Clean H_2 from Natural Gas using microwaves

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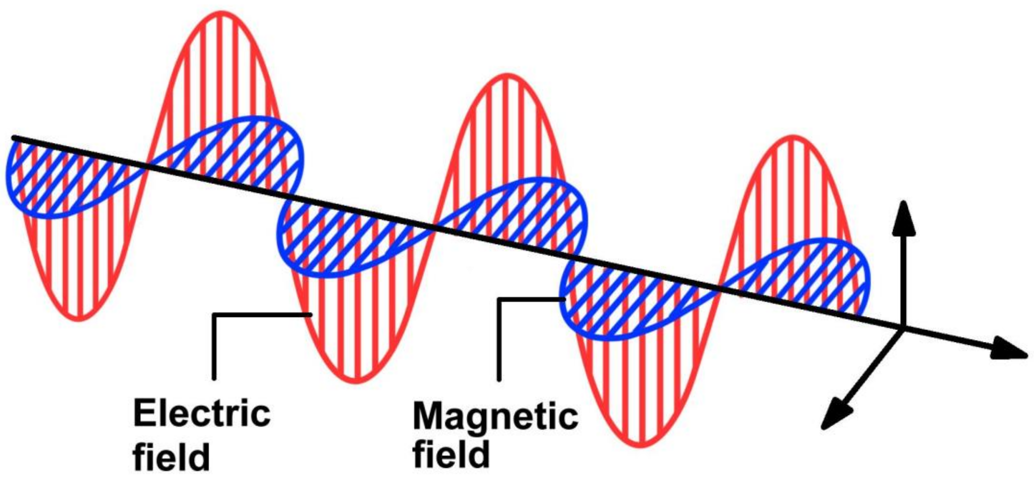
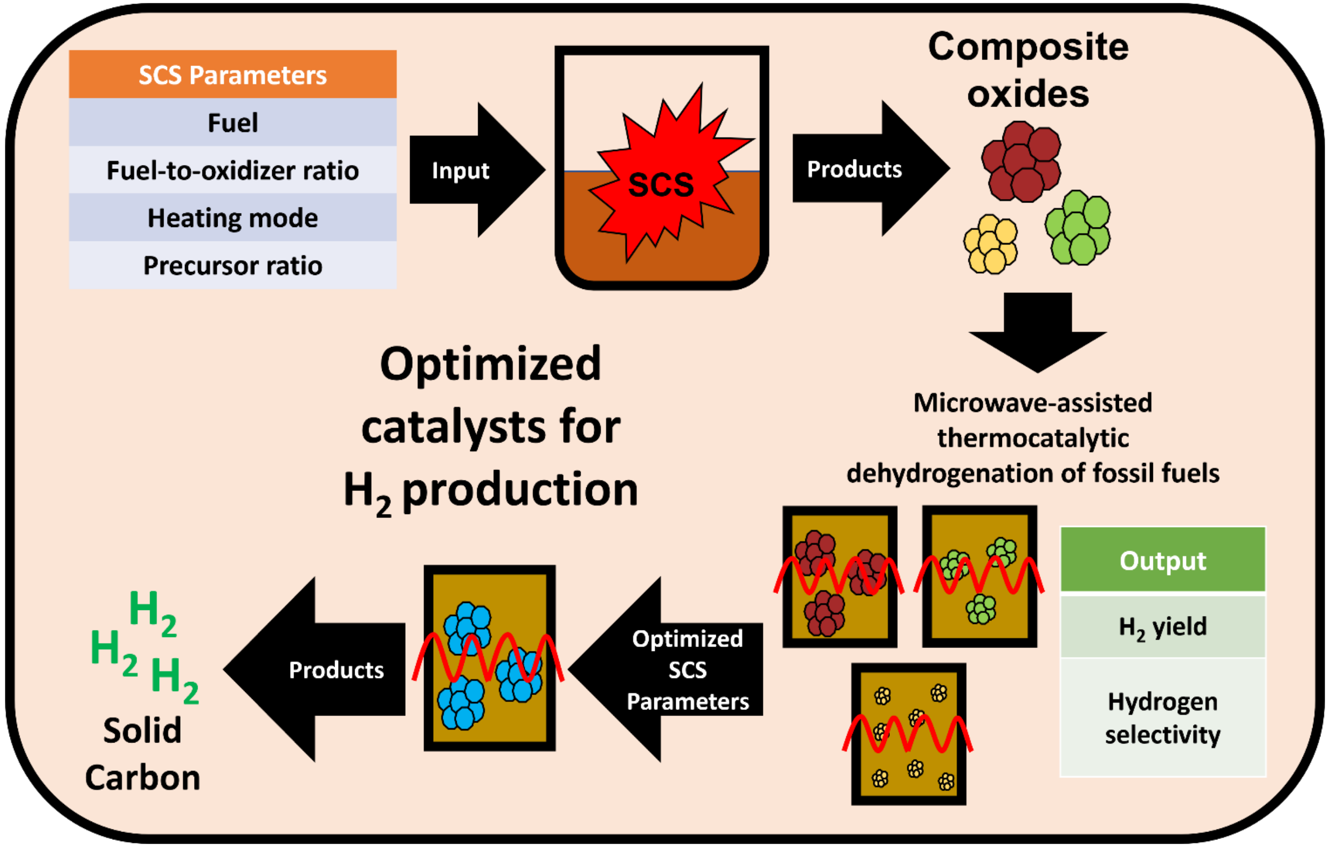
Using FeAlOx catalysts fabricated via solution combustion synthesis

CHRES Intern: Zachary Chanoi, Mentor: Dr. Pranjali Muley





CHRES CONSORTIUM OF HYBRID RESILIENT ENERGY SYSTEMS

DE-NA0003982

Background: Hydrogen and Microwaves

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The Paradox of hydrogen

- The demand for hydrogen is increasing dramatically – from **120 Mt** (2020) to a projected **530 Mt** (2050) [1]
- 95% of H_2 is produced from fossil fuels
  - Methane steam reforming – 5.5 kg CO_2/kg H_2

Microwave-assisted H_2 production

- Instantaneous and selective heating of catalyst make it ideal for **hybrid energy systems** by being paired with intermittent **renewable energy**

Methane pyrolysis

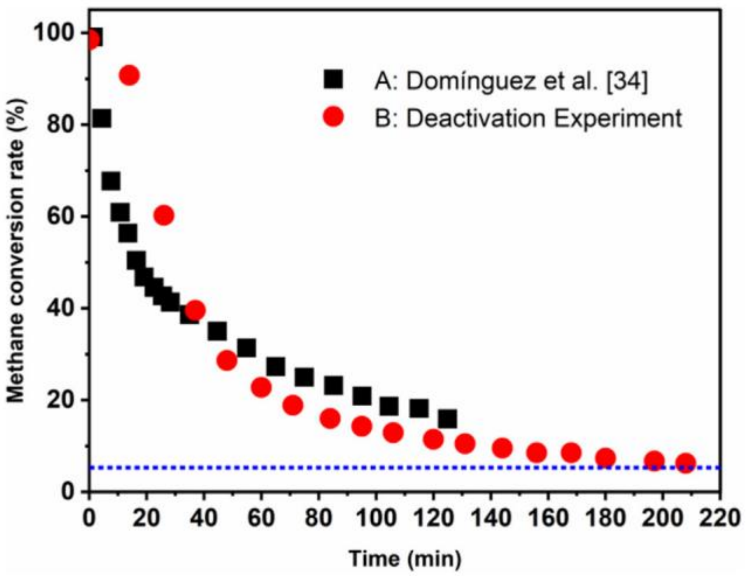
$$CH_4 \rightarrow 2H_2 + C$$

Challenges?

