FOA 2614 Round 3 Kickoff

Engineering-Scale/Pilots – Power and Industrial

Solutions for Today | Options for Tomorrow

Wednesday, August 7, 2024

Ron Munson
Point Source Carbon Capture Technology Manager

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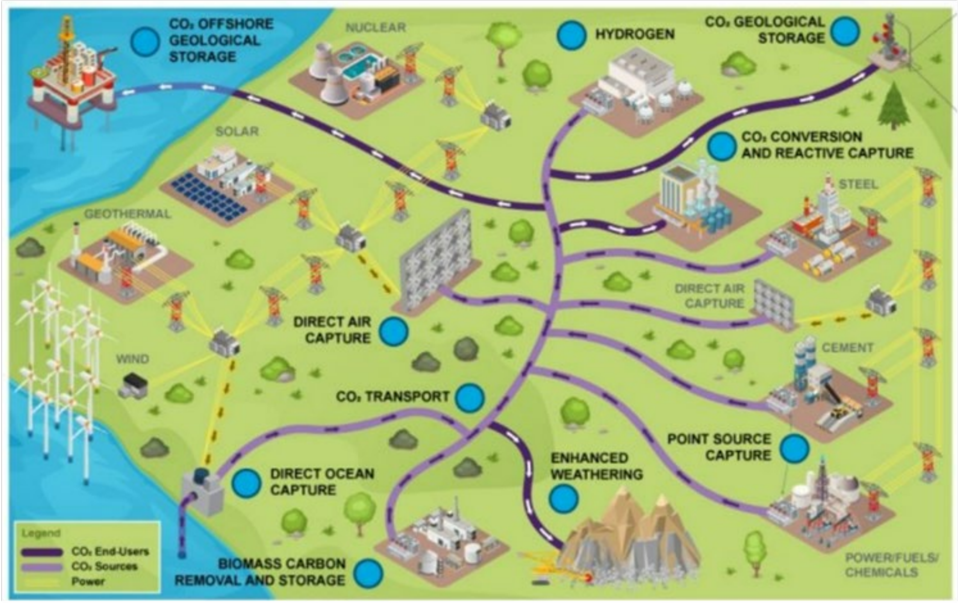
PSC Strategic Vision

Support demonstration of first-of-a-kind carbon capture on power and industrial sectors coupled to dedicated and reliable carbon storage, that will lead to commercially viable carbon hub opportunities for widescale deployment and facilitate a carbon-free economy by 2050, emphasizing robust analysis of life cycle impacts, and understanding air/water quality impacts.

Secure Carbon Storage

Carbon Dioxide Removal & Low C Electricity and Heat



Low C Industry & Flexible Power + PSC

CO_2 Conversion into durable Products

Focus Area 1: Support Power Retrofit Demos

- Enabling technologies

Focus Area 2: Net Zero, Flex Power

- Technology development to support flexible CCS with high capture efficiency
- FEEDs to seed the formation of Carbon Hubs.

Focus Area 3: Support Industrial Retrofit Demos

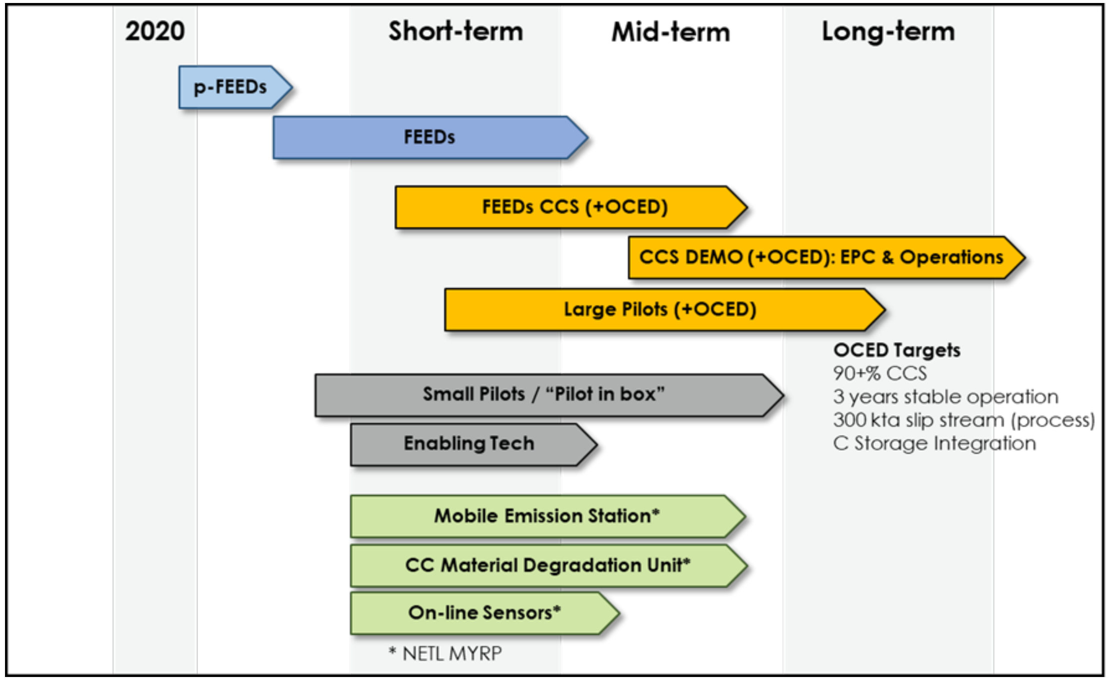
- Enabling technologies

Focus Area 4: Integrated decarbonized industrial + CCS

- Technology development for integrated decarbonized industrial processes coupled with transformational CCS
- FEEDs to seed the formation of Carbon Hubs.

Enabling Power/Industrial CCS Demonstrations

Develop technologies to support successful demonstration of retrofit CCS projects at electricity generation and industrial facilities with the emphasis of measuring, monitoring and controlling CCS-related environmental impacts to assure just and sustainable deployment.



1. Engineering control methods/equipment (e.g., pre-treatment, post-treatment acid wash, upstream filters, aerosol controls, corrosion inhibitors)
2. Evaluate and predict capture media degradation/secondary emissions
3. Reuse/recycle processes for capture material
4. Pollutant air dispersion models
5. Online sensors to measure gas- and liquid-phase degradation products
6. Carbon Capture pFEEDs & FEEDs
7. Mobile Pilots ("Pilots in box")

FOA 2614

FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

Department of Energy (DOE)
Office of Fossil Energy and Carbon Management (FECM)

CARBON MANAGEMENT

Funding Opportunity Announcement (FOA) Number: DE-FOA-0002614

AOI-1. Carbon Conversion Technology
The objective of AOI-1 is to support R&D investigating the conversion of carbon dioxide (CO_2) into environmentally responsible and economically feasible products.

AOI-2. Carbon Dioxide Removal Technology
The objective of AOI-2 is to solicit applications that develop carbon dioxide removal (CDR) technologies (e.g., direct air capture with durable storage, biomass carbon removal and storage, enhanced mineralization, ocean-based CDR, terrestrial sequestration) to support progress towards achieving the U.S. Department of Energy’s Carbon Negative Shot target economically feasible products.

AOI-3. Point Source Carbon Capture
The objective of AOI-3 is to solicit applications that are specifically focused on developing lower cost, highly-efficient, technologies for point source capture from fossil fuel power plants and industrial point sources.

AOI-4. Carbon Storage Technology
AOI-4 aims to support resource assessments to securely store large amounts of CO2.

FOA 2614 – Carbon Management

Round 3 Selections - Overview

AOI-3: Point Source Carbon Capture Technology

AOI-3 sought applications in support of developing lower cost, highly-efficient, technologies for point source carbon capture from fossil fuel power plants and industrial point sources capturing CO_2 with over 95% efficiency that is suitable for secure geologic carbon storage, including in situ mineralization or CO_2 conversion into long-lasting products (e.g., synthetic aggregates, concrete, durable carbon products).

