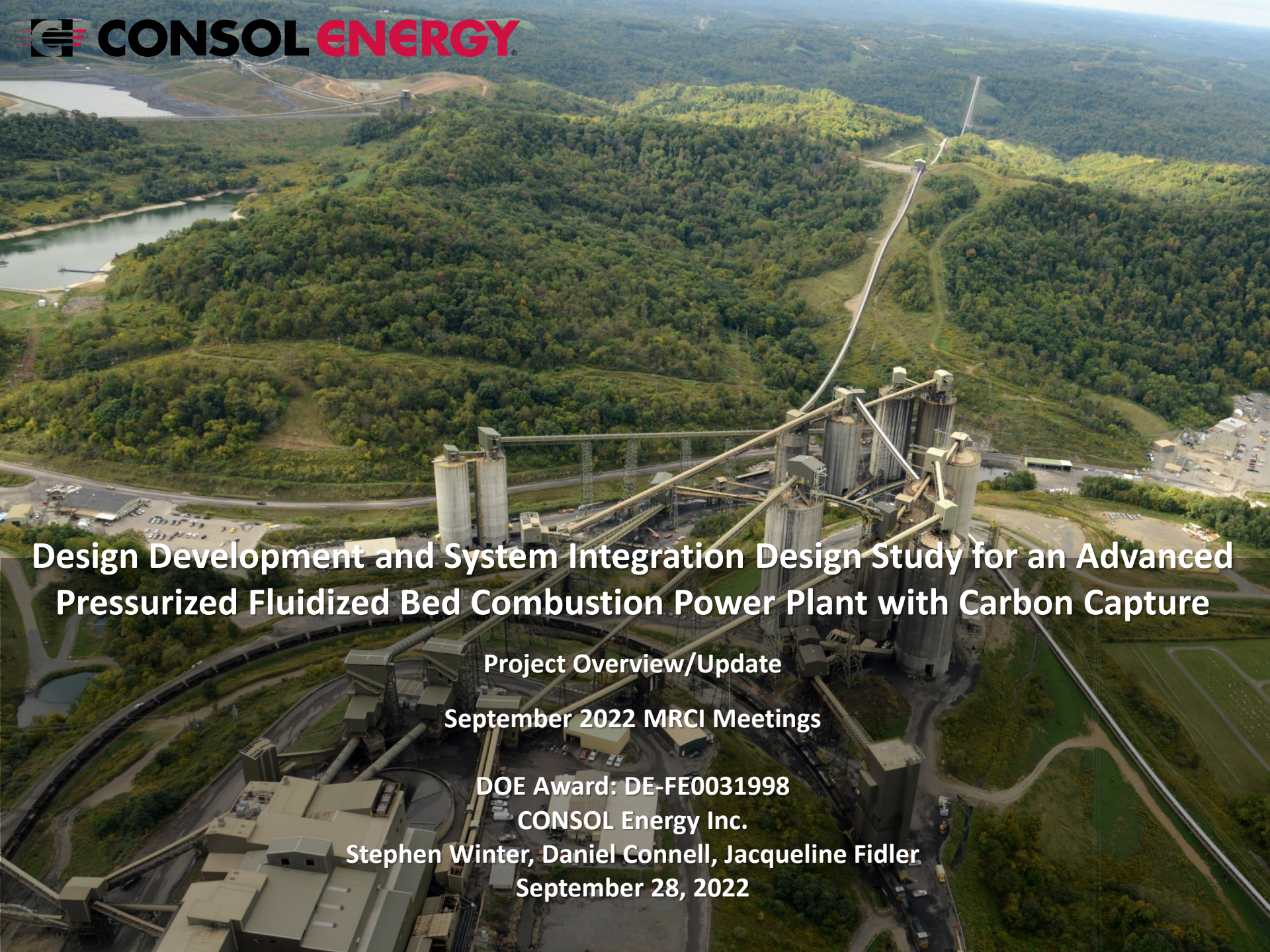

Design Development and System Integration Design Study for an Advanced Pressurized Fluidized Bed Combustion Power Plant with Carbon Capture

Project Overview/Update

September 2022 MRCI Meetings

DOE Award: DE-FE0031998

CONSOL Energy Inc.
Stephen Winter, Daniel Connell, Jacqueline Fidler

September 28, 2022

This material is based upon work supported by the Department of Energy National Energy Technology Laboratory under Award Number DE-FE0031998.

CONSOL Energy

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Agenda

- About CONSOL Energy Inc.
- Project Team & Project Overview
- Key Features
- Overview & Phase I Updates
- Final Thoughts

About CONSOL Energy Inc.

