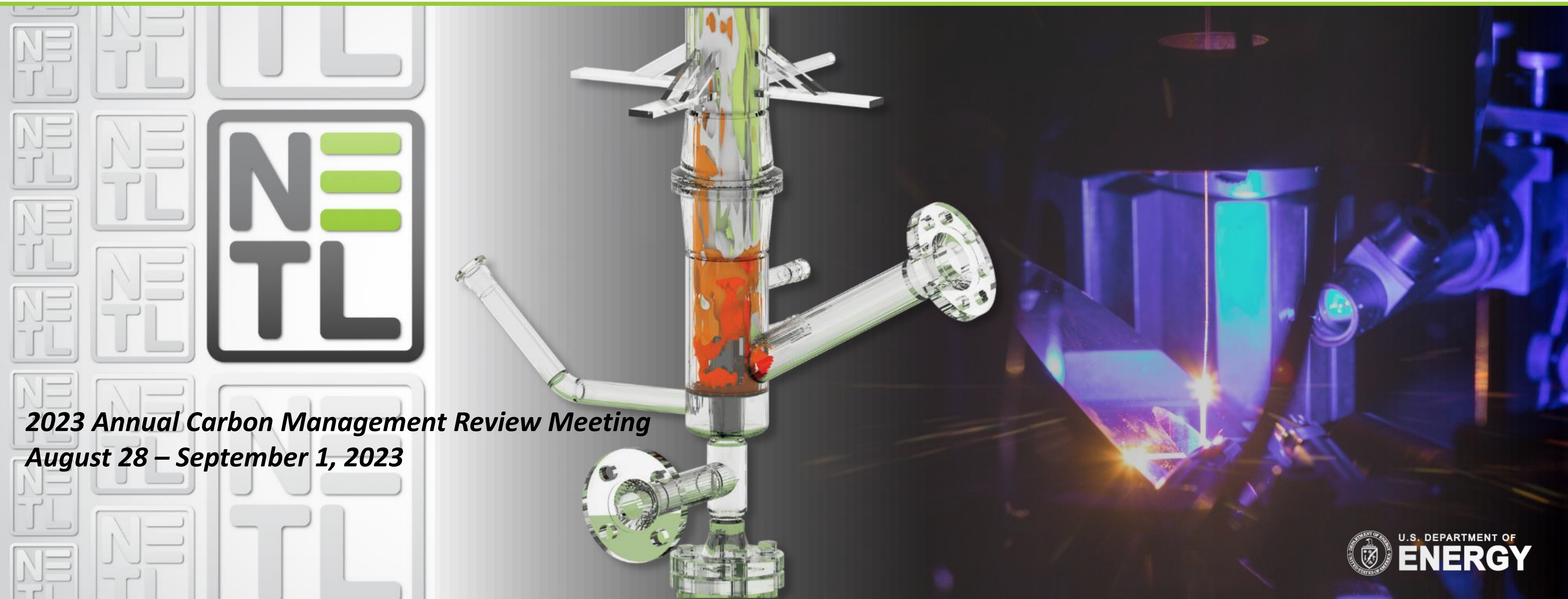
# Systems Analysis for Carbon Dioxide Removal

NATIONAL ENERGY TECHNOLOGY LABORATORY

Solutions for Today | Options for Tomorrow

***Timothy Fout, Senior Research Engineer***
Strategic Systems Analysis and Engineering
Energy Process Analysis Team



***2023 Annual Carbon Management Review Meeting***
***August 28 – September 1, 2023***

U.S. DEPARTMENT OF ENERGY

# Disclaimer

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# Presentation Outline

**2023 Highlights**

- Strategic Systems Analysis & Engineering Overview
- Life Cycle Analysis
- Market Studies
- Process Cost and Engineering
  - DAC Sorbent Case Study Basis
  - DAC Sorbent Case Study – Ongoing Updates
- Next Steps and Notes

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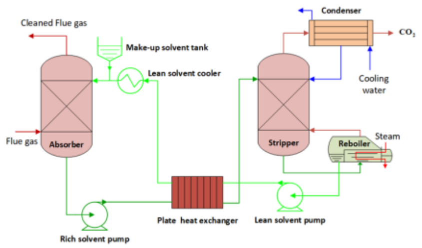
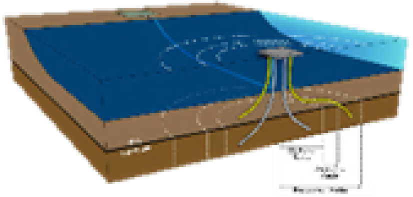
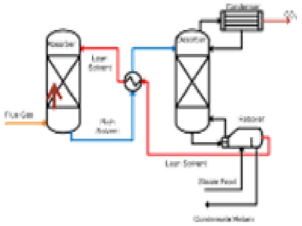
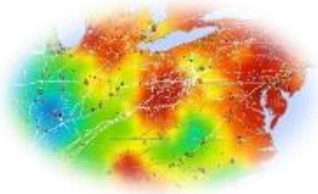
# Strategic Systems Analysis & Engineering

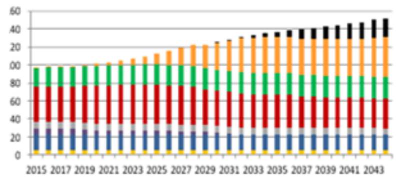
- Multi-scale Modeling and Optimization
  - Conceptual Process Design
  - Predictive Physics-Based Modeling
  - Uncertainty Quantification
  - Technical Risk Reduction
  - Dynamic Modeling/Digital Twins
- Energy Process Design, Analysis, and Cost Estimation
  - Process Modeling & Performance Assessment
  - Capital and O&M Cost Estimation
  - Quality Guidelines for Energy System Studies (QGESS)
- Resource Sustainability and Cost Modeling
  - Techno-economic analysis of $CO_2$ storage systems
  - Fossil fuel resources and extraction
  - Critical mineral sustainability, security, and supply
- Life Cycle Analysis (LCA)
  - National LCA Baselines for Energy Resources
  - LCA Guidance and Best Practices
  - Critical Reviews of Third-party LCA's
  - Open-Source Modeling for Transparency and Confidence
- Energy Economy Modeling and Impact Assessment
  - Enhanced fossil energy representation
  - Multi-model scenario/policy analysis
  - Grid, infrastructure, energy-water
  - Economic impact assessment
  - Regulatory, market and financial expertise









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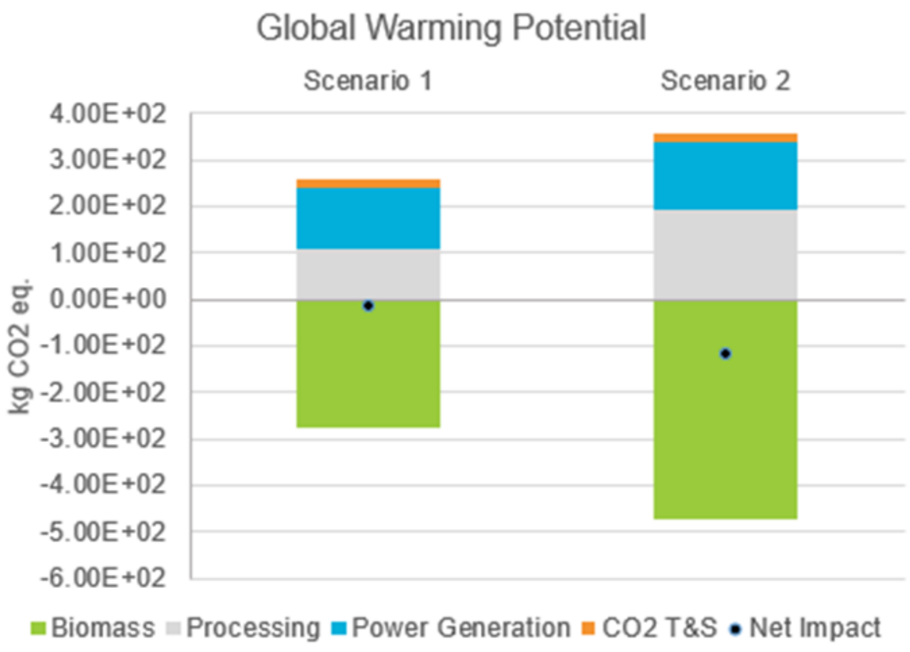
# Carbon Dioxide Removal LCA Scope

