

# Plasma-Enhanced Boudouard Reaction for Low-Temperature CO<sub>2</sub> Conversion in a Packed-Bed DBD Reactor

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## **Highlights**

- Non-thermal plasma enables Boudouard reaction at ambient conditions.
- Activated carbon improves CO<sub>2</sub> conversion compared with biochar.
- Carbon surfaces enhance CO selectivity via oxygen scavenging.
- Raman spectroscopy confirms defect formation in plasma-treated carbon.

## **1. Introduction**

Carbon dioxide (CO<sub>2</sub>) is the dominant anthropogenic greenhouse gas and a major contributor to global climate change. Converting CO<sub>2</sub> into value-added chemicals is therefore an important strategy for both emission mitigation and resource utilization. Carbon monoxide (CO) is a particularly important product because it serves as a key intermediate for fuels and chemical synthesis.

Conventional thermochemical pathways for converting CO<sub>2</sub> into CO require extremely high temperatures due to the strong thermodynamic stability of the CO<sub>2</sub> molecule. For example, the Boudouard reaction ( $\text{CO}_2 + \text{C} \rightarrow 2\text{CO}$ ) is highly endothermic and typically requires temperatures above 700 °C to achieve significant conversion.

Non-thermal plasma (NTP) provides an alternative approach for CO<sub>2</sub> activation under mild conditions. In NTP systems, energetic electrons can dissociate CO<sub>2</sub> molecules while the bulk gas temperature remains relatively low, allowing reactions that are thermodynamically unfavorable under conventional conditions to proceed [1]. Among different plasma technologies, dielectric barrier discharge (DBD) reactors are widely applied because they operate at atmospheric pressure and offer flexible control of plasma conditions.

In a DBD plasma, energetic electrons collide with CO<sub>2</sub> molecules and generate reactive species such as CO and O radicals. These species can subsequently participate in gas-phase and surface reactions, which may enhance CO<sub>2</sub> conversion [1].

In this study, the feasibility of the Boudouard reaction in a packed-bed DBD plasma reactor operating at ambient pressure was investigated. Particular attention was given to the role of carbon materials, including activated carbon and SWP550 biochar, in influencing CO<sub>2</sub> conversion and product selectivity.

## **2. Methods**

Experiments were conducted using a cylindrical dielectric barrier discharge reactor consisting of two concentric quartz tubes and stainless-steel electrodes. The reactor generated a plasma discharge region with a volume of approximately 4.45 cm<sup>3</sup>, and the input power could be adjusted between 0 and 80 W.

High-purity CO<sub>2</sub> was introduced into the reactor at controlled flow rates to vary the residence time. The reactor effluent was mixed with a constant flow of N<sub>2</sub> as an internal reference gas and analyzed using a gas chromatograph equipped with a thermal conductivity detector.

Different packing materials were introduced into the plasma discharge region to investigate plasma–solid interactions. These included BaTiO<sub>3</sub> dielectric particles as well as carbon materials such as activated carbon and SWP550 biochar. All packing materials were ground and sieved to particle sizes of 0.8–1 mm before use.

The structural evolution of the carbon materials during plasma exposure was characterized using Raman spectroscopy. The intensity ratio of the D and G bands (ID/IG) was used to evaluate changes in structural disorder in the carbon materials.

