

Integrated Thermochemical and Electrochemical Valorization of Carbonaceous Waste and CO₂ for Syngas Production

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INTRODUCTION & AIM

Industrial carbon dioxide utilization and the management of carbon-rich waste streams, such as rubber dust, coke, and residual biomass, remain critical hurdles for the circular economy. Conventional **syngas production** often requires significant external hydrogen inputs, which can limit the economic and environmental viability of CO₂ recycling.

The objective of this technology is to **promote the circular economy** by reducing reliance on large-scale external hydrogen supplies and repurposing industrial waste.

The patented system incorporates **multiple thermal zones** and purification systems with a view to **optimizing energy efficiency** and the **quality of the syngas** produced.

The proposed solution thus enables the conversion of harmful emissions and solid residues into valuable chemical resources such as methanol or dimethyl ether (DME).

METHOD

An innovative method is proposed for generating synthesis gas, or **syngas**, using **carbon dioxide** and **carbonaceous waste materials** such as rubber powder or biomass residues.

The process consists of an initial phase in which carbon reacts with CO₂ to produce carbon monoxide through the reverse Boudouard reaction.

Subsequently, **hydrogen**, obtained through the water gas shift reaction or by electrolysis, is introduced to complete the final mixture.

The process is designed to adjust the composition of the syngas, with the objective of achieving S and SN values of 2, which are regarded as optimal for the key syntheses of high-value-added chemicals, such as methanol and dimethyl ether (DME).

RESULTS & DISCUSSION

The following reactions are involved in the process:



In order to achieve a stoichiometric **S ratio** of 2, it is necessary to supplement carbon monoxide production with specific hydrogen enrichment strategies, since gasification alone produces syngas with S values that are too low for industrial synthesis.

$$S = \frac{H_2}{CO} \quad SN = \frac{H_2 - CO_2}{CO + CO_2}$$

The integration of SOECs enables the precise control of hydrogen addition to the carbon monoxide stream until the target values of S and SN are reached. This level of precision is essential for rendering the syngas suitable for the industrial synthesis of methanol and dimethyl ether (DME).

The technology utilizes a vertical, multi-stage cylindrical reactor. In the primary section, carbonaceous residues react with CO₂ to generate carbon monoxide via the [R1] reaction.

