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CO2 BIO-FIXATION POTENTIAL IN POWER PLANT DEVELOPMENT TOWARDS INDONESIA'S DEEP DECARBONIZATION

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ABSTRACT

Indonesia's NDC target, both unconditional and conditional, has not significantly contributed to balancing GHG removals and emissions in three-quarters of the 21st century to keep global temperature increases below 1.5 °C. A more in-depth analysis is needed to reduce GHG emissions to preserve global temperatures at 1.5°C. The AIM-ExSS and AIM/Enduse models analyze Indonesia's long-term (2050) power mitigation through several scenarios. (i) The BaU (Business as Usual) or baseline scenario assumes no effort to improve energy efficiency or add renewable energy since the base year, resulting in additional electricity needs being met by conventional fossil power plants. CM1: extended-conditional NDC (iii) CM2: Extended-unconditional NDC (iv) CM3 is an ambitious power decarbonization scenario. In 2050, CM1 and CM2 reduced GHG emissions by 22% and 24%, respectively. CM3 potentially reduces 2,422 million tons of CO2e, or 92% of the 2050 baseline emissions. CCS (carbon capture and storage) technology is a key technology for deep decarbonization in the power sector. In addition to geologic sequestration, CO2 bio-fixation by cultivating microalgae can be considered as CCS. This study assessed Airlift-Vertigro bio-reactors to cultivate Botryococcus braunii for CO2 bio-fixation and biofuel (microalgal oil), which can be used to achieve carbon neutrality in the power sector.

Keywords: CO2 storage, climate change mitigation, microalgae, renewable energy

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1. INTRODUCTION

Indonesia's electricity demand consistenly higher than other energy types. Electricity demand increased 6.63 percent annually from 169,786 GWh in 2010 to 234,612 GWh in 2018 [1], [2]. Existing plants still highly dependent on fossil fuels, especially coal with inefficient technology (coal generated 58.41% of the total Indonesia's electricity in 2018). Power plant energy combustion may significantly impact future GHG emissions in Indonesia's energy sector. In accordance with the Paris Agreement and global efforts to mitigate climate change, Indonesia has committed to reducing GHG emissions by 29% in 2030 compared to baseline emissions and up to 41% with international support [3]. The GHG emissions reduction target will be achieved mainly through mitigation actions in the energy sector, considering that GHG emissions from the energy sector will surpass the forestry sector's future. Power sub-sector strength would be crucial for achieving the energy sector's GHG reduction target.

The IPCC's Special Report on Global Warming of 1.5 °C (SR15) shows that global warming above 1.5 °C threatens life's sustainability. The SR15 document supports the Paris Agreement's scientific targets. Indonesia's and other countries' unconditional and conditional NDC targets have not significantly contributed to balancing GHG removals and emissions in the first three-quarters of the 21st century to limit global temperature increases to 1.5 °C above pre-industrial levels. In order to keep global temperatures below 1.5 °C, a deeper investigation is needed to identify ways to reduce GHG emissions. Several reports have evaluated the effectiveness of energy-saving and GHG reduction strategies in Indonesian power plants. Low-carbon technology, accelerated energy transition through renewable energy, and demand-side management reduce emissions and mitigate costs, according to IESR and UNDP, and AFD[4][5]. The result concluded that energy prices are a major factor in expanding power plants (fossils and renewables). Some reports discuss power sector emission mitigation. However, the simultaneous evaluation of energy-saving and emission reduction, which includes CCS approach has not been accomplished. Given this background, this study analyzes potential GHG emission mitigation that is still possible to increase in the power sub-sector by considering the success rate of power sub-sector mitigation efforts in the NDC Indonesia roadmap by 2030, potential mitigation actions not yet covered in the NDC roadmap, international issues related to 'coal phase-out' although it is still difficult for Indonesia to implement, and analyzed the potential. The AIM-ExSS and AIM/Enduse models were used to analyze Indonesia's long-term (2050) potential mitigation in the power subsector using a baseline scenario and three mitigation scenarios. This paper also examines Botryococcus braunii microalgae as a CO2 fixation alternative.

