Microwave-Assisted Co-Gasification of Mixed Plastics and Corn Stover to Produce Clean Hydrogen Using Fe-Based Catalyst

NATIONAL ENERGY TECHNOLOGY LABORATORY

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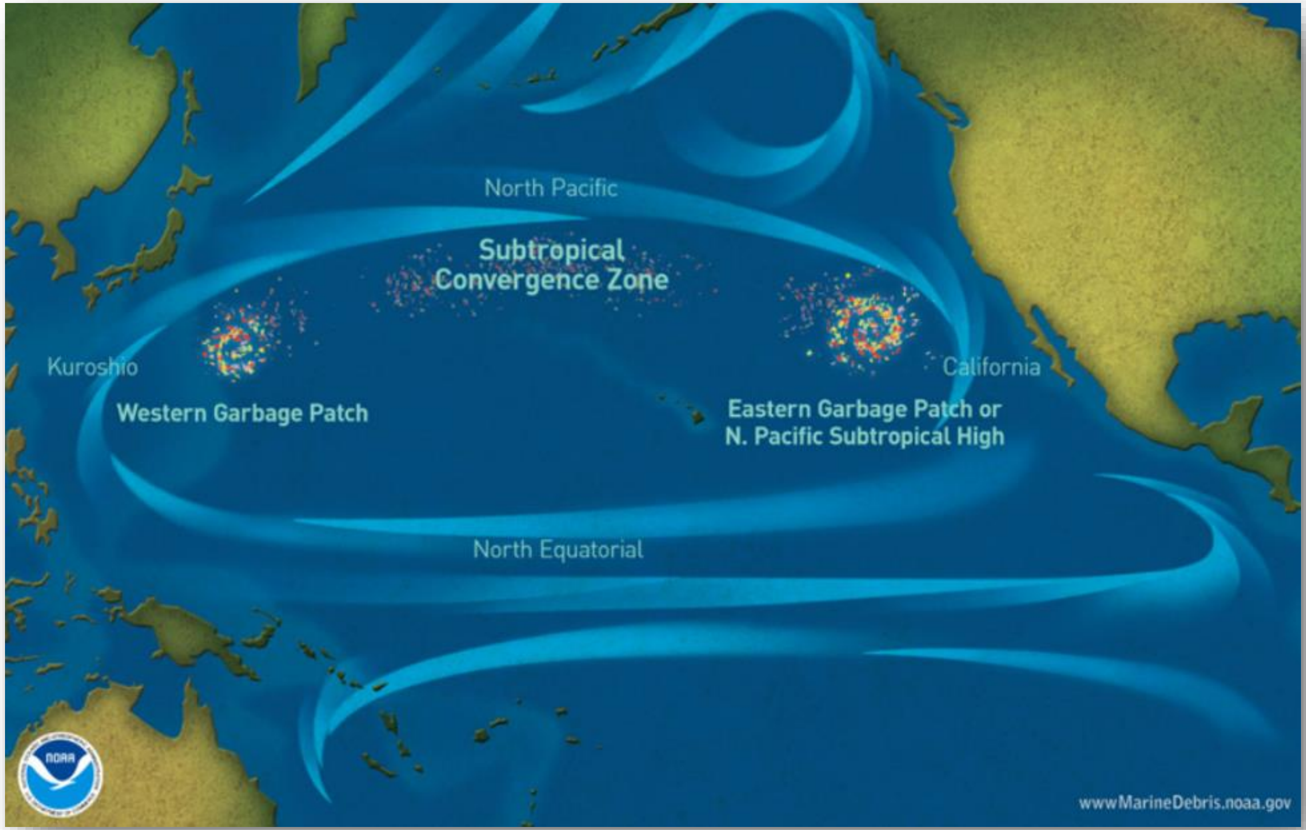
Introduction

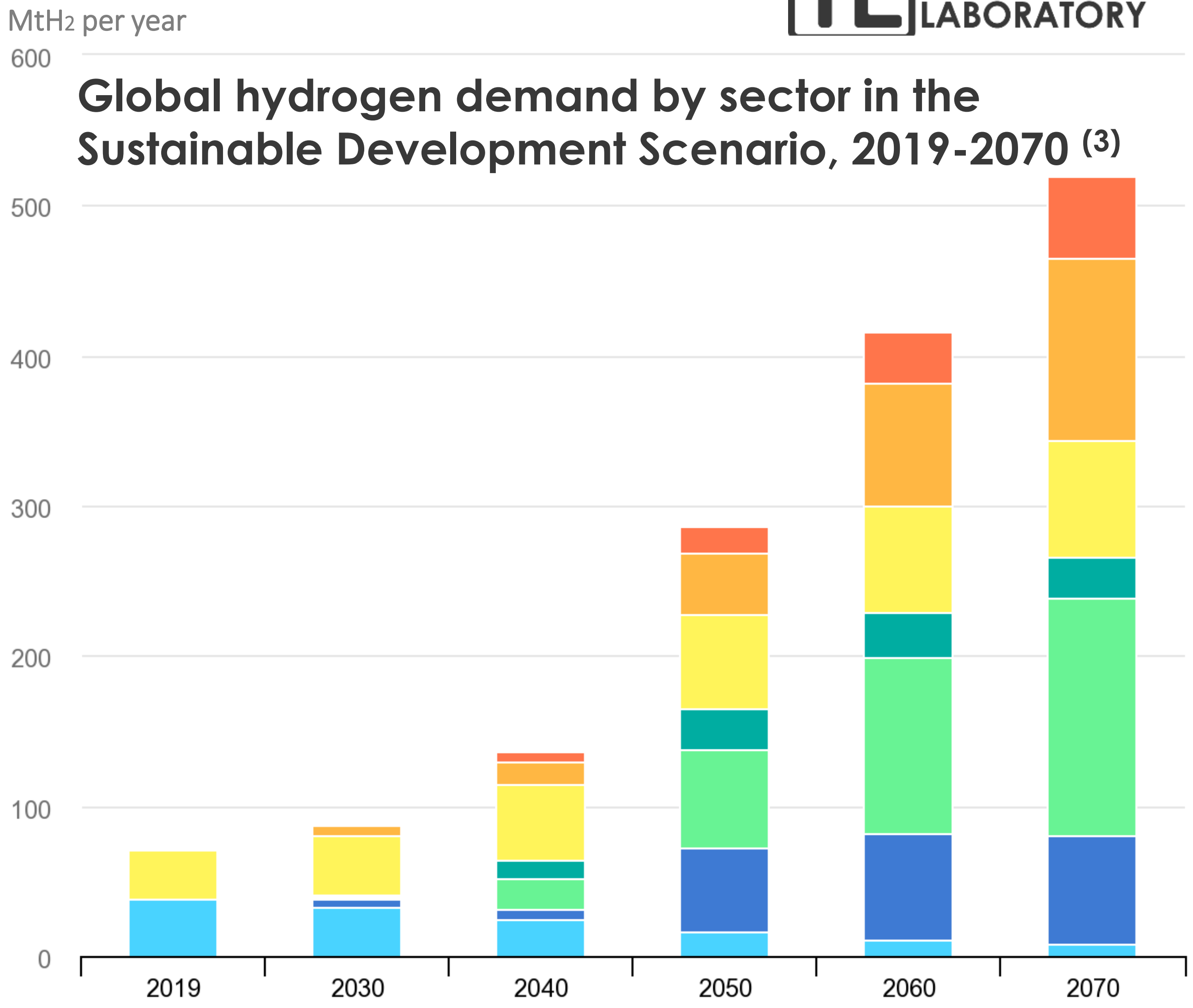
- Plastic Waste
  - 42 million metric tons generated in the United States each year with only 8% being recycled [1]
  - 79 kt of plastic waste inhabits the Pacific Ocean [2]
  - Most commonly polyethylene (plastic bags) and polypropylene (bottle caps)
  - UV rays from the sun break down visible plastic to small microplastics



1. https://marinedebris.noaa.gov
2. https://www.nationalgeographic.com/environment

Introduction

- Hydrogen Energy
  - Heat of combustion three times greater than natural gas
  - Microwave technology can significantly reduce the energy loss associated with conventional heating
  - H_2 efficiency $\left(\frac{mmol}{kWh}\right)$ nearly 24 times greater than conventional heating

