CORE Natural Resources

21st Century Power: Operator Perspectives on CCUS

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Pennsylvania Energy Ecosystem Conference

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Acknowledgement

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

- DOE Award: DE-FE0031998

- 21st Century Power Plant Program

- June 2021 – December 2025

Progress Requires Collaboration

CORE Natural Resources

Power Plant Partners

- Worley — *Plant Design Engineer*
- PFBC environmental energy technology — *Boiler Technology Licensee*
- Nooter Eriksen — *Boiler Engineer*
- Farnham & Pfile Engineering & Construction — *Fuel Prep Engineer*

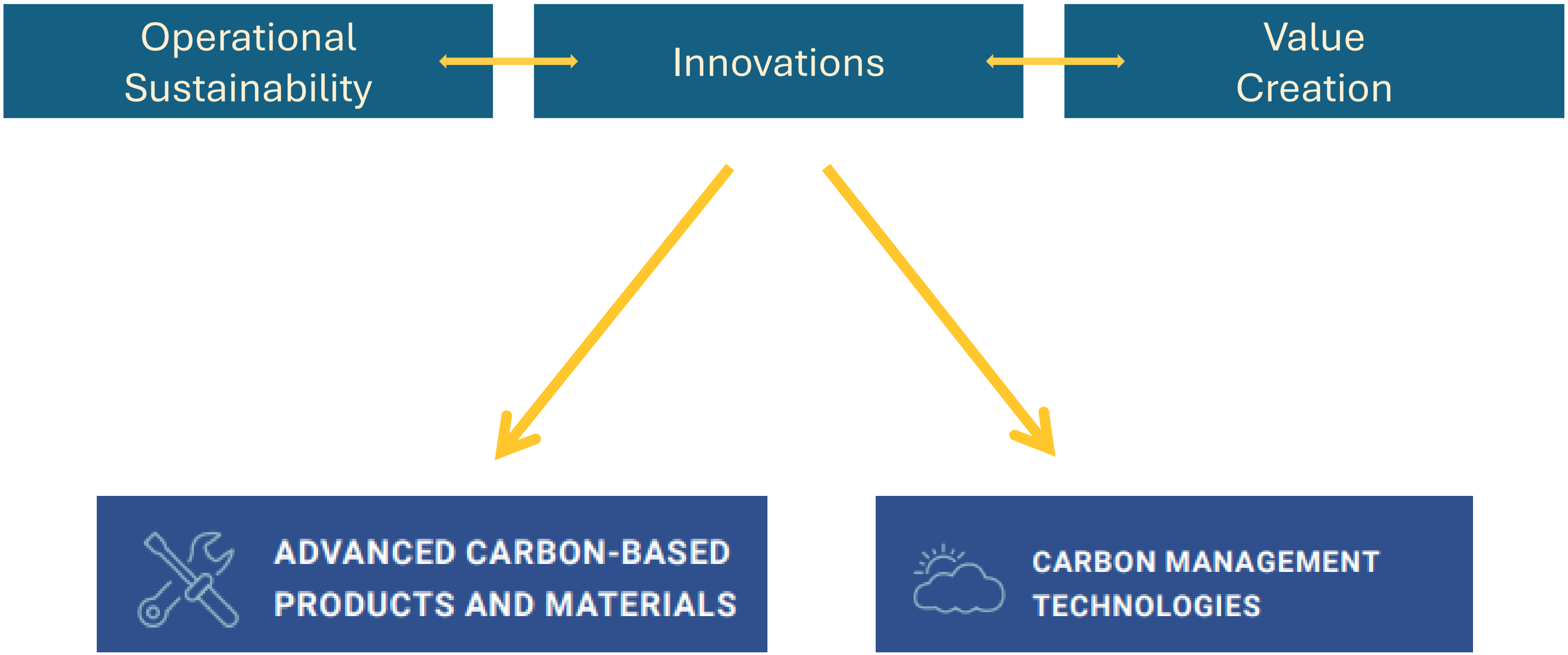
CO_2 Disposition Partners

- Osomono — *CO_2 Disposition Coordinator*
- Battelle — *CO_2 Sequestration*
- Carbon Solutions LLC — *CO_2 Transport & Modelling*
- Pennsylvania Geological Survey / WVGES — *Geological SMEs – PA &WV*

Focused Study Participants

- Fluor — *CO2 Capture*
- Babcock & Wilcox, Honeywell UOP — *CO2 Capture*
- Elliott Group, Ebara Corporation — *Gas Turbomachinery*

