



Advanced Green Technologies Toward Future Sustainable Energy Systems

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ABSTRACT

Currently, the usable energy is basically harvested from the fossil energy sources, including coal, oil, and gas, which are believed to harm the environment due to the emitted GHGs. The awareness to the climate change and limited reserve of fossil energy sources has led to a strong motivation to develop a new energy system which can facilitate three important pillars: security, clean environment, and economic opportunity. This future energy system is strongly expected to be able to blend both fossil and renewable energy sources, while minimize its environmental impacts. To realize it, the primary energy sources are converted to the efficient secondary energy sources, including electricity and hydrogen. These two kinds of secondary energy source are considered very promising in the future, following a high demand in many sectors. In transportation sector, both electricity and hydrogen are believed to become the future fuels as the deployment of electric and fuel cell vehicles is increasing rapidly. In this paper, several potential technologies to produce the energy cleanly from primary energy sources are introduced and evaluated. In addition, clean and efficient technologies in storage and utilization are also described.

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1. INTRODUCTION

The development of technology, as well as the global economic growth, have led to

the increase of the global energy consumption. In the current phase of industry, Industry 4.0, there are several technologies which are adopted also in the energy sector, including internet of things, big data, and artificial

intelligence. Both energy supply and demand can be predicted and shared in relatively real time and higher accuracy. It is strongly expected that these kinds of technology are able to increase the energy sustainability, in terms of energy security, economic opportunity, and environmental impacts. **Figure 1** shows the main three pillars in energy security.

However, currently, there is an energy paradox due to low diffusion of related technologies leading to inefficiency in their application (Weber, 1997). The policies to facilitate smooth and dialectical communication among the technologies are demanded. European Union has decided to harmonically develop smart grid and smart and green energy technologies to reduce the emitted carbon, as well as achieve the future target of sustainability and high quality of energy to its citizens (Bireselioglu *et al.*, 2018).

To reduce the impact of energy utilization to the environment, the strategies related to energy transition also have been summarized. These transition strategies should be pursued simultaneously in order to

realize the 2°C scenario. First, the decarbonization in power generation sector should be carried out with the extended electrification to achieve more efficient and environmentally friendly energy utilization. Decarbonization is defined as the decline of average carbon intensity following the used of primary energy sources over time. Furthermore, decarbonization in non-electricity sector also needs to be accelerated, including the utilization of hydrogen and other non-carbon-based fuels. In addition, the energy productivity also needs to be improved, leading to high energy efficiency, especially in manufacturing and other industrial sectors. Finally, following the transition, the minimization of fossil fuel use and its strategic scenarios in order to diminish the emitted amount of CO₂ also needs to be conducted. The energy transition does not only cover the technological aspects, but also combination of economic, socio-cultural, political, and institutional aspects (Child *et al.*, 2018). Therefore, this energy transition should be guided by acceptable agreements and standards toward sustainability and resiliency (Andika and Valentina, 2016).

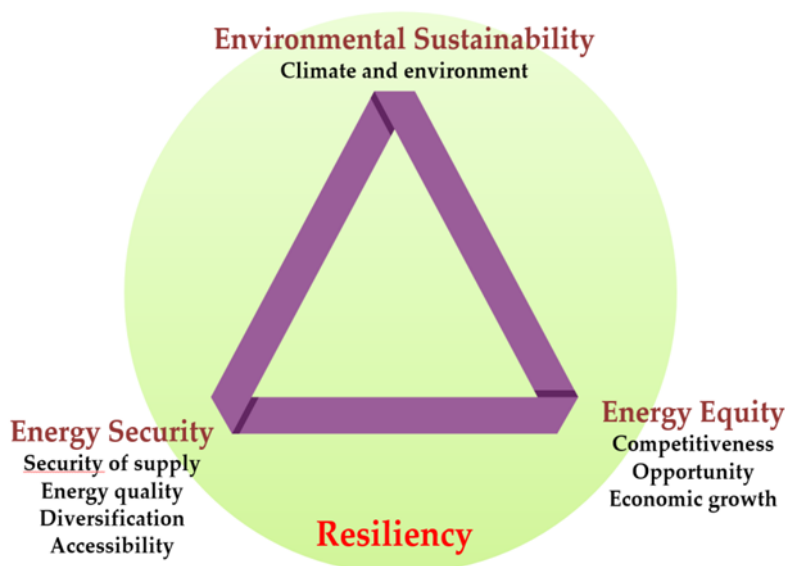


Figure 1. Three pillars in energy sustainability

In this study, several important points and scenarios related to green energy technology towards successful energy transition are discussed and explained. In addition, several strategic plans for Indonesia, as one of the greatest energy consumer, are also further described.

