Abstract:

Since mid-2016, the “energy transition policy” has been launched in Taiwan to establish low-carbon, stable and sustainable energy systems, during the next decade. The target of electricity from renewable energy is set as 20%, and the portfolio of natural gas (NG) in electricity generation increases significantly as well. In Taiwan, the price of natural gas is relatively higher than that of coal; moreover, the limited receiving and storage capacity of liquefied natural gas (LNG) poses concern for energy security on the island at present, while commissioning of additional LNG terminals can relieve the situation in the future. Starting from 2014, the costs of fossil fuel keep descending. Especially, the seasonal average prices per mmBtu for LNG drop from $15.51 to ~ $8.5, due partially to massive production of shale gas; nevertheless, the cost of LNG is subject to variation, while the unit price difference between LNG and coal remains around $4.5. The target of electricity out of LNG in 2025 is 50%, ascending from 31.38% in 2015, which means that the safety issue of electricity supply needs to be solved as the usage of natural gas increases greatly. Moreover, lack of long-term LNG contracts might cause deficiency of gas supply and the impact of price fluctuation of LNG on the cost of electricity. Hence, it would be beneficial to convert coal to synthetic natural gas (SNG) that can feed the NGCC units in Taiwan, provided that the SNG price is comparable with that of LNG. This would help stabilize the price of electricity by softening the impact of high and volatile LNG price, and more importantly, it can be of help to alleviate the energy security concern.

The objective of this study is to investigate the performance as well as the pros and cons between integrated and non-integrated SNG plants. Considering the complexity of building an integrated, once-through SNG power plant and the uncertainty of the long-term SNG market in Taiwan, the concept of utilizing a non-integrated approach to produce SNG and power has become attractive for the best interests of various stakeholders (in spite of the lower overall plant efficiency of the non-integrated approach). In Taiwan, there are several other reasons that drive the consideration of pursuing non-integrated systems. First, the long-term need of SNG in Taiwan is not certain. It is risky for investors to make a decision when the future market conditions of SNG are uncertain. Second, making SNG is not the specialty of the government-owned utility company, which prefers to have the flexibility of purchasing either LNG or SNG, whichever is cheaper, under contractual terms, rather than build and operate integrated SNG plants. Third, it is more attractive to investors to build the gasification plant separately from the SNG plant because the syngas market is broader. The fourth reason is related to Taiwan’s future carbon policy. The current trend in Taiwan’s carbon policy involves imposing regulations on coal-fired power plants such that the total CO₂ emissions would be on the same level as NG-fired power plants. However, these regulations would likely not be placed on other industrial plants for a foreseeable future. In this scenario, the non-integrated approach will
be evaluated by the policy as three independent plants, and only the combined power plant will be subjected to the power plant carbon regulations. By using coal-derived SNG as the fuel, the power plant can easily meet the emissions criteria of a NG-fired power plant.

The non-integrated configuration includes three separated systems: a syngas plant, a SNG plant, and a combined cycle plant. In the integrated configuration, different grades of energy are effectively utilized through steam integration and waste heat recovery. The power system can produce the power for internal usage resulting in a higher efficiency for the entire plant. The commercial chemical process simulator, Pro/II® V8.1.1, is used in this study.

Keywords: Clean Coal Technology, Gasification, Synthetic Natural Gas (SNG), Power Plant Performance, Non-integrated SNG production

1. Introduction

Taiwan is an isolated island with a dense population and limited natural resources. At the end of 2016, 97.64% of the energy produced in Taiwan relied on foreign imports. The status of energy demand in Taiwan, by primary energy statistics, consists of 40.80% crude oil, 31.06% coal, 18.46% natural gas, 7.60% nuclear, and 2.09% others, respectively. The portfolio of electricity generation consists of coal (45.44%), gas (32.41%), oil (4.14%), nuclear (11.99%), pumped hydro (1.25%), and renewables (4.77%). It could be expected that the power generated from fossil fuel plants will be increased to cover the imminent shortage of electricity supply in Taiwan due to the pending retirement of three nuclear power plants.

