# Synergistic Effects of Rare-Earth and Lanthanoid on P123-Modified Ni-HiMO Catalysts for Enhanced $CO_2$ Methanation Under Thermal and DBD-Assisted Conditions

Minh Nguyen-Quang*[a,b,c], Federico Azzolina-Jury[a], Bogdan Samojeden[b], Monika Motak[b], Patrick Da Costa[c]

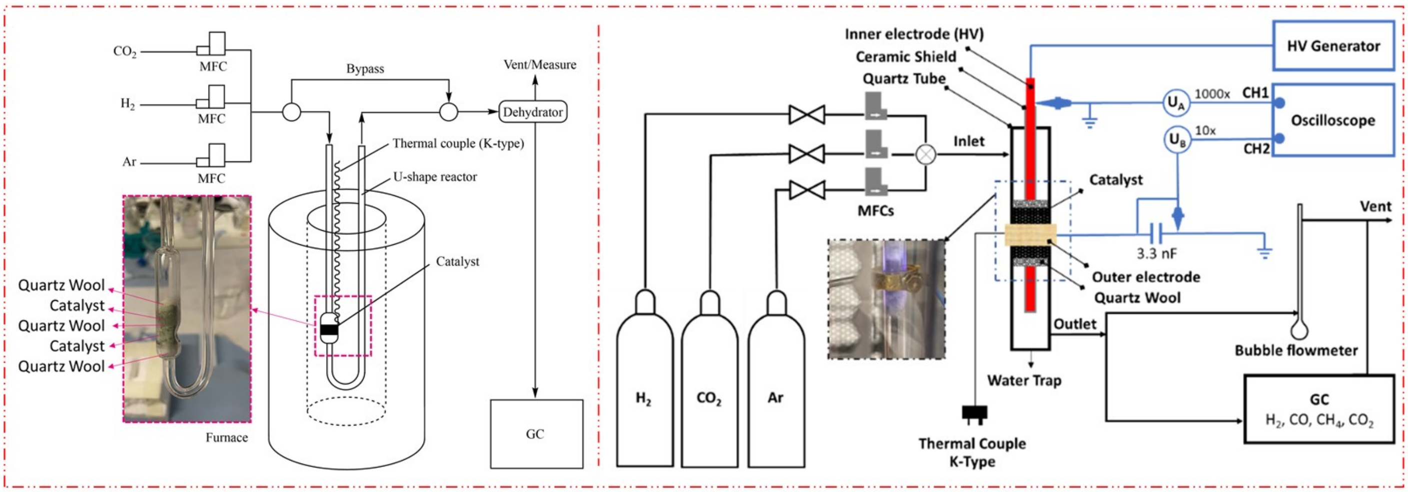
[a.] *Laboratoire Catalyse et Spectrochimie (LCS), CNRS-ENSICAEN-Université de Caen, 6 boulevard du Maréchal-Juin, 14000 Caen, France*
[b.] *Faculty of Energy and Fuels, AGH University of Krakow, Al. Mickiewicza 39, 30-059 Kraków, Poland*
[c.] *Institut Jean le Rond d'Alembert, Sorbonne Université, CNRS UMR 7190, 2 place de la gare de ceinture, 78210 Saint Cyr l'Ecole, France*

*Corresponding author: Minh Nguyen-Quang (m.nguyen-quang@liverpool.ac.uk)

## Supplementary Information

## Supplementary System Setup

**Thermal methanation (TM).** The thermal setup consisted of a U-shaped quartz reactor coupled with an external K-type thermocouple for temperature monitoring. The thermal reactor was placed inside a furnace, which allowed the temperature to reach 900 °C. Three mass flow controllers, one of each for $CO_2$, $H_2$, and Ar gas, were used to control reactant flows. They were mixed together before being injected into the reactor. The catalyst was covered by two layers of quartz wool in the reactor gourd (10 mm I.D.), see Supplementary Fig. 1a.




**Supplementary Fig. 1.** a. Thermal and b. Plasma $CO_2$ methanation setup

**Plasma methanation (PM).** The DBD plasma reactor was composed of a cylindrical quartz tube (10 mm O.D. × 7.6 mm I.D.), an external copper ring (thickness = 8 mm and height of 6 mm) - the ground electrode, and an inner tungsten rod (2 mm O.D.) aligned coaxially, which served as the high voltage electrode. The tungsten rod was covered by a thin layer of dielectric alumina (3 mm O.D), resulting in the double dielectric barrier discharge configuration. The ground electrode was circuited in series with a capacitor, $C_m$ = 3.3 pF. Electrodes were powered by an alternate current (AC) high-voltage power supply (Minipuls 6) with a maximum input voltage up to 29 kV and a frequency of up to 70 kHz. The electrical signals applied voltage ($U_A$) and the voltage across the capacitor ($U_C$) were recorded by a digital Pico oscilloscope (PicoScope® 5000 Series) via two voltage probes (1000X and 10X for $U_A$ and $U_C$, respectively). The studies were conducted in pseudo-adiabatic conditions, in which the plasma reactor was not insulated by a thermal insulator and was not heated externally. The discharge length and the gap of the DBD reactor were 6 mm and 2.3 mm, respectively, as a result of this setup, Supplementary Fig. 1b.