

A Step Toward Process Electrification: Microwave-Assisted Co-Gasification of Waste Plastics and Biomass To Produce Clean Energy



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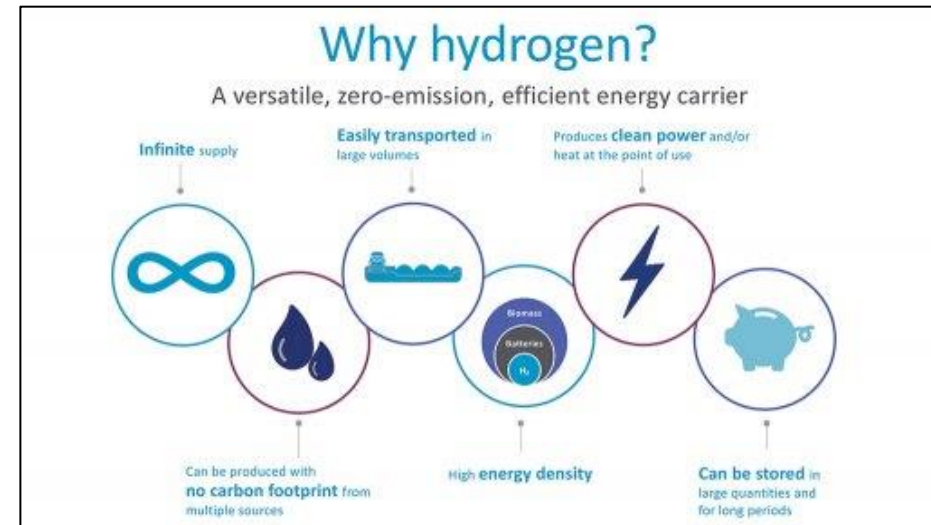


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- Global plastic waste generation: 353 million metric tons over the past two decades.
- The majority of the plastic waste is (1) landfilled or (2) incinerated. Only 9% of the plastic waste is recycled.
- Microwave (MW) gasification offers higher H₂ yield and enhanced selectivity to syngas over tars with higher energy efficiency as compared to existing conventional processes.



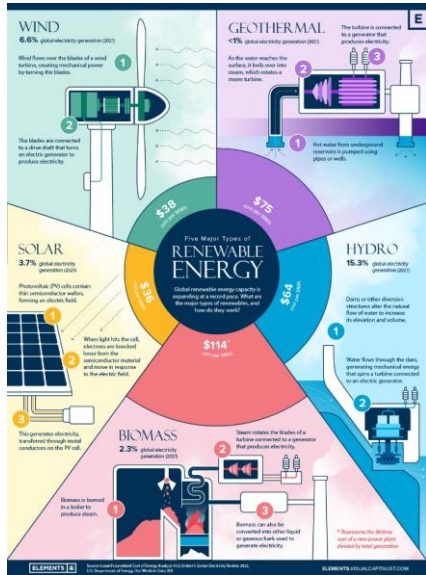
1. IEA Global Hydrogen Review 2021
2. <https://www.international.com/hydrogen-in-industry/>

This work presents parametric optimization study of microwave catalytic co-gasification of mixed plastics and corn stover for clean H₂.

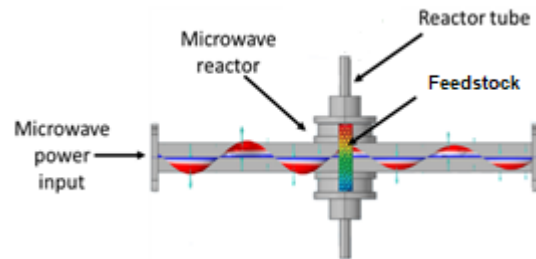
Proposed Approach: Microwave Gasification

Feedstocks: Biomass, Plastics

Coupling with Energy Resources



Microwave Reactor



H₂, Syngas

Fuels & Chemicals

Process Intensification

- Process modularity
- Efficient rapid heating and promoting favorable reaction
- Electrification of process – cleaner H₂

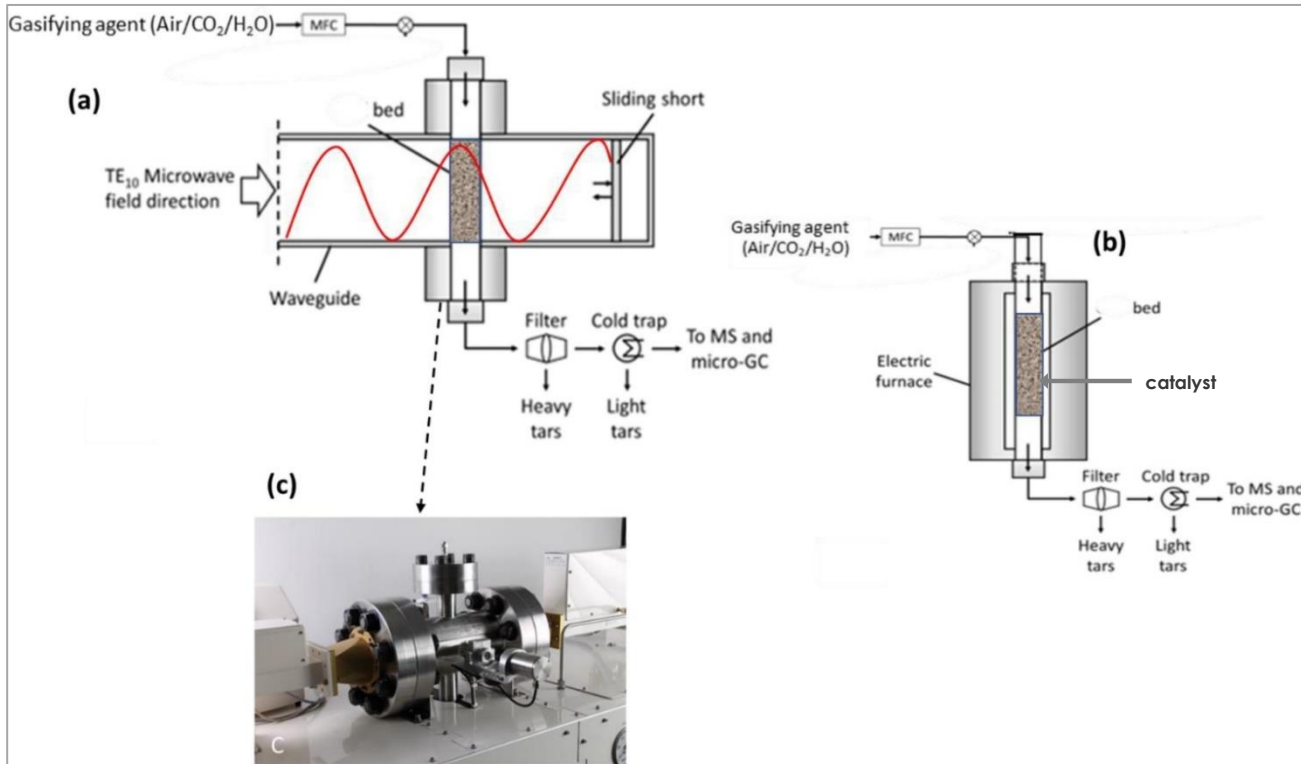


Part 1

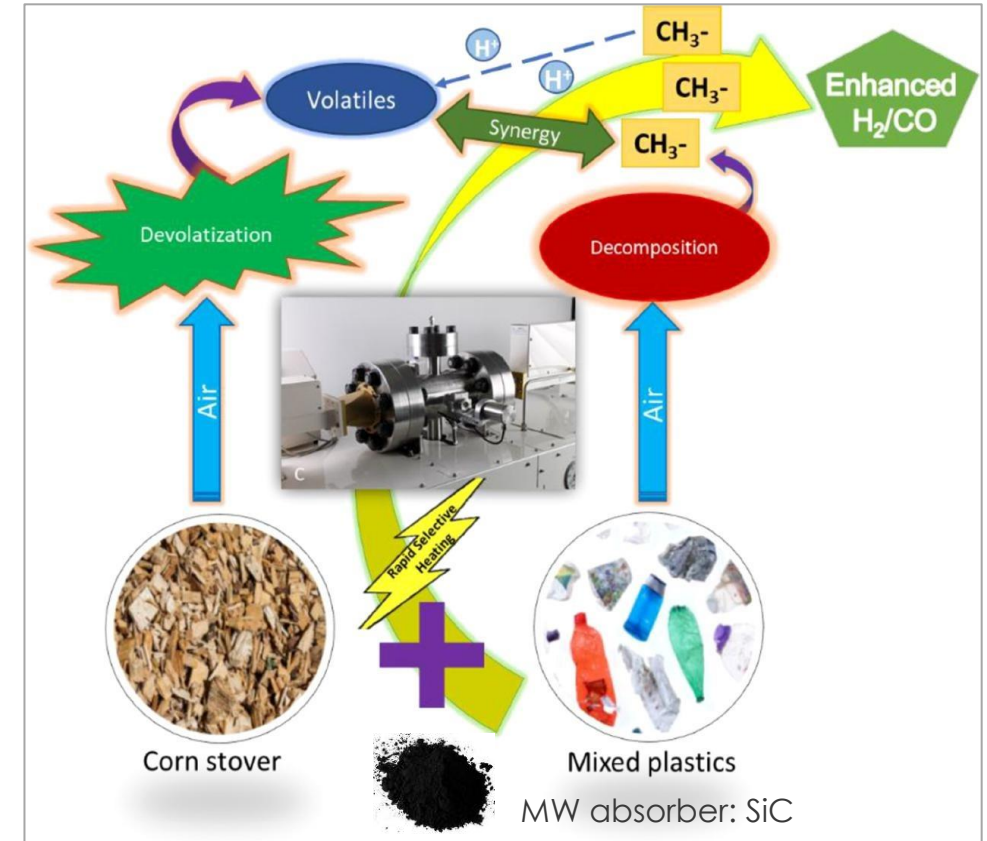
Gasification of Plastic-Corn Stover: Synergy in Microwave

