Chapter 2

Defossilizing Chemical Industry as an Integrated Solution for Indonesia's Climate and Pandemic Crisis

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A. The Impact of The Chemical Industry on Climate Change

In light of international commitment to limit global warming at a level of 1.5° to 2°C, it is no exaggeration that all countries must put "net-zero emissions goal" as their utmost priority. This target, however, requires holistic efforts from multiple stakeholders and will reshape the way contributing sectors develop for decades to come. According to Indonesia's Nationally Determined Contribution (NDC), the country's total greenhouse gas (GHG) emissions would skyrocket from 1,334 Mton-CO_2e (in 2010) to 2,869 Mton-CO_2e (in 2030) if no countermeasures were implemented. Also, although the levels of emissions from industrial processes and product use (IPPU) were

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lower than in other sectors, such as energy, waste, agriculture, and forestry, the 2030's business-as-usual projection level of this sector was almost 2-fold higher than the number of emissions in 2010 (Government of Indonesia, 2021).

Unfortunately, to date, most discussions about climate change focus heavily on the energy and forestry sectors only. Meanwhile, improvements in the IPPU sector could also help enhance the emission reduction from both sectors. The emissions from the chemical industry, to be specific, are somewhat underestimated. Thus far, many attempts still focus on reducing and recycling industrial wastes, which is also an important objective. However, it is even more crucial to address the most fundamental problem—the dependency of the chemical industry on fossil resources as its raw materials. At the same time, as the world has progressively phased out fossil fuels as the primary energy source, many natural gases and oil exploration projects worldwide will end soon. This trend means that the chemical industry needs immediate undertakings to find alternative resources to secure its material input supply.

In the case of the energy sector, decarbonization is practicable by substituting fossil fuels with zero- or low-carbon power sources, such as wind, solar, hydro, and nuclear power. However, "decarbonizing the chemical industry" is impossible because almost all products we use today contain GHG. Moreover, most of those products contain materials originating from fossil-based resources. As a result, the extensive industrial revolution has resulted in the surplus of carbon concentration in the atmosphere transferred from the lithosphere. This CO_2 emission "leaks" from the manufacturing process of chemicals (production phase) during the period when commercial derived products deliver their functions (use phase) and after the disposal of those products (end-of-life phase). Hence, decoupling chemical production from fossil resources is arguably the most effective climate change mitigation measure for this sector.

Amid the struggle of fighting climate disasters, the entire world faces the second global crisis—the COVID-19 pandemic. Many climate campaigners expressed their concerns about how policymakers in many nations take this pandemic situation as an excuse to renege on their climate commitments (Harvey, 2020). Interestingly, accelerating climate action by greening the chemical industry could unlock the possibility of creating new jobs—one keyword that is pivotal for any post-pandemic recovery plan. Therefore, mitigation of climate disaster and the COVID-19 pandemic can be executed by outlining approaches that simultaneously address both crises.

This chapter explains the general concepts and recent progressions of defossilization technologies in the chemical industry to meet the "net-zero emissions" goal. As CO_2 predominantly contributes to global GHG emissions compared to other gases, the discussion in this chapter is limited to this emitter only. Moreover, even though the chemical industry also employs carbon as a source of energy, this chapter mainly focuses on the topics related to carbon utilization as raw materials (feedstocks). Lastly, the interconnection of the defossilization concept in the chemical industry with post-pandemic recovery is also discussed.

B. Decoupling Chemical Industry from Fossil Resources

Aside from being employed as fuels, fossil resources are now still the primary components to manufacture various important chemicals utilized by plastic, electronic, textile, food, cosmetic, pharmaceutical, and other manufacturing industries. These so-called petrochemicals are extracted or processed from non-renewable carbon sources, such as natural gas, petroleum, and coal. The vast majority of daily products used by humans contain components manufactured from these fossil-based raw materials. Besides, the International Energy Agency (IEA) report shows that the oil consumption as a feedstock for plastic production in the United States, Europe, China, and India would outnumber the quantity of oils utilized for transportation (International Energy Agency, 2018).

