# Metal Organic Framework-Based Heterostructure Catalyst in Smart Photothermal System for $CO_2$ Conversion to Fuels

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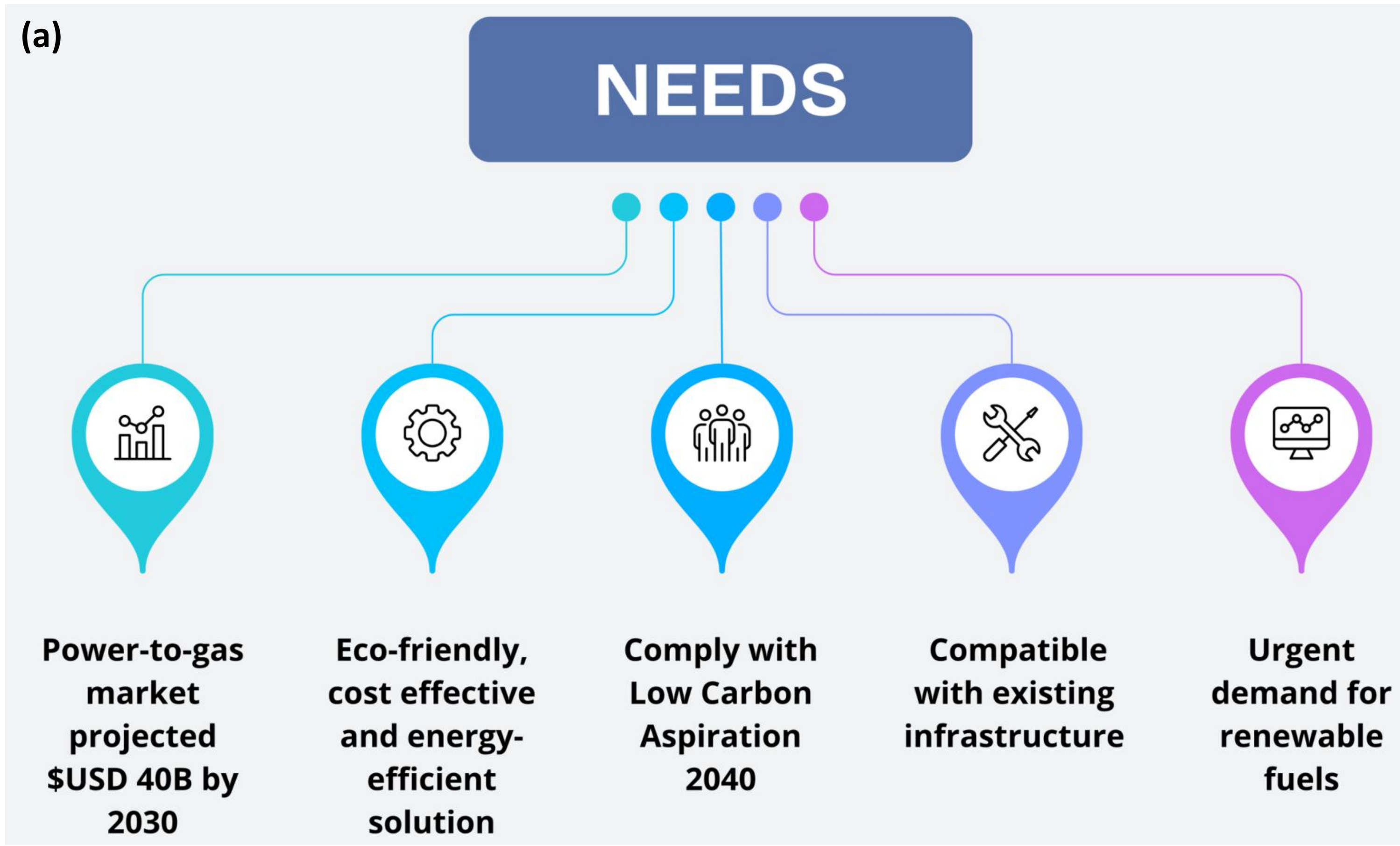
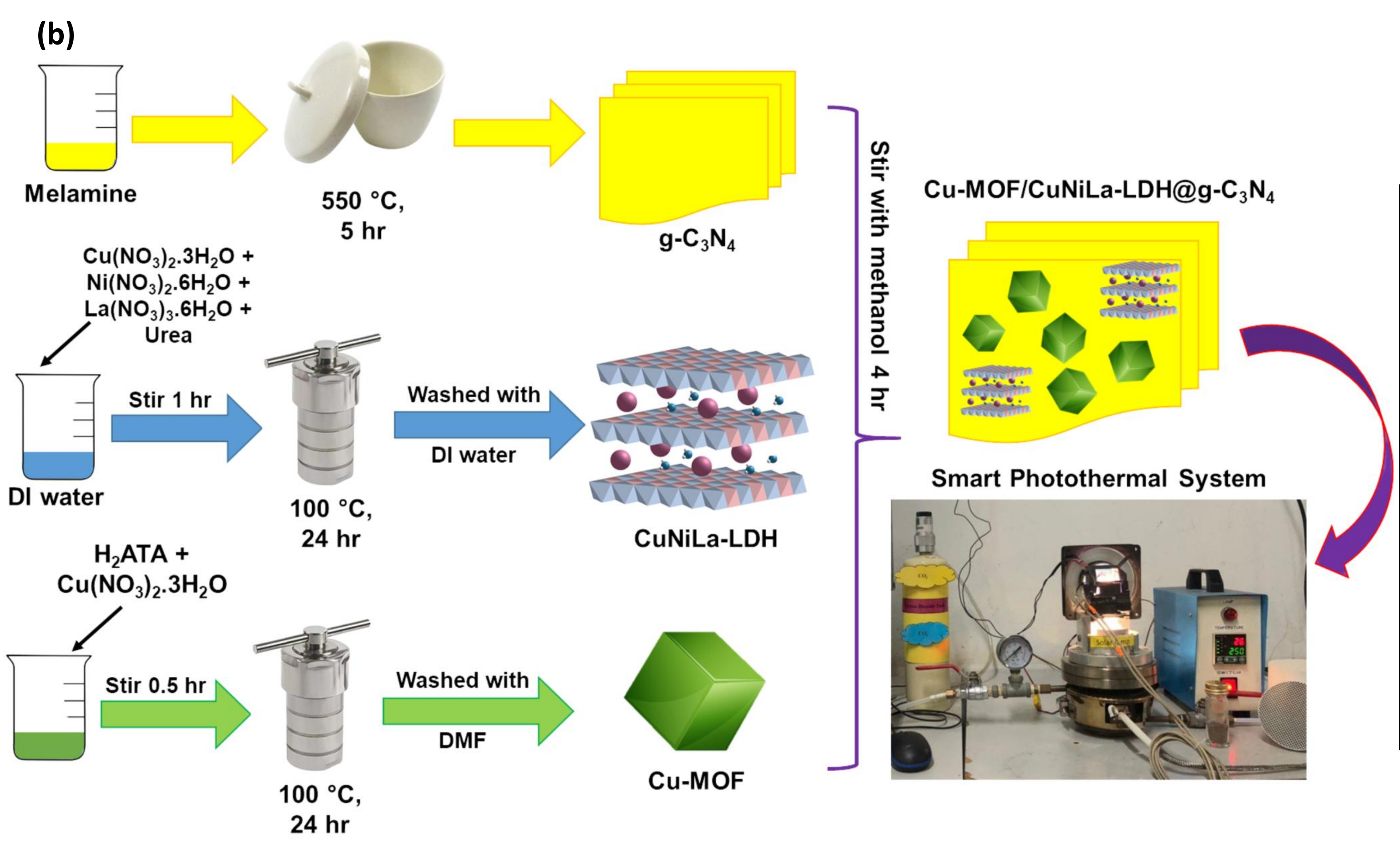
## Priority Topic Area: **Environmental Protection and Improvement**

