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Net-Carbon-Negative Capture Technology: Evaluation of the Impact of Coal and Biomass Blends on Pre- and Postcombustion Carbon Capture Solvents

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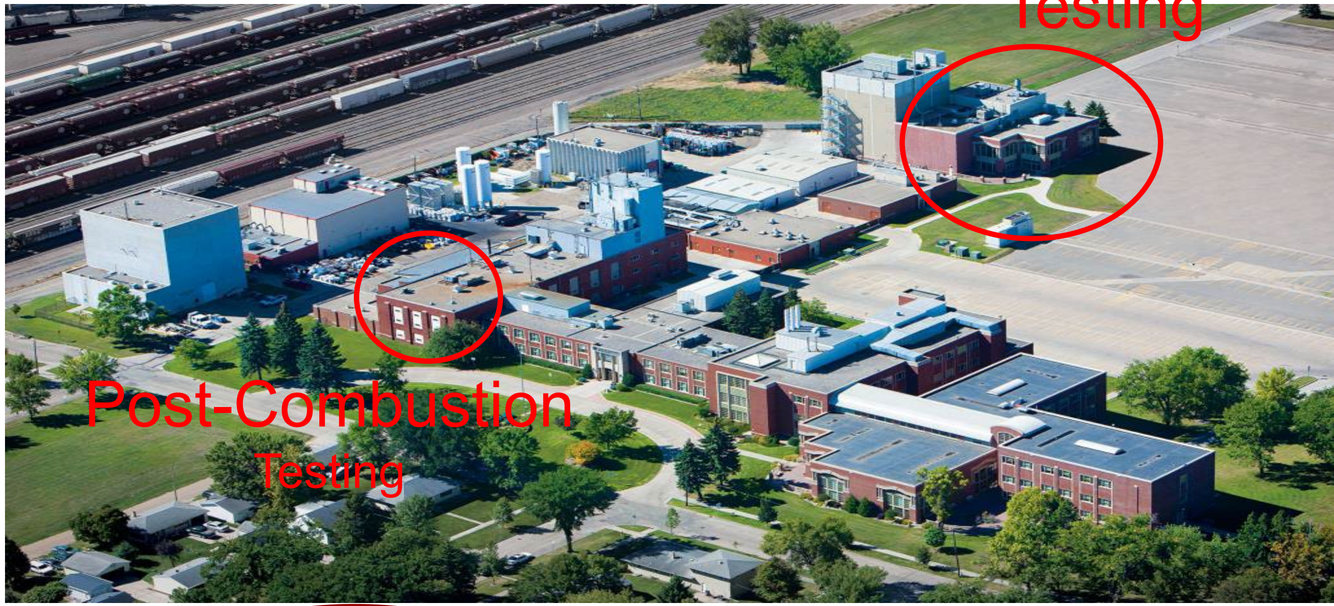
ENERGY & ENVIRONMENTAL RESEARCH CENTER (EERC)

- Nonprofit branch of the University of North Dakota focused on energy and environmental solutions.
- More than 254,000 square feet of state-of-the-art laboratory, demonstration, and office space.

Precombustion Testing



Ideal Carbon Storage Geology

EERC

PROJECT OVERVIEW/OBJECTIVES

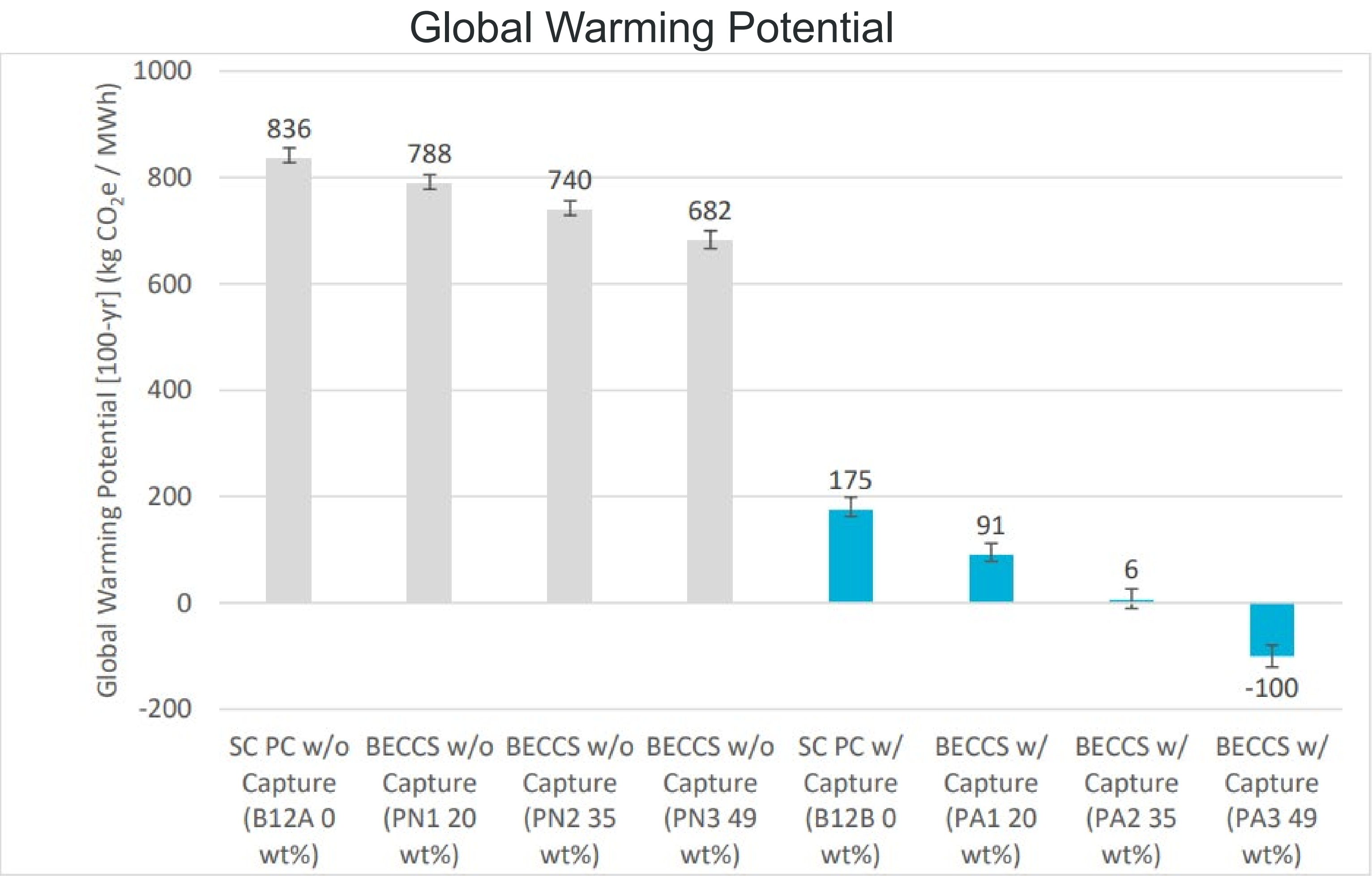
- Negative-emission technologies are being explored by NETL and the EERC. One of these technologies includes coal and biomass-generated syngas that, when combined with carbon capture, could result in net-negative carbon dioxide (CO_2) emissions.

- Funding: $6,682,031
- Period of performance: September 21, 2020, through June 30, 2022
- Project participants
  – DOE NETL
  – LRST
  – EERC

BIOENERGY WITH CARBON CAPTURE AND STORAGE (BECCS)

- Technology Background: Develop technology that results in power generation or hydrogen production with a net-carbon-negative footprint by using coal and biomass blends with carbon capture.

IMPACT OF BIOMASS BLENDS ON GHG



Note: blue bars indicate the presence of 90% CCS

- Data developed using bituminous coal and hybrid poplar as the feedstocks.
- Net negative greenhouse gases (GHGs) at more than 35.9% biomass with 90% carbon capture.

- Source: Buchheit et al. Technoeconomic and Life Cycle Analysis of Bio-Energy with Carbon Capture and Storage (BECCS) Baseline; DOE National Energy Technology Laboratory; July 16, 2021.

TECHNICAL APPROACH/PROJECT SCOPE

EERC PRECOMBUSTION TEST MATRIX

Run/ Weeks	Coal Type	Biomass Type	Biomass Blend	Testing Duration, days	Actual/ Planned Completion Date	Run Time on Solvent, h
1A	Subbituminous	None	0%	2.5	10/23/20	47
2	Subbituminous	Wood	25%	5	10/30/20	72
3	Subbituminous	Wood	50%	5	11/20/20	84
4	Subbituminous	Corn stover	25%	5	12/04/20	74
5	Subbituminous	Corn stover	50%	5	12/11/20	78
6	Lignite	None	0%	5	12/18/20	98
7	Lignite	Wood	25%	5	1/08/21	103
8	Lignite	Wood	50%	5	01/15/21	104
9	Lignite	Corn stover	25%	5	01/29/21	104
10	Lignite	Corn stover	50%–40%	5	02/05/21	17/45 (62 tot.)
1B	Subbituminous	None	0%	2.5	02/19/21	55 (102 tot.)
11	Bituminous (Sufco)	None	0%	5	03/05/21	35
12	Bituminous (CAPP)	Wood	25%	5	02/26/21	60
13	Bituminous (Sufco)	Wood	50%	5	03/19/21	98
14	Bituminous (Sufco)	Corn stover	25%	5	03/26/21	42
15	Bituminous (Sufco)	Corn stover	20%	5	04/09/21	96
16	Bituminous (Sufco)	Wood	25%	5	4/16/21	101
			Total	75		1311

EERC POSTCOMBUSTION TEST MATRIX

Run/ Weeks	Coal Type	Biomass Type	Biomass Blend	Testing Duration, days	Completion Date	Run Time on Solvent (h)
1	Subbituminous	None	0%	5	5/7/21	88
2	Subbituminous	Wood	17.5%	5	6/18/21	92
3	Subbituminous	Wood	35%	5	7/02/21	94
4	Subbituminous	Corn Stover	17.5%	5	5/14/21	91
5	Subbituminous	Corn Stover	35%	5	6/11/21	79
6	Lignite	None	0%	5	7/16/21	74
7	Lignite	Wood	17.5%	5	8/20/21	81
8	Lignite	Wood	35%	5	9/03/21	93
9	Lignite	Corn Stover	17.5%	5	7/23/21	77
10	Lignite	Corn Stover	35%	5	8/13/21	81
11	Bituminous (CAPP)	None	0%	5	9/17/21	81
12	Bituminous (CAPP)	Wood	17.5%	5	10/15/21	93
13	Bituminous (CAPP)	Wood	35%	5	10/29/21	95
14	Bituminous (CAPP)	Corn Stover	17.5%	5	9/24/21	95
15	Bituminous (CAPP)	Corn Stover	35%	5	10/08/21	94
16	None	Corn Stover	100%	~15	03/03/22	229
			Total	90		1537