As shown in Figure 2.1, numerous commodity chemicals are derived from fossil-based feedstocks. Natural gas liquids (NGLs) drilled from the Earth's surface, including ethane, propane, and butane, are intermediates to generate olefins, such as ethylene propylene, which are raw materials to produce various platform chemicals, e.g., ethanol and 1,3-butadiene (for synthetic rubbers), and polymer, e.g., polyethylene (PE; for plastic packaging), polyvinyl chloride (PVC; for pipes and electric cables) and polyacrylic acid (PAA; for superabsorbent and disposable diapers). Meanwhile, benzene, toluene, and xylene (BTX) are formed from catalytic reforming of naphtha, one of the fractions from petroleum refining. These chemicals are starting materials to produce commercial polymers, such as polystyrene (PS; for Styrofoam products), nylon-6 (for synthetic fibers), bisphenol-A (BPA; for food ware products), polyurethane (PU; for kitchen foams, automobile interiors, and decorations), polyethylene terephthalate (PET; for plastic bottles) and phthalic anhydride (for plasticizers and dyestuffs). Coal gasification generates syngas consisting of hydrogen

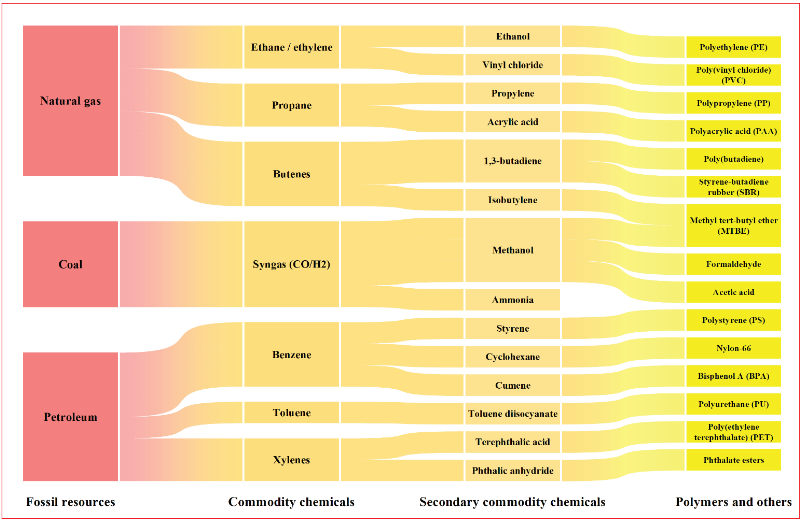


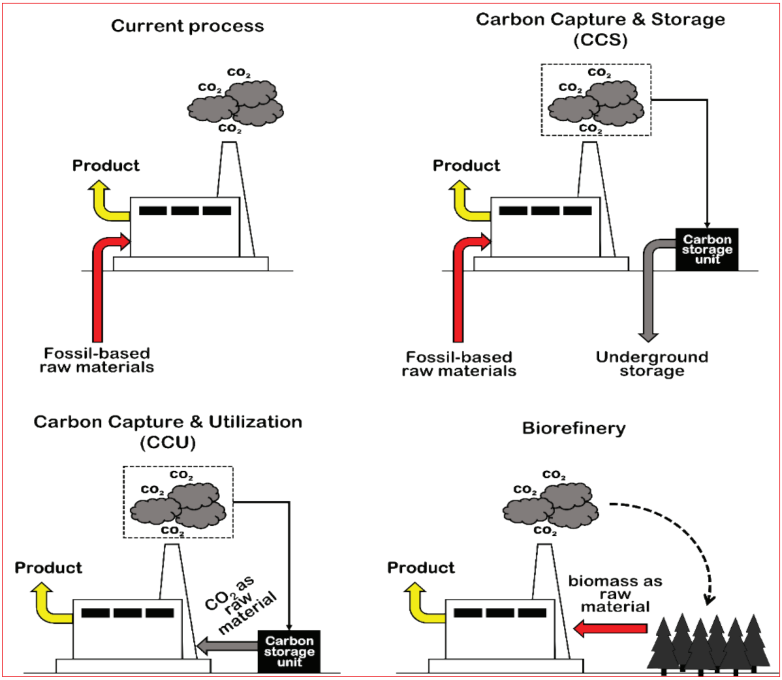
Figure 2.1 Production Flow of Several Fossil-Based Commodities in the Chemical Industry

and carbon monoxide, precursors for producing methanol and ammonia. Both chemicals, plus ethylene and propylene, are commodities with the most significant global production volumes and the highest GHG emissions compared to other chemicals (International Energy Agency, 2013).