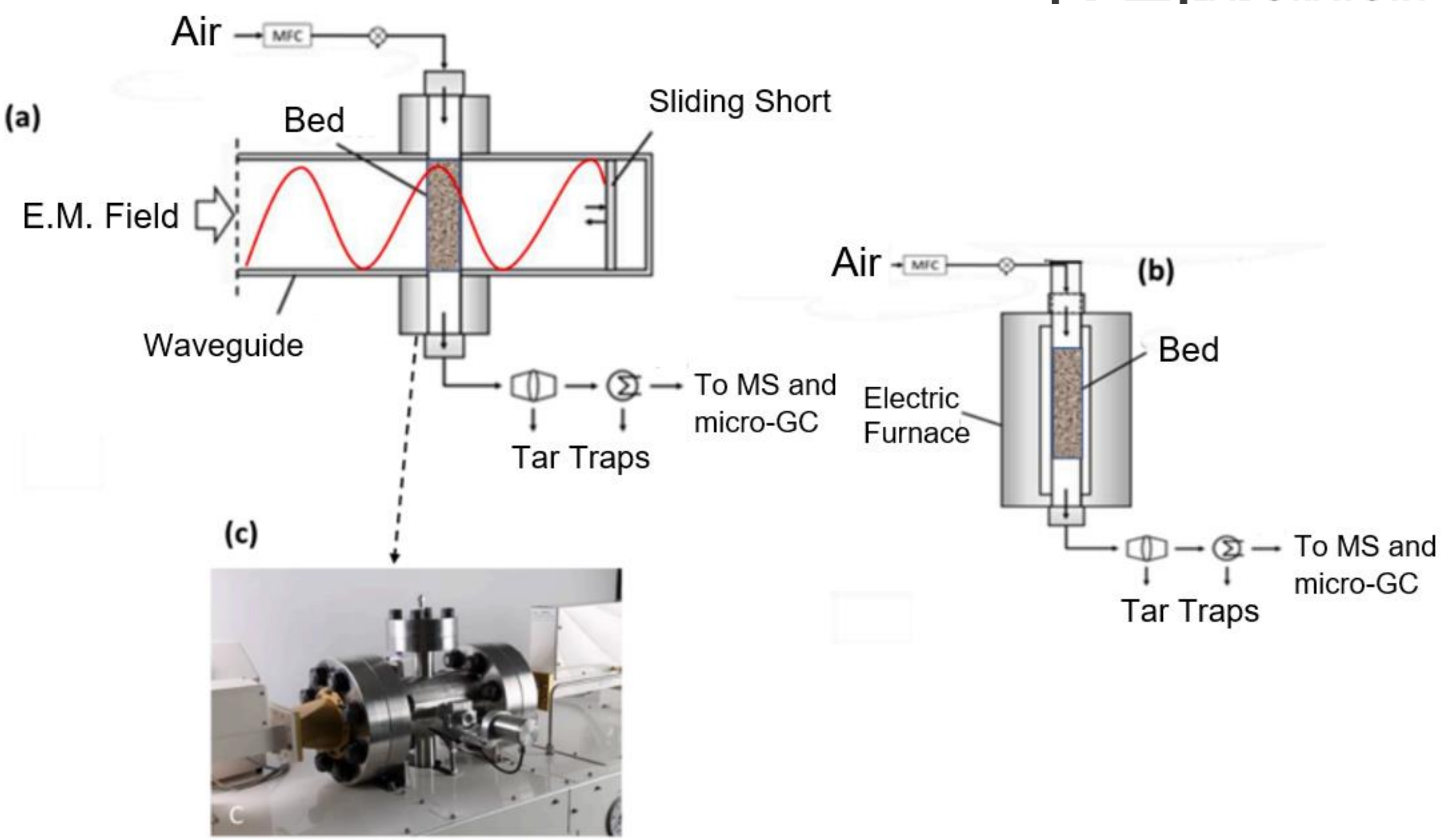


3. IEA Global Hydrogen Review 2021

Methodology

- Microwave Co-Gasification
  - Selective heating
  - Saves more energy than conventional gasification
  - Synergistic effects

- Iron-Based Catalysts
  - Fe_2O_3 used as microwave active catalyst
  - Highly abundant
  - Interact with the electromagnetic field to transfer heat



Experimental setup: (a) microwave, (b) conventional, and (c) original high-pressure microwave reactors used for the gasification testing.

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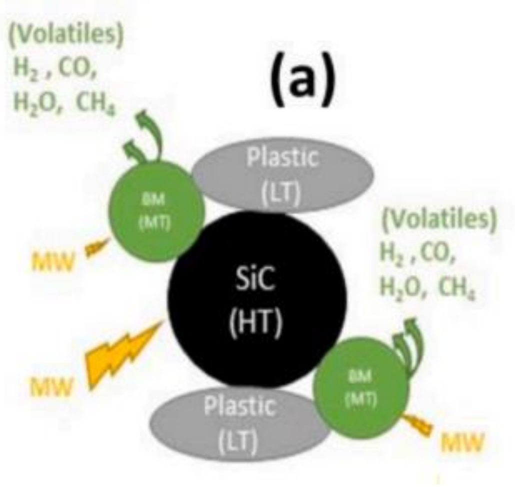
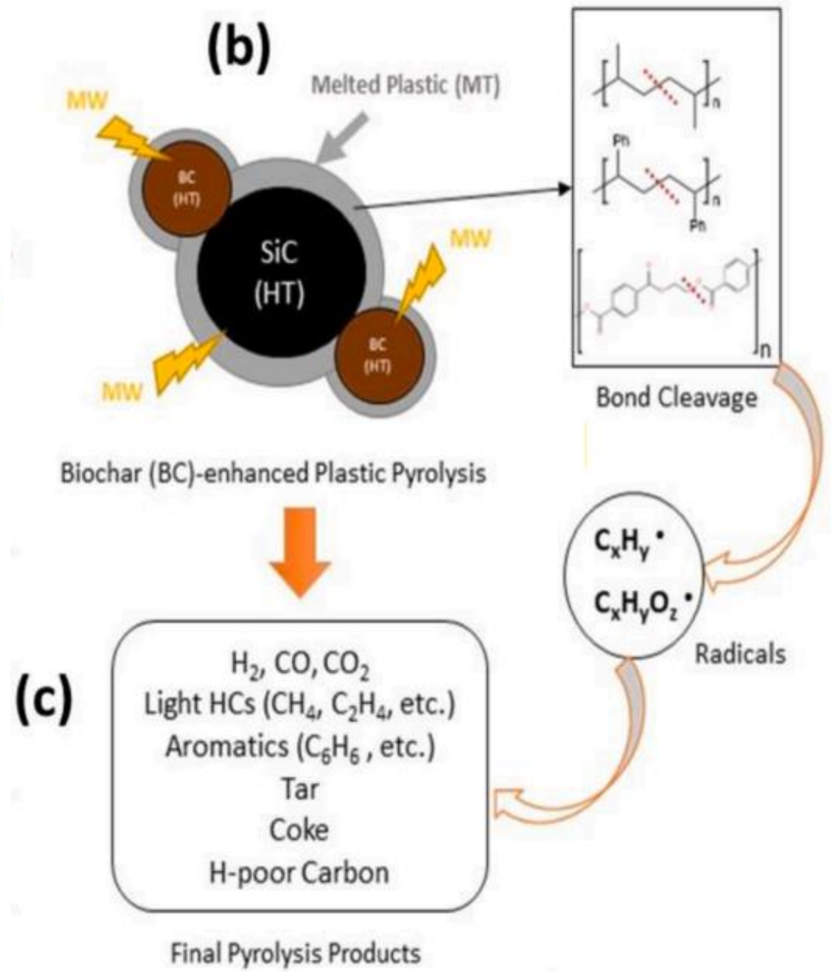
Methodology

- Reaction Mechanisms
  - Plastic, alone, is microwave inactive
  - Biomass interacts with the catalyst to raise internal heating
  - Feedstock becomes devolatilized due to initial interactions with microwave active material