Process Setup

Microwave Reactor



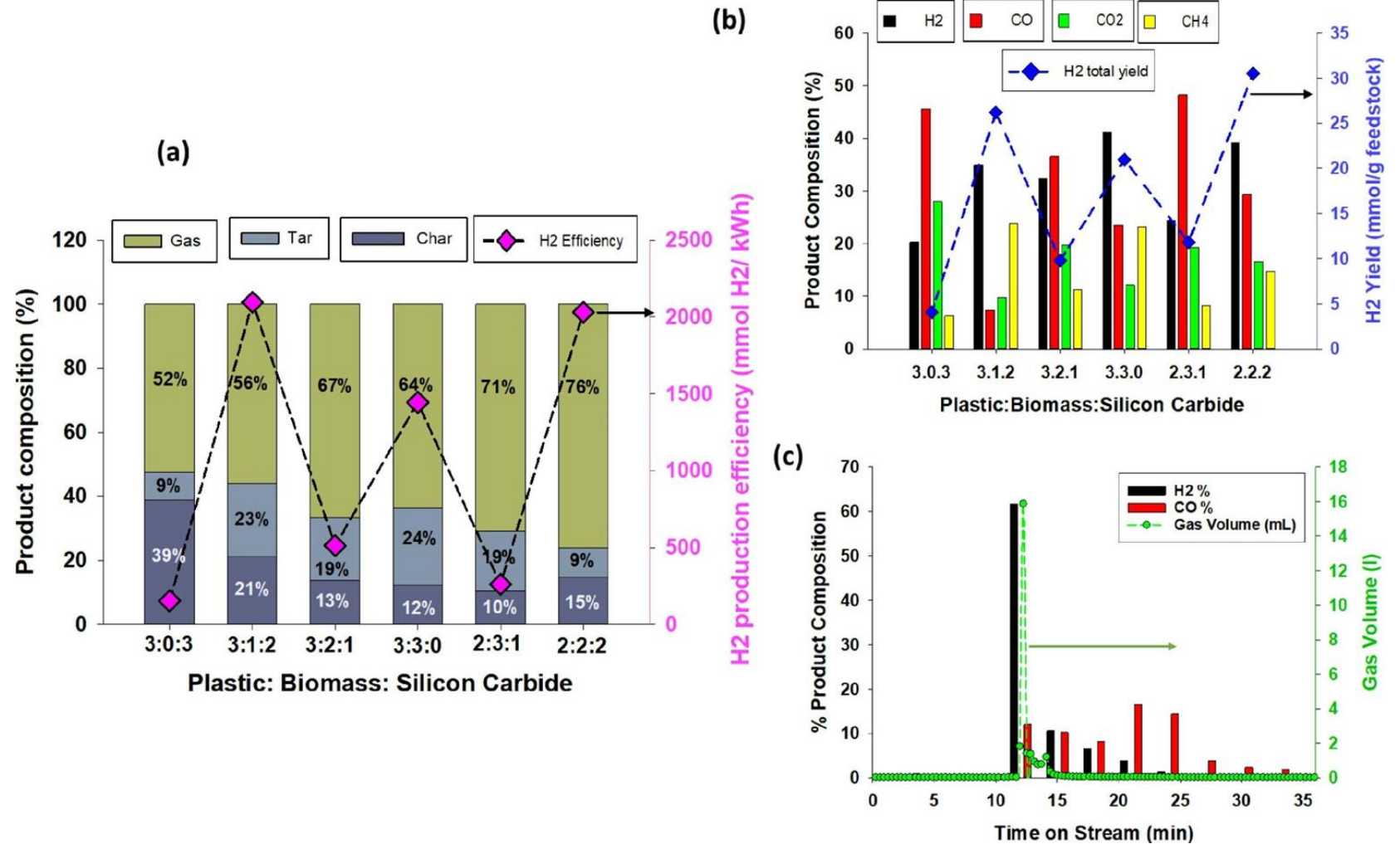
Reaction Mechanism



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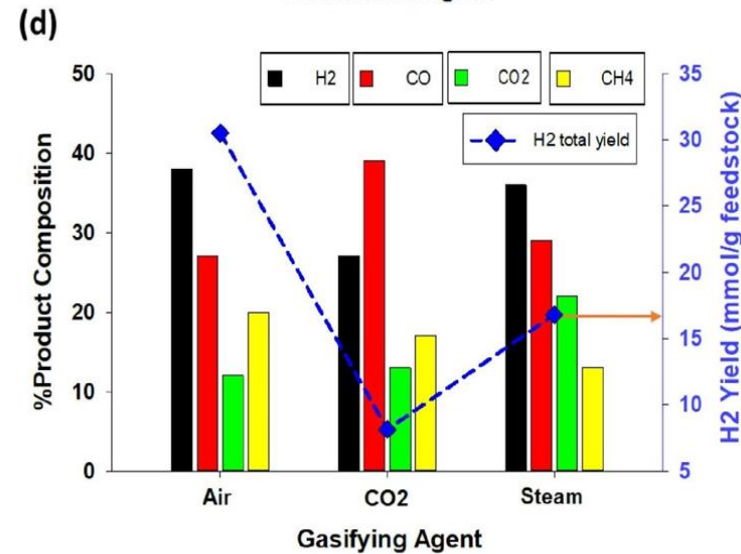
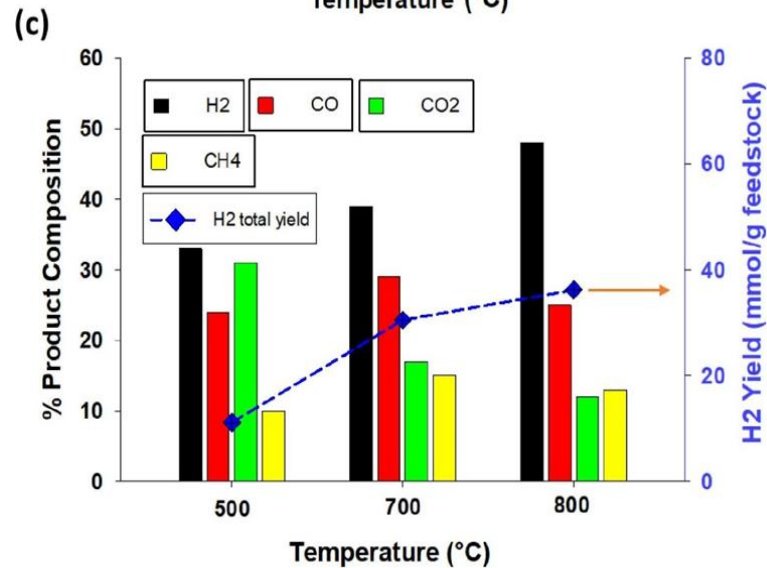
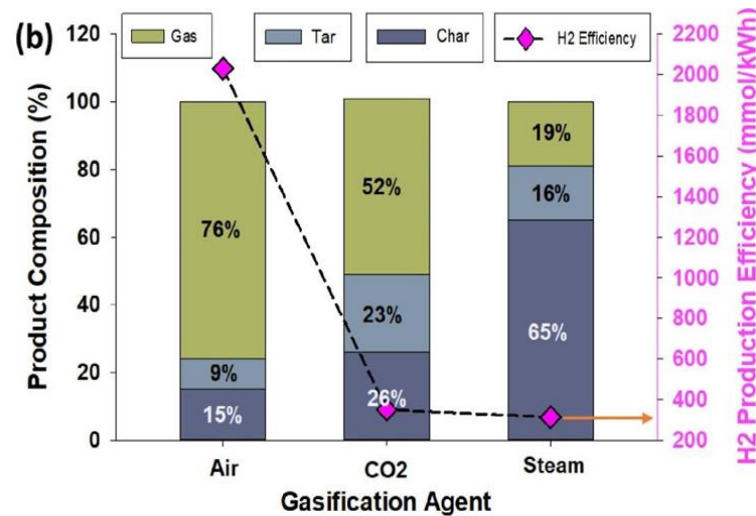
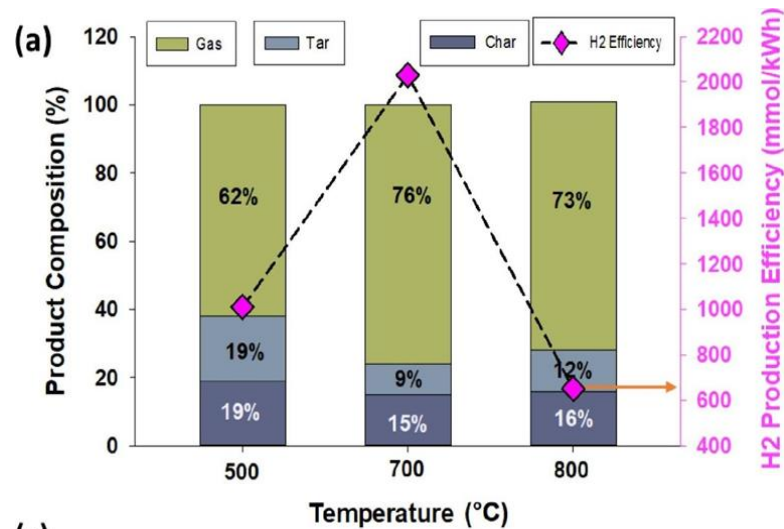
Effect of Plastics to Biomass Ratio