One of the clean energy resources is nature gas (NG). However, lacking indigenous reserves of NG, Taiwan has relied on importing large amount of liquefied nature gas (LNG) to generate electric power or as a feedstock to produce chemicals. The price of LNG in the Asian market is quite expensive; it had been around US$15/MMBtu in the past. Recently, the natural gas (NG) price has significantly reduced due to continuously advancement of hydraulic fracturing (fracking) technology in the United States. Although the spot market price of LNG in Asia has also reduced, the price is still volatile and much higher than coal (per million Btu). Furthermore, major purchases of LNG, used for power generation, has always been based on long-term contracts, so the advantage of short-term low spot market LNG price does not exert a great impact to the local economy in Taiwan. Therefore, for the consideration of reducing long-term energy cost in Taiwan as well as securing diversification of energy resources, utilization of low-priced coal is going to continuously be an important strategy in Taiwan’s energy policy.

Coal gasification is an important technology that can produce not only clean energy from conventional coal resources, but it can also produce various fuels and chemicals. Popular coal-derived fuels include gaseous fuels such as CO, H₂, substitute natural gas (SNG), gaseous methanol as well as liquid fuels such as diesel, jet fuels, and liquid methanol (Figure 1). The coal-derived chemicals, in turn, can be as broad as petroleum-derived chemicals. The most popular coal-derived chemicals are ammonia, urea, dimethyl ether, ethylene, and propylene. Gasification technology becomes more important as environmental policies and regulations are moving toward imposing carbon tax and carbon reduction through carbon capture and sequestration (CCS).

Coal gasification technology can be used to produce synthetic (or substitute) natural gas (SNG) by generating synthesis gas (syngas), followed by converting syngas to SNG using well-developed catalytically methanation process. The purpose of producing SNG is to use it to replace LNG because the energy content and gas composition of SNG can be made very close to that of LNG, and hence, the combustors or reactors and associated operations/controls as well as infrastructures such
as gas transport and storage don't need to alter. This convenience is attractive and warrants the efforts to investigate the feasibility of building SNG plants in Taiwan.

A massive blackout occurred on August 15, 2017 in Taiwan that affected 6.68 million households. Due to human errors during instrumentation overhaul, natural gas supply was disrupted. This incident was compounded by lower than 5% operation margin in Taiwan, resulting in six generators to trip in the largest NGCC power plant in Taiwan. The ripple effect spread to the entire network causing a nationwide blackout with a reduction of 4.2 million kilowatts of power supply. This incident reveals that natural gas supply stability is very important. Therefore, the production of SNG from coal via gasification in this study is a vital possible option to provide an alternative natural gas.

Considering the complexity of building an integrated once-through SNG plant and the uncertainty of long-term SNG market in Taiwan, the concept of utilizing non-integrated approach to produce SNG for power generation has become attractive for the best interests of various stakeholders. An integrated SNG plant typically consists of three components: a syngas production plant, a SNG conversion plant, and a power plant. The integration among these three systems typically is implemented through thermodynamic, mechanical, and electrical processes. The goal of thermodynamic integration is to efficiently utilize different grades of energy for processing heats and layout smart networks for recovering waste heats. For example, the high-temperature and high-pressure steam generated in the syngas cooling process immediately at the exit of gasifier can be used to feed the high-pressure steam for the steam turbine. The heat generated from the WGS reactor can be used to generate steam for use in the low pressure steam turbine. Mechanical integration, for example, can be accomplished by extracting high-pressure air at exit of the compressor of the gas turbine and sending it to the gasifier to save the compression power of the ASU unit. The power generated by the power plant can be used for all the auxiliary power consumptions. On one hand, the advantage of integration is that it augments the overall thermal cycle efficiency several percentage points; the drawbacks are integration makes the overall plant more complex to build and operate, and inevitably adversely affects the availability and reliability of the plant.

