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Questão **1**
Não respondido
Vale 1,00 ponto(s).

Analise as proposições a seguir, segundo o texto, e assinale a alternativa **CORRETA**.

I – O artigo de revisão em questão aborda pontos importantes sobre a utilização ou implementação do sistema de $CO_2$ e $CH_4$ e suas limitações.

II – A emissão da concentração de $CO_2$ na atmosfera aumentou consideravelmente em relação ao século passado.

III – Gases de efeito estufa são consequências da queima de combustíveis fósseis, gerados a partir do suprimento da demanda de energia de hoje.

IV – A rápida crescente concentração de $CO_2$ e $CH_4$ no mundo ocasiona mudança climática e ameaça a vida marinha.

V – Além da poluição ambiental, verifica-se alta dependência de combustíveis fósseis, que dependem de centenas de milhões de anos para se formarem.

Escolha uma opção:

- Todas as alternativas estão corretas.
- As alternativas II, IV e V estão corretas.
- As alternativas I, II, IV e V estão corretas.
- As alternativas I, II, III e V estão corretas.

Questão **2**
Não respondido
Vale 1,00 ponto(s).

Em relação aos objetivos e aos aspectos metodológicos do estudo, é **INCORRETO** afirmar que:

Escolha uma opção:

- A Malásia, por meio do Plano Mestre de Tecnologia Verde, almeja combater a questão da mudança climática até 2030.
- A China deve reduzir a emissão de gás carbônico de 60 a 65% por unidade do PIB nas próximas duas décadas.
- Assim como a China, a Índia também compromete-se a reduzir a mesma quantidade de emissão de gás carbônico até o ano de 2030.
- Ainda que não possa contar com todos os líderes de 197 nações, o principal foco é o controle da temperatura global, sendo a Malásia um dos principais aliados à causa.

Questão **3**

Não respondido

Vale 1,00 ponto(s).

Analise as proposições a seguir e assinale a alternativa **CORRETA:**

I – Apesar de promissora, a redução eletroquímica envolve uma tecnologia que não garante boa eficiência de conversão de dióxido de carbono.

II – A redução eletroquímica envolve uma tecnologia que garante maior eficiência de conversão de dióxido de carbono em relação a outras tecnologias de utilização do $CO_2$.

III – A literatura citada pelos autores acerca da redução eletroquímica aponta pelo menos cinco catalisadores de metais utilizados.

Escolha uma opção:

- A alternativa II está correta.
- A alternativa III está correta.
- A alternativa I está correta.
- Nenhuma alternativa está correta.

Questão **4**

Não respondido

Vale 1,00 ponto(s).

Segundo o texto, em relação aos demais sistemas avançados de catalisadores, é **INCORRETO** afirmar que:

Escolha uma opção:

- A metanação consiste na utilização de $CO_2$ por meio da implementação de irradiações de luz. Ela inclui, por exemplo, a reforma seca do metano.
- A implementação da tecnologia de plasma tem o potencial converte gases de efeito estufa em combustíveis renováveis. Um dos tipos de plasma utilizados é o reator de descarga luminescente.
- A redução fotocatalítica consiste na utilização de $CO_2$ por meio da implementação de irradiações de luz. Ela envolve absorção de luz solar, separação dos elétrons e redução do dióxido de carbono na superfície dos fotocatalisadores pelos fotoelétrons gerados.
- A conversão fotocatalítica de $CO_2$ é afetada pelo fotocatalisador usado, o design do fotorreator e as variáveis experimentais, como a temperatura da reação, pressão e tipos de solventes usados.

Questão **5**

Não respondido

Vale 2,00 ponto(s).

Com vistas a solucionar o problema da emissão excessiva de gases de efeito estufa, muitas abordagens têm sido propostas. Duas delas compreendem a diminuição do uso de combustível fóssil e o incentivo ao uso de energias limpas e renováveis. Quais são as outras duas abordagens citadas pelos autores? Explique-as, fornecendo suas principais características.

Questão **6**

Não respondido

Vale 2,00 ponto(s).

Discuta, apoiando-se nos argumentos dos autores, sobre a aplicação de tecnologia de plasma, mencionado, ao menos, um benefício e uma limitação.

Questão **7**

Não respondido

Vale 2,00 ponto(s).

Segundo os autores, há diversos catalisadores que podem ser usados no processo de utilização do $CO_2$. Contudo, o catalisador adotado deve conseguir reduzir o $CO_2$ e $CH_4$, e não converter $H_2O$ em $H_2$. Discuta a importância desse aspecto, com base nos argumentos dos autores.

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# Greenhouse gases utilization: A review

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ABSTRACT

The excessive global emission of greenhouse gases (mainly carbon dioxide, $CO_2$ and methane, $CH_4$), especially due to the burning of fossil fuel for energy and power generation, is the main cause to the air pollution and greenhouse effect. This has eventually brought many issues, such as climate change and global warming, that will affect the standard life of human beings. Many strategies have been proposed to further reduce the excessive emission of greenhouse gases, including $CO_2$ and $CH_4$ utilization. This method not only reduce the $CO_2$ concentration in the atmosphere, but also producing renewable energy (syngas) at the same time. Hence, $CO_2$ and $CH_4$ utilization is also a promising approach to assist in overcoming the energy crisis due to the increasing population in time. Basically, the utilization of $CO_2$ and $CH_4$ system can be categorized into four: (i) electrochemical reduction, (ii) advanced catalyst system, (iii) photocatalytic reduction, and (iv) plasma technology. In this review paper, the mechanism implemented on the four abovementioned categories and their respective limitations are presented. Besides, future recommendations to optimize the greenhouse gases utilization system for up-scaling purpose is also highlighted.

## 1. Introduction

Recent studies found that the concentration of carbon dioxide ($CO_2$) emission in the atmosphere has risen drastically when compared to the past century due to the growth of technology [1]. The uptrend of human population results in higher needs of energy. Nowadays, most of the energy demand is fulfilled by the burning of fossil fuel, which emits massive amount of greenhouse gases (GHG) [2]. Greenhouse gases are mainly made up of carbon dioxide ($CO_2$) and methane ($CH_4$). GHG trap heat in the atmosphere and contributing significantly to the rise in temperature and global warming [3–5]. The fast growing of the $CO_2$ concentration globally also leads to the potential of irregular climate and rise of sea-level that can threat sea life and most importantly the activity and survival of human beings [6]. In other words, the increase of energy demand leads to the growing of carbon footprint and brings a lot of negative impacts on the environment [7]. Other than environmental pollution, the fossil fuel depletion issue has also risen due to the high dependency on fossil fuels [8–10]. Fossil fuel requires hundreds of million years for its formation. However, the energy consumption rate is far beyond its formation rate, this causes society to lean more onto a sustainable development technology [11].

In order to solve this problem, The Paris Agreement was introduced at the United Nations Framework Convention on Climate Change's (UNFCCC) during the annual 21st Conference of Parties (COP21), since 1995 that was agreed upon 12th December 2020, represented by 197 nations leader that agreed to act upon battling with the danger of climate change together with adapting the huge impacts on the humans existence, The Paris Agreement targets to control the global temperature rise below 275.15 K as further precautions will be taken to restrict the temperature rise to 247.65 K [12]. Malaysia is one of the proud nations to support this cause of achieving a reduction in GHG emission and able to achieve the carbon neutral country. China executed the proper measure to reduce the carbon emission as per unit of gross domestic product (GDP) by 60 to 65 percent by the year 2030, India also aims to

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generate 40 percent of its electricity from renewable source and reducing the dependency on fossil fuel by 2030, hence enabling to decrease the emission intensity by 33 to 35 percent [12].

Malaysia through Ministry of Energy, Green Technology and Water Malaysia introduced the Green Technology Master Plan Malaysia 2017–2030 to support current effort to tackle the climate change issue together with developing the strategy in line with the megatrends of the world. Malaysia aims to reduce up to 45 percent of GDP by 2030 as an initiative for participating in the Paris Agreement. Strategic plans for the development of green technology to initiate a resource efficient economy together with a low-carbon emission. This effort is important to support Transformasi Nasional 2050 (TN50), the government vision to put Malaysia as one of the top nations on the economic development, innovation, and the citizen well-being by 2050 [13]. Fig. 1 shows the renewable energy generation targets and performance from the year 2018 and the target by the year 2025, Malaysia Government targets to achieve 20 percent of renewable energy capacity by 2025, that brings to total of 6,371 MW to comply with the demand of the industrialised Central Region (Greater KL) that consumes 43 percent of total electricity demand in Peninsular Malaysia, Malaysia succeeded to rank 37 in the Energy Trilemma Index that calculate the performance of countries that able to achieve a sustainable mix of policies and the balance score highlights on how excellent the country in managing the concession in the Trilemma, Malaysia is ahead of Australia (38) and Qatar (39) and closing in with Hong Kong (34), South Korea (35), and United Arab Emirates (36), the performance of the energy sector highly contributes to the achievement as the electricity and gas supply industries play a major role together with the oil and gas industries which are the pillar of the Malaysian economy, The Energy Commission is planning few strategies to achieve greatness following the Government's vision for environmental sustainability in the electricity and gas supply chain [14].