Spent sample

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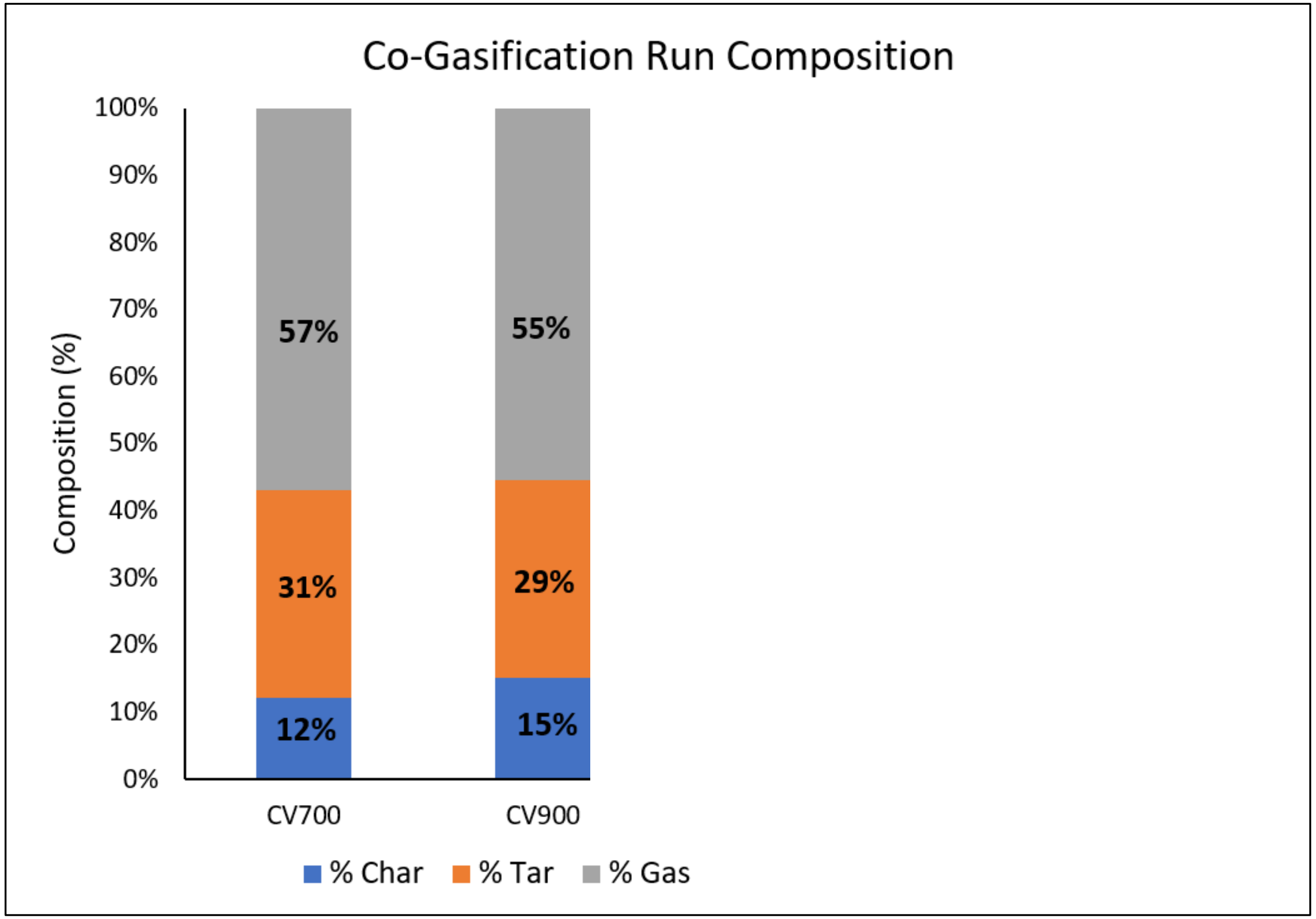
Reaction Data

- Conventional Heating
  - Requires bulk temperatures
  - External heating
- Results
  - Similar output in syngas yield between the two conventional runs
  - Excessive tar production

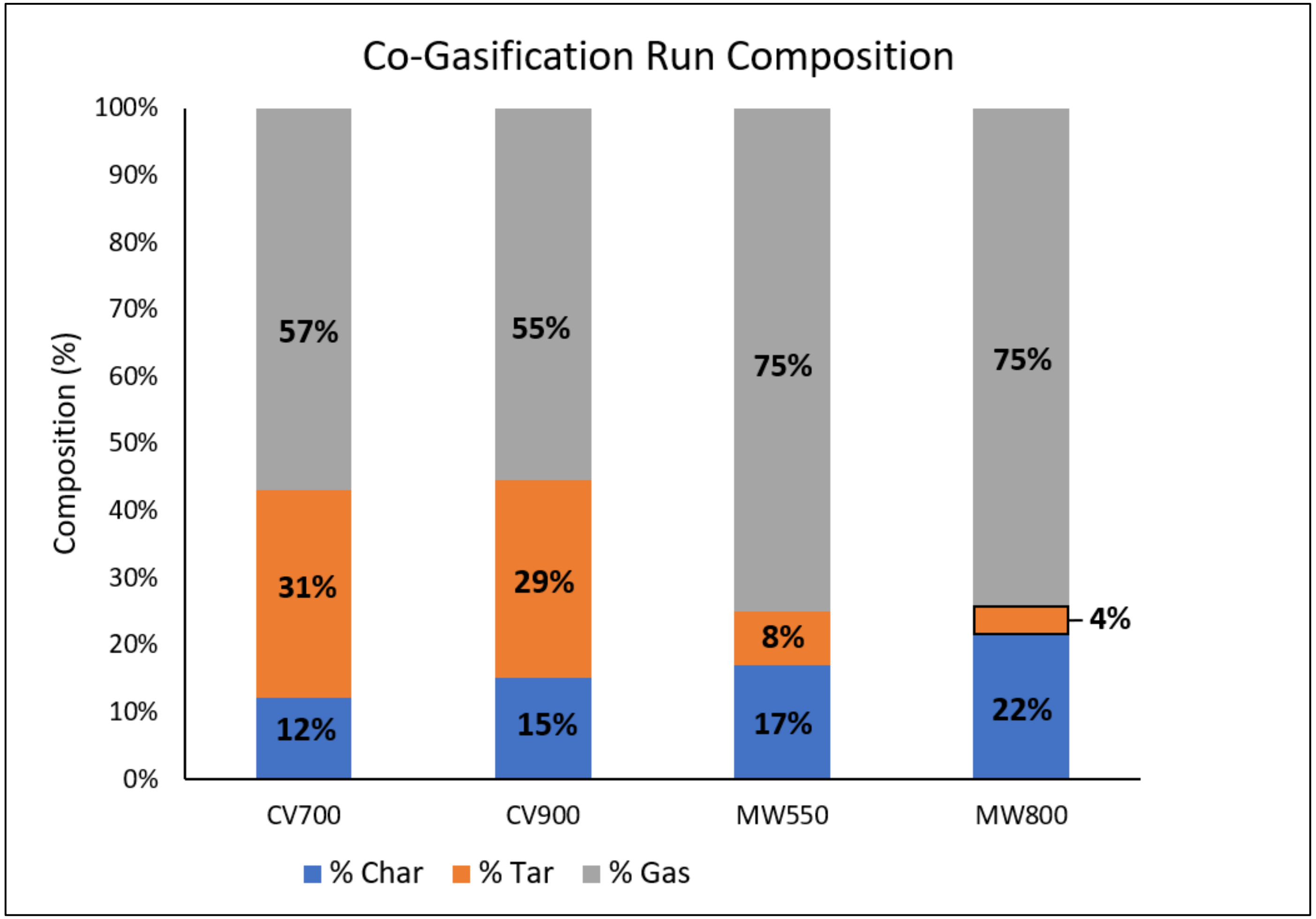


Material composition after conventional and microwave reactions.

Reaction Data

- Microwave Heating
  - Applies an electromagnetic field
  - Selective heating

- Results
  - Significantly reduced tar formation
  - Increase in hydrogen-rich syngas