Core's Sustainability Approach



[Learn more about the future of carbon]

Project Overview and Goals

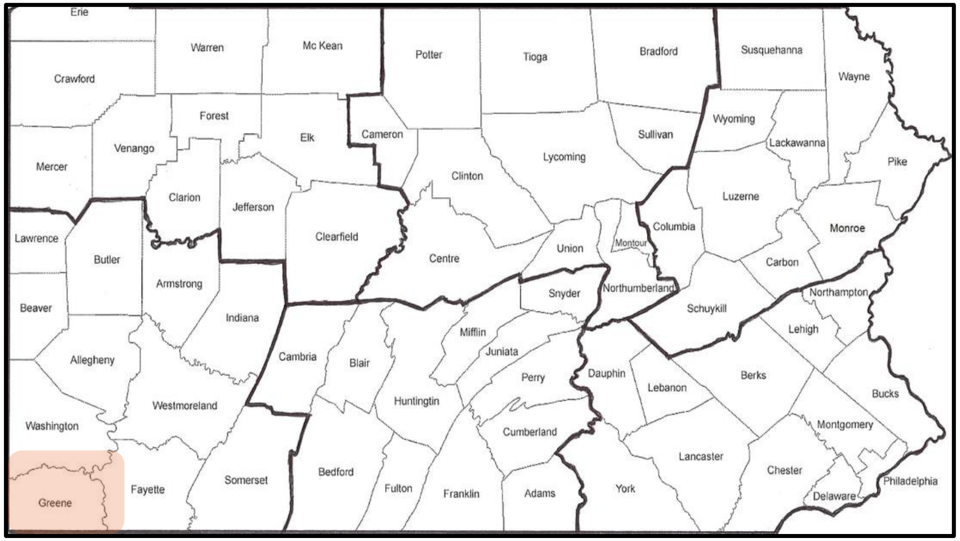
- **Design a 21st Century Power Plant (up to 350 MW)**
  - *Commercially viable in by early 2030's*

- **Deliver a Power Supply That Is:**
  1. CO_2 Negative
  2. Waste Coal Based
  3. Resilient and Dispatchable
  4. Base Loaded to Support An Evolving Grid
  5. Cost Competitive

Two-Phase Study (June 2021 – December 2025)	**Project Deliverables**
• Design Optimization • FEED	• Detailed Plant & CO2 Storage Design • Cost Estimate • Overall CO2 Disposition Plan • Life Cycle Analysis (LCA) • Investment Case

Key Design Features

- Plant Location in Southwestern PA
- PFBC (Waste Coal) & CFB Technology (Waste Wood)
- Waste Coal – Reliable, Abundant, Lower Cost Fuel Supply
- Waste Wood + 97% CO_2 Capture = Net Negative
- Near Zero Air Emissions & Zero Liquid Discharge
- Sequester ~ 2 Million Tons of CO_2 Annually in PA and/or WV.



Project Status

- Design Optimization (Phase 1) Completed in June 2024
  - CO_2 Storage & Regional CO_2 Transport and Utilization Evaluation
  - Environmental Information Volume
  - Preliminary LCA - Determined the Plant as Net Negative CO_2
  - Investment Model and Economic Assessment

- Phase 1 Conclusions:
  1. CO_2 Negative ☑ ?
  2. Waste Coal Based ☑
  3. Resilient and Dispatchable ☑
  4. Base Loaded to Support An Evolving Grid ☑
  5. Cost Competitive ?

