Microwave Reactions for Gasification

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Presentation Outline

- Background
- NETL Microwave Capabilities
- Modular Moving-bed Microwave Gasification
- Future Work

Objective

Demonstrate the benefits of applying microwave technology to modular-scale coal gasification to syngas

Benefits of Microwave-Assisted Processes

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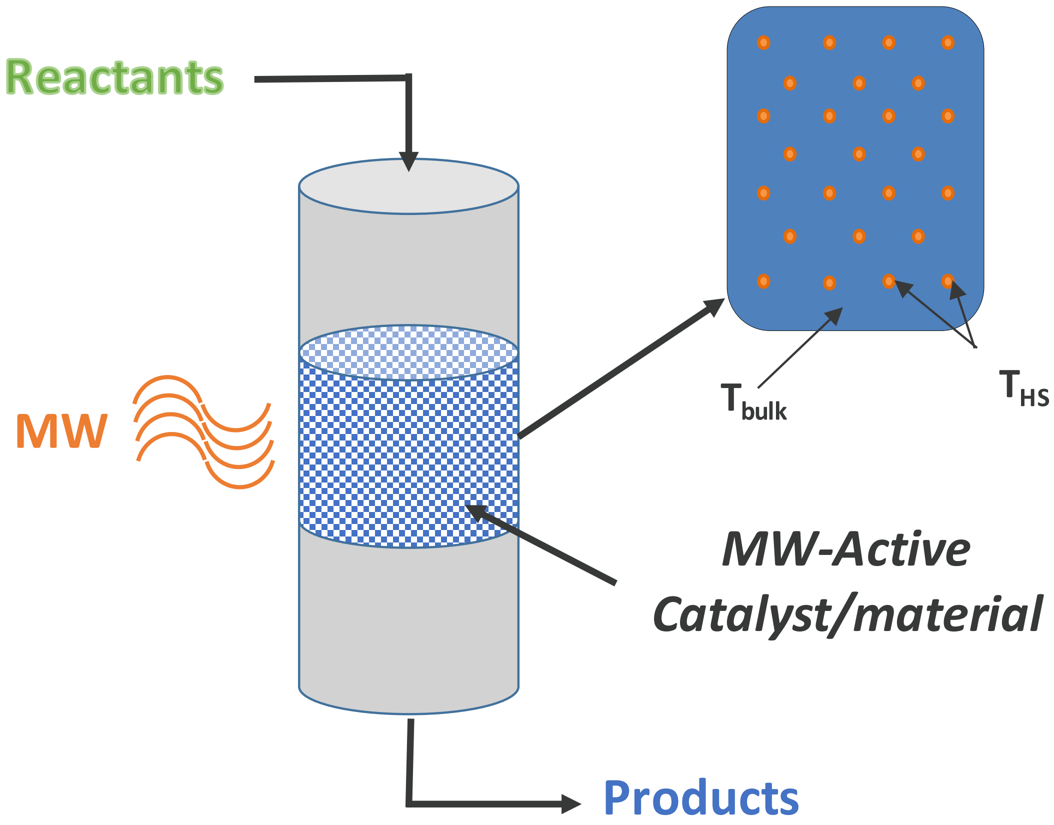
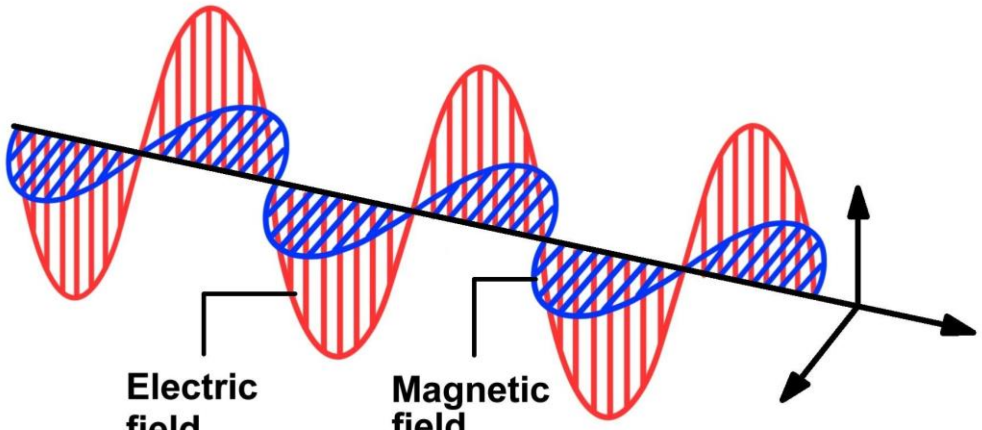
- **Rapidly achieve desired temperature (seconds to minutes)**
  - Minimize start-up and shut-down time
- **Selective activation/heating of coal and other reacting species**
  - Improve product distribution and selectivity
  - Reduce size of reactors to modular scale
  - Reduce catalyst deactivation that occurs from bulk heating
- **Eliminate or reduce size of other process units (e.g. separations, compressors, heat exchangers)**