2. METHODOLOGY

2.1. Model, Scenario, and Assumptions

ExSS (Extended Snapshoot) is a non-linear programming model used to estimate the rational of electricity consumption by the user side. The ExSS tool's structure, includes its input parameters, exogenous variables, and intermodule variables. The two principal factors determining energy demand are population growth and economic development. AIM/Enduse optimizes electricity supply by selecting the most cost-effective technological option based on ExSS-projected demand. The AIM/Enduse model's optimization is based on backcasting, which assigns goals and then tries to achieve them. The AIM/end-use model will choose the technology to meet demand based on energy and technology data input; determining electricity demand up to the simulation target year based on socio-economic factors; ii) the energy model will estimate the energy demands and GHG emissions released from the operation of the selected technology[6]. Additional technology and generating capacity to meet the nation's energy needs (service demand) is a mitigation step if GHG emissions are reduced compared to baseline conditions. Selected technology and capacity are combined to develop a plan for the power subsector and achieve GHG emission reduction targets and sustainability[7]. To meet Indonesia's Paris Agreement commitments, the power generation sub-sector will contribute to national efforts. The service demand (electricity) projection base year is 2010, and the target years are 2030 and 2050.

A baseline (BaU) and three mitigation scenarios (CM1, CM2, and CM3) were prepared to analyze the possibility of increasing mitigation efforts in the power subsector to reduce GHG emissions. Assumptions used to prepare projections for each scenario are presented in in Table 1 to Table 2. Table 2 presents the power supply mix by fuel type, the share of renewable energy is determined exogenously based on the government's power plan (includes co-firing efforts and optimistic penetration of solar energy through solar PV installation). Table 2 shows the power supply mix by fuel type, with the share of renewable energy determined by the government's power plan (includes co-firing efforts and optimistic penetration of solar energy through solar PV installation). In addition, CCS technology that is integrated with coal, biomass, and co-firing is carried out to address the challenges of carbon emissions.

Table 1. Assumed parameters in the model

Parameters	Baseline	CM1	CM2	CM3
GDP growth (constant price $ 2010)	5.50% (2020-2030) & 5.40% (2040-2050)			
Economics structure	Economic structure in 2030 & 2050 is still the same as that of 2010			
Share of energy in power	Share of energy in 2030 is the same as that of 2010	Following RUPTL	Following RUPTL and more renewables	Refer to RUPTL and maximizing share of renewables
Electricity demand	High demand			Low demand
Renewable energy	No additions of renewable energy generation since 2010	Geothermal, hydro, solar & wind, biomass, biofuel	Geothermal, hydro, solar & wind, biomass, biofuel	Geothermal, hydro, solar & wind, biomass, biofuel, cofiring (more biomass for existing 18.154 GW coal fired plant since 2030), begin to use nuclear energy in 2040
Others				- No new coal fired plant (coal w/o CCS) construction from 2040 - CCS is integrated with coal fired, natural gas, biomass plants (BECCS) since 2040

*RUPTL: general plans of power generation issued by state owned electricity company [8]

Table 2. Share of electricity generation by the source of energy for the scenarios

Energy type	2010	2030				2050			
	BaseYear	Baseline	CM1	CM2	CM3	Baseline	CM1	CM2	CM3
Coal	40.33%	80.00%	57.28%	51.88%	19.46%	94.47%	75.50%	74.90%	0.00%
Oil	20.11%	6.07%	0.36%	0.36%	0.36%	1.68%	0.10%	0.10%	0.12%
Natural gas	23.70%	9.15%	22%	22%	22%	2.53%	6.08%	6.08%	5.15%
Hydro	10.28%	3.10%	9.63%	10.6%	17.5%	0.86%	6.45%	6.45%	12.2%
Solar	0.00%	0.00%	0.14%	0.62%	4.85%	0.00%	0.86%	1.08%	8.98%
Wind	0.00%	0.00%	0.72%	1.67%	2.36%	0.00%	1.08%	1.18%	4.10%
Biomass	0.06%	0.02%	0.35%	0.35%	9.83%	0.00%	0.23%	0.40%	5.68%
Geothermal	5.51%	1.66%	7.86%	10.90%	14.41%	0.46%	8.60%	8.60%	11.24%
Biofuel (include diesel)			1.66%	1.66%	3.41%	0.00%	1.10%	1.20%	5.91%