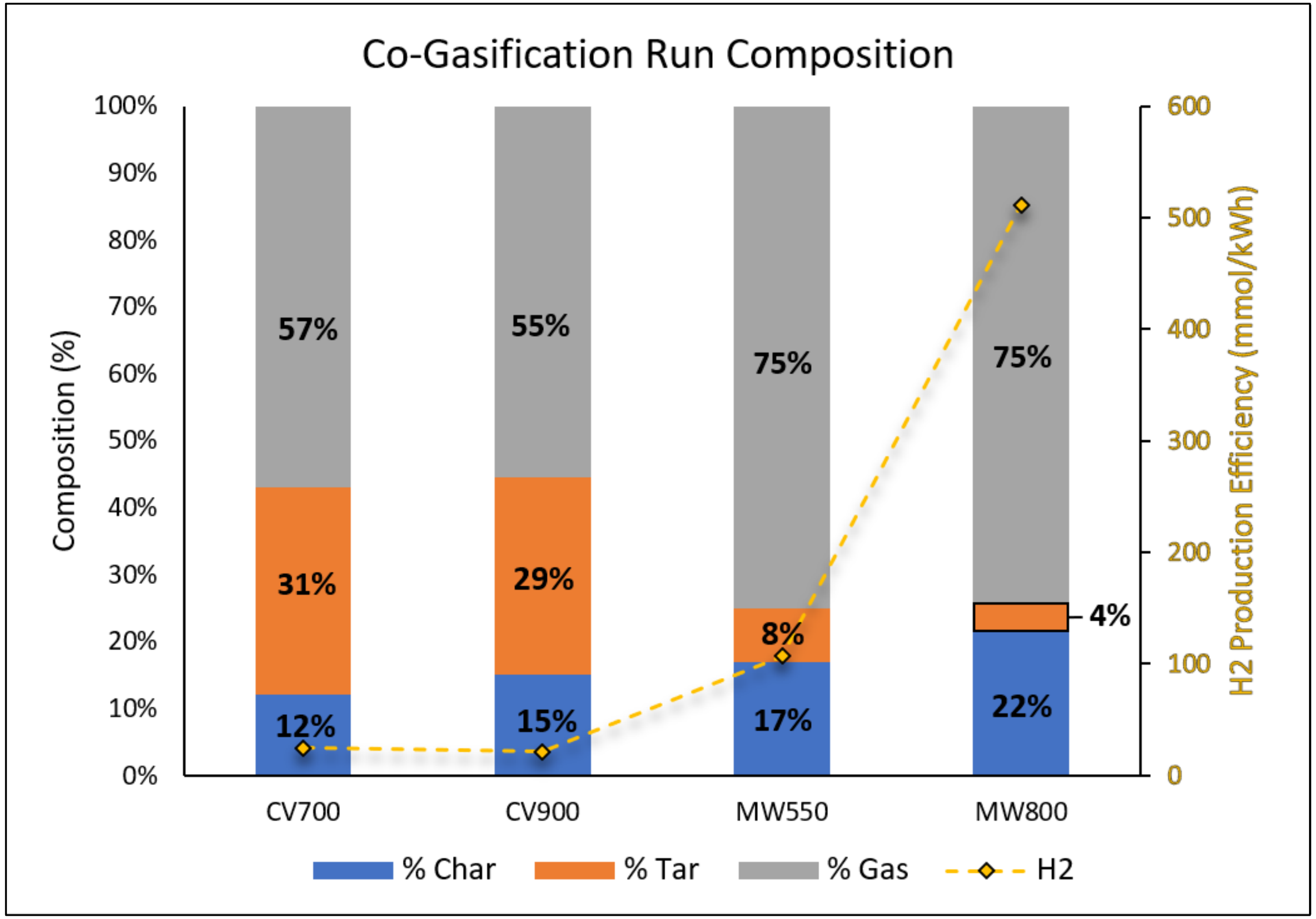


Material composition after conventional and microwave reactions.

Reaction Data

- Microwave Heating
  - Applies an electromagnetic field
  - Selective heating

- Results
  - Significant improvement in hydrogen production efficiency
  - Selective heating manipulates order of feedstock devolatilization

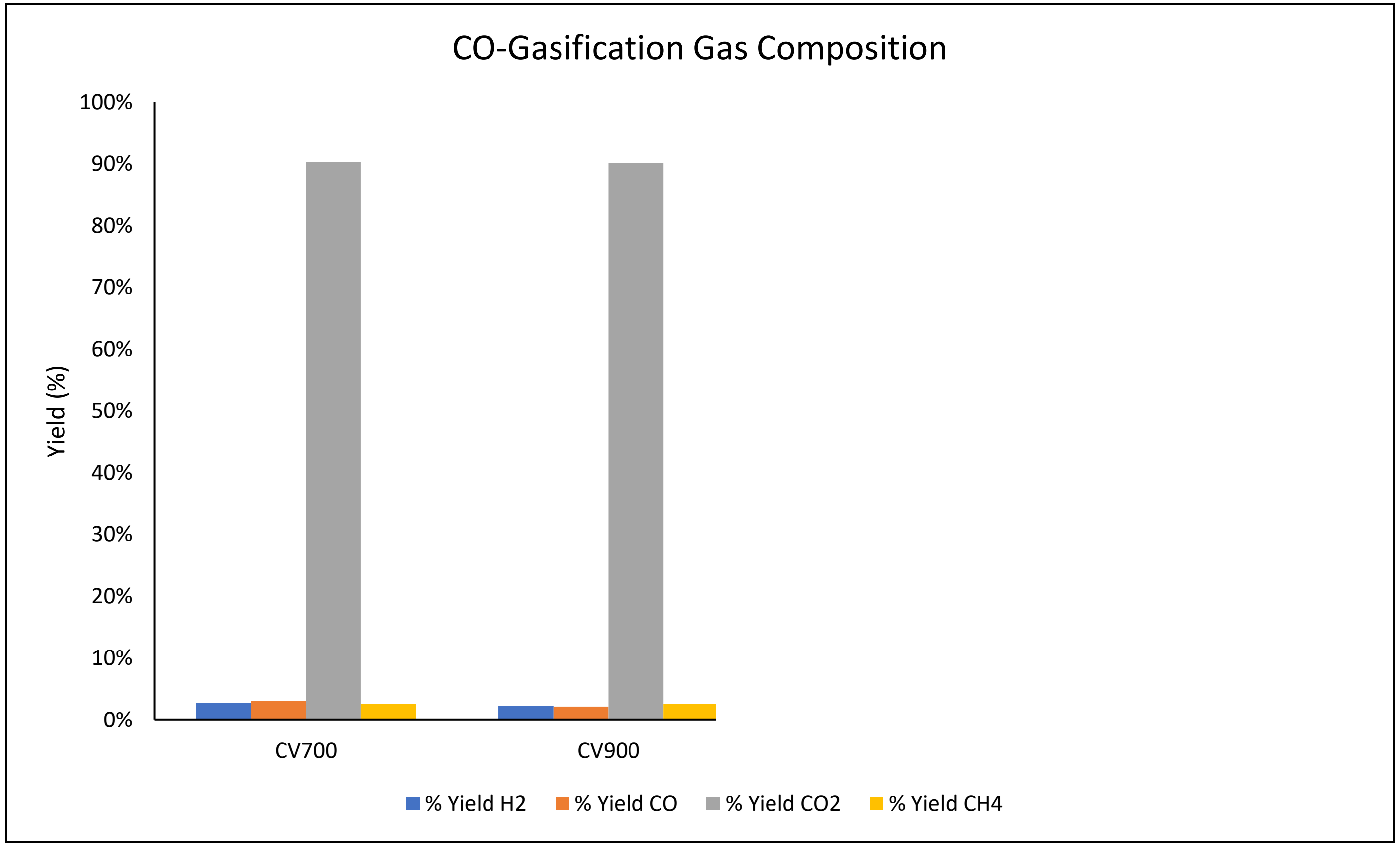


Material composition including hydrogen material balance.