- LCA of Enhanced Weathering and Mineralization
  - Literature Review & Screening level analysis – Fall 2023
  - Full LCA incorporating monitoring, verification, and assessment – Spring 2024
- LCA of Marine CDR
  - Literature Review & Screening level analysis – Fall 2023
  - Full LCA incorporating monitoring, verification, and assessment – Spring 2024
- Bioenergy with Carbon Capture and Storage
  - Emissions potentials, water consumption and scarcity, and land use for nine biomass types
  - Parameter sensitivities include region, processing options, moisture content, transportation distance
- Direct Air Capture Toolkit – Fall 2023




Comparison of carbon emissions for biomass profiles: Hybrid Poplar (scenario 1) and energy cane (scenario 2)

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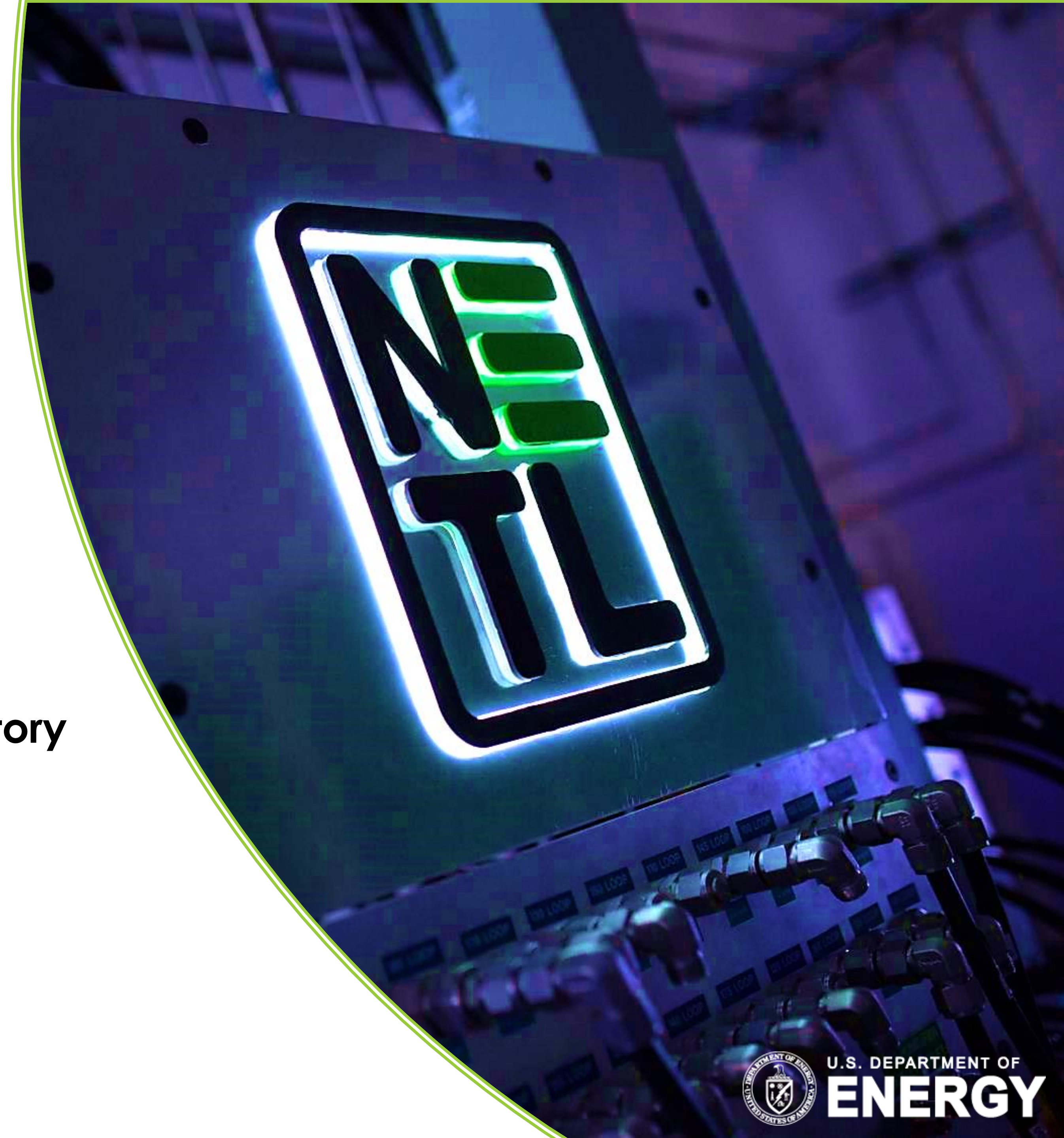

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# Market Evaluation of Direct Air Capture

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## Rationale

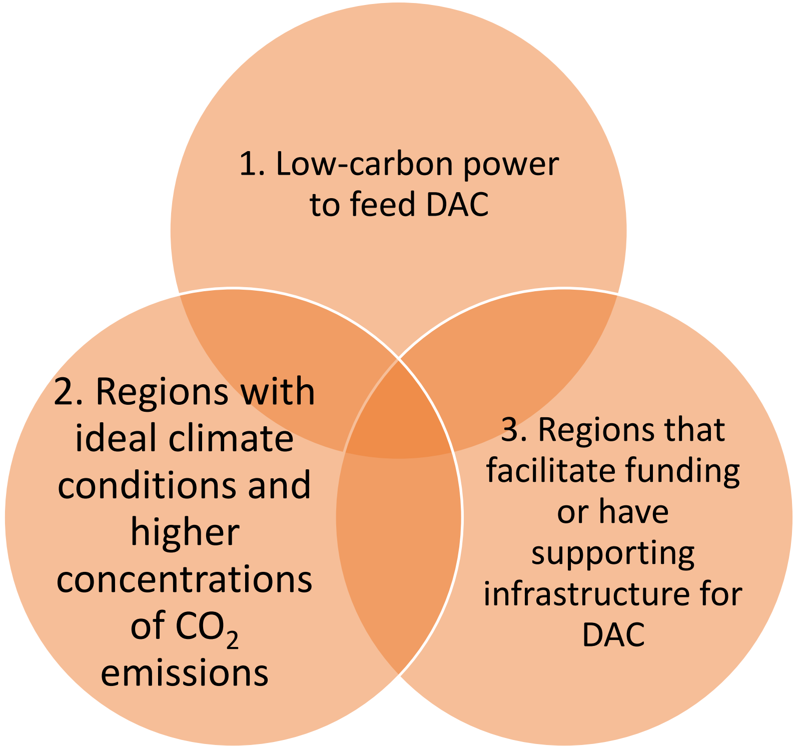
- This effort will focus on the evaluation of optimal DAC location both from economic as well as decarbonization impact perspectives.

## Approach

- Literature search on existing DAC proposals
- Identifying the best regional slice for analyzing DAC location
- Performing preliminary scouting for DAC locations
- Examination of the implications of identity of $CO_2$ being captured
- Initial listing of optimal DAC sites

## Outcome

- Screening tool to compare DAC sites using a "what if analysis" (next slide)
- Paper detailing the proposed list and the methodology used to develop it.