To tackle climate change and to meet the renewable energy production target set by the Malaysia's government, $CO_2$ utilization plays an important role. It offers benefits to not only reduce the $CO_2$ concentration in the atmosphere, but also to produce valuable products, such as formic acid and synthetic gas. Generally, the opportunity and possibility of $CO_2$ utilization not only on the $CO_2$ conversion, it also can be implemented on the non-conversion methods, for example, used as solvent for extraction, material processing, and catalyst system [15]. The term "$CO_2$ conversion" refers to the process such as conversion of $CO_2$ into chemical and fuels, and conversion of $CO_2$ into glucose by photosynthetic organism (e.g.: algal cultivation). Fig. 2 summarizes the strategies to minimize the $CO_2$ concentration level in the atmosphere, which are (i) by avoiding the $CO_2$ production, (ii) through the conversion and utilization of $CO_2$, and (iii) by extracting and storing the produced $CO_2$ from climate balance [16]. Among these, $CO_2$ utilization has gained a lot of interest, especially in the sustainable and renewable energy area [17,18]. Besides, it is more economically preferable because the product obtained through the $CO_2$ conversion process can be sold to counter the production cost. Conversion of $CO_2$ into biogas, bioelectricity, heat, and valuable chemicals are some of the examples of $CO_2$ utilization [19]. Among these, $CO_2$ conversion with methane ($CH_4$) is the most attractive as it allows the conversion of two greenhouse gases, $CO_2$ and $CH_4$, simultaneously into valuable synthetic gas, such as hydrogen ($H_2$) and carbon dioxide (CO). However, the molecular structure of both $CH_4$ and $CO_2$ are stable and hence, significant amount of energy, in other words, high production cost, is needed to convert it into valuable syngas. This is one of the major issues that must be resolved for commercialization [20]. In this review paper, the author focuses on the $CO_2$ and $CH_4$ utilization process, as it has high potential to be the permanent solution in tackling the global warming and achieving the Government's vision of neutral carbon cycle. Other than this, with this technology, energy demand can be fulfilled by the renewable energy alternatives and hence, the dependency on fossil fuels can be reduced.

## 2. Current technology in carbon dioxide and methane utilization

In order to solve and overcome the dramatically increment of GHG emission, many approaches have been proposed, including the carbon capture and storage (CCS), carbon capture and utilization (CCU), lowering the usage of fossil fuel, and pushing the needs of clean and renewable energy usage [21–23]. Besides, the spread of climate change awareness, the rise and fall price of fossil fuel, and the sustainability of energy security has promoted the research on the related area to seek for a better approach or to enhance the current technology to tackle the issue [24].

Carbon capture and storage (CCS) is a technique which can capture up to 90% of the $CO_2$ emitted. Generally, CCS consists of 4 main processes, which are (i) capture of $CO_2$, (ii) separate the $CO_2$, (iii) send the $CO_2$ to desired storage location, and (iv) store the $CO_2$. Nevertheless, this method requires large capital investment and has restricted by the

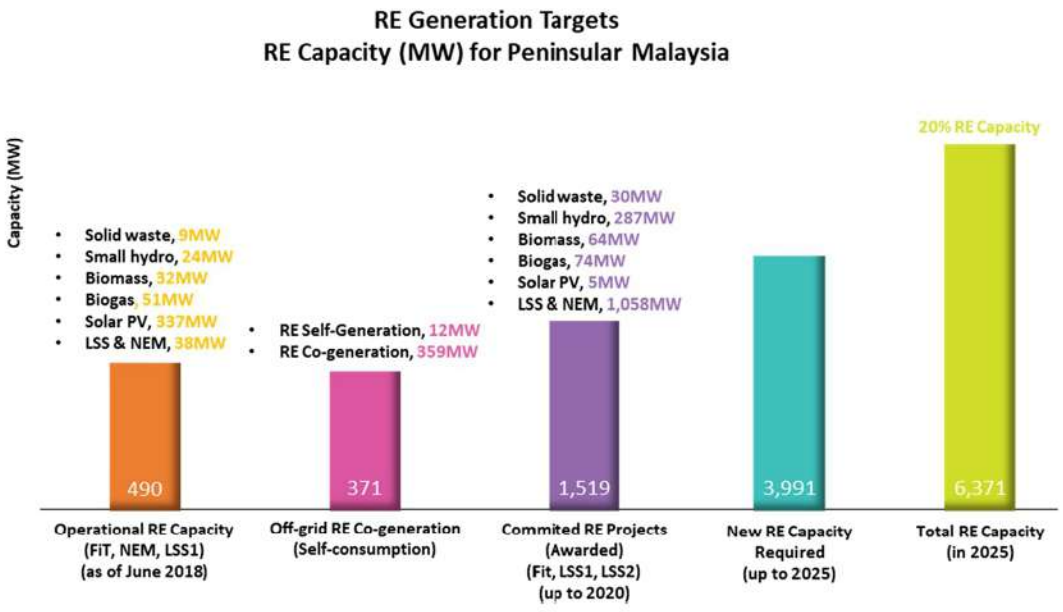


**Fig. 1.** Renewable energy generation targets for Peninsular Malaysia.

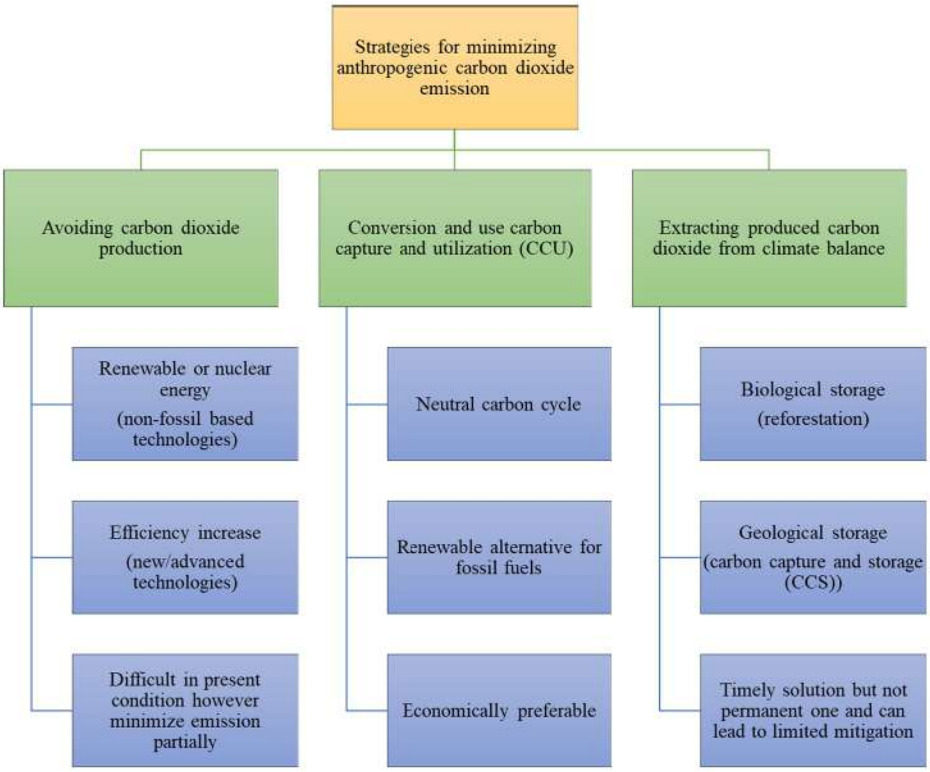


**Fig. 2.** Strategies for minimizing anthropogenic carbon dioxide emission.

limited geological sites that is suitable for $CO_2$ storage. Moreover, CCS treats $CO_2$ as waste and hence, this method does not meet the aim of sustainability [25]. Hence, carbon capture and utilization (CCU) has been introduced as it handles $CO_2$ as renewable carbon source, instead of waste. The goal of this technology is to recycle the unwanted $CO_2$ into valuable products. For example, formic acid (FA) is one of the valuable products that can be produced through $CO_2$ utilization. As compared to the conventional FA production process, the $CO_2$ utilization technology offers a greener option. Through this method, the $CO_2$ can be recycled, the dependence on fossil fuel can be reduced and thus resulting in positive environmental impact [26]. Other than this, carbon dioxide reforming of methane (CDRM) technology is also one of the famous $CO_2$ utilization processes. This technology consists of high potential in environmental aspects, but still not ready for commercialization since the catalyst deactivation cannot be optimized due to the slow kinetics of catalyst [22]. However, it still cannot be denied that CCU has high potential in solving the issue of GHG emission, although the investment costs for breaking down $CO_2$ are much more complicated to be defined [23]. Hence, more works should be done to fully understand the mechanism of the technology and to significantly reduce the void between a laboratory research and industrial processes for fully commercialization.

