SCIENTIFIC CONTRIBUTIONS OIL AND GAS
Vol. 41, Number 1, April 2018: 5 of 5
RESEARCH AND DEVELOPMENT CENTRE FOR OIL & GAS TECHNOLOGY
LEMIGAS
Journal Homepage:http://www.journal.lemigas.esdm.go.id
ISSN: 2089-3361, e-ISSN: 2541-0520

CONVERSION OF CO_2 TO HYDROCARBON SYNFUEL BY UTILIZING NUCLEAR HYDROGEN COGENERATION

APLIKASI KOGENERASI HIDROGEN NUKLIR UNTUK KONVERSI CO_2 MENJADI BAHAN BAKAR SINTETIS HIDOKARBON.

Djati H Salimy
Center for Nuclear Reactor Technology and Safety (PTKRN)
National Nuclear Energy Agency of Indonesia (BATAN)
Puspiptek Area Serpong Tangerang Selatan 15310 Indonesia
Email: djatihs@batan.go.id

First Registered on November 11th 2017; Received after Correction on April 19th 2018
Publication Approval on: April 30th2018

ABSTRAK

Telah dilakukan studi pemanfaatan kogenerasi hidrogen dengan energi nuklir sebagai teknologi kunci untuk proses konversi CO_2 menjadi bahan bakar cair sintetis hidrokarbon. Tujuan studi adalah untuk memahami konversi CO_2 dan H_2 menjadi bahan bakar sintetis, serta peran kogenerasi hidrogen nuklir untuk produksi hidrogen dan sebagai sumber energi panas proses. Metode yang digunakan adalah studi pustaka berdasarkan hasil penelitian yang sudah ada. Secara konvensional, produksi bahan bakar sintetis dari batubara diproduksi melalui proses gasifikasi batubara, dilanjutkan dengan mereaksikan gas sintesis (campuran CO dan H_2) dalam reaktor Fischer-Tropsch menjadi bahan bakar sintesis. Dalam studi ini, dipelajari produksi bahan bakar sintetis dengan bahan baku CO_2 dan H_2. CO_2 berasal dari emisi pembangkit berbahan bakar batubara, sedangkan H_2 dihasilkan dengan sistem kogenerasi hidrogen nuklir. Hasil kajian menunjukkan bahwa dibanding proses konvensional, proses berbasis CO_2 dan H_2 dengan didukung sistem kogenerasi memberikan keuntungan yang sangat signifikan dari sisi emisi CO_2. Proses berbasis gasifikasi batubara dan kogenerasi nuklir, mampu menurunkan emisi sampai 75% dan menghemat konsumsi batubara sampai 40%. Sedang proses hanya berbasis CO_2 dan H_2 kogenerasi nuklir tanpa batubara, sama sekali tidak mengemisi CO_2 bahkan dapat memanfaatkan emisi CO_2 pembangkit listrik batubara sebagai bahan baku proses.

Kata Kunci: *sistem kogenerasi nuklir, konversi CO_2, emisi CO_2, bahan bakar sintetis*

ABSTRACT

A study of the utilization of hydrogen cogeneration with nuclear energy as a technology for the conversion of CO_2 into synthetic liquid hydrocarbon fuels has been carried out. The aim of the study is to understand the conversion of CO_2 and H_2 into synthetic fuels, as well as the role of nuclear hydrogen cogeneration for the production of hydrogen and as a source of process heat energy. The method used is literature study based on the results of existing research. Conventionally, synthetic fuel production from coal is produced through coal gasification process, followed by reacting synthesis gas (mixture of CO and H_2) in FT reactor to synthesis fuel. In this study, we studied the production of synthetic fuels with CO_2 and H_2 raw materials. CO_2 comes from emissions of coal-fired plants, whereas H_2 is produced by nuclear hydrogen cogeneration systems. The results show that compared to conventional processes, CO_2 and H_2-based processes supported by coal cogeneration systems provide significant advantages in terms of CO_2 emissions. The process based on coal gasification and nuclear cogeneration, capable of reducing emissions by up to 75% and saving up to 40% of coal consumption. While the process based only on CO_2

and nuclear hydrogen cogeneration (without coal gasification), teoretically can operate witout any CO_2 emission at all. Even this process can captured and utilize CO_2 emissions from coal fired plant, and use it as a raw material for the process.

Keywords: nuclear cogeneration system, CO_2 conversion, CO_2 emission, synfuel

How to cite this article:

Salimy, D.H., 1, 2018, CONVERSION OF CO2 TO HYDROCARBON SYNFUEL BY UTILIZING NUCLEAR HYDROGEN COGENERATION, *Scientific contributions Oil and Gas*, 41 (1) pp, 51-59
DOI: 10.29017/SCOG. 41.1.51-59.

I. INTRODUCTION

Cuurently, fossil fuels are still the primary energy source of the earth's surface, although it has since long been recognized fossil fuels are not renewable materials and a time will run out. Among fossil fuels, liquid type fuel is the fuel most used primarily for the transportation sector. Due to the pace of demand always exceeds the production rate, various means are used to meet the very high demand. Converting solid form of energy source (coal) to liquid (petrol, diesel) is an alternative to support the supply demand continues to increase.