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# Market Evaluation of Direct Air Capture

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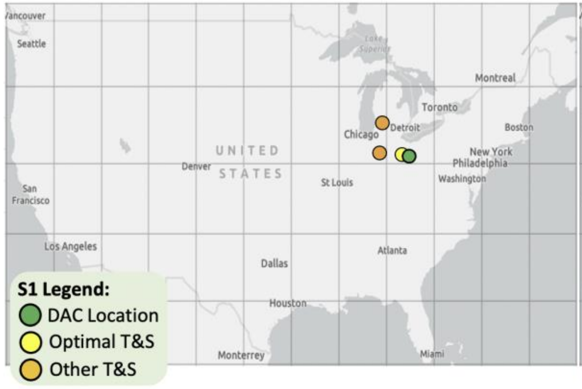
## Tool Development

| Input | Scenario 1 (S1) | Scenario 2 (S2) |
|---|---|---|
| **Plant Capacity (Tonnes of $CO_2$/year)** | 1,000,000 | 1,000,000 |
| **Type of DAC** | Solvent | Solvent |
| **$CO_2$ Concentration (ppm)** | 415 | 415 |
| **Plant Performance at $CO_2$ level (% of baseline)** | 100% | 100% |
| **Plant Location (City, State Initials)** | Columbus, OH | Jacksonville, FL |
| **Source of Energy** | Integrated NGCC | Integrated NGCC |





**Tool to perform WHAT IF ANALYSIS based on location and type of DAC technology**

| Output | Columbus, OH | Jacksonville, FL | Units |
|---|---|---|---|
| **Average Temperature** | 12 | 22 | Degrees Celsius |
| **Average Humidity** | 70% | 76% | % |
| **$CO_2$ Concentration** | 415 | 415 | ppm |
| **Capture Rate** | **66%** | **75%** | % |
| **Tons of $CO_2$ Captured per hour** | 101.09 | 114.16 | $tCO_2$/hour |
| **Tons of $CO_2$ Inflow per hour** | 152.21 | 152.21 | $tCO_2$/hour |
| **Gross $CO_2$ Captured** | 885,542 | 1,000,000 | $tCO_2$/year |
| **Water Consumption per $tCO_2$** | 3.87 | 6.60 | $tH_2O/tCO_2$ |
| **Energy Consumption per $tCO_2$** | 2.53 | 2.39 | $MWh/tCO_2$ |
| **Total Energy Requirement** | 2,235,994 | 2,388,891 | MWh/year |
| **Energy Emissions Intensity** | 16.2 | 16.2 | $kgCO_2$/MWh |
| **Upstream Emissions from NGCC** | 176,223 | 199,000 | $tCO_2$/year |
| **$CO_2e$ Emissions from Energy** | 39,928 | 42,659 | $tCO_2$/year |
| **Net $CO_2$ Captured** | 669,390 | 781,118 | $tCO_2$/year |
| **$CO_2$ Capture Efficiency** | 75.6% | 78.1% | % |
| **$CO_2$ Captured from CCS (90%)** | 354,217 | 400,000 | $tCO_2$/year |
| **Net $CO_2$ Flow T&S (DAC+NGCC w/ CCS)** | 1,239,758 | 1,400,000 | $tCO_2$/year |
| **Transport and Storage Cost** | $18.32 | $21.11 | 2018$/$tCO_2$ |
| **Optimal Storage Formation** | Mount Simon10 | Lower Tuscaloosa4 | |
| **Storage Site State** | OH | FL | |
| **Total T&S Cost** | $22.7 | $29.6 | 2018M$/year |



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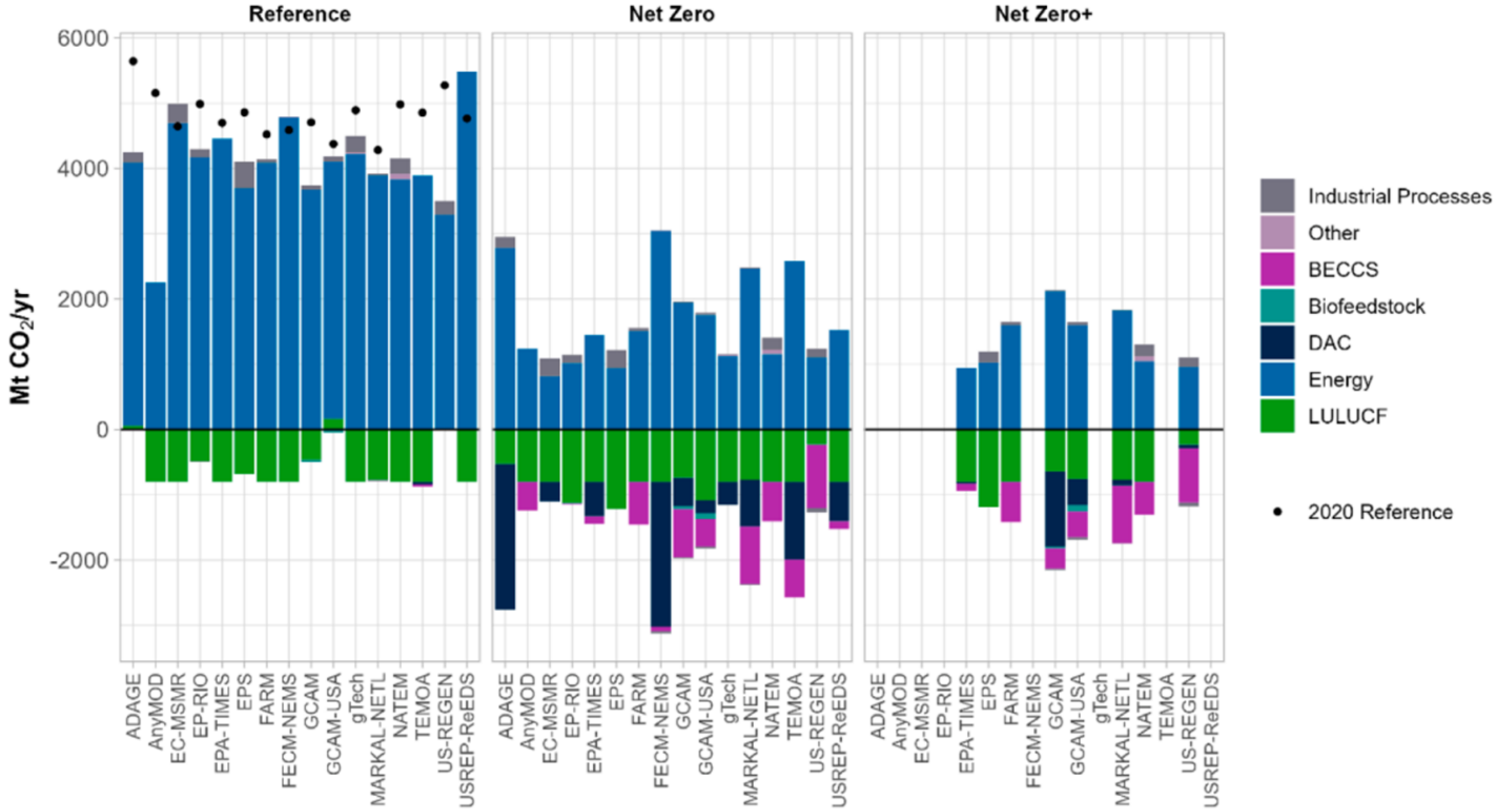
# MARKAL modeling of DAC deployment

## Energy Modeling Forum 37 scenarios

- NETL-MARKAL participates in EMF 37 under this task
- We have provided data to other modelers on DAC to help them integrate into their models
- All models show that negative emissions technologies are essential to meeting net zero goals by 2050
- In the NetZero+ scenario, reductions across all sectors are enabled, reducing reliance on DAC, but it still is a critical backstop