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Co-firing	5.65%	0.00%	0.00%	0.00%	3.92%
Coal w/ CCS					14.06%
Co-firing w/ CCS					3.14%
Biomass w/ CCS					3.80%
Nuclear					16.53%
Waste	0.13%				0.05%
Natural gas w/ CCS	0.00%				5.15%

2.2. An overview of CO2 Bio-fixation using Airlift-Vertigro Reactor

Dewi et al. studied microalgae cultivation in an Airlift Vertigro bioreactor for CO2 biofixation. The airlift reactor used a closed system for better productivity than the open system (ponds). Airlift reactors are difficult to scale up and require a lot of energy if made on a plant scale. Integration between the airlift reactor and Vertigro (looped solar receiver) will make it easier to scale up the cultivation reactor, and the use of Airlift-Vertigro has high productivity (4-5 times compared to open pond system). Growing microalgae in the Airlift-Vertigro reactor will significantly reduce space area. Refers to the studies of microalgae cultivation using Airlift-Vertigro bio-reactor "submitted for publication[9]", several related parameters used to analyze the CO2 bio-fixation ability of microalgae Botryococcus Braunii to capturing the emitted CO2 from the fossil-fueled power plants (see Table 3)

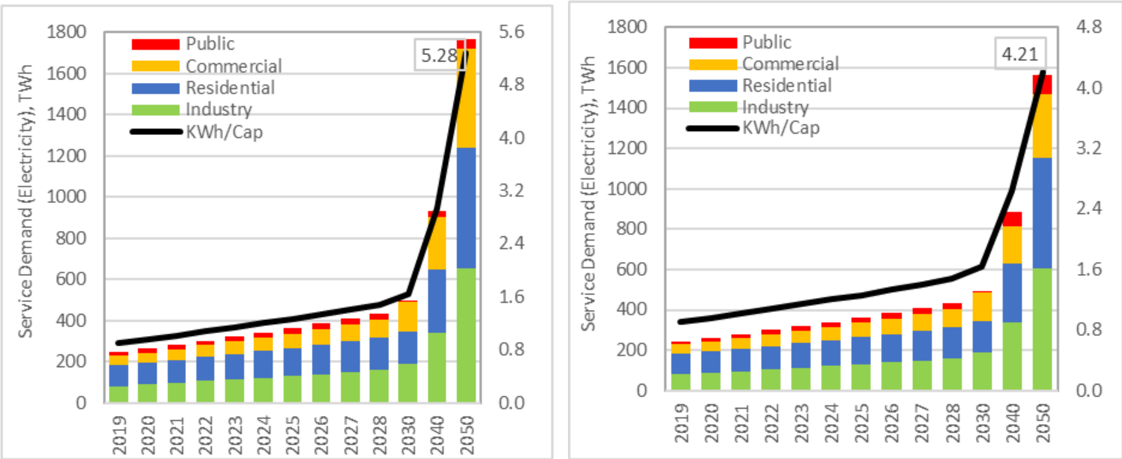
Table 3. Optimum parameter from research on Botryococcus braunii cultivation using integrated Airlift-Vertigro system[9].

Parameter	Results
Volume, L	150
Medium	Modified Chu
Volumetric flow rate of air, L/minute	22
CO_2 rate (15% on the basis of air flow rate), L/minute	3
Growth cycle, h	187
Dry weight, g/L.9days	0.145

3. RESULT AND DISSCUSION

3.1. AIM/Enduse Model Results: Power Sector Development Scenario

A rational national electricity demand projection is compiled to meet the service demand of end-user consumers, including industry, commercial, public services (PJU, city parks, houses of worship, etc.), and residential. Figure 1 shows the projected electricity demand growth for high (HD) and low (LD) demand. LD is national electricity consumption after consumer efficiency efforts toward deep decarbonization. Figure 1 shows that electricity consumption per capita will increase 5.7 to 7.2 times by 2050, to 5.28 kWh/cap (HD) and 4.21 kWh/cap (LD). Electricity demand is expected to grow 6.5% (2019-2028), 6.5% (HD) (2028-2050), and 4.8% (2050-2080). (LD).