Reaction Data

- Conventional Heating
  - Requires bulk temperatures
  - External heating

- Results
  - Low hydrogen yield
  - Excessive carbon dioxide production

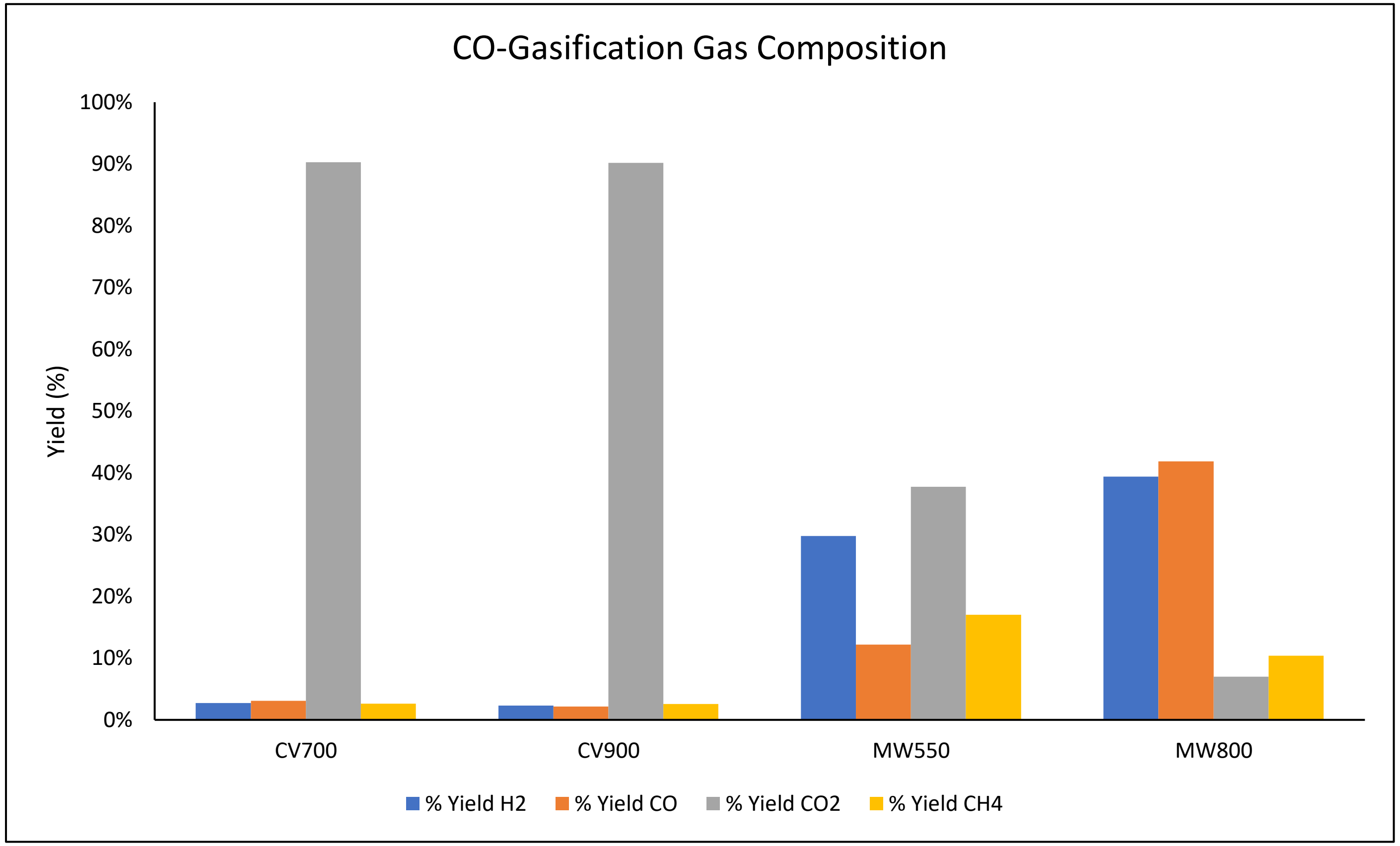


Gas composition after conventional and microwave reactions.

Reaction Data

- Microwave Heating
  - Applies an electromagnetic field
  - Selective heating

- Results
  - Significantly improve hydrogen yield percentage
  - Maximizing energy output with better methane production



Gas composition after conventional and microwave reactions.

Reaction Data

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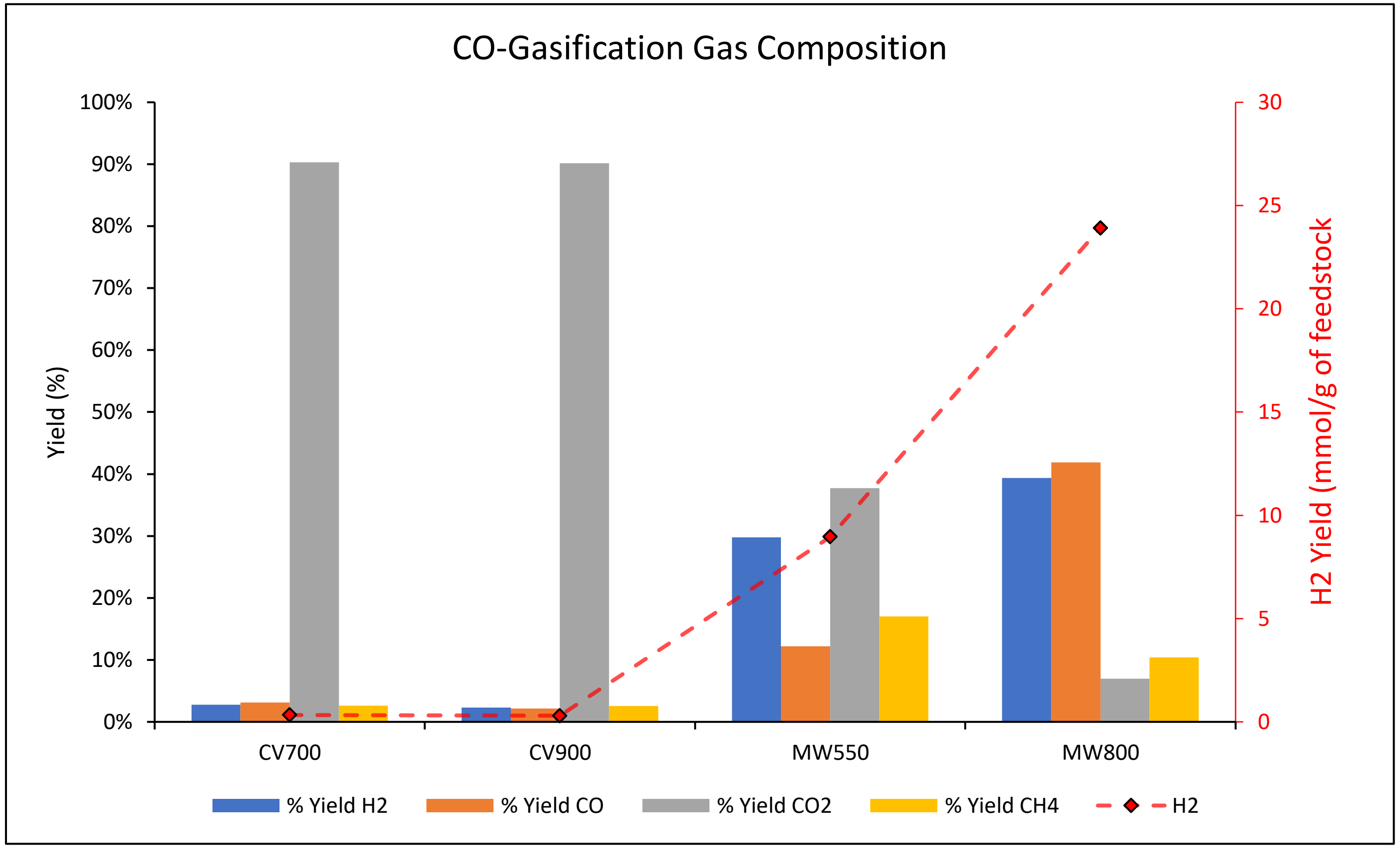
- Results
  - Significantly improve hydrogen yield per gram of feedstock
  - Maximizing energy output with better methane production



Gas composition after conventional and microwave reactions.

Characterization

- X-Ray Diffraction
  - Reduction of α−Fe_2O_3 to metallic Fe
  - Identified active phases
  - Reaction pathways:

    (Boudouard reaction)

