



Energy & Environmental Research Center (EERC)

Tar Formation and Mitigation in Pressurized Biomass and Cofired Gasification

tcbiomass+2026

Denver, Colorado

August 26, 2026

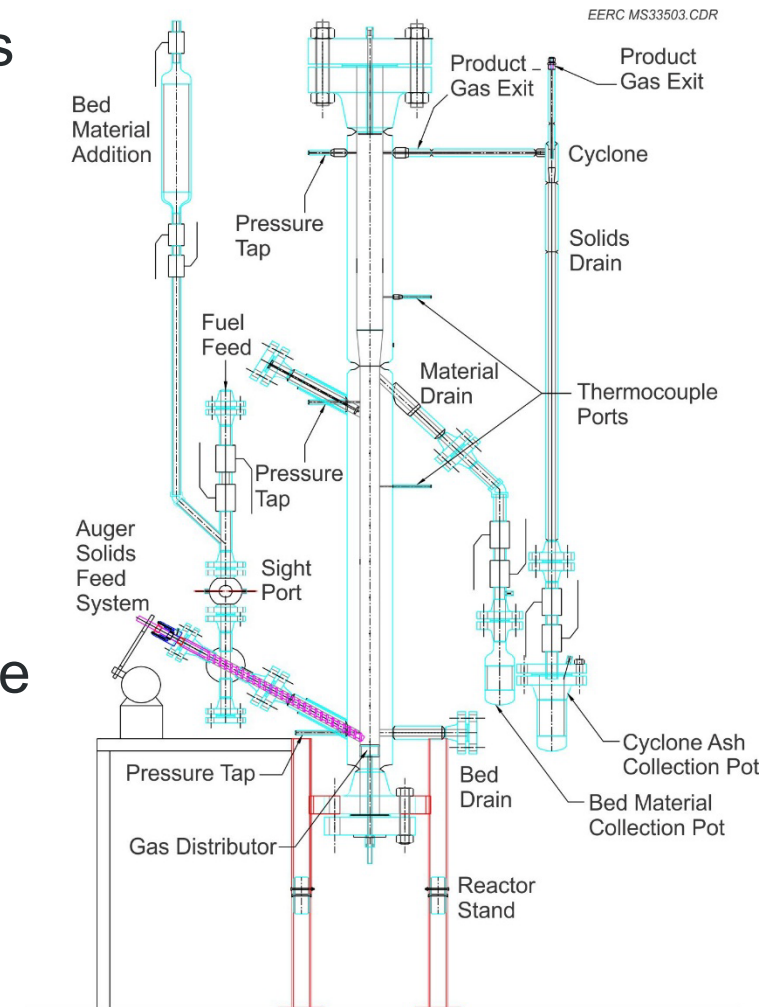
Joshua Strege

Assistant Director for Energy Systems



History of Pilot-Scale Gasification at the EERC

- EERC has been operating a pilot-scale gasifier on a variety of fuels for nearly 20 years
- Many lessons learned on how to operate with biomass and blends of coal and biomass
- Some of the very first tests on this system involved cofiring with coal up to 100% biomass
 - DDGS (ethanol byproduct)
 - Switchgrass
 - Olive pits
- In the years since, we have also gasified wood, corn stover, and various other materials



Pilot-Scale System

Pressurized feeder, live loss-in weight

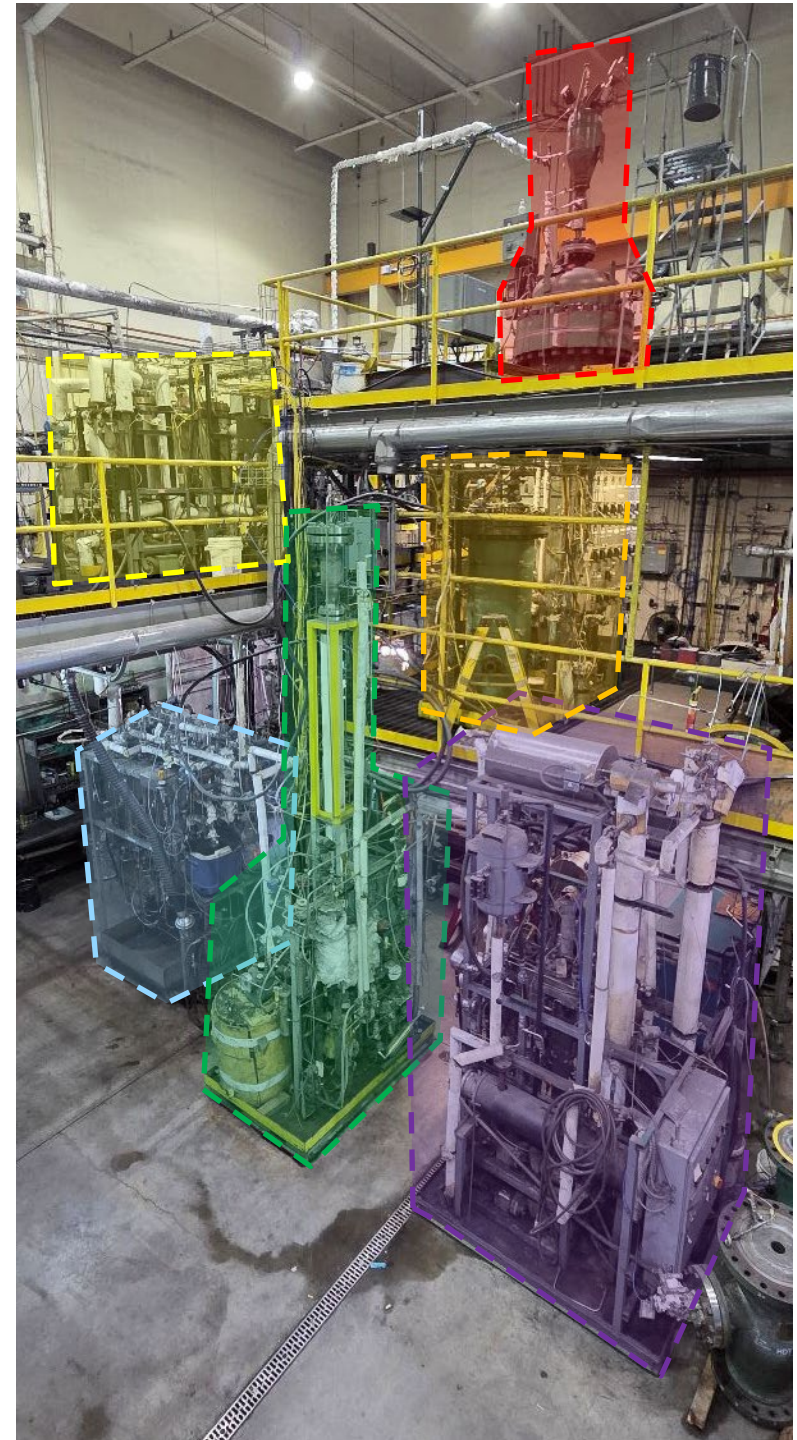
Gasifiers (fluidized bed, entrained flow)

