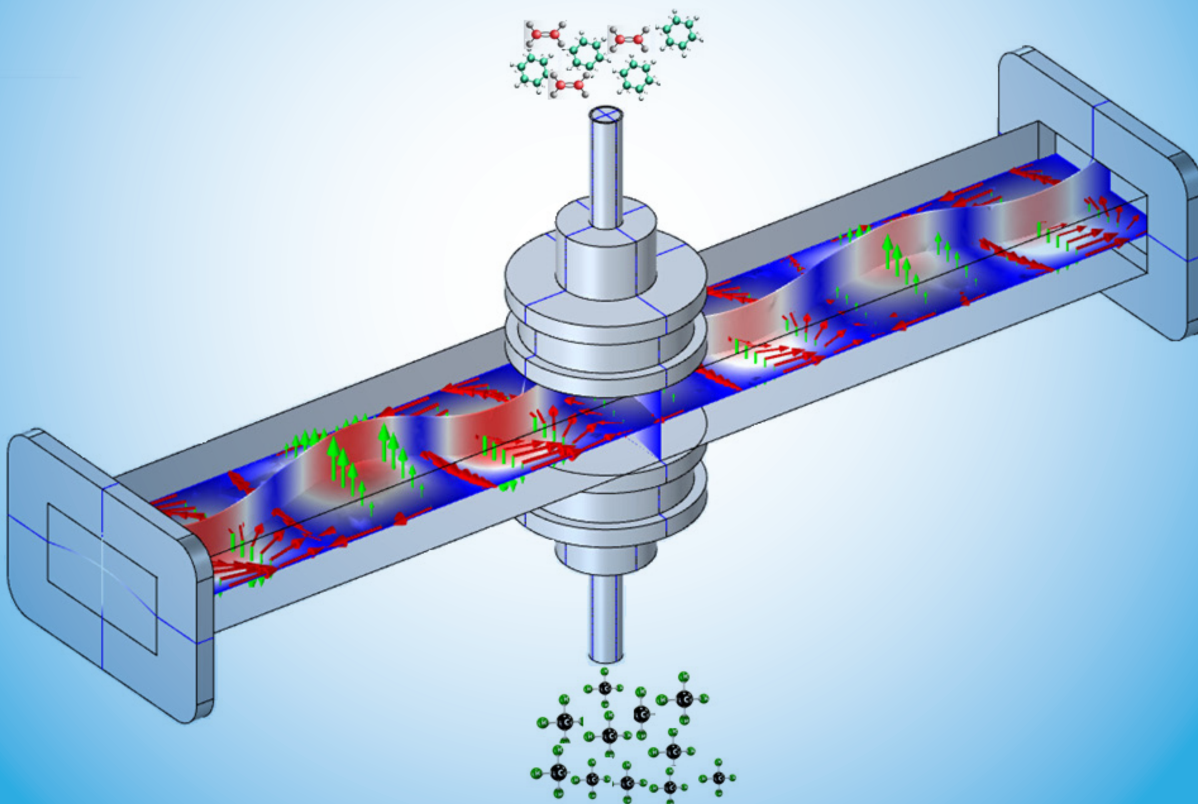
MICROWAVE ENERGY
FOR FUEL CONVERSION PROCESSES



NATIONAL ENERGY TECHNOLOGY LABORATORY

BACKGROUND

NETL has demonstrated microwave (MW)-assisted technologies for a number of process chemistry and manufacturing applications. Microwave technology offers rapid, selective, and direct heating of material that eliminates the lag times observed in heating the medium during conventional conversion methods. Microwave-assisted reaction chemistry is a complex phenomena extending beyond selective heating, possibly including field-specific effects resulting in enhanced conversion and selectivity, which exceed equilibrium values in MW-reactor. However, the detailed mechanisms of the MW-catalyst interactions are not completely known.

NETL has developed in-house expertise in this area, and we are currently developing a unique and signature test facility for real-time analysis of microwave enhanced reactions. This signature facility, along with state-of-the-art microwave reactor systems and simulation efforts, will allow for the optimization of microwave systems so that they may be incorporated into a broad range of chemical conversion technologies. Furthermore, new catalysts that produce enhanced interactions with the electromagnetic fields will be designed and synthesized to promote yet-undiscovered effects in this emerging area of charged, particle-driven chemistry.

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BENEFITS

The application of radio frequency/microwave fields to chemical reactions may transform the way chemical processes are performed. Microwave effects can result in greatly enhanced reaction rates, generation of completely different products, and changes in product selectivity or position of chemical equilibria - in many cases requiring far less energy.