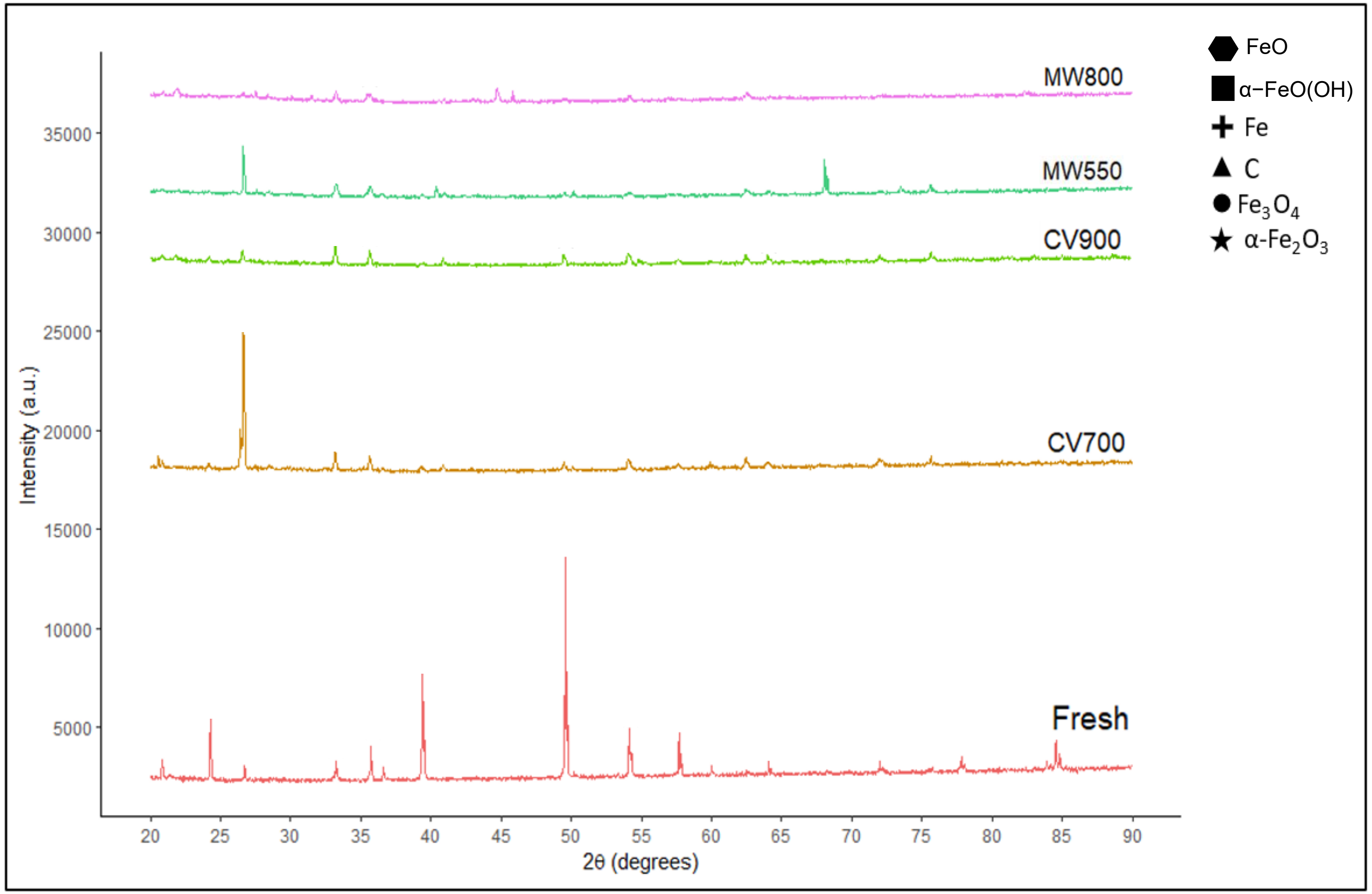
    $$C + CO_2 \rightleftharpoons 2CO$$

    (Water-Gas Shift)

    $$H_2O + CO \rightleftharpoons H_2 + CO_2$$

    (Hematite Reduction)

    $$Fe_2O_3 \rightarrow Fe_3O_4 \rightarrow FeO \rightarrow Fe^0$$



X-ray diffraction of fresh and spent catalyst sample.

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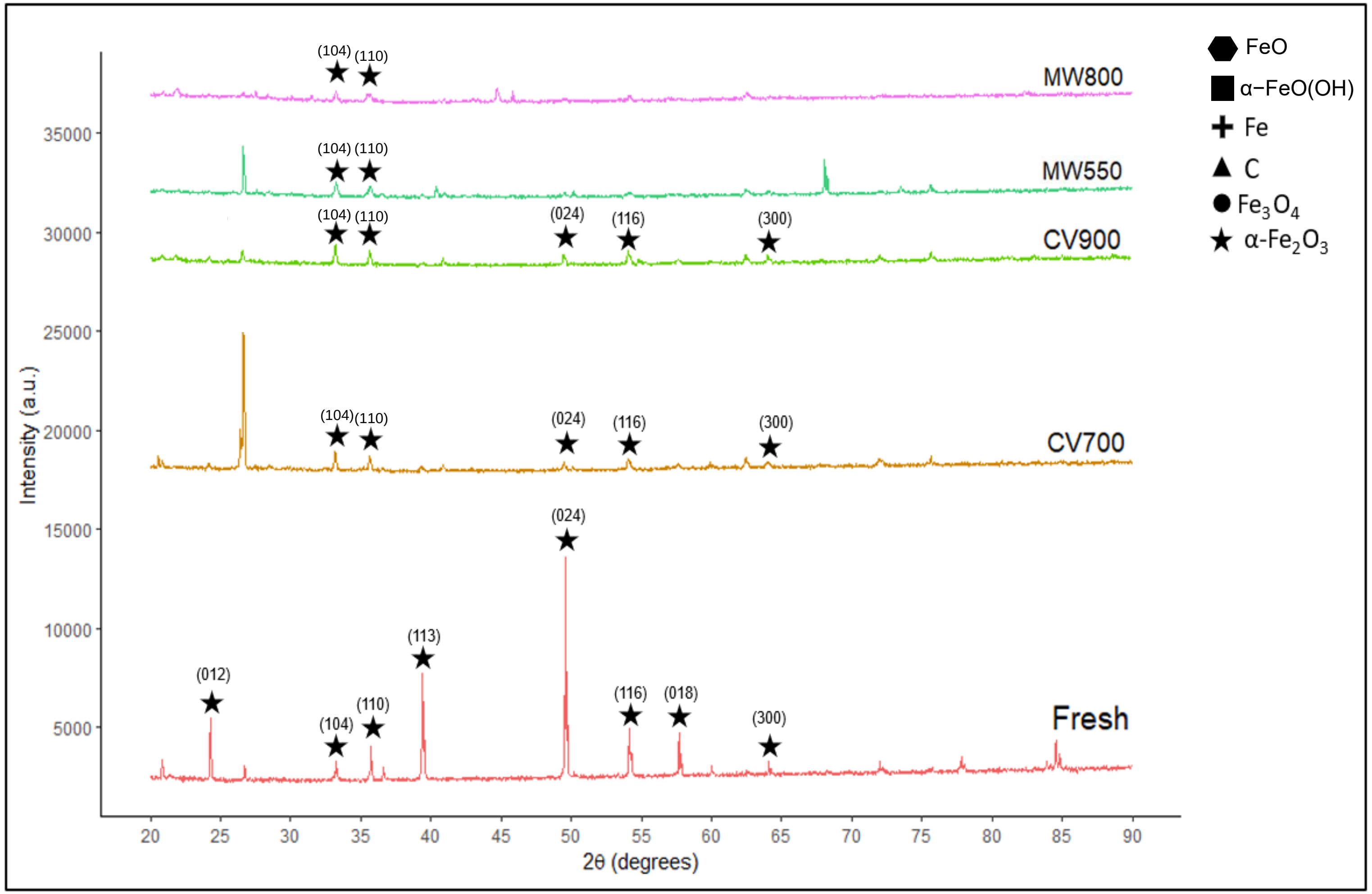

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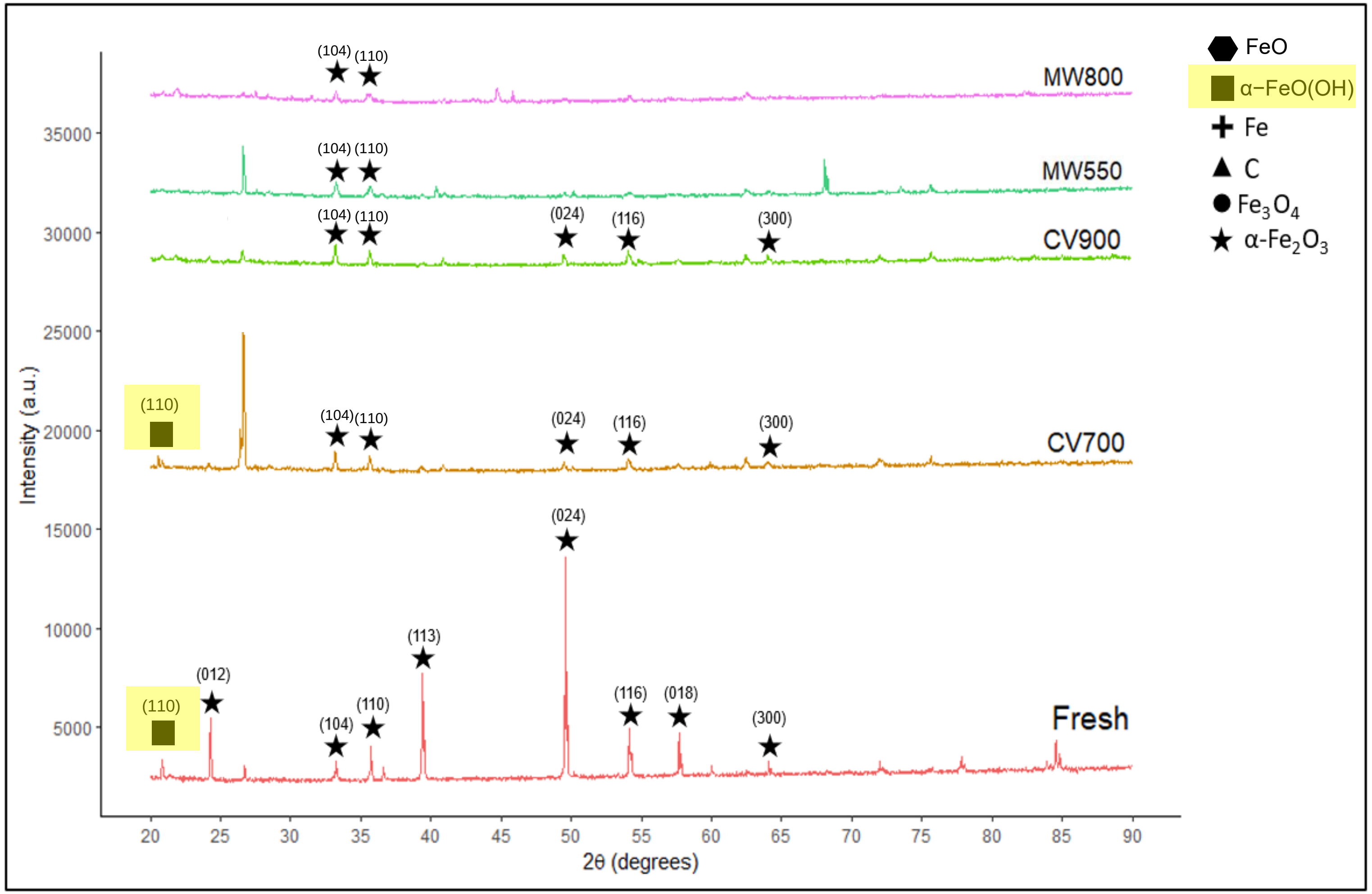