Previous attempts at methane pyrolysis

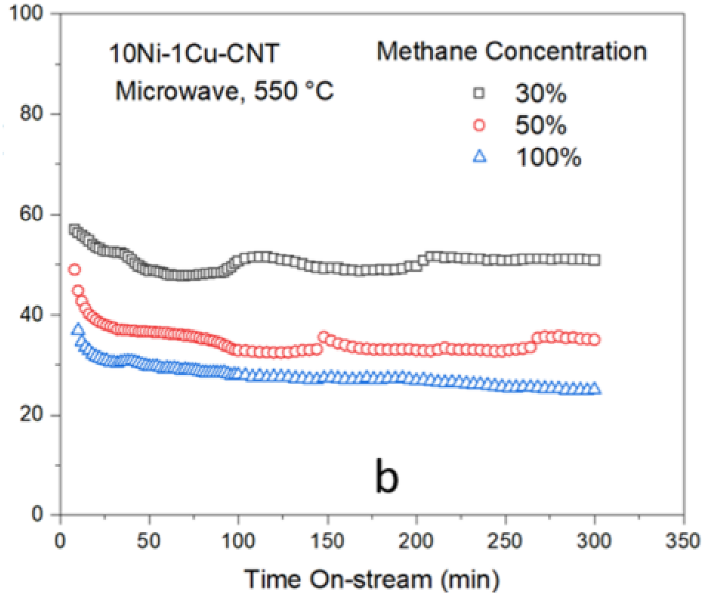
High energy consumption and unideal catalysts

[2] Catalyst: activated carbon
Temperature: 1000°C



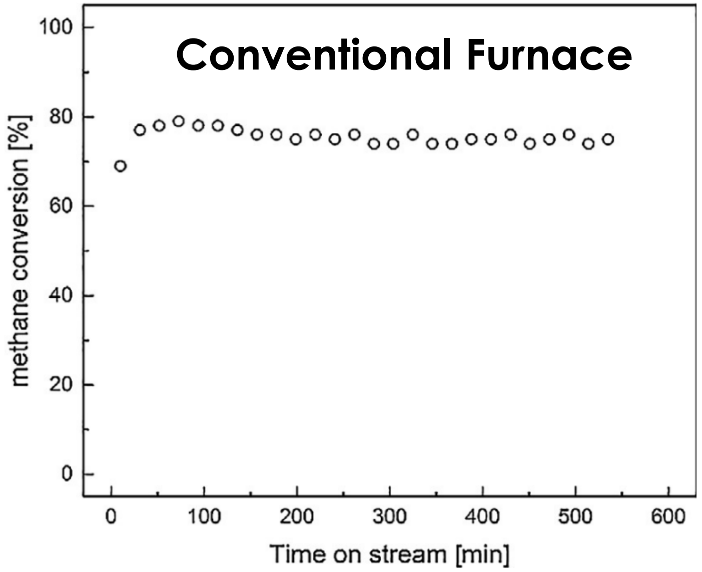
Despite initial high conversion, activated carbon dropped **below 50% conversion in just 40 min** even **at high temperatures**.

[3] Catalyst: 10Ni-Cu/CNT
Temperature: 550°C



Microwave heating **improved conversion**, but still <60%. Expensive and **toxic catalysts** used.

[4] Catalyst: Fe/FeAl_2O_4
Temperature: 750°C



Catalysts require long synthesis times with high temperature calcination step needed for activation. This activation **consumes energy and H_2** before pyrolysis even begins.

Objectives

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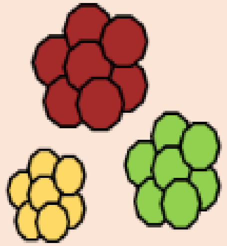
1. Synthesize **FeAlOx** catalyst using **solution combustion method**
   - **Simple**, **rapid**, no **pretreatment**
   - Characterization will enable the **linking** between material **properties** and MW **performance**

SCS Parameters
Fuel
Fuel-to-oxidizer ratio
Heating mode
Salt concentration
pH

Input

Products

Nanoscale metal oxides



Fe:Al

1:1-H

Objectives

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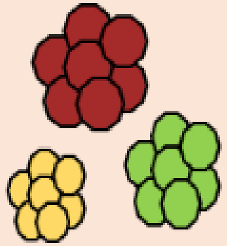


Heating mode

1:1-H
1:1-F
2:1-H
2:1-F

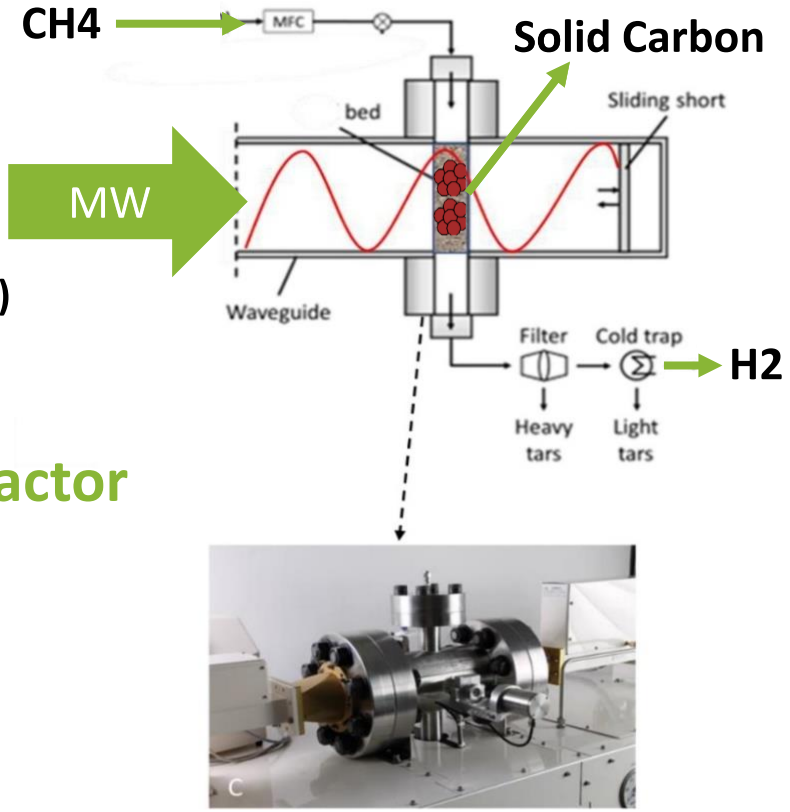
4 catalysts synthesized

Objectives

2. Pair FeAlOx catalysts with **microwave energy** in search for **higher hydrogen production and reduced energy consumption**