2. ENERGY SUSTAINABILITY FRAMEWORK

There are several possible frameworks to achieve the energy sustainability. They can be classified into short, mid, and long terms frameworks. In the short term frameworks, energy efficiency and integration of low carbon technologies and renewable energy are supposed to be adopted in the next five to ten years. As the number of integrated renewable energy increases, the fluctuation in the electrical grid becomes higher and more frequent. To minimize this fluctuation, especially in the supply side, the bidirectional and dynamic conversion of electricity and hydrogen is considered very crucial. In addition, as the adoption of clean and carbon-free technologies in the energy production, zero emission in several sectors can be projected. This utilization of electricity and hydrogen as the main secondary energy source which are consumed and setting of zero-emission target are considered as two main frameworks which can be adopted as the mid-term strategy in several decades of period, such as up to 2050. As the long term frameworks, and also as the final goal of sustainability, a closed loop of production and consumption is expected. This condition leads to the optimization of local production and local consumption (Beretta *et al.*, 2018), in which all the involved entities, including individuals and communities, become the important player and share equal rights and duties in energy production and consumption.

Energy transition does not only cover the low-carbon transition, but it is a long-term socio-technical changes toward optimum configuration of involved institutions, infra-

structures, policies/governance, and technologies. As energy transitions includes basically all of the life sectors, it is very important to synergize the energy transition with the change of those life sectors.

3. KEY SUPPORTING TECHNOLOGIES

Several key technologies to accelerate the development of green energy technologies and achieve the sustainability include smart grids (electricity, thermal and gas), hydrogen, information technologies and big data, and energy storage.

3.1 Smart grids

Smart grids deal with the approach to combine storage technologies with smart electricity, thermal and gas, and coordinate them to measure the dynamic synergy among them. It is carried out with the purpose of achieving an optimal solution for each individual and the whole energy systems. Basically, there are three different smart grids: smart electricity grid, smart thermal grid, and smart gas grid (Lund *et al.*, 2017).

Smart electricity grid connects all the entities related to power generation, transmission, distribution, and consumption. However, until today, there is no clear definition on smart grid, as it is a complex and still evolving concept (Biresselioglu *et al.*, 2018). The intermittent renewable energy sources also become very important player in the future, therefore, an intensive attention is being paid to anticipate high and frequent fluctuation due to large introduction of renewable energy sources. In addition, heat pumps and electric vehicles are also predicted to increase significantly in the future. Massive charging and discharging behaviors of electric vehicles potentially lead to a huge power consumption and fluctuation if both them are not coordinated well (Aziz, 2015a). However, a good coordination of electric vehicles is very potential to provide ancillary services

to the grid, including energy storage, frequency regulation, voltage regulation, and congestion mitigation (Aziz, 2015b).

Smart thermal grid synergizes both electricity and heating sectors. This includes the adoption of thermal energy storages to provide additional flexibility, as well as minimize the thermal loss, in the whole energy systems. At the last, smart gas grid basically coordinates electricity, heating and transport sectors. This smart gas grid also enables the gas storage and possible bidirectional conversion of gas and electricity to create adaptive and flexible coordination in the grid (Lund *et al.*, 2017).

There are several required key characteristics of smart grid, include: (a) the use of information technology to optimize the route of electricity, heat and gas from the supply side to consumer side, (b) the possible and permission to the consumer to interact and participate to the market (open market), (c) the integration of new and developed technologies into the operation, (d) self-healing capability due to disaster, etc., (e) capability to balance and provide high quality of energy, and (f) transforming capability of energy sector into secure, adaptive, sustainable, and digital. In smart grid, energy management includes both supply and demand sides, therefore, the energy price can change in real time due to changes in both supply and demand (Crossley and Beviz, 2010).