7 selections
4 AOI-3A
1 AOI-3B
2 AOI-3C

AOI-3A

Test transformational carbon capture technologies under real flue gas conditions from process streams at an industrial facility, achieving ≥ 95% carbon capture efficiency and 95% CO_2 purity.

AOI-3B

Execute and complete FEED studies of commercial-scale, advanced carbon capture systems that separate CO_2 with ≥ 95% capture efficiency at existing NGCC power plants.

AOI-3C

(1) Test transformational, post-combustion, carbon capture technologies under real flue gas conditions from NGCC power plants achieving ≥ 95% carbon capture efficiency and 95% CO_2 purity.
(2) Demonstrate significant progress towards a 30% reduction in cost of capture versus a reference NGCC power plant with carbon capture for the same carbon capture efficiency (i.e., 95%).

FOA 2614 – Carbon Management

NATIONAL ENERGY TECHNOLOGY LABORATORY

Round 3 Selections

Key Deliverables

AOI-3:

- **EH&S Risk Assessment:** Due 90 days prior to project completion.
- **Technology Maturation Plan**: Initial TMP due 90 days after award; final TMP submitted 90 days prior to project completion.
- **Project Management Plan:** PMP update due 30 days after award.
  - Success criteria should be objective and stated in terms of specific, measurable, and repeatable data. Define success metrics for each budget period (BP).
  - Risk Management Plan: Updates should be provided as new risks are identified and/or as risks are retired.
- **R&D Community Benefits Plan:**
  - Specific, Measurable, Achievable, Relevant, and Timely (SMART) milestones: One per Budget Period.
  - Report on progress in quarterly and final reports.

AOI-3B Only:

- **Life Cycle Analysis (LCA):** Initial LCA is due 120 days after award and updated as needed throughout the project period of performance. A final LCA to be submitted 90 days prior to project completion.
- **Business Case Analysis** and **Project Cost Estimate:** Due 90 days prior to project completion.
- **Initial Engineering Design Package:** Due 180 days after award.
- **Final Engineering Design Package:** Due 90 days prior to project completion.

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Round 3 Selections

AOIs-3A and -3C Only:

Key Deliverables

Host Site Agreement: Due 6 months after project begins.
Techno-Economic Analysis: Initial TEA due 120 days after award and updated as needed throughout the project; final TEA submitted 90 days prior to project completion.
State Point Data Table: Final table due 90 days prior to project completion.

Other Project Requirements

Period of Performance:

- Up to 48 months with 4 Budget Periods
  - Exception for AOI-3C: if using existing carbon capture equipment at a test center such as NCCC, up to 36 months with 3 BPs

Success Metrics:

- Minimum of two months of steady-state testing at engineering scale
- Development of rigorous, first-principles, multi-scale, validated process models that include uncertainty quantification (UQ) that can be used to guide pilot scale test conditions

Emissions Measurements:

- Collection and reporting of the inlet and outlet criteria pollutants (e.g., NOx, SOx, PMs) and technology related emissions (e.g., solvent/sorbent losses and their degradation by-products) during the engineering-scale testing to assess the co-benefit emissions reduction of installing carbon capture technology
- Utilize NETL's mobile air emissions testing unit or collaborate with a third party for measuring emissions (e.g. nitrogen containing emissions, HAPs, aerosols).

Examination of Pilot Test Plan Requirements: Relevance of Uncertainty, High Capture, and Economics

Benjamin Omell[1]

1. National Energy Technology Laboratory

Carbon Management Research Project Review Meeting
Wednesday, August 7th, 2024

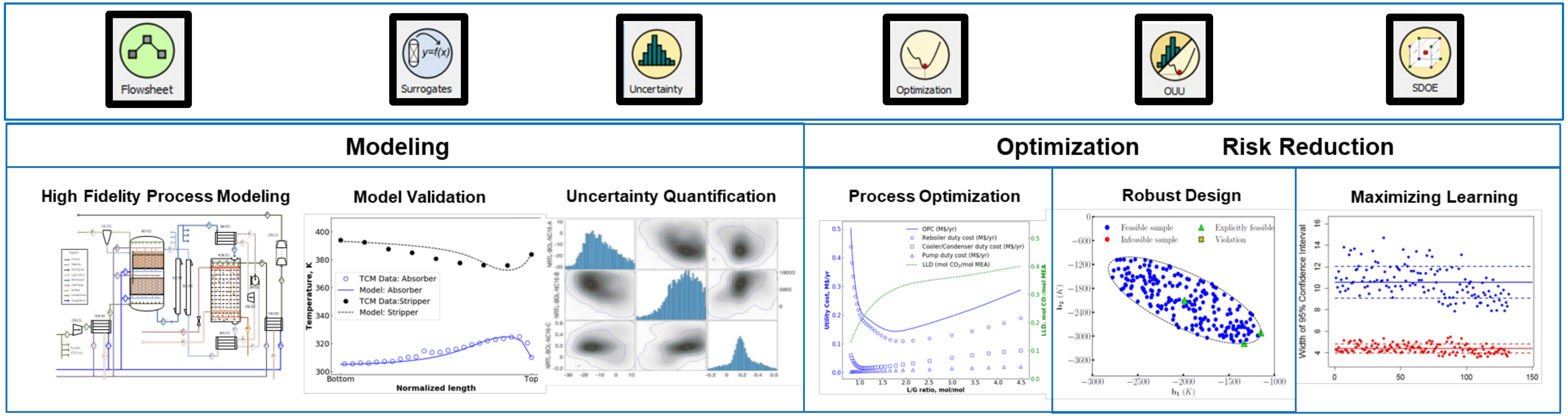
Validation of Models

- **First principle process models** are a key component in demonstrating **risk reduction** for process scale-up
- **Model demonstration and validation** at pilot scale is understood to be an **important component** of the FOA
- **All pilots** in 2614 Round 3 expected to **develop and validate process models** of their technology
  - Models **do not** have to be provided to NETL/FECM, however details of models and submodels, data sets, and validations will be examined
- **CCSI^2 can provide support** for model development, optimal DoE, uncertainty quantification and validation

CCSI2
Carbon Capture Simulation for Industry Impact

Fossil Energy Involvement in Pilot Campaigns

- **Optimizing the Value of Industrial Collaboration**



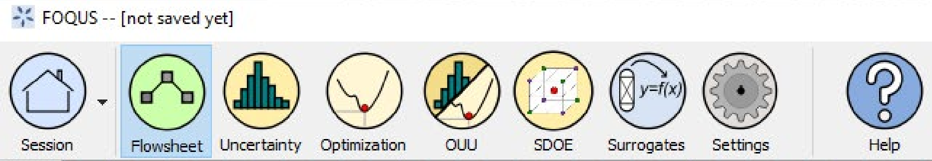
NATIONAL CARBON CAPTURE CENTER

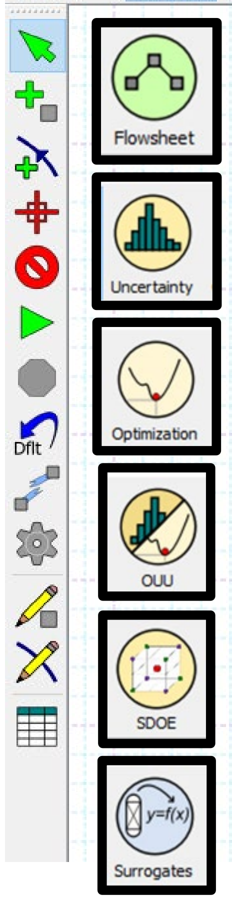
TECHNOLOGY CENTRE MONGSTAD

- Ensures an integrated modeling and testing framework demonstrated to ***eliminate years from scale up***
- Underpins ***Sequential Design of Experiments (SDoE)*** for ***optimizing value of pilot test data***
- ***Can save millions of dollars*** in test costs
- ***Minimizes commercial technology costs*** with rigorous, large-scale optimization
- ***Reducing uncertainty to increase confidence*** in commercialization of carbon capture technologies