To avoid the above issues related to an integrated system, consideration of using a non-integrated system becomes attractive, even though the overall plant efficiency will be lower. In Taiwan, there are several other reasons that drive the consideration of pursuing non-integrated systems. First, the long-term need of SNG in Taiwan is not certain. It is risky for investors to make a decision when future market of SNG is uncertain. Second, making SNG is not the specialty of the government-owned power company, which prefers having the flexibility of purchasing either LNG or SNG, whichever is cheaper, under contractual terms than building integrated gasification combined cycle (IGCC) plants or building integrated SNG plants to supply the fuel for the existing LNG fired combined cycle power plants. Third, for financial consideration, it is more attractive to banks, alternate financial institutes or investors to build a gasification plant dedicated to producing only syngas separately from the SNG plant because the market for syngas is broader than SNG. The syngas can also be sold as a fuel for any new power plant built specifically for burning syngas, which is cheaper than SNG. It can also be sold as a fuel for heat production in boilers for different industries or as a feedstock for producing value-added hydrogen or other chemicals. An investment in non-integrated SNG plants also diversifies the risks if the SNG market tanks. Using coal gasification to produce different products, called “polygeneration”, rather than just one product, SNG is a more favorable forward-thinking approach because it increases the profits, broadens the market, and reduces risks.

There is another reason for considering a non-integrated system—this is related to Taiwan’s future carbon policy. The current trend in Taiwan’s carbon policy tends to imposing stringent CO₂ emission regulations only upon coal-fired power plants but not on other industrial plants. In this scenario, the non-integrated approach will be evaluated as three independent plants, and only the
combined power plant will be subjected to the new power plant carbon regulations. By using syngas or SNG as the fuel, the power plant can easily meet the emission criteria of a NG-fired power plant, while the burden of reducing carbon emission are left to the gasification plant which is subject to the emission regulations of a chemical plant. On the other hand, the process of CCS is more in line with the specialty of a gasification or SNG plant as a chemical processing plant than with a power generation plant.

Considering the aforementioned reasons, the objective of this study is to investigate the performance as well as the pros and cons between an integrated and non-integrated SNG plant with the application of supplying SNG for power generation in a combined cycle plant.

![Diagram of Products derived from gasifying coal or any carbon source](DoE/NETL, 2015)

### Figure 1: Products that can be derived from gasifying coal or any carbon source

#### 2. Process Description

The commercial chemical process simulator, Pro/II® V8.1.1, is used in this study to build the analysis model. The overall process of employing coal gasification to produce SNG for fueling a combined power plant to produce electricity consists of three major sections as shown in Fig. 2: a coal gasification plant to produce syngas, a SNG plant to convert syngas to customer-specified SNG, and a combined cycle plant to produce electricity.
2.1 Specifications for the simulated system

This study is benchmarked with Case 1 SNG plants without CCS in Volume 2 of DOE report (NETL, 2011). The key specifications are summarized as follows:

- Oxygen-blown gasifier technology: Siemens
- Oxidant from the air separation unit (ASU): 99 vol% Oxygen
- Coal: Illinois No. 6
- Coal Feed Rate: 10,502 tonne/day
- COS Hydrolysis Reactor: 99.5 percent conversion of the COS
- Water Gas Shift Reactor: the ratio of H$_2$/CO in syngas needs to be 3:1
- Acid Gas Removal Process: Two Stage Selexol
- Steam Cycle with reheat: 12.4 MPa/839.15K/807.15K
- Methanation System: Based on Haldor Topsoe TREMP™ Process