Filter vessel, sorbents, and catalyst beds

Quench pots (tar and water removal)

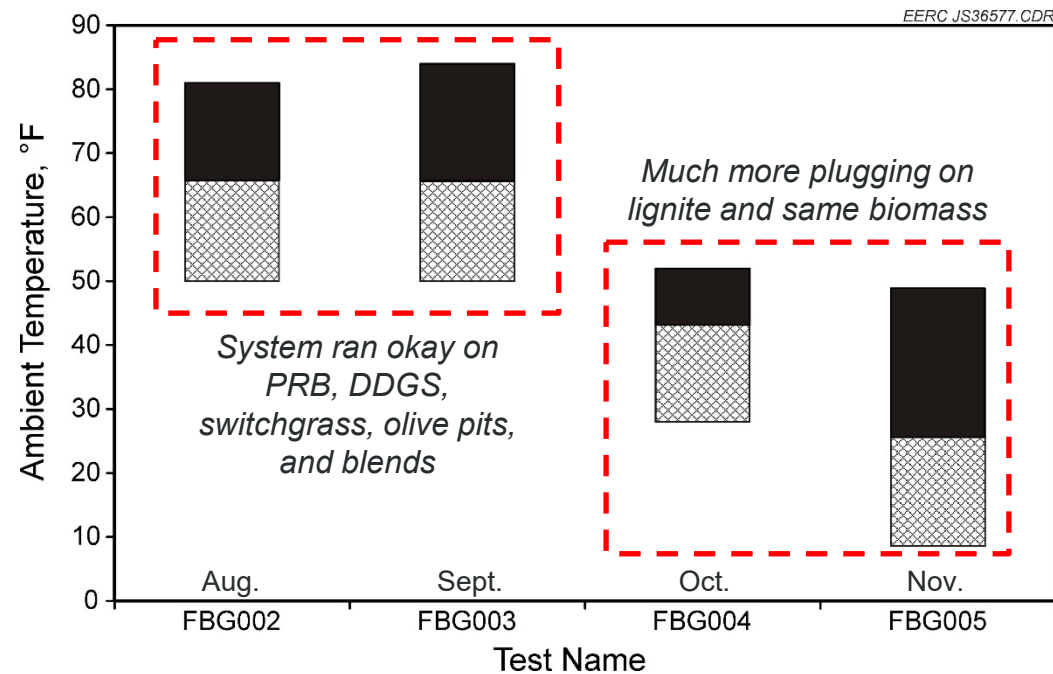
Physical solvent CO₂ removal

Fischer-Tropsch reactor



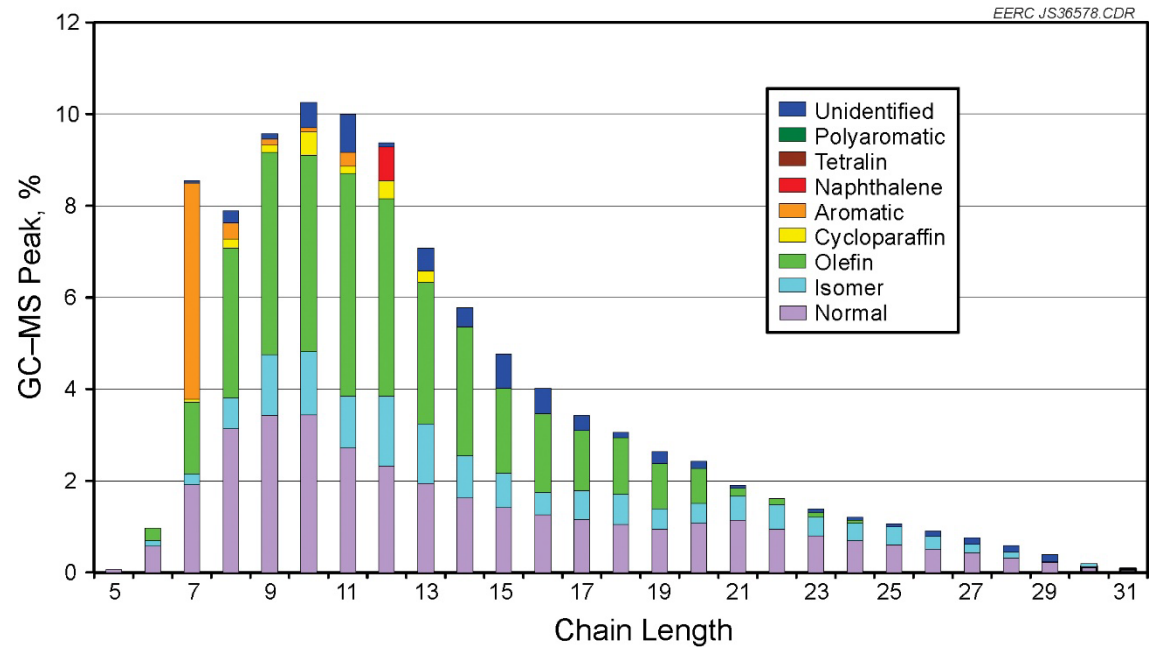
Early Experience: Tar Plugging in Quench Pots, Outlet Lines, and Recycle Syngas Compressor