CCSI[2]
Carbon Capture Simulation for Industry Impact

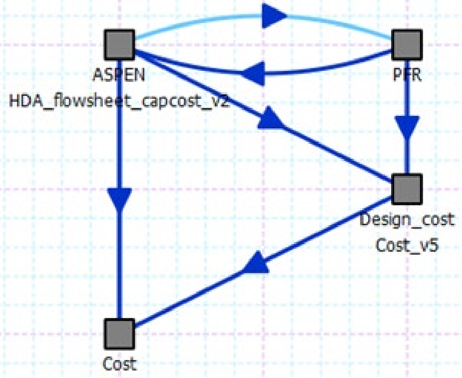
CCSI^2 FOQUS Framework





- Interface connecting commercial and open source modeling platforms (Aspen, Python, Pyomo, Excel). Uses <u>your</u> models.

- Propagates uncertainty through modeling hierarchy. Data visualization, parameter screening.



- Simulation based optimization of modeling ensemble.

- Optimization of modeling ensemble incorporating parameter-based uncertainty.

- Sequential Design of Experiments (SDoE) maximize learning from experimentation. Uniform and non-uniform space filling. Ordering.

- Surrogate modeling capabilities to reduce computational burden of simulation-based engineering. Now coupled with optimization.

CCSI^2 Carbon Capture Simulation for Industry Impact

Key Points

- **Standard Design of Experiments at Pilot Scale:**
  - Has unanticipated consequences
  - Can be inefficient

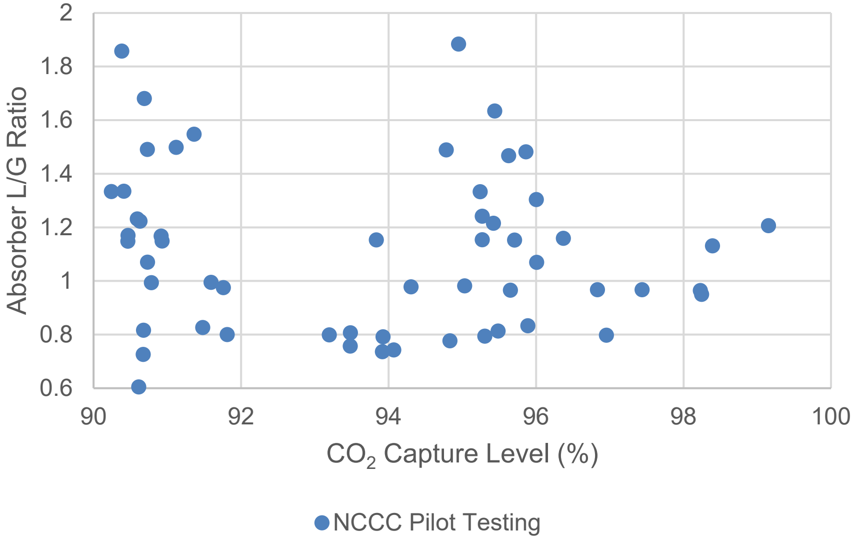
- **Economic Modeling**
  - Supports guarantee of operation in commercially optimal scenarios

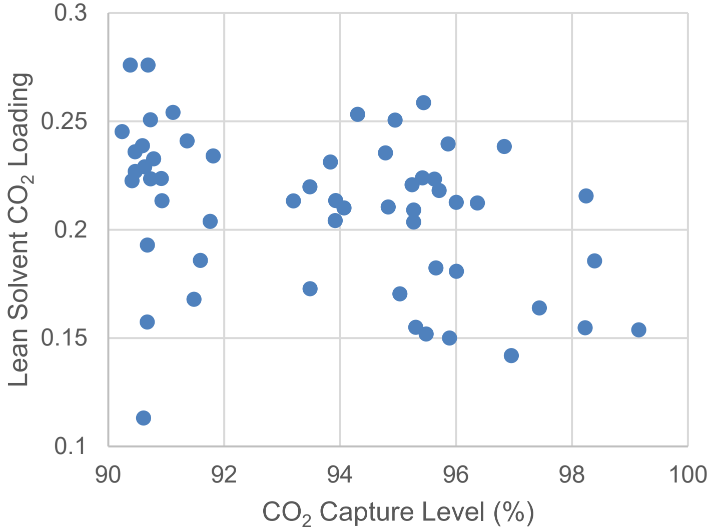
- **Uncertainty Should be Explicitly Considered**
  - Characterizes most impactful behavior
  - Uncovers process improvement opportunities

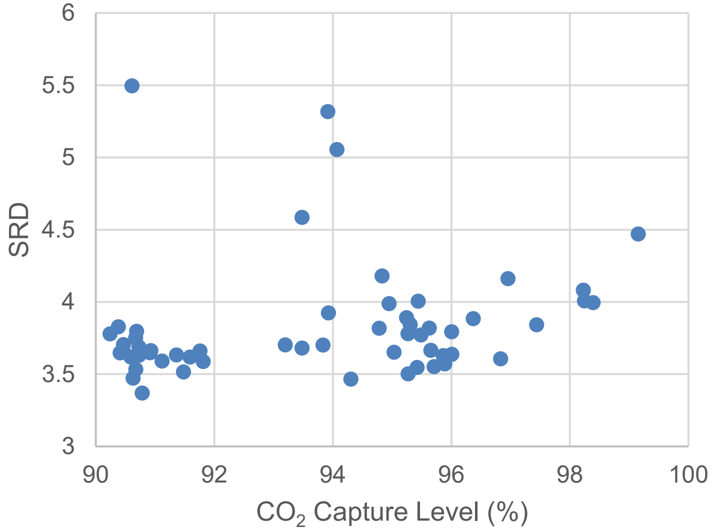
- **How to Implement the right test plan**
  - Activities, Data Requirements, Model Requirements, Schedule

High Capture Example: Considerations for Model Validations

- 2022 NCCC Campaign that targeted high capture
  - 88 runs with NGCC conditions
  - Far more parametric runs than a normal campaign