- Evaluate based:
  - **H_2 produced**
  - **Energy expenditure**

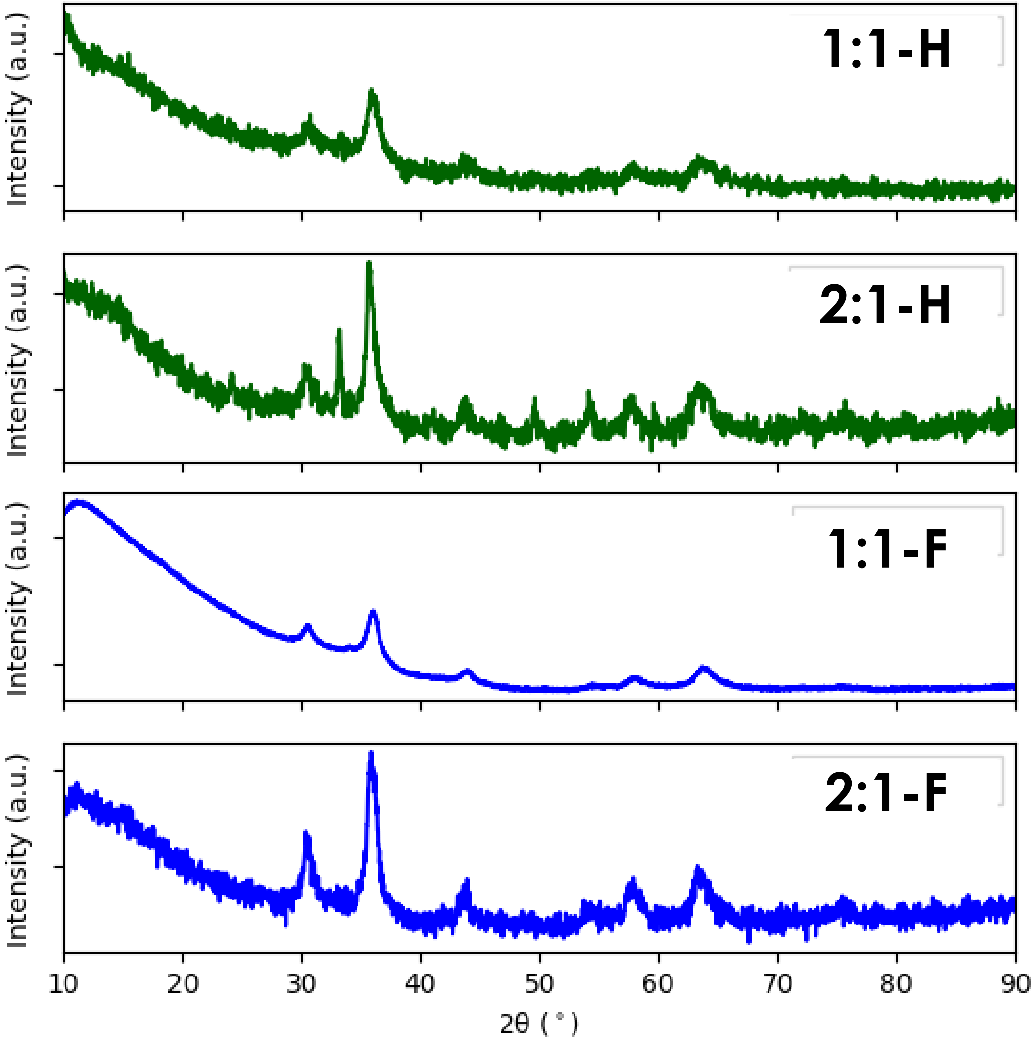
Microwave Energy (Electric and **magnetic** field**)**



Microwave reactor setup

Characterization: X-Ray diffraction

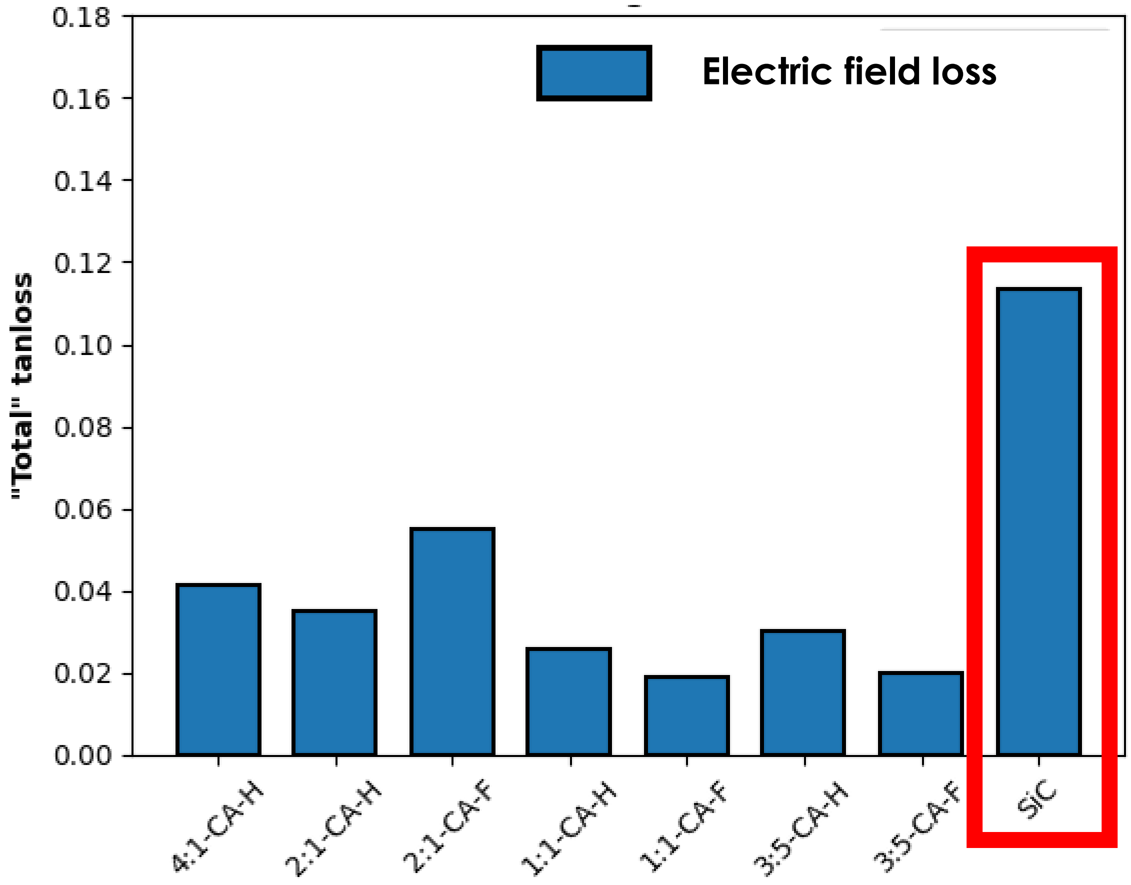
Did we synthesize FeAlOx?



- Confirmed formation of FeAlOx catalysts.
- Showed how changing **synthesis parameters** affected the composition.

Characterization: microwave properties

How well can FeAlOx absorb microwaves compared to other catalysts?