Conventionally, synfuel can be made by converting coal (Patzek 2009; Xu et al. 2013). In principle, the production begins with the coal gasification process to produce syngas, a mixture of CO and H_2. Then the Fischer-Tropsch (F-T) process, can produce a variety of products derived, one of them is hydrocarbon synfuels. In the conventional process, either CO, or CO_2 and H_2 are produced from the coal gasification process as an intermediate product before converting them to synfuels. In several decades, the process was carried out by reacting H_2 and CO_2 originating from the outside of the system. CO_2 emissions can be obtained from industrial or power plants, which is abundant and to date become the problem because it is a greenhouse gas that is damaging to the environment. While the H_2 can be produced from the decomposition of water, electrolysis or steam reforming of natural gas.

Nuclear cogeneration for the decomposition of water is thermochemical hydrogen production process by utilizing nuclear energy as a source of heat energy to run the process (Merajin et al. 2014; Borgard & Tabarant 2011). Among the decomposition of water by nuclear, process with iodine-sulfur cycle is relatively advanced R & D process. The process was originally developed by General Atomic in America in 1970, then adopted and developed by several countries such as Japan, Germany, China, France, and South Korea. In addition, the United States, and South Africa are also developing a hybrid process cycle of sulfur to produce hydrogen with nuclear energy. Hybrid process is combination of electrolysis and thermochemical processes. Nuclear cogeneration system is also used to develop high-temperature electrolysis process, which is believed to generate hydrogen with better thermal efficiency.

The issue of global warming induced by CO_2 emissions has become a global issue that is increasingly important in the world and is considered as the main cause of climate change and the negative impact on human life. One of the technologies used are carbon capture and storage technologies are often referred to as Carbon Capture and Storage (CCS). In principle, the CCS technology is to capture emissions out of the emission sources (plant or power plant), to separate CO_2 from other gases, and then transporting and storing the CO_2 to CO_2storage (Hong et al. 2015).

Since several decades, CCS technology developed to the technology Carbon Capture and utilization (CCU) (Yan at al. 2014). In the CCU technology, the captured CO_2 will be used as industrial raw materials. In this way, beside getting the the advantages obtained in the form of decreasing the rate of emission of CO_2, the process also obtained added value from the use of CO_2 for industrial processes.

This paper discusses the process prodution of liquid hydrocarbon synfuel from H_2 and CO_2, by utilizing nuclear as a heat source, because it is believed that nuclear energy to an important source of heat energy to produce hydrogen. While the use of CO_2 as a raw material becomes an important part solution addressing greenhouse gas emissions. Conventional processes based on coal gasification technology is used as a benchmark, to analyze the positive aspects of the alternative process in terms of environmental issue.

II. METHODOLOGY

Nuclear Cogeneration for Co_2 Conversion to Hydrocarbon Synfuel

This chapter describes an alternatif technology to produce hydrocarbon synfuel from CO_2 and H_2. An assumption used is that H_2 obtained from the process of nuclear water splitting, while CO_2 come from emission from coal filred plant. The conventional technologi of hydrocarbon synfuel production is used as comparison.

A. Nuclear Hydrogen Cogeneration

Cogeneration, also known as combined heat and power (CHP), is very efficient, clean, and reliable approach to generate power and thermal energy from a single fuel source (Khamis 2013). Countries embarking on nuclear power should consider co-generation and the use of waste heat from a nuclear power plant (NPP) to increase energy utilization and overall efficiency. In a number of countries, co-generation and heat production using nuclear reactors is an effective way to meet the variety types of energy needs. Currently, there are 79 reactors operating the cogeneration mode. In addition, is the potential for applying this technology more widely promising (Hong et al. 2015). Heat applications cover a wide range of specific temperature requirements starting from low temperatures i.e., just above room temperature for applications such as hot water and steam for agro-industry, district heating, and sea water desalination; reaching more than 1000°C for process steam and heat applications i.e., for chemical industry and high-pressure injection steam, enhanced oil recovery, oil shale and oil sand processing, oil refinery, refinement of coal and lignite, and water splitting for the production of hydrogen. With the rapid increase in energy demand (for both electricity and heat), concern over global warming could pave the way for nuclear energy to exert a major positive impact on energy security and climate change.

The R & D of nuclear water splitting to produce hydrogen from water has been developed very intensively in the developed countries. One of the promising process is the process of water splitting thermochemical iodine-sulfur cycle (IAEA 2012; Noguchi et al. 2016). The process was originally developed by General Atomics in America in the 1970s. The technique then adopted and developed by several countries such as Japan, Germany, China, France, and South Korea. The other process is hybrid process that known as sulfur cycle developed by Westhinghouse (IAEA 2013). The hybride process is the combination between thermochemical and elec-trolysis. This process was also developed intensively in South Africa (Botha 2012; Telsnig et al. 2013).