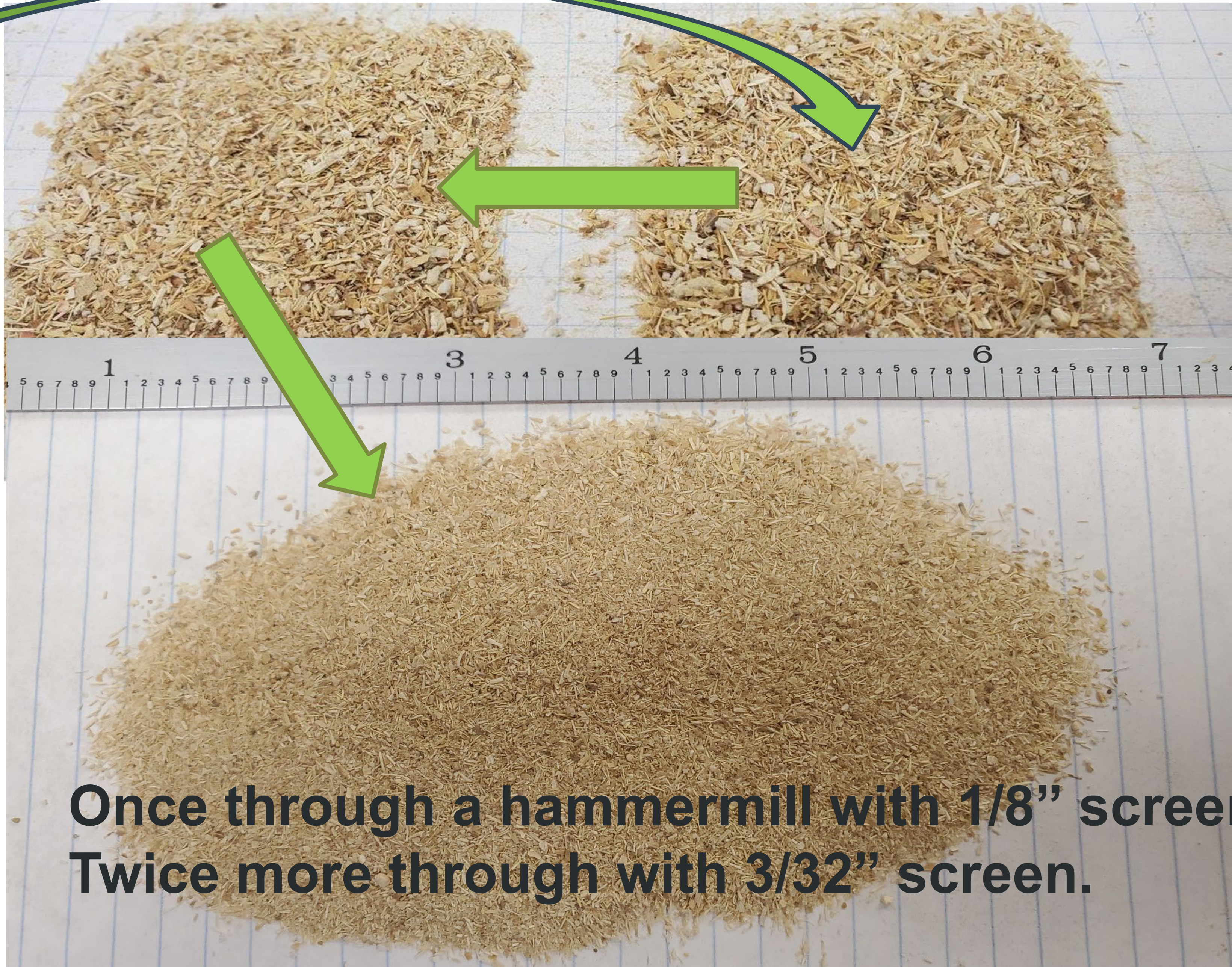
Lignite – Falkirk Mine, ND   Subbituminous – Antelope (Rochelle Mine), WY
Bituminous – Central Appalachian Basin (CAPP), provided by Blackhawk Coal Sales

FUEL PREP – WOOD PELLETS

Wood pellets were ground in a hammer mill once with an 1/8” screen and then reprocessed through a 3/32” screen.

FUEL PREP – CORN STOVER

Past Example



Once through a hammermill with 1/8” scree
Twice more through with 3/32” screen.

SELECTED RESULTS, ASH-FORMING CONSTITUENTS

Falkirk Lignite–9.3% Ash

Component	wt%
SiO_2	43.63
Al_2O_3	14.05
Fe_2O_3	5.37
TiO_2	0.58
P_2O_5	0.15
CaO	15.77
MgO	4.61
Na_2O	3.39
K_2O	1.67
SO_3	9.88
SrO	0.35
BaO	0.50
MnO	0.05

PRB Antelope Coal–5.6% Ash

Component	Norm., wt%
SiO_2	37.90
Al_2O_3	18.91
Fe_2O_3	5.97
TiO_2	1.20
P_2O_5	0.63
CaO	18.49
MgO	3.43
Na_2O	1.20
K_2O	0.73
SO_3	10.81
SrO	0.24
BaO	0.44
MnO	0.05

Southern Pine–0.5% Ash

Component	wt%
SiO_2	7.53
Al_2O_3	3.13
Fe_2O_3	1.03
TiO_2	0.08
P_2O_5	7.91
CaO	31.86
MgO	10.80
Na_2O	5.18
K_2O	25.05
SO_3	7.43

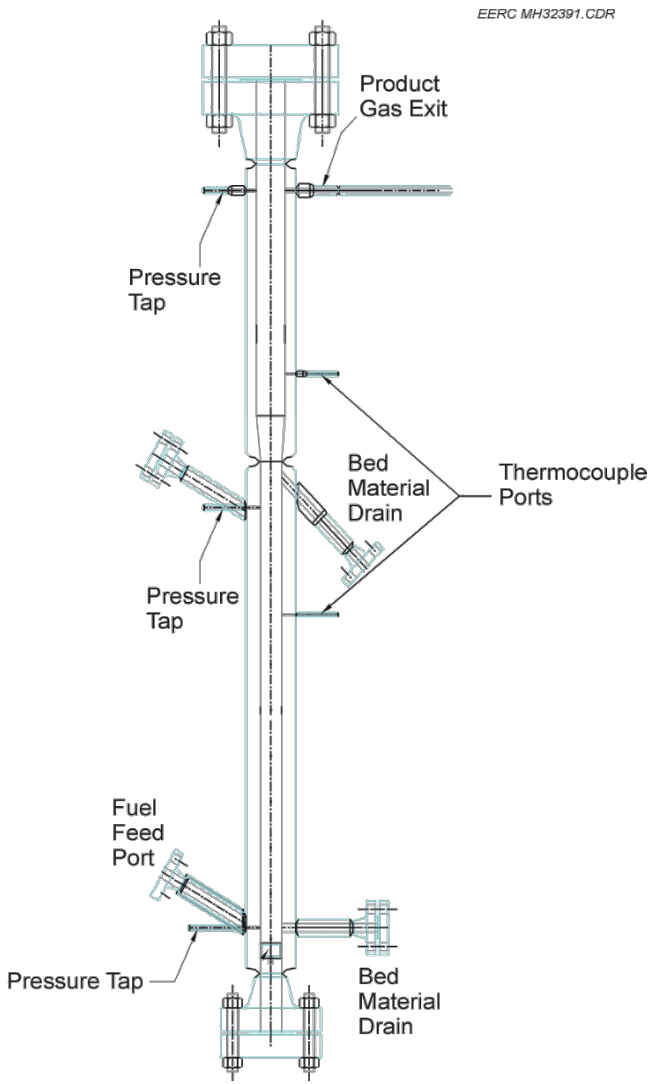
Corn Stover–6.1% Ash

Component	Norm., wt%
SiO_2	65.73
Al_2O_3	2.89
Fe_2O_3	1.19
TiO_2	0.13
P_2O_5	1.64
CaO	5.97
MgO	4.97
Na_2O	0.75
K_2O	15.85
SO_3	0.68
SrO	0.02
BaO	0.03
MnO	0.15

PRECOMBUSTION CARBON CAPTURE SELECT TESTING RESULTS

HIGH-PRESSURE FLUID-BED GASIFIER (HPFBG)

- Original height 3 m (9 m with extension)
- 2–9-kg/hr feed rate
  - K-Tron feeder provides real-time feed rate.
- Syngas recycle
- O_2-blown
- Up to 70 bar
- 850°C at max. pressure
- Multiple thermocouple ports up-bed to watch for hot spots, agglomeration



ACID GAS SEPARATION SYSTEM (AGSS)