- Early on, system would plug in cool weather
- Overcame with additional condensation, better quench pot design, heat trace, improved operating conditions, and a warmer building



Tar Carryover to Fischer–Tropsch (FT) Products

- Purpose of this test was to assess warm-gas cleanup potential for FT (no gas sweetening)
- During cold weeks, heat trace had to be added to the gasifier's pressure control valve and FT regulator to prevent plugging
- This pushed a lot of tar to the FT reactor, leading to coking and contamination.
 - Once, when the system was idled for several hours for auger repair, every fitting in the syngas recycle system plugged 13 minutes after startup—the surge tank had gotten excessively warm with no flow and volatilized weeks' worth of tar, which then condensed downstream
- When gas sweetening was first brought online, the distributor plate initially plugged with tar.
 - Overcome with better tar condensation, warmer temperatures in the gas sweetening system, and selective syngas reheat

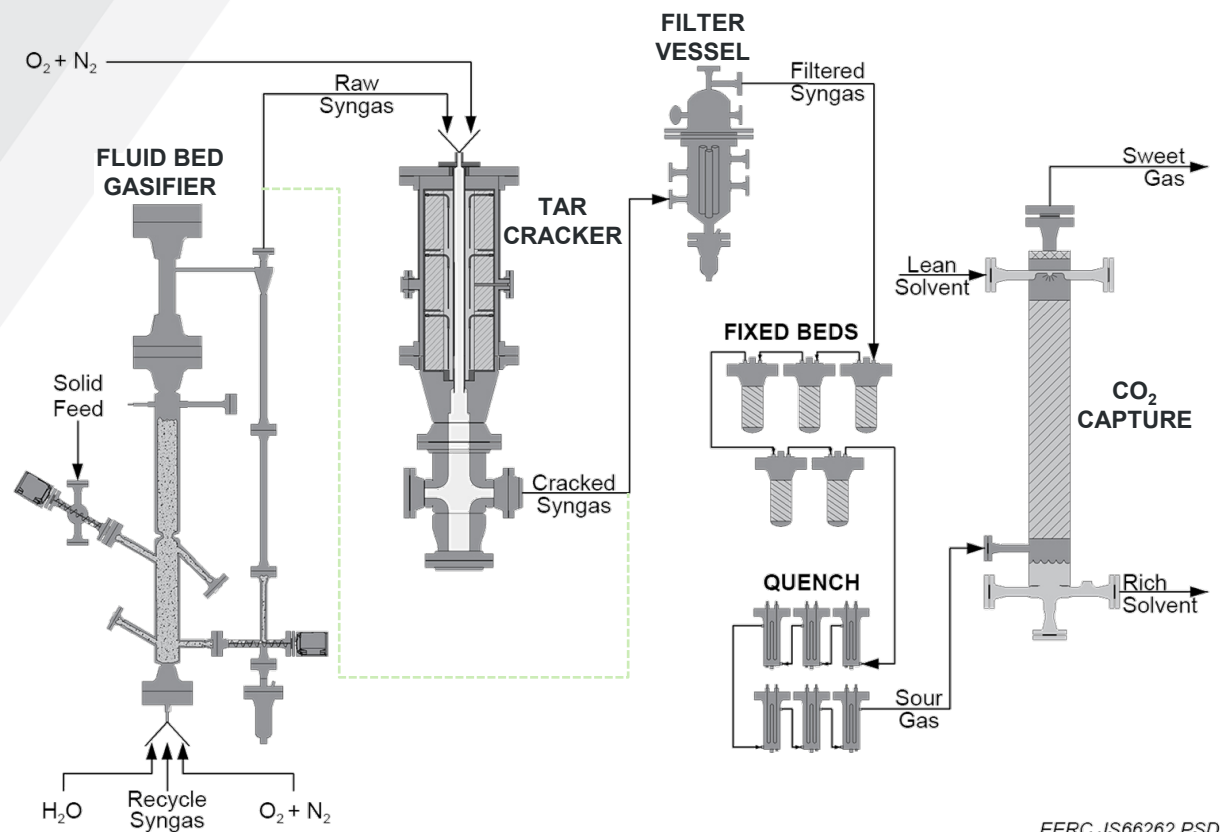


Reference: doi.org/10.2172/1060009

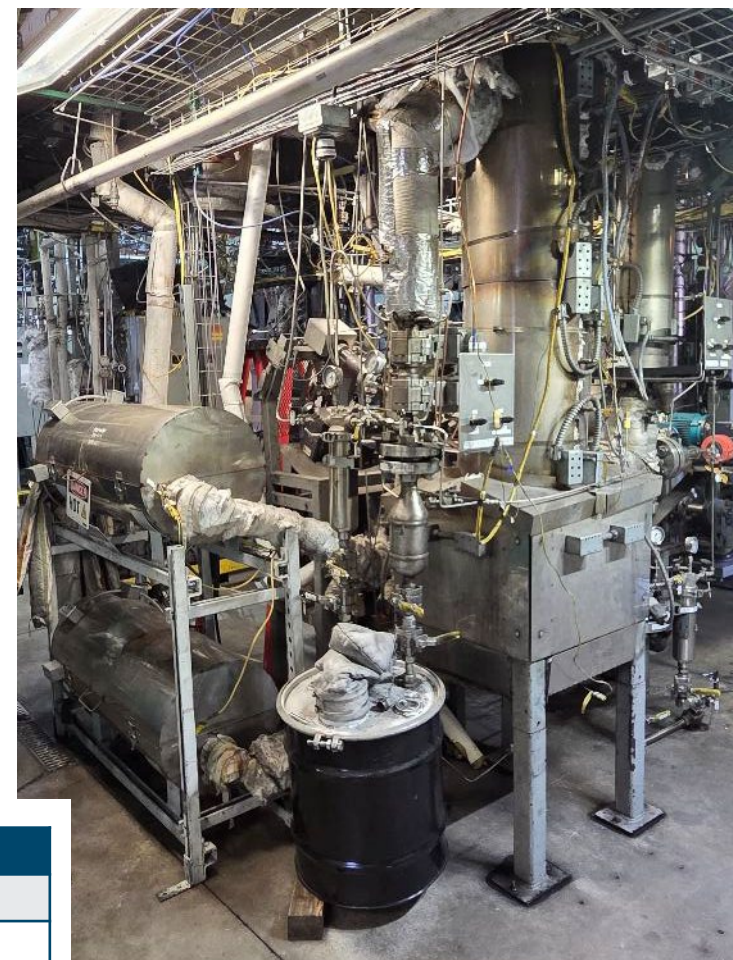
Recent Work

