Smart Integrated Clean Energy Residental House (SICLEAN) Based on Carbon Capture Storage and Engineering Wood Products to Realize Carbon Free Cities 2035

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ABSTRACT

To support the achievement of SGD, especially pillar No.13 (Climate Change), the existence of a technological model that enables to reduce negative impact of carbon emissions is one of the prerequisites for supporting the sustainability of life on Earth. To answer these challenges, this paper aims to introduce the idea of carbon capture technology in residential called SICLEAN (Smart Integrated Clean Energy Residential House). This idea aims to introduce the use of engineering wood products as one of the innovative solutions to combat the adverse effects of carbon emissions. SICLEAN is arranged in a housing complex inside there are Transparent Wood, Transparent Nano paper, Wind Turbines, Structural Applications, Water Treatment, and Energy Storage Devices. In the end, consideration of the negative impacts of SICLEAN and the need for regulations supporting the implementation of SICLEAN at the public level is conveyed. The SICLEAN idea will also initiate the achievement of zero carbon city in Indonesia 2035. In contrast to efforts to reduce carbon emissions by using alternative energy approaches and mobilizing the use of electric cars, efforts to reduce carbon emissions through a residential management approach based on carbon capture technology is a breakthrough that overlooked by Indonesian policymakers.
Keywords: *zero carbon, carbon capture, smart integrated clean energy residential house (SICLEAN), engineering wood products*

INTRODUCTION

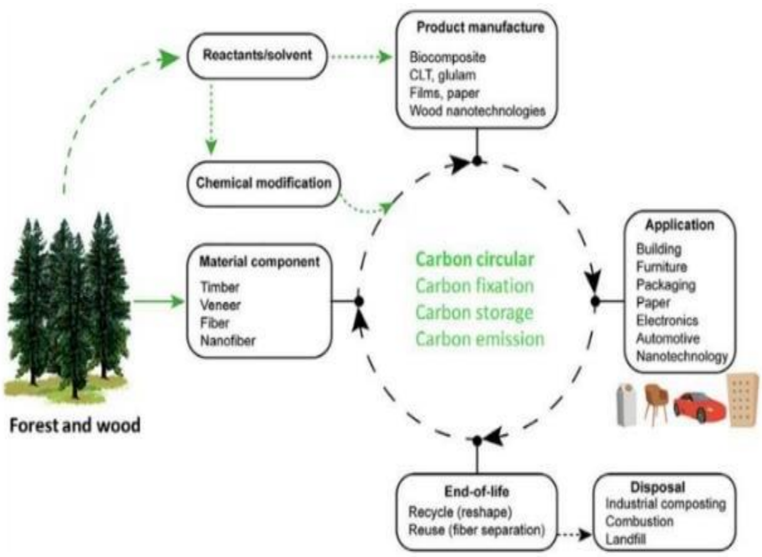
Indonesia has various industries which are sources of CO2 emissions, including those from coal-based steam power plants, oil and gas processing installations, steel factories, fertilizer factories, and cement factories. The total industrial emissions resulting from CO2 emissions from power plant exhaust and gas processing are estimated to be around 80 million tons per year, of which 17.5 tons per year are responsible for oil and gas processing. The power generation sector remains a major contributor to future CO2 emissions in Indonesia. With the current electrification ratio (64%), the growth in electricity demand in Indonesia is expected to remain strong in the coming decades to supply electricity especially in remote areas. Responding to this growing demand, PLN (State Electricity Enterprises Agency) issued a Ten-Year Electricity Development Plan to build several power plants which will be dominated by coal. Thus, coal-fired power plants in the future will continue to be the main contributor to CO2 emissions in Indonesia. To reduce carbon emissions, it is necessary to carry out technological innovations that can process carbon so that it does not have a negative impact on the environment.

Recently, new technologies have been explored regarding the use of wood to capture CO2 from the air, such as membrane adsorption, electrocatalytic reactions, and photocatalytic. The most potential wood producer is forest. Forests serve as one of the most important carbon sinks contributing to removing CO2 from the atmosphere

(Favero, 2017). Carbon can be absorbed and stored in trees through the photosynthetic reaction CO_2, which gives forests an important role in adjusting atmospheric carbon concentrations during the global industrial age. As a result of uncontrolled illegal logging and excessive consumption of wood and an increase in the amount of plastic waste which is difficult to decompose naturally, it causes an increase in CO_2 concentrations in the atmosphere which results in global warming (Mitchard, 2018). Therefore, proper management of the sinks and utilization of forest carbon and wood products can positively reduce CO_2 emissions and the consequent climate change (Favero, 2020).