(a) (b)

Figure 1. Projection of electricity demand and intensity, high demand (a) and low demand (b)

Electricity production will rise along with consumption, electricity production in 2050 will reach 1,771 TWh (HD) and 1410 TWh (LD), assuming 13% transmission and distribution heat losses. According to the 2019–2028 RUPTL (Figure 2), coal still makes up the majority (54.4%), followed by natural gas (22%) and oil (0.4%). Geothermal, hydropower, and other renewable energies (solar, wind, biomass, and waste) supply 23.2% of the electricity in 2028. GHG emissions in the power subsector depend on electricity production, fuel consumption, and GHG emissions, which vary by technology, efficiency, and fuel type. Figures 3 show electricity production by fuel type and technology in baseline and mitigation scenarios.

In 2010, coal produced 68.48 TWh (40.33%), oil 3.54 TWh (20.11%), natural gas 40.25 TWh (23.70%), hydropower 17.46 TWh (10.3%), geothermal 9.36 TWh (5.5%), biomass 0.10 TWh (0.06%), and other RE (solar and wind) 0.005 TWh (see Figure 2). In the baseline scenario, total electricity production is targeted at 563 TWh (2030), which 80% arriving from coal-fired power plants and 5% from renewables. Coal fossil plants will produce 1,929 TWh, or 94.5% of total electricity in 2050. In the extended NDC scenarios CM1 (unconditional) and CM2 (conditional), although coal power generation still dominates the national electricity production, the portion is reduced to 1,542 TWh (75.6%) and 1,516 (74.3%) in 2050. Coal plants are replaced by renewable energy and natural gas, and coal significantly decline from 34 TWh (1.67%) to 2 TWh (0.10%) in 2050. The CM3 mitigation scenario (deep decarbonization) assumes that in 2030-2050, the mitigation scenario has considered the existence of various emission mitigation intervention activities, including: (i) increasing the use of low-carbon technologies such as clean coal technology and advanced technology, (ii) increasing the use of renewable energy generation, (iii) fuel switching from oil to gas, and (iv) substituting diesel with biofuel in PLTD. In 2050, the renewable electricity supply will reach 69%, while CCS will reach 26%. Renewable energy and CCS increase 2050 capacity to 402 GW, or 1.4 times baseline (see Figure 3).