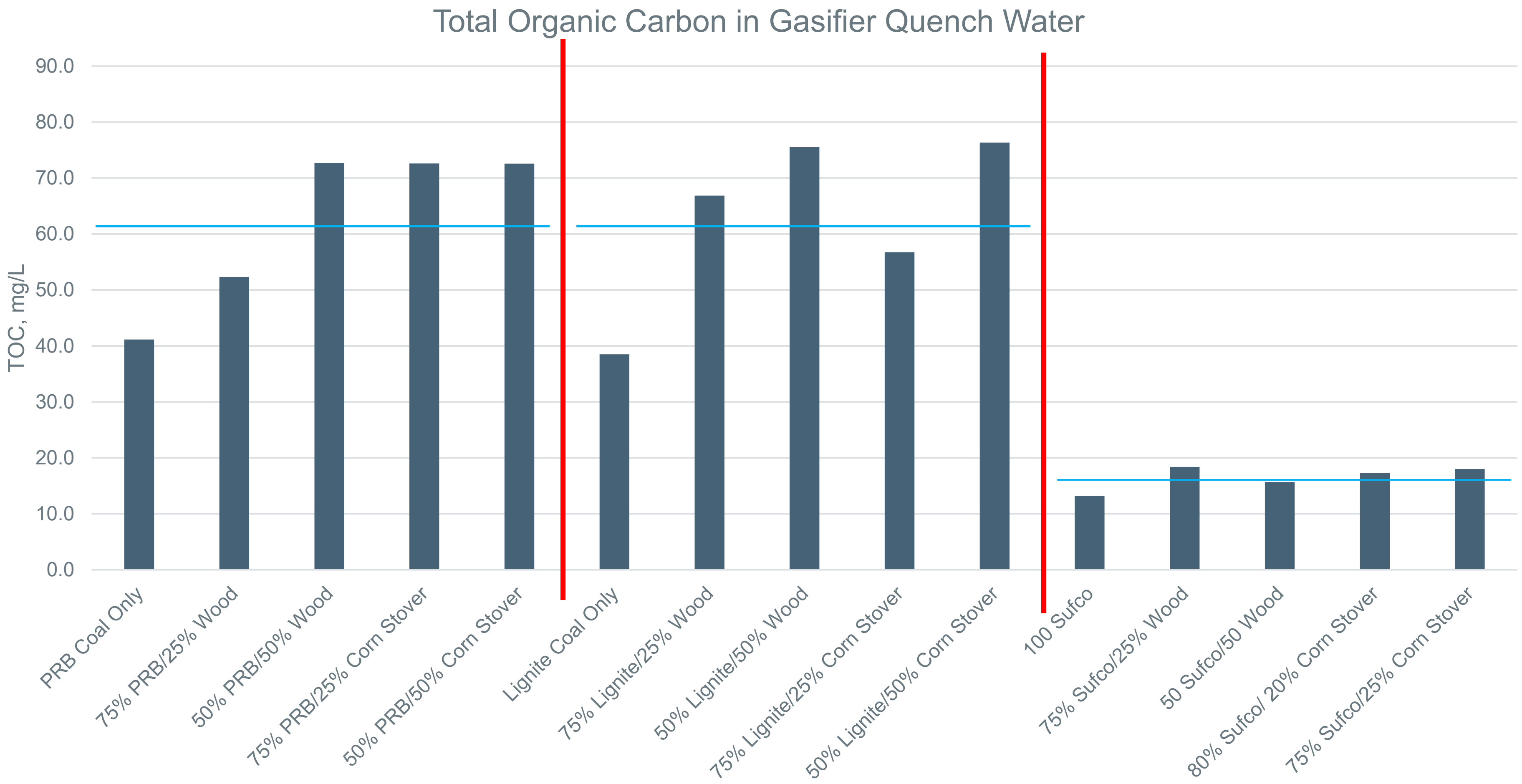
EERC MS55469.CDR

- AGSS design conditions
  - Stand-alone skid for portability
  - 3”-i.d. by 11’-tall column packed with Koch–Glitsch IMTP-15
  - Temperature: 10° to 40°C
  - Pressure: 1000 psig
  - Gas flows: 1000 scfh in air-blown mode; 240 scfh in O_2-blown mode
  - Previous Selexol™ results
    - ♦ >97.5% CO_2 capture
    - ♦ >98.7% H_2S capture

ANALYTICAL SAMPLING AND MEASUREMENT CAPABILITIES

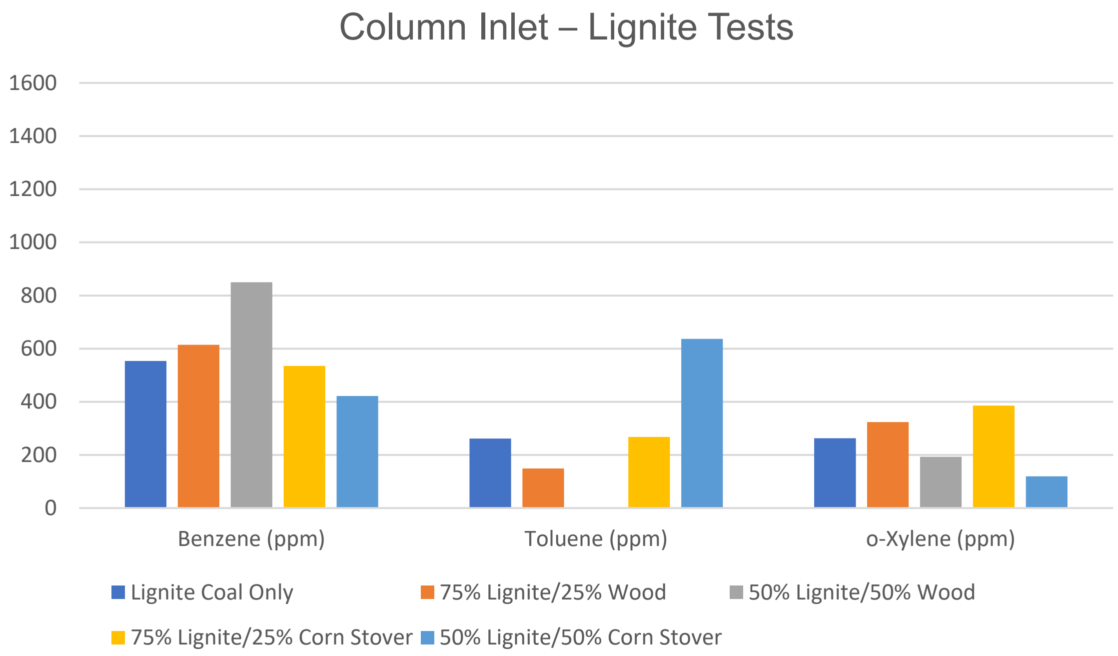
Analyzer	Number of Analyzers	Analysis Method	Components Measured	Frequency
LGA	Four	Raman Spectroscopy	H_2, CO, CO_2, N_2, O_2, H_2O, H_2S, CH_4, total hydrocarbons	Continuously
Varian GC	One	TC–FID	H_2, CO, CO_2, N_2, H_2O, H_2S, COS, Individual gas phase hydrocarbons C1–C8	Every 15 min
Yokogawa GC	Two	TC	H, CO, CO_2, N_2, H_2O, H_2S, COS, Individual gas phase hydrocarbons C1–C3	Every 10 min
Liquid Samples	Offline	Various	TOCs, NH_3; trace elements	Per test
Gas Bag Samples	Offline	GC–MS	H_2, CO, CO_2, N_2, H_2O, H_2S, COS, Individual hydrocarbons C1–C8	Per test
FTIR	One	FTIR	Nondiatomic molecules, e.g., NH_3, HCl, HCN trace organics	Continuously
Drager Tube			Trace Species H_2S, CS_2, NH_3, HCN, HCl, HF, C_6H_6, C_7H_8, C_8H_{10}, $Ni(CO)_4$, CH_2O, mercaptan	Per day
Method 29	Offline	ICP–MS	Gas Phase Trace metals; F, Br, Cl, NO_3, SO_4, Al, Ca, Fe, Mg, Mn, Ni, K, Si, Na, V, Zn, As, Cr, Co, Cu, Se, Hg	Per campaign
Solvent	Offline	Various	Benzene, toluene, biphenyl; naphthalene plus other organics above MDLs Soluble water content	Per day

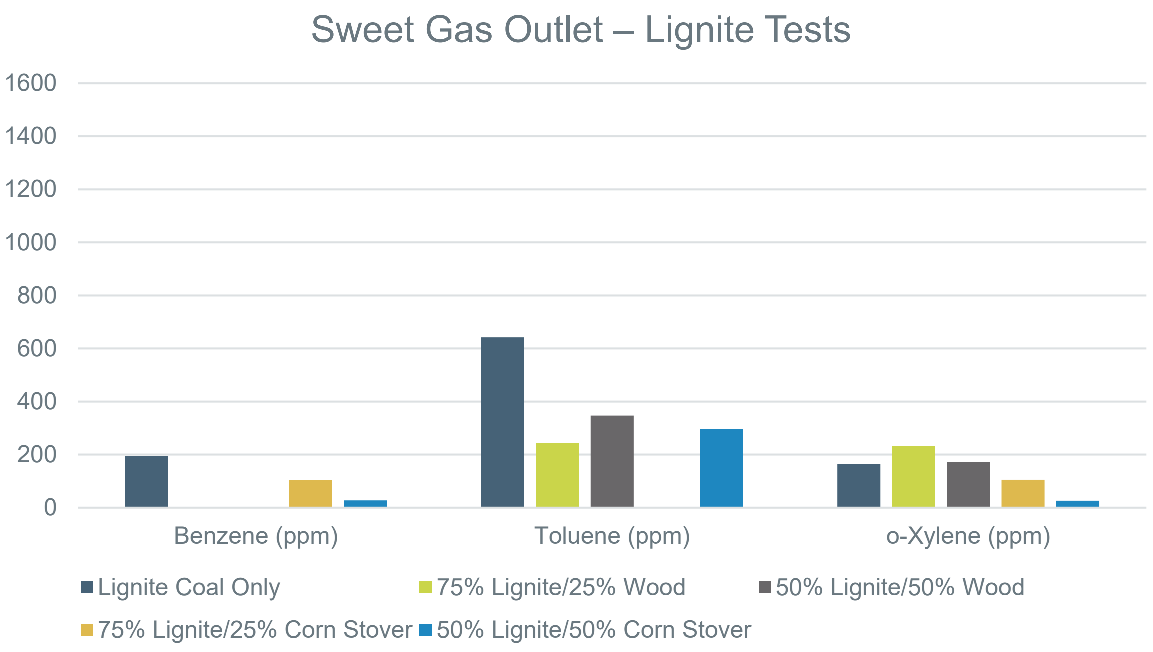
ORGANIC CARBON CONDENSED IN QUENCH WATER

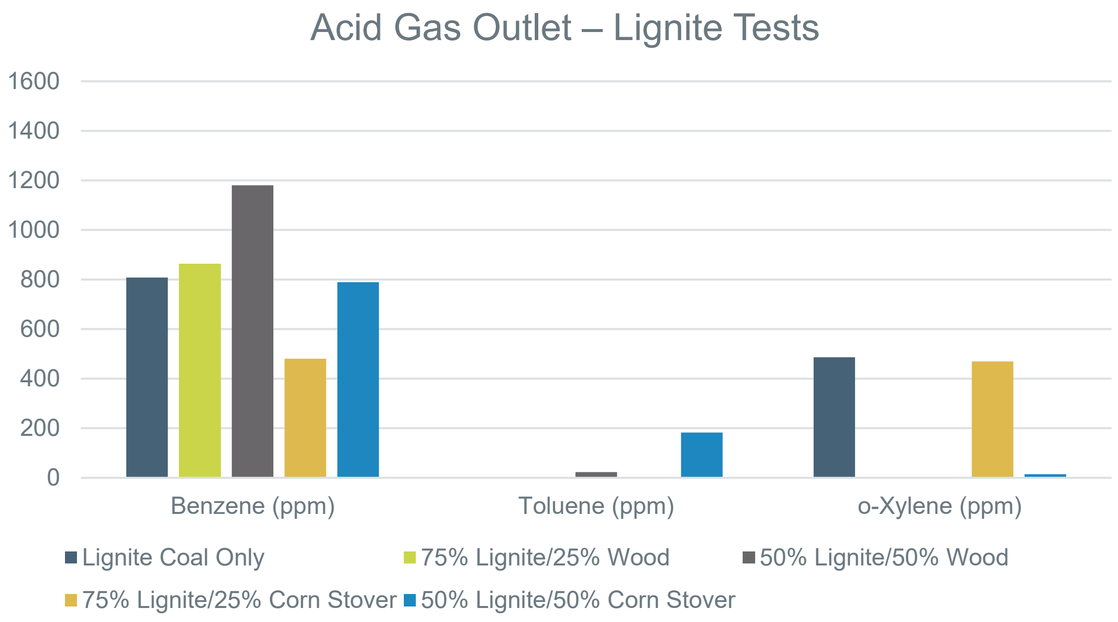


Correlation between the addition of biomass and increased organic production.