## 1 – Introduction

The escalating global $CO_2$ emissions demand urgent solutions for carbon capture and utilization to combat climate change. As highlighted in the figure, key needs include a projected $40B power-to-gas market by 2030, eco-friendly and energy-efficient technologies, compliance with Low Carbon Aspiration 2040, compatibility with existing infrastructure, and surging demand for renewable fuels. The MOF-based heterostructure catalyst in a smart photothermal system directly addresses this by reducing $CO_2$ emissions through efficient photothermal conversion into valuable fuels, integrating captured carbon into renewable energy carriers in a cost-effective, sustainable manner.



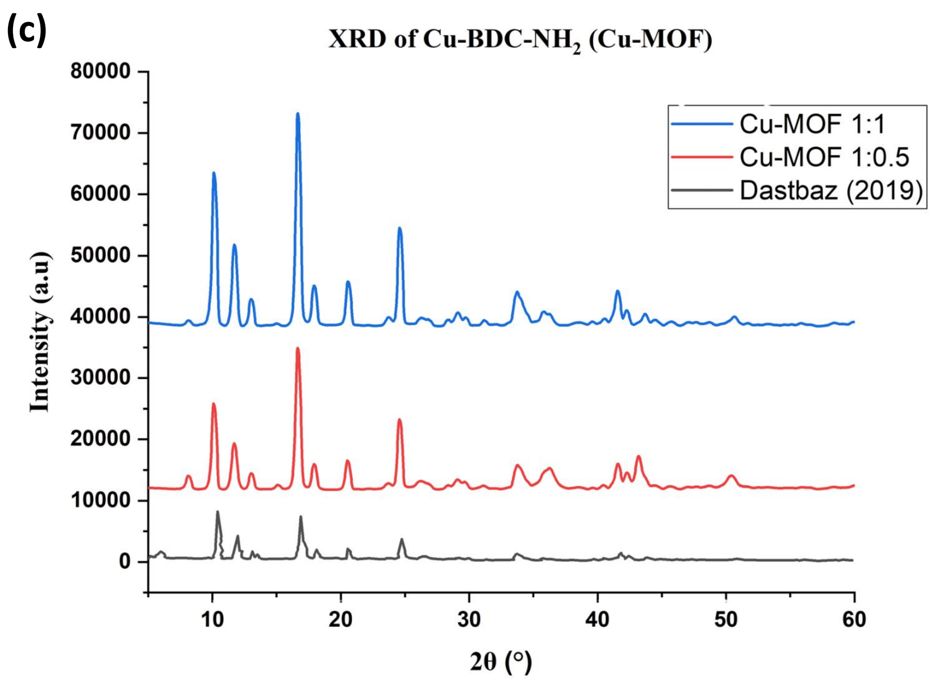



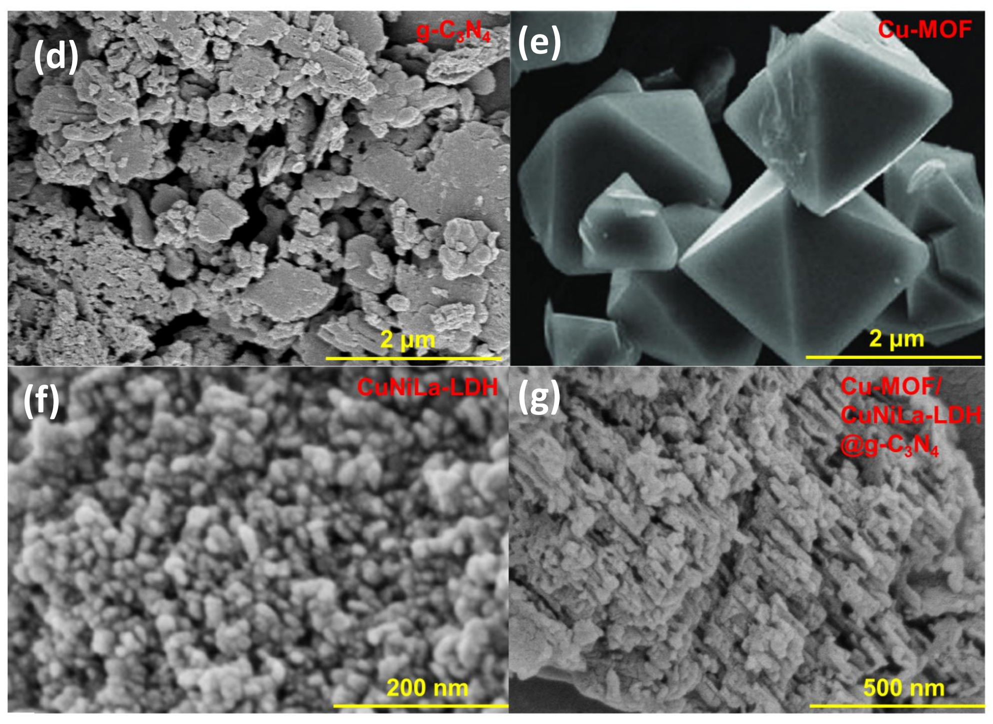

## 2 – Methodology

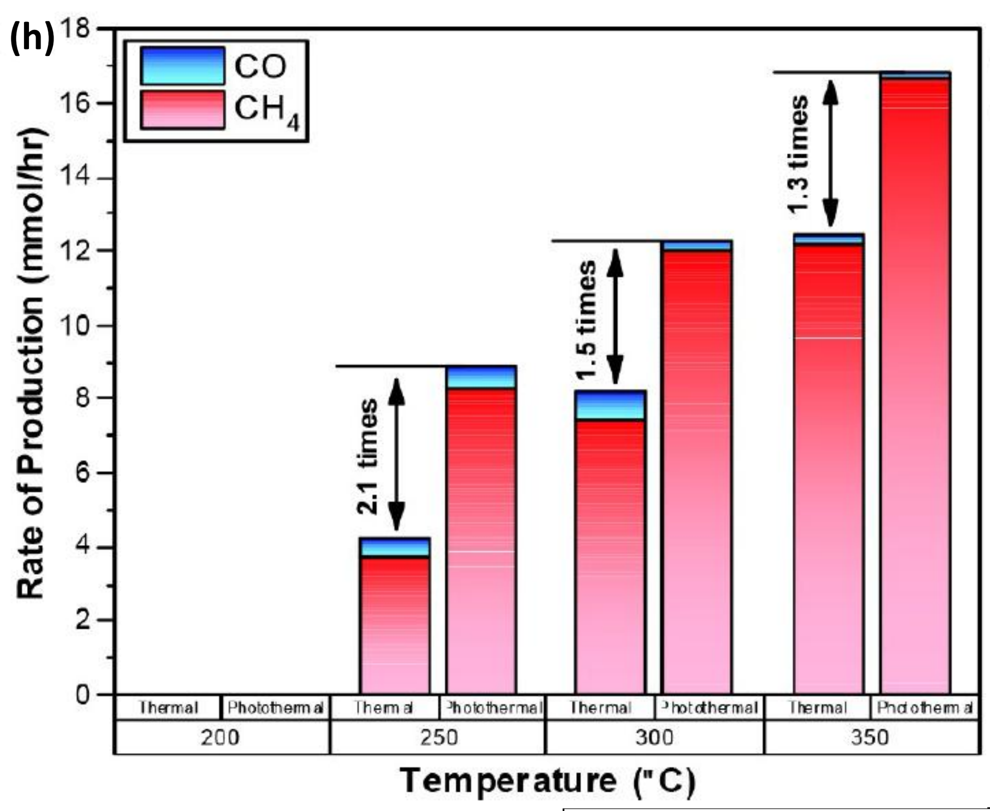
The MOF-based heterostructure catalyst was synthesized as follows: Cu-MOF via solvothermal method, CuNiLa-LDH via hydrothermal route, and g-$C_3N_4$ through calcination. The three components were integrated into the heterostructure using a simple mechanical assembly approach. The resulting catalyst was loaded into a fixed-bed reactor integrated with the smart photothermal system. Simultaneous light irradiation and controlled heating were applied to drive efficient $CO_2$ hydrogenation into renewable fuels, achieving photothermal-enhanced conversion while minimizing energy input.