Microwave-assisted technology provides an opportunity for modular and distributed solutions that transform low-value chemical feedstocks into stored, high-value energy for on-demand use. It shows particular promise for dramatically improving energy efficiency of the conversion process, reducing capex requirements, and rapid start/stop operation. At NETL, our focus is to exploit unique properties of microwave-driven catalysis, with the goal of providing enabling technology for energy-intensive reactions.

FACILITIES

To assist in developing new technologies, researchers utilize NETL facilities:

- **Gas-solid microwave reactor systems:** a pulsing single-mode microwave cavity from Sairem with fixed frequency (2.45 GHz) 2kW magnetron (Figure 1), a continuous variable frequency (2-8 GHz), 0.5kW microwave reactor from Lambda Technologies, Inc., and high-pressure (35 bar) microwave reactor (2.45 GHz, and 3 kW) from Malachite Technologies.
- **Electromagnetic properties measurements at High temperatures:** Microwave vector network analyzers (VNAs)with frequency ranges of 300 kHz to 43.5 GHz to study the electric and magnetic properties of the material. The VNAs can also be coupled to a high-temperature coaxial airline sample holder cell (up to 500°C), (under development at NETL) to provide information about the electromagnetic properties of catalytic materials as a function of temperature.
- **An in-situ dielectric measurement system** is being developed at NETL that will allow researchers to measure EM properties in real time during a microwave-driven process. Accurate characterization of EM material properties is important for microwave process optimization as the EM material properties influence the absorption of microwave energy within materials.
- **High Speed camera (Phantom):** allows imaging of transient arc discharges that occur between particles of some materials under electromagnetic fields, sometimes called microplasmas, which are of particular interest in some reactions, as they may help explain observed process enhancements under microwave irradiation.
- **Vibrating Sample Magnetometer (VSM) unit:** unit used to study the magnetometry and field-dependent electrical transport properties of materials from cryogenic temperatures to elevated temperatures up to 1,000°C and with magnetic field of up to 2 tesla (T).

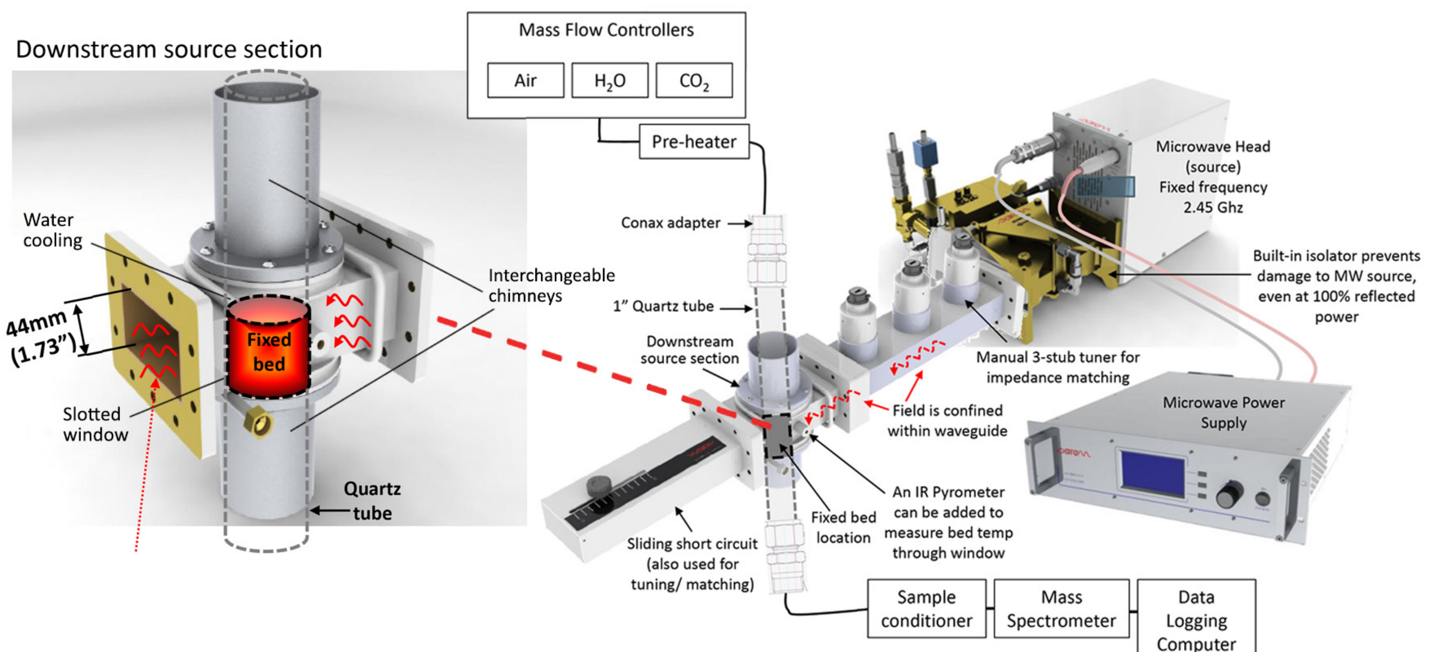

FIGURE 1. Microwave reactor.