The **larger** the tanloss, the more microwave **heating.**

- Silicon carbide is better than FeAlOx at heating in a microwave…

when only considering heating due to the **electric field**

Characterization: microwave properties

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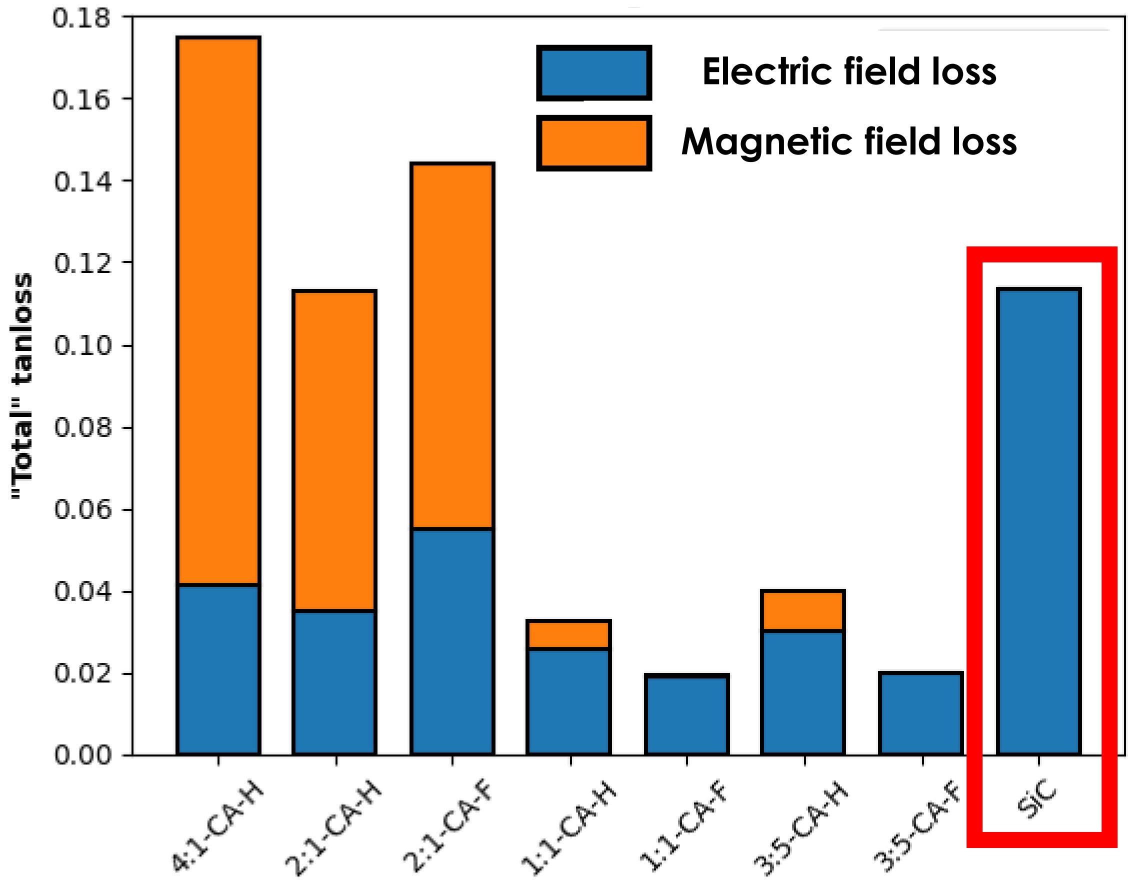
How well can FeAlOx absorb microwaves compared to other catalysts?



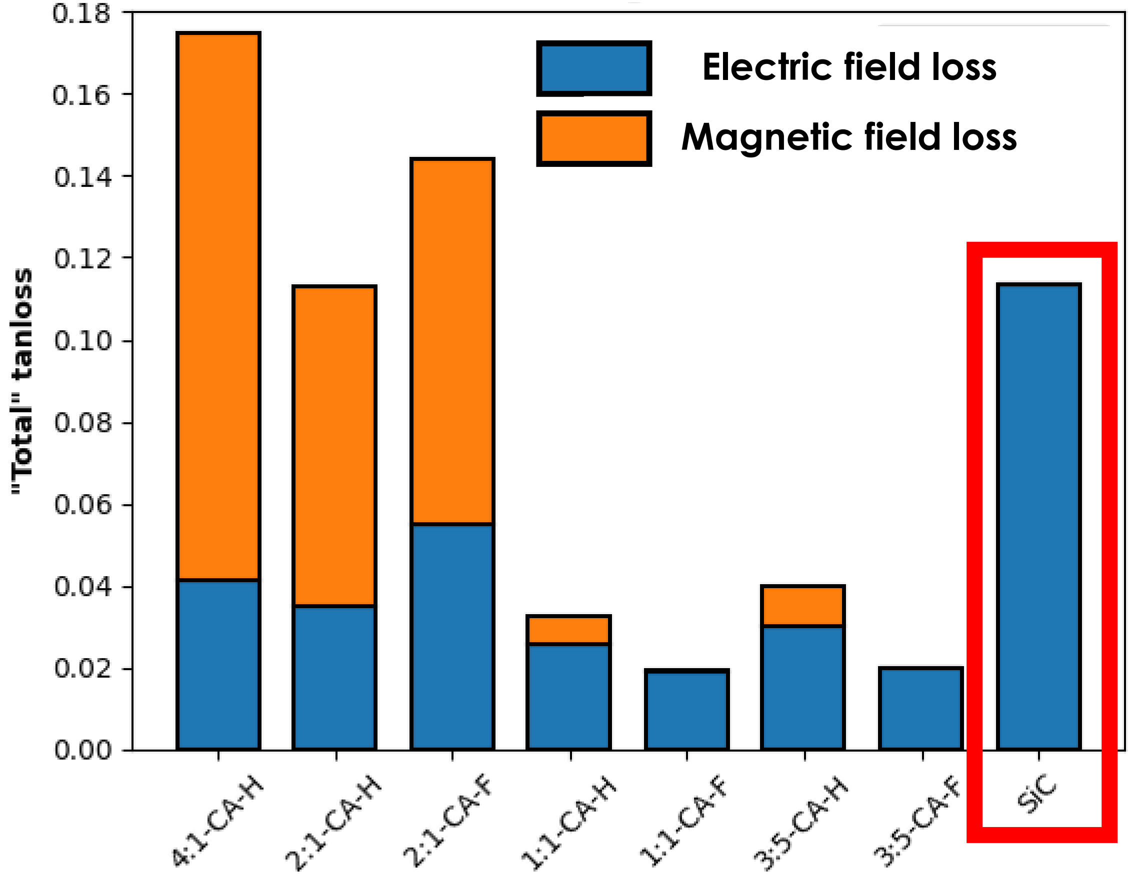
The **larger** the tanloss, the more microwave **heating.**

- When considering heating effects from both the **electric** and **magnetic field** of a microwave…

Some FeAlOx catalysts perform notably better!

Characterization: microwave properties

How well can FeAlOx absorb microwaves compared to other catalysts?