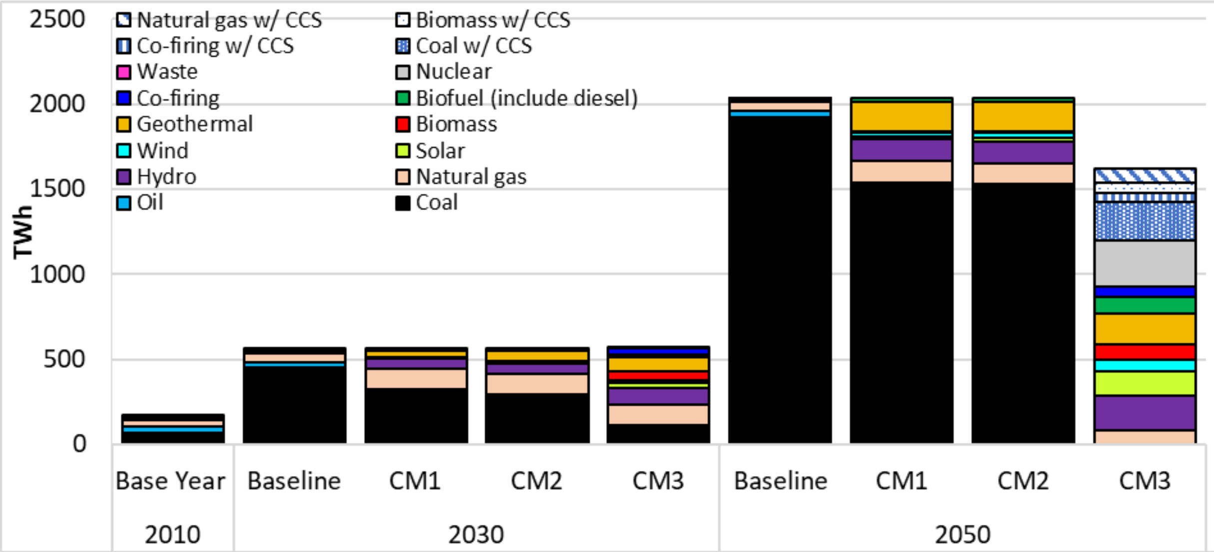


Figure 2. Projection of electricity supply in Power sub-sector

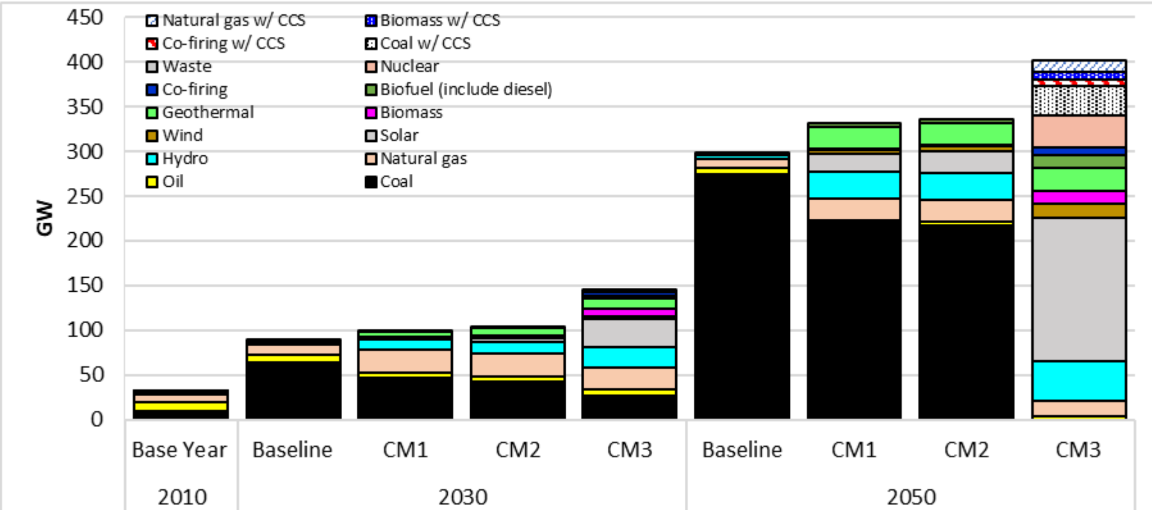


Figure 3. Technology mix in power subsector under baseline and mitigation scenarios

3.2. Projection of GHG Emissions and Its Potential Reduction

Population, economy, and income growth will increase energy demand, especially electricity. The high rate of emission growth in the power sector is due to the dominance of coal-based power plants (see Figure 3), especially with conventional technology. Figure shows that baseline GHG emissions are expected to rise from 138 million tons of CO2e in 2010 to 2,036 million tons in 2050 (7.61%/year).