- **Publicly-traded (NYSE:CEIX) coal producer and exporter based in Canonsburg, PA**
- **Assets Include:**
  - Pennsylvania Mining Complex (PAMC) – largest producing underground coal mining complex in North America
  - CONSOL Marine Terminal (CMT) in Baltimore, MD
  - Itmann low-vol metallurgical coal project in Wyoming County, WV
  - ~1.4 billion tons of undeveloped coal reserves and resources[1]
- **Together with our predecessors, have been mining coal since 1864**
- **CONSOL's Legacy is built on Safety, Compliance, and Continuous Improvement**
  - First U.S. coal company to operate privately-funded R&D facility (1940s)
  - Strong ESG emphasis
- **CONSOL's Future is based on Efficiency, Technology, and Innovation**
  - Sustainable growth and diversification goals

(1) As of December 31, 2021. Undeveloped reserves and resources do not include any of the 612 million tons of reserves associated with PAMC or 21 million tons of reserves associated with Itmann

Project Team and Project Overview

- ✓ Project Team

Plant **CO_2 Disposition**

osomono WILDLIFE, HABITAT & ENERGY CONSERVATION STRATEGIES

Worley energy | chemicals | resources

BATTELLE It can be done

FARNHAM & PFILE ENGINEERING & CONSTRUCTION

Carbon Solutions LLC

PfBC environmental energy technology

PENNSYLVANIA GEOLOGICAL SURVEY EST. 1836

NOOTER ERIKSEN

WVGES Geology Underlies It All

OMNIS BAILEY

- ✓ Project history
  - ✓ 1MWt Pilot demo at CONSOL R&D (2006-10)
  - ✓ Conceptual Design Study completed 2019
  - ✓ Pre-Feed Study completed 2020
  - ✓ **Current Award**
    - ✓ **Design Optimization (6/2021 – 12/2022)**
    - ✓ **FEED Study (1/2023 – 3/2024)**
- ✓ Project Goals
  - ✓ Develop critical info for site selection, design, environmental, CO_2 disposition, and proforma financials
  - ✓ Study is targeted for use by DOE, investors, and EPC firms for follow-on work needed to construct the plant
  - ✓ Design a 21st century power plant(~350 MWe net) that is an innovative clean energy solution
  - ✓ Be commercially viable in the U.S. power gen market and demonstrated within 5-10 years

Key Features

Design Feature	Benefit
Waste fuel	• Abundant supply of low/zero cost fine waste coal readily available for dispatch
PFBC technology	• Supercritical pressurized fluidized bed technology able to fire wet fine waste coal • Can achieve high efficiency by coupling gas turbomachinery (e.g., 42.3% efficiency HHV demonstrated at Karita w/o CO_2 capture)
Environmental Performance	• Capture 97% of the CO_2 emissions • Realize near zero air emissions • ZLD
Biomass & BECCS	• Co-fire up ~ 10% by BTU forestry waste • Achieve net neutral or net-negative performance
CO_2 Disposition in Northern Appalachian Region	• **Sequester ~ 3 million tons/year of CO_2** • **Serve as a regional hub to connect with expected gigaton/year scale CO_2 infrastructure in the USA**

Serves as a model for cleaning up coal waste & slurry impoundments while generating zero-emission power

Design Tasks

Phase I – Design Optimization

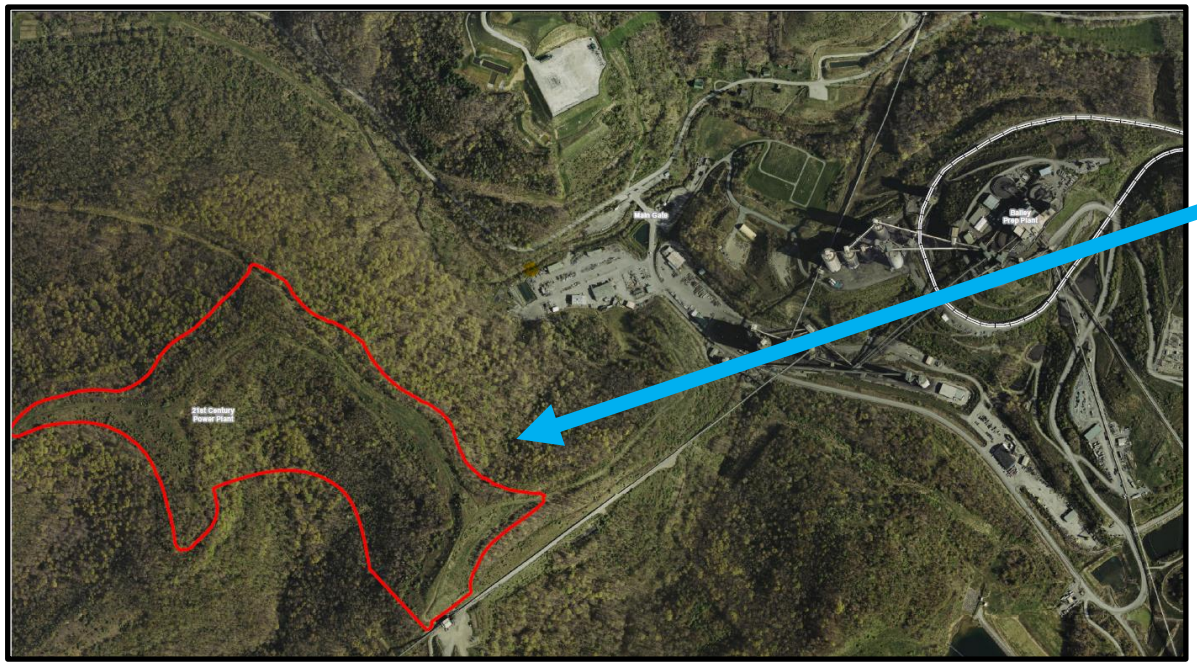
- Evaluate candidate sites and make selection
- Develop fuel processing options/specifications
- Evaluate PFBC design
- Optimize water balance, cooling, and identify re-use strategies and alternative sources
- Identify a gas turbomachinery technology
- Study post-combustion CO_2 capture technologies for performance and cost and optimum design
- Conduct value engineering/cost reduction analyses
- Initiate EIV and evaluation of environmental, community, socioeconomic, health & safety factors to inform site selection
- Evaluate options and opportunities for CO_2 geologic storage
- Investigate regional CO_2 transport and utilization opportunities
- Develop Preliminary Investment Case