C. Achieving Net-Zero Emissions in the Chemical Industry

To date, there are three approaches to achieving net-zero emissions (or, in this case, net-CO_2 emission) in the chemical industry. Briefly, as illustrated in Fig. 2.2., the CO_2 emission produced from converting fossil resources into target chemicals in the current industrial process leads to the positive accumulation of GHGs in the atmosphere. For that reason, many scientists explore methods to avoid the release of CO_2 by capturing the gas and storing it underground, i.e., geological storage, in the form of supercritical fluid, known as carbon capture and storage (CCS). However, this strategy still uses fossil resources as feedstocks. Therefore, rather than transferring the gas below the surface, the second approach, termed carbon capture and utilization (CCU), attempts to employ the generated CO_2 as a raw material to synthesize various chemicals. Unfortunately, there are still numerous technological limitations to efficiently obtaining the CO_2 with high purity from the air and performing the chemical conversion using CO_2 as the substrate due to its low reactivity. Meanwhile, the third approach uses organisms, such as plants and microorganisms, as a natural CO_2 capturer and converter before its utilization.

In CCS, CO_2 is captured using various methods, such as chemical adsorption, physical absorption, membrane separation, and biofixation. However, amine solution absorption is the most common technique (Rahimpour et al., 2020). The emitted gas can be directly captured from the ambient air (emitted during production, use, and end-of-life phase) and from point sources (emitted during production and end-of-life phase). Point-source-CO_2 captured from post-combustion of coal using the amine method has been well-established with a technological readiness level (TRL) of 9 (The Highest Score from 0 to 9). In contrast, direct capture of CO_2 from the air via the adsorption-desorption process has a TRL of 7 (Bui et al., 2018). The captured gas is then transported using pipelines or ships and stored underground. CO_2 is sequestrated by injecting it (in a supercritical fluid form) several kilometers below the Earth's surface in the location of depleted oil and gas fields, deep un-minable coal seams, or deep saline aquifer formations. It can also be stored in stable carbonate forms by a subsequent reaction with metal oxides (called mineral carbonation) (Nocito & Dibenedetto, 2020).



Source: Recreated with several adaptations from Gabrielli et al. (2020)

Figure 2.2 Schemes of the Current Industrial Process to Produce Chemicals from Fossil Resources and Three Approaches for Defossilizing the Chemical Industry: Carbon Capture and Storage (CCS), Carbon Capture and Uutilization (CCU), and Biorefinery

Despite public debates regarding its long-term safety, CCS's impact on reducing atmospheric CO_2 concentration is somewhat undeniable. Data in 2018 shows that there were 37 major commercial-scale CCS facilities worldwide; most of them were in the United States and China (Bui et al., 2018). Meanwhile, in Indonesia, Pertamina and several multinational companies have initiated CC(U)S projects in Java, Sumatra, and Papua by 2021 (Karyza, 2021; Maulia, 2021; Pertamina, 2021a).

CCS may avoid the CO_2 release but not necessarily solve the unsustainability issue with fossil-based resources in the chemical industry. Therefore, in CCU, the carbon released during the manufacturing process is recycled to synthesize CO_2-based chemical products, thus supporting the circular carbon economy concept. It is worth noting that the captured CO_2 can also be utilized as fuels, mineral carbonization, construction materials, and others. However, its utility for chemical production is the only subject discussed here. A production-scheme scenario by Kätelhön et al. (2019) examined the conversion reaction of captured CO_2 into methanol (eq. 1) and methane (eq. 2) by reaction with hydrogen obtained from water electrolysis, as expressed by the following reactions:

$CO_2 + 3\,H_2 \rightleftharpoons CH_3OH + H_2O$ (eq. 1) (Rihko-Struckmann et al., 2010)

$CO_2 + 4\,H_2 \rightleftharpoons CH_4 + 2\,H_2O$ (eq. 2) (Rönsch et al., 2016)

Obtained methane is convertible to generate ammonia, whereas methanol can be an intermediate to produce olefins and BTX. Therefore, the second reaction is analog to the production flow depicted in Fig. 2.1. In France, theoretically, this route could reduce up to 50% of GHG emissions from the chemical industry over the entire product life cycle (from production until the end-of-life phase). Besides, further improvements could still be achieved by employing lower carbon-footprint electricity sources, such as solar or wind power, for the process. In terms of TRL, these methane-and-methanol-based

CCU strategies are assessed at a score of 7 or higher (Kätelhön et al., 2019); thus, adequately mature for industrial-scale development.