- Recent work with high biomass feed rates included detailed characterization of condensable tars and their fate
- The fluidized bed gasifier has been heavily modified since early testing:
 - Cyclone solids are recycled to the bed
 - New distributor plate provides better gas and solids mixing in the bottom of the bed
 - Nitrogen dilution is typically minimized during oxygen-blown gasification and extra steam is injected
 - Extra quench pot volume, and an ice-cooled condenser for recycle syngas
 - Selective reheat on key lines to keep tars in a vapor state
 - Building temperature is kept warmer
- Despite these changes, when operating on 100% stover at similar conditions to early work, the system did repeatedly plug with tars.

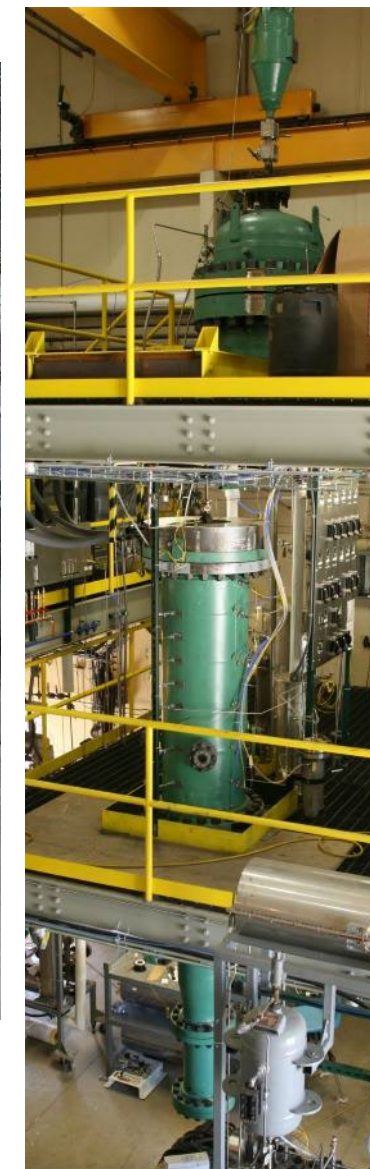
Recent Pilot-Scale Testing Configuration



Fixed-Bed Reactor	Catalyst or Adsorbent
Fixed Beds Nos. 1, 2	RVS-1 regenerable sulfur sorbent
Fixed Bed No. 3	Clariant ActiSorb® S 2 sulfur-polishing sorbent
Fixed Bed No. 4	Clariant ShiftMax® 120 high-temperature WGS catalyst
Fixed Bed No. 5	Clariant ActiSorb CI sorbent with ShiftMax 240 low-temperature WGS catalyst



