Power FEED Study Review Summary

and Comparison to NETL Baseline

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Background

Since 2019, the U.S. Department of Energy Office of Fossil Energy and Carbon Management has been sponsoring front-end engineering design (FEED) studies on retrofitting the existing U.S. fossil-fueled power fleet with state-of-the-art carbon capture technology

Award terms stipulate the publication of a FEED study report (Available on OSTI)

In addition to investing in specific project maturation, this initiative informs DOE, technology developers, and the public of real-world considerations associated with point-source carbon capture at power plants.

Background: FEED Studies vs TEA

FEED studies provide a unique opportunity for systems analysis and can advance understanding of capture system deployment.

FEED Studies

- FEED studies report on performance and costs for specific projects with better accuracy than TEA because they report on more defined projects.
- Examining FEED study reports in concert can identify typically overlooked factors that must be evaluated for near-term implementation of fossil-fueled power plants.

Techno-Economic Analyses (TEA)

- Guiding principles for TEA provide a framework for high-level estimation and comparison of system cost and performance on a common basis.
- TEA-based capital and operating cost estimates **are not reflective of costs associated with actual project deployment conditions** that deviate from the design, market, or financial structure assumptions in any way.

Objective

The objective of this presentation is to highlight five high-level findings resulting from NETL's review of recently completed FEED studies:

1. Under 2020–2022 market conditions, steam extraction from the host plant was more economical than utilizing an auxiliary boiler
2. Data gaps regarding steam extraction and host plant tie-in at the stack exist
3. Multiple factors impact the number of parallel capture trains required
4. The host plant operational mode and capacity factor significantly impact the business case
5. Data gaps regarding solvent reclamation and air emission control requirements exist

Reviewed FEED Studies

NATIONAL ENERGY TECHNOLOGY LABORATORY

Membrane Technology and Research, Inc. (MTR)

- Site: Basin Electric Dry Fork Station, WY
- Capture technology: MTR membranes
- https://www.osti.gov/biblio/1897679

Minnkota Power Cooperative, Inc.*

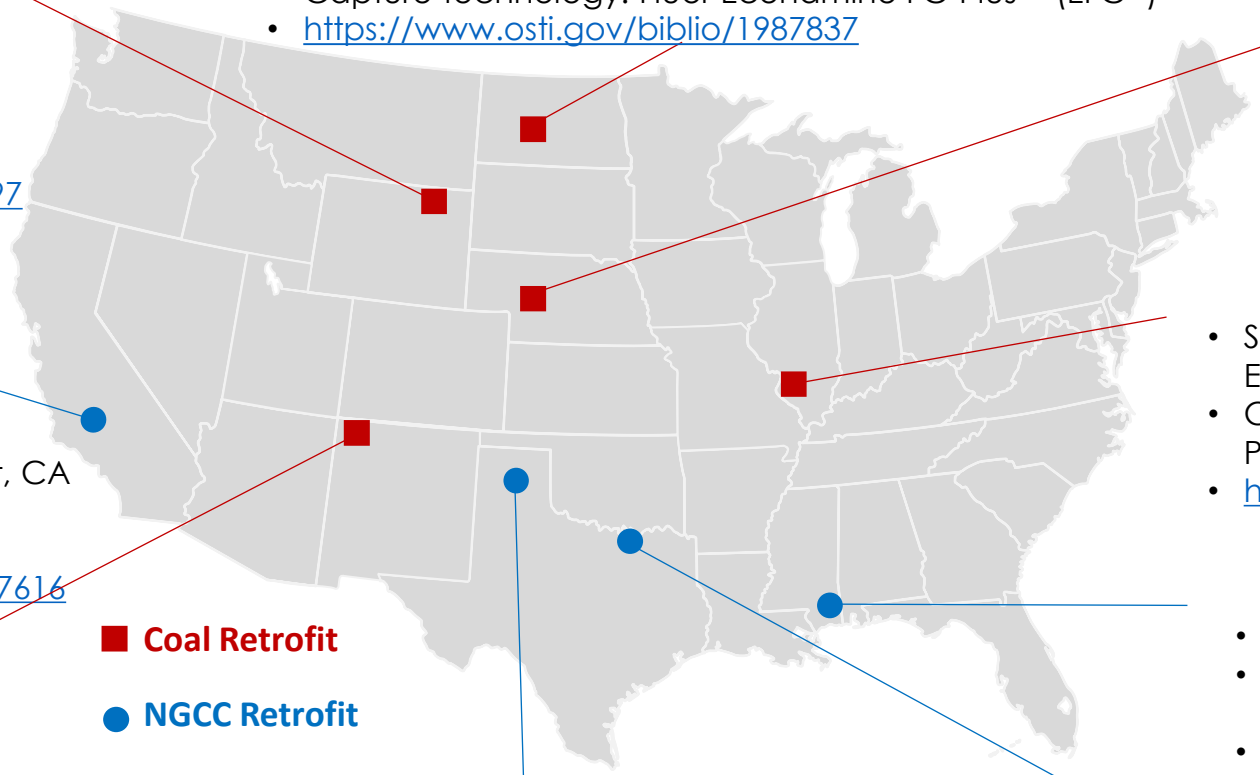
- Site: Milton R. Young Station, ND
- Capture technology: Fluor Econamine FG Plus℠ (EFG+)
- https://www.osti.gov/biblio/1987837