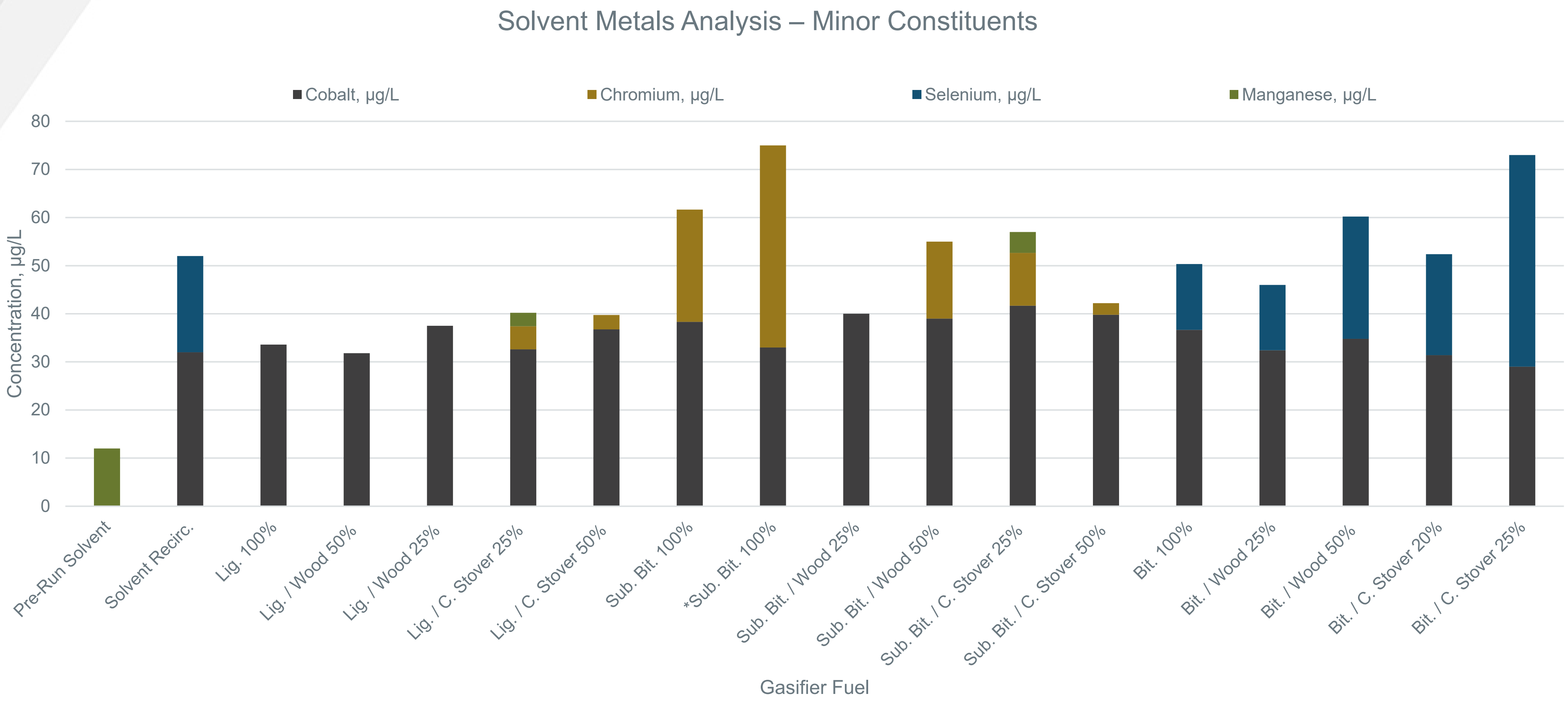
ANALYSIS OF LIGHT ORGANICS SPECIATION







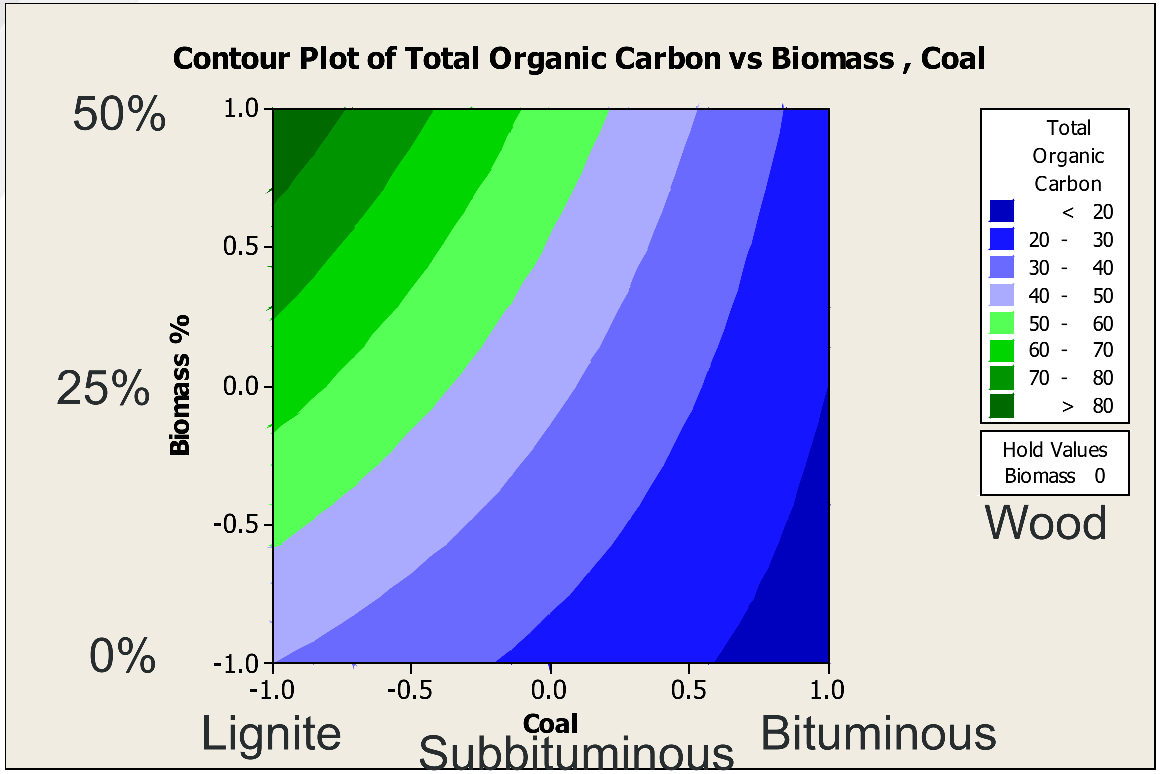
SOLVENT ANALYSIS – ELEMENTAL

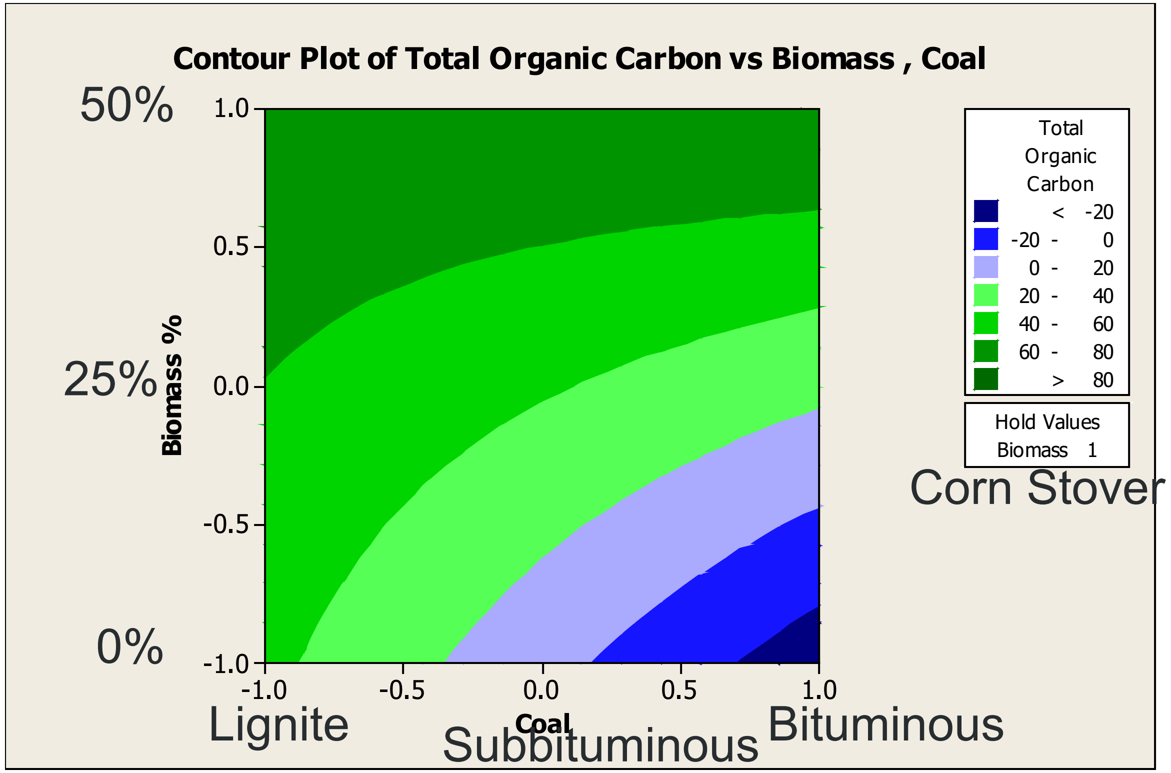


STATISTICAL ANALYSIS

- A statistical analysis was performed on the major responses from the test matrix to determine any statistically significant trends between coal types, biomass types, and biomass concentration.
  - Two-level full-factorial matrix analyzed with a regression approach and with center points.
- Both coal and biomass type had a statistically significant impact on organic impurities including total organics, benzene, toluene, and others.
  - Increases in organic contaminants did not impact the performance of the CO_2 capture unit over the duration tested; longer-term performance data are needed.
- There was no significant difference observed in inorganic impurities based on coal or biomass type.
  - Impurities after 5 days appear to be coming from the column or already inherent to the raw solvent.
  - Longer-term data would be needed to determine impact, if any, of inorganic contaminants.