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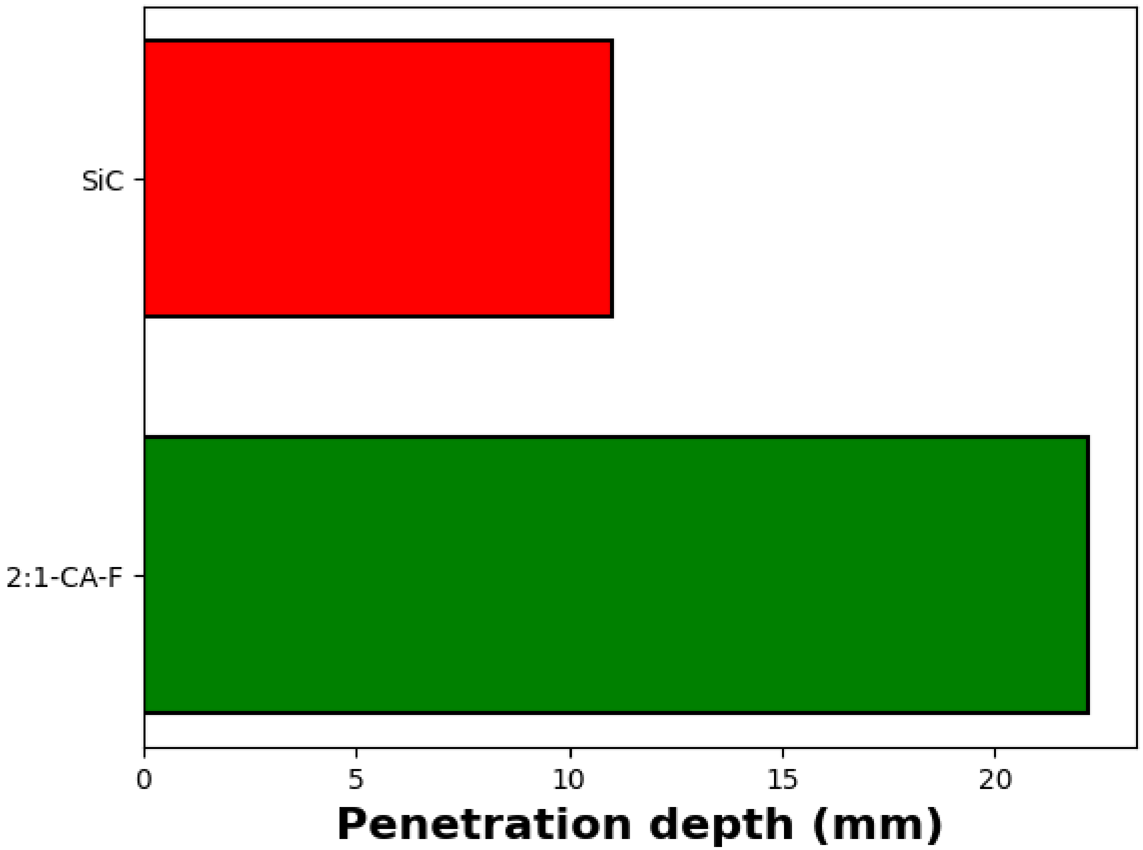
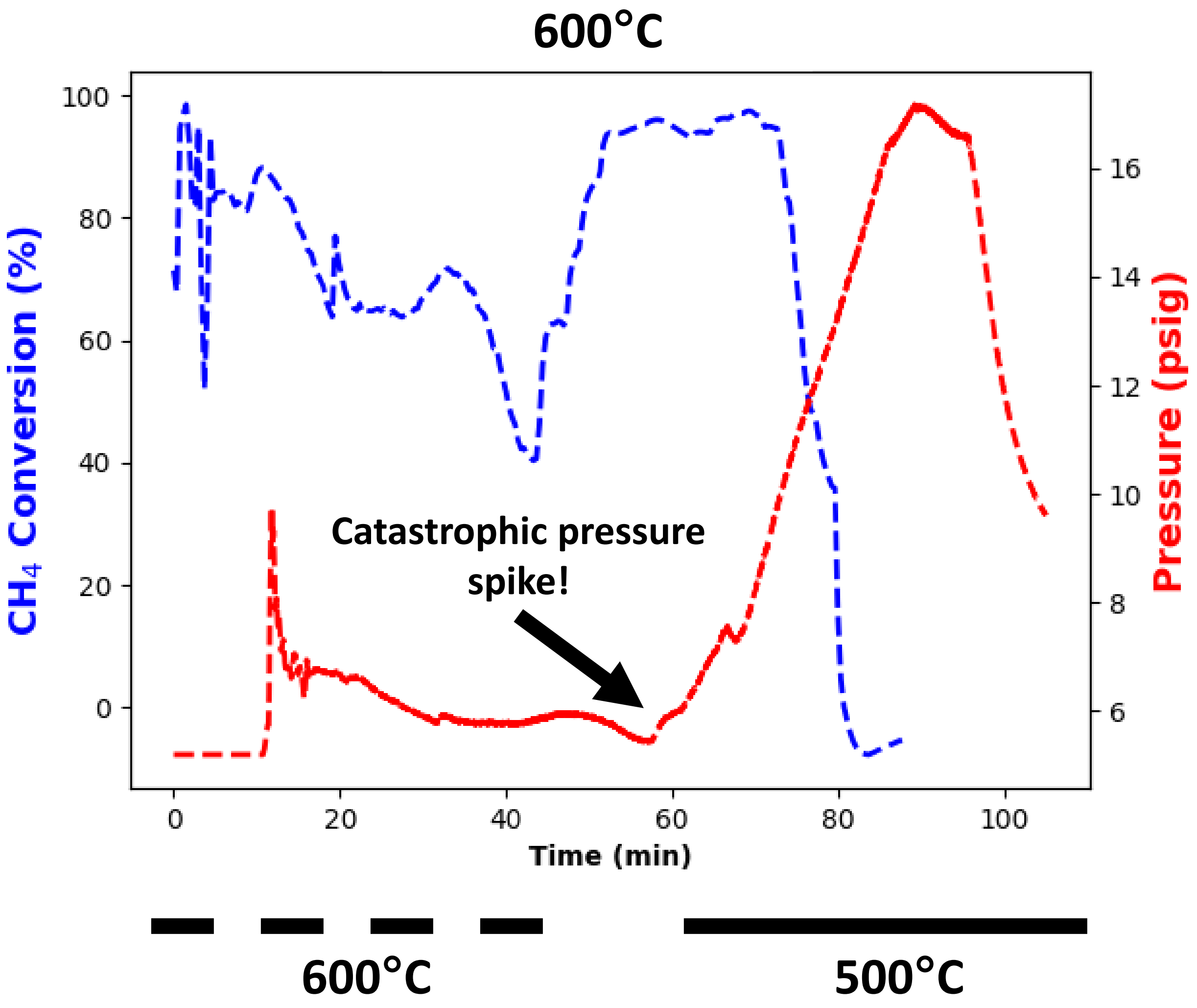
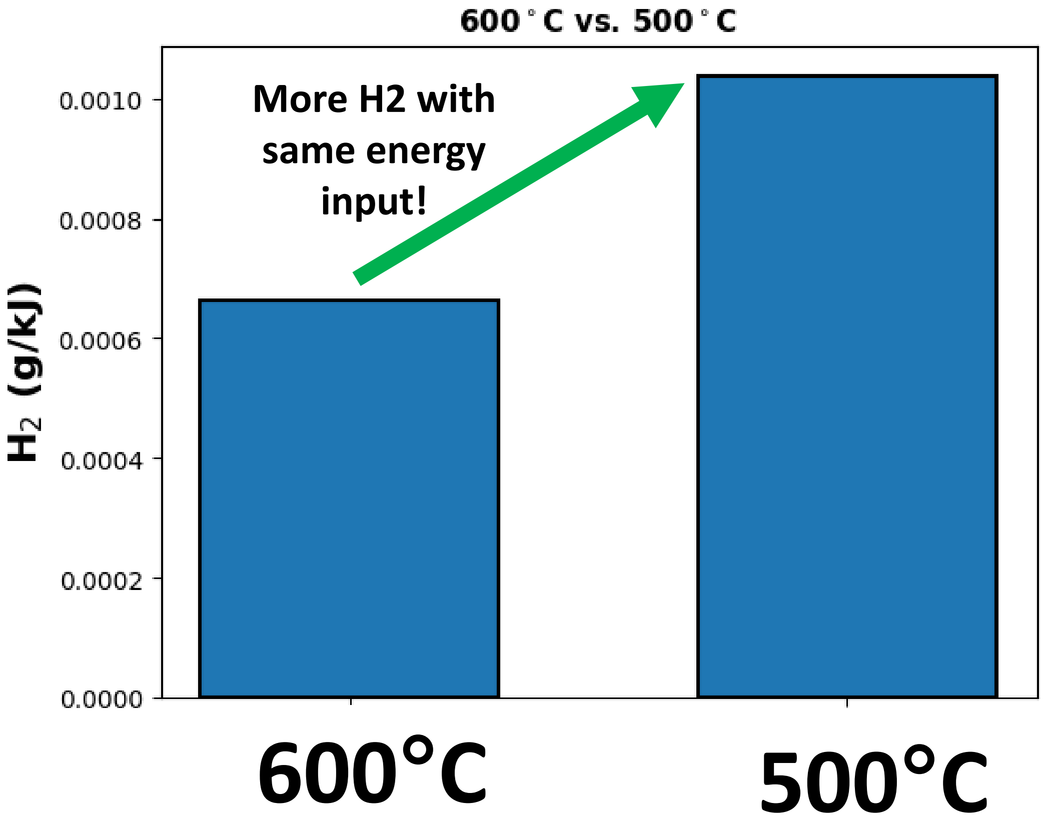


Greater penetration depth enables the use of **larger reactors**.