ION Engineering, LLC*

- Site: Nebraska Public Power District Gerald Gentleman Station, NE
- Capture technology: ION
- https://www.osti.gov/biblio/1963720

Electric Power Research Institute (EPRI)

- Site: California Resources Corporation Elk Hills Power Plant, CA
- Capture technology: Fluor Econamine FG Plus℠
- https://www.osti.gov/biblio/1867616



Board of Trustees of the University of Illinois (UIUC)

- Site: Prairie State Generating Company Energy Campus, IL
- Capture technology: MHIA's KM CDR Process™
- https://www.osti.gov/biblio/1879443

Southern Company Services, Inc.

- Site: Southern Company Plant Daniel, MS
- Capture technology: Linde-BASF OASE® blue solvent
- https://www.osti.gov/biblio/1890156

Enchant Energy, LLC

- Site: San Juan Generating Station, NM
- Capture technology: Mitsubishi Heavy Industries America (MHIA) KM CDR Process™
- https://www.osti.gov/biblio/1889997

The University of Texas at Austin (UT)

- Site: Golden Spread Electric Cooperative Mustang Station, TX
- Capture technology: Piperazine Advanced Stripper (PZAS™) process
- https://www.osti.gov/biblio/1878608

Bechtel National, Inc.

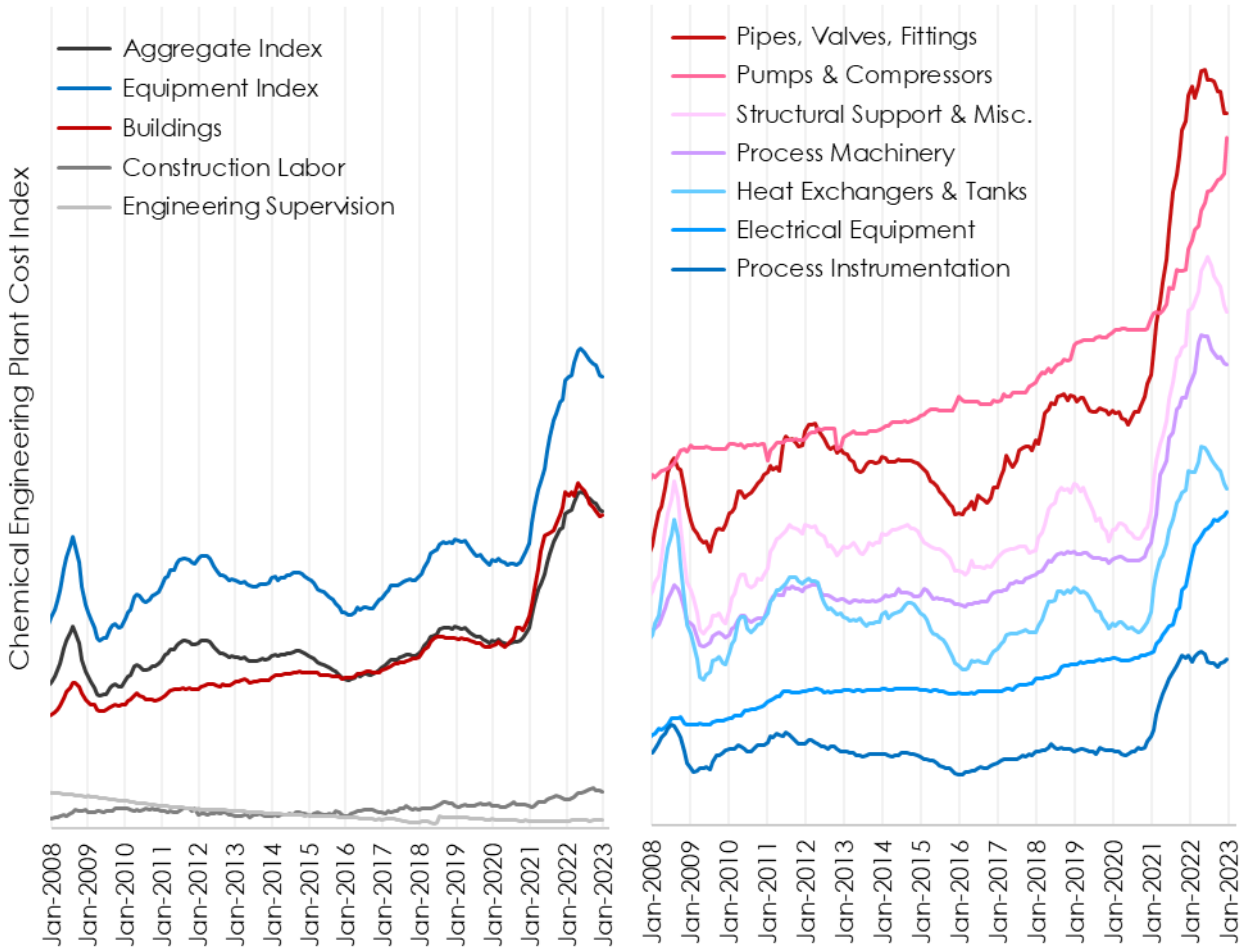
- Site: Panda Power Sherman Power Plant, TX
- Capture technology: 35 wt% monoethanolamine (MEA)
- https://www.osti.gov/biblio/1836563

*** - Public FEED report published after completion of this insights analysis**

Cost Comparison Disclaimer

Direct Cost Comparison is Inadvisable

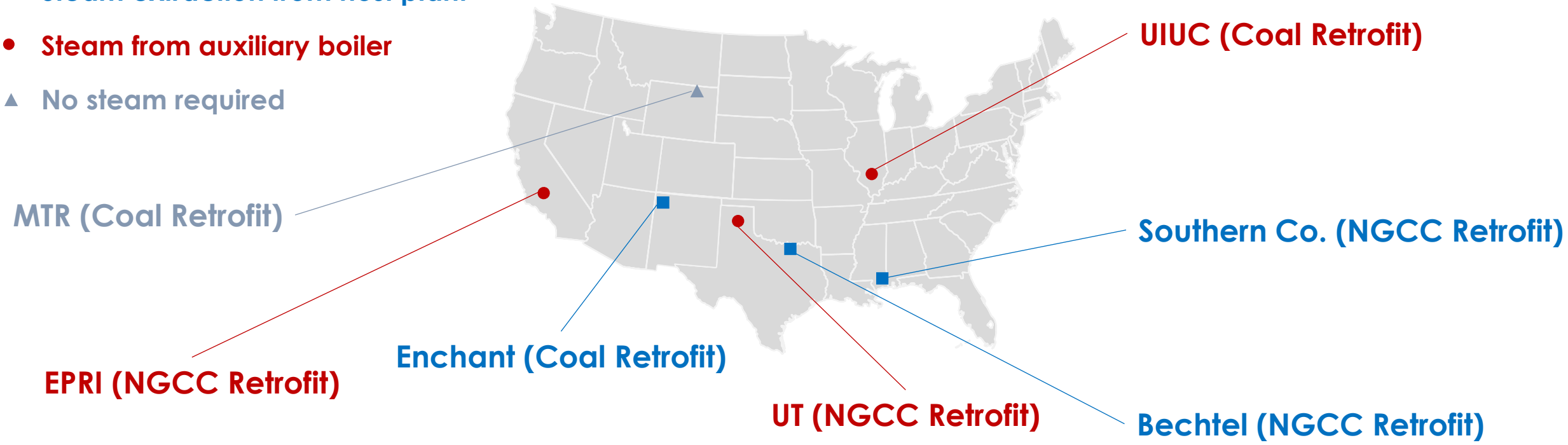
- **Costs were developed over a period of significant market variability (2020–2022)**
- **Costs were not developed on a similar basis** (different costing assumptions were made across projects), and capital and operation and maintenance (O&M) costs were defined differently across projects (different tax assumptions, escalation, owner's cost assumptions, insurance, etc.)
- **Costs were impacted by many different inextricable factors**, such as sparing philosophies, local labor rates, geotechnical impacts, ambient conditions, climatic conditions, and other project-specific constraints that lead to different design choices