As mentioned previously, $CO_2$ utilization is one of the strategies to reduce the $CO_2$ emission and can be further classified into 4 categories (refer to Fig. 3), including (i) electrochemical reduction, (ii) photocatalytic reduction, (iii) advanced catalyst methanation, and (iv) plasma technology. The detailed processes related to the respective technologies will be explained in the next section. The problem or issue that were encountered for the $CO_2$ utilization technologies were also described. Hence, an overview of $CO_2$ utilization is presented. The objective of this review paper is to give a basic knowledge towards $CO_2$ utilization to researchers for the betterment of humanity.

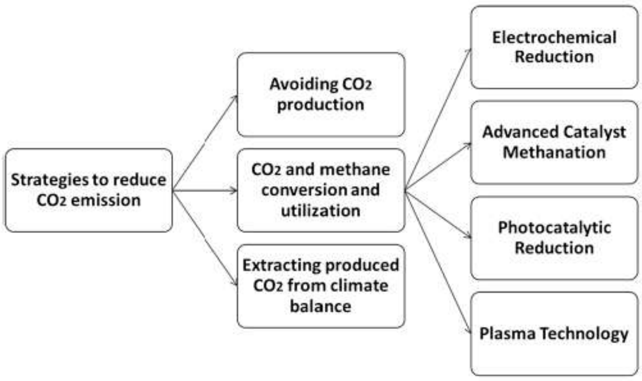


**Fig. 3.** Taxonomy of strategies to reduce carbon dioxide emission.

### 2.1. *Electrochemical reduction*

The electrochemical reduction technology of carbon dioxide has managed to gain the attention of researchers, due to its high reaction rate, good carbon dioxide ($CO_2$) conversion efficiency, and it is potentially more efficient and economical as compared to the others $CO_2$ utilization technology [27,28]. Usually, electrochemical reduction of $CO_2$ is done on metal electrodes and results in various valuable products [29,30]. The potential drop at electrodes regions can be altered from the voltage, it will excite electrons, achieving higher energies, and generating more direct-collision-based reactions [31]. Higher electron density also associates with a higher thermal conversion of the feedstock [32]. Basically, electrochemical reduction of $CO_2$ can be understood as a direct reduction process of carbon dioxide into reduced forms of carbon, such as methane, methanol, oxalate, formate, formaldehyde, carbon monoxide, and others [33]. The potential drop at electrodes regions can be altered from the voltage, it will excite electrons, achieving higher energies, and generating more direct-collision-based reactions [31].

Higher electron density also associates with a higher thermal conversion [32].

There are several works reported so far in utilizing $CO_2$ through this technology. Different approaches have been proposed to further enhance the efficiency. One of them is through the design of a stable and efficient electro-catalyst that can ensure electroreduction of $CO_2$ to CO with high faradaic efficiency (F.E.) at lower overpotentials. Fig. 4 shows the schematic drawing of the carbon dioxide electroreduction system, that has been designed from formate dehydrogenase (FDH) of *Thiobacillus* sp.. With this system, 40% faradaic efficiency was achieved [30]. In another study done by Rashid N. et al., the faraday efficiency of $CO_2$ utilized into CO and ethane in a $CO_2$ saturated acetonitrile solution is also 40% [34]. While the faraday efficiency production of formic acid from electrochemical reduction of $CO_2$ was found to be 91.3% [35]. and the Cu oxides/ZnO-based electrocatalytic has a faraday efficiency of 91.1% [36]. Sn-based electrolysis also can be a solution in conducting efficient electrochemical based as it achieved a maximum faraday efficiency of 94% [37]. Table 1 shows the metal catalyst used and summary of the description and findings for electrochemical reduction that was extracted from recent research articles.

Many electrochemical reduction technologies were developed in recent years. One of them is the concept of "Gas Switching Dry Reforming" (GSDR). GSDR is an experimental procedure to demonstrate dry methane process, that utilizing $CO_2$ in the production of synthetic gas (hydrogen gas and carbon monoxide). A reactor was built on the concept of utilizing a single fluidized bed reactor to operate reaction sequences from the oscillating air and gaseous fuel feeds, generating heat, and closely pure $CO_2$ for the implementation in a continuous dry reforming phase [43]. Moreover, Hou P. et al. stated that a novel technology that implemented membrane-electrode assembly to carry $CO_2$ electrolysis process showed high catalytic activity and selectivity to produce formate with faraday efficiency of 92.2% [44]. Furthermore, the introduction of solid oxide electrolyzer cell (SOEC) technology that can utilize, transport, and store the utilized $CO_2$ into renewable fuels

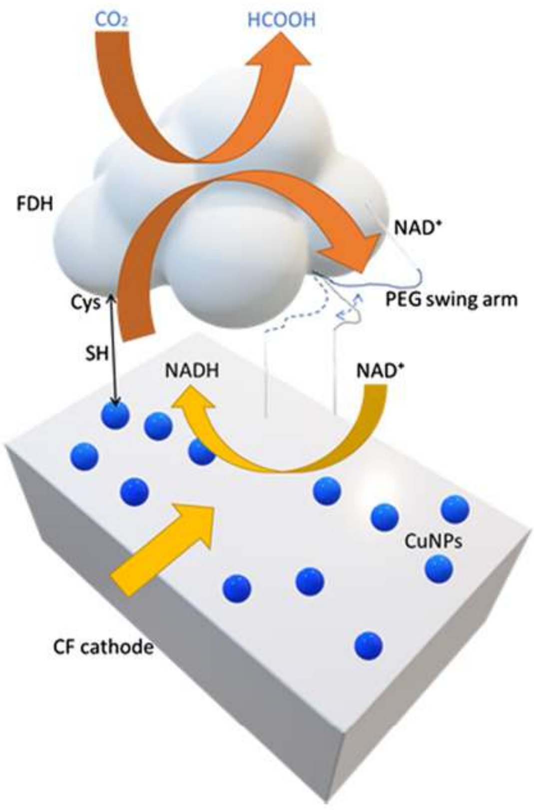


**Fig. 4.** The schematic illustration of the $CO_2$ electroreduction system.

**Table 1**
The catalyst used for electrochemical reduction.

| Metal catalyst used for electrochemical reduction | Description | Findings | Ref |
|---|---|---|---|
| Titanium aluminide powders from low titanium chloride pulp | • The electrochemical properties of aluminium ions were observed by square wave voltammetry (SWV) and cyclic voltammetry (CV) techniques.<br>• A platinum rod of 4 mm diameter as a quasi-reference rod, a 0.5 mm diameter of molybdenum wire as working, and 6 mm diameter graphite rod placed as counter electrode.<br>• The experiment was conducted in 673.15 K of the molten KCl-LiCl-$MgCl_2$ system containing 1.48 wt% $AlCl_3$ (0.18 mol $dm^{-3}$). | • The composition of the electrolyte and cathodic product of aluminium anode is found to be much more stable compared to graphite anode during electrolysis.<br>• The utilization of electrochemical reduction process from the preparation of Ti-Al alloy LTC proven to cost lesser engineering implementation compared to conventional industrial methods.<br>• The implementation of direct electrochemical reduction of LTC to Ti-Al alloys found to be short-cut process and green technology. | [38] |
| Oxide derived copper (Cu) | • Researcher focussed on the research review of reaction mechanisms oxide-derived copper catalyst that can increase the performance of $CO_2$ utilization compared with metal copper.<br>• Copper oxides is an important aspect in preparing copper catalyst as the oxide-derived copper catalysts will improve the catalytic performance compared to the non-treated metallic Cu. | • Copper has the unique capability to appropriately binds with CO to generate valuable $C_n$ products.<br>• The active sites of oxide-derived copper catalyst are still under investigation and needs more study to enable it for practical use.<br>• Cu is sensitive to ambient environment making it is hard to obtain a consistent result from the *ex situ* measurements of copper-based catalysts. | [39,40] |
| Silver (Ag) dendrite-type catalyst | • The production of dendrite-type silver catalyst with ethylenediamine (EN) additive from the electrochemical reduction process in an ammonia-based Ag deposition solution.<br>• The hydrogen evolution reaction (HER) involves at the cathode surface in the electrochemical reaction and needs to be considered in catalyst design since it can effect the CO production due to the reduction of | • The structure of dendrites were noted at a deposition potential of −0.45 V on Ag/Cl with 40 mM of EN additive.<br>• The intensity ratio of 220 and 111 of X-ray diffraction (XRD) that was ran by researcher can show the $CO_2$ utilization from the peak shown.<br>• Higher intensity ratio of 220 and 111 XRD was found indicating in better CO faradaic efficiency. | [41] |