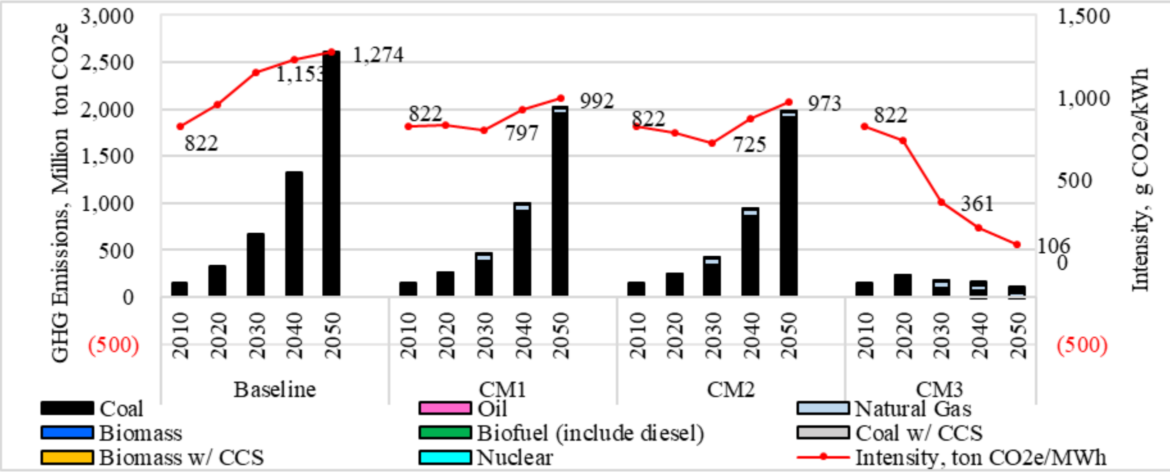


Figure 4. Projection of GHG Emissions Level

The CM1 and CM2 scenarios, which refer to Indonesia's extended NDC, can provide the potential for emission reductions of up to 200 million tons of CO2e (CM1) and 241 million tons of CO2e (CM2) in 2030—referring to the target of GHG emissions reduction in the energy sector by 314 (unconditional) and 398 (conditional) in 2030. The electricity sector can support the energy sector's NDC target of 65% unconditional and 61.2% conditional. Both scenarios reduce 575 and 612 million tons of CO2e by 2050. In the CM3 scenario, intensive GHG emission reduction targets (reaching 4 times the CM1 reduction potential) can reduce intensity by 92% from the 2050 baseline level. The significant reduction shows that CCS implementation is a crucial approach to achieve GHG emission reductions to a deficient level (deep decarbonization). The potential amount of capturable CO2 emitted from the fossil-fueled power plant is expected to reach 85.9 million ton CO2e in 2040 and 310.4 million tons CO2e in 2050 (details amount of CO2 to be captured see Table 4).

Table 4. Amount of CO2 to be captured by type of power generation plant

CCS type	Amount of CO_2e (Mt/a)	
	2040	2050
Biomass_CFB w/ CCS	0.000	0.216
Biomass_IGCC w/ CCS	0.512	0.755
Cofiring_PC w/ CCS	23.486	46.972
Coal_IGCC w/ CCS	0.002	0.002
Coal_Sub critical w/ CCS	0.003	0.002
Coal_USC pulverized w/ CCS (PCC)	0.003	0.002
Coal_SC (Supercritical) w/ CCS	44.732	229.287
Natural gas Combined cycle w/ CCS	17.151	33.205

Refers to Table 4, the CO2 emission can be further injected into geological storage (geologic sequestration) such as unused deep saline aquifers. Besides geologic sequestration, CO2 bio-fixation can be considered as another option for CO2 storage. Regarding the CO2 fixation, one of the options is photosynthesis by growing intensively managed Botryococcus braunii microalgae using the Airlift-Vertigro bioreactor. Microalgae is an attractive alternative to reduce CO2 emissions since they can utilize CO2 as a carbon source for their growth with implications on bio-fixation of this CO2 emission. Referring to the CO2 bio-fixation ability of microalgae (Table 3), the absorption of 1 million ton CO2 emissions requires 47.634 m3 volume of bio-reactor. In addition, the vertical growth system design is easier to scale up and significantly reduces space requirements. The required land to absorb same amount of CO2 is 5% in open pond system, 3% oil palm land, and 0.4% jatropha land[10]. Botryococcus braunii microalgal farming is seen only for mitigation measures through photosynthesis, probably uneconomical. Since the algae produce biofuel (microalgal oil) and chemicals, if it is designed for CO2 mitigation measures through photosynthesis and all at once for fuel/chemical production, such an endeavor could be economically justifiable.

4. CONCLUSIONS

The study concludes that the development of GHG emission levels in the power subsector is dependent on each generating system's level of electricity generation with fuel consumption and the related GHG emissions, which vary based on technology, fuel efficiency, and fuel type. Due to the dominance of coal-based power plants with inefficient technology, GHG emissions are projected to increase dramatically from 138 million tons of CO2e in 2010 to 2,036 million tons of CO2e in 2050 (at a rate of 7.61% per year) under the baseline scenario. CM1 and CM2 refer to the targets in Indonesia's extended NDC that have the potential to reduce emissions by up to 200 million tons of CO2e (22%) and 241 million tons of CO2e (24%) in CM1 and CM2, respectively. In the meanwhile, the level of GHG emissions in the CM3 scenario must decrease significantly. The mitigation efforts can provide opportunities for emission reductions of up to 2,422 million tons of CO2e (more than four times the CM1 reduction potential) and trends of decreased intensity between 822 and 106 gCO2e/kWh, which is equivalent to a 92% reduction from the 2050 baseline intensity level. CO2 carbon capture technology is crucial to achieving deep decarbonization in the energy industry. CO2 biofixation might be considered as an alternate CO2 storage method. Regarding CO2 fixation, photosynthesis using the Airlift-Vertigro bioreactor to cultivate intensively managed Botryococcus braunii microalgae is one of the solutions.

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