3.2. Advanced hydrogen production and utilization

Similar to electricity, hydrogen is also the secondary energy source (energy carrier) which is clean and produce no CO₂ in its utilization. Electricity and hydrogen can be mutually converted. Therefore, utilization of both electricity and hydrogen can lead to adjustable and adaptable energy system, as well as higher energy security. In addition, hydrogen has characteristics of high energy efficiency

in its conversion (Zaini *et al.*, 2017), many technological options in its utilization and production (Juangsa, F.B., *et al.*, 2018), and high gravimetric energy density (Aziz *et al.*, 2017). However, as the volumetric energy density of hydrogen is very low, storage technologies to store and transport effectively the hydrogen are demanded (Aziz *et al.*, 2017).

Hydrogen can be utilized as both fuel and chemical materials. In transportation sector, hydrogen can be utilized directly as fuel for fuel cell vehicles, and it can also be converted to several synthetic fuels or utilized to upgrade the biomass-based fuels. In addition, it can also be utilized as reactant in several material processing process include ammonia, metals refining, and others.

3.3. Big data and information technologies

Digital transition in energy sector leads to big data acquisition and its analysis (Zhang *et al.*, 2017). Huge amount of data, including energy production and consumption, needs to be analyzed critically to create a secured and sustainable energy system. There are several important aspects related to this big data, including volume, velocity, variety, veracity, visibility and value. Veracity deals with the uncertainty because of data inconsistency and incompleteness, ambiguities, latency, and deception. In energy sector, as the human behavior also influences strongly the pattern of energy usage, the data related to the human lifestyle will be very important to be analyzed and predicted. Using big data, the prediction of renewable energy generation, air conditioning demand, charging demand for electric vehicles can be conducted leading to more interactive and adaptive change in energy system. In addition, the move from centralized to distributed energy system also leads to high demand of accurate energy planning, in which big data acquisition and analysis are very crucial. The collected

big data is then analyzed using any artificial intelligent or machine learning technologies to develop more accurate forecasts and optimum balancing mechanisms.

3.4. Energy storage

To balance and provide high energy quality, energy storage is very crucial in the energy system. Energy storage can decouple both supply and demand, and time-shifting delivery of energy (Lund *et al.*, 2015). Energy storage is strongly expected to accelerate the adoption of distributed energy system, open energy market, and introduction of renewable energy. Energy storage can be generally classified into mechanical, electrical, electro-chemical, thermal and chemical (Gallo *et al.*, 2016). In mechanical energy storage, the energy is stored in potential or kinetic forms of

energy, involving several mechanical processes, including pumping, compression, expansion, acceleration, and deceleration. This kind of storages cover pumped hydro, compressed air, flywheel, liquid air, and pumped-thermal energy storages. Furthermore, electrochemical energy storages include conventional, high temperature, metal-air, and flow batteries. In addition, electrical energy can be performed by using supercapacitors and super conducting magnetic energy storage. Chemical energy storage is carried out through power-to-gas, power-to-liquid, and solar-to-fuels technologies. Figure 2 shows the concept of electric vehicles utilization in the grid as energy storage to provide ancillary service to the grid (Aziz, 2015a). Battery and electric vehicles are considered as the main player energy storage in the future (Aziz *et al.*, 2016a).