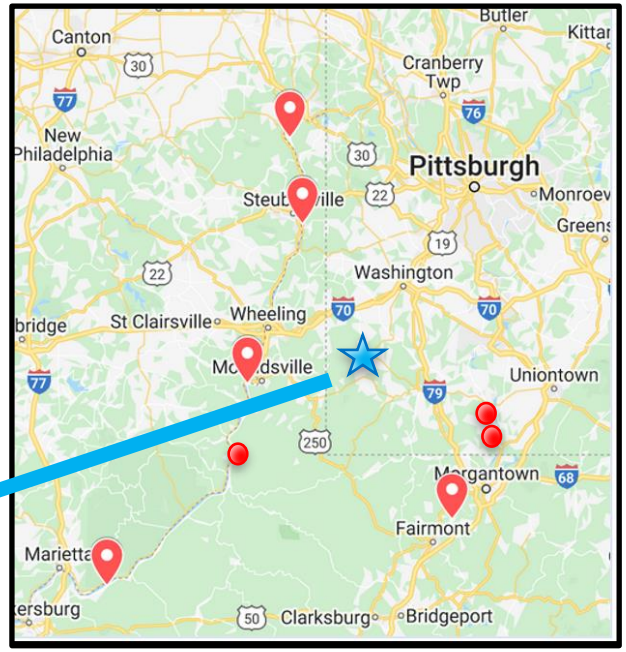
Phase II – Feed Study

- Detailed Engineering/FEED
- Detailed On-Site CO_2 Storage Planning and Design
- Development of Overall CO_2 Disposition Plan and Economic Optimization
- Finalize Life Cycle Analysis
- Develop Final Investment Case

Siting of the Plant at CONSOL's PAMC

Sites were evaluated for acreage, topography, road access, rail, river frontage, site access for construction, site access for heavy equipment, water, community impacts, space for waste coal and biomass storage, transmission, and proximity from CO_2 sequestration areas identified for storage potential





(1) inland (denoted by blue star)

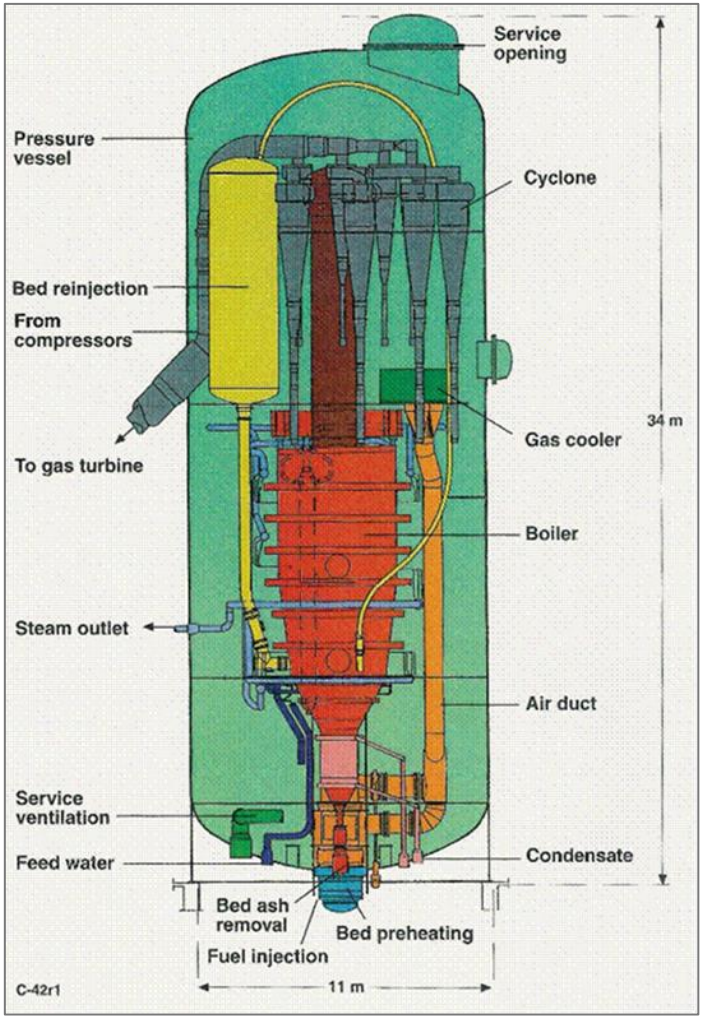
- An area at CONSOL's Pennsylvania Mining Complex (PAMC) near the coal preparation plant
- ☑ Integration into existing mine site infrastructure to promotes the sustainability of the coal supply chain.