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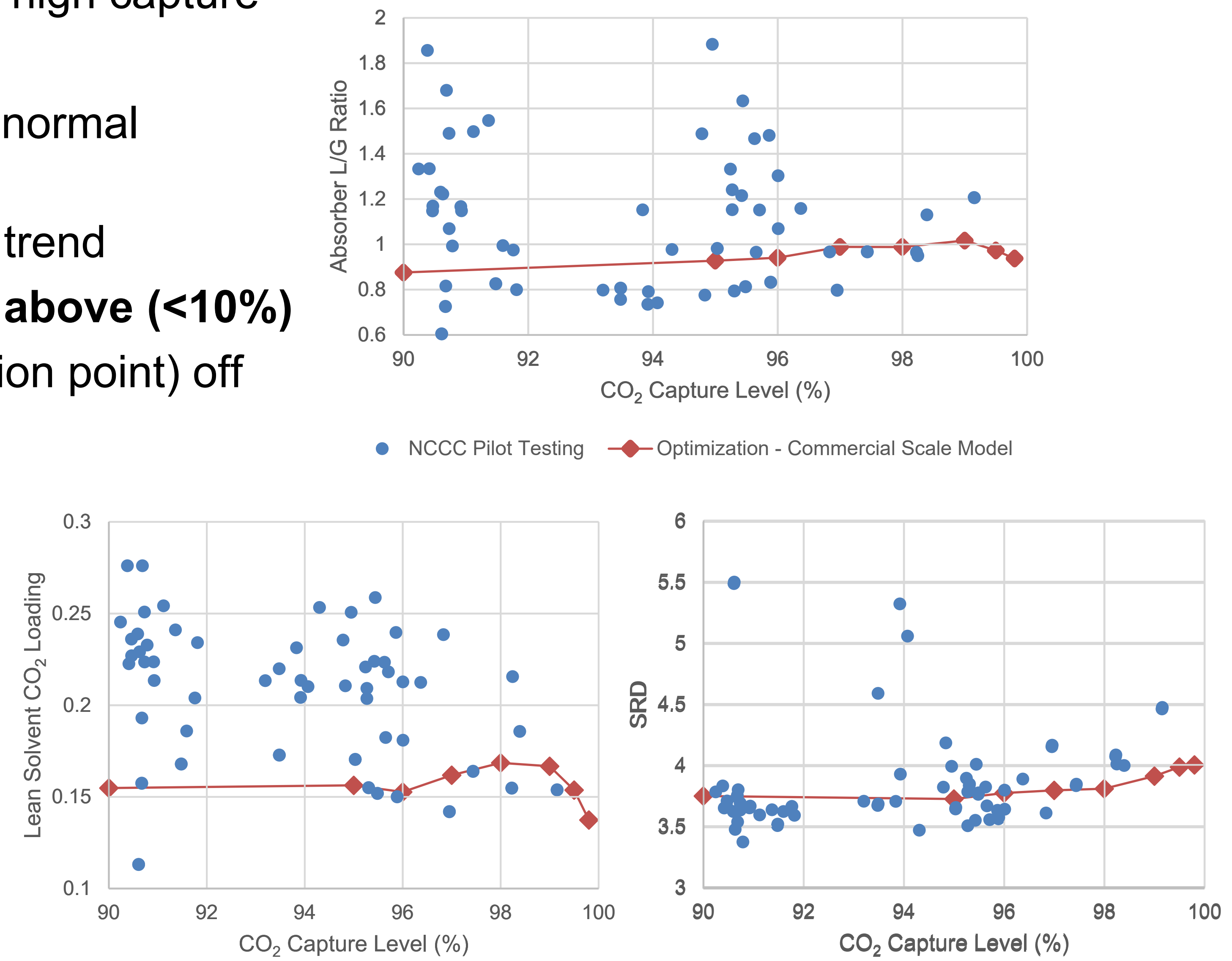
Carbon Capture Simulation for Industry Impact

High Capture Example: Considerations for Model Validations

- 2022 NCCC Campaign that targeted high capture
  - 88 runs with NGCC conditions
  - Far more parametric runs than a normal campaign
  - Of those, 12 are close to optimal trend
  - **Of those, 8 are 95% capture or above (<10%)**
  - Only 99%+ case (past the reflection point) off the trend



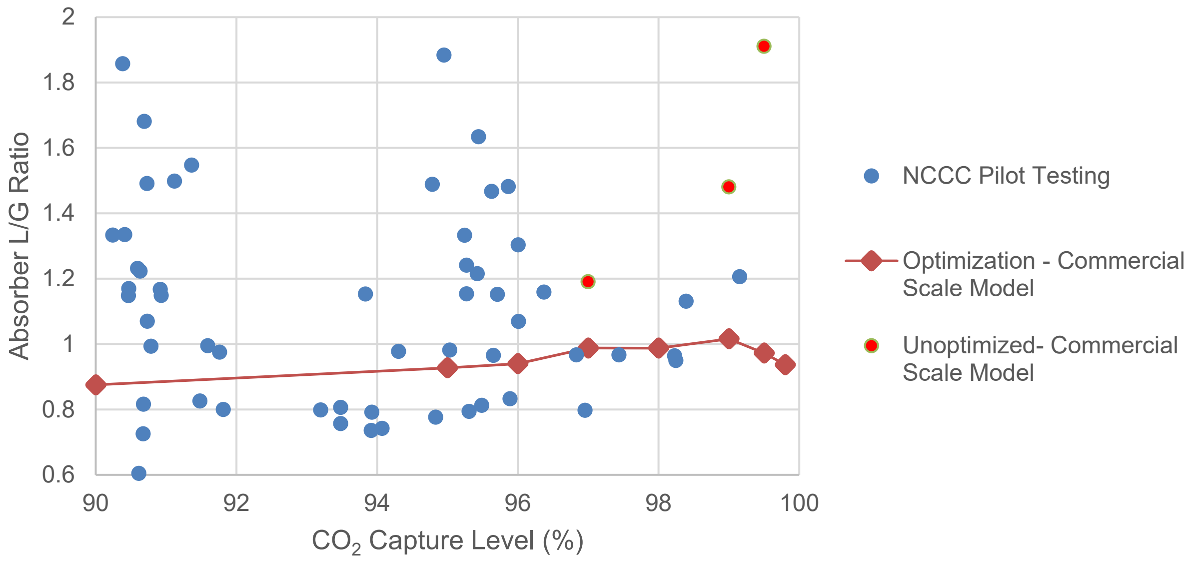
- High capture rates **not well represented**

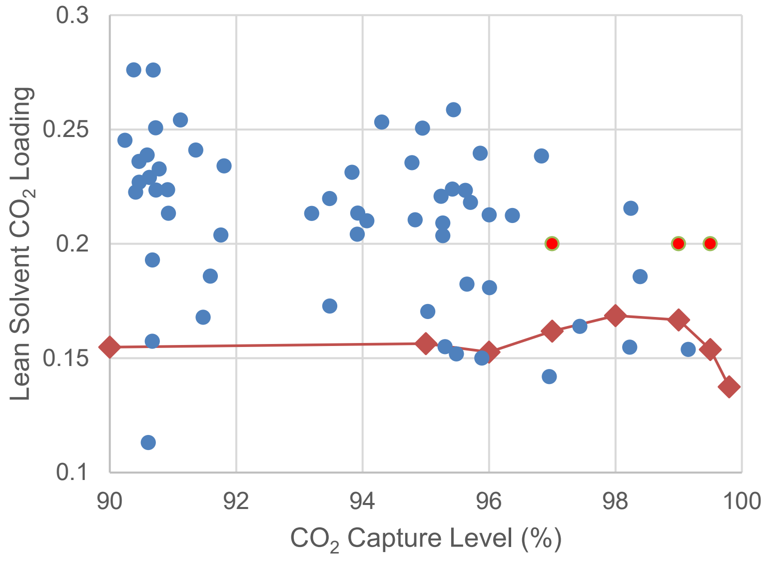
- Optimal operation **not well represented**

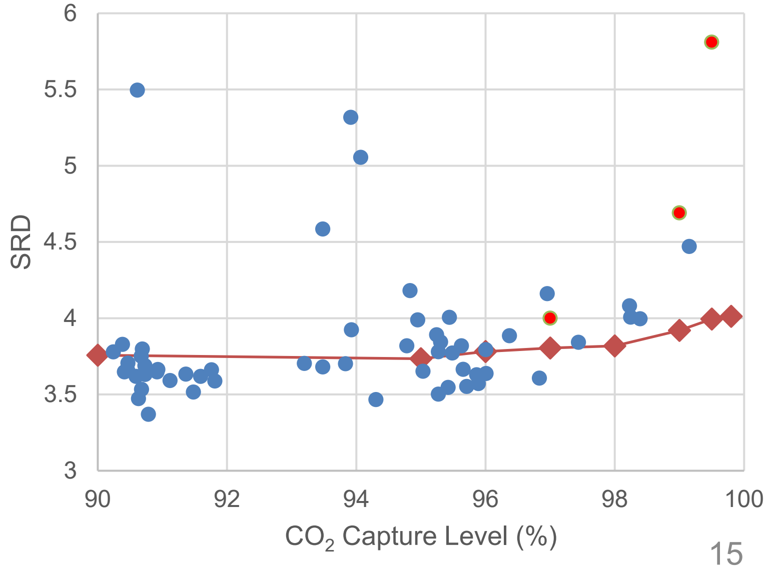
CCSI[2] Carbon Capture Simulation for Industry Impact

