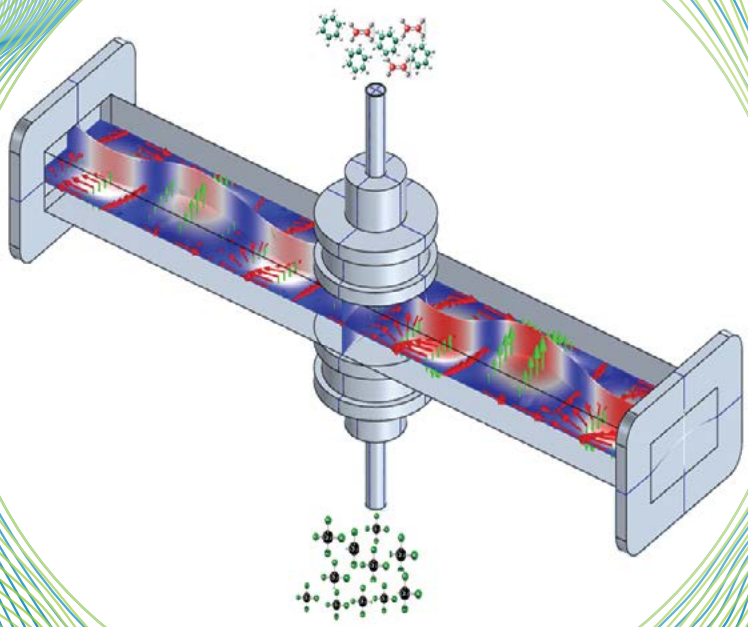
µWave

Center for Microwave Chemistry



U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

What Is MICROWAVE ASSISTED TECHNOLOGY?

Microwave-assisted reaction chemistry is a complex phenomenon. It extends beyond selective heating, potentially including field-specific effects resulting in enhanced conversion and selectivity, which exceed equilibrium values in µWave-reactor. *NETL is investing in signature capabilities to explain the unique attributes of microwave-assisted technologies.*

Microwave (µWave) catalysis technology can open the next frontier of science in the chemical process industry.

At The National Energy Technology Laboratory, our focus is on exploring unique properties of microwave-assisted catalysis, enabling technology that substantially reduces the carbon footprint for a wide range of industrial processes through reduced energy requirements, increased process selectivity, and reduced capital cost.

What makes it unique?

Microwaves interact directly with materials at a molecular level enabling rapid, selective, and direct heating that enables point of use manufacturing that can be integrated with renewable energy. Chemical production can be re-designed economically at small scale with the ability to load follow using microwaves.

HOW DOES THIS **BENEFIT** THE ENERGY COMMUNITY?

The application of microwave fields to chemical reactions may transform the way chemical processes are performed.

Microwave effects can result in these benefits:

Generation of completely different products

Changes in product selectivity or position of chemical equilibria

Greatly enhanced reaction rates

ALL WITH LOWER ENERGY REQUIREMENTS

Microwave-assisted technology provides an opportunity for modular and distributed solutions that transform low-value chemical feedstocks into high-value chemicals and/or energy for on-demand use.

OUR **FACILITIES**

1

ELECTROMAGNETIC PROPERTIES MEASUREMENTS AT HIGH TEMPERATURES

Electromagnetic material characterization equipment at NETL includes one-of-a-kind test fixtures used for material characterization under a microwave field from room temperature to 1000°C, to provide information about the electromagnetic properties of materials as a function of temperature and under reaction conditions.

2

GAS-SOLID MICROWAVE REACTOR SYSTEMS

A pulsing single-mode microwave cavity from Sairem with fixed frequency (2.45 GHz) 2kW magnetron, a continuous variable frequency (2-8 GHz), 0.6kW microwave reactor from Lambda Technologies, Inc., and high-pressure (36 bar) microwave reactor (2.45 GHz, and 3 kW) from Malachite Technologies.

3

IN-SITU SURFACE REACTION DIAGNOSTICS

Diagnostics being developed at NETL that allows for real time analysis of surface chemistry on a catalyst during a microwave-driven process. This fundamental characterization ability gives insight into the mechanism changes of a reaction under an electromagnetic field and assists in innovative catalyst development for microwave reactions.

MAJOR ACCOMPLISHMENTS & DISCOVERIES

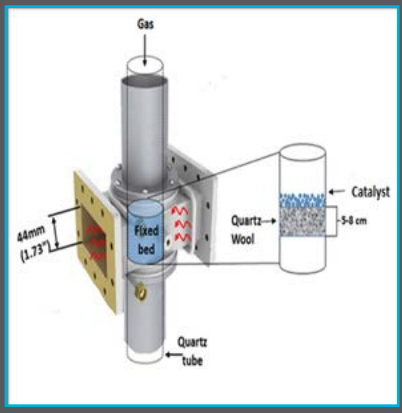
A microwave enhanced process for producing hydrogen from methane gas (dry methane reforming) shows an energy cost equal to DOE's 2020 cost goal for electrolytic production of hydrogen; with optimization energy costs could rival the economics of producing hydrogen using steam-methane reforming, the mainstay of hydrogen production in the U.S.