- Optimum conditions:
 - Plastic: corn stover: SiC = 1:1:1
 - 700 °C, air
- Highest gas yield (76%) with most H₂ yield (30.52 mmol/g_{feed})
- Minimal heavy tar formation (9%) and lowest power input (200W)



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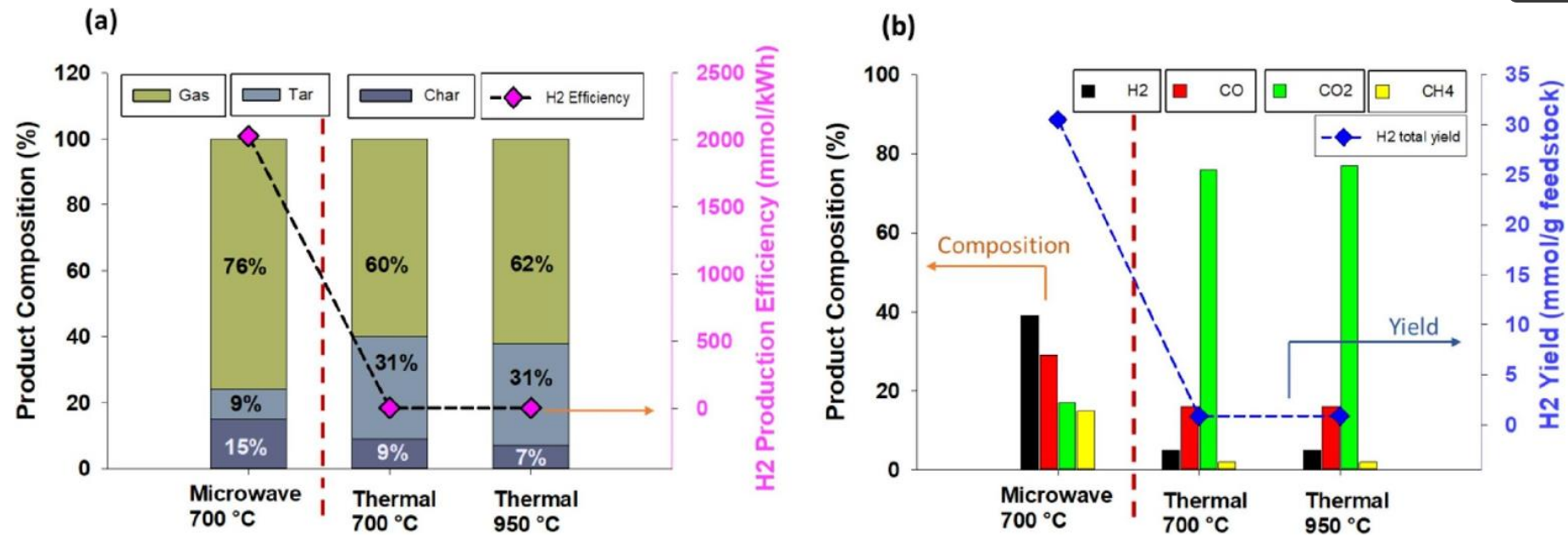
Effect of Temperature and Gasifying Agent



- At higher temperatures, volatiles from biomass devolatilization were enhanced by radicals from plastic decomposition, making higher gas yields for the mixed plastics, and decreasing char and tar yield.
- O₂ in air improves the heating value of the feed, which instantly burns under microwave, allowing intermediates to crack down and produce more H₂.

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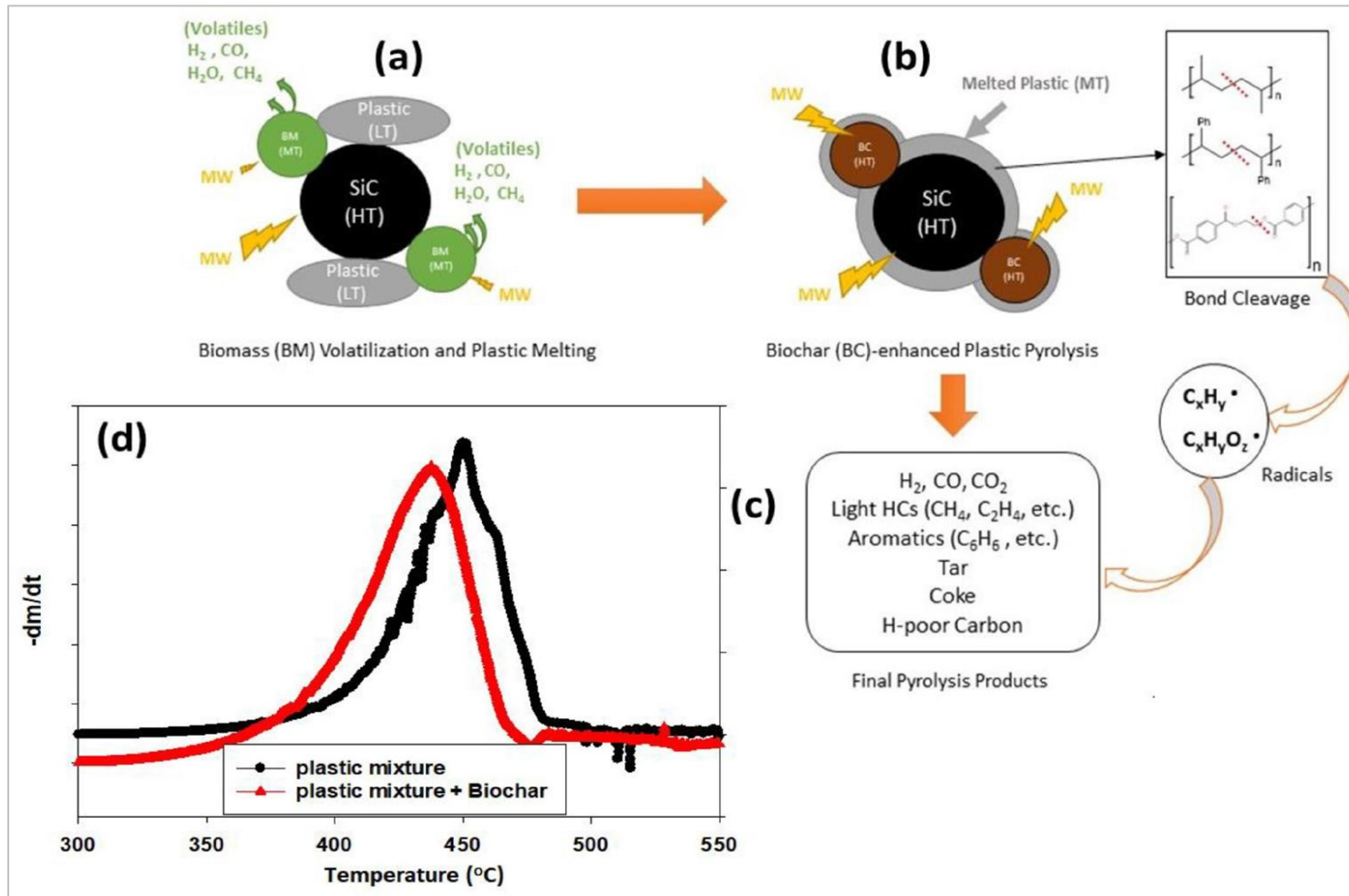
Microwave vs. Conventional Studies



- Rapid and enhanced selective heating of the microwave reactor gasifies plastics and generates the required radicals that contribute to the plastic and corn stover synergy, allowing enhanced H₂ yield ($30.5 \text{ mmol/g}_{\text{feed}}$ vs. $0.9 \text{ mmol/g}_{\text{feed}}$ at 700 °C).
- During conventional heating, the mild gasification temperature of 700–950 °C alone is not enough to drive the endothermic Boudouard reaction after plastics and corn stover gasify and produce carbon.