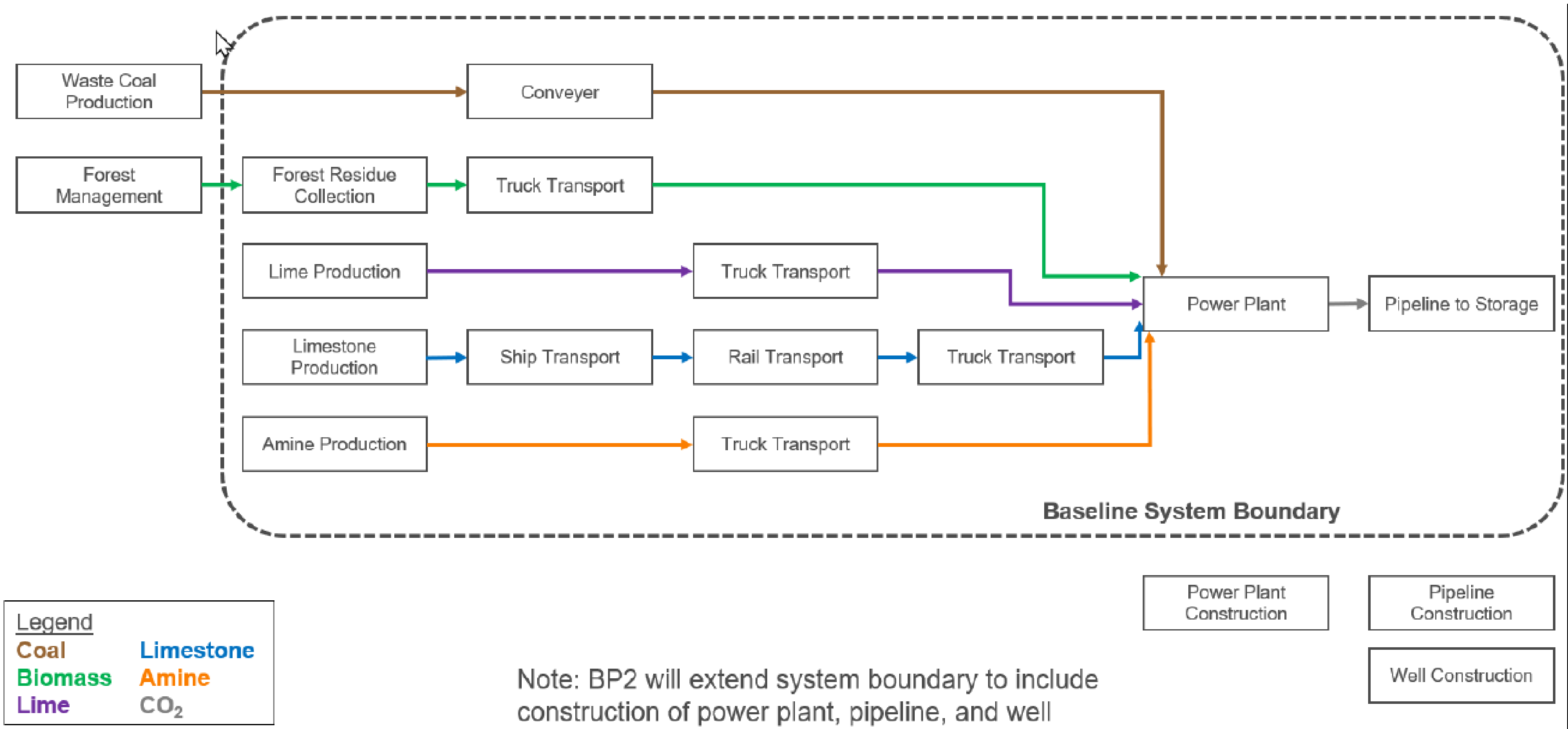
Project Team Elected to Reconfigure Plant for Phase 2 (Feed Study) to Promote Commercial Viability

Design Basis for Phase 2

Parameter	Value
Boilers	(3) PFBC (coal) (1) CFB (biomass)
Plant Fuel (by BTU)	80% coal (50% waste coal, paste feed) 20% waste wood biomass
Environmental	Boilers limestone (SOx) Cyclones (PM) Boilers + SNCR (NOx) CDS/FF (PM, Acid Gases, Hg) 97% Removal Amine Solvent CO2 Capture ZLD (wastewater)
Gross MW	304
Net MW	237
CO_2 MM t/yr (85% CF)	2.33
Site	SW PA