Reaction temperature

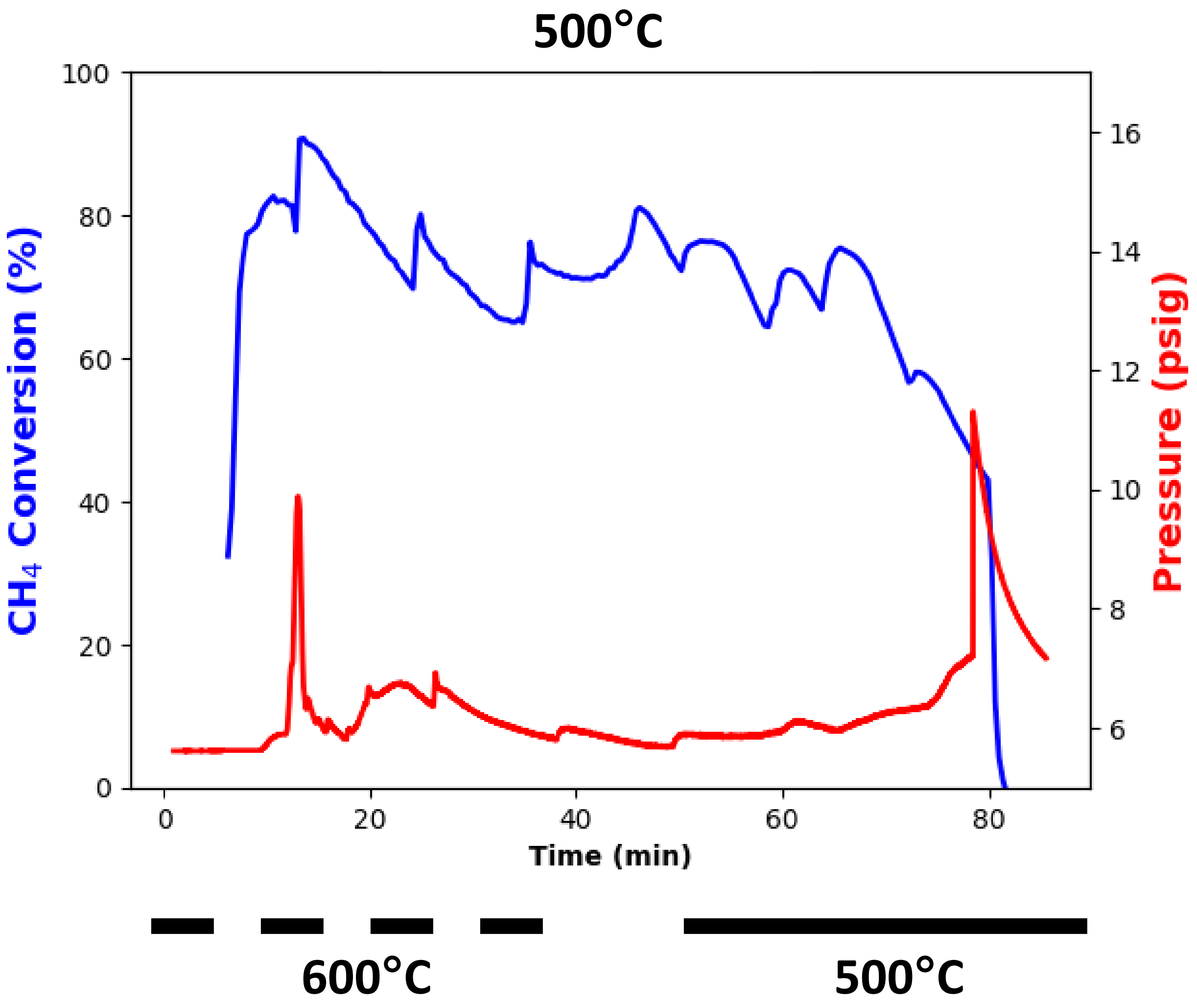
600°C vs 500°C

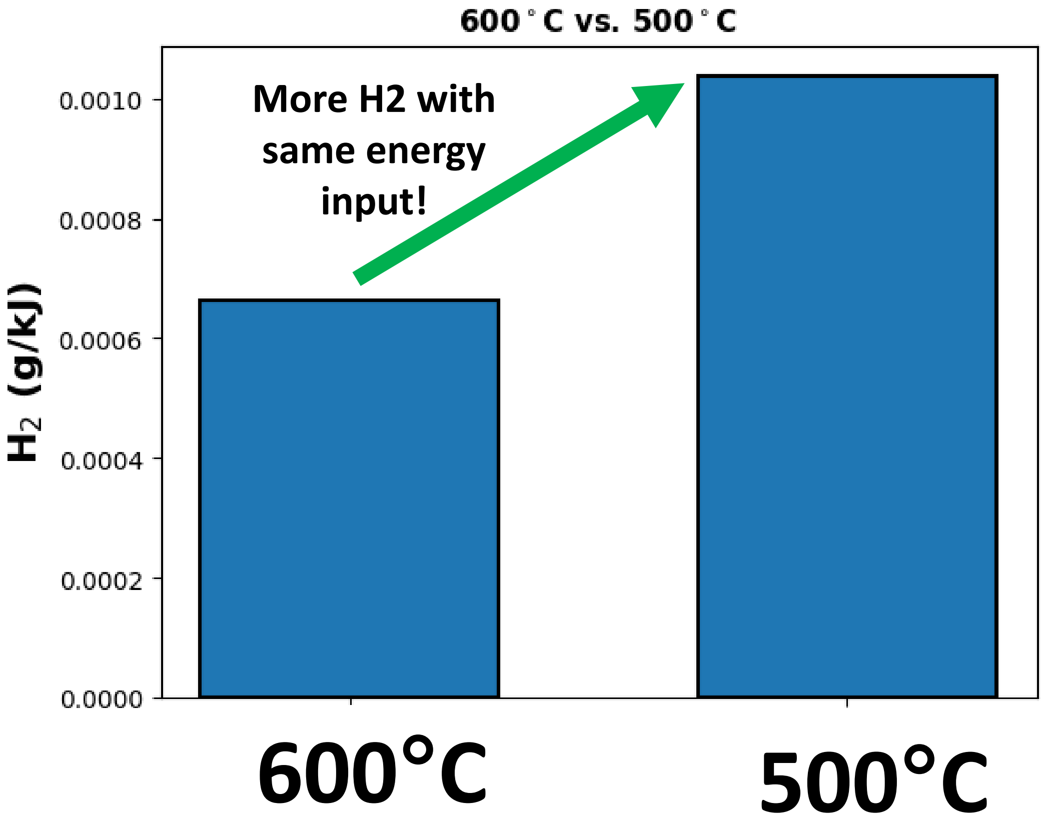




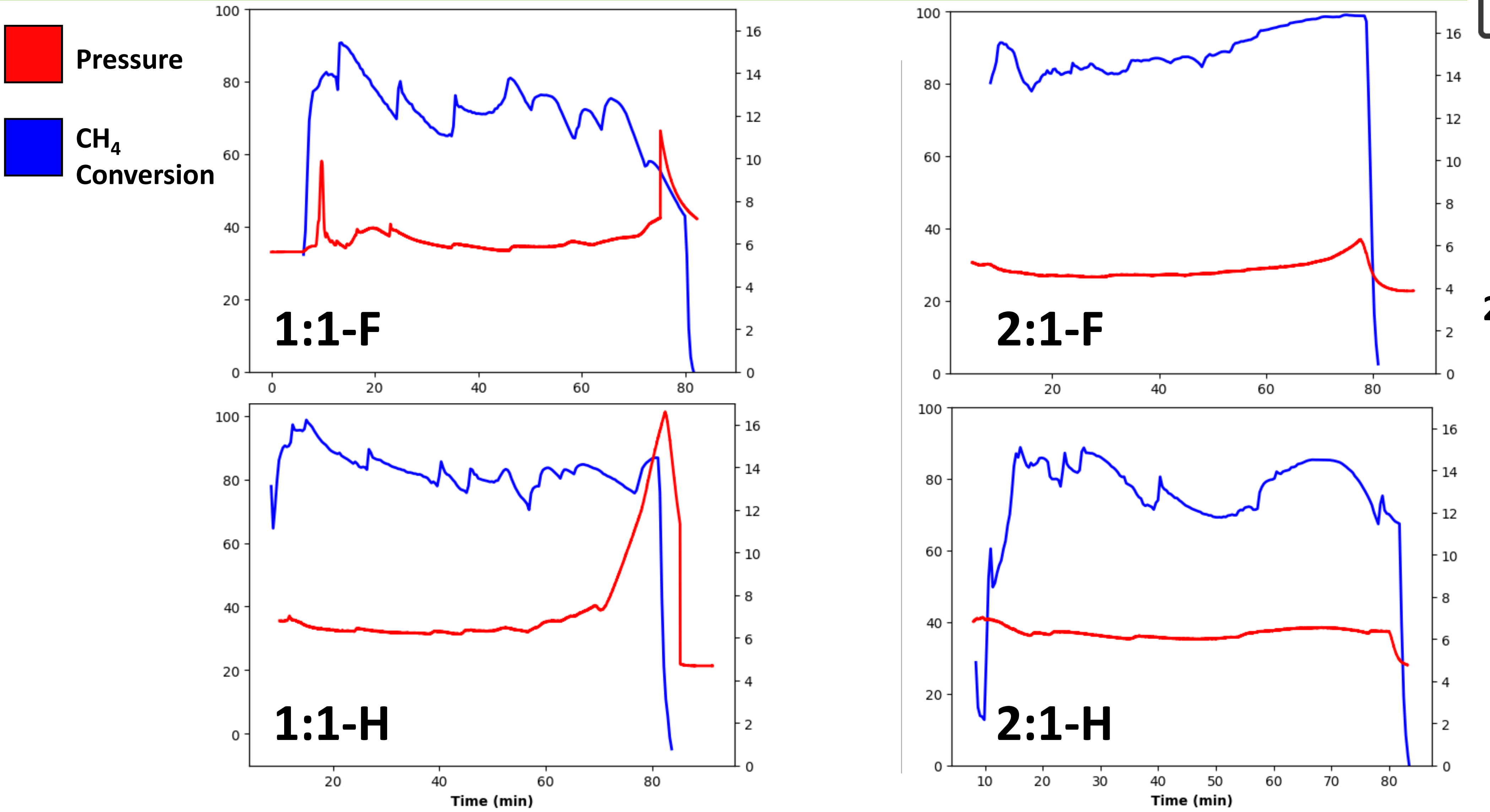
Reaction temperature

600°C vs 500°C





Comparison of FeAlOx variations

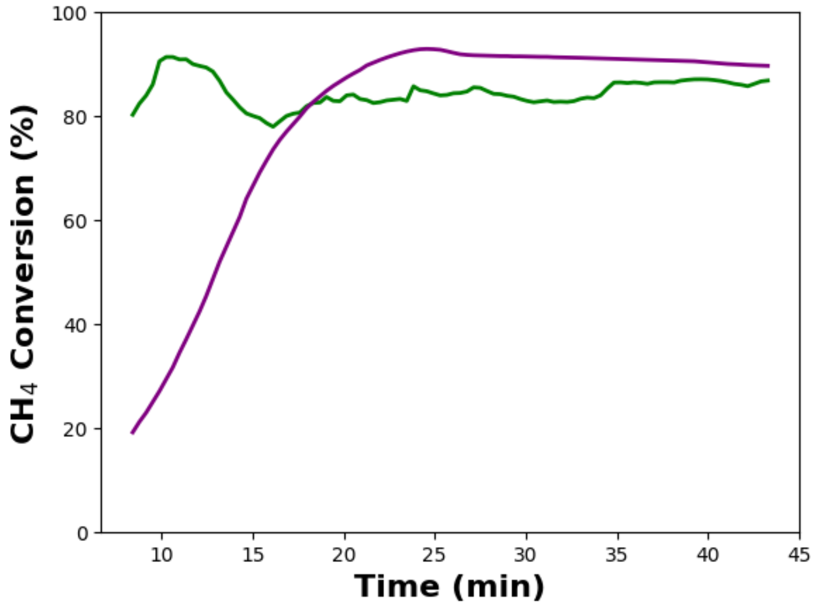