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Microwave Gasification Mechanism

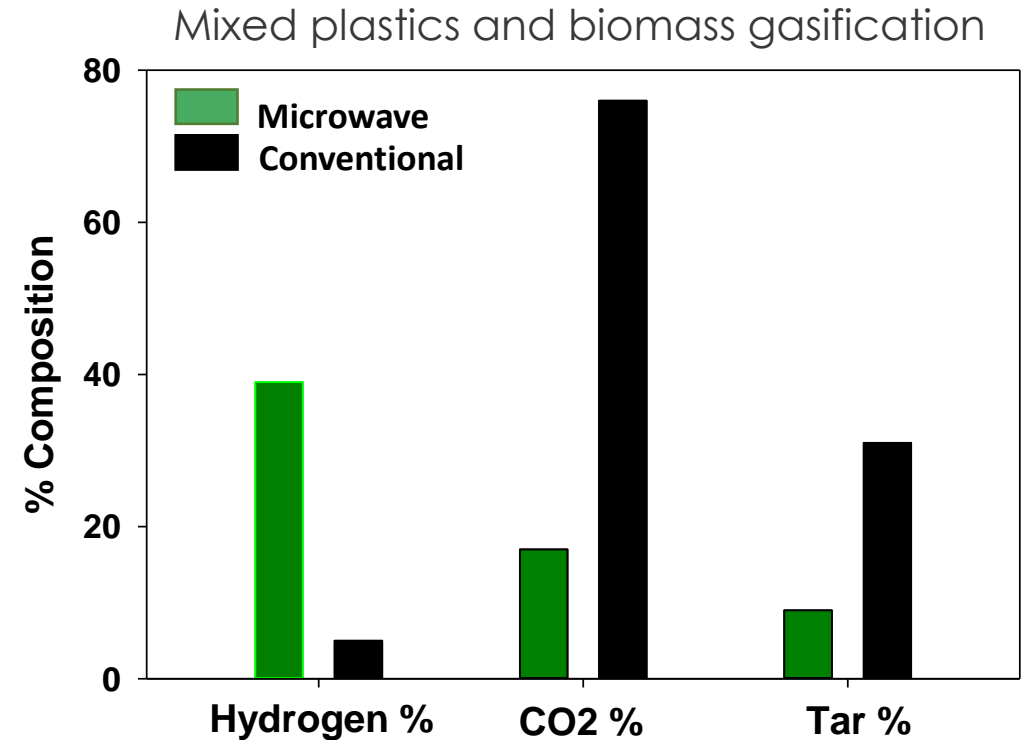


- Plastics heat only through proximity to SiC and corn stover, directing the heat flux and mass transfer away from corn stover.
- This mass transfer direction reduces side reactions and repolymerization of intermediates.
- With biochar, plastic decomposition shifts to lower temperatures, altering the product distribution with higher yields of low molecular weight compounds.

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Key Findings: Part 1

- Microwave enhanced synergy between plastic and biomass.
- Optimum 1:1:1 feedstock ratio: High syngas yields and H₂ yield (30.5 mmol/g_{feed}).
- At a temperature range of 700–800 °C, enhanced H₂ formation.
- Higher syngas yields under air (76%) compared to CO₂ (52%) and steam (19%).
- 30.5 mmol H₂/g_{feed} at 700 °C in microwave reactor 0.9 mmol H₂/g_{feed} at 700–950 °C with conventional heating.
- The synergy between plastic-biomass increased at optimum conditions under the microwave reactor, yielding higher amounts of H₂.



Part 2

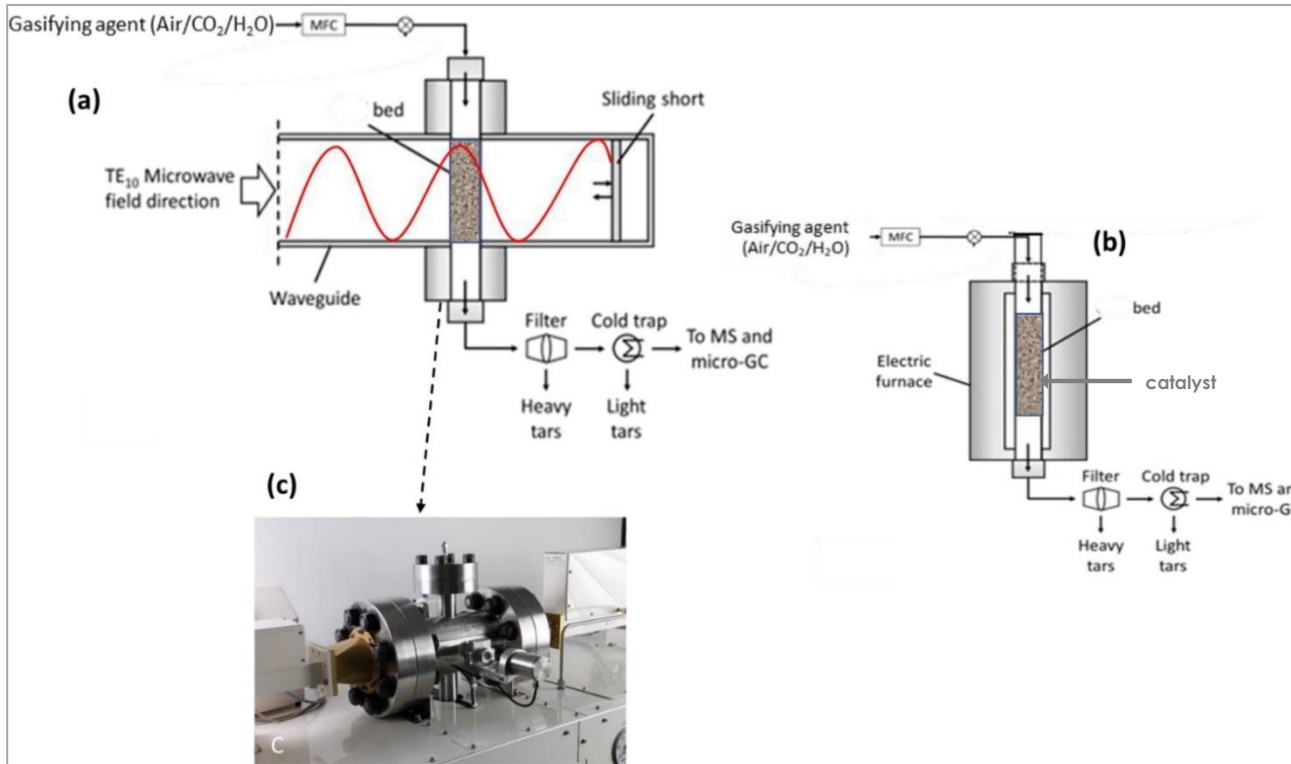
Microwave-Assisted Catalytic Gasification of Plastic-Corn Stover

Goals:

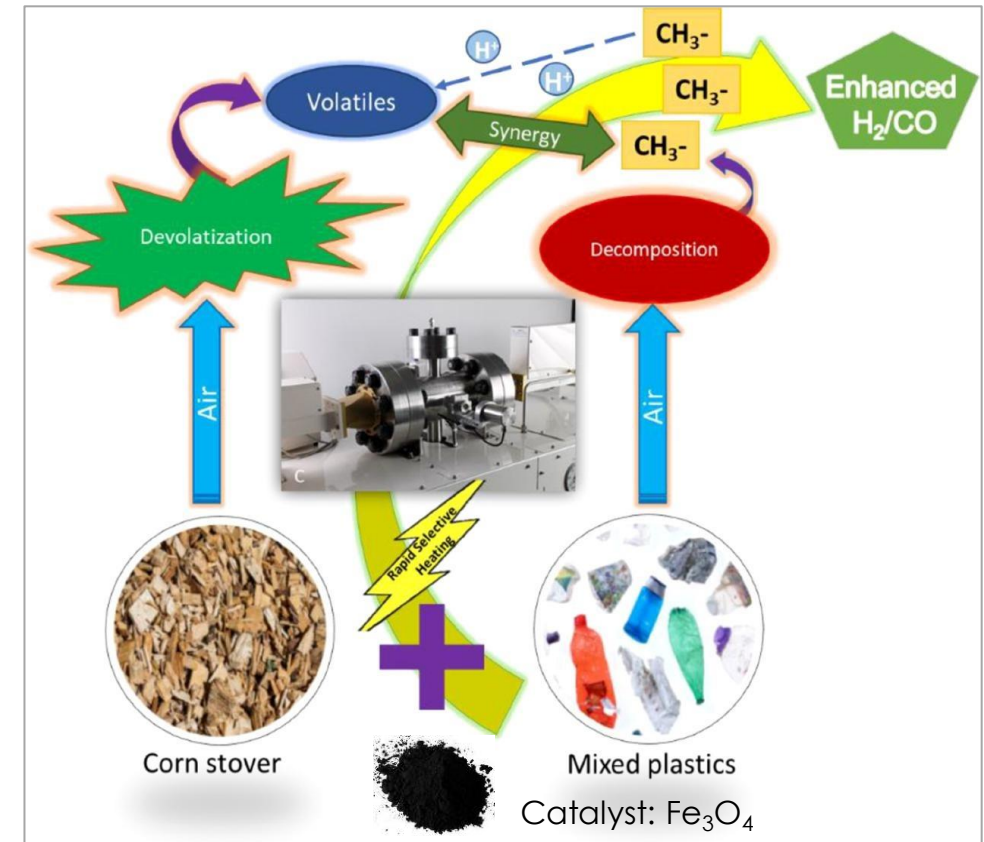
- ✓ Improve H₂ Yield
- ✓ Reduce Tar Formation
- ✓ Enhance Energy Efficiency