2.2 Coal gasification syngas plant

2.2.1 Gasification island

Gasification reaction is a partial-oxidation reaction, which can convert solid fuel to gas fuel with a useable heating value. A gasifier operates at a high temperature typically in the range of 1,073K to 2,073K. The exact temperature depends on the type of the gasifier, characteristics of the feedstock, and operation conditions (Higman and Burgt, 2003). The main non-inert compositions of syngas in the gasification reaction are H$_2$ and CO. There are three major reaction equations for gasification, which are listed as follows. Equations (1) and (2) are endothermic gasification reactions, to which the heat is supplied from pyrolysis. Equation (3) is the CO shift reaction that can be manipulated to produce a specific ratio of H$_2$ and CO in the syngas for various downstream needs.
\[
\begin{align*}
\text{C} + \text{CO}_2 & \rightarrow 2 \text{CO} & \Delta h^0_r = 167 \text{ kJ/mol} \\
\text{C} + \text{H}_2\text{O} & \rightarrow \text{CO} + \text{H}_2 & \Delta h^0_r = 125.4 \text{ kJ/mol} \\
\text{CO} + \text{H}_2\text{O} & \rightarrow \text{CO}_2 + \text{H}_2 & \Delta h^0_r = -42 \text{ kJ/mol}
\end{align*}
\]

where $\Delta h^0_r$ is the heat of reaction at standard temperature (298K) and pressure (1 atm).

The Gibbs reactor (Chen et al., 2013; Syed et al., 2012) is used to simulate the gasification process in the Siemens entrained-flow gasifier operating at 4.24MPa and 1772K. The inputs are coal, steam, and 99% purity oxygen produced from ASU. To fit in with the input condition of Pro II, the compositions of coal are divided into three streams consisting of carbon content, ash, and other elements. A component “mixer” is then used to merge these three streams into a single stream. The outputs are the raw syngas and the slag. The raw syngas is cooled down through a quick water quench, followed by convective cooling via three heat exchangers to 533K. The heat recovered from these three heat exchangers is used to generate high-pressure (HP) superheated steam from the feed water to 12.4MPa/839K and to reheat intermediate pressure (IP) steam exhausted from the HP steam turbine to 3.4MPa/807K. The simulation model is shown in Fig. 3.

![Process flow diagram of oxygen-blown gasification unit followed by water quench and convective syngas cooling via three heat recovery heat exchangers.](image)

**Figure 3: Process flow diagram of oxygen-blown gasification unit followed by water quench and convective syngas cooling via three heat recovery heat exchangers.**

### 2.2.2 Gas clean-up unit

Acid gas removal process consists of COS hydrolysis, water-gas shift, two-stage Selexol Process, and sulfur recovery processes. The COS hydrolysis converts COS to H$_2$S following the reaction below:

\[
\text{COS} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2\text{S}
\]

Due to the reaction being exothermic, COS conversion is operated under low temperature at 488K. Since the ratio of H$_2$/CO needs to be 3:1 to meet the requirement for methanation process, water-gas shift reaction is used to adjust the syngas composition to meet this specific ratio. The water-gas shift reaction equation is shown as follows:

\[
\text{CO} + \text{H}_2\text{O} \leftrightarrow \text{CO}_2 + \text{H}_2
\]

The simulation model of COS hydrolysis and water-gas reaction is shown in Fig. 4.
Figure 4: Process flow diagram of COS hydrolysis and water-gas reaction unit

Figure 5 shows the simulation model of the two-stage Selexol process. The Selexol solvent is a mixture of dimethyl ethers of polyethylene glycols. The raw syngas is fed into the H$_2$S absorber to remove H$_2$S, and then it flows into CO$_2$ absorber to remove CO$_2$. The solvent is introduced to stripper column to regenerate the solvent. Clean syngas will feed into the SNG plant.