Economic Feasibility of Unoptimized Cases

Unoptimized Case Comparison (lean loading set at 0.2)			
% CO_2 Capture	97	99	99.5
L/G (kg/kg)	1.19	1.48	1.91
SRD (MJ/kg CO_2)	4.00	4.69	5.81
LCOE ($/MW-hr)	73.37	76.18	80.16
COAC ($/tonne CO_2)	90.50	96.63	107.77
Incremental COAC ($/tonne CO_2)		341.45	1937.15
Optimized Incremental COAC ($/tonne CO_2)			







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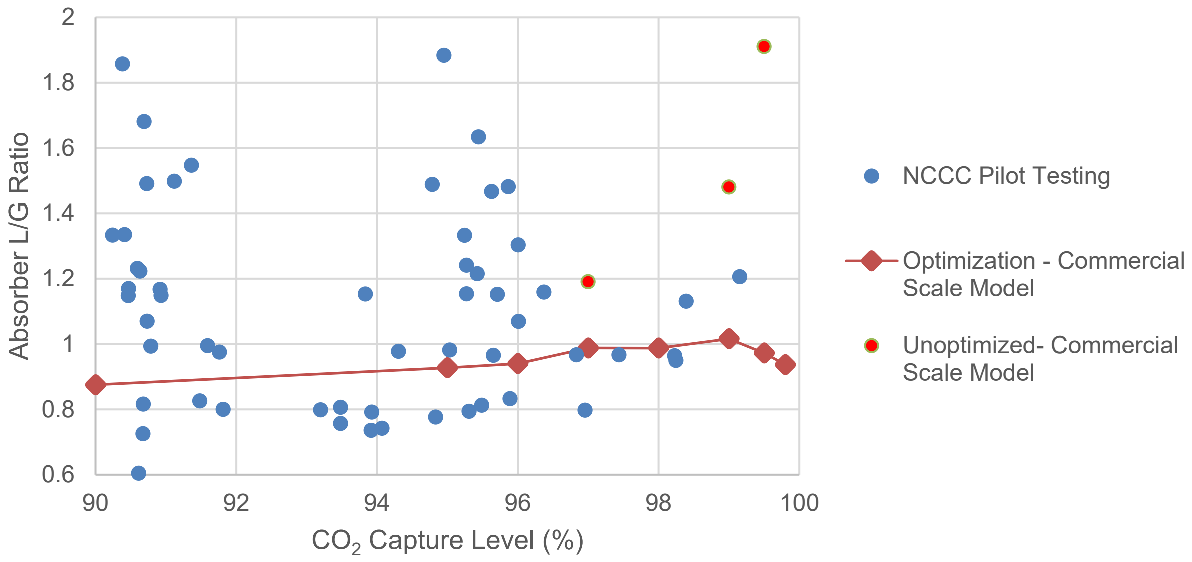
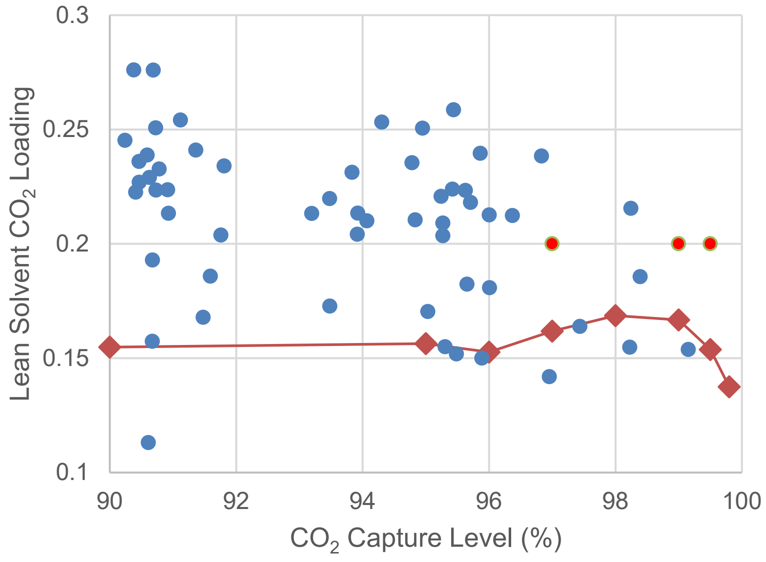
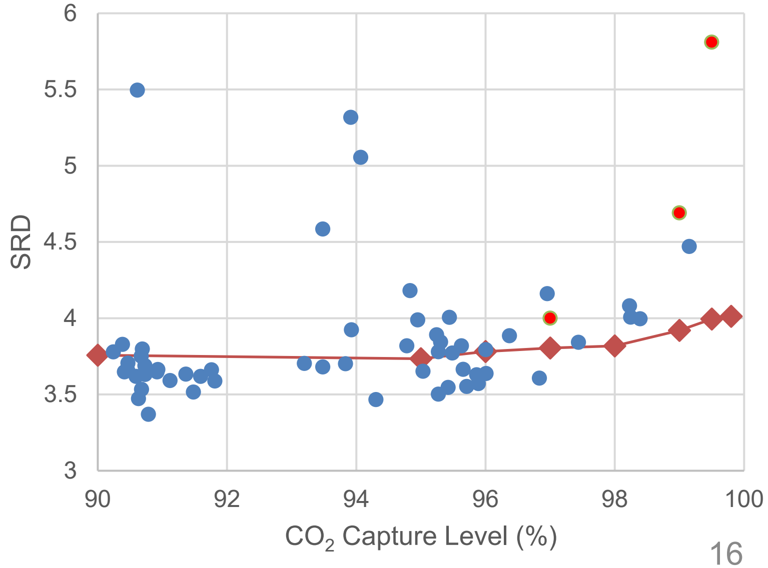
Incremental COAC ($/tonne CO_2)		**341.45**	**1937.15**
Optimized Incremental COAC ($/tonne CO_2)		**269.40**	**406.07**



Incremental cost to achieve net-zero is almost x5

Models are important to determine test cases!