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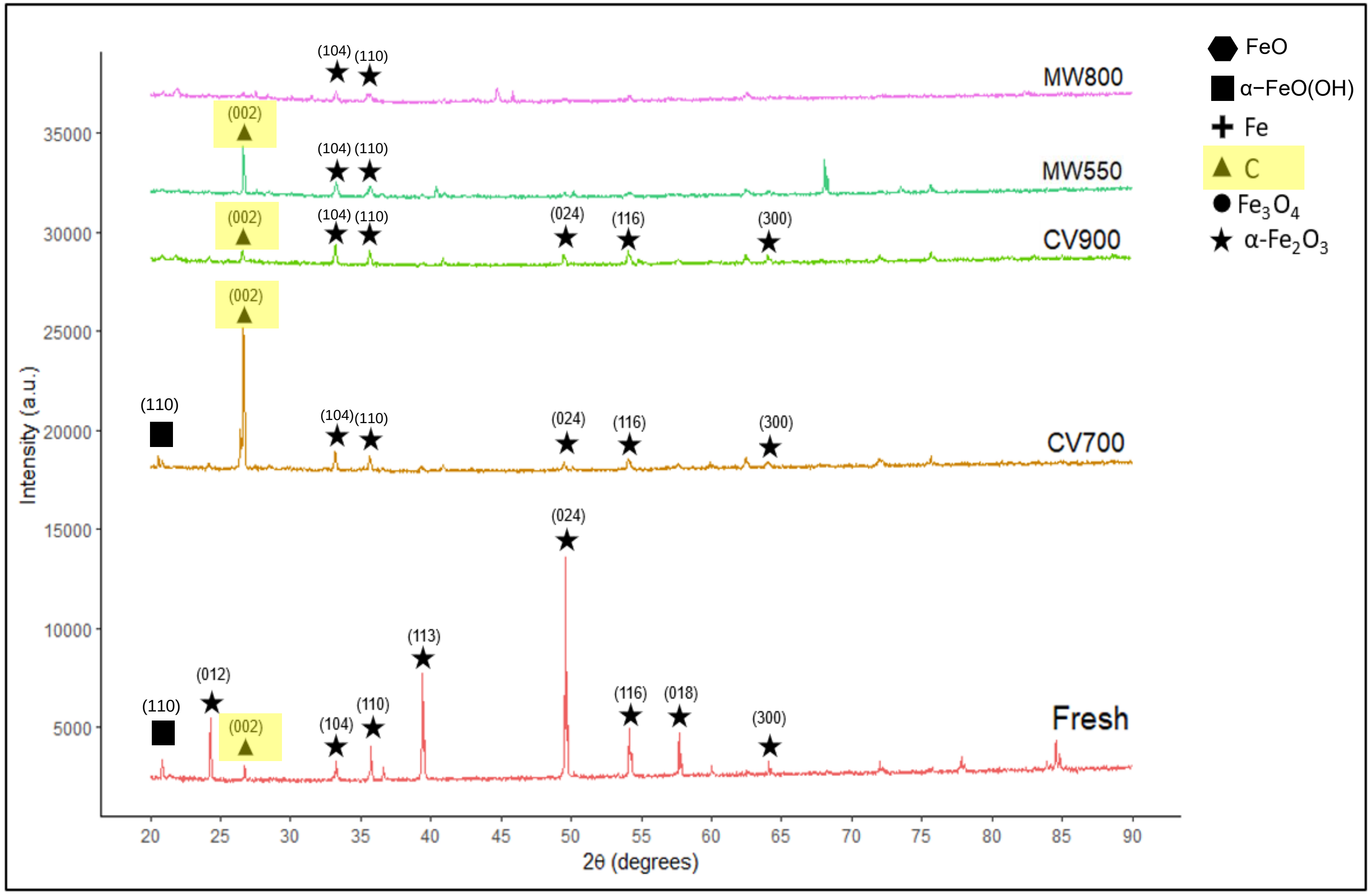

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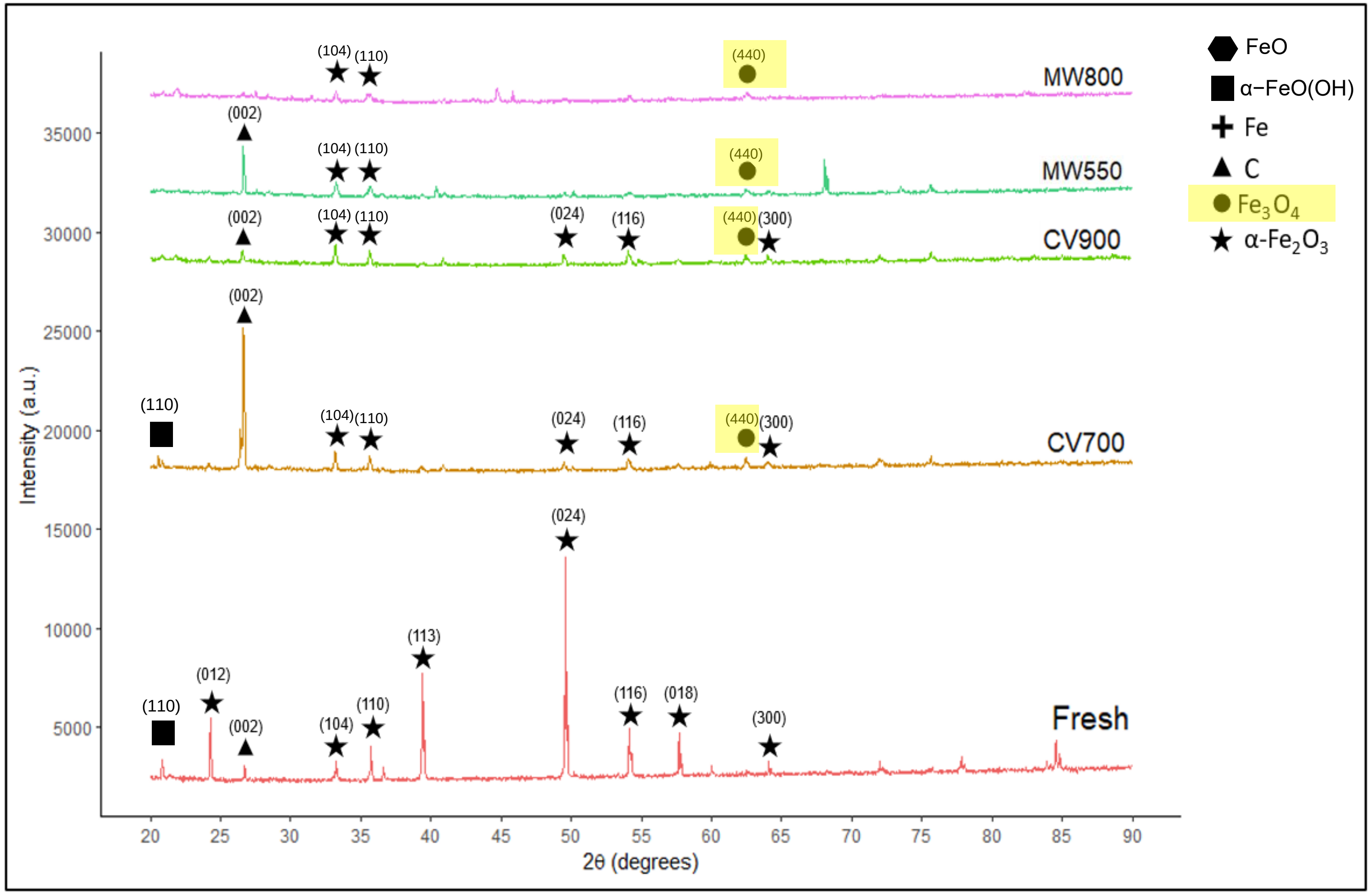