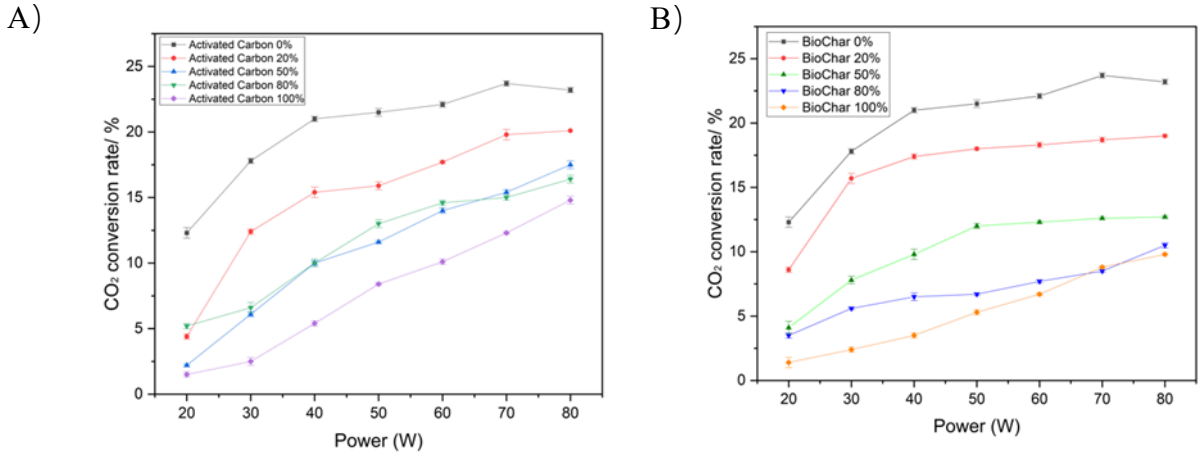
### **3. Results and discussion**

In the packed-bed DBD reactor, CO<sub>2</sub> conversion increased with increasing discharge power for all packing configurations. When carbon materials were used as packing, activated carbon consistently exhibited higher CO<sub>2</sub> conversion than SWP550 biochar. At an input power of 80 W, activated carbon achieved approximately 15 % CO<sub>2</sub> conversion, whereas biochar reached around 12 %.

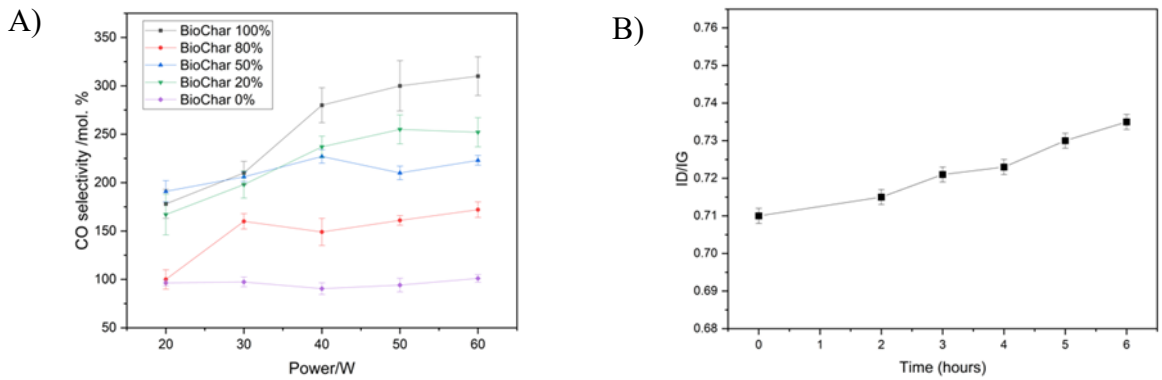
The superior performance of activated carbon can be attributed to its structural and electrical properties. Activated carbon possesses a significantly larger specific surface area than biochar, providing more adsorption sites for CO<sub>2</sub> molecules and plasma-generated reactive species. In addition, its higher electrical conductivity enhances local electric field intensification and promotes the formation of microdischarges within the packed bed [2,3].

The introduction of carbon materials also significantly influenced product selectivity. When carbon packing was present, CO selectivity exceeded 100 %, while O<sub>2</sub> selectivity decreased substantially. This observation indicates that additional CO was generated through the Boudouard reaction and through the consumption of oxygen radicals on the carbon surface. In this mechanism, carbon acts as an oxygen scavenger by reacting with plasma-generated O atoms and thereby suppressing the recombination of CO and O to form CO<sub>2</sub> [2].

Raman spectroscopy revealed a noticeable increase in the ID/IG ratio after plasma treatment, indicating an increased density of defects in the carbon structure. These defects likely originate from plasma-induced etching and oxidation processes, in which energetic oxygen species attack the carbon lattice and create vacancies as well as oxygen-containing functional groups [2].



**Figure 1.** A) CO<sub>2</sub> conversion of %Activated carbon packing reactor with respect to discharge power B) CO<sub>2</sub> conversion of % Biochar packing reactor with respect to discharge power



**Figure 2.** A) CO selectivity of % Biochar with respect to discharge power B) ID/IG of Biochar with time

#### 4. Conclusions

This study demonstrates that the Boudouard reaction can be initiated in a dielectric barrier discharge plasma reactor under ambient pressure and relatively low temperature conditions. Activated carbon showed superior CO<sub>2</sub> conversion performance compared with SWP550 biochar due to its higher surface area and stronger interaction with the plasma discharge.

The presence of carbon materials significantly enhanced CO selectivity by scavenging oxygen radicals and promoting additional CO formation through the Boudouard reaction. Raman spectroscopy further confirmed that plasma treatment increased defect density in the carbon structure.

These results highlight the potential of plasma-assisted carbon–CO<sub>2</sub> systems for low-temperature CO<sub>2</sub> conversion and provide insights into plasma–carbon interactions in packed-bed DBD reactors.

### **References**

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### **Keywords**

Non-thermal plasma; CO<sub>2</sub> conversion; Boudouard reaction; DBD reactor