(8) river sites (denoted by orange teardrops or circles)

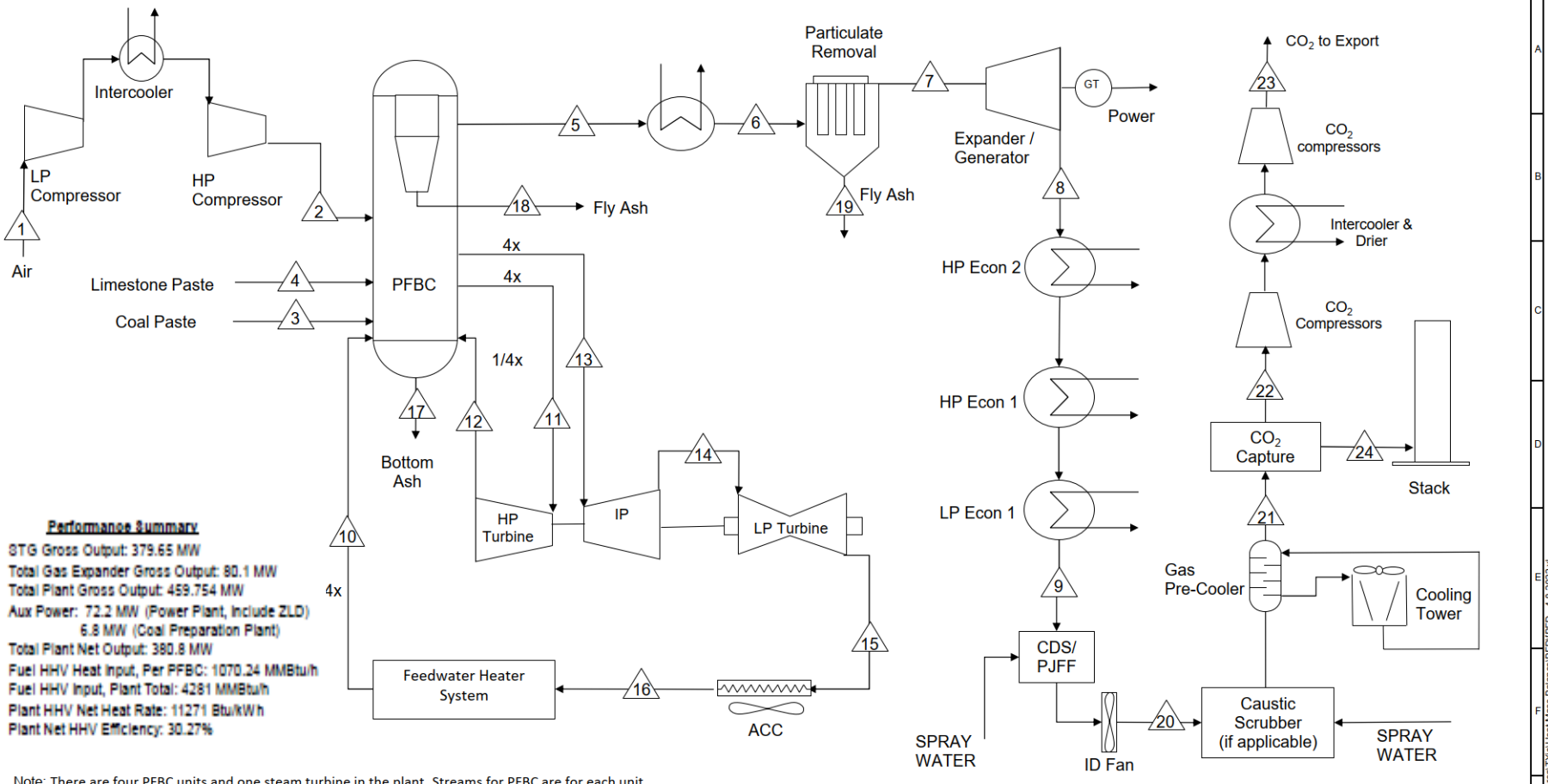
- Ohio and Monongahela
- ✘ Significant challenge to ship fine wet waste coal from PAMC by rail/river to these sites