(continued on next page)

**Table 1** (*continued*)

| Metal catalyst used for electrochemical reduction | Description | Findings | Ref |
|---|---|---|---|
| | Faradaic efficiency (FE).<br>• Silver-displacement deposited Cu foil, a platinum mesh, and Ag/AgCl with saturated KCl was used as working, counter, and reference electrodes. | | |
| Dendrite-type bismuth (Bi) catalyst | • Non-noble metals can be implemented as the metal catalyst for electrochemical reduction process due to the high stability features together with the low cost of the material.<br>• Bi dendrites contain higher index facets compared to Bi foil.<br>• The electrochemical surface area (ECSA) used to measure the Bi foil and Bi dendrite electrode by using the oxide monolayer method. | • It was found that a larger active surface area very beneficial for the electrochemical reduction process since it will provide larger number of active sites.<br>• The needle-like tips can enhance the local concentration of reactants and alter the adsorption energy that will enhance the production rate of electrochemical reduction. | [42] |

showed potential but is needed to be further explored in the future [45]. But few issues need to be addressed such as selectivity efficiency and stability of the electrocatalyst before it can be utilized in industrial scale [45,46]. Besides, the contaminants during the electrochemical reduction process can lead to performance loss over time [47].

The electrochemical reduction of $CO_2$ can provide a periodical energy storage in the shape of fuels and chemical. It can be very useful in the utilization of renewable electricity in chemical and fuel. The products of $CO_2$ reduction have wide application, such as CO that produced can be further processed into synthetic gas when reacting with hydrogen gas [48]. Hence, a complete understanding of the process is needed and it can be accessed through a profitability analysis of the process to show the whole view of the technology's practicability and sustainability [49].

### 2.2. *Advanced catalyst methanation*

As mentioned before, methane can be utilized with the presence of $CO_2$ into valuable syngas via direct methane conversion [42]. The utilization of $CO_2$ into valuable fuels and chemical products from catalytic transformation enables variation of green developments in industry [50]. Catalyst can enhance the process of $CO_2$ utilization but different catalysts require specific polymeric binder and specific manufacturing process to result individual optimum production [51,52]. A common heterogeneous catalyst has three parts which are, active phase (phase where reaction happens), support, and promoter [53]. Besides, by including a little amount of noble metals into the system, it can be a good strategy to boost the performance [54,55]. The enzyme catalyst can utilize $CO_2$ to produce valuable carbon-based chemical and fuel products [56].

The common technique to produce syngas in the industry is dry reforming of methane (DRM) [57]. DRM discovered to be an effective way in using GHG, methane, and $CO_2$ to produce syngas. Catalysts, such as Cerium (Ce) can be acted as a main role in DRM mechanism to transfer oxygen containing side products that will activate and extent the reactions according to Co/Ce ratio. Ce is known for its strong reaction with oxygen related groups from the ability of enhanced oxygen transfer [58]. Ce also known to provide huge improvement to convert $CO_2$, as Ce catalyst is more active and selective [59]. Besides, 873 K was found to be a practical DRM work temperature to be implemented as catalysts [60]. In short, performing DRM process needs a catalyst with strong ability to activate both $CO_2$ and $CH_4$ together with the capability to resist the deactivation during reaction process [61].

Even in this advanced time of technology, it is very challenging to come up with a technology to utilize $CO_2$ to methane with a highly efficient of heterogeneous catalysts that can be implemented for selective hydrogenation. A heterogeneous bimetallic Ni-Pd alloy was found to be a highly efficient catalyst from the catalyst system for selective hydrogenation that was designed and developed by the researchers. It was found that the synergistic effect between Ni and Pd from alloyed Ni-Pd catalysts that was supported on SBA-15 resulted a negligible metal leaching and high catalytic activity. It is very important to understand the composition and structure of bimetallic alloy to enable researchers designing a technology to utilize $CO_2$ to methane in a highly active heterogeneous catalyst that can be utilized for selective hydrogenation [62]. A pre-treated zero valent scrap iron (ZVSI) with green tea that resulted 10% higher production of hydrogen gas and has higher final pH value [63]. Fly ash also can be implemented as a catalyst for $CO_2$ breakdown. Fly ash is known to be a metal oxide with thermally stable feature. Fly ash can enhance the reactivity due to the unique pore characteristic and structure when utilize with porous materials such as zeolite. The utilization of fly ash can reduce the energy utilization and further optimizing the cost via mineralization [64].

The ability to synthesize an economical and green chitosan grafted multi-walled carbon nanotubes (CSMWCNTs) that used for chemical fixation formed on solid adsorbents for the carbon dioxide capture together as an efficient catalyst [65]. The decomposition of $CO_2$ from metal oxide catalyst, such as spinel-type nickel (Ni)-ferrites and strontium (Sr) / Iron (Fe)-based non-perovskites was investigated and it was found that approximately up to 90% of decomposition was achieved and more than 80% of $CO_2$ decomposition continued for an hour at moderate temperatures. $SrFeCo_{0.5}Ox$ catalyst was selected according to the theoretical mechanism that presents good manufacturing producibility and high decomposition, it is believed that it can contribute to reduce the emission of GHG [66]. Another catalyst activation to utilize $CO_2$ is under hydrogen that is needed to reduce nickel oxide (NiO) into nickel ion [67]. Nickel (Ni) can enhance the catalytic activity, stability, and resistance to carbon deposition during $CO_2$ utilization process [68]. Ni is recommended as catalyst as it can be utilized at high temperature [57,69,70]. It showed excellent catalytic activity with 85% conversion of $CO_2$ [71]. $Ni\text{-}MgO\text{-}Ce_{0.8}Zr_{0.2}O_2$ catalyst, however, achieved 72% of $CO_2$ conversion at 1073.15 K [72]. In another study done by Guo X. et al., 91.8% of $CO_2$ conversion has shown when utilizing metallic Ni at 523.15 K [73]. The implementation of NiO as catalyst resulted in 55.97% of $CO_2$ utilization [74]. As DRM process required to be conducted at high temperature, thermal stability will be an important aspect in selecting catalyst and Ni-based catalyst can be a promising way to further develop a high efficiency conversion of CO2 in the future [70,75].

Therefore, researcher needs to deal with the challenge of the thermodynamic stability of $CO_2$ that requires high energy to overcome the kinetic stable and the issue of a limited range of products that can be obtained from the utilization of $CO_2$. The low profit margin on chemical products as this new synthetic method from utilization of $CO_2$ requires to be economically viable for industry companies to trust and change their current process. This will require a larger expense to introduce such system for a large chemical producer, such as methanol, to construct a new and promising plant. Besides, current solid fuels technology still contributes to a high level of harmful pollutants emissions [76]. Current technology to come out with chemicals, such as CO, methanol, and formic acid, are still depending on fossil fuel-based feedstocks processes that have been optimized and can be run on a large-scale industry. Hence, the advanced catalyst methanation require to show a significant positive impact that can bring on economic despite the absence of any policy changes. A novel plant that implemented the advanced catalyst methanation that utilize $CO_2$ as a feedstock is needed despite the technology is still not ready for widespread implementation.

### 2.3. Photocatalytic reduction

Sunlight is a primary natural energy resources for life on Earth. The fossil fuels, that are being used extensively by human being nowadays, are also originated from the microorganism, which use sunlight as their main energy source, back to million years ago. In this section, the utilization of solar light for the conversion of greenhouse gases, particularly carbon dioxide $CO_2$, is presented. This technique is also known as photocatalytic reduction of $CO_2$ and it is important approach in utilizing $CO_2$ [77]. The working principle of photocatalytic $CO_2$ reduction with water ($H_2O$) is similar with the natural photosynthesis process, in which the $CO_2$ and $H_2O$ can be converted into oxygen ($O_2$) and carbohydrate in the presence of sunlight. Process of converting sunlight (solar energy) into carbohydrate (chemical energy stored in the bond) involves 2 main reactions, the water oxidation and carbon dioxide reduction [56]. The process can utilize $CO_2$ into valuable product such as methanol [78]. The photocatalytic agents in this process or so-called artificial photosynthesis are usually semiconductor or dyes photocatalysts. Some of the photocatalysts that are used for the $CO_2$ utilization process are reported in Table 2.