Process Setup

Microwave Reactor



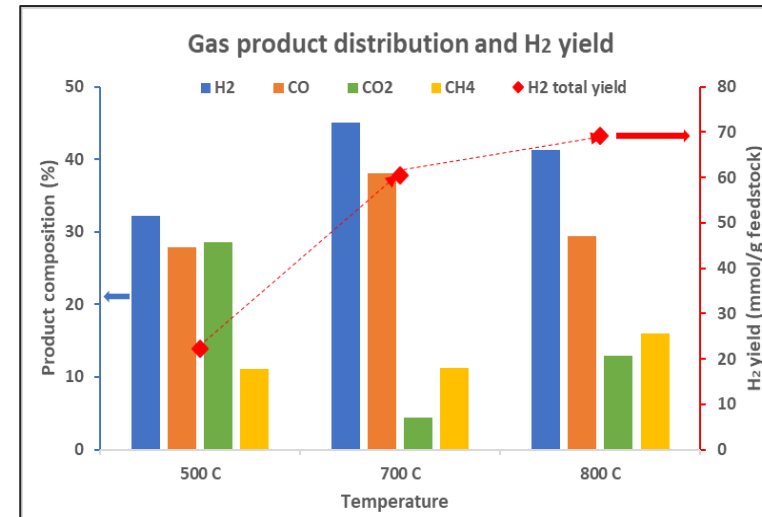
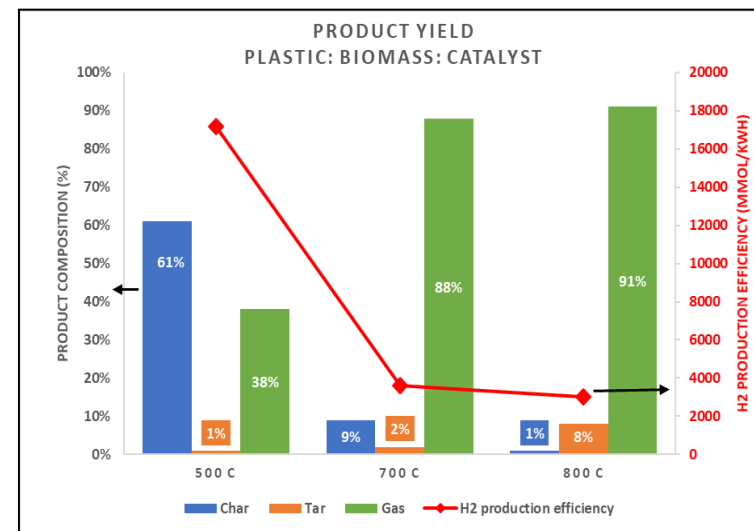
Reaction Mechanism



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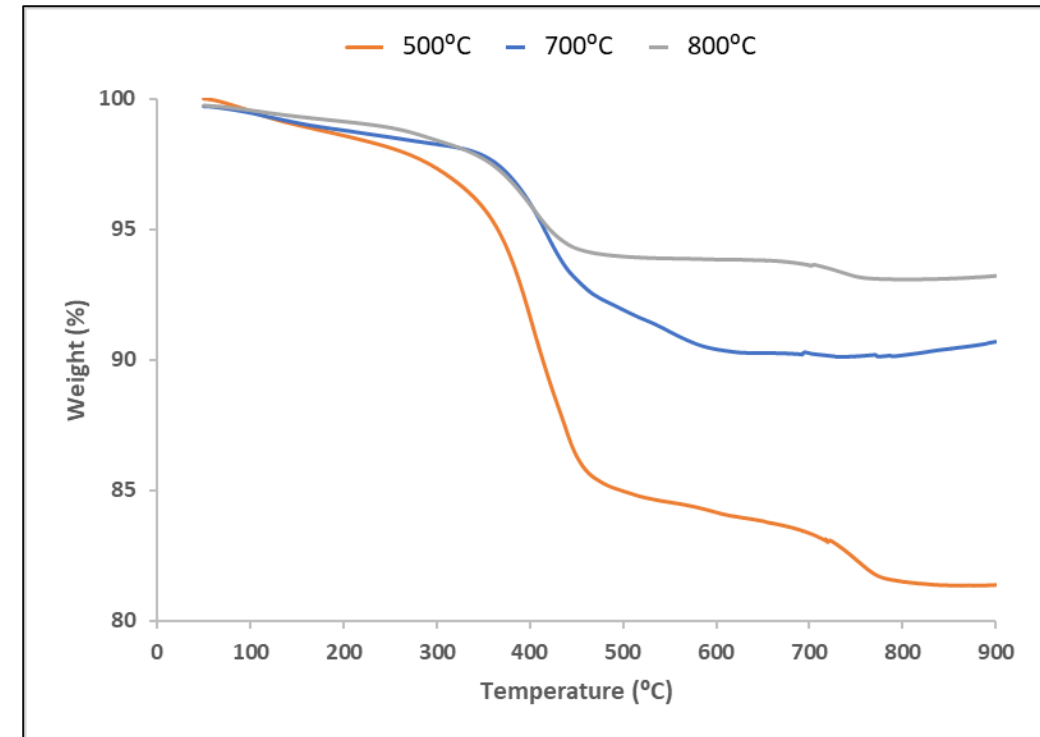
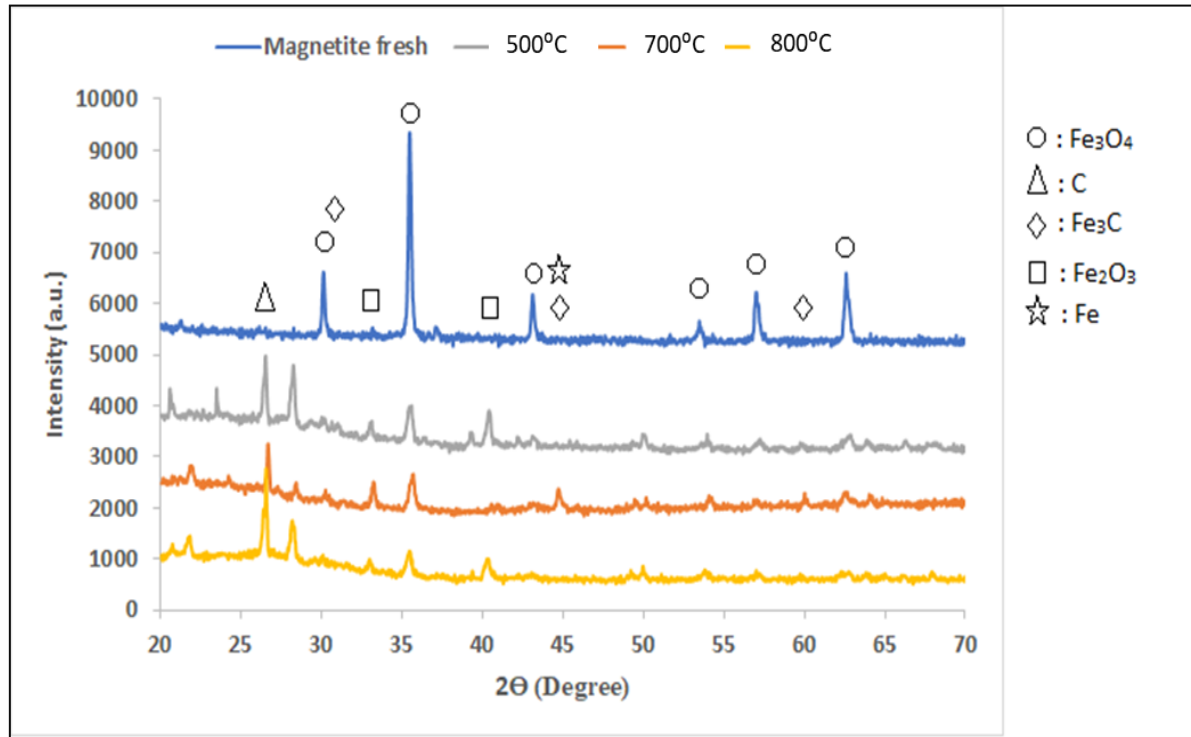
Results: Effect of Temperature