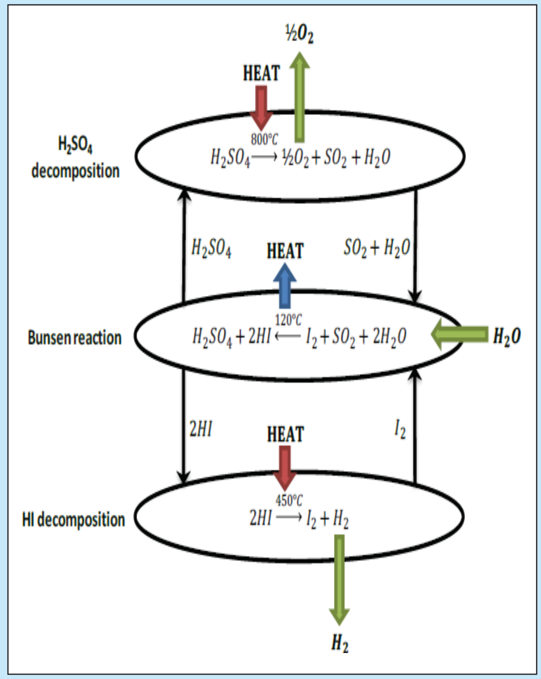

Figure 1
The sulphur Iodine cycle (Botha, 2012).

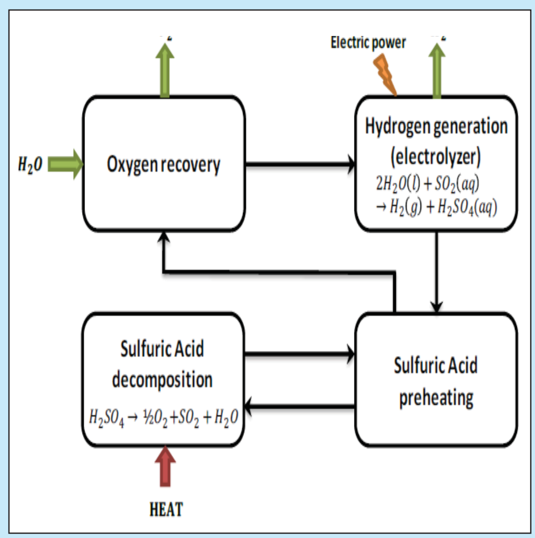

Figure 2
The hybride sulphur cycle (Botha, 2012).

The sulphur-iodine (SI) cycle consists of three steps, as shown in Figure 1. The second step occurs at 800°C and requires the addition of heat. The High Temperature Gas-cooled Reactor (HTGR) is the only one type of nuclear reactor that have capability to supply energy at thus temperature (Khamis et al. 2013; Verfondern et al. 2017).

The Hybrid Sulphur (HyS) cycle, is the combination of thermal and electricity processes. The HyS cycle is shown in Figure 1. Consists of 2 steps, in the first step, water and sulphur dioxide is electrolysed at around 87°C to produce hydrogen and sulphuric acid. The second step is the decomposition of sulphuric acid into sulphur dioxide, steam and oxygen at around 800°C. Optimisation studies suggested that thermo-dynamic efficiency for the HyS cycle of 47% is possible by using a temperature of 930°C and 10 bar pressure in the decomposition step (Botha 2012; Chiuta 2010). Again, HTGR is the only one type of nuclear reactor that have capability to supply energy at thus temperature.

B. Capture and Utilization of CO_2

The emergence of the concept of CO_2 captured and storage (CCS) as a potentially viable technology for the reduction of greenhouse gas emissions (GHG) emissions in the world have spawned a parallel interest in the concept known as the CO_2 captured and utilization (CCU) [16]. In contrast to the CCS which only mitigate, CCU seeks to convert CO_2 on a large scale into value-added products. In other words, CO_2 is not to be stored or mitigate but used as raw materials. In spite of carbon dioxide is considered to be a thermodynamically and chemically stable molecule under standard conditions, it can react with other chemical feedstocks given sufficient energy or using a catalyst to produce value added commodity chemicals (Aresta et al. 2013) and fuels (Jiang 2010).

In principle, the CCS is technology to capture and separate CO_2 from other gases, and then transported to another place to be stored in the stable geological disposal (Telsnig et al. 2013; Li et al. 2013). While, in the CCU technology, captured CO_2 will be used as raw materials for industries. In this way, beside the advantages of a decreasing the rate of CO_2 emissions, also obtained added value of CO_2 as raw materials. Some industries that use CO_2 as the raw material become the target of this program.

The concept of CO_2-recycled synthetic hydrocarbon fuels is not new. Likely spurred by the oil crisis of the 1970s, Steinberg and Dang first envisioned the closed-loop version of CO_2-recycled synthetic fuels with CO_2 captured from ambient air. In a series of journal articles and patents, they explored various options to capture CO_2 from the atmosphere using hydroxide or carbonate absorbents, produce H2 by water electrolysis, and synthesize methanol by reaction of the CO_2 with H_2, with nuclear fission or fusion supplying the electricity and heat (Graves 2010).