NETL is exploring microwave-based concepts for fuel-flexible gasification at a modular scale. Co-production of energy, value-added chemicals, and carbon materials at low temperature is enhanced with microwave application to blended feed streams of biomass, waste plastic, and/or MSW.

µWave significantly enhanced the formation of hydrogen (H_2) at low gasification temperatures (600°C) and ambient pressure compared to conventional operation.

Microwave reactions showed highest reported ammonia production at low temperatures (< 300°C) and ambient pressure using metallic supported catalyst systems (under development at NETL).

A rapid start/stop operation with ability to load follow and be integrated with renewable energy producing fully green ammonia. This type of operation is not possible with existing technology *(Haber-Bosch process)*.



Microwaves show promise for upgrading natural gas into more valuable chemicals. NETL has demonstrated that µWaves significantly enhance selectivity to benzene over conventional heating for the methane dehydroaromtization reaction.

AMMONIA TECHNOLOGY & CATALYTIC PROCESSES

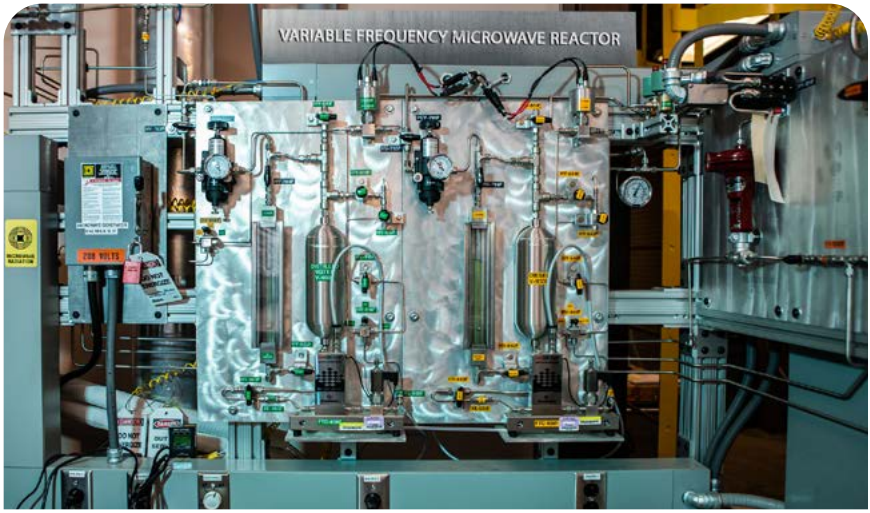
We applied NETL's world-class expertise in microwave-assisted catalytic processes to traditional ammonia synthesis.

HERE'S HOW IT WENT

1. By utilizing µWave's to develop a low temperature and pressure process, we created a flexible and modular scale version of the ammonia.

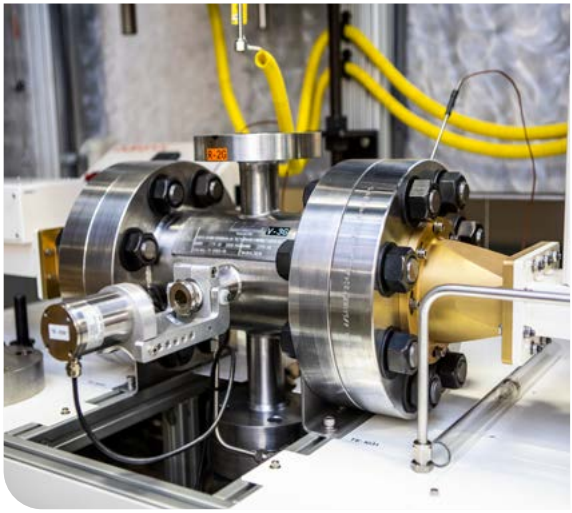
2. We have demonstrated the capability of on-demand ammonia synthesis for use in the storage of renewable, intermittent energy as a carbon neutral fuel.

3. Enabling point of use ammonia generation for local economies, we showed how small scale can also be economic.



2020 IChemE Global Award

NETL's microwave-assisted ammonia technology won the award for **Pioneering Potential to Aid in Energy Production While Lowering Costs and Overall Use.**



IMAGINE A NOVEL, SCALABLE DISTRIBUTED PROCESS FOR HYDROGEN PRODUCTION.

With NETL's µWave technology, the future of hydrogen STARTS NOW.

Initial findings using µWave technology show:

Natural gas conversion to value-added chemicals could result in a **42%** improvement of energy efficiency and a **56%** reduction in capital costs.

Superior energy efficiency compared with electrolytic water splitting or CO_2 conversion through dry reforming.

Point-of-use hydrogen energy storage and generation with advantages of reduced infrastructure and transport costs, and lower carbon footprint.

NETL's µWave research holds the promise of disruptive innovation.

We look forward to collaborating with you!

NETL established early leadership in the development of µWave catalysis, and we are developing signature research infrastructure to conduct cutting-edge science studies of microwave reaction chemistry. This multi-year investment offers the opportunity for unique capabilities in experimental research that pushes the boundaries of current scientific capabilities.

Our team is looking for clients and partners to pursue this exciting field of applied energy research. We look forward to innovating and shaping the future of energy with you!

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