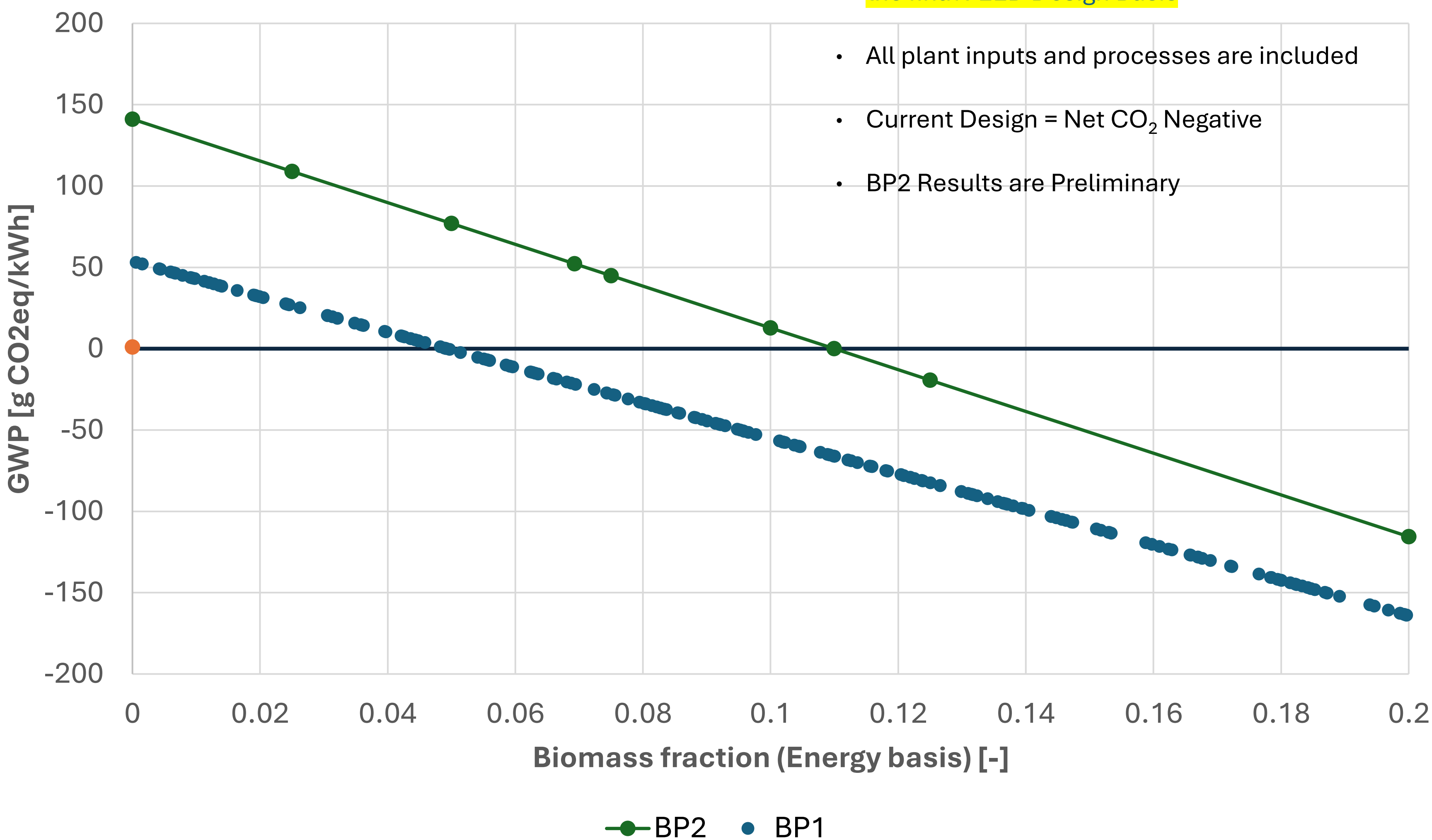
- The project's equipment and materials escalated approximately 40%, and the overall installed TPC costs escalated by approximately 25%.
- Present day costs are a major challenge for large scale project developers.

1. Phase 1 Lifecycle Analysis



Note: BP2 will extend system boundary to include construction of power plant, pipeline, and well

1. Phase 1 Lifecycle Analysis



- Using the LCA to drive engineering decisions. E.g., increased the biomass to 20% to offset changes for the final FEED Design Basis
- All plant inputs and processes are included
- Current Design = Net CO_2 Negative
- BP2 Results are Preliminary

2. Biomass - BECCS

- Collaborating with several major PA forestry producers to use waste wood (dirty chips) byproduct from their process

- Working at a grass roots level with forestry industry on understanding their large-scale supply, logistics, and investment, needs

    → *Mid-Atlantic Sustainable Biomass Consortium for Value-Added Products (MASBIO)*

- Win/Win Potential…Better forestry practices, improved ecosystems and CO_2 removal

3. CO_2 Storage and Transport

- Performed a rigorous assessment of the regional geology including CO_2 storage zones, caprocks, and geologic structures.
- Conducted 2D, 3D seismic, reservoir/plume modelling, and injection studies.
- Developed a Design Basis for CO_2 Storage. Hazard Analysis completed.
- Developed a test well plan.
- Modeled CO_2 disposition strategies using SimCCSPro, CostMAPPRO, SCO2TPRO, and NICO2LEPRO . Cost scenarios developed with respect to storage, pipeline transport, regional sinks, point sources, EJ, and 45Q.
- Completed preliminary feasibility analysis into Marcellus well conversion for additional CO_2 storage.