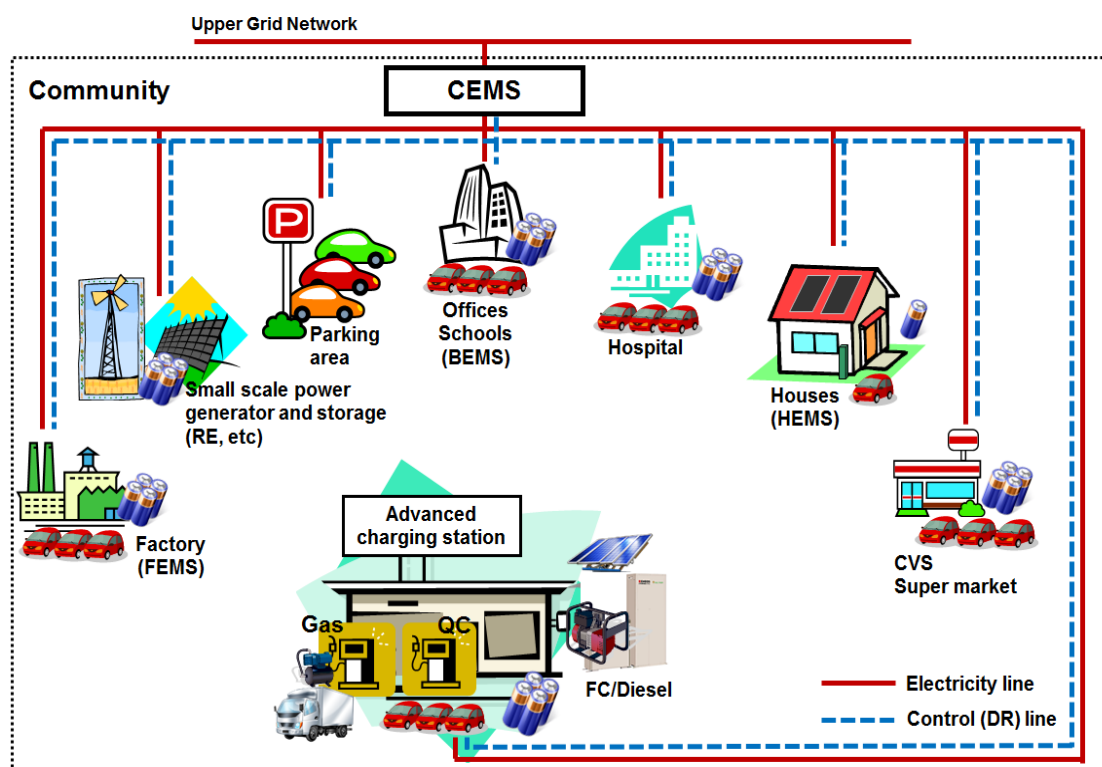


Figure 2. Concept of developed integration of electric vehicles to the grid to provide ancillary services to the grid.

3.5. Other decarbonization and CO₂ capture/utilization technologies

Decarbonization of carbon-based fuels is carried out, hence, the formation of CO₂ in the demand side can be avoided. Many technologies are available today to convert carbon fuels to non-carbon-fuels, including methane reforming, shift reaction, gasification, and chemical looping (Aziz *et al.*, 2016b). In case of carbon-based fuels are utilized, capture and separation of the formed CO₂ are demanded. CO₂ capture can be performed in three different stages: post, pre, and oxy fuel combustion. In post combustion CO₂ capture, CO₂ is separated from the flue gas emitted from the combustion. In this case, CO₂ separation can be conducted via absorption, adsorption, cryogenic, and membrane separation. In pre combustion CO₂ capture, carbon-based fuels are converted initially to hydrogen which is combusted further. Finally, in oxy fuel combustion, the combustion is conducted with pure oxygen or oxygen-rich air, therefore, the emitted flue gas basically contains CO₂ or CO₂-rich gas.

The separated CO₂ can further be sequestered through several options, including biological fixation, ocean storage, geological storage, and mineral decarbonisation. In addition, CO₂ also can be utilized for several purposes, covering material for fuels, fertilizers, polycarbonates, fire extinguishers, foods and drinks, and flavours/fragrances.

4. TOWARD ENERGY SUSTAINABILITY IN INDONESIA

Indonesia is one of the great developing countries having about 260 million of population. The economic growth is considered high, about 5% annually. Although the energy consumption per capita is currently low (1 MWh per capita), it is predicted that it is gradually increasing following the rise of economic condition in the country. In addition,

the country also facing several social, technological, and political challenges related to energy sector. The increase of both population and economic growth lead to the significant increase of energy demand in the future. It is predicted that the total energy consumption in 2025 is about 400 Mtoe, and it increases to about 1,000 Mtoe in 2050.

Although Indonesia has very huge potential of energy sources, including fossil-based fuels and renewable energy sources, their utilization still cannot fulfill the whole domestic energy demand. Related to renewable energy sources, Indonesia has huge potential for geothermal, biomass, hydro, and solar power. However, regarding the solar power, as Indonesia is located in tropical area, high atmospheric humidity leads to the drop of solar intensity reaching the surface (solar panel). This lead to the reduce of potentially generated power from solar panel. The average solar irradiance is about 4.8 kWh/m². Furthermore, as tropical country, wind energy in Indonesia is considered low due to low wind speed and fluctuating wind speed and direction.

Several recommendations to enhance and accelerate the energy sustainability in Indonesia include:

- (a) development of integrated and smarter energy system,
- (b) diversification of energy sources, with geothermal, hydro and biomass as the main player in the future,
- (c) development and deployment of low environmental impact technologies,
- (d) clear and sustainable energy policies,
- (e) open and transparent market for higher participation,
- (f) deployment of local production and local consumption concept, and

(g) domestic technology transfer and creation.