CONTOUR PLOTS FROM STATISTICAL ANALYSIS

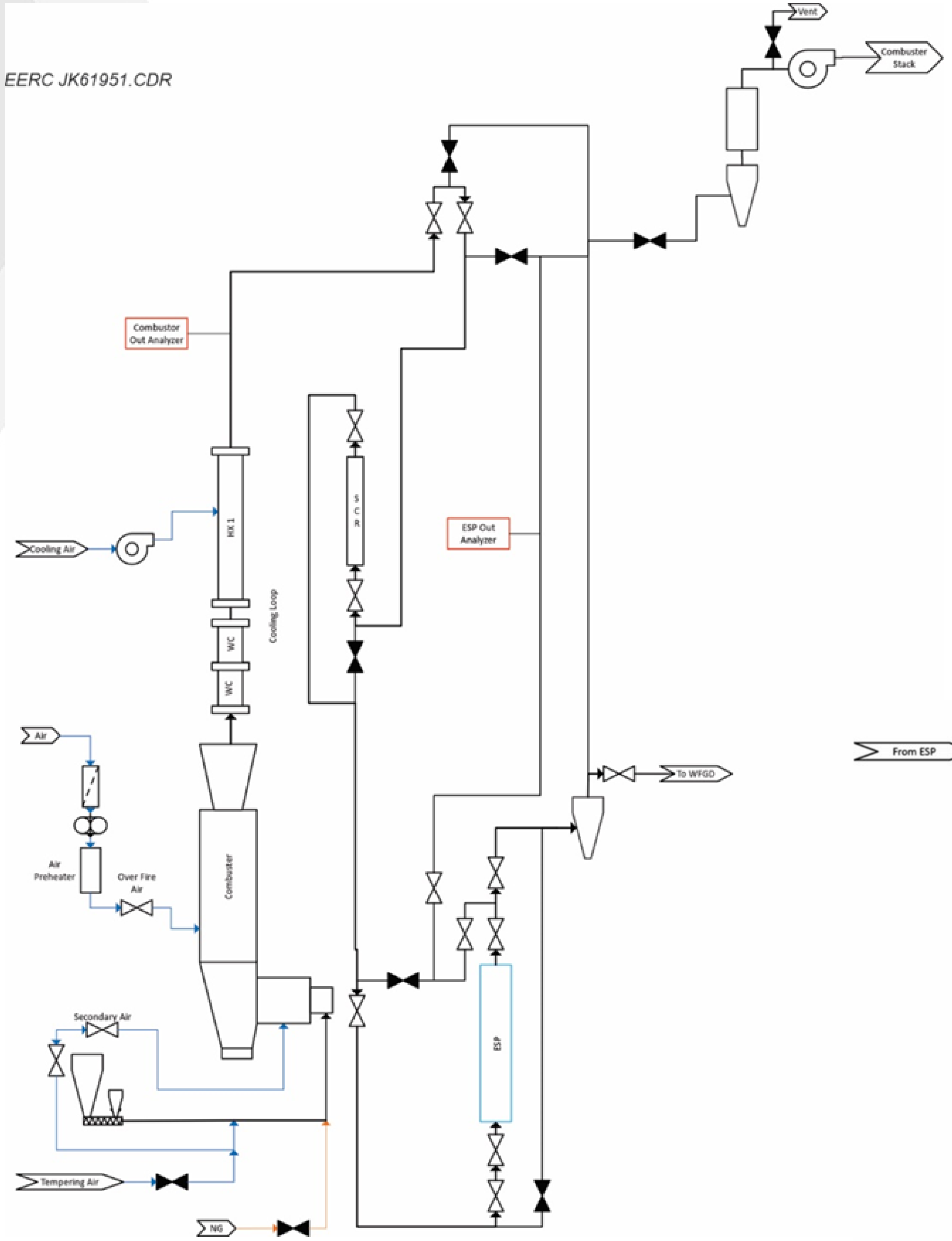




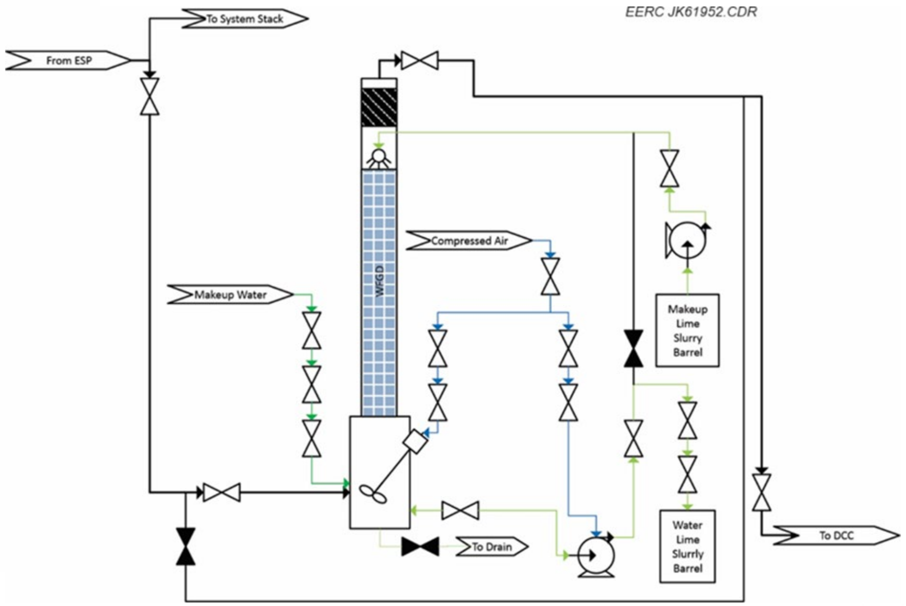
- Data show that organic levels are highest with lignite coal and high biomass blends.
- Coal type becomes irrelevant when high levels of corn stover are used, indicating a significant interaction.