1. Under 2020–2022 Market Conditions, Steam Extraction From the Host Plant Was Preferred

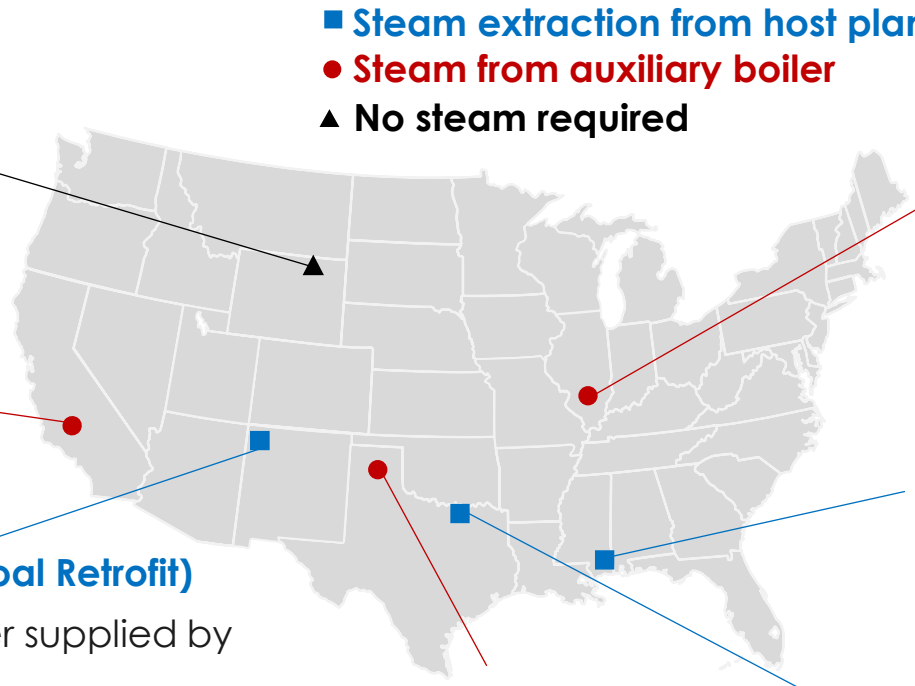
In all cases considered here, the design decision to utilize auxiliary steam generation was motivated by host plant-specified restrictions against steam extraction

- Steam extraction from host plant
- Steam from auxiliary boiler
- No steam required



1. Under 2020–2022 Market Conditions, Steam Extraction From the Host Plant Was Preferred (continued)

In configurations utilizing steam from the host plant, overall performance and cost are not only impacted by eliminating the dedicated steam generation systems but also by increasing water availability.