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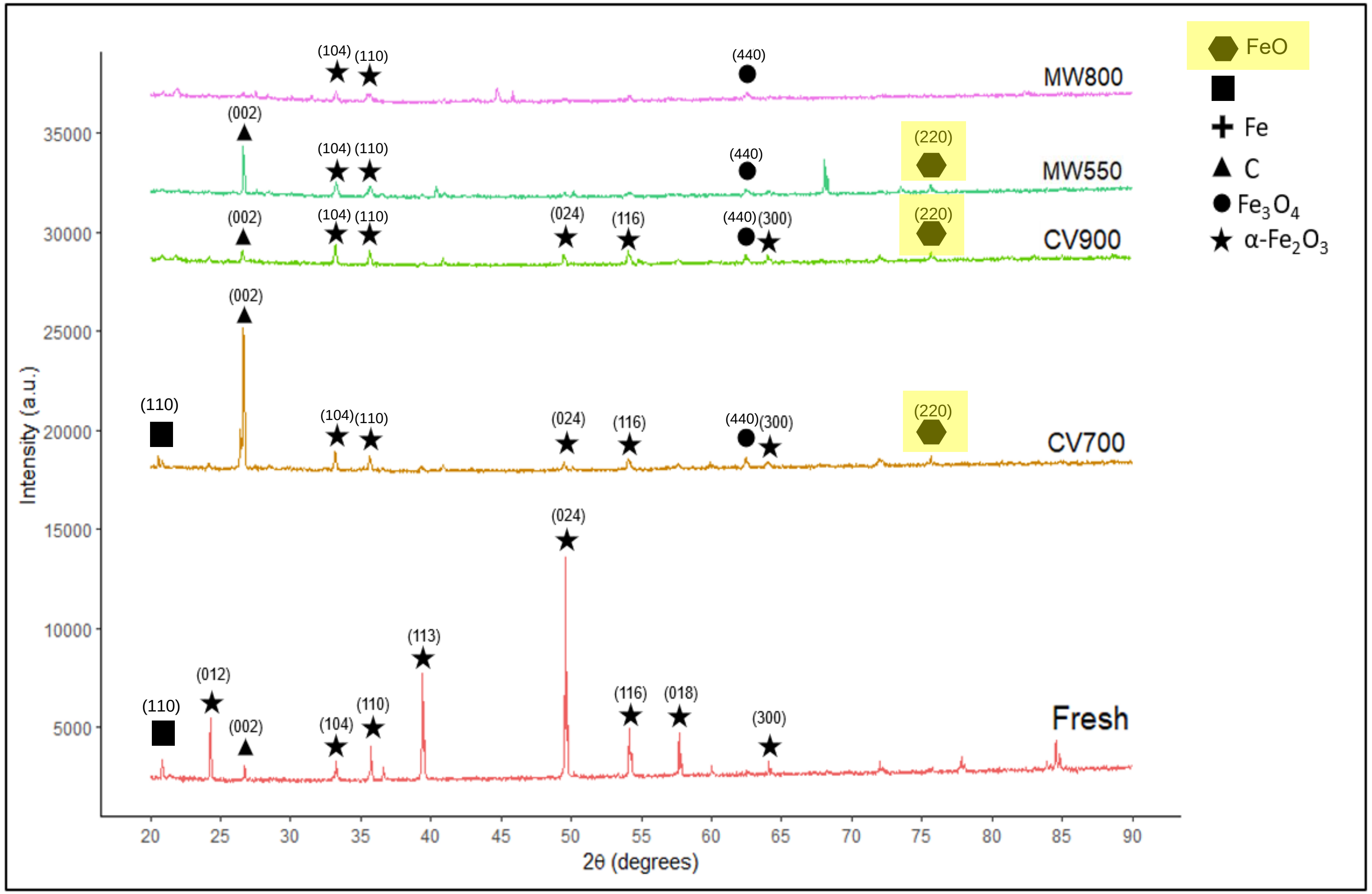

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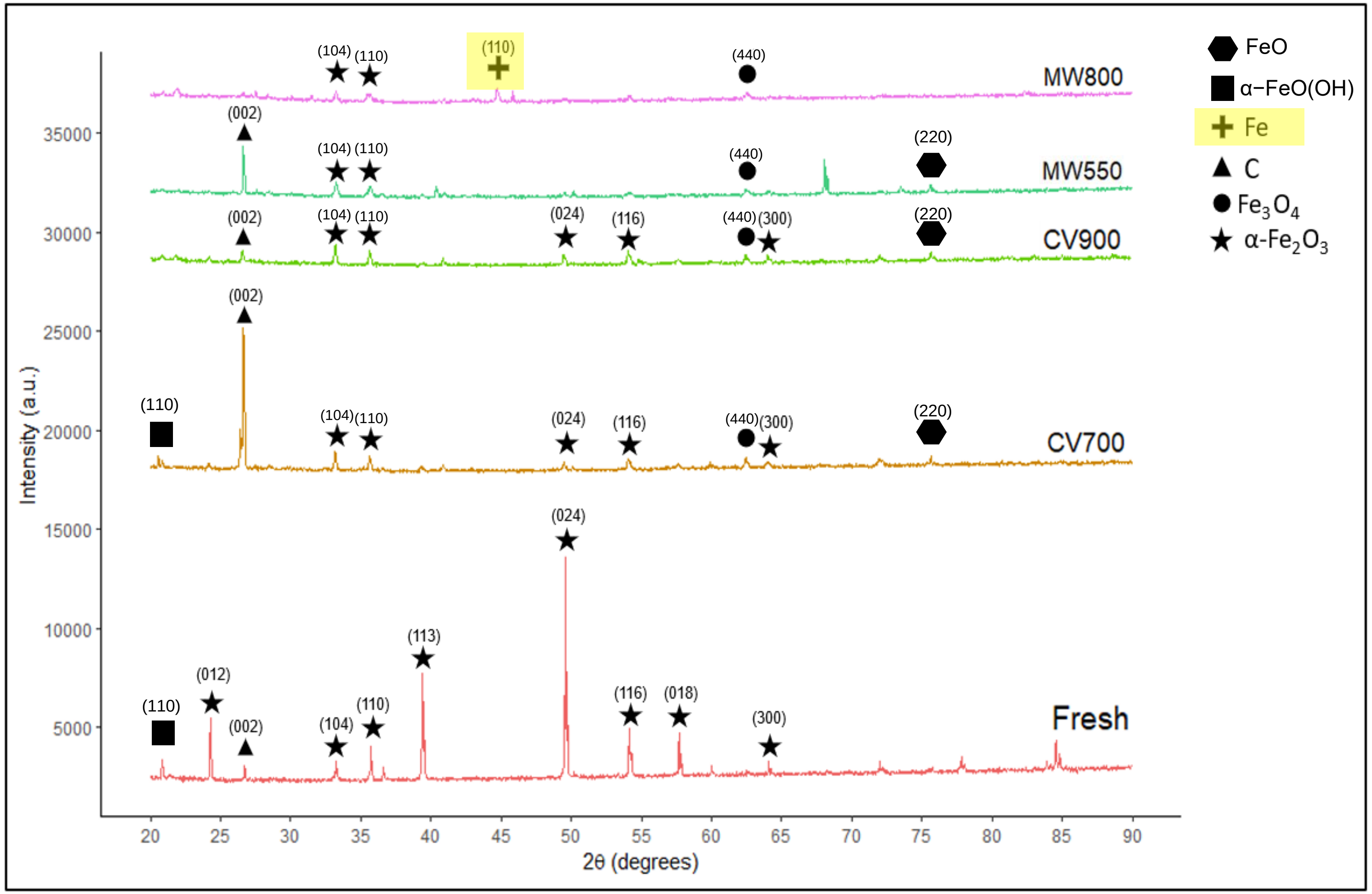

X-ray diffraction of fresh and spent catalyst sample.

Conclusion

- Discoveries
  - Microwave heating at 800 °C produced 24 times more mmol of hydrogen per kWh and 80 times more per gram of feedstock than the conventional run at 900 °C:
    - 0.3 mmol $H_2/g_{feedstock}$ produced in the conventional run at 900 °C
    - 23.9 mmol $H_2/g_{feedstock}$ produced in the microwave run at 800 °C

- Future Works
  - Exploring additional characterization techniques for carbon analysis (Raman, Thermogravimetric Analysis, Scanning Electron Microscopy)
  - Assessing dielectric properties of Fe oxide at reaction temperatures

Microwave Gasification Team

- Pranjali Muley
- Ashraf Abedin
- Xinwei Bai
- Charles Henkel
- Anitha Linge Gowda
- Divakar Reddy
- Heath Gregg
- Ben Gibens (Summer 2023 Research Associate)

During NETL MLEF Summer 2023 Project:
Ben Gibens & Ashraf Abedin

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