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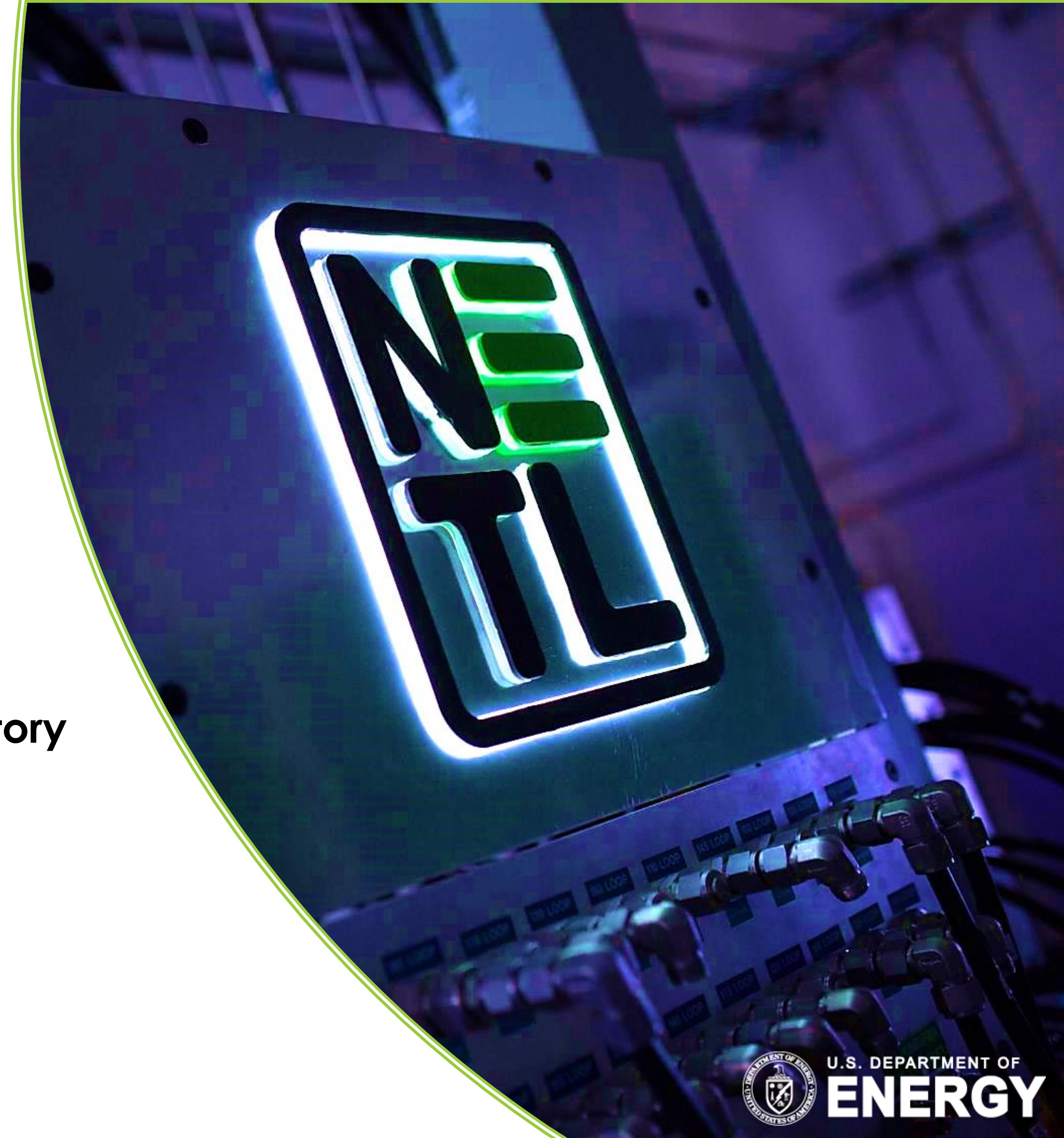

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# Case Matrix

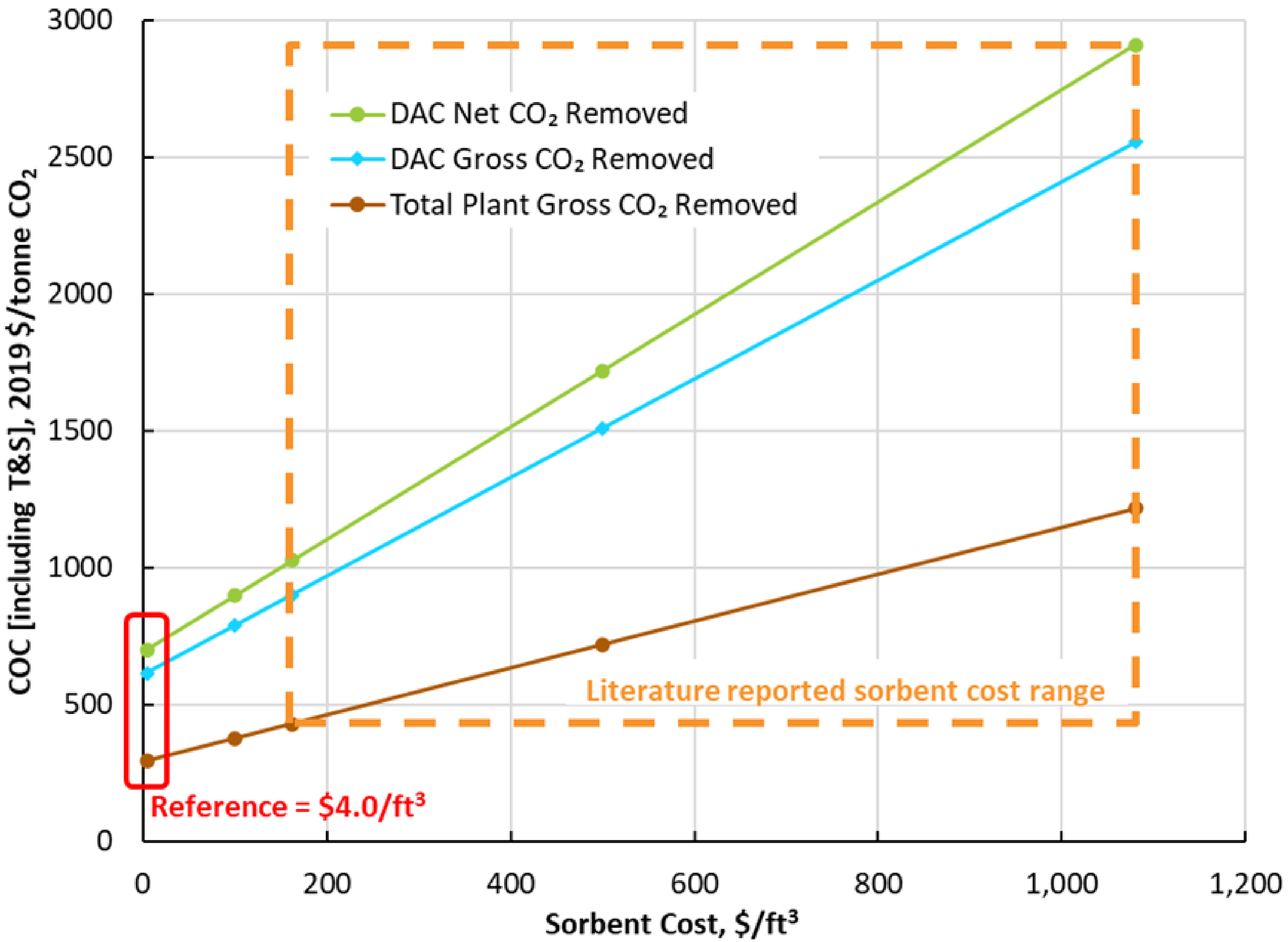
- Case 0B
  - Monolithic DAC Sorbent System with NGCC supplied power and steam
  - 90% Post Combustion Capture on NGCC
  - Sized to account for 100,000 tonnes $CO_2$ / year net removed from atmosphere
- Case 0B-EB
  - Monolithic DAC Sorbent System with Electric Boiler for steam
  - Carbon footprint of electricity considered to be zero
  - Included in report but not highlighted due to time
- Case 0 and 0-EB
  - Fixed bed DAC Sorbent Systems
  - High pressure drops led to high costs and very un-optimal results
  - Included in the report appendix for reference

# Simplifying Assumptions

- Absorber vessel outlet air exits w/o stack or dispersion considerations
- Assumed to be compliant with Effluent Limitation Guidelines
  - Produced water from DAC or NGCC w/capture
- **Non-type NGCC Turbine used**
  - **“Rubber” turbine**
- Single reciprocating compressor for $CO_2$ compression
- Scaled **NGCC w/ 90% capture** for steam and electricity use
- **Industrial sorbent cost used for base case**

*R. James, A. Zoelle, D. Keairns, M. Turner, M. Woods, N. Kuehn “Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity," National Energy Technology Laboratory, Pittsburgh, September 24, 2019. https://netl.doe.gov/projects/files/CostAndPerformanceBaselineForFossilEnergyPlantsVol1BitumCoalAndNGtoElectBBRRev4-1_092419.pdf