Figure 3 shows the possible pathways of CO_2 and H_2O utilization as raw materials for producing synfuel. This concept is interesting because it is

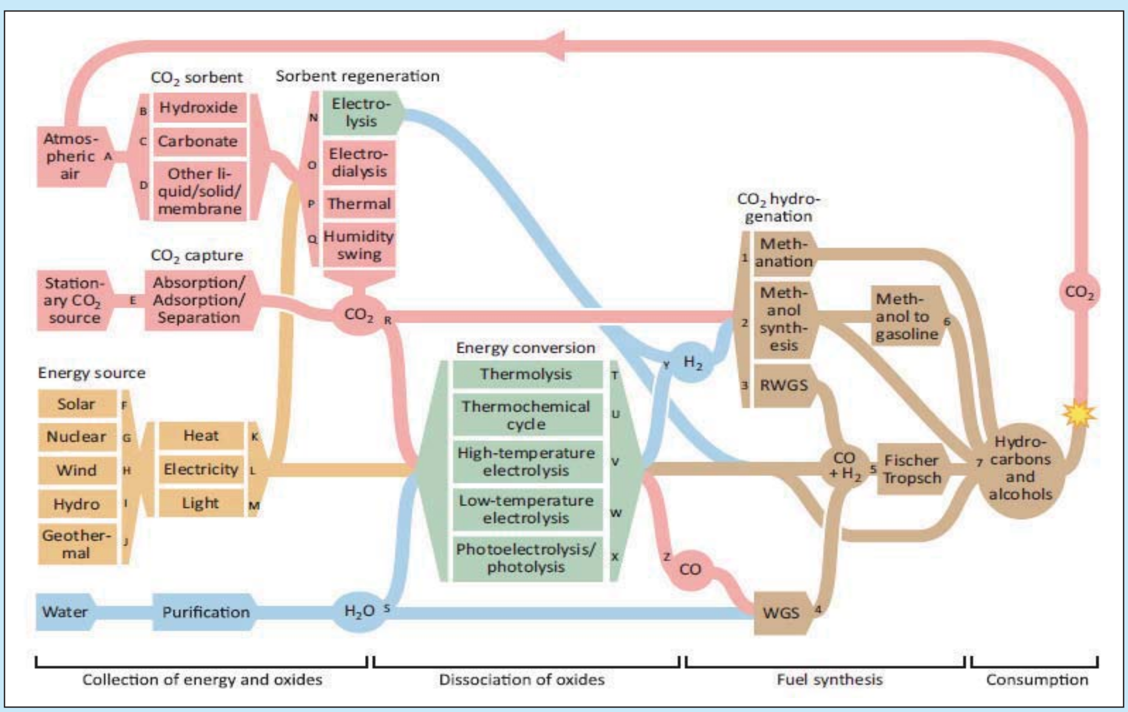

Figure 3
Map of the possible pathways from H_2O to CO_2 to hydrocarbon synfuels (Graves, 2010).