- Highest gas yield (91%) with most H₂ yield (72 mmol/g_{feed}) was observed for 800 °C.
- Unstable reactor conditions occurred at 800 °C, power was fluctuating due to sudden temp loss.
- Minimal heavy tar formation (2%) and lowest power input (200 W) was required for 700 °C.
- Optimum conditions:
 - **700 °C, 200 SCCM air**



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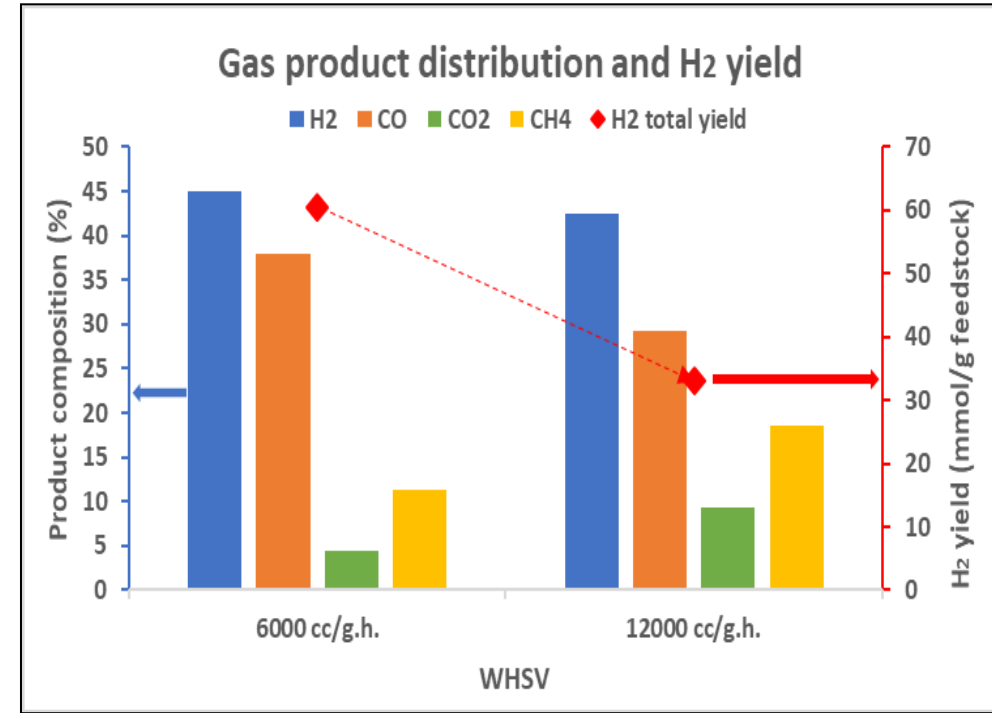
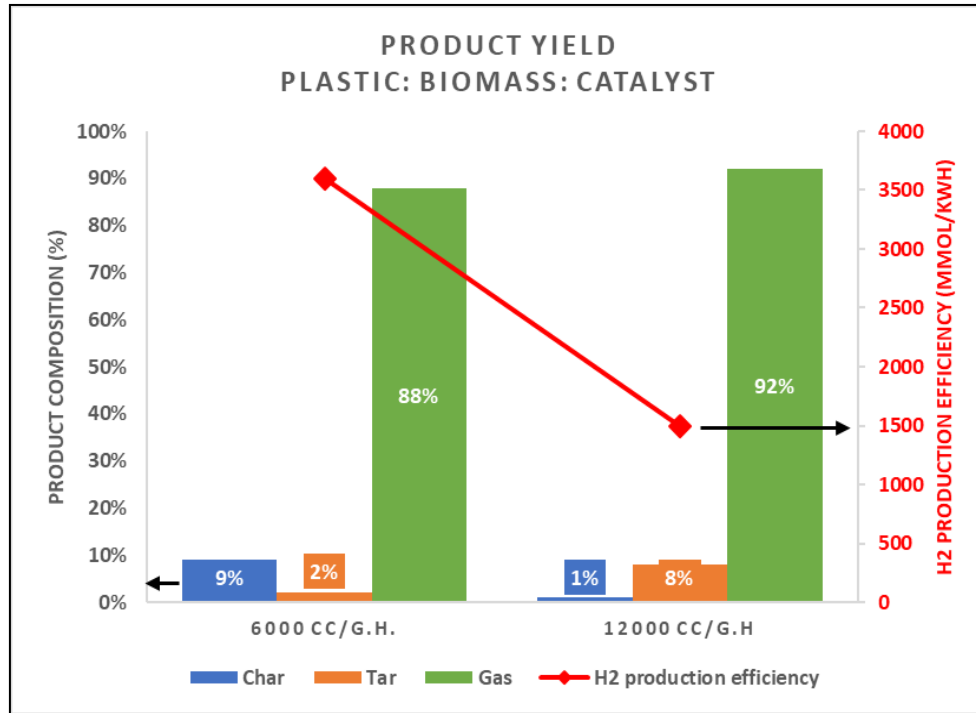
Characterization: Effect of Temperature



- For higher temperature runs, a greater degree of reduction was observed for Fe oxide, **indicating** higher activity due to the availability of more surface oxygen.
- **Filamentous/graphitic C deposition increased with temperature**, corresponding to a greater H₂ formation.

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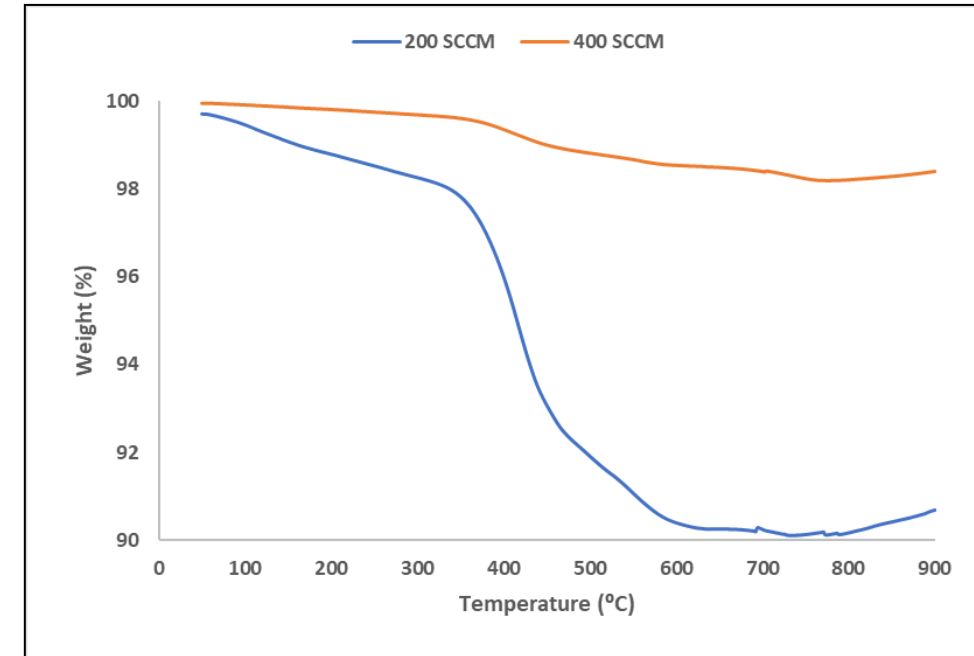
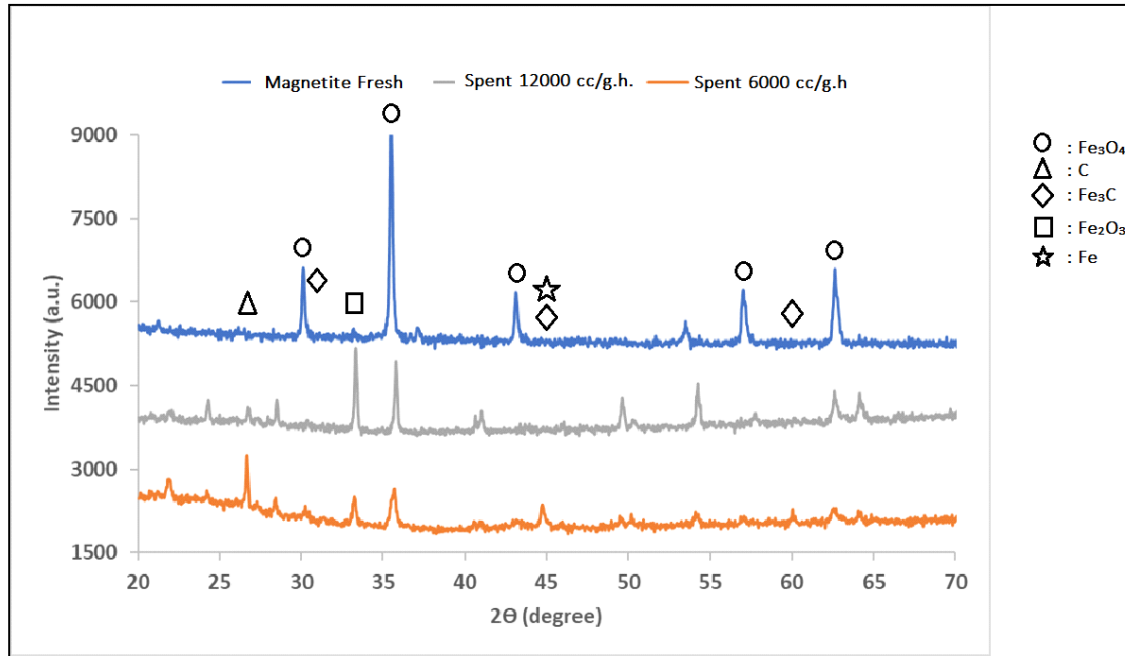
Results: Effect of Space Velocity (WHSV)



- At lower WHSV (200 vs. 400 SCCM), in presence of magnetite, volatiles from biomass devolatilization spent more time with the radicals from plastic decomposition, making higher H₂ yields for the mixed plastics, and decreasing tar yield.
- Tar reduces to produce more H₂-rich syn gas at lower WHSV due to an enhanced reaction period in MW.