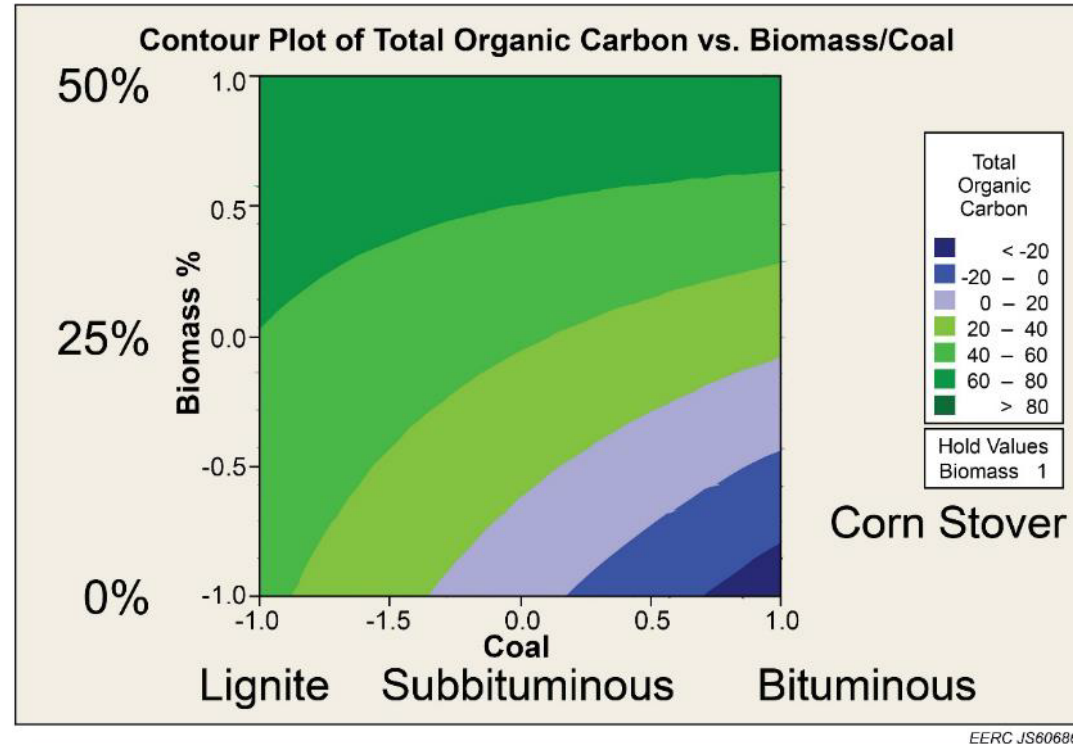
Fluidized Bed



Entrained Flow

TOC Content of Condensate During Cofiring

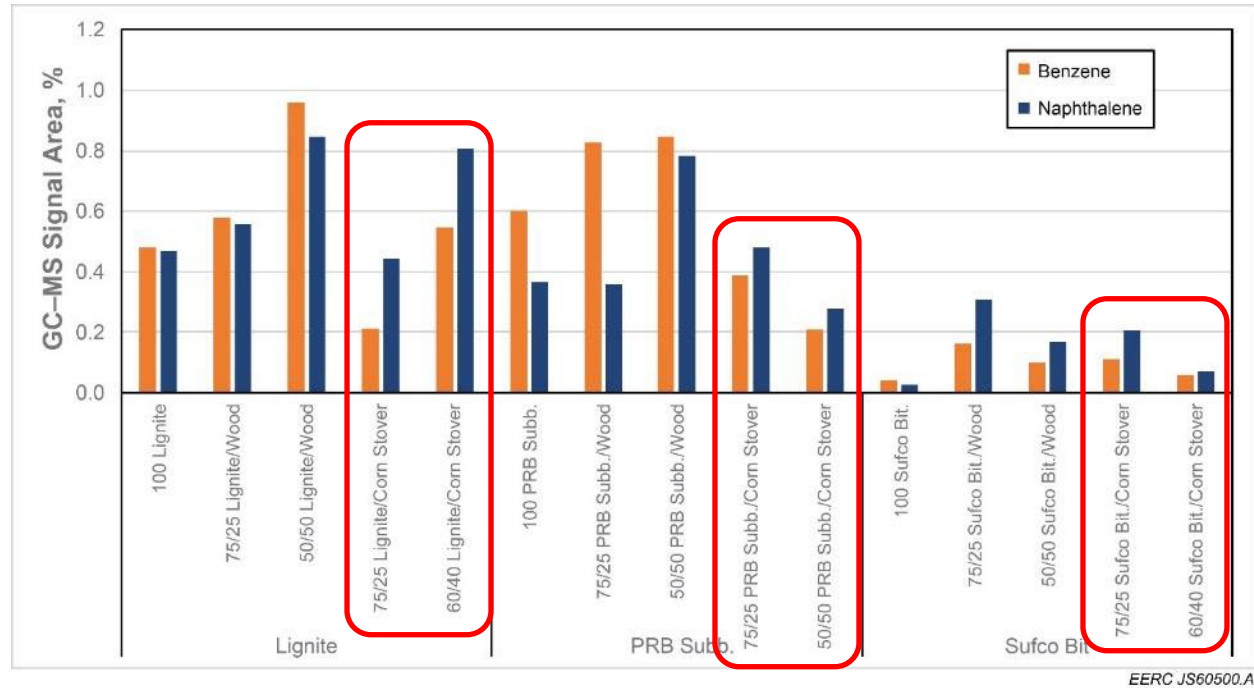
Gasification, Cofiring Corn Stover with Coal



When blending corn stover, TOC (indication of tar production) is nonlinear and indicates possible interactions between coal and biomass depending on blend ratio. As a result, the effect of 100% stover gasification cannot be extrapolated from cofiring data.

Solvent GC-MS Analysis During Cofiring

Gasification with CO₂ Capture, Cofiring Corn Stover with Coal



Although corn stover always resulted in more condensable tar upstream of the capture system, it did *not* result in the most tar accumulation in the CO₂ capture system; in several cases, there was *less* tar when cofiring corn stover than when using 100% coal. This again shows that the effect of gasifying 100% corn stover cannot be extrapolated from cofiring data.

Run Conditions During 100% Stover Gasification

Gasification with CO₂ Capture

Test	Pressure	Feed	Gasifier	Water-Gas Shift (WGS)
Cofiring	38.2 bar	0%–50% stover, oxygen, and steam	Single-stage fluidized bed	Sour shift followed by sulfur removal
Week 1		100% stover, oxygen, and steam		Sulfur removal followed by sweet shift
Week 2	21.7 bar	100% stover, air, and steam		
Week 3	19.7 bar			
Week 4	15.5 bar			

- 760°–790°C, silica sand fluidized bed
- 250 g of kaolin added to every 9.1 kg of corn stover to help reduce agglomeration.
- DEPG (dimethyl ethers of propylene glycol)-based CO₂ absorption system used for carbon capture.