# Sensitivity - Sorbent Cost



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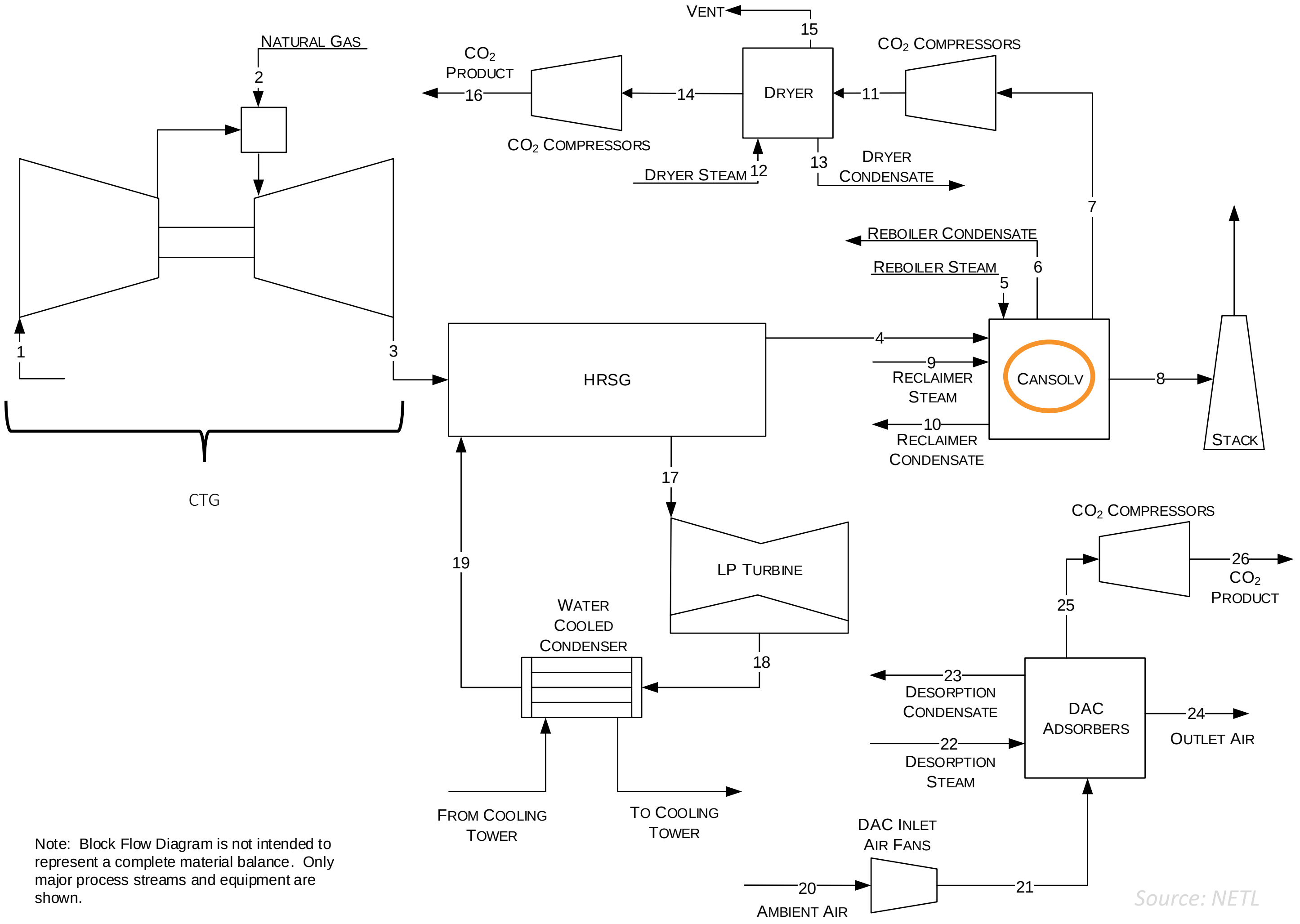
# Ongoing Sorbent DAC Case Study Updates

## NGCC CANSOLV System Modifications

- Change the CANSOLV system performance from 90% $CO_2$ capture to 97% (utilizing the updated 2021 CANSOLV quote)
- Impact includes:
  1. Lower $CO_2$ stack emissions
  2. Lesser DAC throughput requirement to maintain the 2018 minimum 45Q tax credit threshold of 100,000 tonne/yr net $CO_2$ reduction
  3. Lower total $CO_2$ compression demand
  4. Reduced CTG power requirements results in a smaller CANSOLV system