Photocatalytic process to transform $CO_2$ emerges to be a promising renewable technology that utilize $CO_2$ reduction through the implementation of light irradiations. Basically, the photochemical reduction of $CO_2$ involves the absorption of sunlight, separation of charge carriers (electrons) and followed by the process of $CO_2$ reduction on the surface of the photocatalysts by the generated photoelectrons. Photocatalytic conversion of $CO_2$ can be done in gas or liquid phase system. There are few products that can be obtained through the photocatalytic $CO_2$ reduction, including formic acid (HCOOH), carbon monoxide (CO), formaldehyde (HCHO), methanol ($CH_3OH$), ethanol ($C_2H_5OH$) and methane ($CH_4$) [83]. The photocatalytic $CO_2$ reduction is non-spontaneous (external energy is needed) to initiate the reaction, with the least for the formation of formic acid and maximum for the formation of $CH_4$. Among the abovementioned products, CO and $CH_4$ are the main products during the photocatalytic conversion of $CO_2$ in the gas phase system, but the production of CO can also be manipulated by altering the electron density [84–86]. These products can be used as fuel and it is important in reducing the dependency on non-renewable fossil fuel-based energy.

**Table 2**
Summary of photocatalytic technology.

| Photocatalytic technology | Remarks | Conversion efficiency | Ref. |
|---|---|---|---|
| Nickel ions incorporated in $TiO_2$ photocatalyst | • $CO_2$ utilization was experimented in a liquid photoreactor $TiO_2$ and Ni-$TiO_2$S<br>• $TiO_2$ and Ni-$TiO_2$ size of 10 to 20 nm<br>• The products were analyzed in a gas chromatography (GC) | 14 μmol/gcat during 60 mins<br><br>The efficieny is considerable low | [79] |
| p-n type heterojunction $ZnFe_2O_4/TiO_2$ photocatalysts | • Synthesized using hydrothermal method<br>• $ZnFe_2O_4/TiO_2$ ratio of (1:1.5)<br>• Conducted for 5.5 h in methanol<br>• 200 to 400 nm material size<br>• 500 W xenon lamp light source | 527.4 μmol/gcat during 5.5 h | [76,80,81] |
| Nano-$TiO_2$ materials | • Process of photocatalytic reduction of $CO_2$<br>• Presence of $H_2O$ vapor to produce hydrocarbons and syngas<br>• Presence of ultraviolet (UV) light source<br>• 300 W lamp with intensity of 154 mW/$cm^2$ | 30.019 μmol/gcat during 3 h | [82] |

In general, the photocatalytic conversion of $CO_2$ is affected by many parameters which can be categorized into 3 groups, including the photocatalyst used, the photoreactor design, and the experimental variables (reaction temperature, pressure, types of solvent used, catalyst concentration, light intensity and wavelength) [87]. Numerous works aiming to optimize the photocatalytic $CO_2$ conversion efficiency have been done by many researchers [81,88]. Some of the researchers suggested that accelerating the charge transfer in the interface of photocatalysts is a promising method to enhance the charge separation efficiency and in turn improve the photocatalytic $CO_2$ conversion efficiency. Shi et al. concluded that cobalt (Co) ion plays a huge role in bridging (titanium dioxide) $TiO_2$ and graphitic carbon nitride (g-$C_3N$) to accelerate the charge transfer, resulting a greater reaction stability and photocatalytic activity for the utilization of $CO_2$. Furthermore, it was also found that cobalt complexes $Co(bpy)_3Cl_2$ does not have photocatalytic activity in the presence of sunlight. However, it can work as a cocatalyst and active site for the electrons from other photocatalysts to further enhance the $CO_2$ conversion efficiency [56]. Other than photocatalysts, there are also researchers worked on optimizing the photoreactor design [89]. In designing a photoreactor, the light intensity and wavelength range should always be taken into consideration [89]. Silica and quartz are usually proposed to relay light as it has great transparency range, especially in the ultraviolet (UV) region. In addition, heat exchanger must be majorly considered when designing the photoreactor in order to allow proper interaction between the catalyst and the reactants [90].

Photocatalytic reduction emerges to be a good technology to be implemented in the utilization of greenhouse gases to produce valuable products [89]. The relying on sun ray can reduce the full dependency on grid electricity that can be very beneficial in reducing the dependency on fossil fuel and decreasing the greenhouse gases emission [91]. Nevertheless, this technology has few limitations. One of the major limitations is that the difficulty in developing methodology to obtain an accurate analytical measurement. Since photocatalytic $CO_2$ conversion involves multi-electrons process, and hence, there are various of products and intermediates by-products might be produced. This has increased the difficulty to identify and quantify the products which is critical to understand the process mechanism [92]. In short, there is a lack of selectivity toward a single product in the process. Moreover, photocatalytic $CO_2$ reduction efficiency is also restricted by the narrow range of suitable semiconductors to be used as the photocatalysts and shortage of full understanding on the response of the photocatalysts [93]. Furthermore, there are also problems associated with the use of water as sacrificial reducing agent. This is because the reduction of water is more favorable and results in hydrogen generation since the surface adsorption of water is preferable over $CO_2$ in liquid state [1,20,35,49].

Another photocatalytic conversion of hydrocarbon feedstock to produce solar fuels is from solar decarbonization process. It concentrates solar energy for high-temperature heating process, the conversion of $CO_2$ depends on the implementation of oxygen carrier material such as metal oxides. The oxygen carrier material can be mixed with reducing agent to reduce the endothermic reduction temperature [94]. This process can reduce the dependency of fossil fuel and focus on the chemical storage of solar energy. It can also reduce the GHG emissions and the non-appearance of contamination from the combustion of gases that can utilize solar energy to run the endothermic chemical reactions, resulting the capability of storing solar energy into moveable energy carriers [95]. In conclusion, there are still many barriers that must be rectified to create a sustainable and green technology that utilize only sunlight as the main energy source in producing valuable products, meeting the increasing human needs on fuels and chemicals, solving the fossil fuel depletion issue, and at the same time, reducing the $CO_2$ concentration in the atmosphere.

### 2.4. Plasma technology

Plasma is one of the four fundamental state of matter. It is usually made up of fully/partially ionized gas, and the characteristic is significantly affected by the electromagnetic field. There are several ways to produce plasma from neutral gas, for instance, through thermal excitation and by applying electricity on it. Firstly, the lighter electrons of the neutral gas absorbed most of the applied energy and become energetic. Then, the energy is transferred between the electrons and other heavy particles through collision, until thermodynamic equilibrium is achieved. Generally, plasma technology can be classed into two that is: (i) thermal plasma technology and (ii) non-thermal plasma technology [96]. In thermal plasma, the temperature equilibrium between the plasma particles is achieved and hence, most of the plasma particles consist of similar temperature. Therefore, thermal plasma can be expressed with a single temperature value. On the other hand, in non-thermal plasma, the temperatures between the particles are not balanced, which might be due to the insufficient of time or energy to achieve equilibrium state or certain cooling mechanism is implemented to avoid the heating of entire gas. Hence, non-thermal plasma can also be referred as low-temperature plasma or non-equilibrium plasma. Besides, non-thermal plasma is usually described by various temperature values, unlike the thermal plasma, in which the lighter electrons are usually higher in temperature (about 10,000 K) and consists of high energy [1,20,35,49].

The implementation of plasma technology to utilize and convert the greenhouse gases into value-added compounds and renewable fuels has attracted the interest of researchers, especially non-thermal plasma technology as the technology allow the process to be conducted at milder conditions [97]. Hence, in this paper, focus is given to the application of non-thermal plasma technology on the $CO_2$ utilization. Commonly, non-thermal plasma technology has various types of discharge methods which are: (i) radio frequency discharge (RF), (ii) microwave (MW), (iii) nanosecond pulse discharge, (iv) corona discharge (CD), (v) glow discharge (GD), (vi) dielectric barrier discharge (DBD), and (vii) gliding arc (GA) [98]. Table 3 shows the summary of different non-plasma technology implemented in $CO_2$ utilization and their respective conversion efficiency and energy efficiency in the recent studies.