Microwave Interaction with Materials



Real part represents the ability of the dielectric to store the energy

Permittivity →

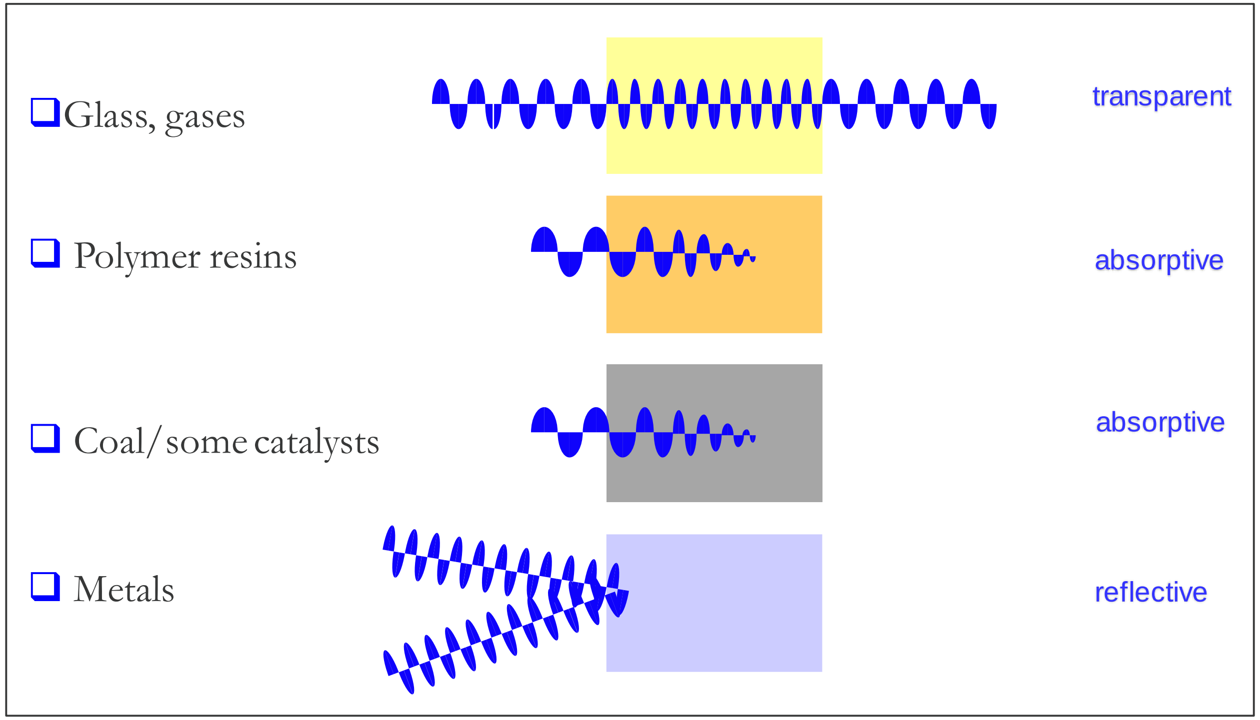
$$\hat{\varepsilon}(\omega) = \varepsilon'(\omega) - i\varepsilon''(\omega)$$

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'}$$

Loss tangent measures the magnitude of the loss process

Imaginary part represents the ability of material to dissipate the energy

Magnetic field: Permeability
Magnetic loss tangent: $tan\delta_m = \mu''/\mu'$



MW frequency range between 0.3 GHz and 300 GHz (1 m to 1 mm)

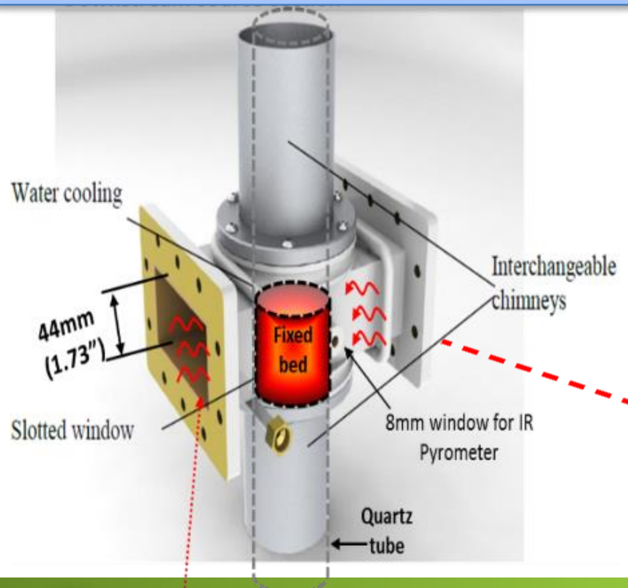
$\upsilon =$ 2.45 GHz

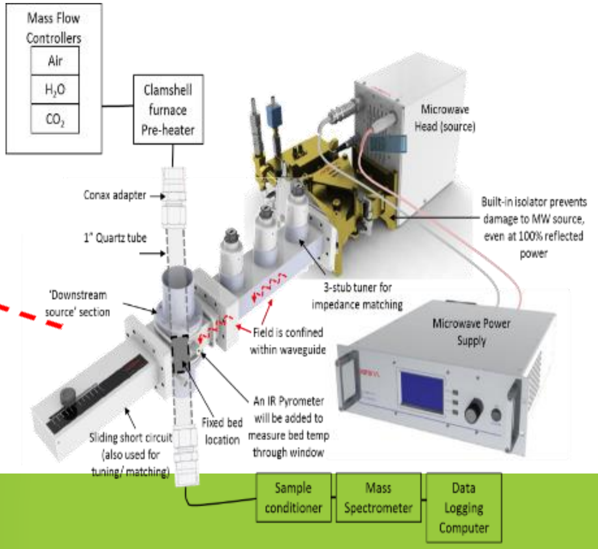
$\lambda =$ 12.25 cm

E = 0.098 cm^{-1} (0.978 J/mol)

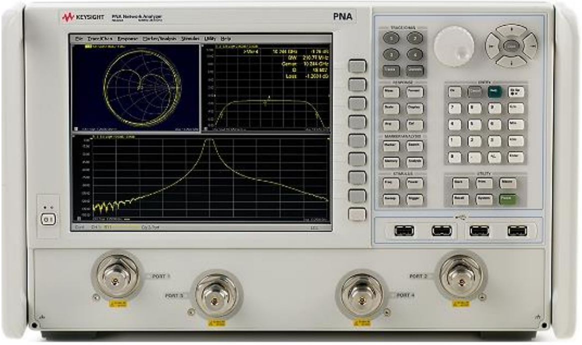
NETL Microwave Capabilities

- **Reactor Systems**
  - CEM Discover Microwave System
    - Frequency: 2.45 GHz
    - Small scale (batch)
  - Fixed frequency MW system
    - Frequency: 2.45 GHz & Power: 0 - 2kW
  - Variable frequency MW system
    - Frequency: 2 to 8 GHz & Power: 0 – 0.5 kW
    - Two different applicator configurations: Horizontal & vertical