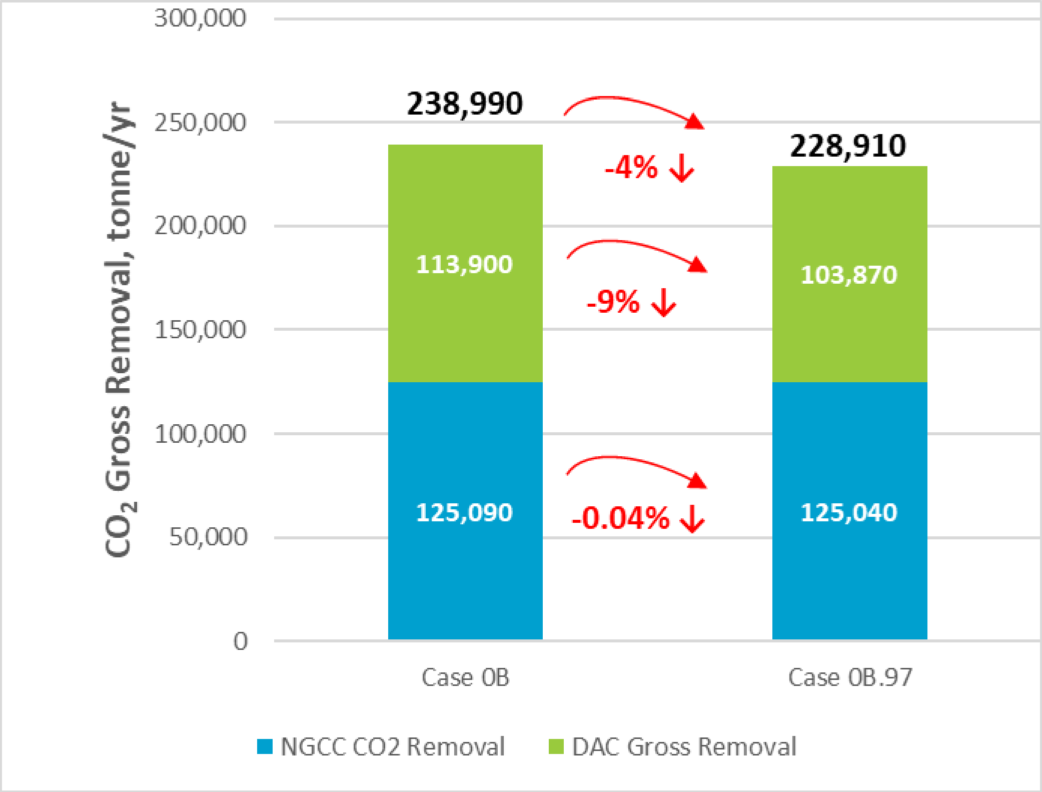


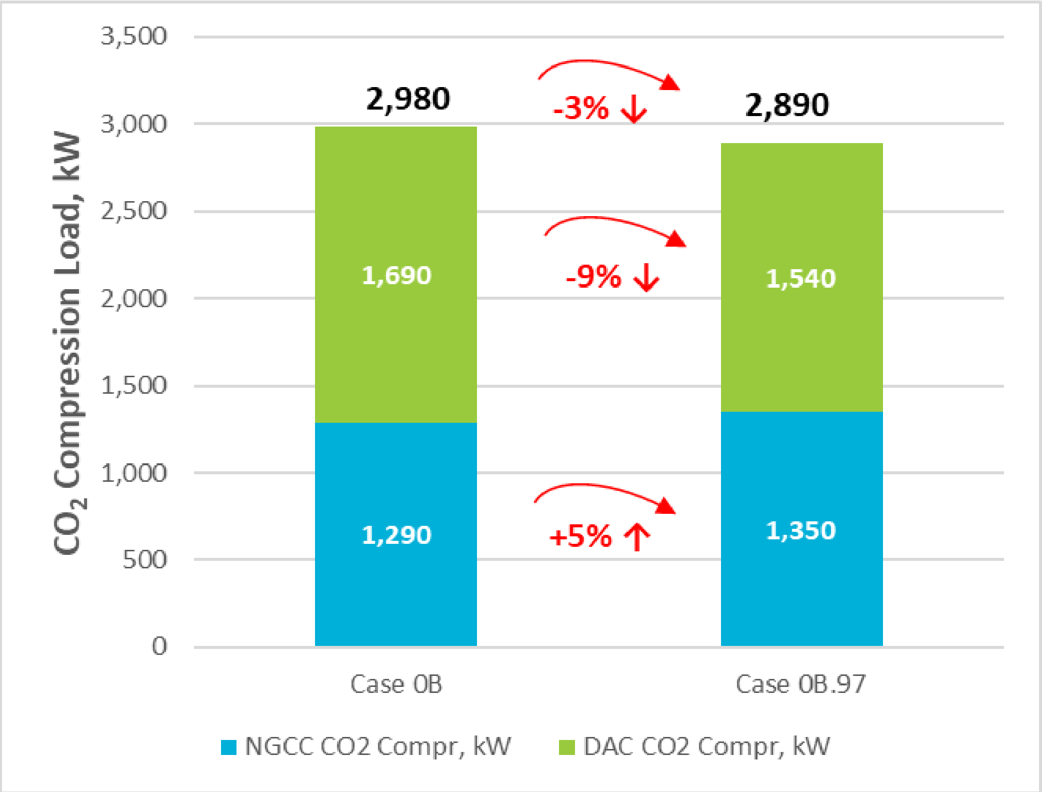

HRSG = heat recovery steam generator; LP = low pressure

# Improved CANSOLV Performance

## NGCC CANSOLV System Modifications (con't)

1. CTG stack emissions fall from 13,901 tonne/yr to 3,868 tonne/yr: 72% reduction
2. DAC throughput reduces from 90,655,822 lb/hr to 82,689,482 lb/hr: 9% mass (horsepower) reduction
3. NGCC $CO_2$ compressor flow was unchanged (only 0.04% decrease); however, the horsepower is 5% higher because the new suction pressure is 4 psi lower than the 2016 CANSOLV pressure