Fuel & Limestone Considerations With Respect to PFBC

- OMNIS beneficiation process improves waste coal quality(32MWe increase at 16bar) by lowering % ash from ~ 45 to 7%
- PFBC's bubbling bed requires optimum balance between fuel & limestone chemistry with the combustion process to prevent sintering and to maximize desulfurization
  - Adopted lessons learned from AEP TIDD plant which fired Pittsburgh No 8 coal
    - ✓ Switched to high quality dolomitic limestone
    - ✓ 850F design bed temperature (sweet spot)
    - ✓ Target particle sizes for fluidization and sorbent efficiency
    - ✓ Maximize heat distribution and eliminate high temperature zones to prevent unwanted agglomeration
- Paste testing in progress to confirm recipe (waste coal/biomass/limestone moisture) and rheology



Current Plant Design



Performance Summary

STG Gross Output: 379.65 MW
Total Gas Expander Gross Output: 80.1 MW
Total Plant Gross Output: 459.754 MW
Aux Power: 72.2 MW (Power Plant, Include ZLD)
6.8 MW (Coal Preparation Plant)
Total Plant Net Output: 380.8 MW
Fuel HHV Heat Input, Per PFBC: 1070.24 MMBtu/h
Fuel HHV Input, Plant Total: 4281 MMBtu/h
Plant HHV Net Heat Rate: 11271 Btu/kWh
Plant Net HHV Efficiency: 30.27%

Note: There are four PFBC units and one steam turbine in the plant. Streams for PFBC are for each unit.

DRAWN: TX DATE: Apr-8-2022
CHECKED: DS DATE: Apr-8-2022
ENGINEER: DATE:
PROC ENG: DATE:

Department of Energy/Consol
PCS-PFBC-CONS

Gas Path
Process Flow Diagram
CO2 Capture Case-Dry Cooling

DRAWING No. | TITLE | No. | DATE | DRAWN | CHECKED | APPROVED | DESCRIPTION | ENG | CLIENT
REFERENCE DRAWINGS | REVISIONS
SCALE | DRAWING NUMBER | REV

WorleyParsons SelectDraw Version 2.12

Filename:P:\Client\Consol Phase1a\Workarea\TXiel\Heat Mass Balance\BFD\[BFD - 4-8-2022.xl

(4) P200 PFBC, 16 bar, 97% CO_2 Capture, Paste Fuel (26% moisture)

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Biomass Supply and Logistics

- Currently evaluating “dirty chips” but also considering pressed sawdust pellets
- PA Forestry Industry has potential for generating significant forest waste for use in energy projects
- Increased demand from energy projects would lead to
  - Industry growth/investment
  - Better forestry practices & healthier forests
  - Improved ecosystems
  - Better CO_2 removal
  - Win-Win for Energy - Forestry
- Current industry supply is centered around truck model… CONSOL is working with forestry industry to explore rail/river/e-trucks and hybrid supply strategies (to minimize carbon footprint)