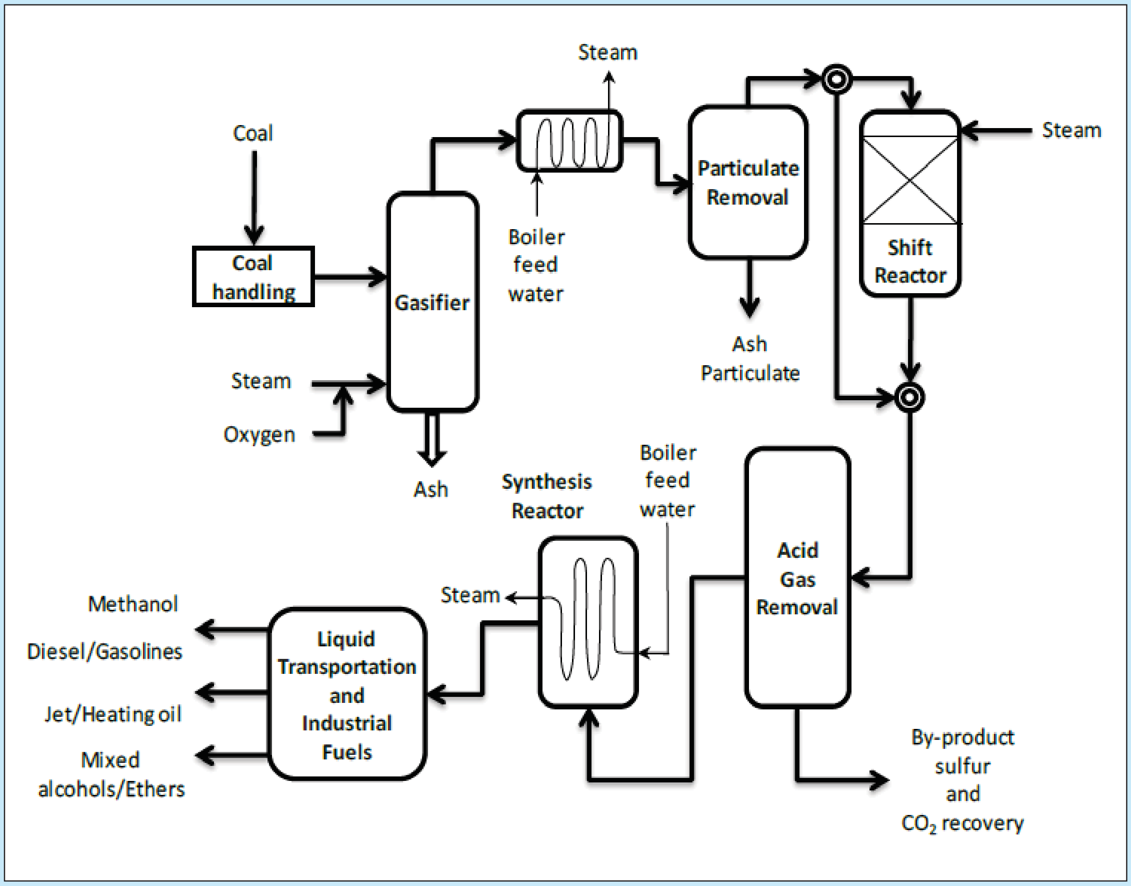

Figure 4
Synfuel from coal gasification (Botha, 2012; Schultz et al. 2012).

based solely on relatively abundant raw materials of H_2O and CO_2. Energy sources without no CO_2 emissions are chosen as energy sources to generate hydrogen from water. Nuclear, solar, wind, hydro, and geothermal energy are attractive options because they do not emit CO_2 (Chiuta 2010; Choi et al. 2017).

C. Synthetic Fuel Production

Liquid hydrocarbons synfuel have been synthesized for more than three-quarters of a century from non-liquid feedstocks, principally coal but also natural gas in recent years. The leading process is the F-T process which uses synthesis gas, hydrogen, and carbon monoxide, as its feed and produces a synthetic "crude" that undergoes further processing to a range of commercial finished products.

D. Conventional Process

The conventional process that commercially in operation now, is based on the process of coal gassification to produce synthesis gas, the is mixture of H_2 and CO. This reaction than followed by water gas shift reaction to produce CO_2 and additional H_2. Main reaction of synfuel production is allowed in synfuel reactor following the F-T reaction (Chiuta, 2010; Schultz et al. 2012). The complete reactions of the process are as follow:

Gasification $2C + 1/2O_2 + H_2O \rightarrow 2CO + H_2$

Water gas shift $CO + H_2O \rightarrow H_2 + CO_2$

F-T reaction $CO + 2H_2 \rightarrow CH_2 + H_2O$

Net reaction $2C + H_2O + 1/2O_2 \rightarrow CH_2 + CO_2$

From stoichimetric of reaction, side product of the process is CO_2. In this conventional process, beside as a raw material, coal also use as heat energy souce by means of direct burning. The negative effect of this process production of synfuels in a coal to liquid (CTL) plant produces enormous volumes of CO_2. Figure 4 shows the diagram of conventional synfuel from coal.

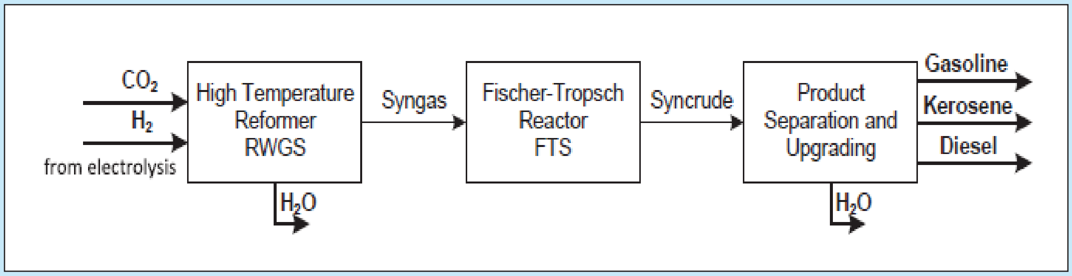

Figure 5
Diagram of the synfuel generation from CO_2 and H_2 (Konig et al. 2015).

E. Synfuel from CO_2 capture and nuclear hydrogen system

The process now under R&D is the proces that utilize CO_2 capture and nuclear hydrogen system. Nuclear hydrogen system is hydrogen production from water by utilizing high temperatur nuclear reactor as a heat source. One important process is thermochemical water decomposition of iodine sulfure cycle.

As raw material in this process, CO_2 is captured from fossil fired power plants or other industrial plant. By utilising the reverse reaction of water gas shift reaction, CO can be produced. Than CO and H_2 feed to the F-T reactor to produce synfuel. The reaction occur in the process are as follow (Schultz et al. 2012; Chen et al. 2015).

Nuclear Water-splitting

$$3H_2O + Energy \rightarrow 3H_2 + 3/2O_2$$

Reverse Water Gas Shift

$$CO_2 + H_2 \rightarrow CO + H_2O$$

F-T reaction

$$CO + 2H_2 \rightarrow CH_2 + H_2O$$

Net reaction

$$CO_2 + H_2O + Energy \rightarrow CH_2 + 3/2O_2$$

In this case, no coal is needed at all, and CO_2 is consumed rather than produced. The excess O_2 would be used in the fossil power plant that provides the CO_2, simplifying CO_2 capture. There is currently considerable effort underway on developing CO_2 capture systems for new and extant power plants. The increasing concern with Global Climate Change suggests that there is a reasonable likelihood of such plants operating in the timeframe associated with synthetic fuel from carbon dioxide. Such a synergistic system, dubbed twice burned coal or recycled coal, has the potential to significantly reduce current emissions of CO_2 since the carbon in the coal is used once for power production and then again for liquid hydrocarbon fuel synthesis (Schultz et al. 2012).