Perspectives: CCUS in Evolving Energy and Economic Scenarios

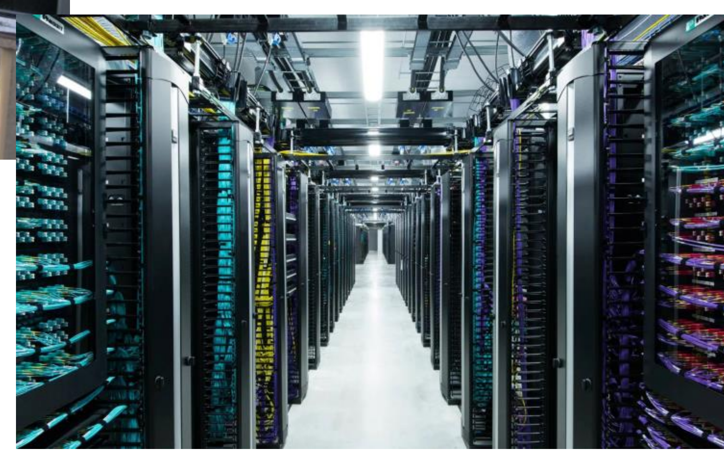
Challenge / Opportunities	Commentary	Consideration	Path Forward
Costs & Commercial	Total plant cost is in the billions. Current investment and commercial risks are ~ med to high.	Cost/social/regulatory/ environmental issues are major challenges for large scale project developers	Continue to pursue ways to reduce costs. Increasing the number of vendor quotes and less dependence on scaling/historical pricing & info Focus design on reliability
CO_2 Capture	Levelized Cost of Capture was ~ $47/ton (US) from BP1	97% capture	Streamlined the design for BP2 FEED. Revised costs TBD
CO_2 Storage	Much of the region's geology is tight, with limited porosity and permeability, and or is confounded with legacy O&G wells. Deep storage is highly uncertain	CO_2 Storage design work has identified some promising storage. Current estimate is nearing project life capacity	Test Wells! Continue to evaluate the potential of Marcellus shale well conversion PA and WV are embracing storage needs of industry
CO_2 Transport	One of the BP1 model scenarios demonstrated a 52% reduction (e.g., $3.9/t versus $8.1/t) in CO_2 transport costs by using shared pipeline infrastructure (CONSOL plant and another large-scale point source)	Potential for reducing CO_2 disposition costs by developing synergies for coordinated regional CO_2 transport and storage infrastructure	Pipelines are a must and need to be part of the solution

Perspectives: CCUS in Evolving Energy and Economic Scenarios

Item	Thoughts/Comments	Recommendations
CO_2 Capture	1. Not the same as with FGD history. CO_2 Transport/Storage, the state of the power market, condensed timeline for development, and cost climate, make it significantly different. 2. Few (TRL >7) technology vendors. Most are project selective and seem to be operating with lean engineering staffs and limited capacity? Only a few APC companies left? 3. Why are costs so high? Not clear if reflective of pricing history, lack of competition, engineering margin, other, etc. 4. CO_2 Capture systems are not much different than what was offered in mid-2000's. Minimal technology improvement and innovation?	1. Improve vendor and industry knowledge of the process limits of the vendor's technology and in turn improve ruggedness/cost. 2. Less FEED and more field, pilot and large-scale testing.
Investment	1. 45Q may not be able to "fully" buffer the significant capital investment and project risk (e.g., NGCC retrofit example). 2. Although maybe not truly FOAK, pricing and supply is ~ FOAK. 3. Equipment costs have escalated 40% and installed capital 25% since the end COVID. Large construction projects are challenging for developers.	1. Increase in Federal and State grants (beyond loans) to help de-risk first wave of large-scale CCS projects.
Other	1. Proposed GHG rule simply does not account for the timing required for technology scaling, storage science, and the regional planning needed with the public for such a transformative issue. Complete disconnect. 2. Significant pushback on pipelines. Lots of misinformation in the public domain. Pipelines are critical to the CO_2 solution.	1. Need increase in $ for geological exploration. 2. Policy makers need to develop certainty around primacy, property rights, permitting, etc. 3. Public education 4. Industry collaboration

Perspectives: 2021 vs 2025

2021 Decarbonization



2025 Reliability, Growth, Affordability

Final Thoughts

1. Resilient and Dispatchable
2. (1A) Cost Competitive
3. (1B) Base Loaded to Support An Evolving Grid

Equally Important: Affordable, Reliable and Efficient Baseload Power

4. (2) Waste Coal Based
5. (2) CO_2 Negative

Enhance Efficiency of Operations