SIGNIFICANT RESULTS AND MAJOR ACCOMPLISHMENTS

- Research at NETL has resulted in the following results and accomplishments: (1) Microwave reactions showed significantly higher ammonia yields, which can be achieved at low temperatures (300°C) and ambient pressure using metallic supported catalyst systems; and (2) a rapid start/stop operation which reaches full operational capabaility in less than 10 minutes from start (see Figure 2). This type of operation is not possible with existing technology (Haber-Bosch process).

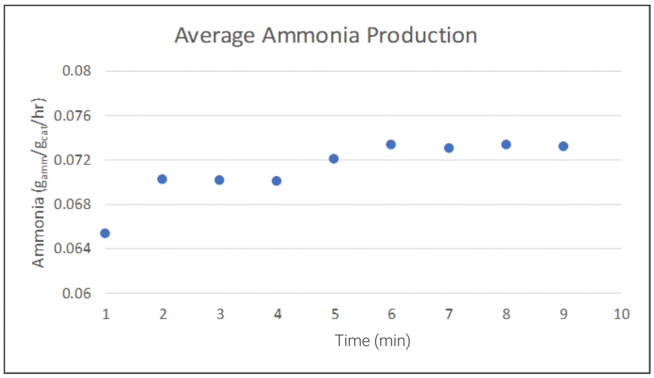

FIGURE 2: On-demand Microwave-assisted Ammonia Production.

- A microwave-enhanced process for producing hydrogen from methane (dry methane reforming) shows an energy cost approaching DOE's 2020 cost goal for electrolytic production of hydrogen. Additionally, the process is comparable to literature reports of state-of-the-art electrochemical technologies (see Figure 3).

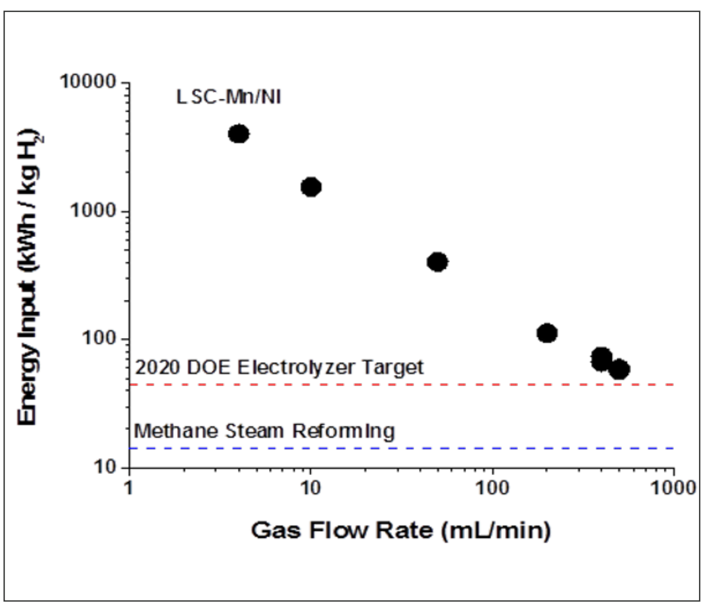

FIGURE 3: H_2 production via MW-Dry reforming.

- Microwave-assisted pyrolysis of coal produced higher gas yields at low temperatures with less tars.
- MW significantly enhanced the formation of hydrogen (H_2) at low gasification temperatures (600°C) and ambient pressure compared to conventional operation (Figure 4).

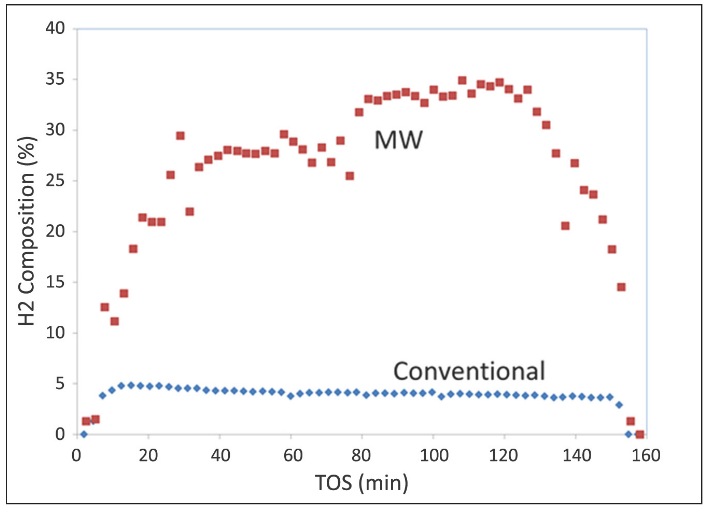

FIGURE 4: Coal steam gasification.