The F-T reactor contains only gas and catalyst (iron-based) with no liquid phase outside the catalyst pores. The operating temperature is between 320^{o}C and 350^{o}C and the reactor is typically operated at a pressure of about 25 bars to yield a highly olefinic hydrocarbon product. Furthermore, the F-T reactor requires syngas with high hydrogen concentration to avoid rapid catalyst deactivation due to carbon formation (Chiuta 2010; Graves 2010; Konig et al. 2015).

The diagram of the process based on H_2 and CO_2 captured is shown in Figure 5. The raw material of CO_2 is coming from idustrial or fossil power plant emission, while H_2 is produce by utilization of HTGR. Beside to produce H_2, the heat from HTGR is also can be used as heat source for the F-T, and RWGS reactors (Kreautz 2011).

III. RESULTS AND DISCUSSION

The use of nuclear energy has mostly concentrated on producing electricity. Another established but much smaller application has been as a power source for ships: submarines, icebreakers, and even merchant ships. Non-electricity applications based on direct use of heat generated in the fission process of water cooled nuclear reactors could include process heat for various low temperature industrial applications, desalination, and district heating. The creation of entirely new applications for nuclear power, such as process heat and hydrogen, is one of the main objectives in the development of Generation IV technologies (El-Genk & Tournier 2017; Locatelli et al. 2013).

Designed from the start to enable deployment in proximity of industrial sites and agglomerations, the Very High Temperature Reactor (VHTR) capability to deliver heat above 600°C to the end user makes them uniquely suited for cogeneration of process heat and electricity (Futterer et al. 2014; Yan et al. 2014). This feature enables them for instance to efficiently produce hydrogen through steam electrolysis or thermochemical processes, to supply both hydrogen and high temperature heat for producing synthetic fuels from coal, biomass or captured CO_2, or to deliver high temperature heat and hydrogen or syngas as chemical reactants to a variety of industrial plants including petrochemical, fertilizer production and steel-making. According to market studies performed in several countries, the potential market for this process heat is approximately as large as the electricity market and currently almost exclusively provided by fossil fuels with the concomitant CO_2 emissions

The efficiency of electricity production can be increased by using higher temperatures, but this also expands the range of possible applications for process heat. Industrial processes which need process heat at high temperatures include wood pulp manufacture (around 400°C), desulphurization of heavy oil in petroleum refining (around 500°C), production of syngas, styrene, ethylene and hydrogen via steam reforming, copper-chlorine (around 550°C) or iodine-sulphur thermochemical processes (around 800°C), and the manufacture of iron, cement and glass (around 1000°C) (Locatelli et al. 2013). In nuclear terms such temperatures can only be achieved by the various Generation IV reactors, which also introduce entirely new operating principles and safety features (Verfondern et al. 2017).

Nuclear hydrogen cogeneration by means of nuclear water splitting, is relatively the most developed technology of high temperature nuclear reactor application. This technology is interesting from the point of hydrogen and thermal energy output from the system. Hydrogen will be used as important feedstocks for CO_2 hydrogenation, while thermal energy from HTGR (in the form of heat, steam or electricity) is absolutely needed to run the process. As nuclear hydrogen cogeneration do not utilize carbon source as raw material, the system need CO_2 source from the other system. Fossil power plant, cement industries, or the other industry that emit CO_2 in a huge quantity can used as CO_2 source. By utilizing technology of CCS and or CCU, CO_2 can be captured and separated from the other gases, and use them as material of carbon source for petrochemical.

Some studies indicated the important of nuclear hydrogen cogeneration as the key technology for CO_2 conversion in the future. Study in US, indicated the role of nuclear hydrogen cogeneration in conversion CO_2 emission from cement plant to produce synthetic fuel (Bicer & Dincer, 2017). The other similar studies, also have been doing in around the world such as nuclear hydrogen cogeneration for CO_2 conversion to: ammonia and urea production (Salimy, 2014; INL-DOE, 2010), methanol (Salimy & Alimah 2015; Faberi et al. 2014), synthetic fuels (Stangeland 2017; Verfondern 2013).

Theoritically, to produce hydrocarbon synfuel from CO_2 and H_2, the ideal ratio of CO_2/H_2 is 1:3 (Konig et al. 2015; Schultz 2012). In other words hydrogen will be needed in large quantities to meet the needs of transportation fuel in the future. The application of nuclear cogeneration to hydrogen production is expected to meet that demand. If nuclear water spliting technology does not reach the commercial level, conventional nuclear-based electrolysis technology can be utilized as intermediate technology for the supply of hydrogen. The operation of the electrolysis process by nuclear power plant operators may be the solution to obtain hydrogen by electrolysis process. When the demand for electricity is high, the electrolysis unit is lowered in capacity, while when the demand for electricity is low, the hydrogen production capacity can be raised.