MTR (Coal Retrofit)
- Water constrained
- Dedicated systems:
  - Supply water treatment
  - Wastewater treatment
  - WSAC

EPRI (NGCC Retrofit)
- Water constrained
- Dedicated systems:
  - Hybrid Wet surface air cooler (WSAC)
  - Dry cooling
  - Glycol cooling
  - Cooling tower
  - Wastewater treatment

Enchant (Coal Retrofit)
- Sufficient water supplied by host plant
- Dedicated systems:
  - Cooling tower
  - Wastewater treatment

UT (NGCC Retrofit)
- Water constrained
- Dedicated system:
  - Dry cooling

UIUC (Coal Retrofit)
- Assume permitting will be granted
- Dedicated systems:
  - Supply water treatment
  - Cooling tower
  - Wastewater treatment

Southern Co. (NGCC Retrofit)
- Sufficient water supplied by host plant
- Dedicated system:
  - Cooling tower system (for critical operating scenarios)

Bechtel (NGCC Retrofit)
- Sufficient water supplied by host plant
- No dedicated systems

2. Data Gaps Regarding Steam Extraction and Host Plant Tie-in at the Stack Exist

Future research and development (R&D) addressing the impact of steam extraction options on host plant performance and operability is recommended.

- Host plants were reportedly concerned that steam cycle modifications could impact system reliability.

- Southern Company's evaluation of steam sourcing and condensate return configurations FEED showed that the LP/IP crossover may not be the best option for steam extraction.
  - **Extracting LP steam directly from the heat recovery steam generator (HRSG) and supplementing with LP/IP crossover steam is recommended; this can have a minor impact on operational flexibility if minimal modifications to the LP steam turbine are made.**

3. Multiple Factors Impact the Number of Parallel Capture Trains Required

In addition to physical equipment sizing, the relationship between measured performance at a small scale and expected performance at a large scale, risk reduction for initial projects, and modularization for site accessibility influence equipment size.

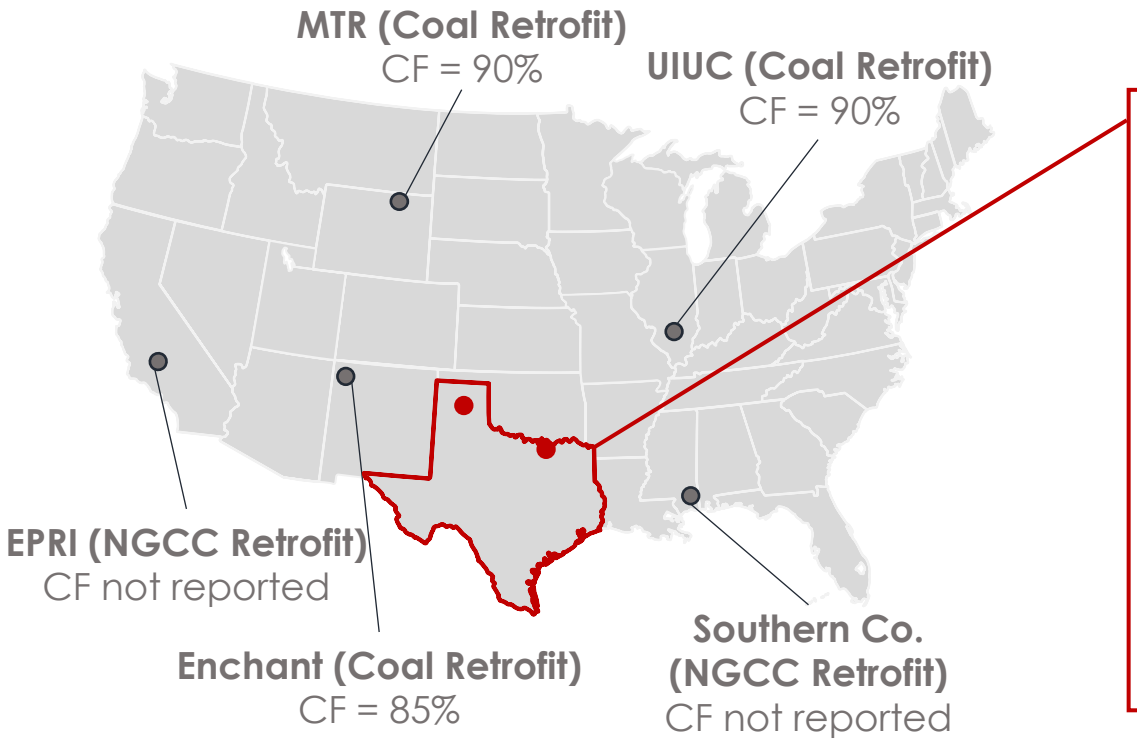
Parameter	Coal Retrofit		NGCC Retrofit			
	UIUC	Enchant	Southern Co.	UT	EPRI	Bechtel
Design basis flue gas, m^3/s	1,800	1,860	1,050	1,050	725	740
Turndown	50%	43%	61%	58%	40%	50%
Absorber vessel	Not reported (MHIA)	Not reported (MHIA)	Cylindrical	Rectangular 40×47×117' ft	Not reported	Cylindrical 39×145 ft
Capture trains	4	2	4*	2	1	2*
Reasoning provided for number of trains	Absorber and quencher modularized for shipping	Accessible for delivery of large modules; maximum equipment sizing	--	--	--	Limited data from internal suppliers supporting operation for >49 ft diameter cylindrical vessels