VSM magnetometry

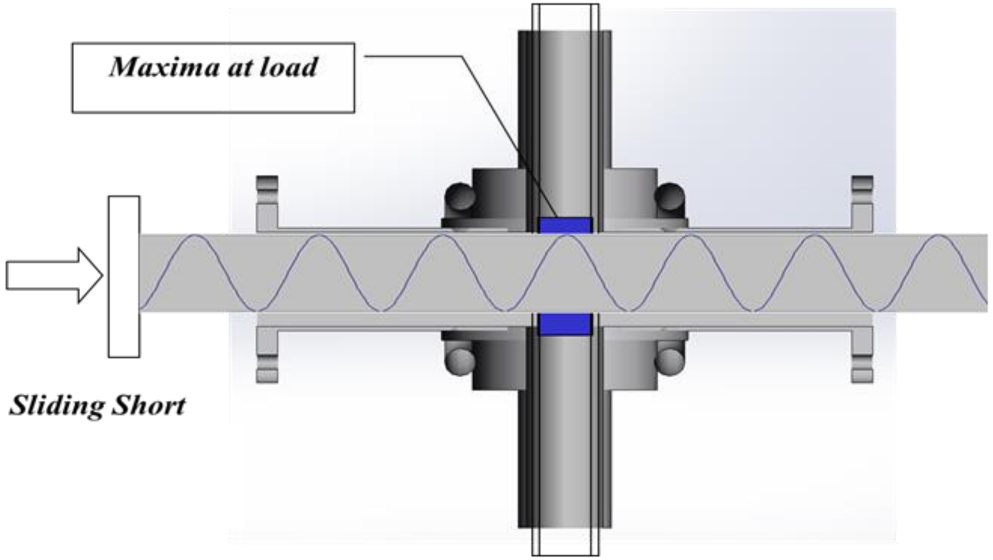


Vector Network Analyzers

Cell for EM measurement

- **Microwave Characterization**
  - Vector Network Analyzer (Keysight)
    - Maximum Frequency: 43.5 GHz
    - To measure electromagnetic (EM) properties of materials
  - Developing a cell to measure the electromagnetic properties up to 1200°C
  - VSM magnetometry and field dependent electrical transport properties from cryogenic up to elevated temperatures

Moving-bed Microwave Gasification



Standing Wave applicator

Test conditions:
Temperature = 700°C
Pressure = 1 atm
Feed gas = 67% CO_2/bal N_2

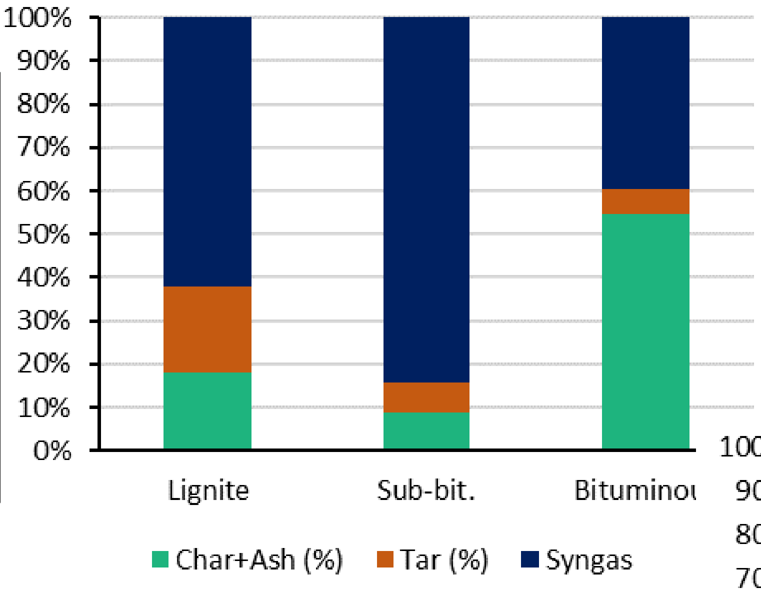
Proximate analysis, dry basis	Lignite	Sub-bit.	Bituminous
Fixed Carbon, wt%	30.5	48.2	77.7
Volatile Matter, wt%	43.8	44.7	17.9
Ash	25.7	7.6	4.6
Ultimate analysis, dry basis	**Lignite**	**Sub-bit.**	**Bituminous**
Carbon, wt%	51.7	76.2	90.6
Hydrogen, wt%	3.57	6.2	4.9
Nitrogen, wt%	1.3	N. D.	N. D.
Sulfur, wt%	0.7	0.4	0.7
Oxygen, wt% (by difference)	17.0	9.6	~0

Goal: Test the effect of coal rank on CO_2 gasification performance in microwave reactor

Gasification Product Yields

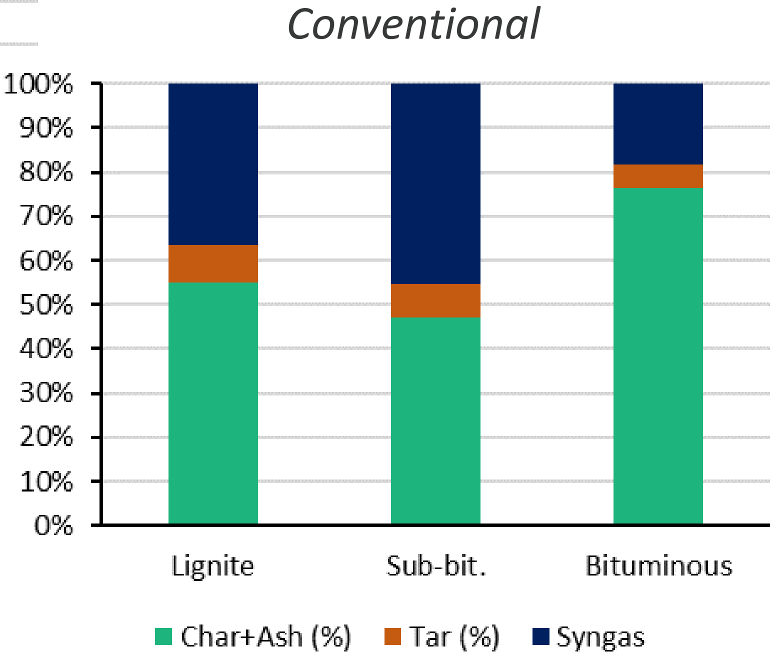
Effect of microwave:

- In all cases, microwave gasification led to greater syngas yields
- Much greater coal conversion (lower char yield) under microwave



Effect of coal rank:

- Sub-bituminous coal led to the greatest syngas yields
- High tar yield from lignite coal
- Low conversion of bituminous coal into syngas (highest fixed carbon content)



Syngas Production

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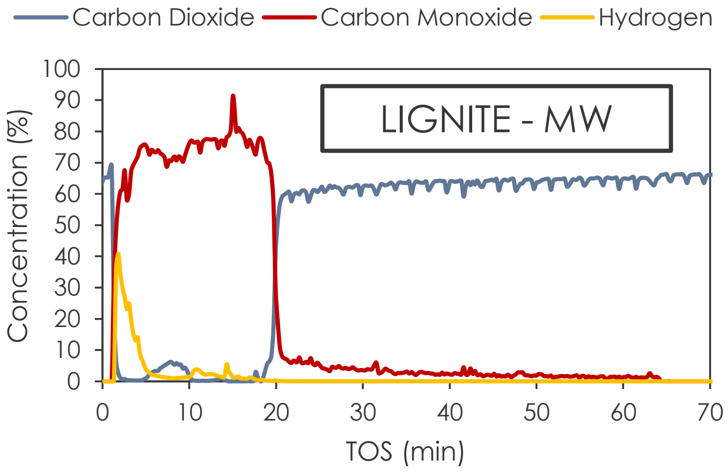
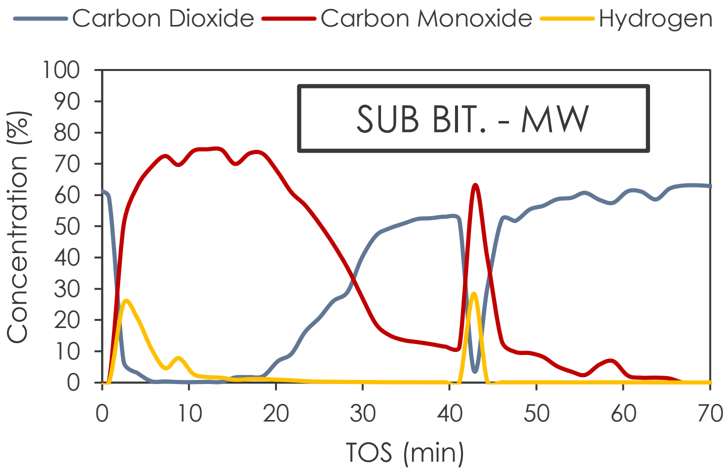
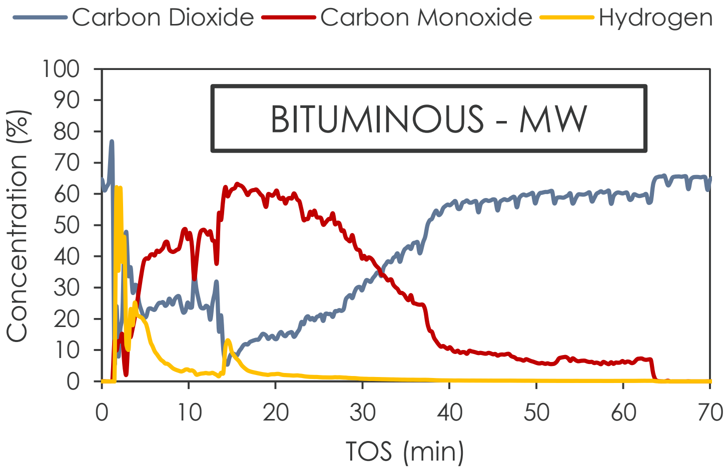
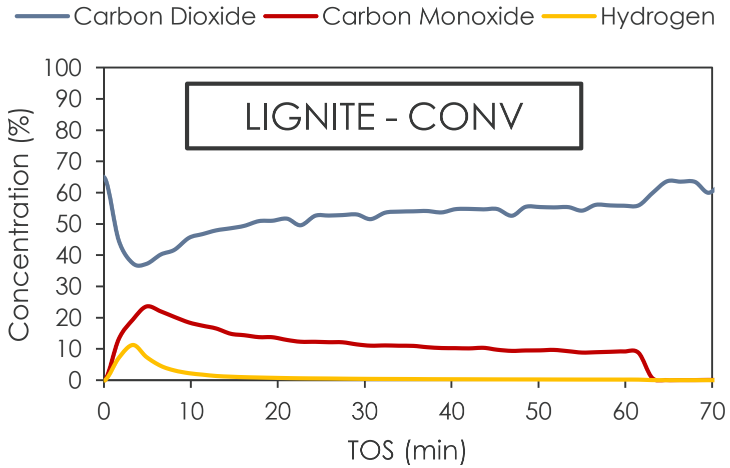
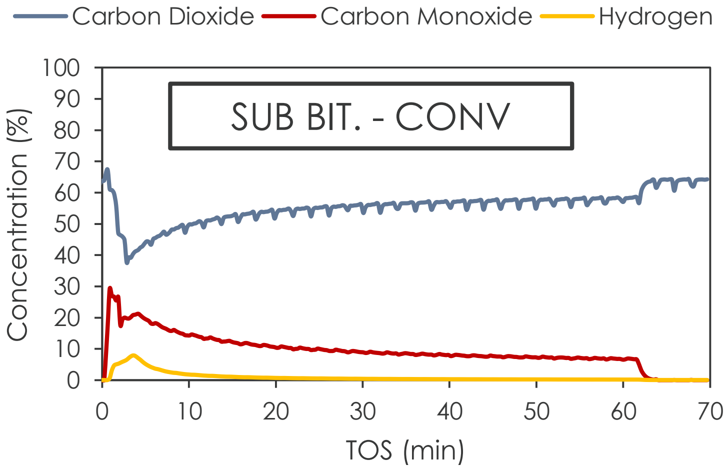
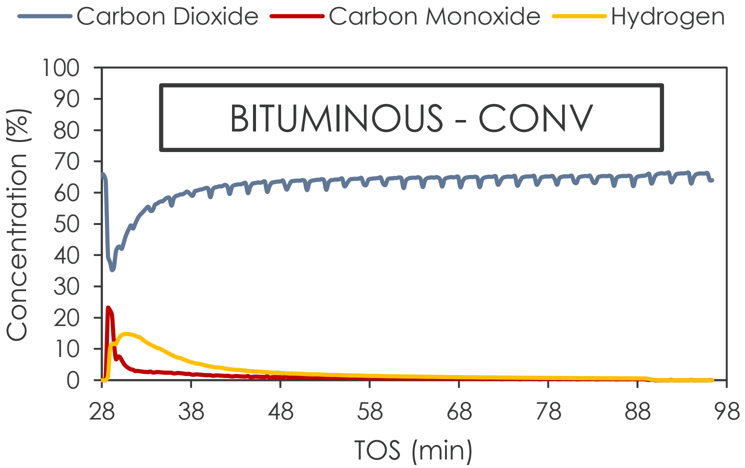