Value Engineering and Cost Reduction Analyses

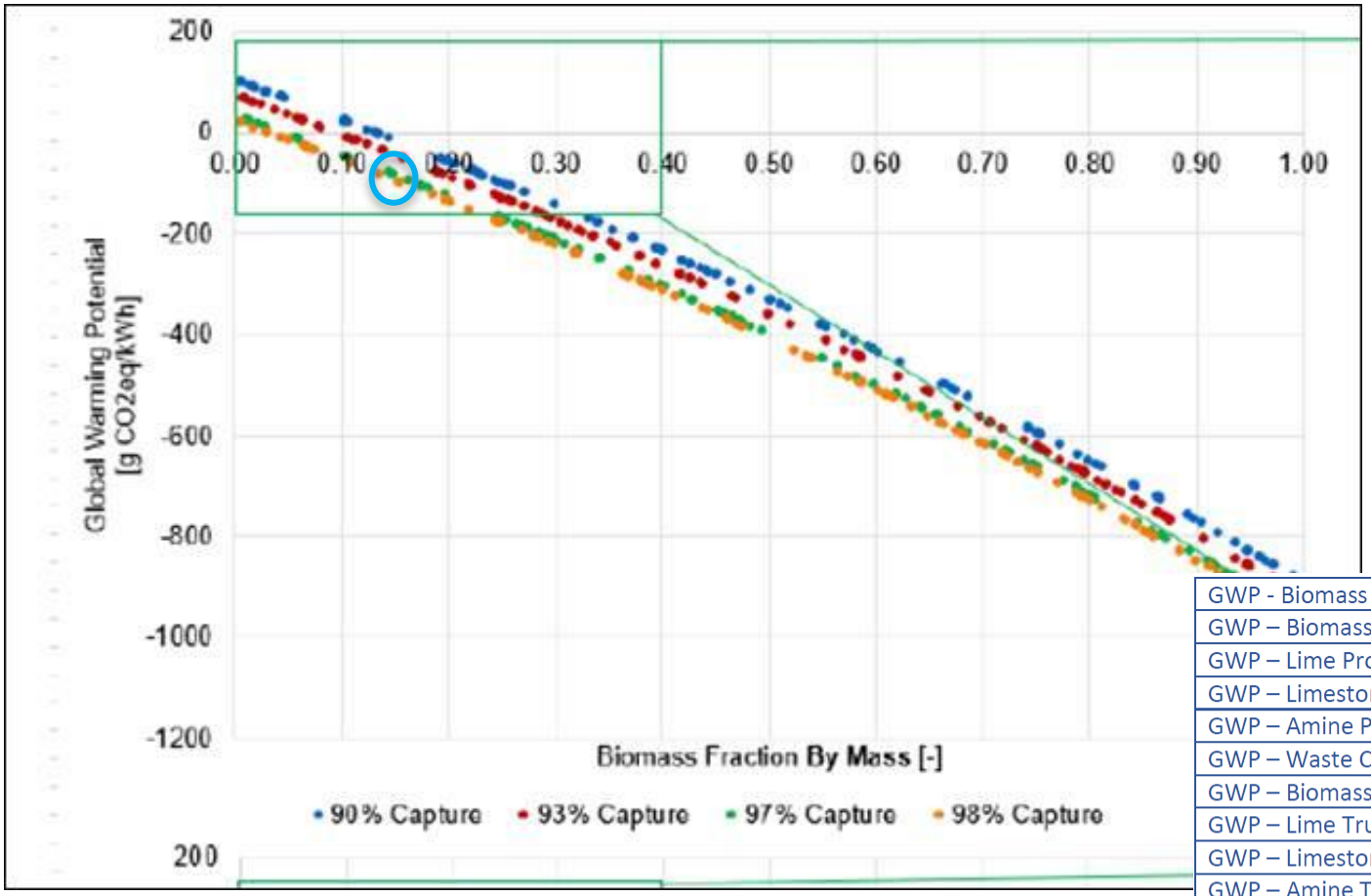
Goal to Start Design Optimization: Value Added Engineering initiatives could increase the net capacity to 308 MW, improve its efficiency to 32.4%, reduce total overnight cost to < $6,000/kW, and reduce COE (including CO_2 capture credit) to $56-62/MWh (from $85.29).

Initiatives	Estimated Capital Cost Reduction ($MM)	Potential Efficiency Improvement (Percentage Points)	Potential Net Capacity Increase (MW)	Design Optimization Phase – Status on Initiative
Redesign PFBC for 16 bar (rather than 12 bar) operation	$100			Successfully engineered PFBC vessels (structural, materials, heat transfer,) and associated process for 16 bar. Basis of design changed to (4) P200 vessels to provide lowest $/KWe.
Direct delivery of pre-fabricated PFBC vessels	$30-50			Not possible with inland PAMC site. Heat treatment, fabrication, and erection will be at the plant site.
Pre-process waste coal to reduce ash content		≥ 2	≥ 28	OMNIS beneficiation process reduces ash from 45% to ~7%. At 16 bar this will result in ~ 32 MWe additional power.
Value engineering process	$45-90			In progress.
Reduce ZLD size	$5-10			Replaced wet scrubber with a dry scrubber (CDS) and in-turn this eliminated the FGD wastewater stream. This may allow ZLD technology from thermal to RO based saving on capital & O&M $. Other water reduction strategies ongoing.
CO_2 capture system optimization, competitive bid	$10-20			Two different CO_2 Capture technology vendors are currently being evaluated under plant specific studies to benchmark sensitivity around performance and cost at 97% (design), 95% and 98% capture.
TOTAL	**$190-270**	**≥ 2**	**≥ 28**	To Be Determined.

However,…….

- **Plant capex rose 11% from end of pre-feed study (May of 2020) to start of Design Optimization Study (June 2021) due to supply chain issues**
- **Prices continue to increase**
- **Copper, structural steel, rebar, fabricate metals, mechanical/electrical equipment**

Preliminary Lifecycle Carbon Analysis



- Preliminary GHG LCA by ***Carbon Solutions LLC***
- Used current fuel and plant design in model
  - 10% woody biomass (BTU) or ~15% (mass)
  - 97% CO2 Capture
  - All lifecycle process inputs included into model. GREET factors used for several of the industry processes (e.g., lime production)
- **Result = Project is Net Negative**

GWP - Biomass Carbon Uptake
GWP – Biomass Farming
GWP – Lime Production
GWP – Limestone Production
GWP – Amine Production
GWP – Waste Coal Transport
GWP – Biomass Truck Transport
GWP – Lime Truck Transport
GWP – Limestone Truck Transport
GWP – Amine Truck Transport
GWP – Biomass Train Transport
GWP – Lime Train Transport
GWP – Limestone Train Transport
GWP – Amine Train Transport
GWP – Biomass Barge Transport
GWP – Lime Barge Transport
GWP – Limestone Barge Transport
GWP – Amine Barge Transport
GWP – Power Plant Emission