*Two absorbers share one regenerator

4. Host Plant Operational Mode and Capacity Factor Significantly Impact the Business Case

With increased renewable penetration in global energy systems, the fossil-powered plant capacity factor (CF) is expected to reduce over time.

Future incentives could positively impact the business case for fossil-fueled plants fitted with capture technology. The CF for plants fitted with capture may increase due to preferential dispatching of clean power, and the electricity sales realizations may increase with a clean energy designation.



UT (NGCC Retrofit)
CF = 52%

Sized to maximize abatement:

- 100% of NGCC emissions are treated when the NGCC plant is operated at full load; this leads to stranded assets when the NGCC is turned down.
- Business case analysis concludes that increasing the CF from 52% to 85% can reduce the cost of CO_2 captured by $40/tonne.

Bechtel (NGCC Retrofit)
CF = 57%

Sized to maximize usage of the capture system:

- 100% of NGCC emissions are treated when the NGCC plant is operated at its minimum load, and 68% of NGCC emissions are treated when the plant is operated at maximum load.

5. Data Gaps Regarding Solvent Reclamation and Air Emission Control Requirements Exist

R&D addressing solvent reclamation requirements is recommended.

- The Bechtel study notes uncertainties in the reclaimer regime and asserts that reclaimer operation, design, performance, and cost may need to be revisited after an on-site testing period.

- The UT FEED report notes a lack of data pertaining to piperazine degradation due to NO_X exposure and states that the system design, both upstream flue gas pretreatment and/or solvent reclamation, may need to be revisited.