POSTCOMBUSTION CARBON CAPTURE SELECT TESTING RESULTS

PILOT COMBUSTOR AND POLLUTION CONTROL

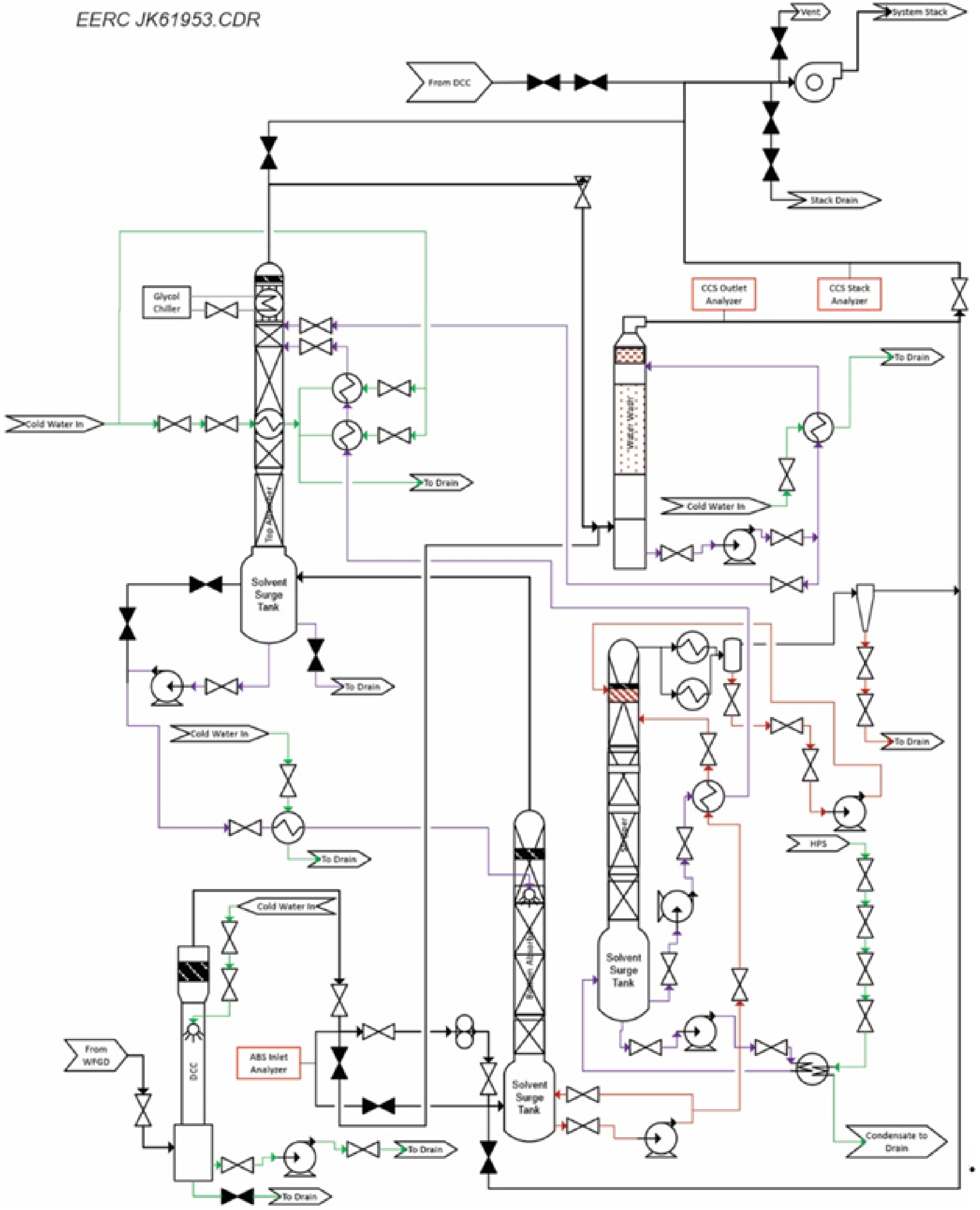


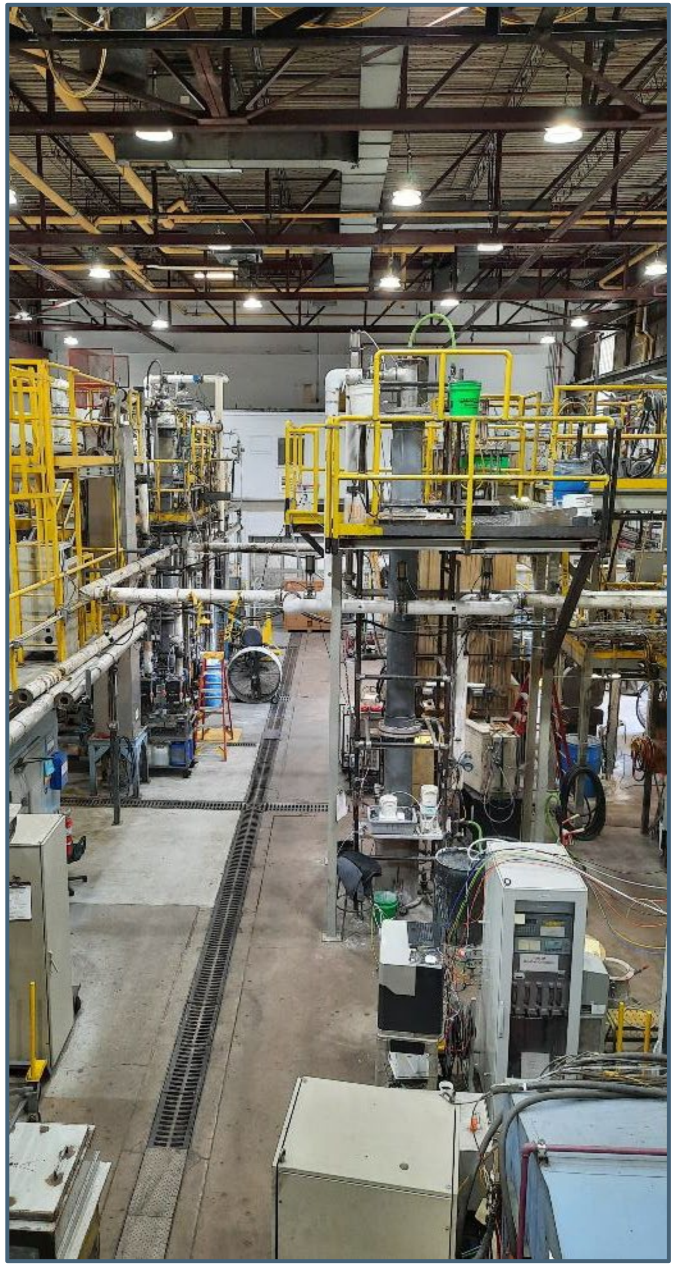
- 500,000-Btu/hr balanced draft furnace
- Selective catalytic reduction (SCR) for NO_x control
- Electrostatic precipitator (ESP) for particulate control
- Wet flue gas desulfurization (FGD) for SO_x control

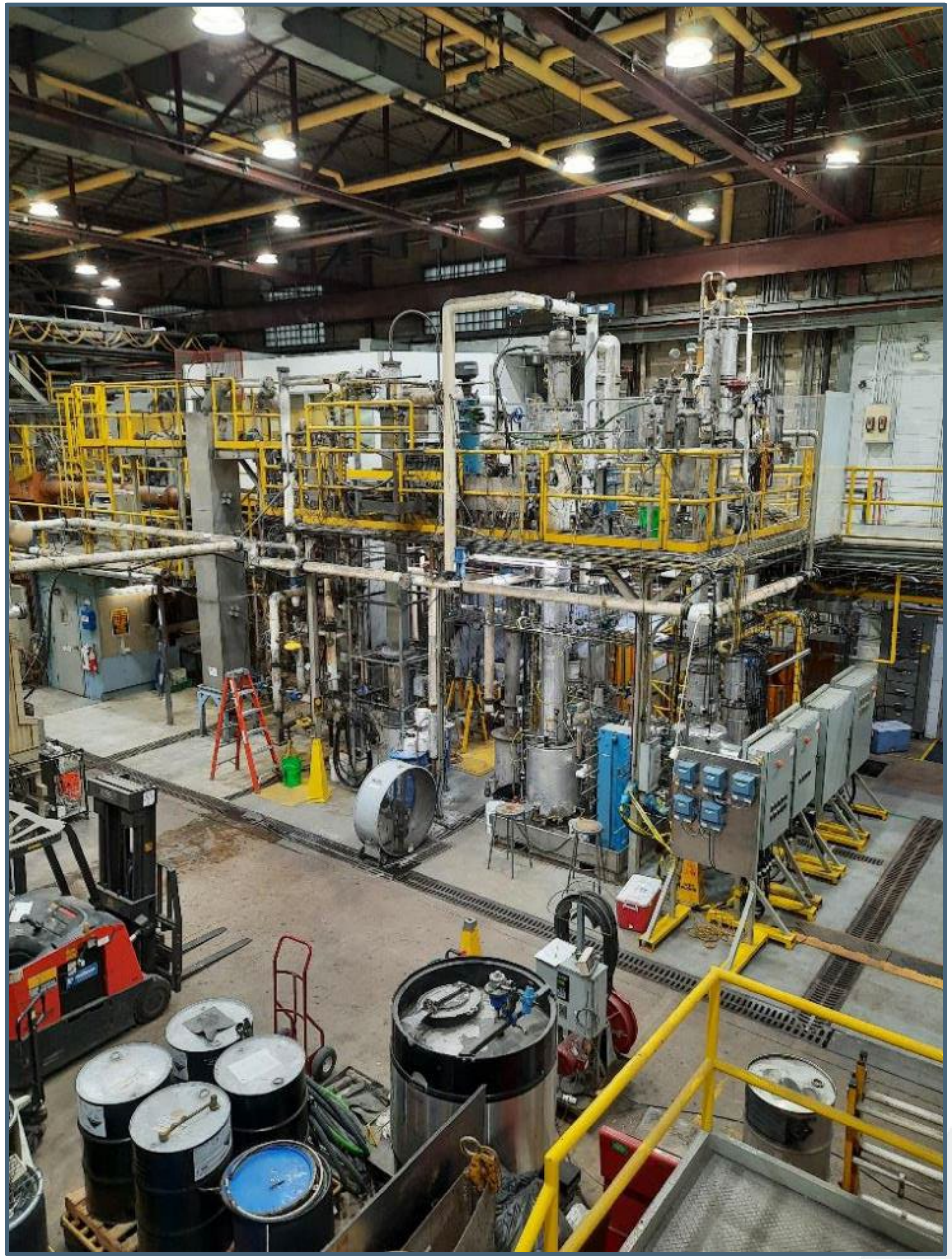


CARBON CAPTURE

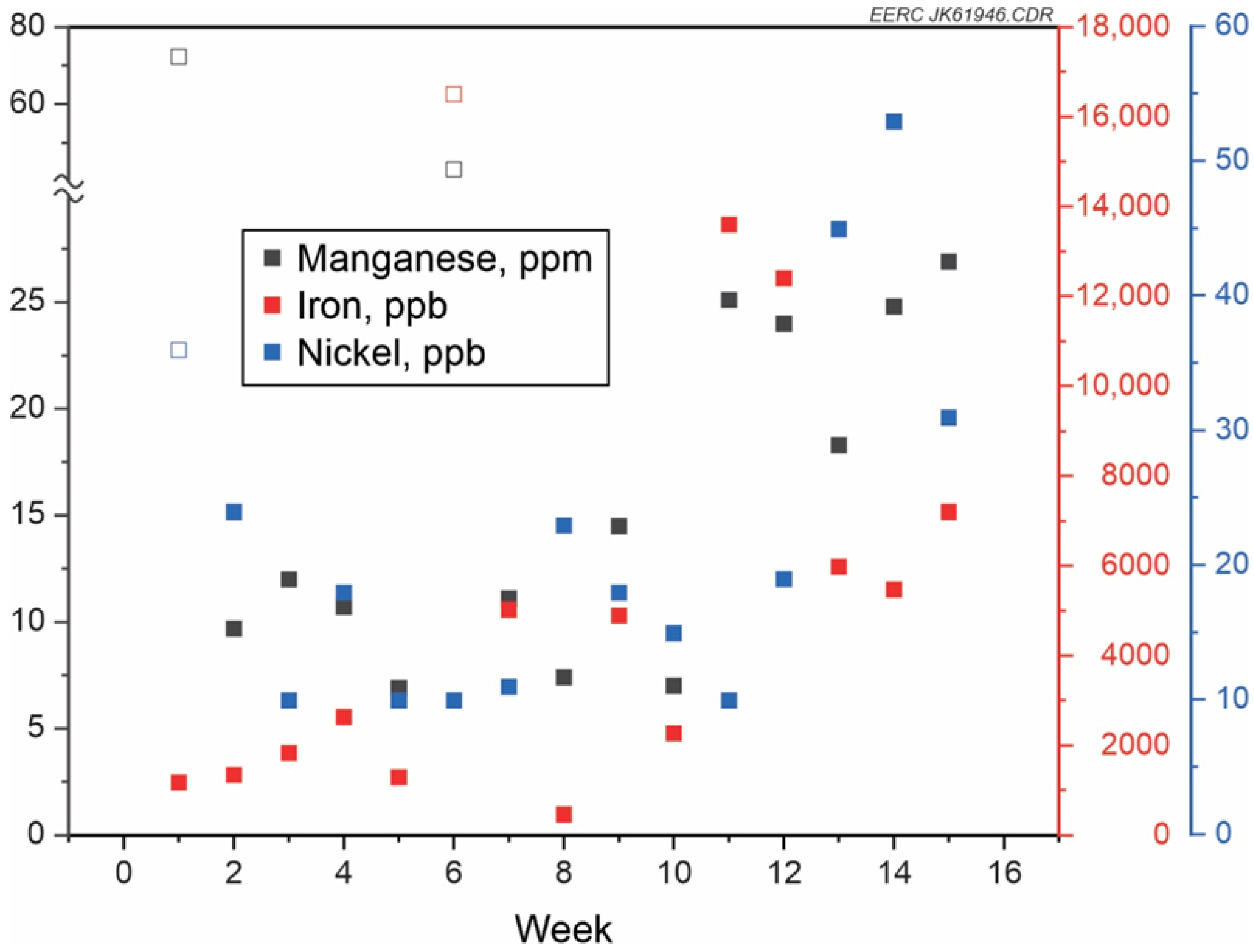
- 1-tonne/day CO_2 capture system
  - Catch and release
- Direct contact cooler (DCC) for inlet flue gas temperature control
- Two absorbers for combined height of 12 meters (40 feet)
- 6-meter (20 feet) stripping column
- Separate 6-meter water wash column