- Microwaves have shown promise for the upgrading of the hydrocarbons present in natural gas into more valuable chemicals. NETL has demonstrated MW's significantly enhance selectivity to benzene over conventional heating for the methane dehydroaromatization reaction (Figure 5).

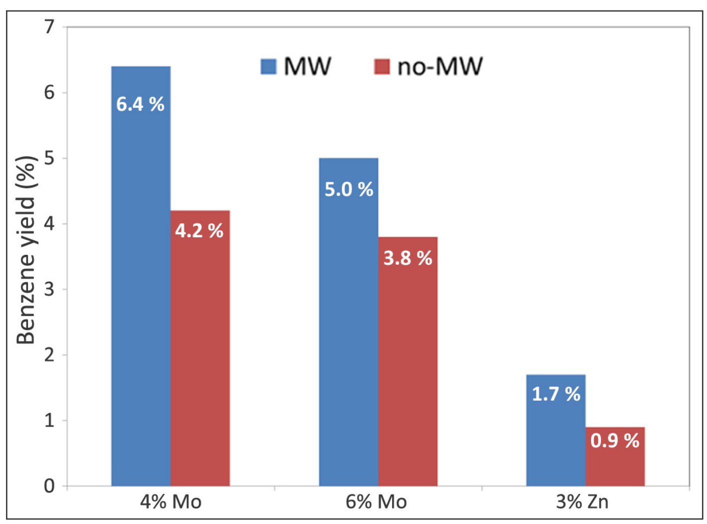

FIGURE 5: Methane to benzene reaction. Microwaves significantly improved the catalyst performance even though the catalyst used was not designed for MW conditions.

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- Product distribution of coal pyrolysis in the presence of H_2 and methane (500°C)tends to shift to lower molecular weight tars under MW heating (Figure 6).
- For CO_2 capture processes, microwave-assisted sorbent regeneration allowed 50% shorter regeneration times compared to steam regeneration. Furthermore, selective heating of CO_2 adsorption sites was shown to lower the bulk temperature required to desorb CO_2.
- Plastic conversion to fuels and chemicals using a microwave reactor is underway at NETL. Proof-of-concept studies have shown promising hydrogen yields and plastic conversion.
- NETL researchers are developing advanced computational models to understand microwave heating and reaction chemistry in the microwave reactors.
- MW-activated materials development, along with further microwave research, will advance electromagnetic field characterization by understanding how geometry and surfaces interact with the microwaves and micro- discharges in the spaces between particles.

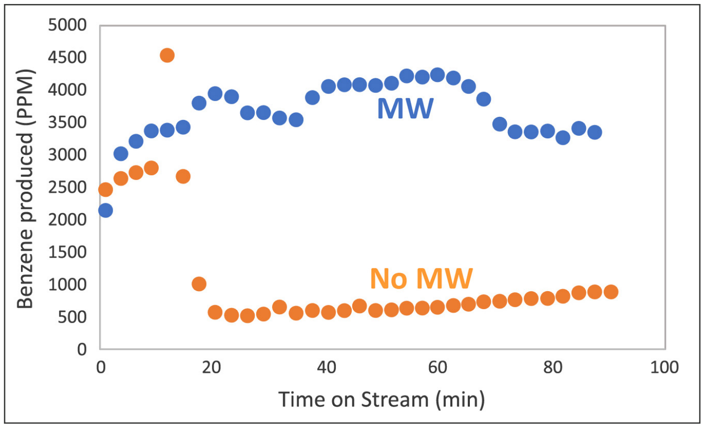

FIGURE 6: Microwave-assisted conversion of low rank coals in presence of natural gas into value-added chemicals.

NETL is a U.S. Department of Energy national laboratory that drives innovation and delivers technological solutions for an environmentally sustainable and prosperous energy future. By leveraging its world-class talent and research facilities, NETL is ensuring affordable, abundant and reliable energy that drives a robust economy and national security, while developing technologies to manage carbon across the full life cycle, enabling environmental sustainability for all Americans.

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