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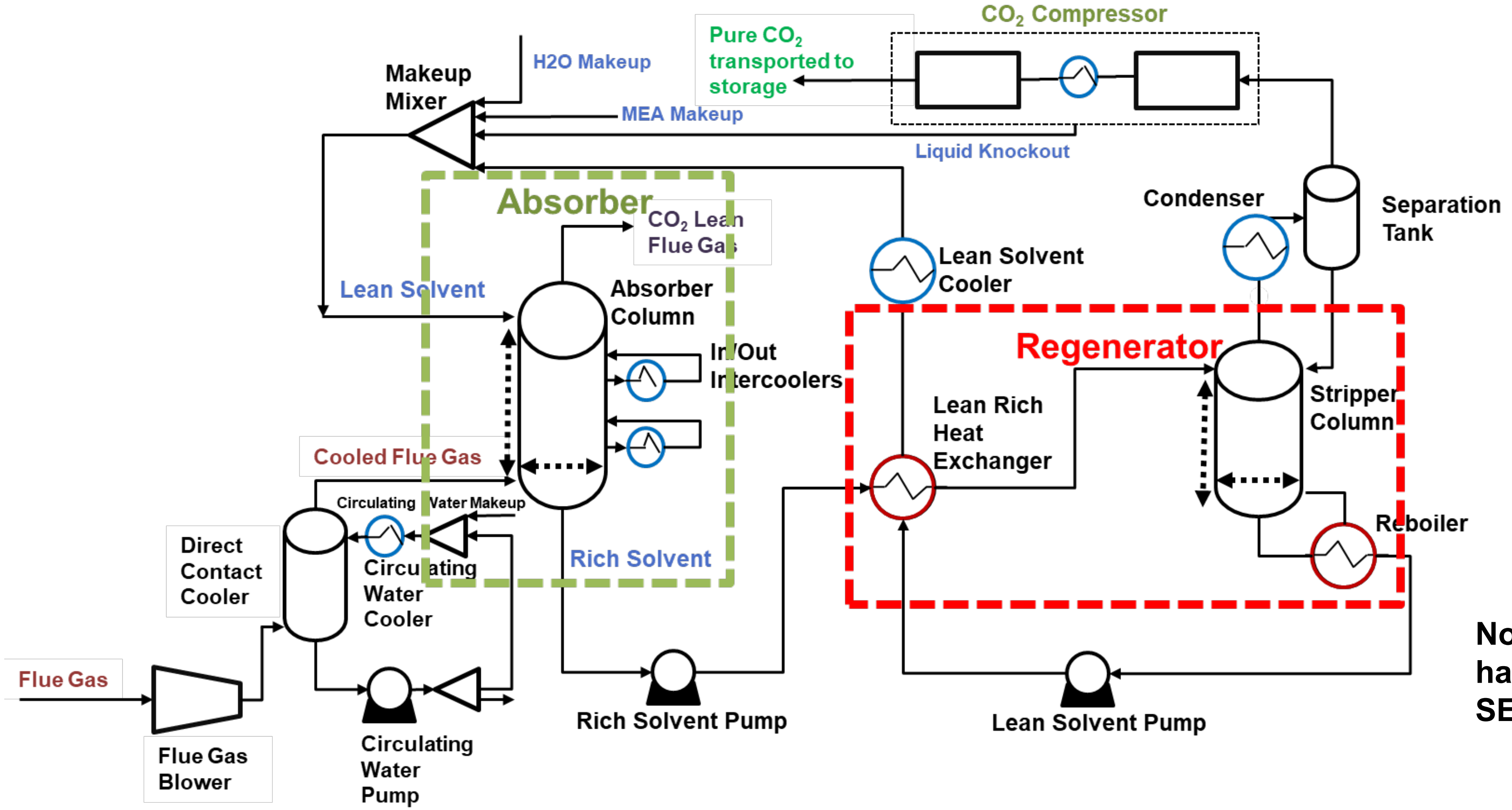
Carbon Capture Simulation for Industry Impact

Uncertainty Analysis at 97% and 99.5% Capture

Thirteen parameters considered in the thermodynamic and mass transfer models, selected based on Sobol analysis[1,2]