Wood is a highly porous material with a hierarchical cell wall structure that provides water transport and mechanical support functions (Cai, 2022). Natural wood is often subject to cracking, degradation, aging and dimensional instability, leading to a reduction in its service life resulting in a return of carbon to the atmosphere. This means that the wood products that are harvested greatly influence the carbon cycle of the forests that depend on the end use of the wood. A study in New Zealand (Buchanan and Levine, 1999), showed that a 17% increase in wood used in the built environment had a direct impact on carbon emissions which were reduced by 20%. These estimates are based on the use of wood as a substitute for brick, aluminum, and other building products that require more energy processing than wood. Many attempts have been made to explore functional wood materials for expanding and enhancing carbon storage and CO_2 capture (Montanari, 2021). Until recently, the human population's higher demand for wood products, incidentally, occurred at a faster rate than the harvesting of trees or timber. The replacement cycle for the 15–25 year rotation period for a tree or wood resource is longer than its use for supplying energy, burning, pulping, and papermaking (Geng, 2017). Therefore, it is necessary to develop new technologies for carbon capture and fixation of wood products over a longer period.

Figure 1. The carbon cycle for forests and wood (Montanari, 2021).



Although various scientific studies have summarized the situation in the processing of functional wood products and their applications, these reviews are less focused on CO_2 capture and carbon storage using modified and functional wood. In this review, the authors review new technologies for wood product development with a focus on enhancing CO_2 capture and carbon storage. Timber functionalization strategies for carbon sequestration or capture will be discussed. New wood nanotechnology is focused on developments in the design and structural engineering of wood for expanding carbon storage and replacing fossil-based plastics. In addition, processed wood products or Engineering wood products (EWP), including compacted and chemically modified wood materials, are also reviewed with an emphasis on an industrial perspective. The impact of woody biomass on the global economy and carbon mitigation is explained. A future perspective is proposed to expand CO_2 capture and carbon storage and sustainably use wood products (Jiang, 2018).

Motivated by the problems above, the authors formulated a concept, namely Smart Integrated Clean Energy Residential House (SICLEAN). The concept of carbon capture technology uses applications from Engineering wood products that can be used to capture better carbon to utilize natural resources and of course to support national energy security and the realization of the Sustainable Development Goal in Indonesia.

LITERATURE REVIEW

A. CCS and Potential Application in Indonesia

Carbon capture storage, which is often referred to as carbon capture and sequestration, prevents large amounts of CO_2 from being released into the atmosphere. This technology includes capturing the CO_2 produced by large industrial plants, compressing it for transport, and then carefully loading it into very deep rock formations, where it is permanent storage (Brinckerhoff, 2011).

Next, for the trend of fossil fuel consumption and its relation to CO_2 emissions in Indonesia. Consumption of fossil fuels is accompanied by increased CO_2 emissions. In 1990, CO_2 emissions were 133.9 MTOE and are predicted to increase in 2050 to 2065.98 MTOE. On the other hand, the NEP scenario will reduce the share of oil to 25% – 30%. However, overall fossil fuel consumption increases to 690 MTOE by 2050. Although the NEP scenario aims to increase the share of renewable energy sources, it will not be sufficient to achieve an overall reduction of CO_2 emissions of 26% by 2020. As a result, CCS must apply as a tool to significantly reduce CO_2 emissions, particularly CO_2 emissions from the oil and gas, electricity, and industrial sectors.

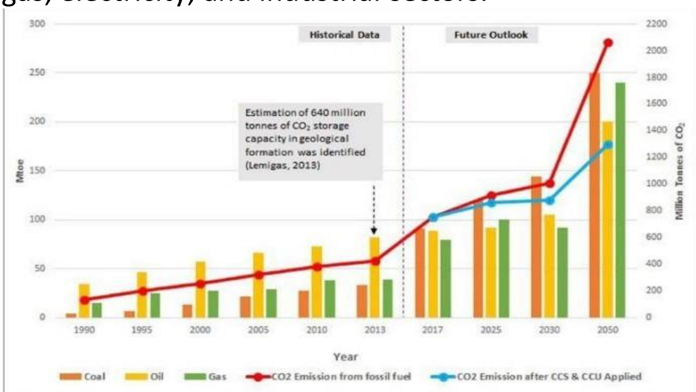


FIGURE 1 | **Past, current, and future outlook of fossil fuel consumption (future consumption according to NEP Scenario) including CO_2 emission from fossil fuel combustion (electricity, heat, manufacturing, transport) and projection of CO_2 emission after application of carbon capture and storage and CCU.** Data source: IEA Energy Atlas (2016), National Energy Council (2014) in IEA (International Energy Agency) (2015), Ministry of Energy and Mineral Resources of Indonesia (2014), and UCL Energy Institute (2013).