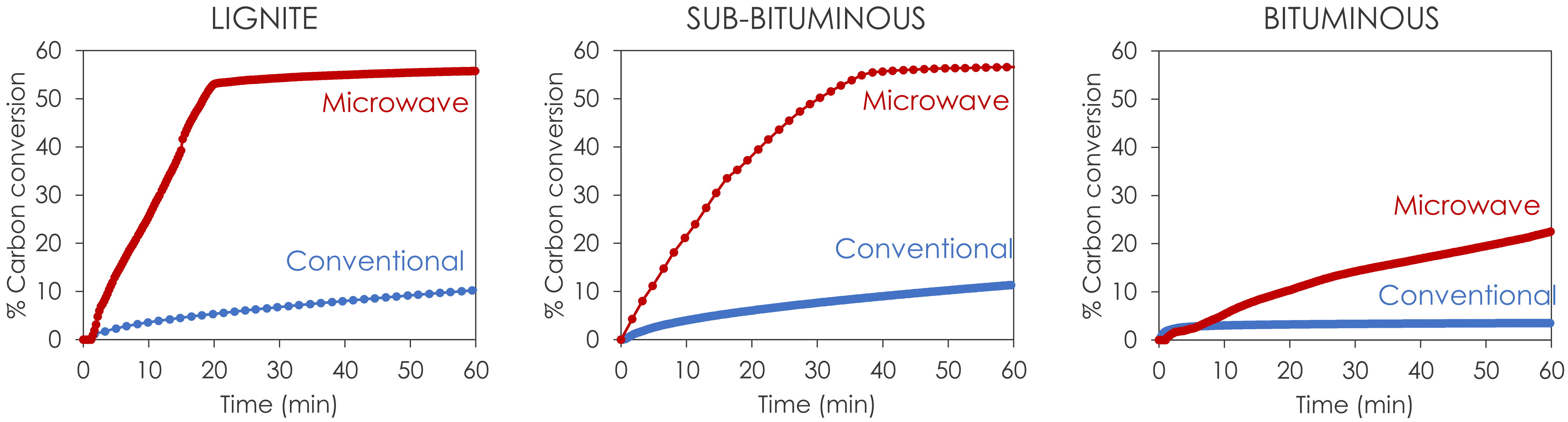






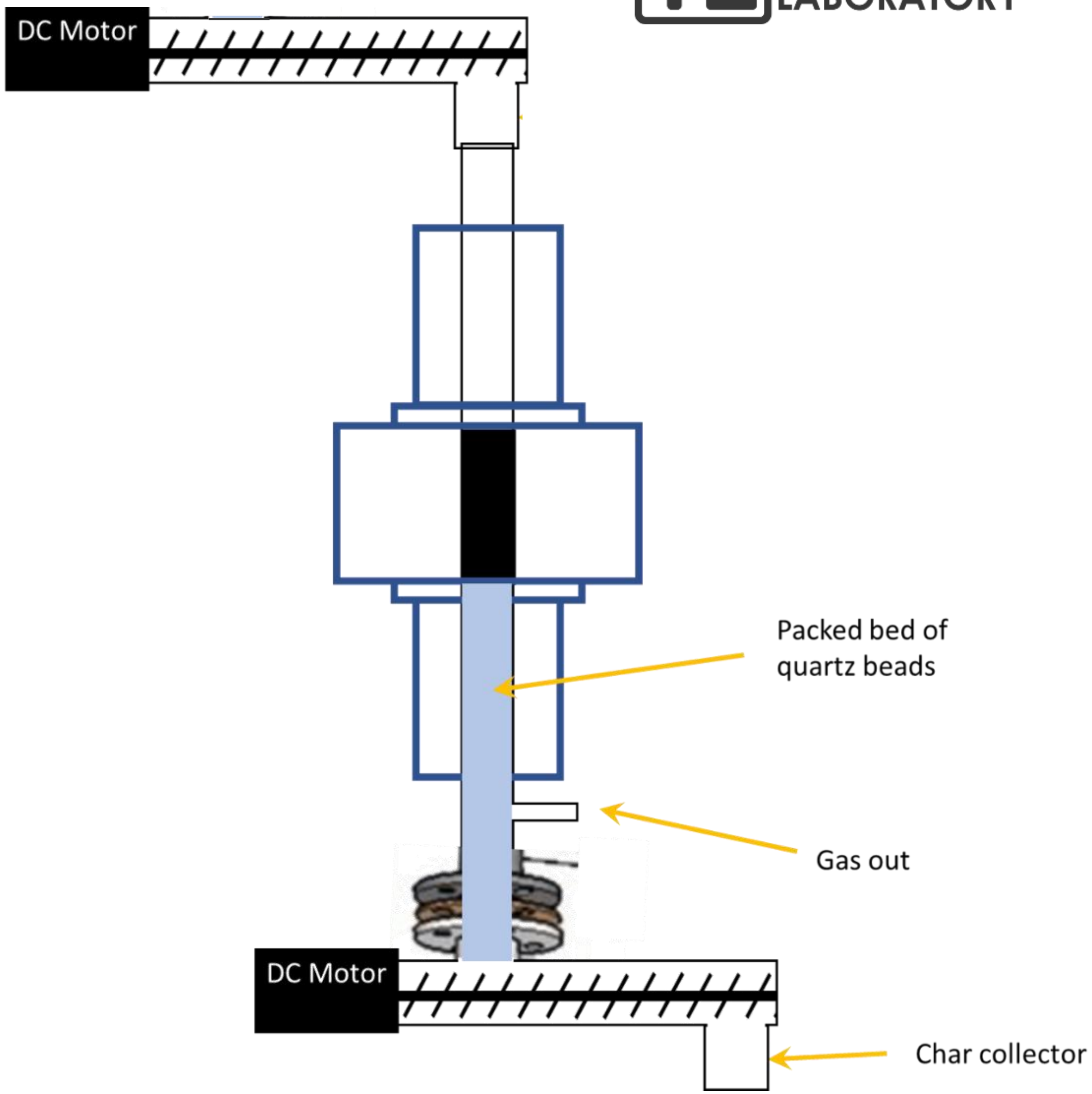
Carbon Conversion Efficiency

- **The percent of carbon in coal converted into gas ($CO+CH_4$)**
  - Lignite: max conversion in 20 mins
  - Sub bit.: max conversion in 40 mins
  - Bituminous: low conversion efficiency after 60 mins

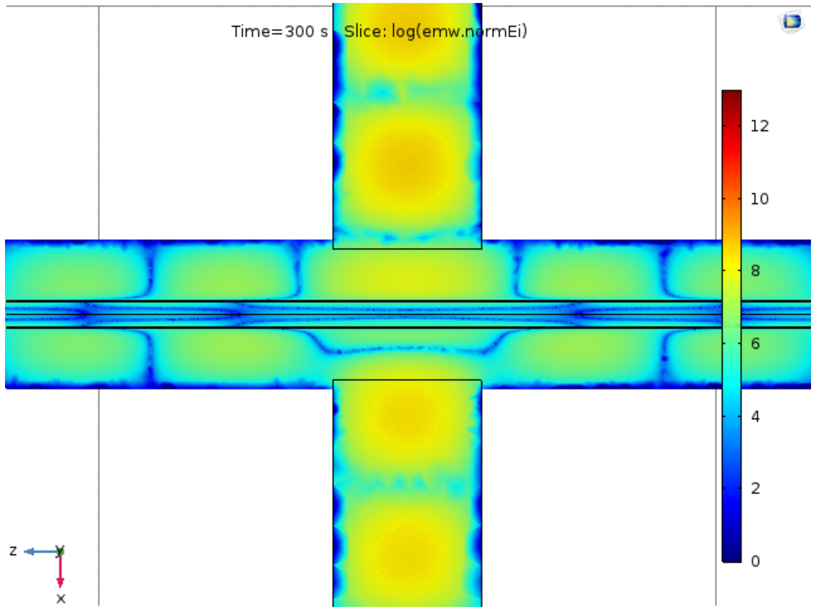


New and Future Work

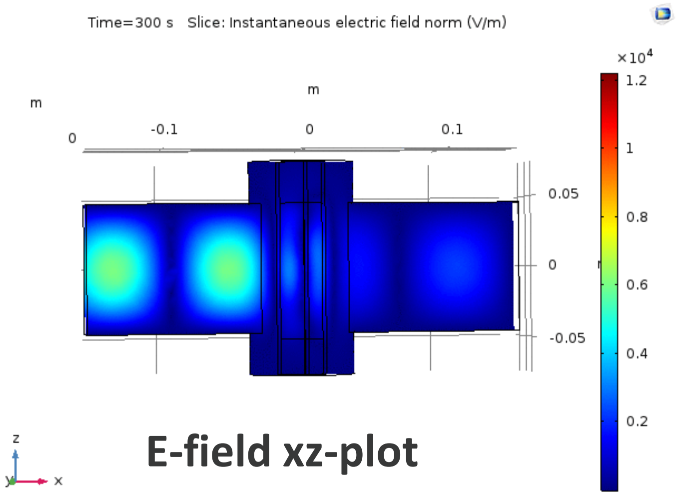
- **Modify current microwave reactor for continuous coal feed**
  - Complete energy balance model for CGE comparisons
  - Optimize gas feed (CO_2/H_2O/air) to maximize CCE and CGE for a selected coal rank
  - Utilize testing results to develop model for reactor scale-up and design
- **COMSOL design of scaled-up Microwave Reactor (Pilot = 10 kg/hr)**
- **CFD Moving-bed Kinetic Model Experimental Validation**
- **Systems and Economic Analysis**
  - Identify and define appropriate progress metrics
  - High-level economics/TEA for concept down-selection
- **Explore additional co-gasification concepts: biomass, plastics, MSW**