As stated before, there are several discharge types of non-thermal plasma, which results in different product distribution [78,109,110]. Among these, the atmospheric dielectric barrier discharge (DBD) has gained interest recently as the design is simple and so, able to generate non-thermal plasma in a cost-effective manner. Besides, it can also convert $CO_2$ into CO with good yield and concentration, and with better energy efficiency [111]. Hence, numerous works have been done on the application of DBD in $CO_2$ utilization process [105]. Nevertheless, it was found that single DBD is not sufficient to fully decompose the contaminants in the carrier gas or treating gas and generate harmful by-products. Besides that, by using single DBD, especially for $CO_2$ and $CH_4$ conversion, there are unwanted solid carbon deposited on the inner wall of the reactor and on the surface of the electrodes. This eventually restricts the conversion efficiency of the reactor. Therefore, double-tube DBD has been proposed in order to protect the inner electrode from

**Table 3**
Summary of plasma technology.

| Plasma type | Remarks | Conversion efficiency | Energy efficiency | Ref. |
|---|---|---|---|---|
| Gliding arc plasmatron (GAP) | • Study the effect of $N_2$ on $CO_2$ utilization<br>• NO and $NO_2$ also formed | 50% | Seven times greater energy efficiency compared to dielectric barrier discharge (DBD) | [99] |
| Bimodal thermal plasma reactor | • Ratio of $N_2/CO_2$ = 1<br>• $CO_2$ flow rate = 25 L/min<br>• Discharge power = 12 to 15 kW | 45% to 48% | 18% to 19% | [100] |
| Glow discharge reactor | • Able to run at stable atmospheric pressure in a $CO_2$ atmosphere<br>• Presence of permanent magnetic field and constant discharge volume<br>• Approximately 70% of energy input used in the plasma | 20% | 14.4% | [101] |
| Magnetically enhanced gliding arc discharge (MEGAD) reactor | • Presence of magnetic field | 12.2% at 3000 mL/min<br>11.2% at 4000 mL/min | 24.3% at 3000 mL/min<br>27.9% at 4000 mL/min | [102] |
| Co-axial dielectric barrier discharge (DBD) reactor | • The utilization of 15% MO/ γ-$Al_2O_3$ (M = Ni, Cu) catalyst in the discharge zone | 15.7% | 1.597 mmol/ kJ | [103] |
| Zero-dimensional chemical kinetics model and vibrational kinetics | • Various conditions of reduced electric field, gas temperature, and ionization degree<br>• Run at a pressure of 100 mbar | 32% | 47%<br>Maximum of 86% by varying the parameters | [104] |
| Zero-dimensional model of a DBD reactor | • Maximum relative error of 5.5%<br>• Discharge length of 100 mm<br>• Discharge gap of 2.5 mm<br>• Discharge power of 10 to 50 W<br>• Discharge flow rate of 25 to 125 mL/min | Low conversion efficiency value,17.4%<br>High conversion efficiency value, 22.7% | At low conversion efficiency value, 8.3%<br>At high conversion efficiency value, 2.2% | [105] |
| DBD plasma reactor | • Three-dimensional porous structure of polyurethane foam was implemented for $CO_2$ utilization process | 27.4% | 9.2% | [106] |
| | • Utilize the process of dry | 68.4% | 90% | [107] |

(continued on next page)

**Table 3** (*continued*)

| Plasma type | Remarks | Conversion efficiency | Energy efficiency | Ref. |
|---|---|---|---|---|
| Microwave plasma torch | methane reformation<br>• Run at atmospheric pressure<br>• Microwave power of 6 kW<br>• $CO_2$:$CH_4$ molar ratio of 1:1 | | | |
| Gliding arc discharge | • Alter the gas temperature by using high frequency discharge<br>• Adjust the power density by using a micro-scale gliding arc reactor<br>• Remove the reverse reaction by adding $CH_4$ | At 1000 K gas temperature, 18%<br>At 3000 K gas temperature, 16.5% | At 1000 K gas temperature, 96%<br>At 3000 K gas temperature, 29% | [9] |
| Fluidized plasma reactor (FPR) | • Low concentration of copper as catalyst<br>• Photovoltaic energy applied for sustainability approach | 41% | 2.1% | [108] |

carbon deposition. Moreover, the production of harmful by-products can also be avoided by applying high energy to the reactor [97]. In the work done by Mustafa et al., a double dielectric barrier discharge (DDBD) reactor was built with single source of input power to examine the utilization of methane ($CH_4$) and to control the downside of single DBD in the generation of hydro-carbon production [98].

The possibility of implementation plasma technology to utilize $CO_2$ and methane has attracted the interest of researchers to further explore the plasma technology as it can be run at mild conditions. Plasma technology can keep and utilize the excessive emission of greenhouse gases into value-added compounds and renewable fuels [112]. Plasma technology can be classed into two that is: (1) thermal plasma technology and (2) non-thermal plasma technology. This article will explain and focus on the application of non-thermal plasma technology. Non-thermal plasma can also be referred as low-temperature plasma or non-equilibrium plasma. Non-thermal plasma is developed from the utilization of electric power to gas as voltage applied is sufficient to break down gas to positive ions, electrons, and other species (breakdown voltage). Other plasma components are heavier than electrons. Electrons can gain the energy from the electric field and characterized by the high energy [113]. Non-thermal plasma technology commonly has seven types which are: (1) radio frequency discharge (RF), (2) microwave (MW), (3) nanosecond pulse discharge, (4) corona discharge (CD), (5) glow discharge (GD), (6) dielectric barrier discharge (DBD), and (7) gliding arc (GA) [114]. Fig. 5 shows the schematic diagram of their DDBD reactor setup. With this design, a maximum $CH_4$ conversion efficiency of 76% was obtained. Moreover, the limitation of conversion efficiency due to the unwanted carbon deposition was resolved by using this design. Furthermore, there are also several ways to improve the $CO_2$ conversion efficiency, such as using catalyst with the plasma technology and to design and to optimize the electrode structure to further improve the catalytic activity and stability [106].

Although plasma technology consists of high potential with wide application, however, the main drawbacks of this technology is that the excitation of neutral gas into plasma requires high amount of energy. As mentioned before, most of the energy today is still fulfilled by the burning of fossil fuel. Hence, to make the plasma technology greener and more sustainable, renewable energy, such as solar energy, is recommended for plasma generation [106]. Dassou et al. investigated and conducted a series of $CO_2$ utilization process using a solar-gliding arc plasma reactor (refer to Fig. 6) [108]. They concluded that this solar-gliding plasma reactor has high potential in achieving better efficiency and continuous operation of solar thermochemical process. This is because by incorporating the solar thermochemical reaction system with the plasma technology, the non-thermal plasma formed might improve the chemical conversion as it assists the absorption of solar energy by the gas reactant [115]. In short, the application of solar-plasma reactor in greenhouse gases conversion offers superior benefits. This method allows the production of high-value products and plays a role in fulfilling the increasing fuels and chemical demand while mitigating climate change issue.

The utilization of $CO_2$ into higher-value products from a gliding arc electrical discharge combined with direct solar receiver-reactor for solar thermochemical synthesis has the great potential to enhance the chemical conversion since the nonequilibrium plasma in the reactor chamber can result to the increase of solar energy absorption [6].