5. Data Gaps Regarding Solvent Reclamation and Air Emission Control Requirements Exist (continued)

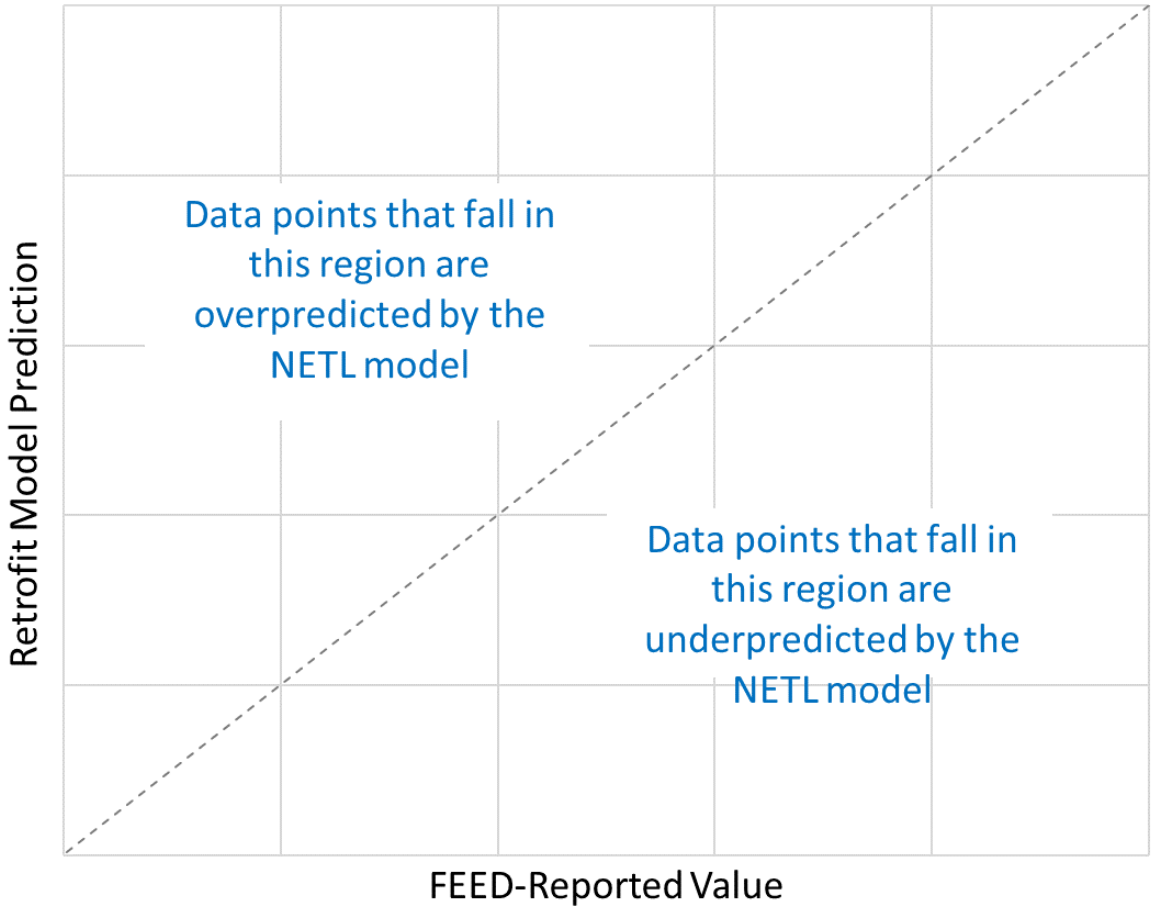
Uncertainties related to air emissions exist. Clearer permitting pathways and requirements, which will dictate emissions profiles, may emerge as projects progress.

- The subject funding opportunity announcement (FOA 2058) does not require minimization of air emissions beyond what was necessary for the CO_2 capture process and emissions permitting; therefore, the reviewed projects were not designed or optimized to minimize or mitigate ancillary air emissions*.
- The design of pollutant emissions control equipment is not finalized in the FEED studies due to uncertainty associated with system emissions and permitting requirements.
- Inclusion of additional control equipment can negatively impact the overall system performance, cost, and construction schedule.
- These uncertainties and their impacts may be reduced with increased understanding of the impact of plant-specific impurities on capture system emissions and by clearer permitting pathways.

* FEED studies were completed prior to EPA's publication of its proposed rule for greenhouse gas emissions from fossil fuel-fired steam-generating units that undertake a large modification (88 FR 33240, published 23 May 2023)