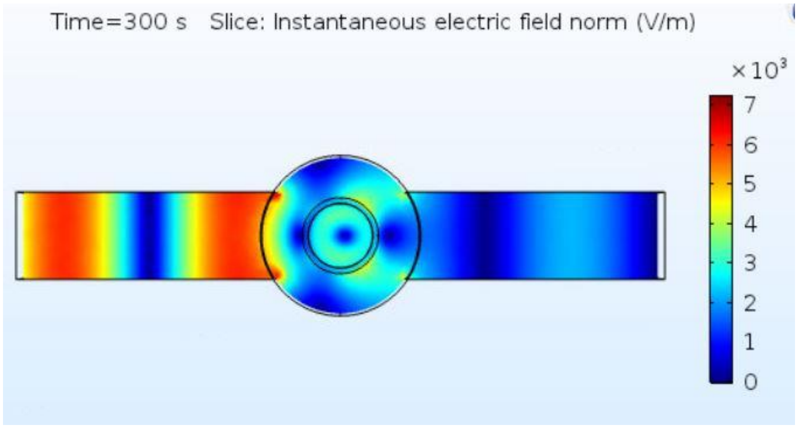
COMSOL Model of Gasification Reactor



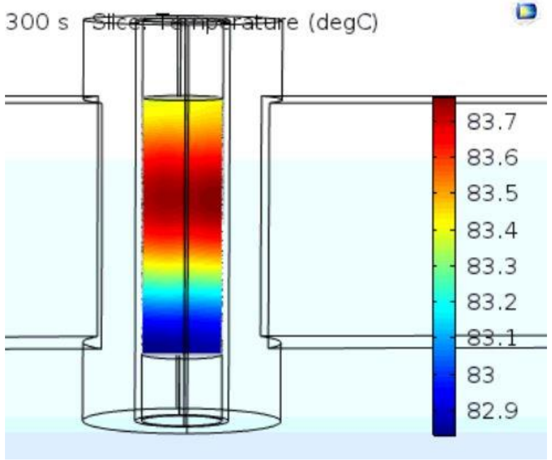
TM01 cavity diameter



E-field xz-plot



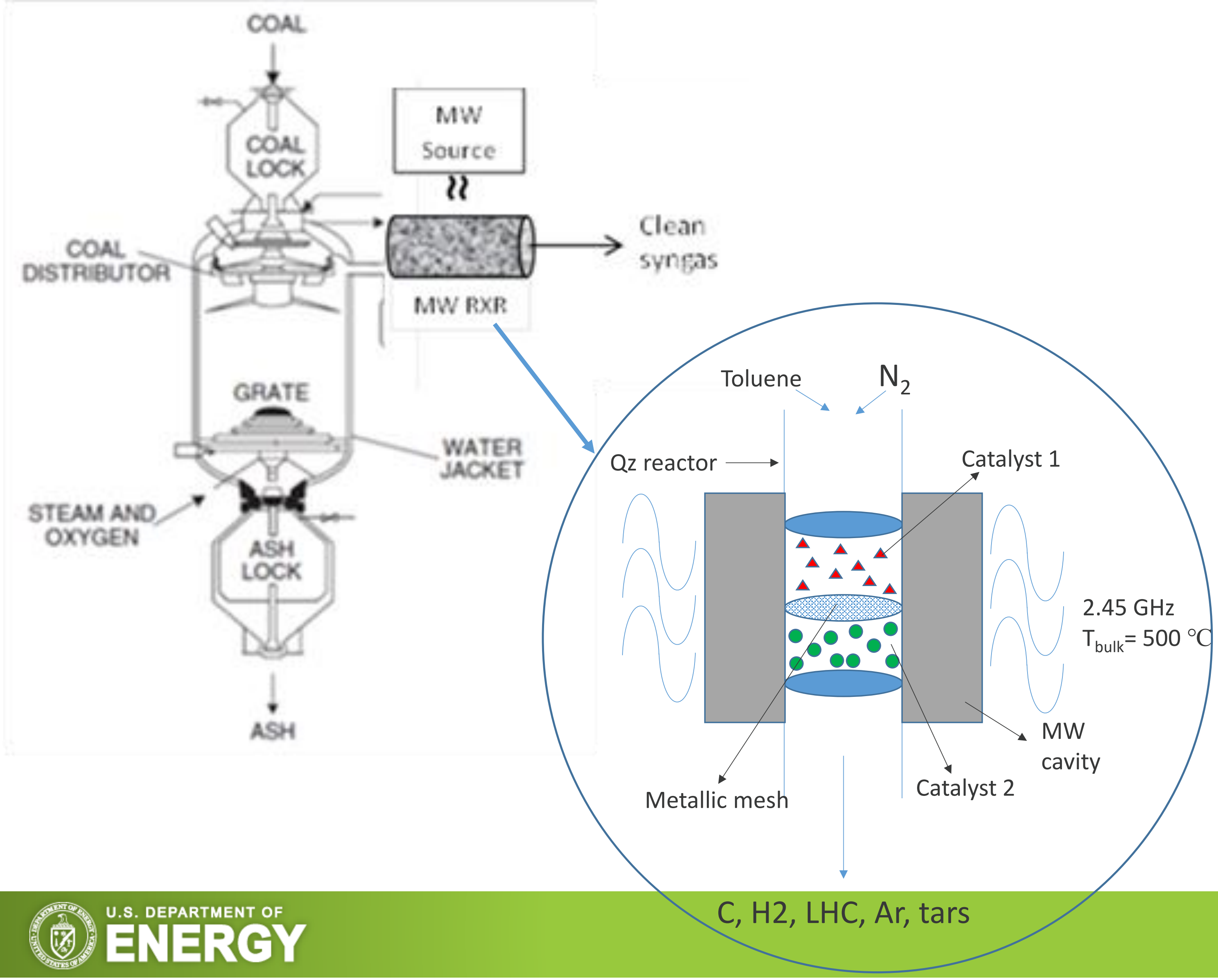
E-field xy-plot



Temperature-plot

- Predict and visualize temperature profiles within the coal bed
- Predict hotspots and maximum temperatures reached
- Electric field distribution inside the reactor
- Optimize microwave reactor geometry and design
- T-profile and heating rate with changing frequency (VFMWR), power (MSU)

