonia. The total CAPEX is normalized against the total ammonia production over the plant life in this paper. The third is overall cost of ammonia production which adds the first and second cost. The resulting ammonia costs are summarized in Table 3.

As a results, the production cost of ammonia increase by about 70$/ton when the surplus electricity cost increase by 5$/MWh.

Table 3. Summary of Ammonia costs

Cost	Case				
Surplus electricity cost($/MWh)	20	15	10	5	1
OPEX cost($/ton)	469	398	328	258	201
CAPEX cost($/ton)	123	123	123	123	123
Overall cost of ammonia production($/ton)	592	521	451	381	324

2.6 Discussion

Currently ammonia price in the international market is around $500/ton in 2018[7]. The surplus electricity cost should be lower than 15$/MWh for feasibility of Power-to-Ammonia process. If it is impossible to lower surplus electricity cost, to lower the CAPEX cost is another way.

In this study, it was computed that the CAPEX of Electrolyzer takes about 60% of that of the overall process. Thus, it can be seen that CAPEX of Electrolyzer is key point to get feasibility this process.

3. CONCLUSION

In this study, the economic feasibility of power to ammonia process using Electrolyzer and ASU is investigated. The overall process is simulated by commercial software, Aspen Plus. Finally, the cost of ammonia production is estimated by surplus electricity cost change.

The power to ammonia process is feasible when the surplus electricity cost is below 15$/MWh or CAPEX of Electrolyzer is lower than nowadays. In the future, the use of renewable energy will increase and the CAPEX of Electrolyzer may be lowered due to the development of technology [6]. Thus, the power to ammonia process will be more economically feasible.

The scope of the process is going to be further expanded by incorporating the hydrogen generation from ammonia to evaluate the overall hydrogen cost in the realistic P2G processes. There is much to be developed to take the advantage of renewable energy. More R&Ds on P2G are going to be conducted with the rising concern on climate change. The economic analysis such as the present paper would be given the further attention because its impact on accelerating the introduction of P2G processes in practice.

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