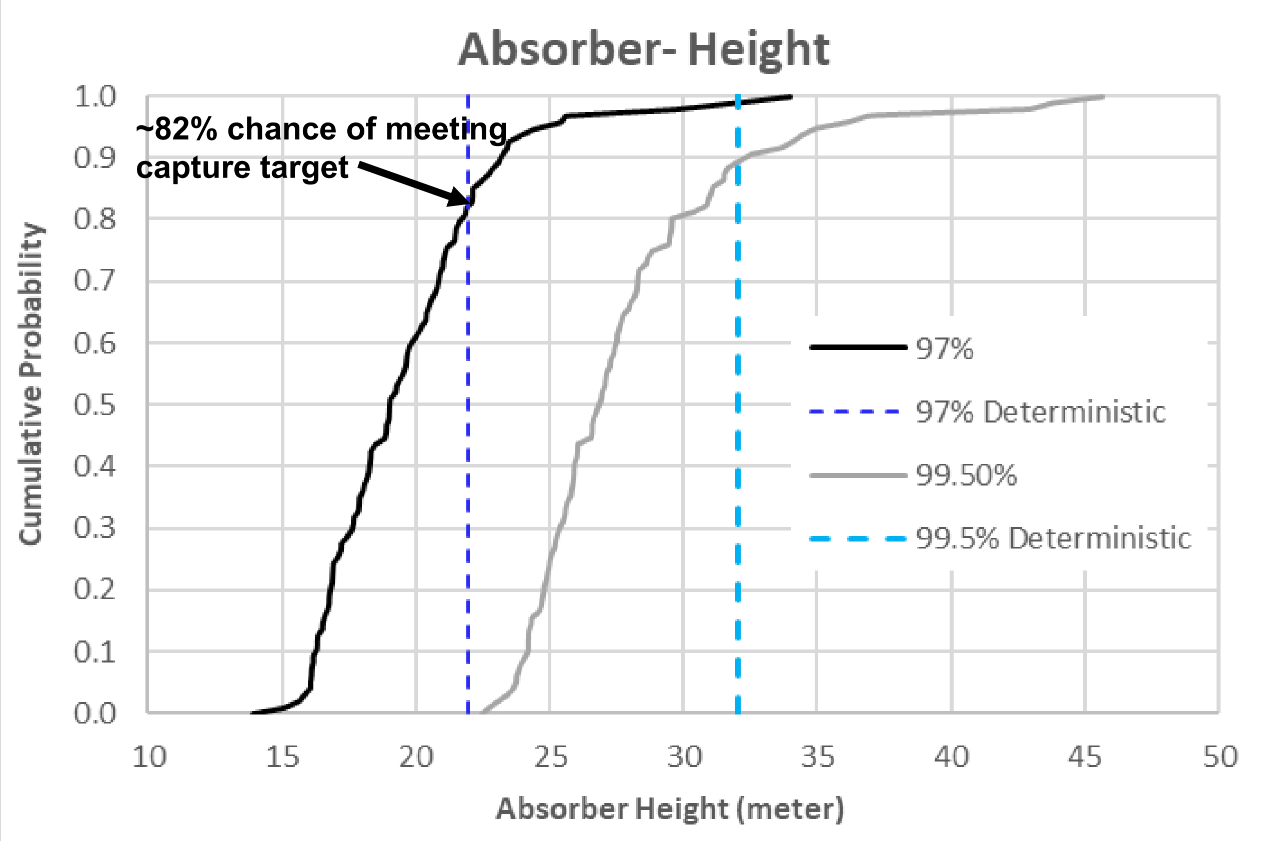


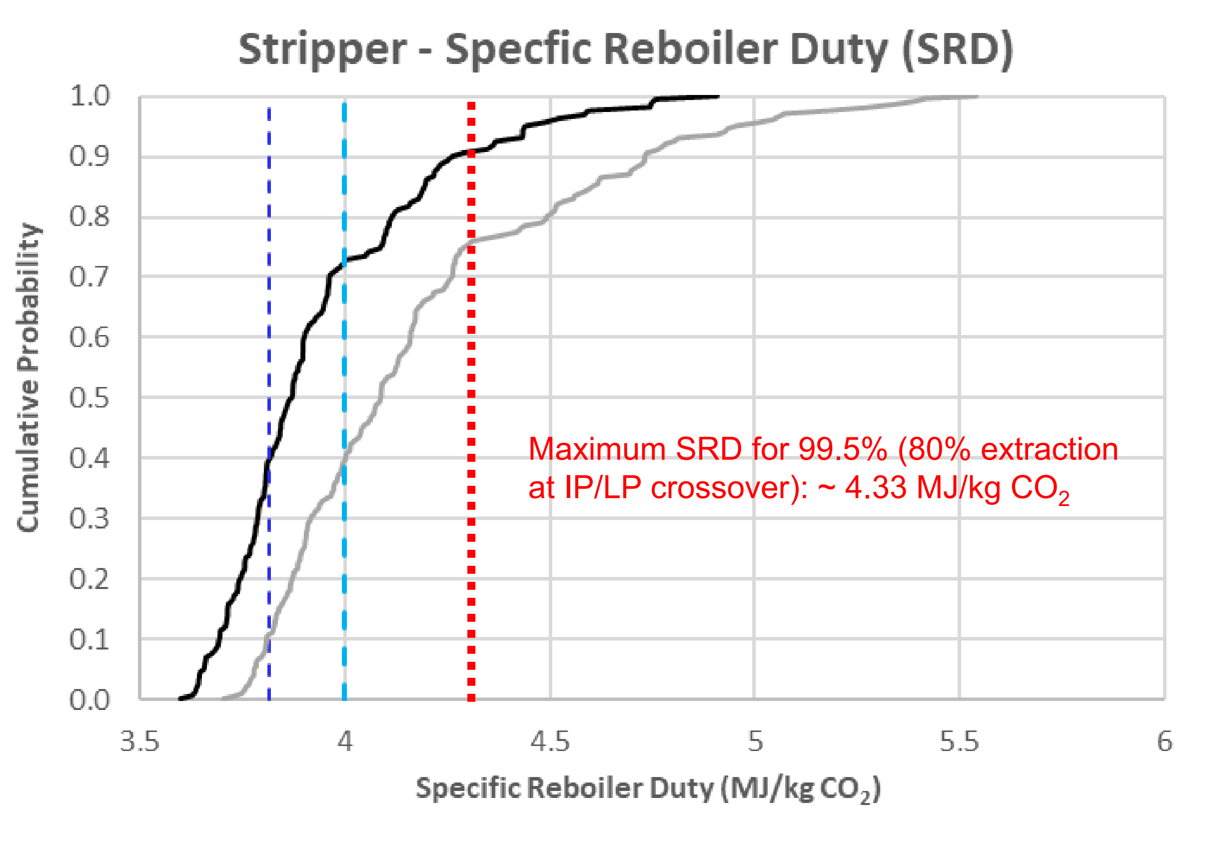
Note: This analysis has been done for the SE case

1. Morgan JC, Chinen AS, Omell B, Bhattacharyya D, Tong C, Miller DC, 2017. Thermodynamic modeling and uncertainty quantification of CO_2-loaded aqueous MEA solutions. Chem. Eng. Sci. 168: 309-324.
2. Chinen AS, Morgan JC, Omell B, Bhattacharyya D, Tong C, Miller DC, 2018. Development of a rigorous modeling framework for solvent-based CO_2 capture. Part 1: hydraulic and mass transfer models and their uncertainty quantification. Ind. Eng. Chem. Res. 57: 10448-10463.

Uncertainty Analysis of Column Height and SRD

Thirteen parameters considered in the thermodynamic and mass transfer models, selected based on Sobol analysis[1,2]





- Driven by mass transfer uncertainty
- Low risk of not meeting performance target

- Driven by thermodynamic uncertainty
- Higher risk of not meeting expected performance (similar in both cases as both use lower lean loadings)
- Steam extraction constraints provide less recourse

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1. Morgan JC, Chinen AS, Omell B, Bhattacharyya D, Tong C, Miller DC, 2017. Thermodynamic modeling and uncertainty quantification of CO_2-loaded aqueous MEA solutions. Chem. Eng. Sci. 168: 309-324.
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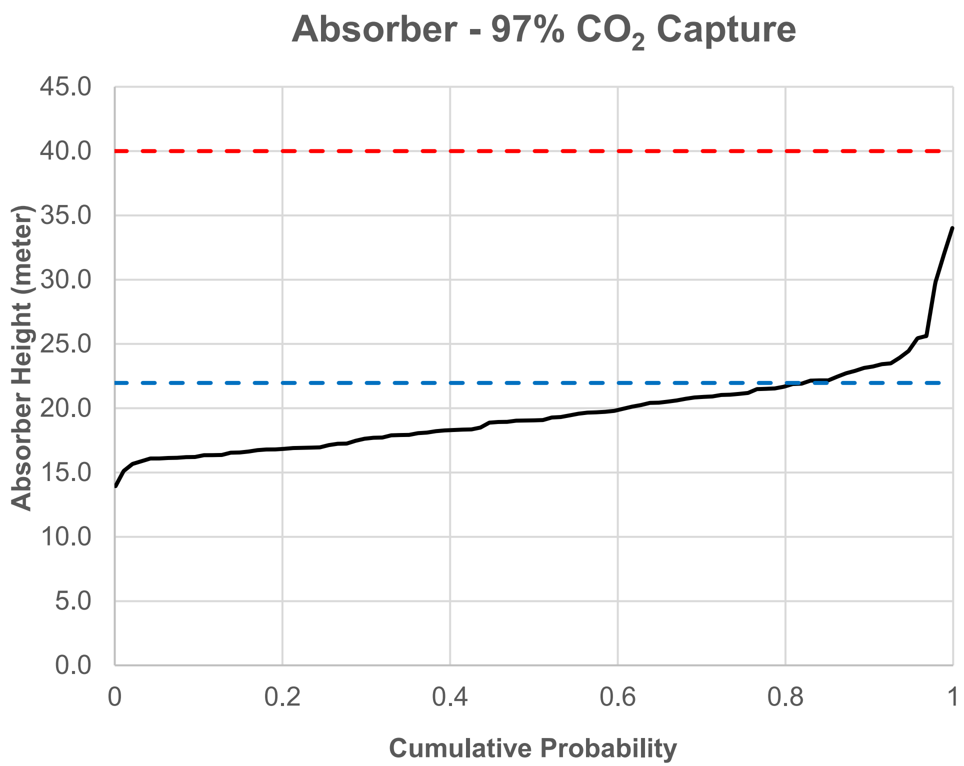
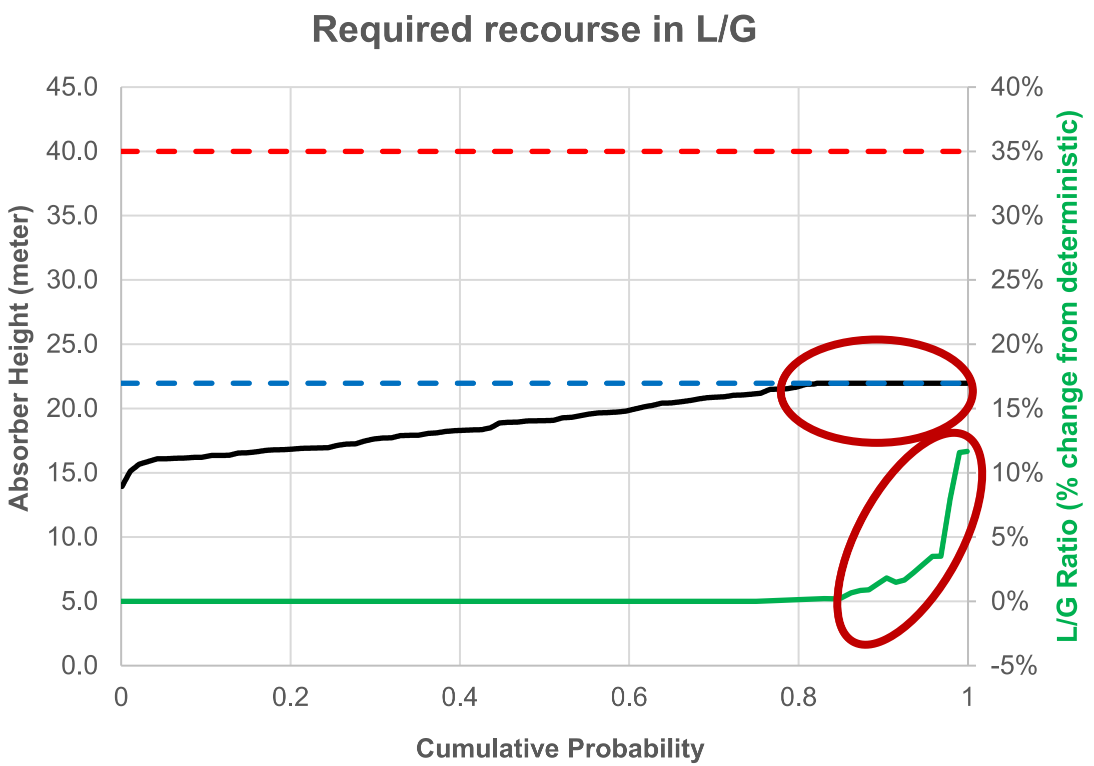
Additional Recourse for 97% Case