Sampling

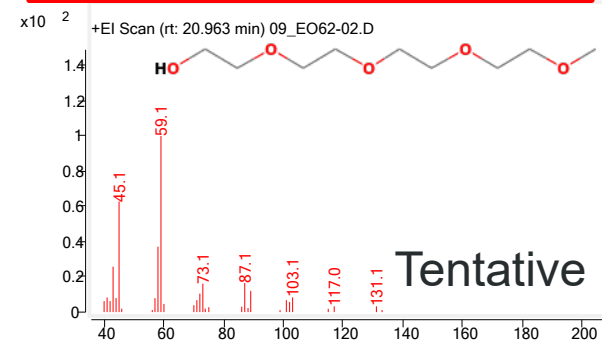
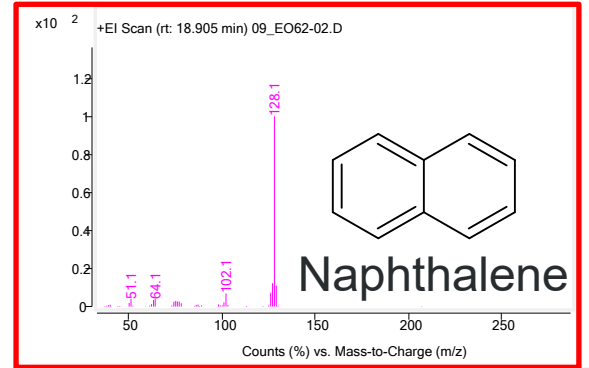
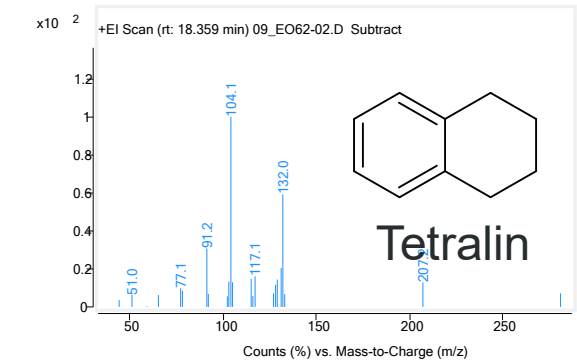
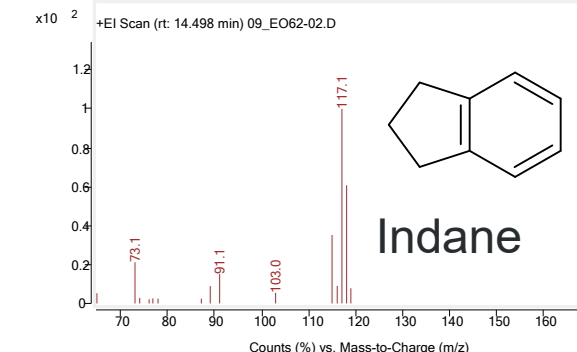
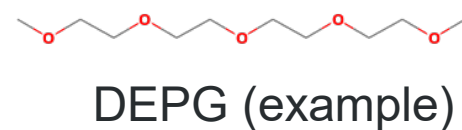
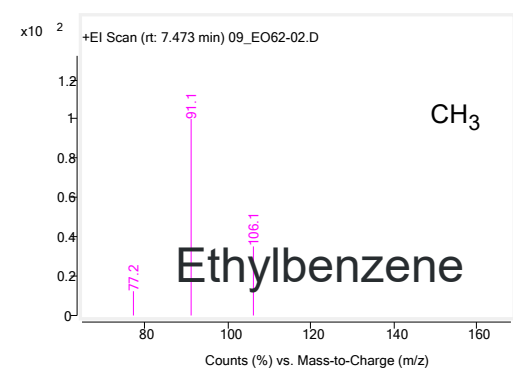
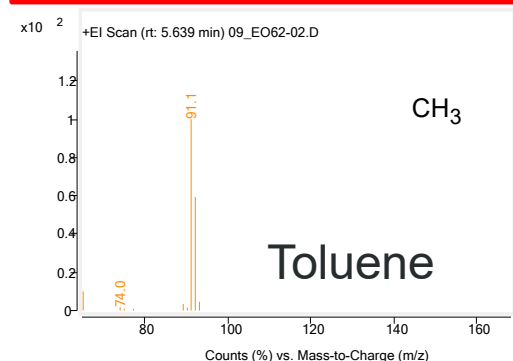
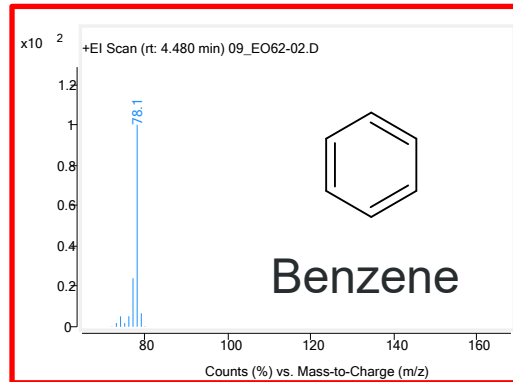
- Proximate/ultimate analyses of solid feed streams
- X-ray fluorescence analysis of ash content of feed streams
- Continuous syngas composition using online Raman spectrometry
- Semicontinuous syngas composition using gas chromatography
- Total organic carbon (TOC) analysis of condensed product stream water
- GC–MS of DEPG solvent

Modeling

- Aspen Plus™ and HYSYS™ models of full-scale gasifier and CO₂ capture system tuned to pilot-scale results
- Aspen Process Economic Analyzer™ used for high-level process economics
- U.S. National Energy Technology Laboratory (NETL) methodology used for cost estimations
- OpenLCA software used for life cycle analysis