Comparisons to NETL Baseline Study Cases

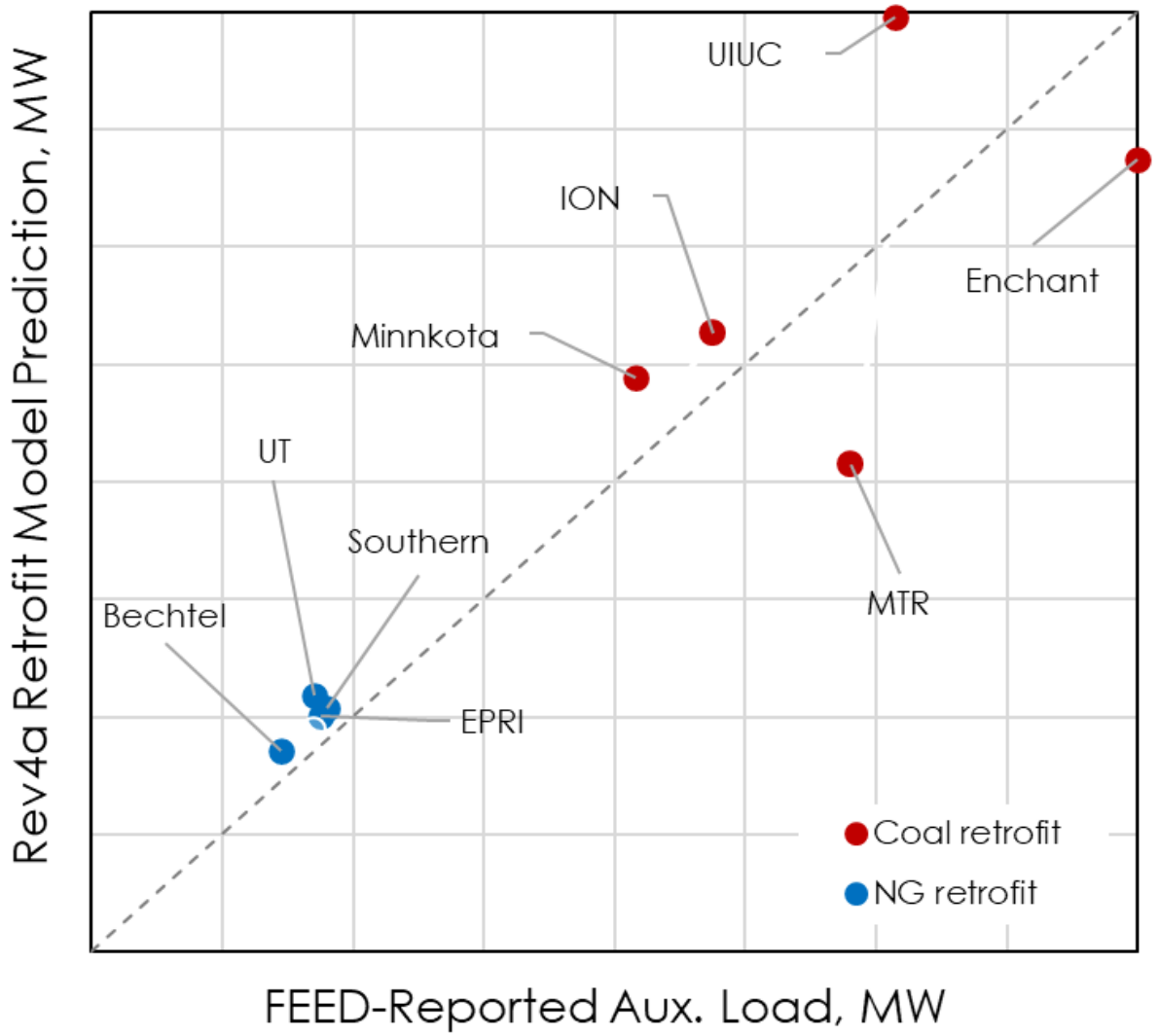
Results Presentation Approach



- **Presenting the results in this manner provides a visual representation of the deviation of NETL models from data presented in each FEED study**
  - For a given parameter of interest (e.g., auxiliary load), a data point comparing the FEED value to a baseline case is plotted
  - For cases using specific configurations not covered by published NETL baseline cases, a second point is plotted to illustrate the updated model

Comparisons to NETL Baseline Study Cases

Example Comparison Results



Key Takeaways

from Comparison of FEED Results to NETL Baseline Cases

- **NETL models generally:**
  - Predict performance metrics such as auxiliary load and steam derate reasonably well, and can be used to highlight project specific deviations
  - Do not predict O&M costs well but do provide sufficient granularity for highlighting where discrepancies lie
    - Solvent costs and reclaimer waste disposal costs are typically underpredicted, and the reviewed FEED studies typically assume lower fuel and power prices
  - Do not predict capital costs accurately, mainly due to a discrepancy in how capital costs are defined and which costing assumptions are made.
  - Predict cost of capture with reasonable accuracy

On-Going and Future Work

- NETL continues to review and provide feedback on incoming FEED studies, to include forthcoming power, industrial, biomass plants, and carbon dioxide removal FEED studies
- Developed a summary insights manuscript that provides more detail on what was presented today – submitted to journal
  - "Insights from FEED Studies for Retrofitting Existing Fossil Power Plants with Carbon Capture Technology"
- Developing a similar publication summarizing the results from recently completed industrial CO_2 capture FEED studies.
- NETL models to be adapted/expanded where appropriate based on gaps identified when comparing to FEED study results

Questions/ Comments

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