Figure 2. Fossil Fuel Consumption according to the NEP Scenario (IEA Energy Atlas, 2016)

The figure above shows a prediction of how CO_2 emissions might change if CCS is implemented in the future. CO_2 emission predictions will change significantly with an increase in emission reductions from 6% in 2025 to 37% in 2050 if the CCS application has been implemented. This estimate is based on assumptions of carbon capture technology that will be applied to CO_2 point sources (industrial facilities, factory electricity, and manufacturing) and considers CCS capacity and efficiency including the potential for CCS implementation in Indonesia. Application of CCS not only reduces CO_2 emissions but also has the potential to decouple economic growth from CO_2. However, development regarding CCS has not been well developed (Prasetyo, 2022).

According to the research in collaboration with LEMIGAS, revealed that regulations and legal aspects regarding the operation and management of CCS projects in the long term must be considered by the Government of Indonesia. The use of CCS technology in Indonesia only focuses on increasing production in old oil and gas wells which are scattered in several locations in Indonesia. Thus, the potential for the spread of CCS in Indonesia is proven to exist, especially in terms of CO_2 storage related to enhanced oil recovery. However, to realize this potential, large funds are needed and the government makes strict regulations for CCS.

B. Wood-Based Carbon Capture Storage (CCS) Technology

CO2 capture has a very important role in mitigating CO2 emissions and consequently slowing down global warming (Gao, 2022). Various types of technologies have been developed to capture CO2. In recent years, various types of new technologies have been developed to modify wood and its cell walls to create new functionalities (Dong, 2020). Membrane-based technology allows for the separation of CO2 from other gaseous components present in the exhaust stream from the combustion process or burned fuel or even air, by taking advantage of the CO2 concentration gradient between the two membrane-separated phases, and the size difference between the CO2 molecules and other gas molecules. in the mix (Gao, 2022). While in the absorption process, a liquid solvent with a high tendency to dissolve CO2 molecules is used to capture CO2, and in the adsorption process, usually a solid medium containing attachment/adhesion sites is used to isolate CO2 from the gaseous medium. Wood and wood-based products, such as cellulose and carbon-based materials, have been widely used for the manufacture of various types of membranes and adsorbents for the isolation of various compounds, including CO2. The most important types of materials with wide application in the development of new membranes and adsorbent products for capturing CO2 are wood cellulose nanofibrils and carbon-based materials such as biochar and activated carbon.

Materials	Technology/Mechanism and operational condition (pressure, temperature)	Performance (adsorption/capture capacity, permeability, or selectivity)	Refs.
Delignified Wood/polyethyleneimine composite	Adsorption, and 1 bar 120 °C	Adsorption capacity mmol *g* − 1 2.96	Wang et al. (2020)
Delignified wood/metal-organic framework composite	Adsorption, and 1 bar 120 °C	Adsorption capacity mmol *g* − 1 1.46	Wang et al. (2021)
Carbonized wood/Au-Pd	Membrane/electrocatalytic reaction	Not Reported	Wang et al. (2022a)

composite			
Lignin-based polyethyleneimine activated carbon composite	Adsorption, 30 °C and 1 bar	Adsorption capacity 2 mmol $g-1$	Atta- Obeng et al. (2019)
Biowaste-based KOH-activated biochar	Adsorption, 25 °C and 1 bar	Adsorption capacity 3.2265 mmol $g-$	Igalavitha na et al. (2020
Pecan nutshell-based biochar prepared using microwave pyrolysis	Adsorption, 0 °C and 1 bar	Adsorption capacity 2.5 mmol $g-1$ and CO2/N2 selectivity ratio of 152	Durán-Jiménez et al. (2021)
Activated carbon prepared treatment of pine bark using potassium	Adsorption, 20 °C and 0.91 bar	Adsorption capacity mmol $g-1$ 3.5	Sessa et al. (2022)

Figure 3. List of research studies on CO2 capture using various wood-based materials.