Figure 5: Process flow diagram of the 2-stage Selexol process
2.3 SNG plant

Methanation is a process to generate methane from the hydrogenation of carbon monoxide. Methanation has generally been used for years in the final purification step in an ammonia plant or hydrogen plant. For SNG production, the methanation process operates at a different level due to the higher content of CO and CO$_2$. Ruthenium, cobalt, nickel and iron are the main catalysts used for this reaction (Mills et al., 1974). The methanation reactions are exothermic and follow the two reactions below:

\[
\begin{align*}
\text{CO} + 3\text{H}_2 & \leftrightarrow \text{CH}_4 + \text{H}_2\text{O} \quad \Delta h^0_r = -206 \text{ kJ/mol} \quad (6) \\
\text{CO}_2 + 4\text{H}_2 & \leftrightarrow \text{CH}_4 + 2\text{H}_2\text{O} \quad \Delta h^0_r = -165 \text{ kJ/mol} \quad (7)
\end{align*}
\]

The methanation system used in this study is based on the TREMP™ Process which is developed by Haldor Topsoe (Li et al., 2014). To achieve high methane content, the major reaction to form methane is based on CO and H$_2$, and the stoichiometric ratio between H$_2$ and CO is 3 (Jensen et al., 2011).

After the gas clean-up unit, the syngas is delivered to the methanation processes. Three reactors and six heat exchangers are built in the model as shown in Fig. 6. The syngas from the Selexol unit is first heated in a pre-heater to 573.15K, and then, it flows into the first reactor. Due to the methanation reaction being exothermic, the flow exiting the reactor is cooled down by a heat exchanger. A part of the product gas is recycled back to the first reactor to maintain the operating temperature at a setting value. The heat released from the methanation process is recovered to generate superheated steam for producing power in the steam turbine.
3. Results and Discussions

Considering the purpose of this study is to replace LNG with SNG for the existing LNG-fired combined cycle power plants, the analysis of this study is focused on the comparison between integrated and non-integrated SNG plants. The current IGCC systems without CCS are using syngas (not SNG) to fuel the combined cycle power plant. Comparison between integrated and non-integrated IGCC systems is more complex and is left for future study. The first step of the analysis is to validate the model built by this study against a well established reference. Case 1 of Volume 2 of a DOE report (NETL, 2001) is selected for validating the current model.

3.1 Validation of integrated SNG plant

Table 1 shows the stream properties and comparison between the results from the simulation model built in this study with the reference data from the DOE report (NETL, 2001). The simulation results show the raw syngas contains 22.13% H₂, 40.62% CO, the clean syngas contains 71.51% H₂, 23.78% CO and the SNG contains 80.92% CH₄. The comparison shows the difference between the
results of this study are within 3% of the reference data. This indicates the simulation model built in this study for an integrated SNG plant is appropriate for further analysis of a non-integrated SNG plant.

Table 1. Stream Properties of the simulated results

<table>
<thead>
<tr>
<th></th>
<th>Raw Syngas</th>
<th>Clean Syngas</th>
<th>SNG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Simulation</td>
<td>Reference</td>
<td>Simulation</td>
</tr>
<tr>
<td>Temperature, K</td>
<td>532.98</td>
<td>533.15</td>
<td>302.00</td>
</tr>
<tr>
<td>Pressure, BAR</td>
<td>38.89</td>
<td>38.90</td>
<td>32.77</td>
</tr>
<tr>
<td>Flowrate, kmole/hr</td>
<td>53,378.55</td>
<td>53,959.00</td>
<td>35,240.60</td>
</tr>
<tr>
<td>Composition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂</td>
<td>0.2213</td>
<td>0.2001</td>
<td>0.7151</td>
</tr>
<tr>
<td>CO</td>
<td>0.4062</td>
<td>0.4228</td>
<td>0.2378</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.0263</td>
<td>0.0380</td>
<td>0.0368</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>H₂O</td>
<td>0.3335</td>
<td>0.3261</td>
<td>0.0002</td>
</tr>
<tr>
<td>N₂</td>
<td>0.0037</td>
<td>0.0046</td>
<td>0.0069</td>
</tr>
<tr>
<td>Ar</td>
<td>0.0019</td>
<td>0.0019</td>
<td>0.0029</td>
</tr>
<tr>
<td>H₂S</td>
<td>0.0058</td>
<td>0.0058</td>
<td>0.0000</td>
</tr>
<tr>
<td>COS</td>
<td>0.0006</td>
<td>0.0005</td>
<td>0.0001</td>
</tr>
<tr>
<td>HCl</td>
<td>0.0007</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