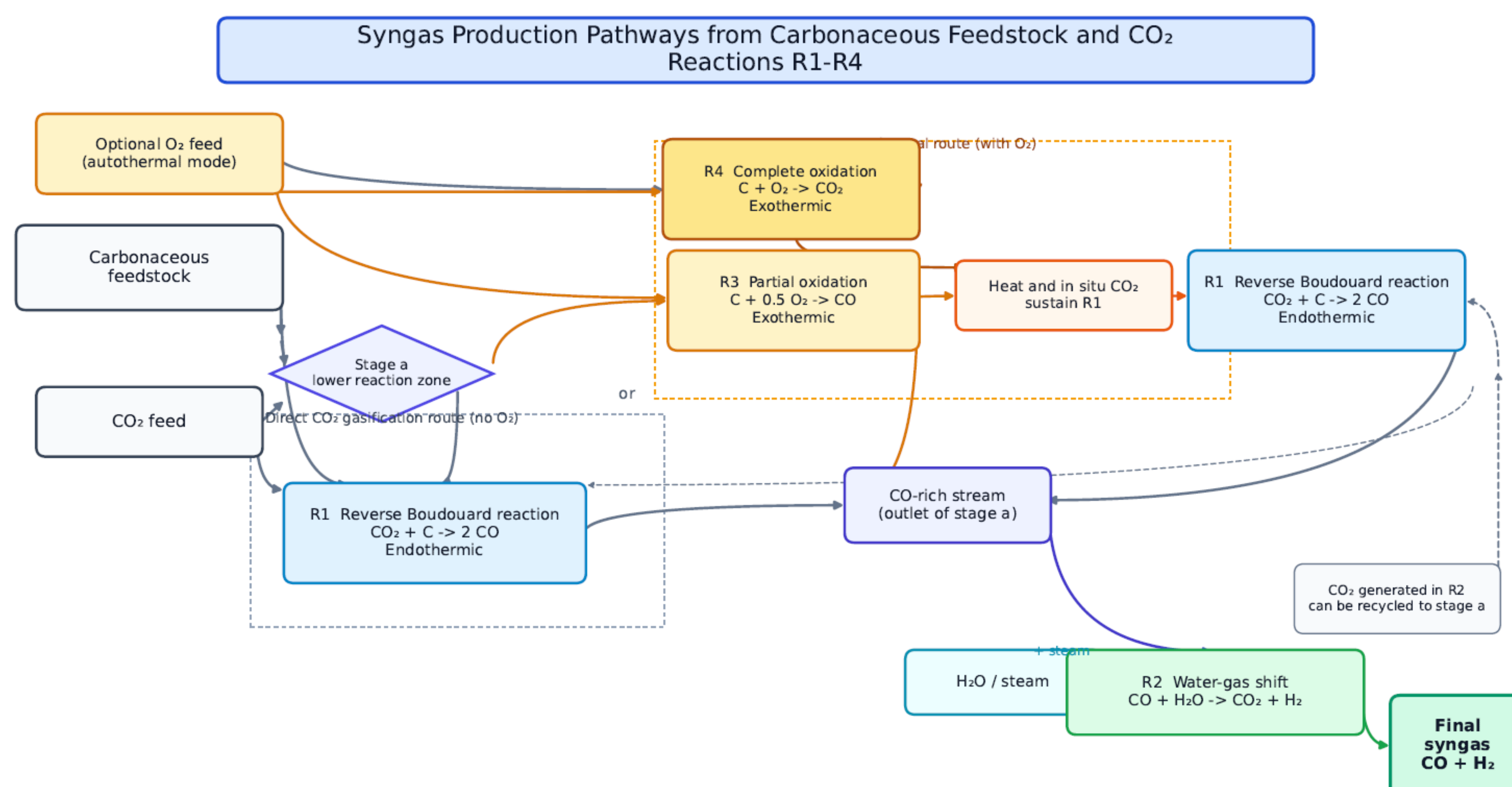
The system is engineered for high feedstock versatility, accommodating solid materials through auger delivery and fluid or slurry-like wastes via specialized atomizers.

The process can operate **endothermically** or in an **autothermal** mode; in the latter, selective oxygen injection triggers exothermic oxidation, providing the necessary enthalpy for the Boudouard transition at temperatures typically exceeding 600 – 900° C.