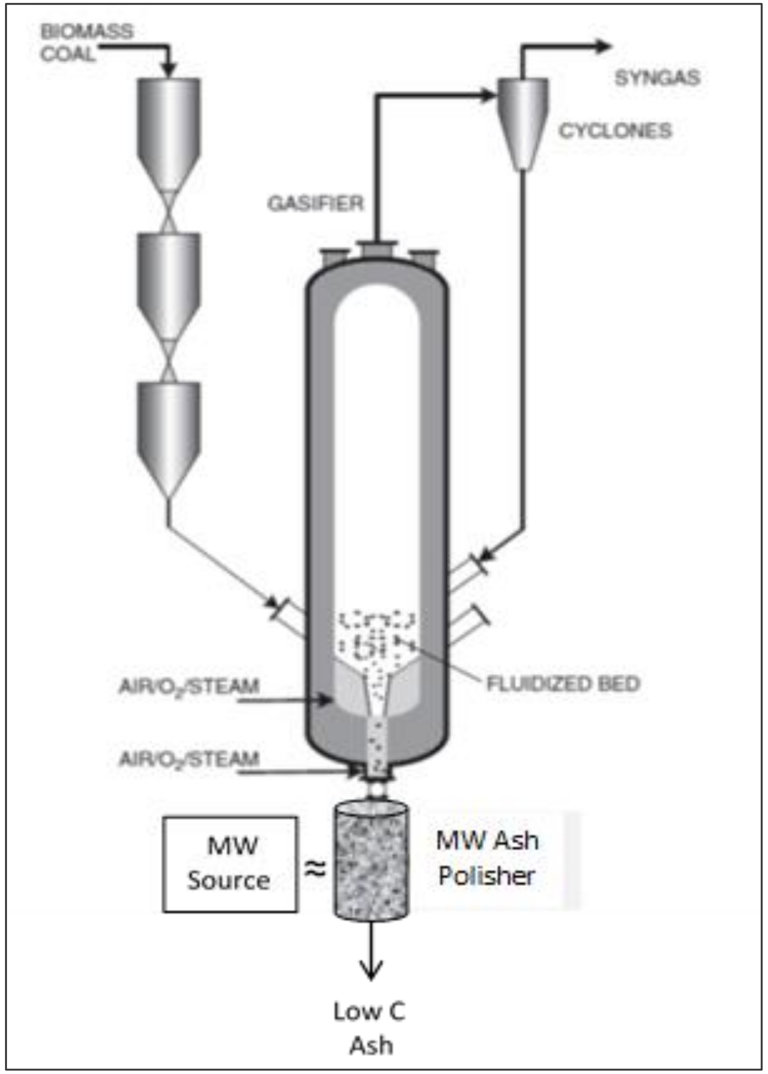
Tar Conversion in Syngas



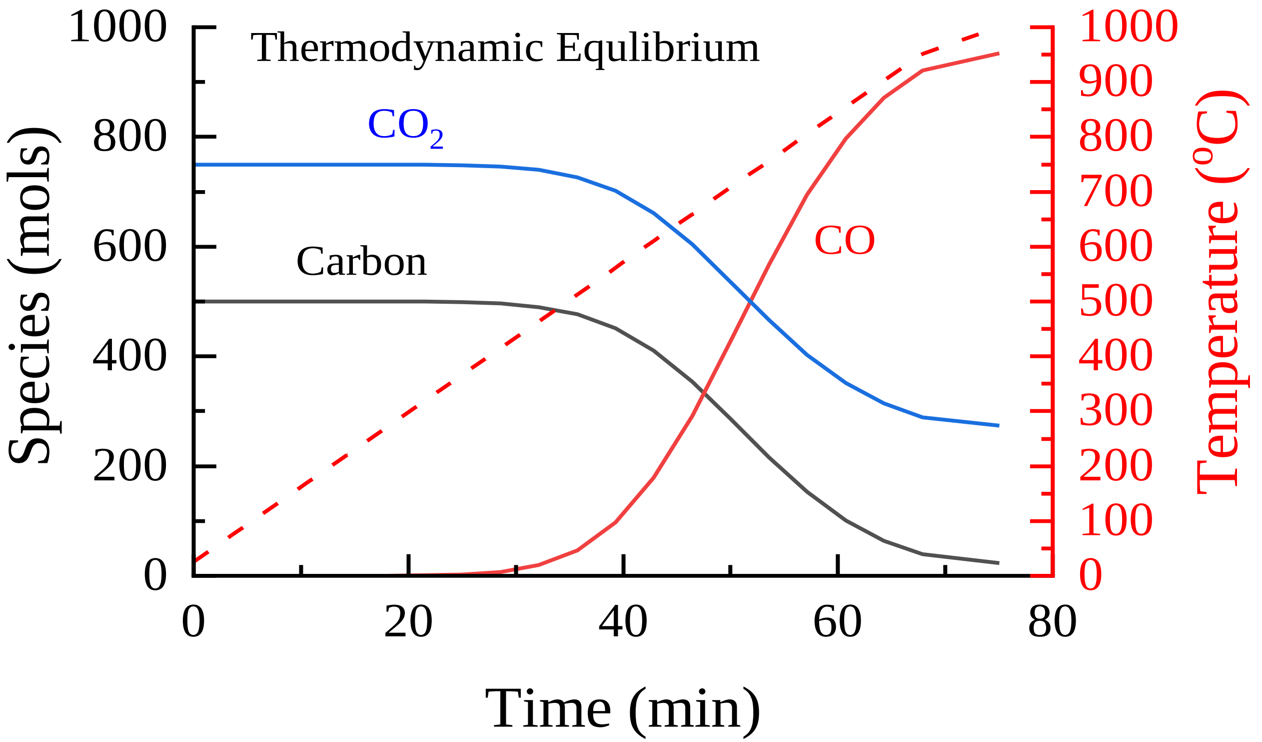
- **Potential Benefits:**
  - Address upstream process upsets and off-spec operation (i.e. spikes in syngas tar concentration
  - Prevent plugging and damage to downstream units that lead to unscheduled shutdowns
  - Reduce quantity of steam needed for tar conversion in gasifier

Carbon Conversion in Ash

Ash Samples Provided by GTI



- **Potential Benefits:**
  - Significantly reduce size of fluidized-bed gasifier
  - Produce low-carbon ash material suitable for construction



Summary

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- Microwave gasification of 3 different coal ranks using CO_2 demonstrated highest syngas yield for sib-bituminous sample
- Most rapid conversion under microwave energy was observed for lignite coal
- Microwave gasification produced significantly more syngas than conventional, thermal gasification for all three coal ranks
- System energy balances will be used during upcoming optimization studies with air and steam addition to compare modular microwave gasification to conventional


Questions?