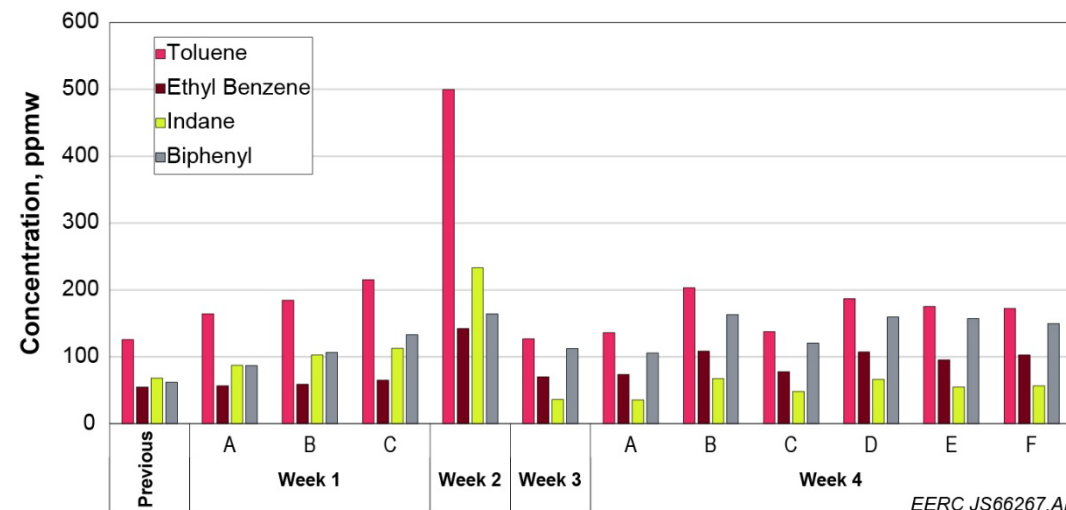
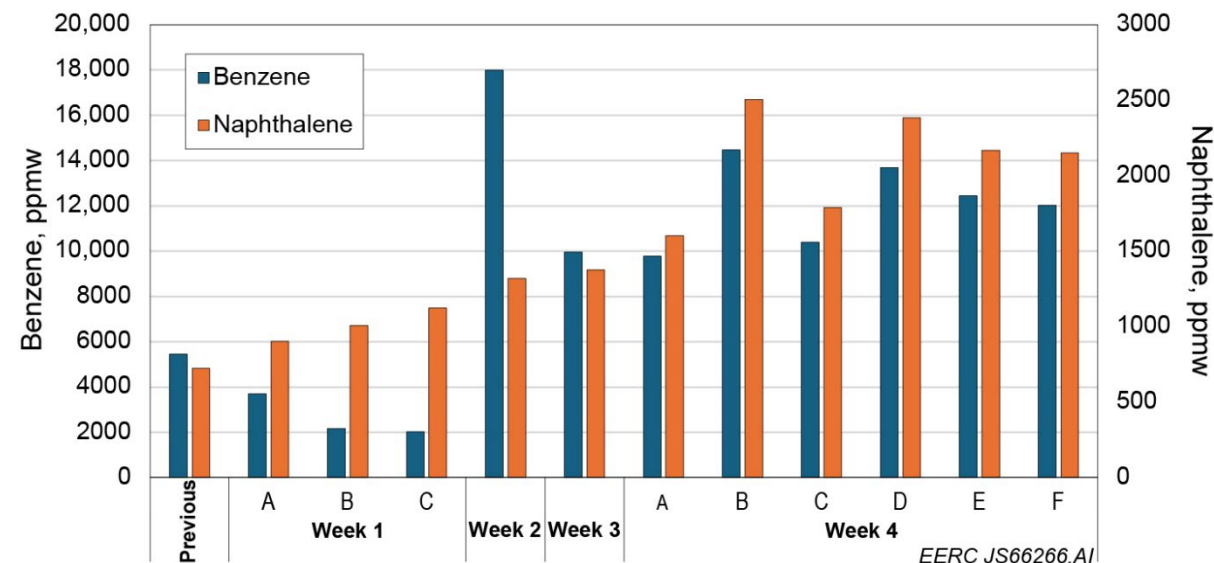
Exposed Solvent

The chromatogram displays 13 numbered peaks, each indicated by a red arrow pointing to a blue box with the peak number. The peaks are distributed across the retention time range, with a significant cluster of peaks between 10 and 15 minutes. The y-axis is labeled with a multiplier of $\times 10^5$ at the top left.



Tar Species Measured in Solvent

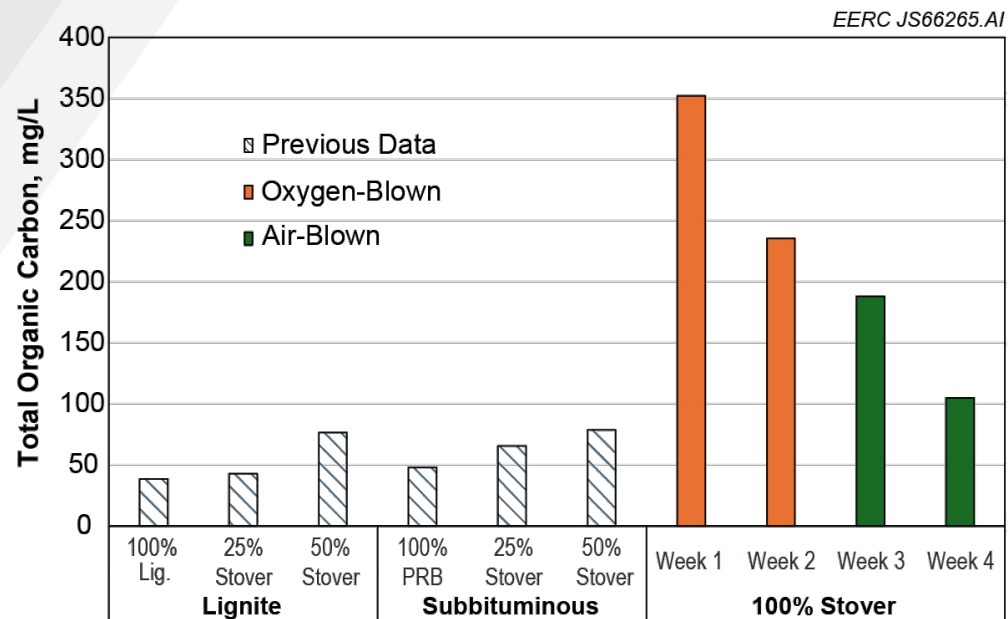
- Benzene dropped in Week 1 even as quench water saw very high TOC
 - High pressure may have allowed benzene to condense in quench pots, though note that all other species analyzed increased
- Large spike in single-ring organics in Week 2 when system pressure was dropped; lesser jump for most two-ring organics
- Fresh solvent in Week 3 (air-blown); naphthalene reached same level as Week 2. Other species lower than Week 2 but higher than previous testing with cofired.
- Much variability throughout Week 4 (low-pressure air-blown), but concentrations generally stable
 - Tars in CO₂ product also stabilized during Week 4 (later slide)