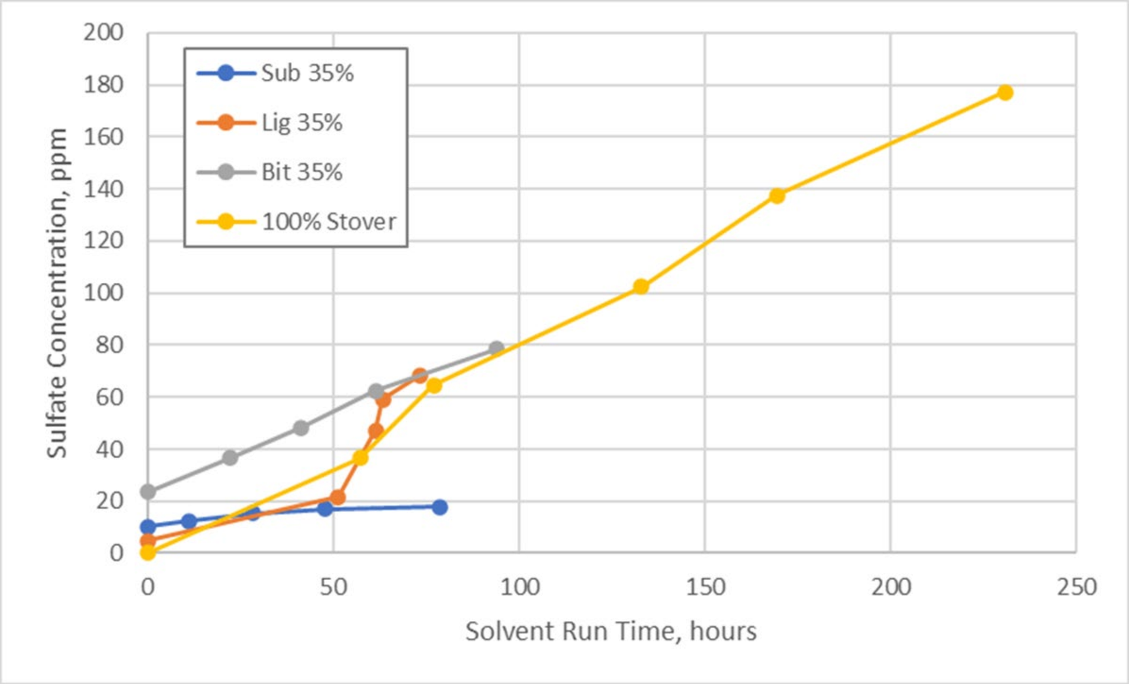


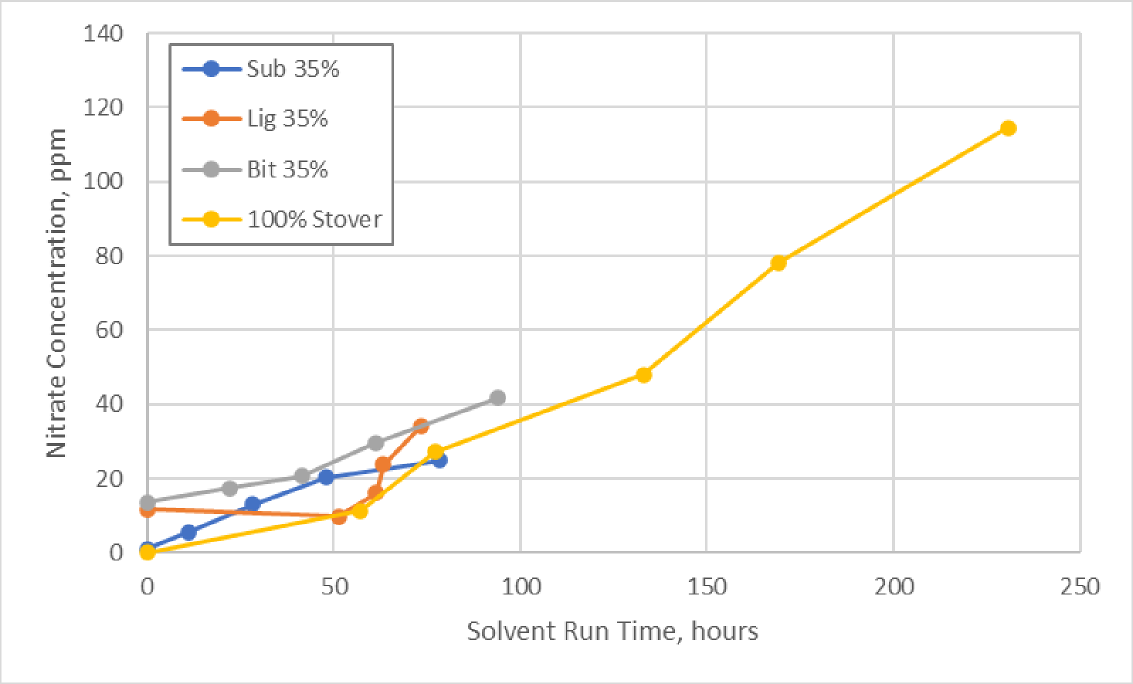


METALS IN SOLVENT – TIME IN BARREL

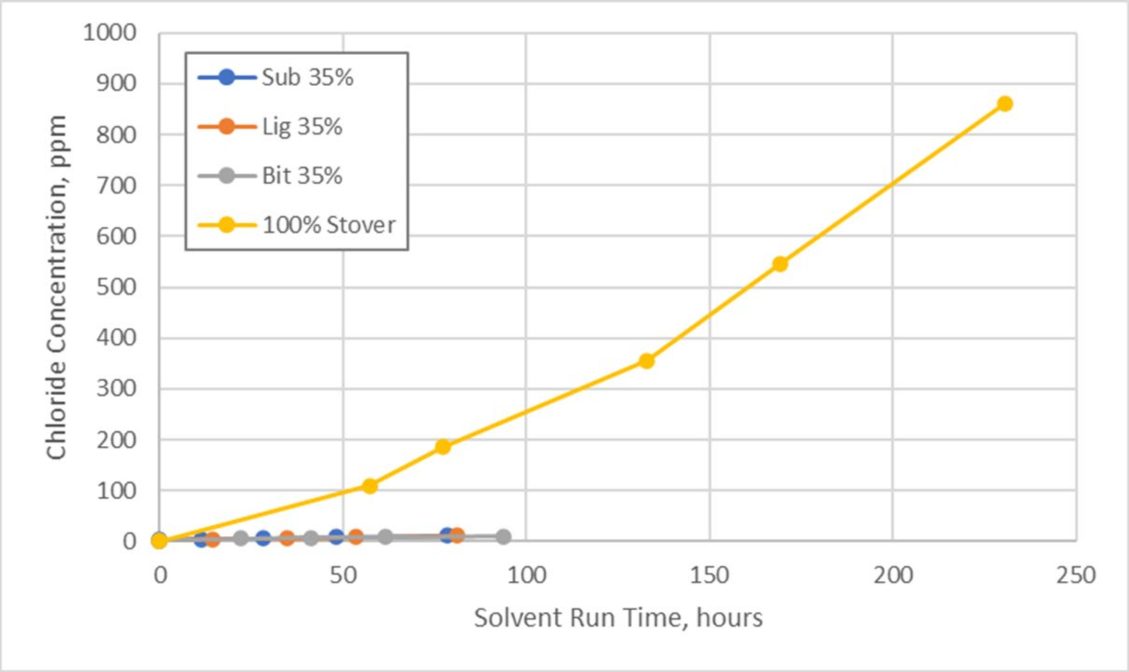


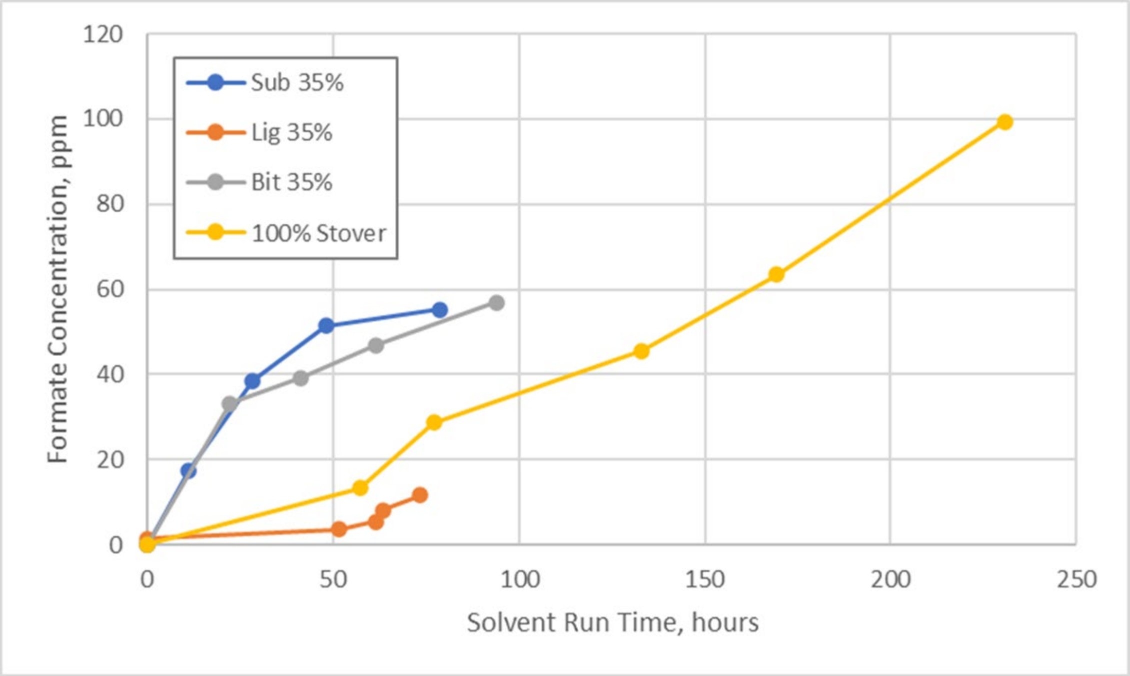
100% CORN STOVER COMPARISON – SULFATE, NITRATE