C. Engineering Wood Products

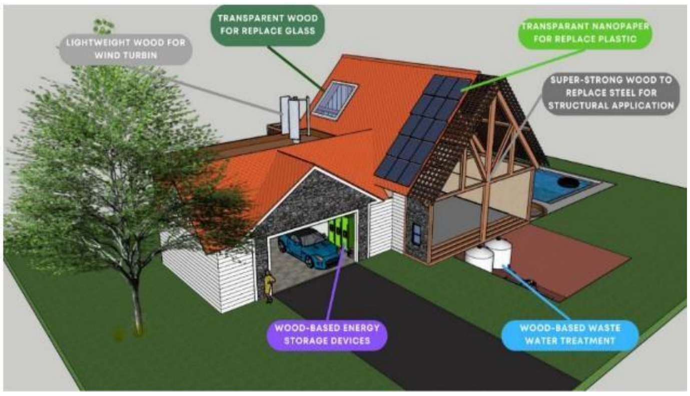
According to the commercial organization Architecture 2030, buildings are responsible for around 40% of global CO2 emissions. Building operations accounted for 28% of emissions, while the remaining 11% was related to building materials and construction (embodied carbon) (Global, 2020). Concrete, steel and aluminum are responsible for 23% of global CO2 emissions. It is estimated that concrete, brick and steel have a larger carbon footprint than wood, and that 14% of global CO2 emissions could be reduced by increasing the use of wood. These figures show the great potential for reducing CO2 emissions by using wood in the built environment. If trees from well-managed forests are harvested, during their use CO2 is locked in the wood product, acting as a temporary carbon sink until the wood cracks. The longer wood lasts, the longer CO2 is removed from the atmosphere.

Wood products are often disposed of in landfills, which slowly release methane and CO2 as they decompose. In some situations, because of the use of metal compounds such as chromated copper arsenate (CCA) for wood preservation, there are limited options other than final dumping at the end of their useful life. Currently, however, besides using CCA as far as wood life and EWP, there are several options where effective use of biocides or wood modification techniques can extend wood life and EWP without much adverse environmental demands (Jones and Sandberg, 2020). Wood modification techniques can be broadly divided into three categories: acetylation, thermal modification, and resin addition or polymer modification.

METHODOLOGY & DATA

The research method used is the study of literature and scientific journals. These data and developments were obtained by means of literature studies in the form of statistical data, research reports, as well as official web pages of various regional, national, and international institutions. Then the results of this literature review are synthesized to produce the proposed SICLEAN model followed by its advantages and disadvantages as well as various things that need to be considered in order to optimize the operation of SICLEAN.

Figure 4. The design of SICLEAN



So it can be concluded that the Smart Integrated Clean-energy House (SICLEAN) is a smart housing model that functions as a carbon capture. SICLEAN itself is a future housing concept that is energy independent and helps carbon reduction which supports efforts to overcome this global warning problem itself. SICLEAN has a system based on the use of Engineering Wood Products. Engineering Wood Products itself is one example of the application of the use of wood where this modified wood will try to capture CO2 emissions in the surrounding environment. Thus, the application of SICLEAN will later be built in areas adjacent to the largest CO2 emitting sources. SICLEAN will later be arranged in a smart housing in which there are components of Transparent Wood, Transparent Nano paper, Wind Turbines, Structural Applications, Wastewater Treatment, and Energy Storage Devices.

DISCUSSION

A. Bio economic Analysis and Net Zero Emission Targets

The concept of bio economy has attracted global attention for many years due to the operation of the bio-based sector in the transformation from traditional fossil fuel- based towards a resource efficient and low carbon economy. Although the implementation path is still ambiguous, there are various initiatives that have prepared framework policies. For example, the EU has listed bio-based industries as a priority area in the EU action plan. Scholars and policy makers treat bio economic to reduce environmental pressures by exploring the value of waste and creating associated job opportunities. Figure 5. presents an example of existing policy plans for selected economies.