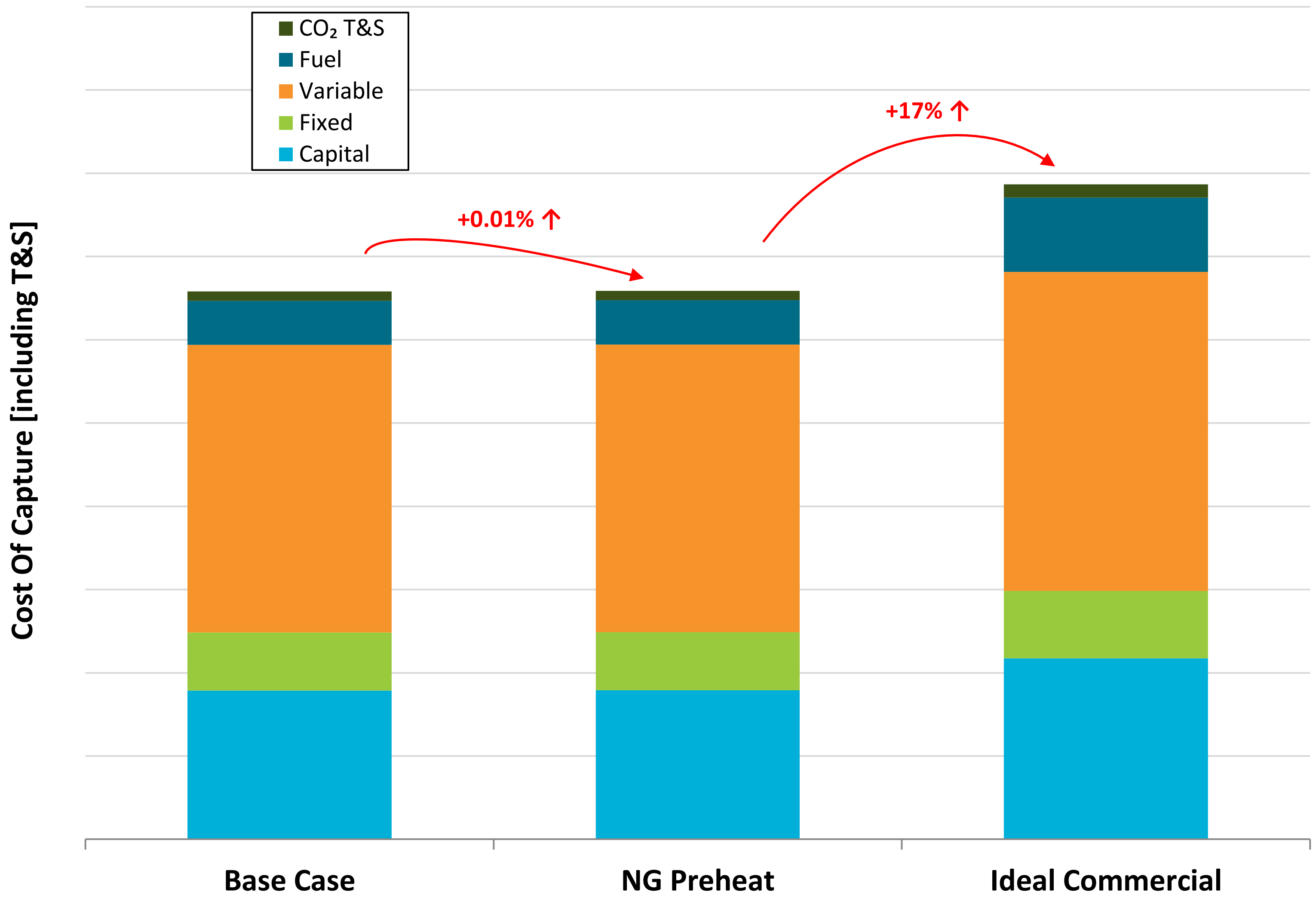




NGCC = NG combined cycle

# NG Preheater Modifications

## Performance and Economic Impacts

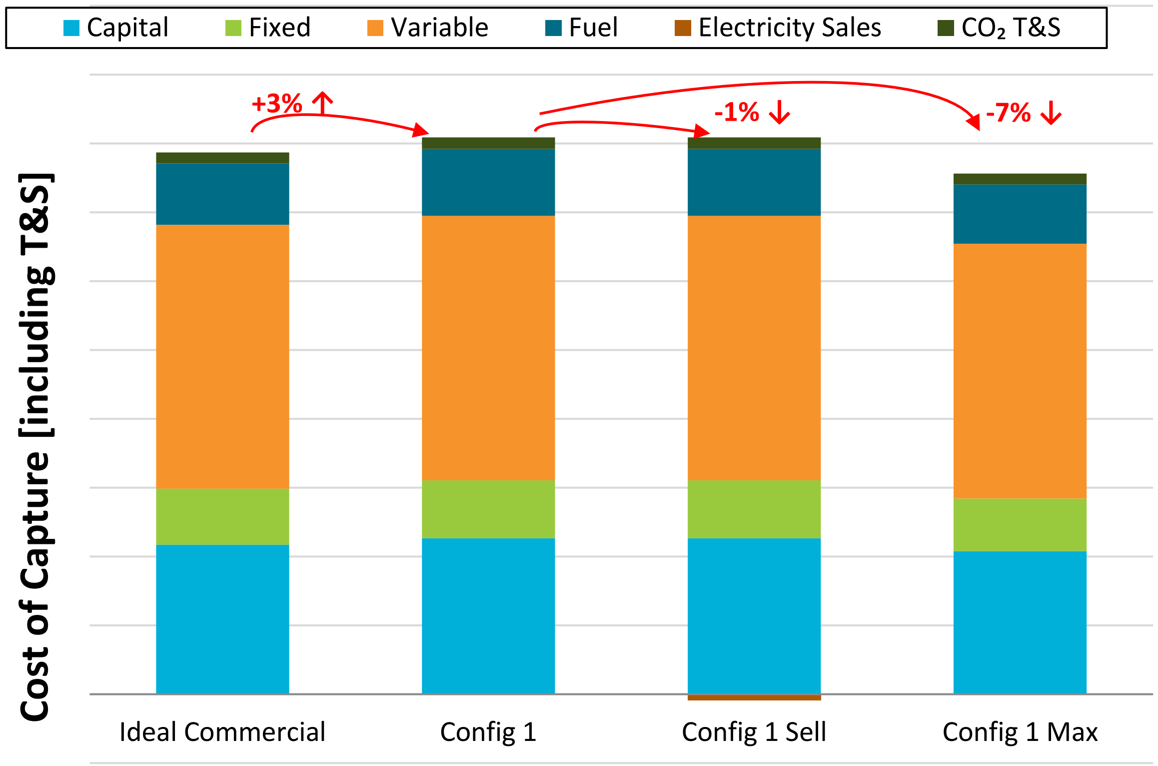
- Incremental step-changes:
  1. Integration of the NG preheater into the process
     - Increased CTG requirements by **0.2** MW (**0.5**% increase)
     - CTG exhaust temp is ~1150°F
  2. Changed the simulated turbine performance to closely match the published conditions for commercially available CTGs
     - CTG exhaust temp is ~1000°F
     - "Ideal" commercial system
     - Ideal based on public Kawasaki L20A data – not enough power

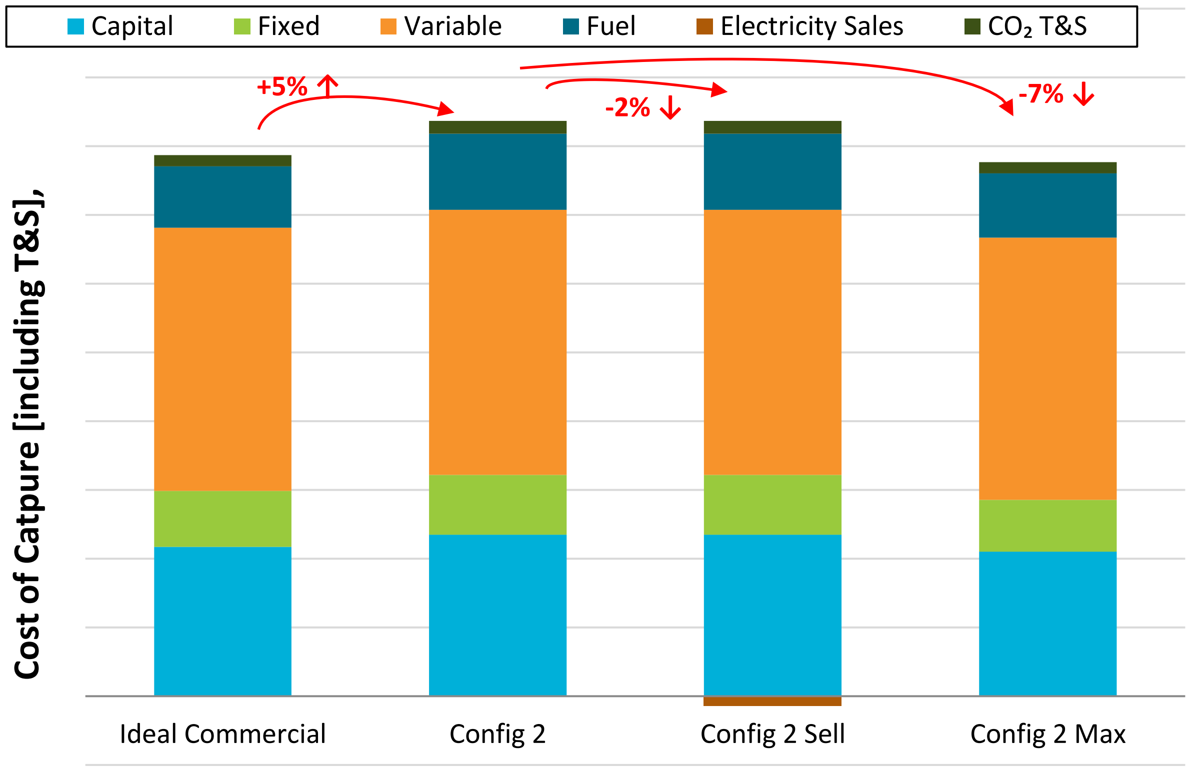


# Options for Excess Net Power Output

## Commercial CTG and STG Systems

1. 2 systems configured and analyzed with different
2. Cases examined to sell excess power to grid or increase size of DAC system to fit the turbine configuration
   1. Config 1 - Extra 4.1 MW power or Maximize DAC system to 112,820 net $CO_2$ tonne/yr removed
   2. Config 2 - Extra 6.2 MW power or Maximize DAC system to 118,600 net $CO_2$ tonne/yr removed