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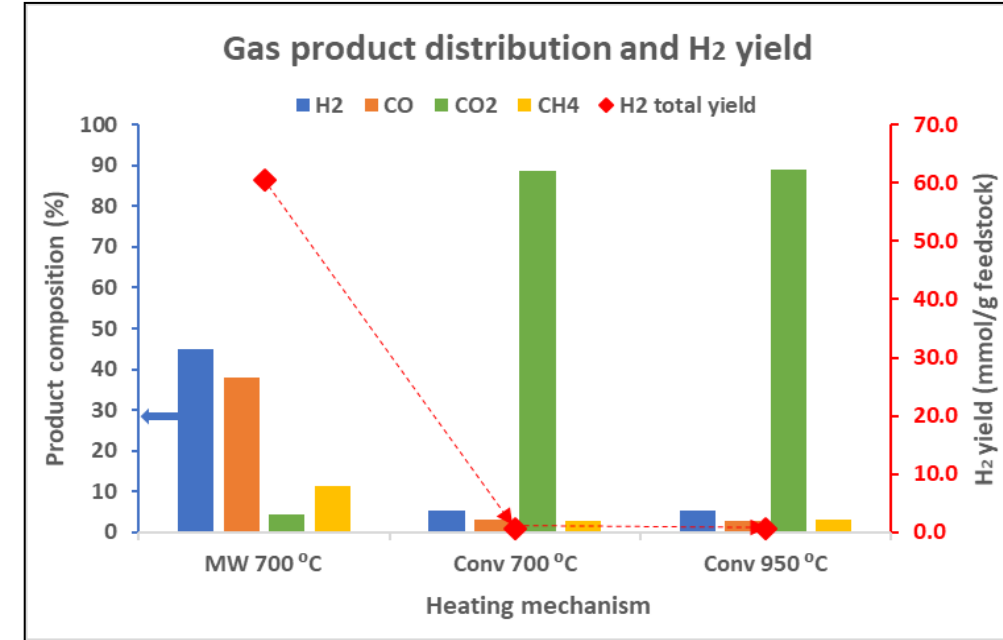
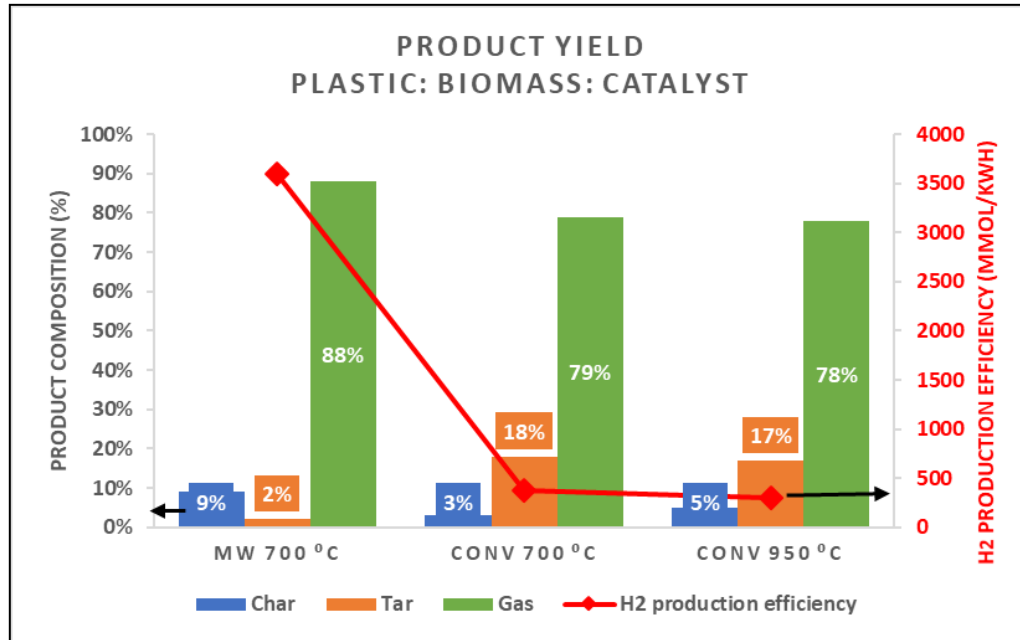
Characterization: Effect of WHSV



- Higher peak intensity on graphitic carbon ($2\theta=26.5^\circ$) was observed in X-ray diffraction (XRD) for lower WHSV (200 SCCM), indicating higher production of graphitic carbon.
- Fe₃C and metallic Fe peaks were detected in XRD for 200 SCCM run, indicating higher degree of magnetite reduction.
- Thermogravimetric analysis indicates major graphitic carbon region for 200 SCCM run, complying with the XRD results.

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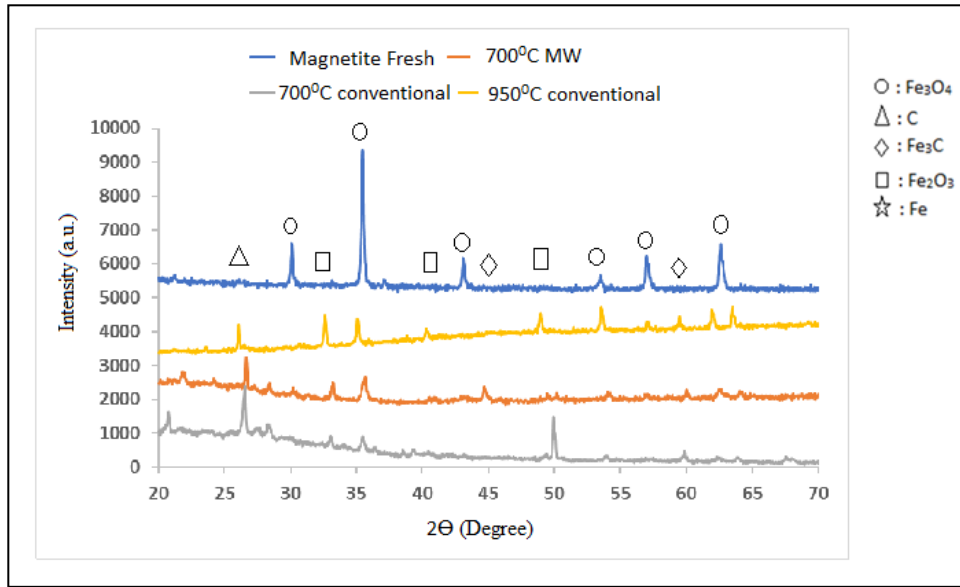
Results: Microwave vs. Conventional Studies