To date, these technologies are still optimized to establish cost-effective processes which use greener catalysts and consume less power and water. Despite its slow development, CCU technology has gained much attention from governments, industries, and investors. According to data from 1980, more than 1,500 patents related to CO_2 utilization for fuels and chemicals have been published, and most of them came from the United States (Norhasyima & Mahlia, 2018). Carbon Recycling International (CRI) was the first company that has started to produce CO_2-based methanol at an industrial scale in 2012 in George Olah Plant, Iceland, and, by 2019, its capacity has reached about 5 million liters of product per year and converted around 5,600-ton CO_2 per year (Richter, 2019). In Indonesia, a feasibility study to build a CO_2-based ammonia production plant in Sulawesi began in early 2021 in collaboration with Japan (Mitsubishi Corporation, 2021).

Both CCS and CCU have numerous obstacles in establishing methods to capture and convert CO_2 effectively and economically. Meanwhile, the biorefinery approach employs a natural system available in organisms, i.e., photosynthesis, to perform those works. This system transforms CO_2 into organic carbons as intermediate chemicals, such as ethanol, lactic acid, acetic acid, and glycerol, to generate target chemicals with higher economic values via well-established chemical reactions. As defined by IEA Bioenergy, biorefinery is a sustainable process to convert biomass into a variation of bio-based products and bioenergy (de Jong et al., 2012). In this process, renewable biomasses, such as grasses, starch, sugar crops, oil crops, lignocellulose, algae, and other organic residues, can substitute fossil-based feedstocks (Takkellapati et al., 2018).

Of all the renewable feedstocks, lignocellulose biomass (LB) is the most studied material. The general processing steps aim to transform LB into so-called 'bio'-based chemicals using various methods, such as thermochemical, chemical, biochemical, or/and mechanical techniques. LB contains three significant convertible fractions based on its chemical structure: cellulose, hemicellulose, and lignin. Cellulose and hemicellulose are polysaccharides; thus, they have sugar(s) as their main monomers. Cellulose is thicker due to its linear glucan structure, whereas hemicellulose is less stiff and also composed of xylans, mannans, galactans, and arabinans (Brunner, 2014). In contrast, lignin consists of aromatic carbons possessing guaiacyl, syringyl, and *p*-hydroxyphenyl groups (Mathews et al., 2015). Commonly, these polymers are separated and broken down into their monomers using pre-treatment and enzymatic hydrolysis steps. Afterward, simpler monomers are transformed into the platform chemicals via the fermentation step.

As depicted in Figure 2.3, numerous petroleum-based chemicals shown in Fig. 2.1. can also be synthesized from LB as feedstock substitutes. For instance, essential commodity chemicals, such as acetic acid, can be produced from cellulose and hemicellulose in lieu of synthe-

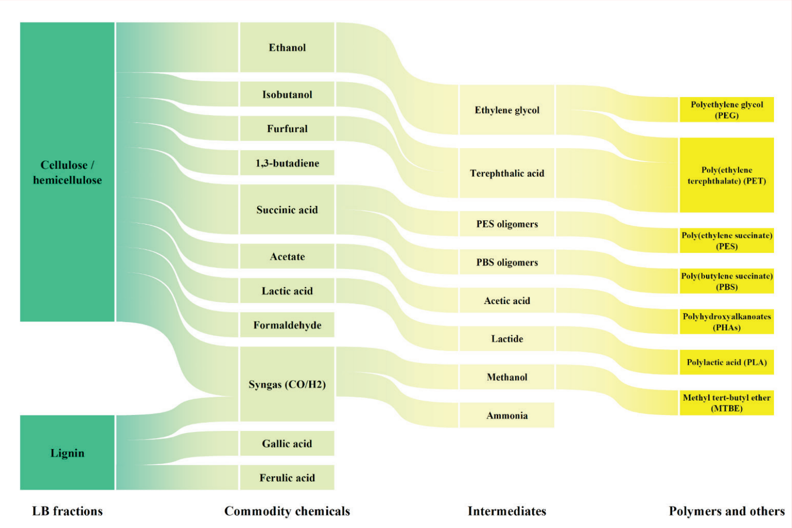


Figure 2.3 Production Flow of Several Bio-Based Chemicals Using Lignocellulose-Based Carbon Feedstocks