3.2 Model of non-integrated SNG plant

Based on the integrated SNG plant, the first step to "disintegrate" the gasification plant from the SNG plant is to draw the boundaries of each plant as shown in Fig. 2, followed by cutting loose the stream lines that cross the boundaries. It is discovered that the integration process has been largely applied on recovering reaction/process heat through steam generation.

Figure 7 shows the flow diagram of heat integration. In the gasification unit, the raw syngas is cooled down from 1316K to 533.15K for COS hydrolysis. The released heat is 413.94 MW which can generate superheated steam and reheat intermediate pressure steam to generate power. In the COS hydrolysis and water-gas shift reactions, the released heat is 406.34 MW, which is recovered by preheating the syngas in the SNG plant and generate steam to steam turbine. In the SNG plant, 92.86 MW of heat is needed to first preheat syngas fed into the first methanation reactor. The methanation process is exothermic, releasing approximately 328.17 MW of heat to generate steam to drive the steam turbine. In the steam turbine, part of the steam (67.70 MW) extracted from the IP steam turbine exit is routed to the reboiler of Selexol unit to drive out H₂S from the adsorbents. The condensate from steam turbine is routed to the Selexol unit to cool the acid gas, recovering about 103.13 MW of the heat. The cooled acid gas is sent to the Clause plant to recover sulfur in the elemental form.
Figure 7: Process flow diagram of heat integration of the studied integrated SNG plant

The streams of aforementioned heat integration are cut off at the boundaries of each plant (See Fig. 2) with the steam turbine being included as a part of the gasification island. Please note that this steam turbine system is not the same steam turbine system as in the standalone combined cycle power plant as shown in Fig. 2. Rather, it is a necessary component in the gasification island to produce electricity by utilizing mainly the process heats from the syngas cooling and WGS process but without receiving heat from the methanation process in the non-integrated system.

Table 2 shows the performance summary of integrated and non-integrated configuration cases. The steam turbine power is 287.96 MW for the integrated case and 217.37 MW for the non-integrated case, respectively. This difference is calculated as the loss of steam supply from the SNG plant based on a steam turbine efficiency of 30%. The efficiency of coal gasification syngas plant is defined as the ratio of higher heating value (HHV) of the syngas plus power generated over the HHV of coal. The efficiency of the two cases are 89.60% for the integrated case and 87.46% for the integrated case, respectively.

The efficiency of a SNG plant is defined as the ratio of HHV of SNG over that of syngas. The efficiency in two cases are 76.17% (integrated) and 72.69% (non-integrated), respectively. The SNG plant needs 92.86 MW of energy to preheat the syngas; therefore, the plant needs to generate this preheat energy at its own facility. The thermal (mainly steam) output of the stand-alone SNG plant is reduced from 328.17 MW produced during the methanation process for internal power generation in the integrated case to 235.31 MW in the non-integrated case. This excess of steam energy can be sold to the standalone gasification island or to other industries.
Table 2. Comparison between the integrated and non-integrated SNG plants