The efficient utilization of CO_2 has attracted considerable attention from fundamental research to industrial application in recent years (Lanjekar, 2011; Ravanchi & Sahebdelfar, 2014). The efficient utilization of (renewable) CO_2 will not only help to alleviate greenhouse effect, but also to obtain useful chemicals (Prokofyeva & Gürtler, 2014). Heterogeneous catalysis, electrocatalysis and photocatalysis are presently the three predominant chemical methods for converting CO_2 into some useful chemicals, such as methanol, formic acid and formaldehyde, etc. (Faberi et al. 2014). This CO_2-to-fuel integrating the heat from nuclear plant reactor could lead towards the sustainable development in the long term since cement industries, pulp and paper industries, as well as steel industries are the boundless sources of CO_2 (Graves 2010). Until now, CO_2 to fuel has been usually considered coupled to renewable sources such as wind power. In France 14% of electrical power is produced by renewable energy but also around 78% is provided by nuclear reactors (IAEA 2012). Nuclear power is also a low CO_2 footprint energy source, which can be used massively for CO_2 to fuel processes (Borgard 2011).

Compared to conventional coal-based gasification processes, alternative CO_2 hydrogenation processes promise significant reductions in CO_2 emissions. From the stoichiometry of the reaction it is seen that in the conventional process, CO_2 produced in large quantities that must be removed from the system. While in the process of hydrogenation of CO_2, CO_2 is not produced but instead used as raw material. Intensive study of HTGR applications for synfuel production has been conducted in South Africa based coal gasification process.The study indictae significant potential benefits compare to the conventional process. The CO_2 emission can be decrease about 75%, and coal requirement can be reduct about 40% (Botha, 2012; Chiuta, 2010). The other study indicate, for the process based on CO_2 capture and H_2, the process will not emit CO_2 at all, and also no requierement of coal. Even this process will utilized CO_2 from the other plants (Schultz, 2012).

IV. CONCLUSSION

The technology of hydrocarbon synfuel production from CO_2 and H_2 will play an important key in the future in supplying the need of liquid transportation fuel. Nuclear hydrogen will also to be important key technology to realize the process. From the point of environtment, the process can mitigate CO_2 emission in very significant amount. Even this technology can clean the electricity production from coal power plant, by capture the CO_2 emission to be raw material of the process.

ACKNOWLEDGMENT

The author appreciates to Center for Nuclear Reactor Technology and Safety, National Nuclear Energy Agency of Indonesia for the financing support through inhouse budget of 2016. Special thanks to Dr. M. Subekti who have been willing to read and correct to improve this paper.

REFERENCES

Aresta, M., Dibenedetto, A., Angelini, A., 2013, Review Article: The changing paradigm in CO_2 utilization, Journal of CO_2 Utilization, Vol. 3–4, Page 65–73.

Bicer, Y., Dincer, I., 2017, Life cycle assessment of nuclear-based hydrogen and ammonia production option: A comparative evaluation, International Journal of Hydrogen Energy, Vol. 42, Issue 33, Pages 21559-21570.

Borgard, J. M., Tabarant, M., 2011, CO_2 to fuel using nuclear power: the French case, Energy Procedia, Vol. 4, Page 2113–2120.

Botha, F. J., 2012, Simulation of a syngas from coal production plant coupled to a high temperature nuclear reactor, Stellenbosch University, 2012.

Chiuta, S., 2010, The potential utilization of nuclear hydrogen for synthetic fuels production at a coal-to-liquid facility, North-West Univer-sity, Potchefstroom, South Africa.

Chen, Q.Q., Tang, Z.Y., Lei,Y., Sun, Y. H., Jiang, M.H., 2015, Feasibility analysis of nuclear-coal hybrid energy systems from the perspective of low carbondevelopment, Applied Energy, Vol. 158, Pages 619-630

Konig, D.H., Bauck, N., Dietrich, R.U., Worner, A., 2015, Simulation and evaluation of a process concept for the generation of synthetic fuel from CO_2 and H_2, Energy, Vol. 91, Page 833-841.

Locatelli, G., Mancini, M., Todeschini, N., 2013, Generation IV nuclear reactors: Current status and future prospects, Energy Policy, Vol. 61, Page 1503–1520.

Futterer, M.A., Fu, L., Sink, C., Groot, S., Pouchon, M., Kim, Y.W., Carre, F., Tachibana, Y., 2014, Status of the very high temperature reactor system, Progress in Nuclear Energy, Vol. 77, Page 266-281.

INL-DOE, 2010, Technical Evaluation Study Project No. 23843: Nuclear-Integrated Ammonia Production Analysis, Idaho National Labo-ratory.

Verfondern, K., 2013, Overview of Nuclear Cogeneration in High-Temperature Industrial Process Heat Applications, OECD-IAEA Workshop, April 4-5, 2013, Paris

Choi, Y. H., Jang, Y.J., Park, H., Kim, W.Y, Lee, Y.H., Choi, S.H., Lee, J.S., 2017, Carbon dioxide Fischer-Tropsch synthesis: A new path to carbon-neutral fuels, Applied Catalysis B: Environmental, Vol. 202, Page 605–610.

El-Genk, M.S., Tournier, J.P., 2017, Reliable and safe thermal coupling of Generation-IV VHTR to a hydrogen fuel production complex, Thermal Science and Engineering Progress, Vol. 3, Pages 164-170.