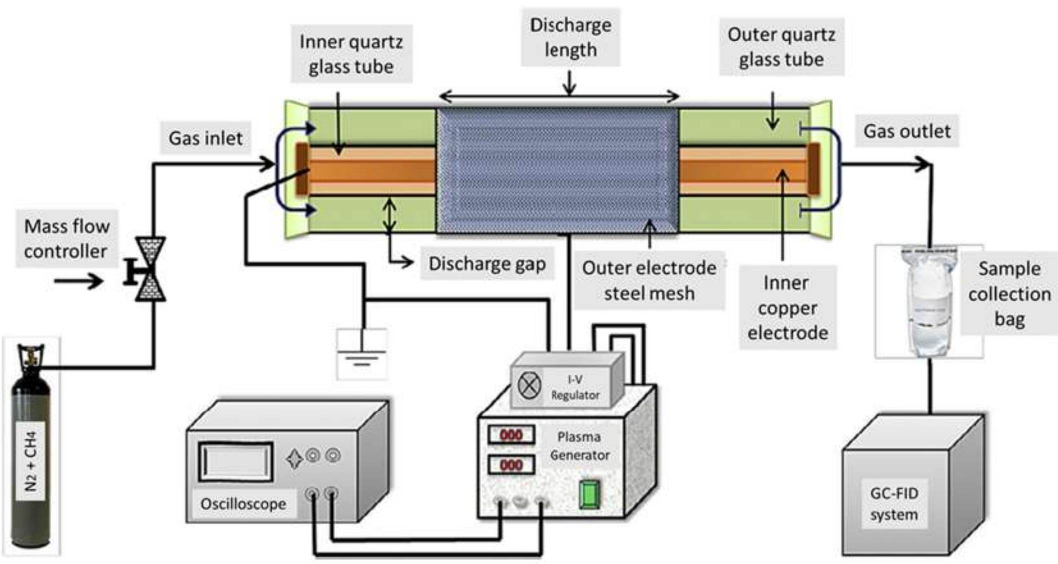


**Fig. 5.** The schematic illustration of DDBD reactor setup for methane utilization.

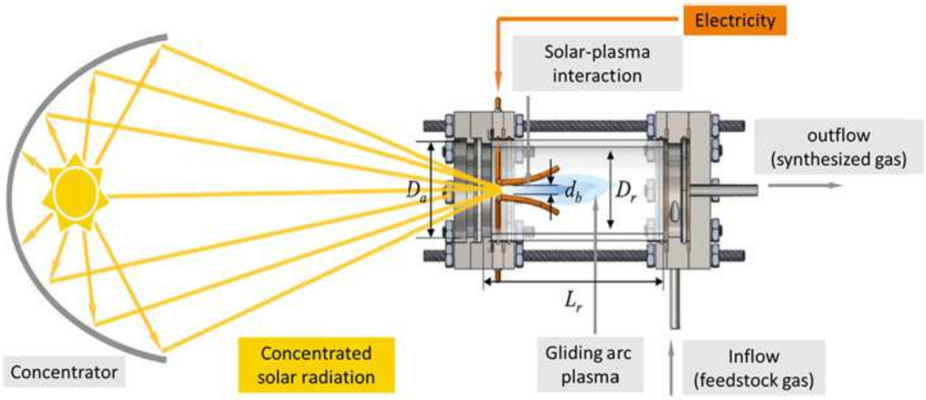


**Fig. 6.** The solar-plasma reactor concept.

Renewable energy also can be implemented for plasma generation since it will cut the operation cost significantly [113]. The solar-plasma reactor can be utilized for breaking down gas-phase feedstock into a valuable renewable gas stream from the reaction with the focussed solar radiation flux, this indicates that the utilization of solar-plasma can enhance the current solar thermochemical technology for $CO_2$ utilization process to reduce the sole intermittency of solar thermochemical system [106]. But a cost-effective fuel conversion technology that can control chemistry cracking without excessive heat and carbon production is much needed, since non-thermal plasma technology results in vibrational and electronic excitation that will ionize into positive ions and electrons [116]. Plasma energy also able to vibrationally excite in gas phase [116]. Among these plasma technologies, the microwave plasma technology was desired, due to the high-degree of non-equilibrium, that is important by the vibrational excitation of $CO_2$ [106]. Furthermore, the electrode structure needs to be designed and optimized according to past $CO_2$ electroreduction performance, so it will able to achieve high catalytic activity and stability [116].

## 3. Conclusions

A promising technology that consists of high potential, especially in term of sustainability and economically, is important for the future [116]. Carbon capture and storage (CCS) technology seems to be promising to battle with the excessive greenhouse gas emission (GHG). CCS technology is currently being implemented to tackle GHG emission issue but in smaller scale as CCS technology is not economically worth. Besides, CCS technology has the potential of leakage during the transportation and storage. CCS also requires additional electricity that can significantly increase the cost for its implementation. Hence, by introducing carbon capture and utilization (CCU) technology, these problems can be solved. CCU technology utilizes $CO_2$ and $CH_4$ to produce valuable products from mainly four processes namely: (i) electrochemical reduction, (ii) advanced catalyst methanation, (iii) photocatalytic reduction, and (iv) plasma technology. In $CO_2$ utilization, catalysts play an important role. There are different catalysts that can be used for $CO_2$ utilization process. However, the catalyst used must have the ability to reduce the $CO_2$ and $CH_4$, not to convert $H_2O$ into $H_2$. This is very important as the hydrogen evolution reaction that accompany along the $CO_2$ utilization processes has a significant negative influence on the specific experimental regulations, and resulting in low $CO_2$ conversion. Hence, further exploration should be done to acquire a functional catalyst that contains high catalytic selectivity and stability, this is very important since the hydrogen evolution reaction that will accompany along the utilization processes has a significant influence on the specific experimental regulations that resulting the low conversion of $CO_2$ that limits its development to be conducted practically. Physicochemical properties of different possible materials or catalysts, such as porosity, surface area, and electronic structure, should be determined and taken into consideration to find the best suitable catalyst for different $CO_2$ utilization process. Furthermore, the economic and technical barriers such as high production cost, low and limited yields of $CO_2$, poor electrical conductivity, and other issues should be further explored and overcome in the future.

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## CRediT authorship contribution statement

**Luqman Jeffry:** Conceptualization, Writing - original draft. **Mei Yin Ong:** Conceptualization, Writing - review & editing. **Saifuddin Nomanbhay:** Conceptualization, Writing - review & editing, Resources, Supervision, Funding acquisition. **M. Mofijur:** Writing - review & editing. **Muhammad Mubashir:** Writing - review & editing. **Pau Loke Show:** Writing - review & editing, Resources.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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# LÍNGUA INGLESA

## BIOMÉDICAS

## GABARITO

**TEXTO-BASE:** Jeffrey, Luqman et al. Greenhouse gases utilization: A review. **Fuel**, v. 301, 2021, p. 1-12.

**QUESTÃO 1:**

Enunciado: Analise as proposições a seguir, segundo o texto, e assinale a alternativa **CORRETA**.

I – O artigo de revisão em questão aborda pontos importantes sobre a utilização ou implementação do sistema de $CO_2$ e $CH_4$ e suas limitações.
II – A emissão da concentração de $CO_2$ na atmosfera aumentou consideravelmente em relação ao século passado.
III – Gases de efeito estufa são consequências da queima de combustíveis fósseis, gerados a partir do suprimento da demanda de energia de hoje.
IV – A rápida crescente concentração de $CO_2$ e $CH_4$ no mundo ocasiona mudança climática e ameaça a vida marinha.
V – Além da poluição ambiental, verifica-se alta dependência de combustíveis fósseis, que dependem de centenas de milhões de anos para se formarem.

Gabarito:
Todas as alternativas estão corretas.

Distratores:

1) As alternativas I, II, IV e V estão corretas.

2) As alternativas II, IV e V estão corretas.

3) As alternativas I, II, III e V estão corretas.

Justificativa: Com relação à alternativa I, o texto utiliza o termo "revisão" no subtítulo do artigo "A review", no resumo (abstract) e no último parágrafo da introdução, explicitando, no resumo, que abordará tanto o mecanismo implementado nas quatro categorias (redução eletroquímica, sistema catalisador avançado, redução fotocatalítica e tecnologia de plasma) quanto suas limitações. Com relação às alternativas II, III, IV e V, o texto explicita tais informações no primeiro parágrafo da introdução do texto: "Recent studies found that **the concentration of carbon dioxide ($CO_2$) emission in the atmosphere has risen drastically when compared to the past century** due to the growth of technology [1]. The uptrend of human population results in higher needs of energy. Nowadays, **most of the energy demand is fulfilled by the burning of fossil fuel, which emits massive amount of greenhouse gases** (GHG) [2]. Greenhouse gases are mainly made up of carbon dioxide ($CO_2$) and methane ($CH_4$). GHG trap heat in the atmosphere and **contributing significantly to the rise in temperature and global warming** [3–5]. **The fast growing of the $CO_2$ concentration globally also leads to the potential of irregular climate and rise of sea-level that can threat sea life** and most importantly the activity and survival of human beings [6]. In other words, **the increase of energy demand leads to the growing of carbon footprint and brings a lot of negative impacts on the environment** [7]. Other than environmental pollution, the fossil fuel depletion issue has also risen due to the high".

**QUESTÃO 2: (QUESTÃO COM DUAS RESPOSTAS CORRETAS)**

Enunciado: Segundo o texto, em relação ao Acordo de Paris, é **INCORRETO** afirmar que:

Gabarito:

a) Ainda que não possa contar com todos os líderes de 197 nações, o principal foco é o controle da temperatura global, sendo a Malásia um dos principais aliados à causa.

Justificativa: O texto aborda aborda parte dessa informação no segundo parágrafo da introdução: "In order to solve this problem, The Paris Agreement was introduced at the United

Nations Framework Convention on Climate Change's (UNFCCC) during the annual 21st Conference of Parties (COP21), since 1995 that was agreed upon 12th December 2020, **represented by 197 nations leader** that agreed to act upon battling with the danger of climate change together with adapting the huge impacts on the humans existence, The Paris Agreement **targets to control the global temperature** rise below 275.15 K as further precautions will be taken to restrict the temperature rise to 247.65 K [12]. **Malaysia is one of the proud nations to support this cause** of achieving a reduction in GHG emission and able to achieve the carbon neutral country".

b) Assim como a China, a Índia também compromete-se a reduzir a mesma quantidade de emissão de gás carbônico até o ano de 2030.
<u>Justificativa:</u> O texto afirma que o percentual de redução de emissão de gás carbônico pela Índia e pela China são distintos: "**India also aims to generate 40 percent of its electricity from renewable source** and reducing the dependency on fossil fuel by 2030, hence enabling to **decrease the emission intensity by 33 to 35 percent**".