<table>
<thead>
<tr>
<th></th>
<th>Integrated Case</th>
<th>Non-Integrated Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Feed Flow Rate, kg/hr</td>
<td>437,604.00</td>
<td>437,604.00</td>
</tr>
<tr>
<td>Thermal Energy of Feedstock, MWth (Based on Coal HHV) (A)</td>
<td>3,298.44</td>
<td>3,298.44</td>
</tr>
<tr>
<td>Syngas Production Rate, kg/hr</td>
<td>353,343.67</td>
<td>353,343.67</td>
</tr>
<tr>
<td>Syngas Production, MWth (B)</td>
<td>2,667.41</td>
<td>2,667.41</td>
</tr>
<tr>
<td>SNG Production Rate, kg/hr</td>
<td>195,711.09</td>
<td>195,711.09</td>
</tr>
<tr>
<td>SNG Production, MWth (C)</td>
<td>2,031.75</td>
<td>2,031.75</td>
</tr>
<tr>
<td>Heat released from SNG plant, MWth</td>
<td>328.17</td>
<td>328.17</td>
</tr>
<tr>
<td>Heat needed of SNG plant, MWth</td>
<td>92.86</td>
<td>92.86</td>
</tr>
<tr>
<td>Net Heat released from SNG plant, MWth</td>
<td>235.31</td>
<td>235.31</td>
</tr>
<tr>
<td>Steam Turbine Power¹, MWth (D)</td>
<td>287.96</td>
<td>217.37</td>
</tr>
<tr>
<td>Efficiency of Coal Gasification Syngas Plant ((HHV_{syngas}+Power)/HHV_{coal},%) ((B+D)/A \times100)</td>
<td>89.60</td>
<td>87.46</td>
</tr>
<tr>
<td>Efficiency of SNG Plant (HHV_{SNG}/HHV_{syngas},%) ((C/B \times100))</td>
<td>76.17</td>
<td>72.69</td>
</tr>
<tr>
<td>Coal to SNG Conversion Efficiency (HHV_{SNG}/HHV_{coal},%) ((C/A \times100))</td>
<td>61.60</td>
<td>N/A</td>
</tr>
<tr>
<td>Extra Energy of SNG Plant, MWth</td>
<td>Internal Use</td>
<td>235.31</td>
</tr>
</tbody>
</table>

¹Thanks to the steam turbine being included in the coal gasification syngas plant, the part of electricity generated from the steam supplied from the methanation process is taken out from the non-integrated case based on a 30% steam turbine thermal efficiency.

4. Conclusions:

Considering the pending retirement of 5,028 MWe generation power from three existing nuclear power plants and strong public opinion against building any new nuclear power plants in the future, using affordable alternative clean energy sources to replace these retiring nuclear power plants is an urgent issue that has been subject to heated discussion in this island country of meager natural resources. One option is to increase the capacity of LNG-fired combined power plants. However, due to the high LNG cost in Taiwan, consideration has been given to employing a clean coal technology to generate electricity either using IGCC technology or producing SNG through coal gasification and feed the SNG to the combined cycle power plants.

Since there is no commercially operated coal gasification facility in Taiwan, concerns have been raised on the complexity of financing, building, and operation of an IGCC or an integrated SNG-combined power system. Therefore, consideration is further given into building non-integrated
SNG-combined power system. Furthermore, there are several other reasons that drive the consideration of pursuing non-integrated systems in Taiwan. First, the CO$_2$ emission regulation is more stringent on power plants than in other industries. Second, the long-term need of SNG in Taiwan is not certain. Third, making SNG is not the specialty of the government-owned utility company. The fourth reason is that syngas has broader market, so it is more attractive to investors to build the gasification plant.

To help analyze the technology difference between an integrated and non-integrated SNG system, this study has employed Pro II commercial software as a tool to build an integrated SNG system. The result of the integrated case has been first validated through comparison with a sample case in a U.S. DOE report.

The non-integrated configuration includes three separated systems: a syngas plant, a SNG plant, and a combined cycle plant. In the integrated configuration, different grades of energy are effectively utilized through steam integration and waste heat recovery, and the power system can produce the power for internal usage, resulting in a higher SNG production efficiency (76.17%) than 72.69% of the non-integrated SNG plant. The non-integrated case can produce process steam equivalent of 235.31 MWt that can then be sold.

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