2:1-F performed the best, so it was used to **compare with conventional heating**

Microwave vs. Conventional Furnace

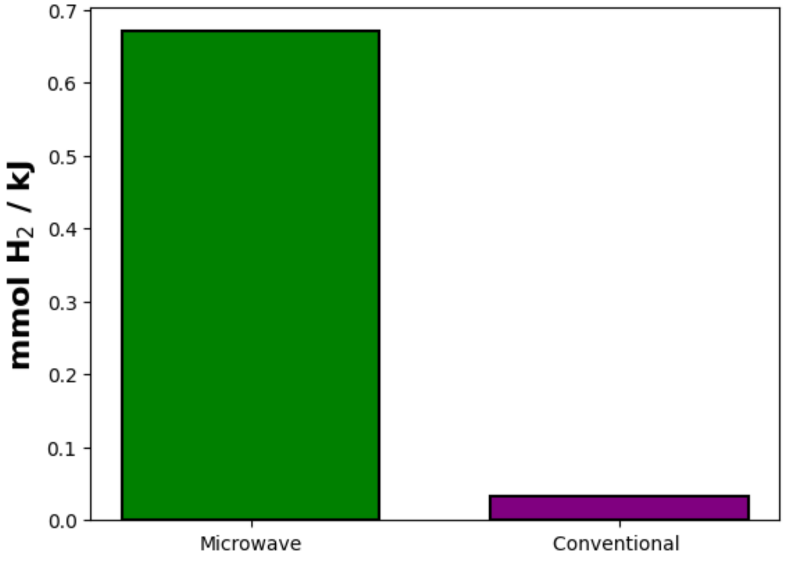
Microwave | Conventional furnace

CH4 conversion



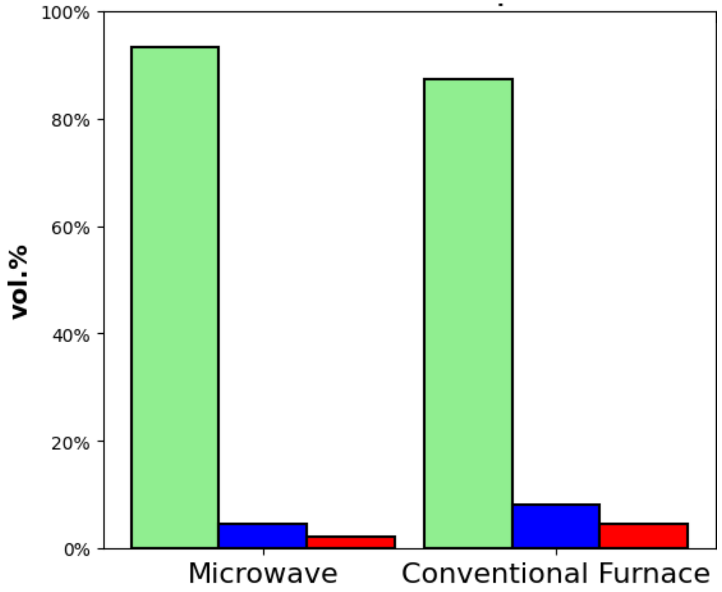
The microwave's **instant heating** led to higher conversions sooner.