sized from syngas-origin methanol. Also, instead of extracting NGLs to manufacture 1,3-butadiene, this chemical can be produced from bioethanol via catalytic conversion or fermentation (Jones, 2014; Mori et al., 2021). Bio-PET, a bio-based version of PET, can be synthesized by mixing bio-ethylene glycol (bio-EG) with bio-terephthalic acid (bio-TPA) obtained from transforming bio-furfural or bio-isobutanol (Nakajima et al., 2017). In addition to bio-based traditional plastics, LB can also be utilized to make "bio-based biodegradable" (originated from renewable sources and can naturally be degraded) plastics, e.g., polylactic acid (PLA) and polyhydroxyalkanoates (PHAs), from bio-based monomers, e.g., bio-lactic acid and bio-acetic acid, respectively. Besides being greener, those commercial biodegradable polymers also possess thermal, mechanical, rheological, and physical properties that are competitive with fossil-based plastics. Thus, they are futuristic plastics that can substitute low-density polyethylene (LDPE), polystyrene, and other mainstream plastics (Naser et al., 2021).

TRL of biorefinery varies depending on the type of feedstock utilized and target chemicals produced. Conventional (starch and sugar crop-based feedstocks), oleochemical (oil crop-based feedstocks), LB, and marine biorefineries (microalgae and macroalgae-based feedstocks) have TRL levels at around 9, 7–9, 6–8, and 5–6, respectively (Lindorfer et al., 2019). Also, several biorefinery projects, especially ones related to biodiesel commodities have been initiated in Indonesia (Pertamina, 2021b). However, despite being less energy-intensive than CCU, biorefinery has one limitation related to its high land use requirement. A large amount of land for crop cultivations must be prepared near production plants to reduce the emissions from transporting process. A calculation shows that bio-based methanol production required almost 50-fold more area than CO_2-based methanol (CCU via direct capture and point source feedstock) (Gabrielli et al., 2020). Extensive deforestation in Malaysia and Indonesia might correlate with biodiesel refineries (Manikandan et al., 2016). Therefore, stricter regulations are needed to avoid a massive biodiversity loss.

In general, all three routes have prospective contributions to reducing CO_2 emissions from the chemical industry. It is also apparent that, unlike CCU and biorefinery, CCS does not entirely fit the "defossilization" concept. Nevertheless, compared to other schemes, this approach requires less fundamental adaptation in terms of infrastructure changes to the existing oil and gas production plants. Hence, this sector can be an immediate and transitional measure to fit low-carbon goals. As a tropical country, developing biorefinery technologies in Indonesia is very attractive. Also, green job creation is one of the foreground benefits of this approach (Kahar et al., 2022). However, the environmental aspect related to land-use change emissions should be carefully considered. Of all, CCU could be the most sustainable alternative. However, the high energy required to perform the chemical reactions is currently one of the most concerning bottlenecks for this approach. Also, the carbon intensity of energy applied to the process must be low carbon; otherwise, the total CO_2 emitted can surpass the emission level from the current industrial processes (Gabrielli et al., 2020).

D. Impact Of Defossilization on Green Jobs

In 2020 alone, the pandemic caused the loss of at least 255 million full-time jobs globally. Several climate-friendly industries, on the contrary, could potentially offer more vacancies for new workers compared to other sectors. For instance, in the case of Indonesia, one estimation claimed that 15.3 million green jobs would be created by 2045, mainly in the energy sector, if the government could adequately implement low-carbon strategies (Srivastava, 2021). Although, by far, the contribution of the chemical industry in expanding the employment rate has not been shrewdly calculated, this sector will undoubtedly help surge the availability of green-collared jobs.

According to Statistics Indonesia (BPS) (2020), manufacturing industries contributed to about 9.6% of jobs in Indonesia—albeit not all are related to the chemical industry. Unfortunately, the current systems adopted in the chemical industry are considered more capital intensive. Since many chemical plants use more robots than humans, expanding production plant capacity does not significantly create jobs. Data from the U.S. Census Department in 2007 revealed that petrochemical manufacturing was the subsector with the lowest labor/capital (L/C) ratio (indicates the number of jobs created per $1 million investment in productive capital) compared to other subsectors in chemical industries (Heintz & Pollin, 2011).