Country/Region	Policy framework	Year	Main sectors
European Union	Innovating for Sustainable Growth: A Bio-economy for Europe	2012	Agriculture and forestry, aquaculture and fisheries, bio-based industries, food chain
United States	National Bio-economy Blueprint; Billion-Ton Strategy	2012, 2016	Health, agriculture, and industry
Australia	Research and Innovation	2013	Primary industry
United Kingdom	Evidencing the Bio-economy (2016); AgriTech Strategy (2014)	2014, 2016	Agriculture, bioenergy, forestry, marine

Figure 5. Economic Policy in several regions (Source: Diakosavvas and Frezal, 2019)

Biomass is a renewable resource, in traditional forms such as wood, manure, charcoal, and modern forms such as biogas, bio refinery and other technologies. It can be burned directly for heating or power generation, with growing demand in the industrial sector for decades to come (IRENA 2021, IEA 2021).

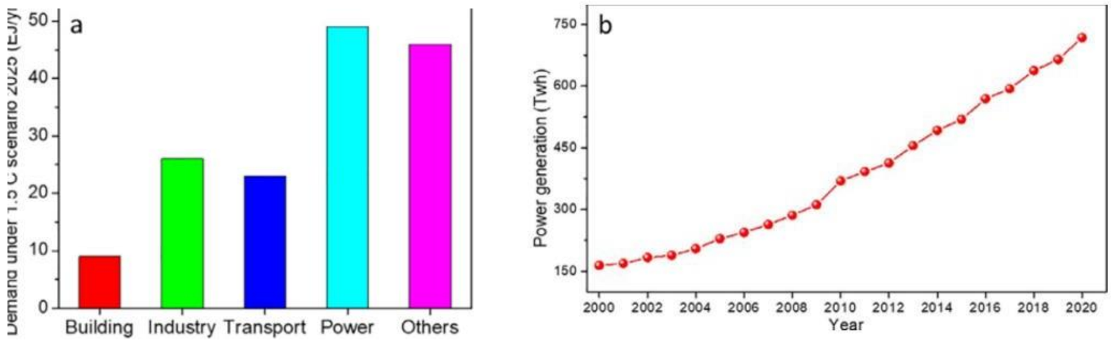


Figure 6. Primary bioenergy demand and global power generation. (a) Demand for primary bioenergy in the 1.5C 2050 scenario; (b) Bioenergy power plants in a net zero emission scenario. (Sources: IEA 2021, IRENA, 2021).

Figure 6 shows the most demanded sectors for bioenergy under the target of 1.5 degrees Celsius (Figure 6a), and historical trends of power generation with bioenergy (Figure 6b). Utilization of biomass resources can contribute to reducing GHG emissions from human activities. The Conference of the Parties to the UN Framework Convention on Climate Change 2021 (COP26) emphasized the urgency of adaptation to climate change, which requires a lot of action to secure a global net-zero target by mid-century.

To achieve this goal, participating countries should make concerted efforts to protect natural habitats, provide financial support between developed and developing economies, and adopt renewable energy in industrial processes. Renewable energy is considered a vital source of emission reduction, replacing fossil fuels by burning carbon compounds. Along with continued policy support, by 2020, renewable energy has accounted for around 29% of global electricity generation. With increasing demand for woody biomass and clean technologies (e.g., carbon capture and storage) to achieve net- zero emission targets, it is important to understand what this brings to our economy. Therefore, the flow sub-chapter discusses the economic impact of using biomass and wood products on the environment and the economy.

B. Economic and Environmental Impact Analysis of Wood and Biomass Products

To achieve the emission reduction target in line with the Paris agreement, keeping global temperature rise below 2 degrees Celsius and ideally 1.5 degrees, each country has set its own implementation path. Among these policies, electricity and transportation are the main focus for sectors trying to reduce their emission intensity. On the other hand, using forests as natural carbon sinks will increase awareness of their ability to absorb CO2 from the atmosphere. However, when forest owners make wood products through logging or harvesting, most of the CO2 is released into the air. Deforestation produces almost 20% of global carbon emissions, while the residue can store carbon for long periods of time. Studies find that 1% of carbon remains in solid wood products even after 100 years. In addition, the carbon stored in wood disposed of in landfills is much greater than in long-lived wood products (Ingerson, 2009).

The use of biomass and wood products is highly dependent on policy support. However, it creates not only environmental benefits but also economic benefits. Traditional Environmental Kuznets Curve Theory exhibits a positive relationship between income and pollution in early development, whereas nexus may turn negative at some point when the economy promotes clean technologies to address environmental concerns. Several studies have confirmed this theory. For example, Wang (2019) points out the importance of creating biomass energy opportunities to ensure sustainable economic growth for BRICS countries (Brazil, Russia, India, China, and South Africa). The authors used a harmonized approach to evaluate carbon capture and biomass use across five energy-intensive industries, and they found that adding biomass helped reduce carbon emissions by a significant amount. In addition, CO2 avoidance costs can be achieved under €100/ton CO2 in the range of €40– 79/ton CO2.