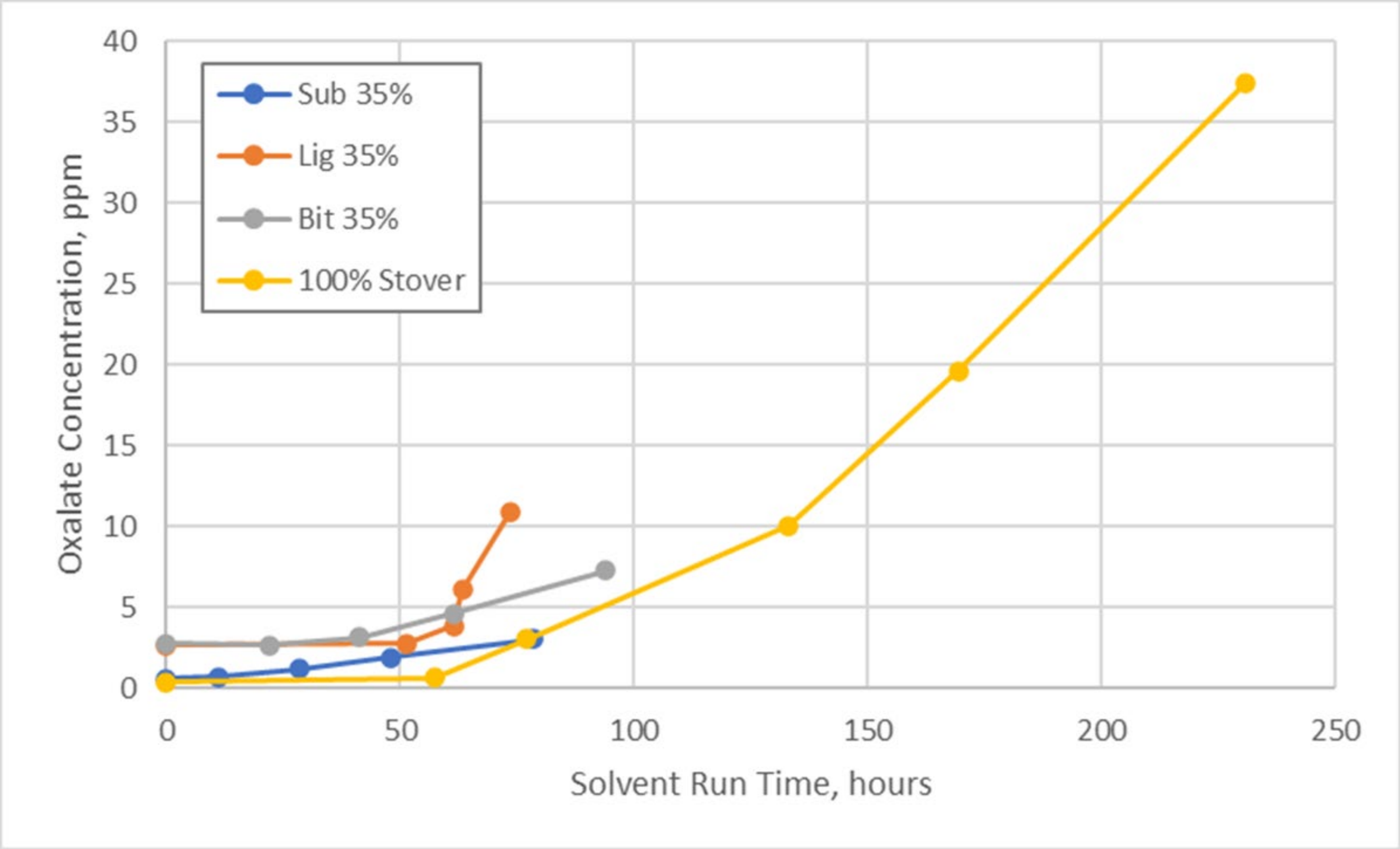


100% CORN STOVER COMPARISON – CHLORIDE, FORMATE





100% CORN STOVER COMPARISON – OXALATE



PLANS FOR FUTURE TESTING/DEVELOPMENT/ COMMERCIALIZATION

- This data set has been posted on the EDX site and is available for users to download.
- The data developed will aid solvent technology vendors in determining if biomass feedstocks are acceptable for their technology as well as determining special design considerations for their reclaimer technology.
- Longer-term data are needed to determine if there is a significant impact in the level of inorganic impurity buildup based on feedstock.
- Longer-term precombustion testing with 100% biomass would help to inform viability and economics of the technology in a commercial application.

SUMMARY SLIDE

- Increased biomass levels contributed to higher levels of organics in the gas stream and solvent.
- Partitioning of organic species in the carbon capture unit suggests that the CO_2 stream could have high levels of benzene and other light organics which may have to be removed, depending on end use considerations.
- There is no clear correlation between biomass concentration and levels of inorganics observed in the solvent, and longer-term data are likely needed to observe any significant effects.
- A robust set of data has been developed for carbon capture with coal and biomass blends, and no significant showstoppers have been identified to date.

ACKNOWLEDEMENTS

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  - Fan Shi
- EERC
  - John Kay
  - Mike Swanson
  - Josh Strege
  - Pilot scale operations support staff

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APPENDIX

APPENDIX – ORGANIZATIONAL CHART

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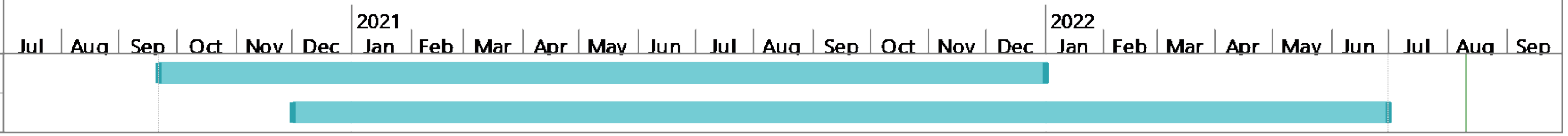
Elliott Roth

Leidos Research Support Team
Kevin Resnik

Energy & Environmental Research Center
Josh Stanislowski

APPENDIX – GANTT CHART

ID	Task Name	Start	Finish
1	TOR 11 Pre-Combustion Testing	9/21/2020	12/31/2021
2	TOR 12 Postcombustion Testing	12/1/2020	6/30/2022



PLANNED SAMPLING ACTIVITIES

- Mercury concentrations at inlet/outlet of FGD
- EPA Method 5 downstream of FGD
- Aerosol particle-size distribution at inlet to direct contact cooler and outlet of water wash
- FTIR measurements at ESP outlet, DCC inlet, absorber inlet/outlet, water wash outlet, and stripper outlet

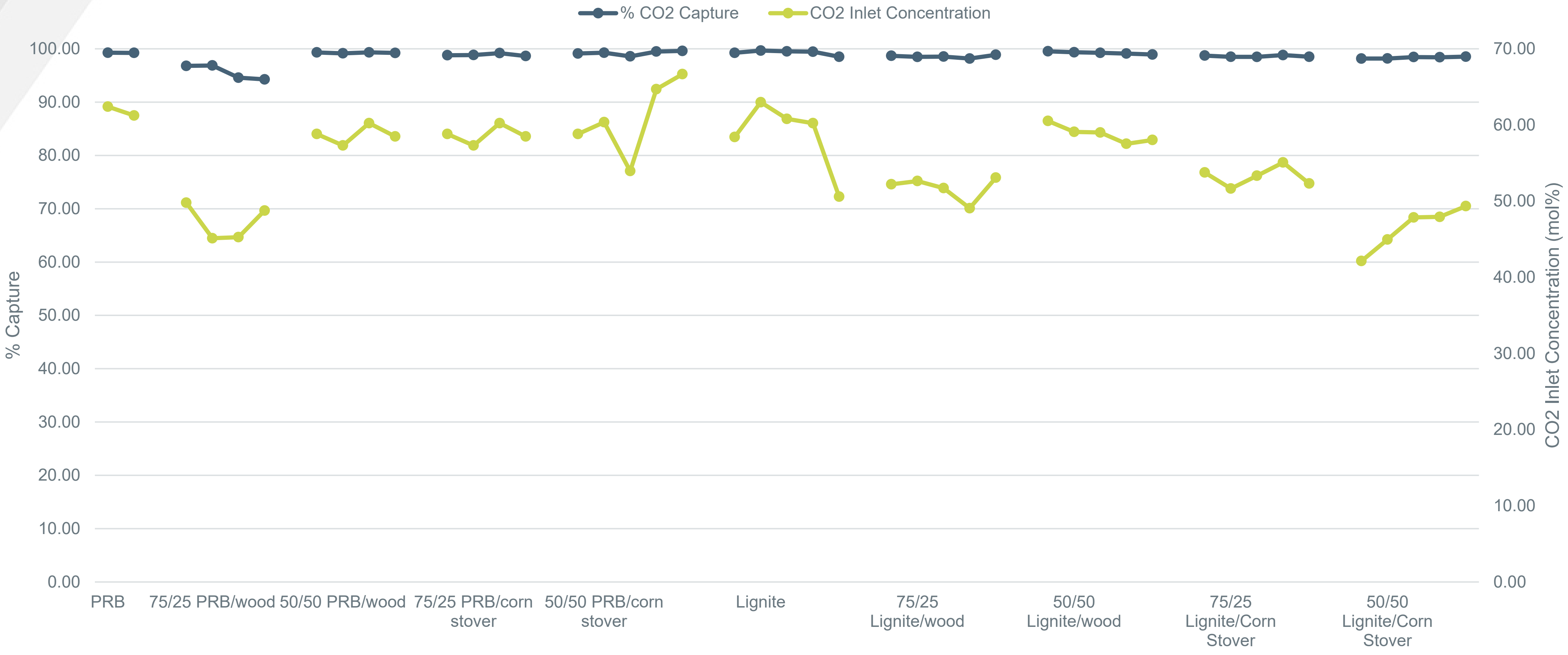
Solvent Analysis

- Aluminum
- Arsenic
- Calcium
- Chromium
- Cobalt
- Copper
- Iron
- Magnesium
- Manganese
- Mercury
- Nickel
- Potassium
- Selenium
- Silicon
- Sodium
- Vanadium
- Zinc
- Acetate
- Bromide
- Chloride
- Formate
- Fluoride
- Nitrate
- Nitrite
- Oxalate
- Sulfate
- Thiosulfate
- pH

WOOD PELLETS

- The wood pellets were obtained for postcombustion testing from Thunderbolt Biomass, Inc., Allendale, South Carolina. The company website is https://thunderboltbiomass.com.
- The material is manufactured from several species of southern yellow pine (SYP) within 150 miles of Allendale, South Carolina. The forest industry in the area operates year-round, and all sources are commercial forest tracts prorated for this purpose.
- The SYP is purchased green (50% moisture content) or dry (approximately 10% moisture content) as sawmill residuals from local sawmills and some remanufacturing operations. The material is 100% virgin preconsumer SYP. Any green material is dried to about 10% moisture content in a dryer. Dry/dried material is sized to about 3–5 mm using a hammermill and then pressed through a pellet die. Pellets are about 6 mm in diameter and 10–24 mm in length. The pellets are cooled and then packaged for shipment. The process uses up to 0.05% starch addition for a binder and as a die lubricant.
- Thunderbolt Biomass produced about 4000 tons of pellets in 2020. The demand appears to be stable, and it is anticipated that production will increase throughout 2021.

CAPTURE AND CO_2 INLET CONCENTRATION



Carbon capture remained high for all of the tests and was mainly a function of the inlet CO_2 concentration.

AERSOLS – CONCENTRATIONS ACROSS THE CAPTURE SYSTEM