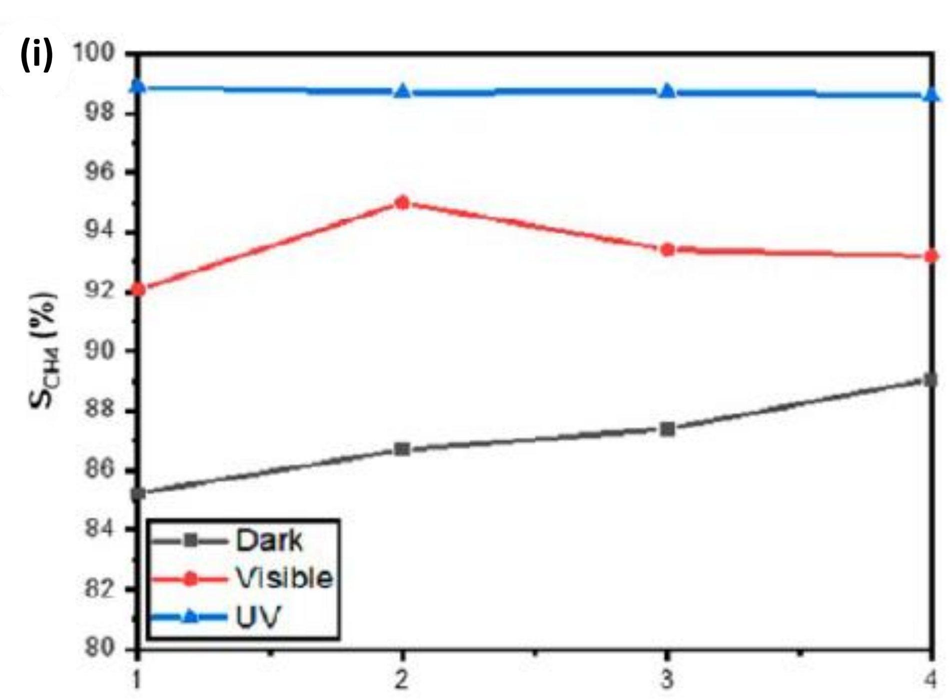
## 3 – Findings

Temperature screening (200–350 °C, GHSV = 9400 mL $g^{-1}_{cat}$ $h^{-1}$, ambient pressure) over the MOF-based heterostructure catalyst showed thermal $CO_2$ hydrogenation peaks at 350 °C with $CH_4$ production rate of 12.2 mmol $h^{-1}$, CO of 0.2 mmol $h^{-1}$ and high $S_{CH4}$. Activity declined sharply below 300 °C and ceased at 200 °C owing to insufficient energy for stable $CO_2$ activation. Under photothermal conditions (20 mW $cm^{-2}$ visible light), rates rose to 16.9 mmol $h^{-1}$ $CH_4$ ($S_{CH4}$ = 98.6 %) at 350 °C (1.3-fold gain). Light enhancement intensified at lower temperatures, delivering a 2.1-fold boost at 250 °C, confirming synergistic thermal-solar contributions. Optimal operation at 250 °C harmonized both energies, cut consumption and suppressed sintering/coking. The mechanically assembled heterostructure outperformed the non-optimized counterpart by 1.2–1.9× under dark/visible/UV irradiation, attributed to intimate interfacial contact, superior dispersion and heterojunction-enabled light harvesting. Blank tests verified all $CH_4$/CO originated exclusively from $CO_2$ hydrogenation. Thus, the smart photothermal MOF system achieves efficient, low-temperature fuel production.




## 4 – Benefit to society

This innovation converts $CO_2$ into renewable fuels ($CH_4$/CO) at low temperature (250 °C) via photothermal synergy, achieving 2.1× higher yields under visible light while slashing energy use and catalyst deactivation. It directly reduces global emissions, closes the carbon loop, and supplies clean, infrastructure-compatible fuels—tapping the $40B power-to-gas market by 2030 and meeting 2040 Low Carbon goals. Society gains cheaper green energy, climate mitigation, job creation in renewables, and a sustainable pathway to energy security without fossil dependence.

## 5 – Next steps

Future development will focus on scaling-up mechanical assembly to continuous-flow synthesis, testing under real sunlight with concentrators, optimizing CuNiLa-LDH loadings for >20 mmol $h^{-1}$ $CH_4$ yield, conducting 1000-h stability trials, and integrating renewable $H_2$ for pilot-scale reactors—accelerating commercialization of low-energy $CO_2$-to-fuels technology.

## References/Acknowledgements

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