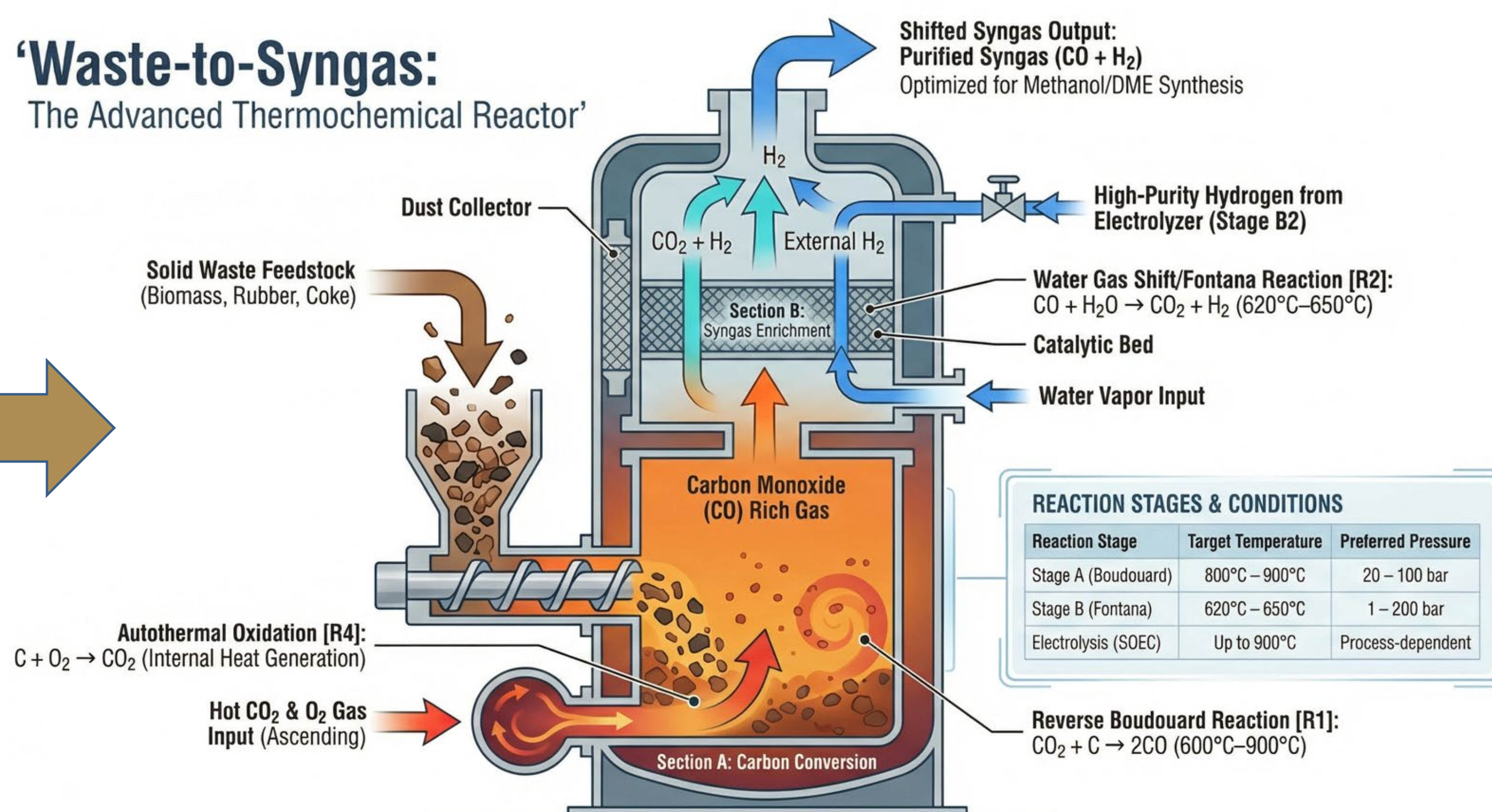
The resulting gas stream is filtered through an integrated dust collector before entering a secondary stage for hydrogen enrichment. This is achieved either through a catalytic Water Gas Shift reaction or via integration with water electrolysis, specifically utilizing Solid Oxide Electrolyser Cells (SOEC).

The integration with electrolysis offers distinct operational advantages, including the internal recycling of pure oxygen to sustain the primary reactor's thermal balance and the precise adjustment of stoichiometric ratios.

This optimization ensures the production of high-quality syngas tailored for the downstream synthesis of value-added chemicals, such as **methanol** and **dimethyl ether**.



'Waste-to-Syngas: The Advanced Thermochemical Reactor'



CONCLUSIONS

The invention described herein constitutes a technologically advanced solution for the transition to a circular economy and the utilization of CO₂.

The apparatus integrates gasification, chemical enrichment, and thermal management operations into a single unit, thus establishing itself as a benchmark for the efficient production of green chemicals.

The main technical and operational advantages of the apparatus and the associated process can be summarized as follows:

- Sustainability and waste utilization
- Feedstock versatility
- Syngas optimization for industrial syntheses
- Energy efficiency

REFERENCES/FUTURE WORKS

An Italian priority patent application was filed in 2024 (patent number: 10202400002160; this was subsequently extended at an international level through the PCT procedure (number PCT/IB2025/050915. Both of them are available on Espacenet.

This technology is licensed to Texelera S.c. A R.l., a joint venture between A2A and Politecnico di Milano.

The subsequent stage in this process is to enhance the TRL of the invention.