Semi-Quantitative Results

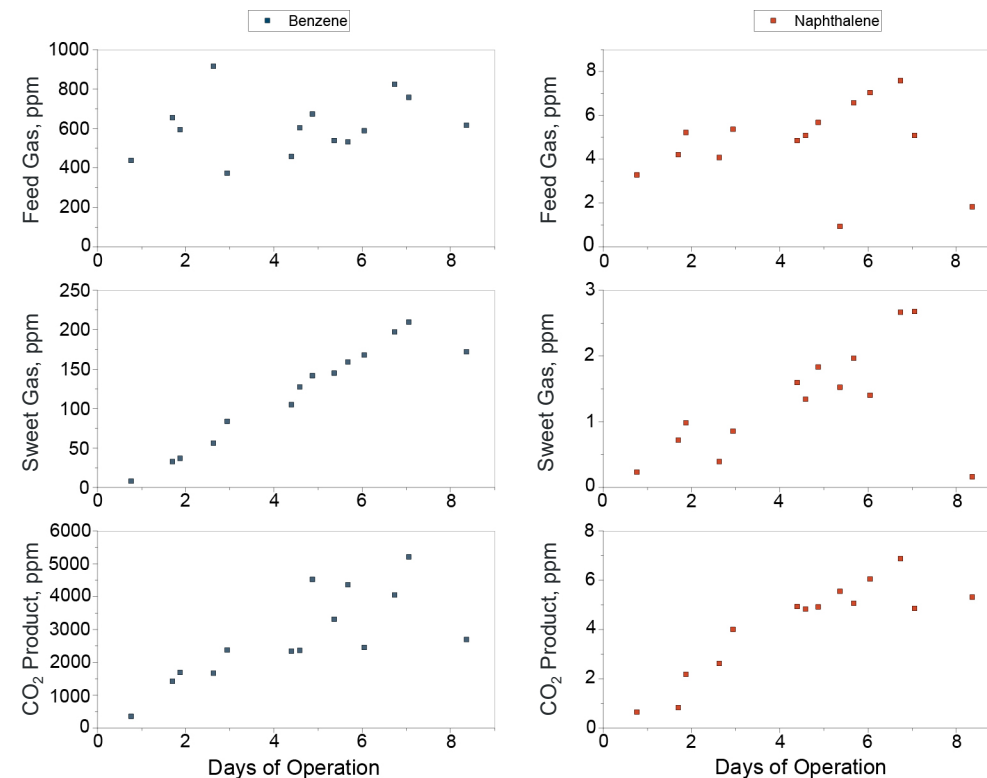
- CO₂ standards were not possible, but relative results can be compared by quantifying CO₂ using a false standard.
- Unused solvent contained nondetectable CO₂. Solvent left from previous testing started with ~77 µg/mL (pseudo-quantitative) after long storage at room temperature and pressure.
 - During high-pressure operation in Week 1, CO₂ jumped to between ~830-1100 µg/mL.
 - CO₂ then dropped to ~185 µg/mL during lower-pressure operation in Week 2, even as benzene and toluene concentrations spiked.
 - CO₂ was not reported in Weeks 3 and 4.
- Other species detected include tetralin, 1-methyl naphthlene, and 2-methyl naphthalene. Acenaphthene and ethylnaphthalene looked for but not detected.
 - Most species present but generally below quantification limits.
 - Tetralin and 1-methylnaphthalene were quantifiable at the end of Week 1 and in Week 2, with signal strength (and concentrations) increasing over time.

Water and Syngas Streams



Quench Water TOC

- Total organic carbon **~6× higher** with 100% stover than with 50% stover.
- Reducing pressure and adding tar cracking in Weeks 2–4 did not get TOC down to cofiring levels.



EERC JS66268.AI

Syngas Streams

- Approaching **6000 ppm benzene** in CO₂ product stream after <2 weeks of operation in air-blown gasification.
- Need to address for compression, transport, and storage.

Summary

- Tar formation can completely plug lines, valves, regulators, and even compressors, particularly in small-scale systems
- Reheating, extra condenser space, solids recycle, optimal bed temperature, and reactor design are all factors that may need consideration.
 - Even with almost 20 years of learnings, the gasifier lines still plugged frequently when running on 100% corn stover at ~300 psig in oxygen-blown gasification, though we have learned to identify and clear plugs much faster over the last two decades
- Fuel- and condition-specific testing **needs** to be done on biomass gasification before full-scale implementation.
 - Tar production is **highly nonlinear** with increasing biomass feed in a pressurized fluidized bed; 100% corn stover generates several times more tar than a 50/50 blend of stover and coal.
 - High variability among biomass types (wood, crop residues, olive pits, energy crops like switchgrass, etc.)
- Tar cracking using a retrofit system was effective at avoiding plugs, but a purpose-built tar cracker would likely be necessary for deep tar reduction.
 - Tar cracker generated ash in Week 3 at 2000°F but plugged with slag in Week 4 at 2500°F; optimal tar cracking needs to balance good organic conversion against potential for slagging
- Volatile tar (benzene, naphthalene) reaching the capture system partitions to the CO₂ stream.
 - Needs to be addressed for compression, transportation, storage, and utilization.

DOE Acknowledgement

This material is based upon work supported by the U.S. Department of Energy National Energy Technology Laboratory under Award No. DE-FE0024233.

DISCLAIMER

This presentation was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.



Joshua Strege
Assistant Director for Energy Systems
jstrege@undeerc.org
701.777.5080

**Energy & Environmental
Research Center**
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018
701.777.5000
www.undeerc.org

A wide-angle photograph of a university campus. In the foreground, there are large trees with yellowing leaves, suggesting autumn. The sun is low on the left, creating a bright glow. In the background, there are several large, multi-story brick buildings, likely university halls or labs, and a parking lot filled with cars.

THANK YOU

Critical Challenges. Practical Solutions.