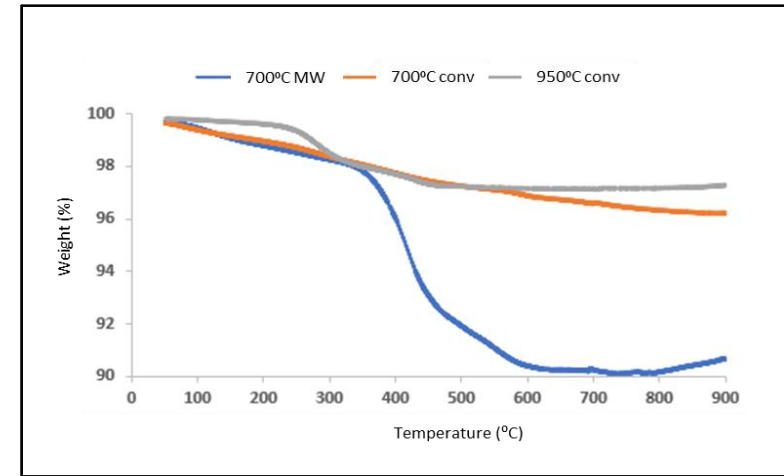
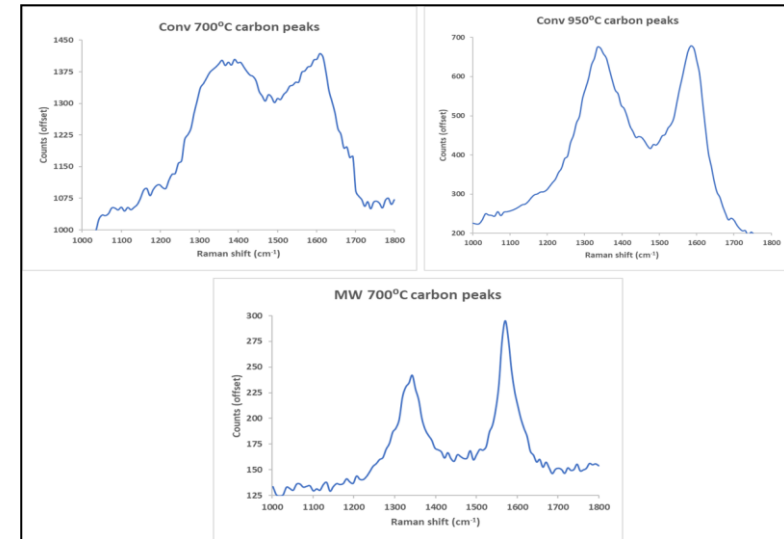
- Along with a greater degree of magnetite reduction, selective heating of the microwave reactor gasifies plastics and generates the required radicals that contribute to the plastic and corn stover synergy, allowing enhanced H₂ yield ($61 \text{ mmol/g}_{\text{feed}}$ vs. $0.9 \text{ mmol/g}_{\text{feed}}$ at 700 °C under air).
- During conventional heating, the mild gasification temperature of 700–950 °C alone is not enough to drive the endothermic Boudouard reaction after plastics and corn stover gasify and produce carbon.

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Characterization: Effect of Heating Media

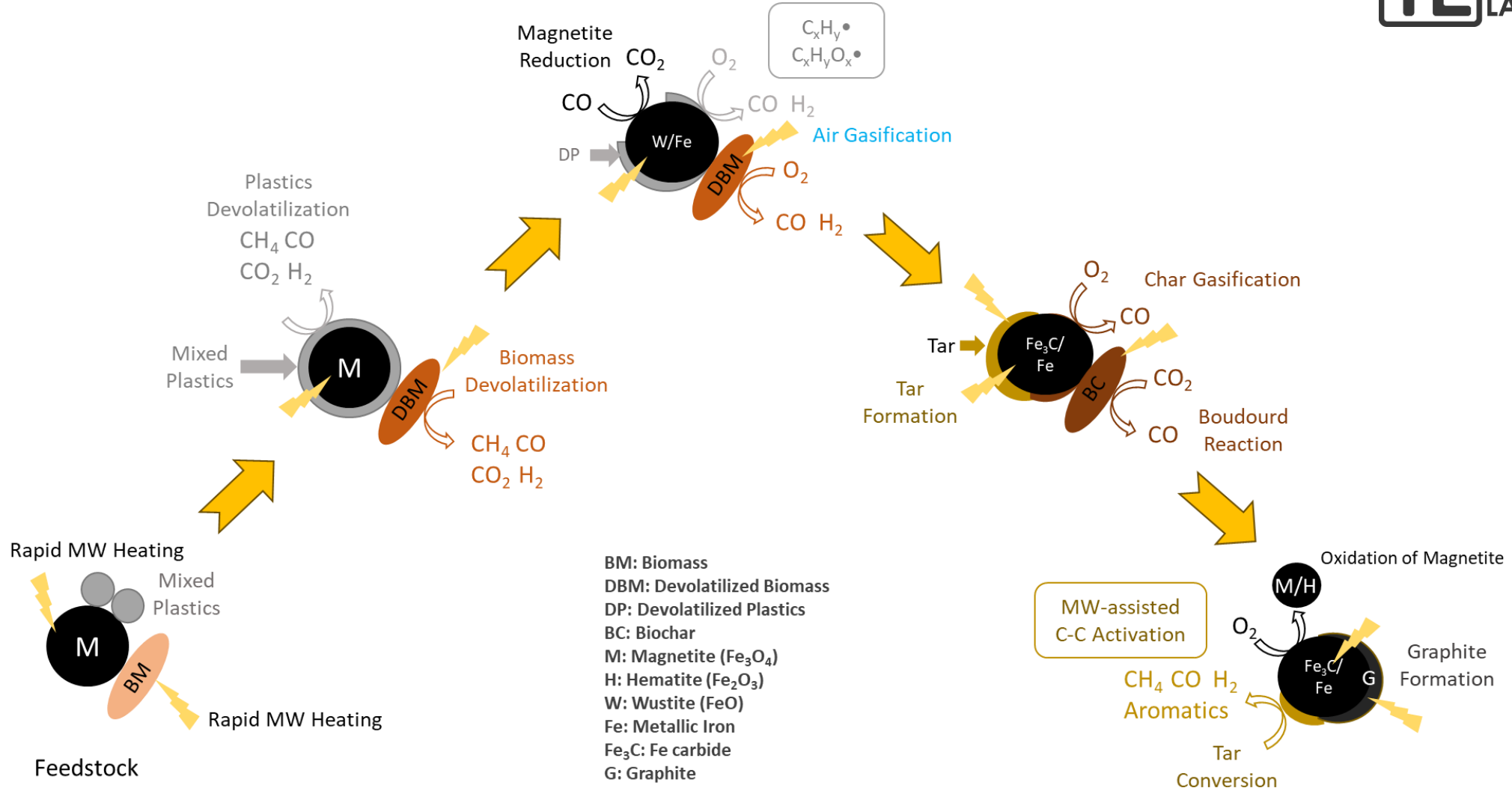


- Reduction of magnetite to reach its active Fe/Fe₃C phases is **absent** in the conventional run (XRD).
- Along with TGA, Raman also suggests the formation of **maximum graphitic carbon** (IG/ID= 1.6).
- Formation of graphitic carbon is responsible for enhanced MW heating, as graphite is an excellent MW absorber, resulting in higher gasification activity.



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Proposed Mechanism (MW)



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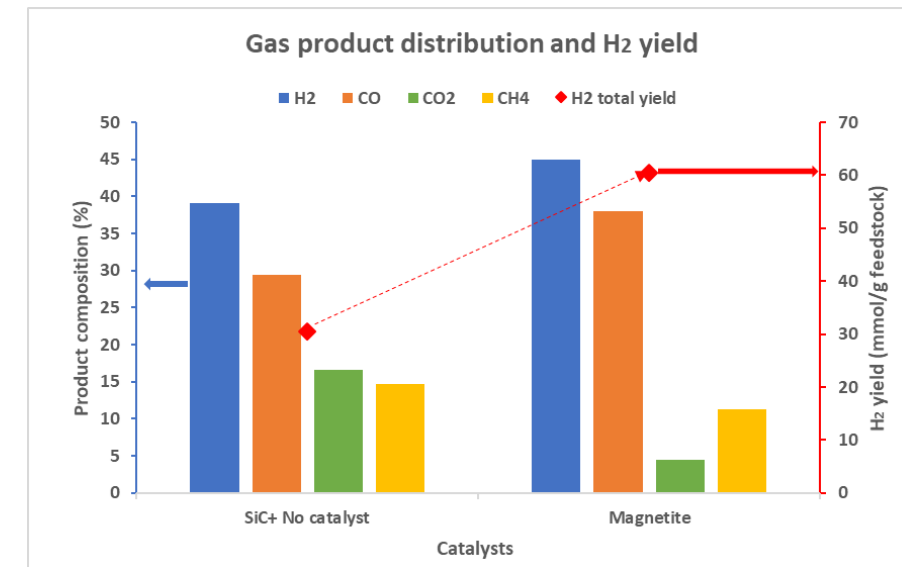
Key Findings: Part 2

- At a temperature range of 700–800 °C, enhanced H₂ yield was observed per gm feedstock.
- Higher syngas yields were detected under lower WHSV (80% vs. 73%).
- **61 mmol H₂/g_{feed}** at 700 °C in microwave reactor vs. **0.9 mmol H₂/g_{feed}** at 700–950 °C with conventional heating.
- Tar amount decreased and gas formation increased with MW vs. conventional runs.
- Fe oxide is reduced to a greater degree and forms graphitic carbon that couples with MW to produce higher H₂ yields under MW.

Magnetite **enhances** MW synergy between plastic and biomass as compared to non-catalytic system (SiC), yielding more H₂ and reducing tar by forming:

- Additional surface oxygen via rapid reduction
- Higher graphitic carbon that couples with MW

Catalytic vs. Non-catalytic
MW plastics and biomass gasification



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The mWave Technology Team

- Diverse team of more than a dozen scientists and engineers
- Access to extensive techno-economic analysis & computational modeling capabilities



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