<u>Distratores:</u>

c) A China deve reduzir a emissão de gás carbônico de 60 a 65% por unidade do PIB nas próximas duas décadas.
<u>Justificativa:</u> O texto aborda essa informação no segundo parágrafo da introdução: "China executed the proper measure **to reduce the carbon emission as per unit of gross domestic product (GDP) by 60 to 65 percent by the year 2030**".

d) A Malásia, por meio do Plano Mestre de Tecnologia Verde, almeja combater a questão da mudança climática até 2030.
<u>Justificativa:</u> O texto aborda essa informação no terceiro parágrafo da introdução: "Malaysia through Ministry of Energy, Green Technology and Water Malaysia introduced the **Green Technology Master Plan Malaysia 2017–2030** to support current effort **to tackle the climate change issue** together with developing the strategy in line with the megatrends of the world".

**QUESTÃO 3:**
<u>Enunciado</u>: Analise as proposições a seguir e assinale a alternativa **<u>CORRETA</u>:**

I – Apesar de promissora, a redução eletroquímica envolve uma tecnologia que não garante boa eficiência de conversão de dióxido de carbono.

II – A redução eletroquímica envolve uma tecnologia que garante maior eficiência de conversão de dióxido de carbono em relação a outras tecnologias de utilização do $CO_2$.

III – A literatura citada pelos autores acerca da redução eletroquímica aponta pelo menos cinco catalisadores de metais utilizados.

Gabarito:

A alternativa II está correta.

Distratores:

1) A alternativa I está correta.

2) A alternativa III está correta.

3) Nenhuma alternativa está correta.

Justificativa: Com relação à proposição I, os autores afirmam, no item 2.1, que a redução eletroquímica envolve uma tecnologia que garante boa eficiência de conversão de dióxido de carbono ("The electrochemical reduction technology of carbon dioxide has managed to gain the attention of researchers, due to its high reaction rate, good carbon dioxide ($CO_2$) conversion efficiency"); com relação à proposição II, no mesmo item, os autores afirmam ainda que a redução eletroquímica envolve uma tecnologia que potencialmente garante maior eficiência de conversão de dióxido de carbono em relação a outras tecnologias de utilização do $CO_2$ ("it is potentially more efficient and economical as compared to the others $CO_2$ utilization technology"); por fim, com relação à proposição III, na tabela 1, os autores citam quatro metais catalisadores usados na redução eletroquímica (pó de aluminetos de titânio, óxido de cobre, catalisador dendrítico à base de prata e catalisador dendrítico à base de bismuto". Portanto, somente a alternativa II está correta.

**QUESTÃO 4:**

Enunciado: Segundo o texto, em relação aos demais sistemas avançados de catalisadores, é **INCORRETO** afirmar que:

Gabarito:

A metanação consiste na utilização de $CO_2$ por meio da implementação de irradiações de luz. Ela inclui, por exemplo, a reforma seca do metano.

Justificativa: Ainda que a metanação inclua a reforma seca do metano como uma técnica comum para produção de energia renovável, como apontam os autores no segundo parágrafo do item 2.2, a redução fotocatalítica consiste na utilização de $CO_2$ por meio da implementação de irradiações de luz, segundo a explicação fornecida no item 2.3, no segundo parágrafo ("Photocatalytic process to transform $CO_2$ emerges to be a promising renewable technology that utilize $CO_2$ reduction through the implementation of light irradiations").

b) A redução fotocatalítica consiste na utilização de $CO_2$ por meio da implementação de irradiações de luz. Ela envolve absorção de luz solar, separação dos elétrons e redução do dióxido de carbono na superfície dos fotocatalisadores pelos fotoelétrons gerados.

Justificativa: A informação é fornecida no item 2.3, no segundo parágrafo ("Photocatalytic process to transform $CO_2$ emerges to be a promising renewable technology that utilize $CO_2$ reduction through the implementation of light irradiations. Basically, the photochemical reduction of $CO_2$ involves the absorption of sunlight, separation of charge carriers (electrons) and followed by the process of $CO_2$ reduction on the surface of the photocatalysts by the generated photoelectrons".

c) A conversão fotocatalítica de $CO_2$ é afetada pelo fotocatalisador usado, o design do fotorreator e as variáveis experimentais, como a temperatura da reação, pressão e tipos de solventes usados.

Justificativa: A informação é fornecida no item 2.3, no terceiro parágrafo ("In general, the photocatalytic conversion of $CO_2$ is affected by many parameters which can be categorized into 3 groups, including the photocatalyst used, the photoreactor design, and the experimental variables (reaction temperature, pressure, types of solvent used, catalyst concentration, light intensity and wavelength)".

d) A implementação da tecnologia de plasma tem o potencial converte gases de efeito estufa em combustíveis renováveis. Um dos tipos de plasma utilizados é o reator de descarga luminescente.

Justificativa: A informação é fornecida no item 2.4, no segundo parágrafo ("The implementation of plasma technology to utilize and convert the greenhouse gases into value-added compounds and renewable fuels has attracted the interest of researchers, especially non-thermal plasma technology as the technology allow the process to be conducted at milder conditions") e na tabela 3.

**QUESTÃO 5:**

Enunciado: Com vistas a solucionar o problema da emissão excessiva de gases de efeito estufa, muitas abordagens têm sido propostas. Duas delas compreendem a diminuição do uso de combustível fóssil e o incentivo ao uso de energias limpas e renováveis. Quais são as outras duas abordagens citadas pelos autores? Explique-as, fornecendo suas principais características.

Resposta esperada: O candidato necessita demonstrar a capacidade de localizar informações específicas no texto e de sintetizá-las. As quatro abordagens mencionadas no artigo são: (i) captura e armazenamento de carbono; (ii) captura e utilização de carbono; (iii) diminuição do uso de combustível fóssil; e (iv) incentivar o uso de energias limpas e renováveis. O candidato deve fornecer informações relevantes a partir de:
(i) captura e armazenamento de carbono: técnica que captura até 90% do $CO_2$ emitido e consiste de 4 processos principais: captura do $CO_2$, separação do $CO_2$, envio do $CO_2$ para um local de armazenamento desejado e armazenamento do $CO_2$;
(ii) captura e utilização de carbono: trata o dióxido de carbono como uma fonte renovável de carbono; recicla-se o dióxido de carbono não desejado, transformando-o em produtos de utilidade.

**QUESTÃO 6:**

Enunciado: Discuta, apoiando-se nos argumentos dos autores, sobre a aplicação de tecnologia de plasma, mencionado, ao menos, um benefício e uma limitação.
Resposta esperada: O candidato necessita demonstrar a capacidade de localizar informações específicas no texto e de sintetizá-las. Benefícios e limitações relativas ao uso da tecnologia de plasma são discutidas no quinto parágrafo do item 2.4. Segundo os autores, a excitação de gás neutro em plasma requer alta quantidade de energia. Os autores também mencionam que a maior da energia hoje é atingida pela queima de combustível fóssil. Assim, para que se possa tornar essa tecnologia mais verde, renovável e mais sustentável, como energia solar, a geração de plasma é recomendada. Baseados em outros estudos, os autores também argumentam que,

com a incorporação da reação termoquímica solar com a tecnologia de plasma, o plasma não-térmico formado pode melhorar a conversão química ao auxiliar a absorção de energia solar pelo gás reagente. Em suma, a aplicação de reator solar-plasmático na conversão de gases de efeito estufa oferece benefícios superiores.

**QUESTÃO 7:**

Enunciado: Segundo os autores, há diversos catalisadores que podem ser usados no processo de utilização do $CO_2$. Contudo, o catalisador adotado deve conseguir reduzir o $CO_2$ e $CH_4$, e não converter $H_2O$ em $H_2$. Discuta a importância desse aspecto, com base nos argumentos dos autores.

Resposta esperada: O candidato necessita demonstrar a capacidade de localizar informações específicas no texto e de sintetizá-las a partir da conclusão do artigo. O aspecto mencionado no enunciado da questão é central em virtude de a reação de evolução do hidrogênio junto aos processos de utilização de $CO_2$ candidato ter uma influência negativa nas regulações experimentais específicas, o que resulta em baixa conversão de $CO_2$. Dessa forma, a exploração futura deve ser feita para se adquirir um catalisador funcional que contenha alta seletividade catalítica e estabilidade, pois a reação de evolução do hidrogênio que acompanhará os processos de utilização de $CO_2$ possuem uma influência significativa nas regulações experimentais específicas que resultam em baixa conversão de $CO_2$. Isso limita o seu desenvolvimento para que possa ser conduzido em termos práticos.