Faberi, S., Paolucci, L., 2014, Methanol: a future transport fuel based on hydrogen and carbon dioxide?

Economic viability and policy options, Science and Technology Options Assessment European Parliamentary Research Service.

Graves, C. R., 2010, Recycling CO_2 into Sustainable Hydrocarbon Fuels: Electrolysis of CO_2 and H_2O, Columbia University, 2010.

Hong, S., Bradshaw, J.A., Brook, B.W., 2015, Global zero-carbon energy pathways using viable mixes of nuclear and renewables, Applied Energy, Volume 143, Pages 451-459

IAEA, 2012, IAEA-TECDOC-1682: Advances in Nuclear Power Process Heat Applications, International Atomic Energy Agency, Vienna.

IAEA, 2013, Hydrogen production using nuclear energy, IAEA Nuclear Energy Series No. NP-T-4.2, IAEA Publ. 2013.

Jiang, Z., 2010, Review: Turning carbon dioxide into fuel, Phil. Trans. R. Soc. A, Vol. 368, Page 3343–3364

Khamis, I, Koshy, T., Kavvadias, K.C., 2013, Opportunity for Cogeneration in Nuclear Power Plants, The 2013 World Congress on Advances in Nano, Biomechanics, Robotics, and Energy Research, Seoul 2013.

Kreutz, T., 2011, Prospects for producing low carbon transportation fuels from captured CO_2 in a climate constrained world, Energy Procedia, Vol. 4, Page 2121–2128.

Lanjekar, K., Gharat, N., Thakare, D., 2011, Green conversion technology for carbon dioxide utilization – A Short Review, Interna-tional conference on current trends in technology, Nuicone, 2011.

Li, L., Zhao, N., Wei, W., Sun, Y., 2013, A review of research progress on CO_2 capture, storage, and utilization in Chinese Academy of Sciences, Fuel, Vol. 108, Page 112–130.

Merajin, M. T., Sharifnia, S., Mansouri, A.M., 2014, Process modeling and optimization of simultaneous direct conversion of CO_2 and CH_4 greenhouse gas mixture over TiO_2/webnet photocatalyst, J. of the Taiwan Institute of Chem. Eng., Vol. 45, Page 869–879.

Noguchi, H., Takegamia, H., Kasaharaa, S., Tanaka, N., Kamiji, Y., Iwatsuki, J., Aita, H., Kubo, S., 2016, R&D status in thermo-chemical water-splitting hydrogen production iodine-sulfur process at JAEA, 5th International Symposium on Innovative Nuclear Energy Systems, INES-5, 31 October – 2 November, 2016, Ookayama Campus, Tokyo Institute of Technology, JAPAN

Patzek, T.W., Croft, G. D., 2009, Potential for Coal-to-Liquids Conversion in the United States Fischer–Tropsch Synthesis, Natural Resources Research, Vol. 18, No. 3.

Prokofyeva, A., Gürtler, C., 2014, CO_2 as building block for the chemical industry, United Nations Climate Change Conference, Bonn, Germany, 2014.

Ravanchi, M. T., Sahebdelfar, S., 2014, Carbon dioxide capture and utilization in petrochemical industry: potentials and challenges, Appl Petrochem Res., Vol. 4, Page 63–77.

Salimy, D. H., 2014, Nuclear cogeneration application for water splitting at CO_2 conver-sion to be urea fertilizer, JPEN Vol. 16, No. 2, Dec. 2014. (in Bahasa)

Salimy, D. H., Alimah, S., 2015, Nuclear cogeneration application of hydrogen production from water for CO_2 conversion to be methanol, JPEN Vol. 17, No. 2, Dec. 2015. (in Bahasa)

Schultz, K., Gorensek, M., Hering, J., 2012, Nuclear power for the production of carbon free energy and fuels. In: Muradov, N., and Veziroglu, V., (Eds) Carbon neutral fuels and energy carriers, CRC Press, Boca Raton, Page 203-289.

Stangeland, K., Kalai, D., Li, H., Yu, Z., 2017, CO_2 methanation: the effect of catalysts and reaction conditions, Energy Procedia, Vol. 105, Pages 2022-2027

Telsnig, T., Tomaschek, J., Ozdemir, E.D., Bruchof, D., Eltrop, L., 2013, Assess-ment of selected CCS technologies in electricity and synthetic fuel production for CO_2 mitigation in South Africa, Energy Policy, Vol. 63, Page 168-180.

Verfondern, K., Yan, X., Nishihara, T., Allelein, H.J., 2017, Safety concept of nuclear cogeneration of hydrogen and electricity, International Journal of Hydrogen Energy, Vol. 42, Issue 11, Pages 7551-7559.

Xu, J., Yang, Y., Li, Y.W., 2013, Fischer–Tropsch synthesis process development: steps from fundamentals to industrial practices, Current Opinion in Chemical Engineering, Vol. 2, Issue 3, Pages 354-362.

Yan, X., Noguchi, H., Sato, H., Kunitomi, K., Hino, R., 2014, A hybrid HTGR system producing electricity, hydrogen and such other products as water demanded in the Middle East, Nuclear Engineering and Design, Vol. 271, Page 20–29.