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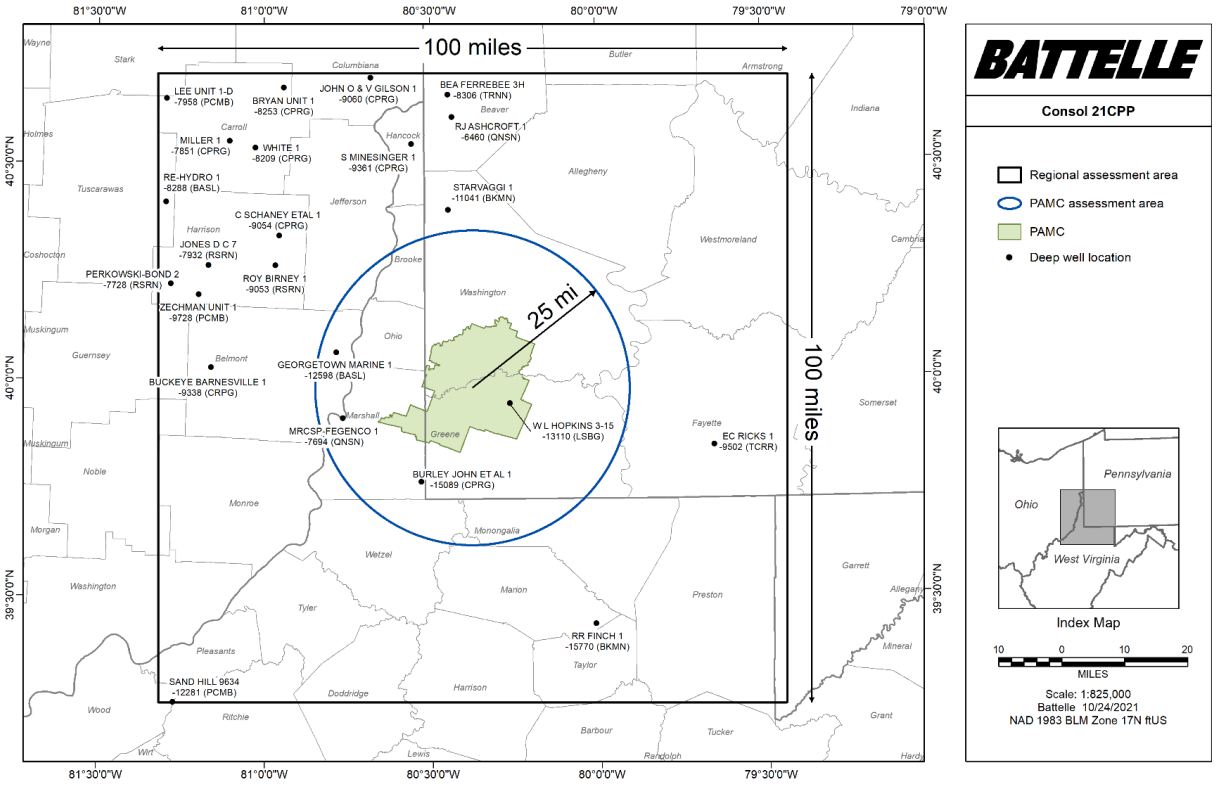
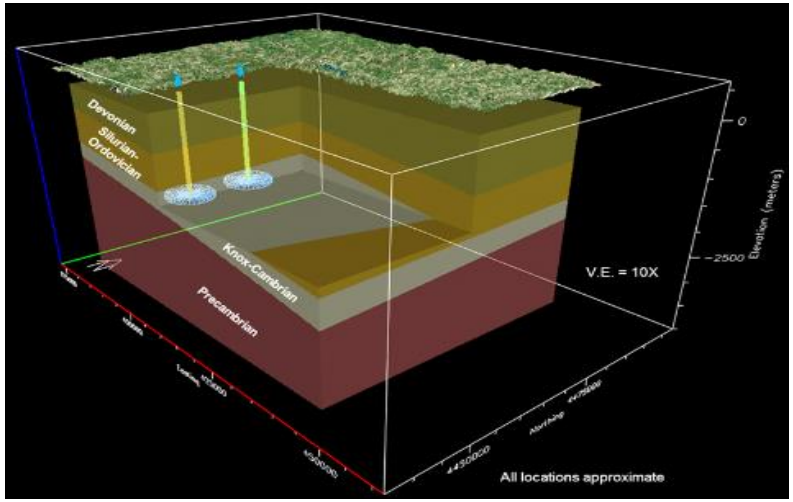
Geological Characterization for CO_2 Sequestration