Tree planting can capture carbon, but engineered wood is also treated as an effective tool for CO2 reduction. The reason is that the use of wood products can: (1) reduce wood- based building production inputs; (2) carbon storage from wood products; and (3) restoration of built-in solar energy that can replace fossil fuel energy at the end of the life of wood products (Hill, 2021). These benefits are a key driver for achieving the bio economic vision, which aims to harness biomass energy and increase resource efficiency. In addition to the environmental functions of trees, modified wood produced by biotechnology also creates market value, especially for countries with a vital wood modification industry. These countries (e.g. the Netherlands and Norway) are pursuing a bio economy of increasing efficiency and maximizing the value of raw materials, where one important factor towards this goal is the unit cost of resource efficiency. Technological advances can improve the quality of wood products, but more importantly, reduce production costs for commercialization. For example, applying herbicide resistance genes to plantation development could save nearly $1 billion annually (Heräjärvi, 2020).

One recent study has confirmed the possibility of substituting less carbon-intensive wood for products produced using fossil fuels in the construction sector under United States emission limits (Winchester and Reilly, 2020). According to their findings, the carbon intensity of wood is about 20% lower than that of manufactured metal products, 50% iron and steel, and 25% cement. Substituting engineered wood for other emission-intensive inputs results in an increase in demand for forestry and timber production by 0.3% and 0.6%, respectively, by 2030, as well as a decrease in primary energy use by 22.4% (2018.8 Mtoe), compared to the baseline where there are no substitution constraints and emissions occur. Furthermore, Caldas et al. (2021) used life cycle assessment to evaluate the impact of recycled wood waste used in the building sector. In fact, the increase in wood products led to a radical reduction in greenhouse gas emissions.

CONCLUSION

CCS is a way to prevent CO_2 emissions in large quantities from being released into the atmosphere resulting from various industries, especially the oil and gas industry. Research and development of CCS in Indonesia is still in a very premature stage and must be properly developed so that within the framework of implementing CCS it can be more efficient to support domestic sustainable energy production. One of the suggested CCS technologies is the use of wood in carbon capture efforts. Several new technologies focused on modifying and functionalizing wood cell walls and lumens targeting extended carbon storage and CO2 capture have been reviewed.

Wood modification technology has achieved cost-effective commercialization. This technology is applied to overcome several drawbacks (eg high water sensitivity, low dimensional stability, pond resistance to fungi, and UV light degradation) of wood products aimed at increasing their durability. Proper modification of wood or treatment of wood and wood products can significantly increase the life of wood, locking in carbon for a long time. Furthermore, the use of environmentally friendly biocides or modification techniques can have minimal negative impacts at the end of life stages, and wood and wood products can be recycled into other materials increasing their sustainability and circular bio economic potential. High-volume demand for high-performance wood products will drive the development of sophisticated methods for improving the quality wood and modified wood product markets.

Despite the development of new technologies, the assessment of the life cycle of wood and functional wood products, treated as a source of woody biomass, will yield environmental and economic benefits. Compared to other engineered materials, such as steel, concrete, brick and alloys, the development of sustainable wood products must reduce energy demand and CO2 emissions. We need to consider power consumption,

carbon economy, environmental impact, material recycling and end-of-life management when developing and using construction materials. Moreover, by implementing energy efficiency improvements and driving innovation in technology, carbon emissions can be largely offset, and potential employment opportunities will become available, further benefiting the entire economy in the long run. Global carbon emission policies in terms of CO2 capture and storage of carbon from the use of wood products should be a focus for future development, although this is not within the scope of the current review.

Therefore, to support the implementation of the SICLEAN development plan, the government still needs to consider several things first, mainly related to the negative impacts of SICLEAN technology and the regulations that cover implementation. It is intended that in the application of SICLEAN technology, unwanted negative impacts will not arise. Among the negative impacts of SICLEAN technology is the potential for leaks which can contaminate water and have a negative impact on air quality. Furthermore, it is necessary to think about regulations that are conducive to the application of SICLEAN technology in line with regulations related to settlements and regional spatial planning that already existed.

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