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# Next Steps

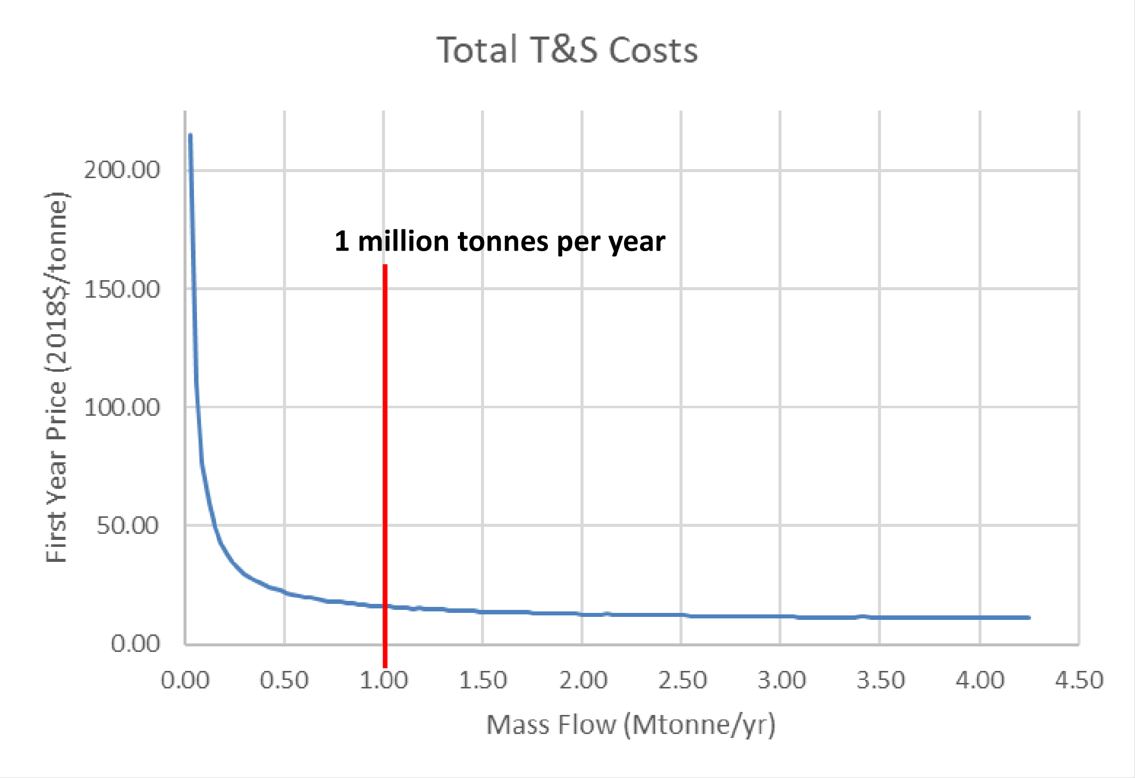
**Sorbent DAC Case Study**

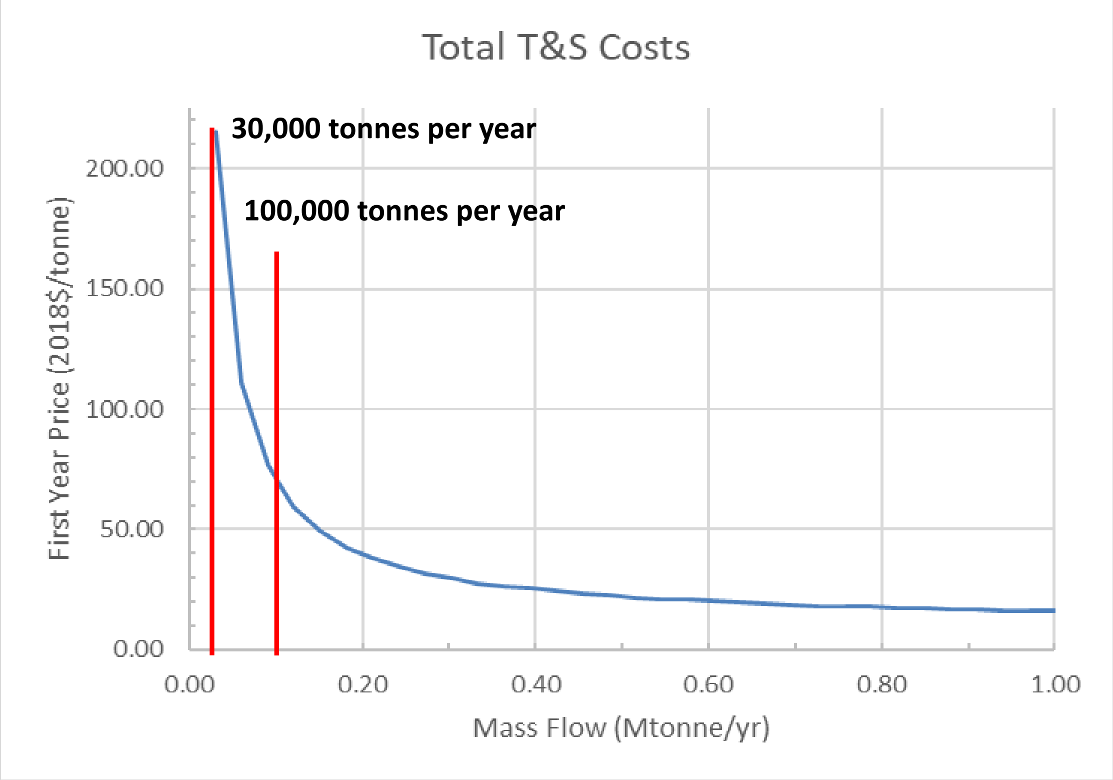
- Sensitivity analysis of updated arrangement/sorbent costs
- Update of electric boiler cases to include carbon content of electricity
- Publish updated Case Study

# Note on Transport and Storage

## Using NETL QGESS T&S Guidance

- Source-to-sink pipeline modeled using NETL Transport Cost model
- Storage costs flat at $8.32/tonne $CO_2$ storage cost (from QGESS in Midwest Illinois Basin)
- Approximately $10/tonne total T&S with 100 km pipeline and 5 Mtonnes/year



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# SSAE Posters and Presentations

**Coming up this week!**

- Posters Tonight (5:45 – 7:45 PM)
  - Carbon Dioxide Removal
    - Techno Economic Analysis Development for Enhanced Weatherization and Marine Carbon Dioxide Removal – Sara Leptinsky
    - Biomass Environmental Analysis in Bioenergy with Carbon Capture and Storage Modeling – Roksana Mahmud and Jorge Izar-Tenorio
  - Point Source Capture
    - Retrofitting NGCC and PC Power Plants with Carbon Capture Technology – Gregory Hackett
    - Techno Economic Analysis of $CO_2$ Capture from Pulp/Paper Plants – Hari Mantripragada
- Presentations
  - Point Source Capture / Thursday/ 11:50 AM
    - Industrial $CO_2$ Capture Studies – Eric Grol

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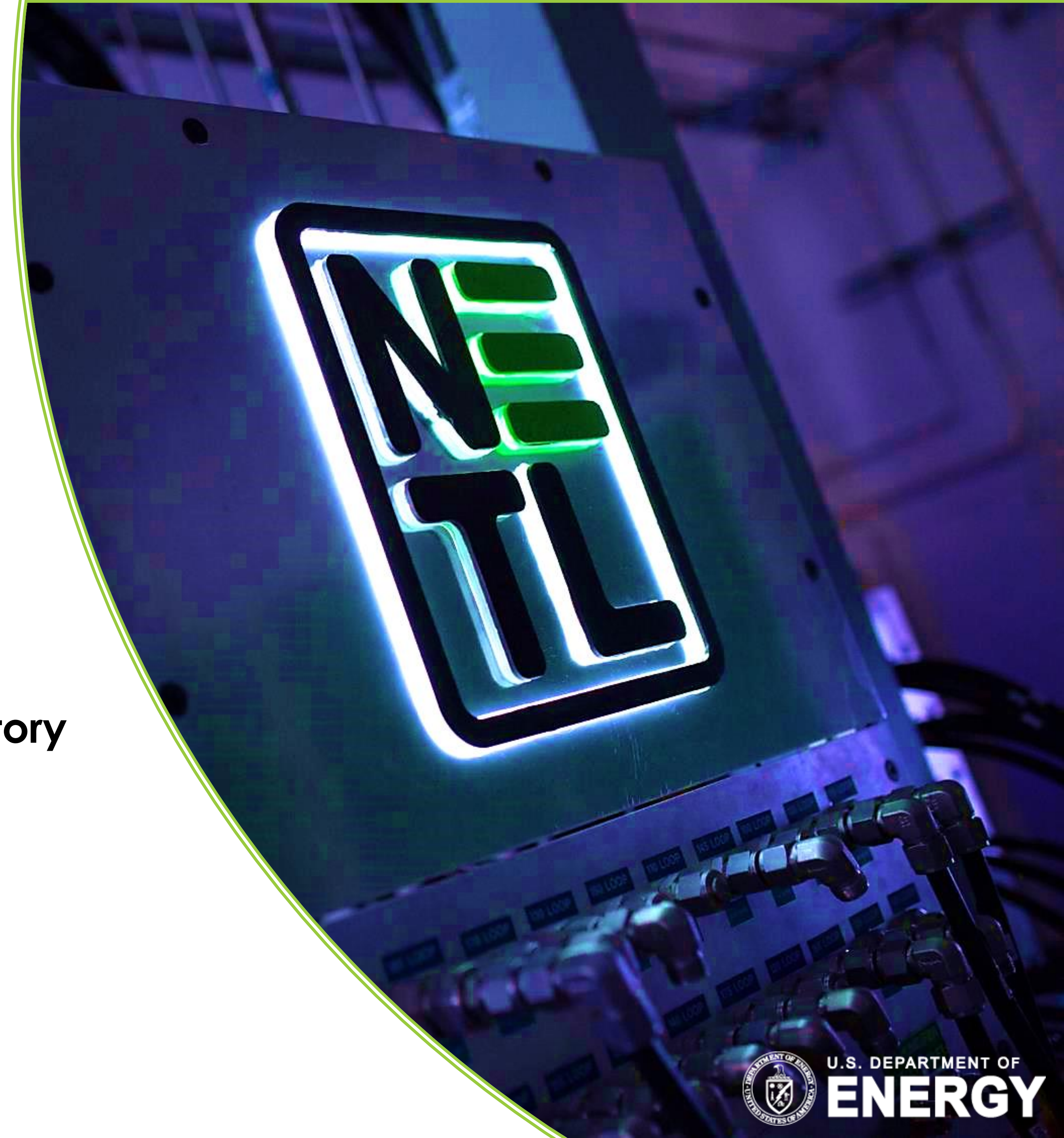


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