5. CONCLUSIONS

Energy sustainability relates strongly to the overall aspects, including security, equity and environmental. In addition, energy transition, to change the current trend of energy production and consumption to more sustainable ones, is urgently required. It does not only deal with the reduction of CO₂, but also deals strongly with the change of the whole life sectors, including social, political, and technological. Several potential technologies to accelerate this energy transition toward energy sustainability have been described, including smart grids, hydrogen production and utilization, big data and information technologies, energy storage, decar-

bonization and CO₂ capture/utilization technologies. Finally, several recommendations for Indonesian case have been described to achieve a greener and sustainable domestic energy systems. Overall, the change and development of paradigms, policies and technologies are urgently required.

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5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the data and the paper are free of plagiarism.

6. REFERENCES

- Aziz, M., Oda, T., Mitani, T., Watanabe, Y., and Kashiwagi, T. (2015). Utilization of electric vehicles and their used batteries for peak-load shifting. *Energies*, 8(5), 3720-3738.
- Aziz, M., Oda, T., and Kashiwagi, T. (2015). Extended utilization of electric vehicles and their re-used batteries to support the building energy management system. *Energy Procedia*, 75, 1938-1943.
- Andika, R., and Valentina, V. (2016). Techno-economic Assessment of Coal to SNG Power Plant in Kalimantan. *Indonesian Journal of Science and Technology*, 1(2), 156-169.
- Aziz, M., Oda, T., and Ito, M. (2016a). Battery-assisted charging system for simultaneous charging of electric vehicles. *Energy*, 100, 82-90.
- Aziz, M., Juangsa, F. B., Kurniawan, W., and Budiman, B. A. (2016b). Clean Co-production of H₂ and power from low rank coal. *Energy*, 116, 489-497.
- Aziz, M., Putranto, A., Biddinika, M. K., and Wijayanta, A. T. (2017). Energy-saving combination of N₂ production, NH₃ synthesis, and power generation. *International Journal of Hydrogen Energy*, 42(44), 27174-27183.
- Beretta, G. P., Iora, P., and Ghoniem, A. F. (2012). Novel approach for fair allocation of primary energy consumption among cogenerated energy-intensive products based on the actual local area production scenario. *Energy*, 44(1), 1107-1120.
- Biresseolioglu, M. E., Nilsen, M., Demir, M. H., Røyrvik, J., and Koksvik, G. (2018). Examining the barriers and motivators affecting European decision-makers in the development of smart and green energy technologies. *Journal of cleaner production*, 198, 417-429.

- Child, M., Koskinen, O., Linnanen, L., and Breyer, C. (2018). Sustainability guardrails for energy scenarios of the global energy transition. *Renewable and Sustainable Energy Reviews*, 91, 321-334.
- Crossley, P., and Beviz, A. (2010). Smart energy systems: Transitioning renewables onto the grid. *Renewable Energy Focus*, 11(5), 54-59.
- Gallo, A. B., Simões-Moreira, J. R., Costa, H. K. M., Santos, M. M., and dos Santos, E. M. (2016). Energy storage in the energy transition context: A technology review. *Renewable and Sustainable Energy Reviews*, 65, 800-822.
- Juangsa, F. B., Prananto, L. A., Mufrodi, Z., Budiman, A., Oda, T., and Aziz, M. (2018). Highly energy-efficient combination of dehydrogenation of methylcyclohexane and hydrogen-based power generation. *Applied energy*, 226, 31-38.
- Lund, P. D., Lindgren, J., Mikkola, J., and Salpakari, J. (2015). Review of energy system flexibility measures to enable high levels of variable renewable electricity. *Renewable and Sustainable Energy Reviews*, 45, 785-807.
- Lund, H., Østergaard, P. A., Connolly, D., and Mathiesen, B. V. (2017). Smart energy and smart energy systems. *Energy*, 137, 556-565.
- Zaini, I. N., Nurdiawati, A., and Aziz, M. (2017). Cogeneration of power and H₂ by steam gasification and syngas chemical looping of macroalgae. *Applied Energy*, 207, 134-145.
- Zhang, C., Romagnoli, A., Zhou, L., and Kraft, M. (2017). From numerical model to computational intelligence: the digital transition of urban energy system. *Energy Procedia*, 143, 884-890.