In contrast, fossil-resources-free industries, such as biorefinery plants, could generate more jobs than the current system. For instance, calculations using the L/C ratio in the plastic industry show that traditional petroleum-based plastic production generated only 1.2 direct and 3.1 indirect jobs (4.3 jobs, in total). In contrast, bio-based plastic production would generate 1.2 direct and 5.7 indirect jobs (6.9 jobs, in total) (Heintz & Pollin, 2011). A higher L/C ratio of indirect jobs from the bio-based plastic industry might be due to the labor-intensive cultivation stage, thereby requiring more human power. Furthermore, a report by one independent research provider unveiled that a direct-air-CO_2-capture plant with a one-million-ton capacity could create about 3,428 direct jobs. However, most of these jobs would be temporary and related to plant investment only. Meanwhile, employment related to the plant operations were estimated to be around 359 jobs (Larsen et al., 2020). These numbers will assuredly amplify if the CO_2 capture plant is also coupled with carbon utilization technology as an integrated CCUS system.

Contrasting the belief that phasing out fossil resources will jeopardize the employment rate, defossilization is, in fact, beneficial from the perspective of economics. The number of green jobs created from this sector can negate the unemployment loss from pandemics and the closure of fossil resource extraction plants. Therefore, phasing out fossil feedstock in the chemical industry must be encouraged.

E. Conclusion and Recommendation

Mitigating the climate threat requires comprehensive undertakings from all contributing sectors. Regrettably, the chemical industry is one area that tends to be overlooked by many. “Fossil fuel phase-out” is one of the most eminent jargons in any climate campaign. However, the fossil feedstock phase-out for the industry also needs to be provoked. By far, there are three schemes to realize this goal, namely via CCS, CCU (or, as an integrated-CCUS), and biorefinery. Altogether, those three defossilization routes provide, to varying extents, novel sustainability employments. These job opportunities can certainly negate the impacts of unemployment caused by the pandemic that began this decade. As the global transition to the green industry is inevitable, the Indonesian government must act post-haste to recognize this trend by preparing its infrastructures and human resources. Besides, this pandemic can be a kickstart to make a momentous shift toward developing a greener economic system.

Above all, actualizing this concept can be burdensome. Howbeit, here are several recommendations to implement the chemical industry defossilization as one of the country’s climate endeavors:

1. As the world is moving faster to implement a low-carbon chemical industry, Indonesia must also promptly immerse this concept. To address this, the development of the three previously discussed approaches must be reinforced altogether into the national strategic master plan. However, in the document of Indonesia’s Long-Term Strategy for Low Carbon and Climate Resilience 2050 (Indonesia’s LTS-LCCR 2050), the employment of CCUS technology still mainly focuses on the energy sector, whereas adopting it for supplying the feedstocks to the petrochemical industry is also indispensable.
2. Various schemes to produce bioplastics from numerous biomass have been invented (Kawaguchi et al., 2022). Stimulating the local manufacturers to develop and adopt these routes into their

production systems can be done by proposing several regulations. Indonesian government, to date, has initiated several bilateral and multilateral partnerships to advance these three technologies. Incorporating these topics into national research fund priorities is also pivotal. In addition, strategies to promote biorefinery through partnership schemes between startup and state-owned enterprises can also be explored.

3. During the transition to defossilize the chemical industry, action plans for resource efficiency must also be executed. Improving waste utilization technologies could help attain resource efficiency (Pangestu, 2021). Regardless, this resource efficiency concept can also reduce the carbon footprint of chemical plants in non-carbon-based commodities, i.e., inorganic chemicals.
4. In addition to the feedstock supplies, GHG emissions from the chemical industry also majorly come from its energy input. Therefore, transitioning to greener energy for the industrial process is also urgent and must be done concurrently.
5. As yet, the studies that examine the economic impacts of these three defossilization schemes in Indonesia, particularly ones related to green job creation, are still inadequate. This information is crucial to proposing strategic policies related to integrating low-carbon industry goals with COVID-19 recovery plans.

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