Energy efficiency



More H2 produced per unit of energy spent.

H2 selectivity



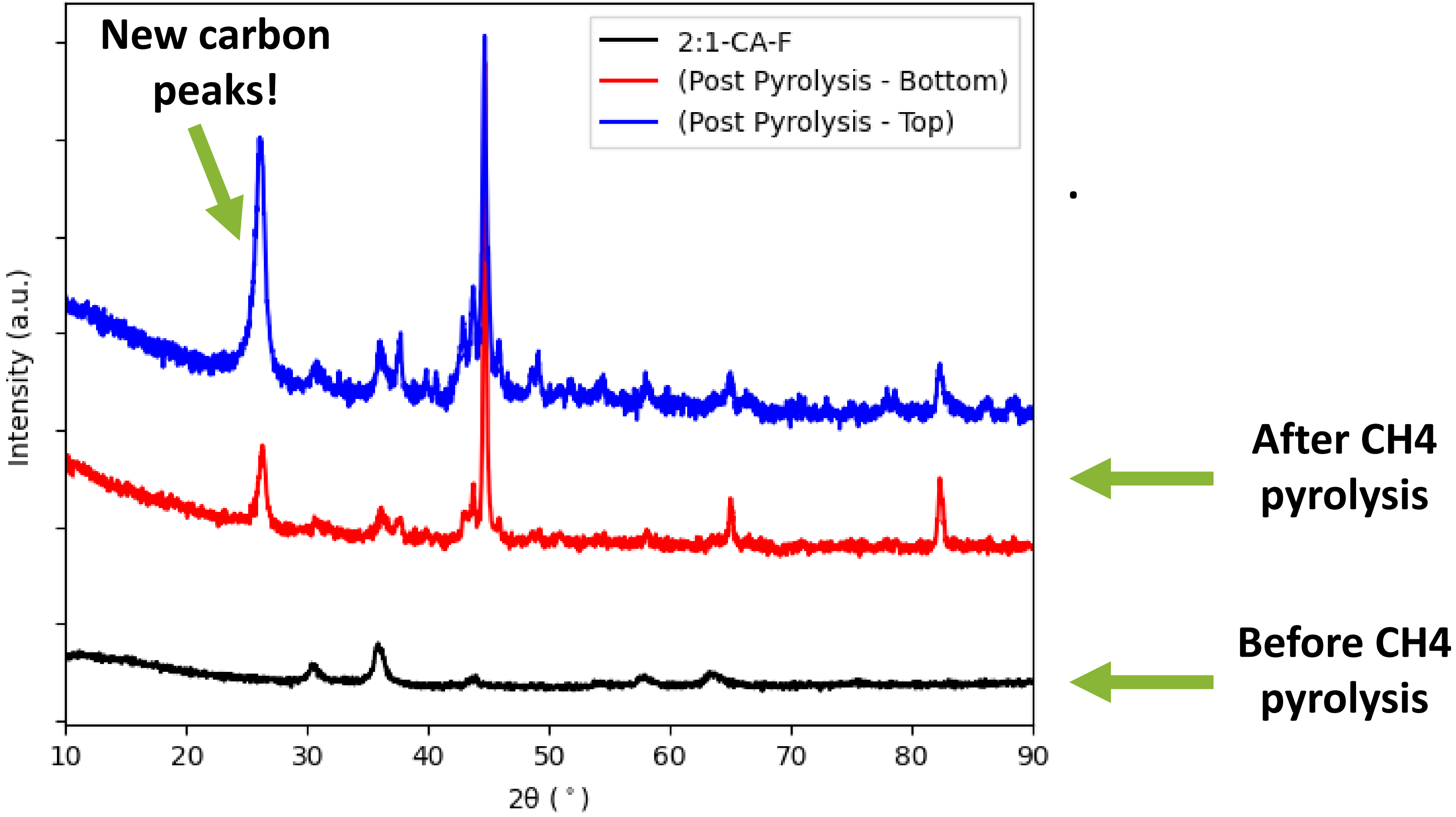
More H2 and **less CO2** produced.

H2 | CO | CO2

Post Characterization: X-Ray diffraction

Where did the carbon go?

Solid carbon may be **valuable**, and inherently easier to deal with than gaseous CO2.



Conclusion and future work

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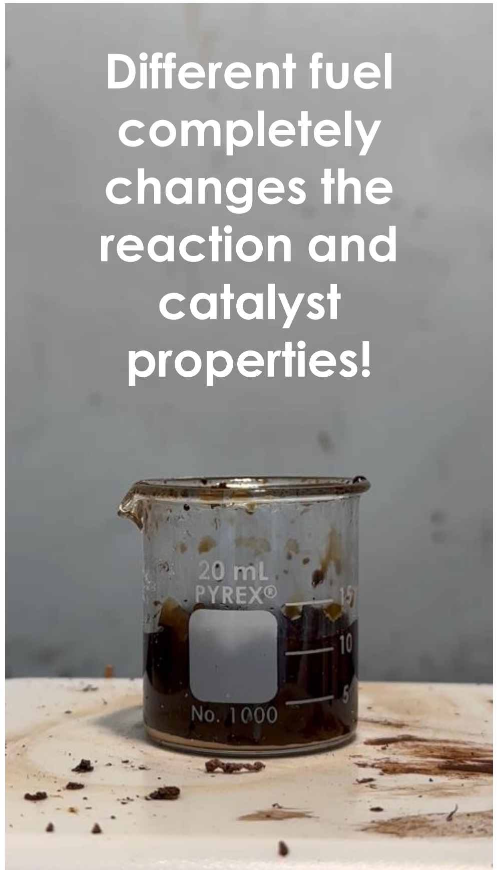
Conclusion

- Microwave energy and FeAlOx catalysts have **enabled high conversion of CH_4** into H_2 with **minimal CO_x and energy expenditure.**
- Microwave energy produced **more H2 with less energy** compared to conventional **furnace** heating.

Future work

- Explore more **synthesis parameters** such as different fuels.
- Explore ways to **regenerate catalysts** for longer performance.
- Explore **scale-up** of process past laboratory scale.



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[1] Hermesmann et al. *Progress in Energy and Combustion Science* 90 (2022) 100996.

[2] Dadsetan et al *International Journal of Hydrogen Energy* 48 (39) (2023) 100996.

[3] Jiang et al. *Ind. Eng. Chem. Res.* 2022, 61, 15, 5080–5092.

[4] Zhou et al. *Chem. Sus. Chem. Comm.* 2016, 9, 1243 – 1248

Acknowledgments

1. **Acknowledgment of NETL should read as follows:**

   This work was performed in support of the U.S. Department of Energy's Fossil Energy and Carbon Management's Advanced Reaction Engineering Program and executed through the National Energy Technology Laboratory (NETL) Research & Innovation Center's Gasification FWP.

2. **Oak Ridge Institute for Science and Education (ORISE)**

   This research was supported in part by an appointment to the U.S. Department of Energy (DOE) Postgraduate Research Program at the National Energy Technology Laboratory (NETL) administered by the Oak Ridge Institute for Science and Education (ORISE).

3. Special thanks to **Dr. Pranjali Muley** for mentoring me during my CHRES appointment, **Charles Henkel** for training me on much of the instruments I used for this study, **Dr. Xinwei Bai** for assisting me in calculations, **Dr. Dushyant Shekhawat** for first inviting me to apply to this program, and the rest of the **NETL Morgantown team** for providing support and feedback throughout the summer.

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