- Challenges for CO_2 storage in SW Pennsylvania: limited deep well drilling, competing exploration, no CO_2 injection test wells.
- Project team is evaluating existing 2D & 3D seismic survey information to address geologic and geotechnical data gaps.
- Multiple stacked CO_2 storage zones are being considered to meet storage volume goals.
- Investigating N. WV and E. Ohio area
- Goal is to develop CO_2 storage system and integration with PFBC plant





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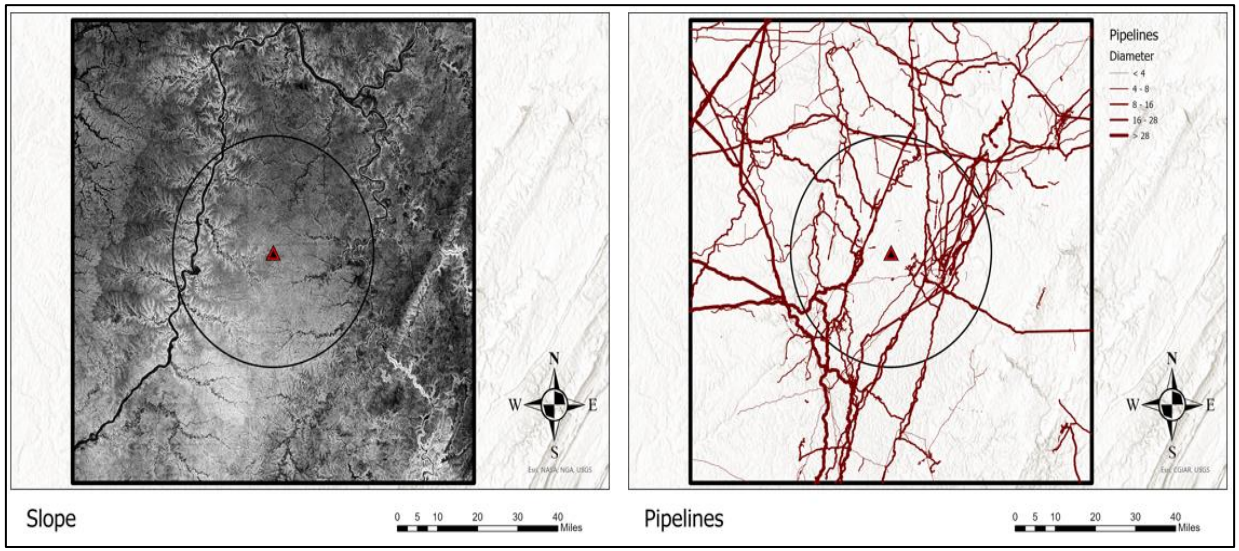
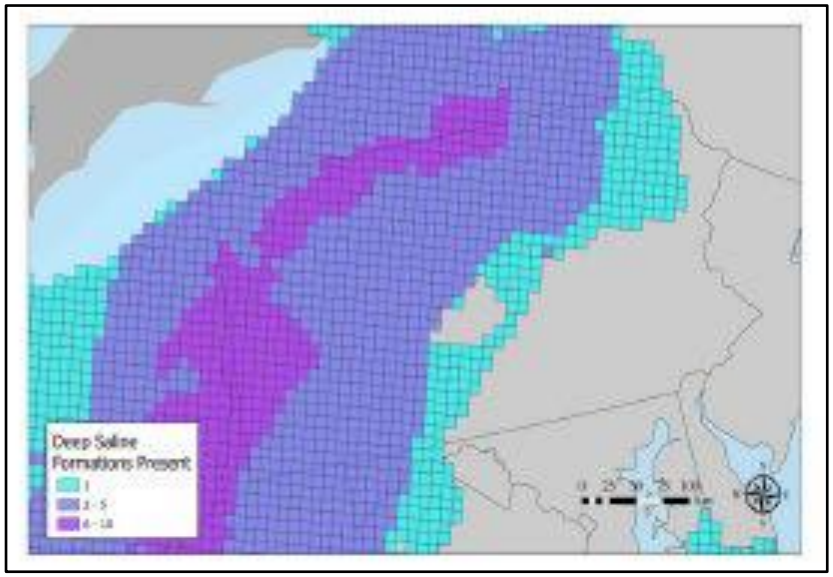
CO_2 Disposition – CO_2 Transport & Infrastructure

Developing a *SimsCCS*^{Pro} model to make informed decisions regarding

- Pipeline needs to support CO_2 storage. Assess local and regional pipelines.
- Integration of project as part of a CO_2 Hub or Ecosystem
- Geological sinks to support the geological sequestration efforts
- Spatial analyses to address the project's ESJ initiatives





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Final Thoughts

- Design Optimization in full progress and to be completed end of December 2022
- Challenge: Cost control! (supply chains, materials, labor, construction….)
- CO_2 disposition activities in early stages…focused on data/model analyses…Stay tuned