Blue dash – deterministic case
Red dash – technical feasible height

- Deterministic design can achieve capture targets amidst uncertainty with a small increase in liquid flowrates (~2%-12%).
- Increase in L/G may have other impacts

CCSI2
Carbon Capture Simulation for Industry Impact

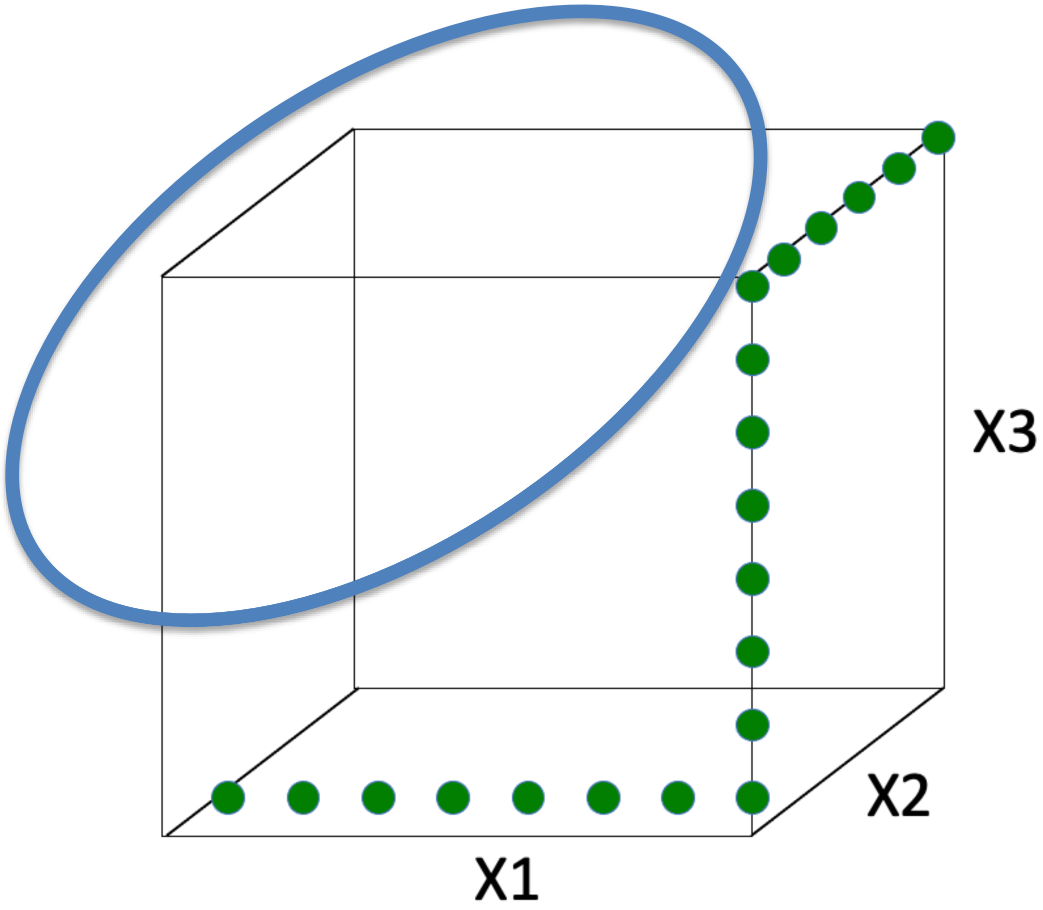
13 parameters considered in the thermodynamic and mass transfer models, selected based on Sobol analysis

What is Design of Experiments (DoE)?

- **Mathematical strategy for selecting input combinations**
  - Compute output (computer experiment)
  - Operate system (physical experiment)
- **Series of these experimental runs/tests forms experiment**
  - **Purposeful changes** to inputs of process or system
  - **Identify the reasons** for any changes in output
- **A well-designed experiment is critical**
  - Results and conclusions depend on how the data is collected

Design of Experiments not the same as One-Factor-at-a-Time

- **OFAAT strategy:**
  - Change only one input (factor) at a time
  - Hold all others constant
- **Inefficient use of budget**
- **Cannot identify interactions**
  - Effect of one factor changes when another factor changes
  - Finding optimal operating conditions is unlikely



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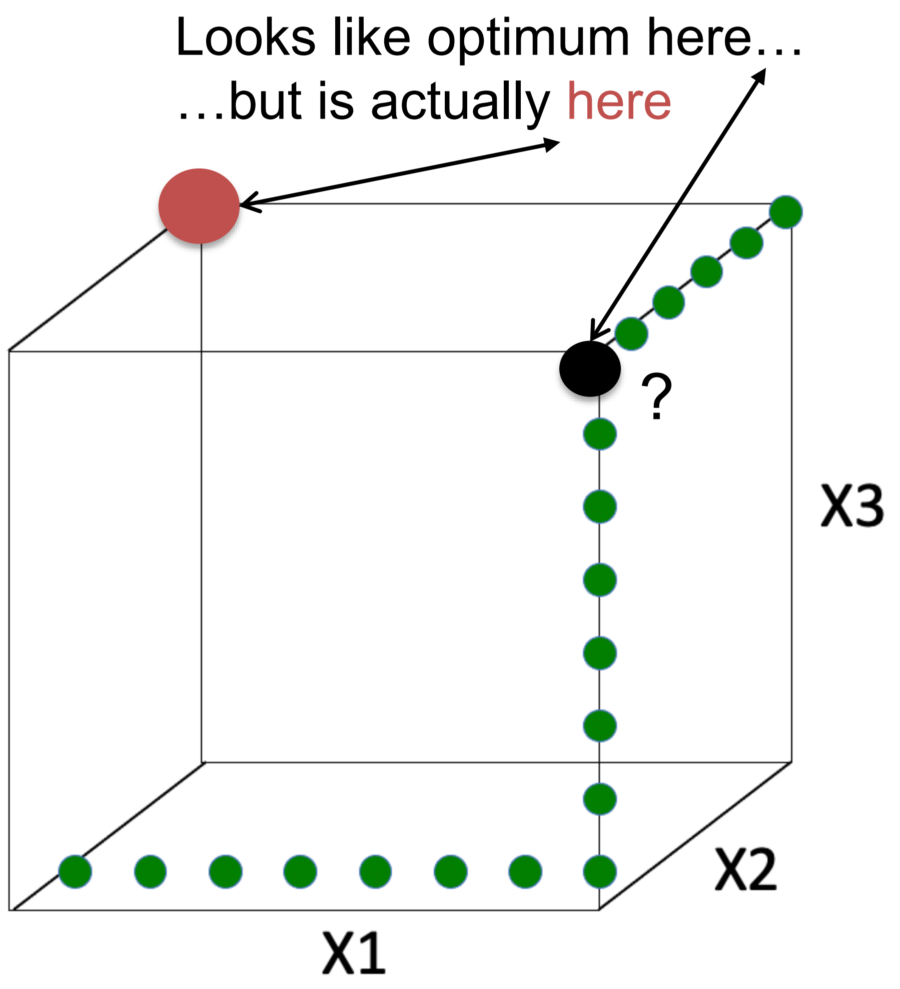

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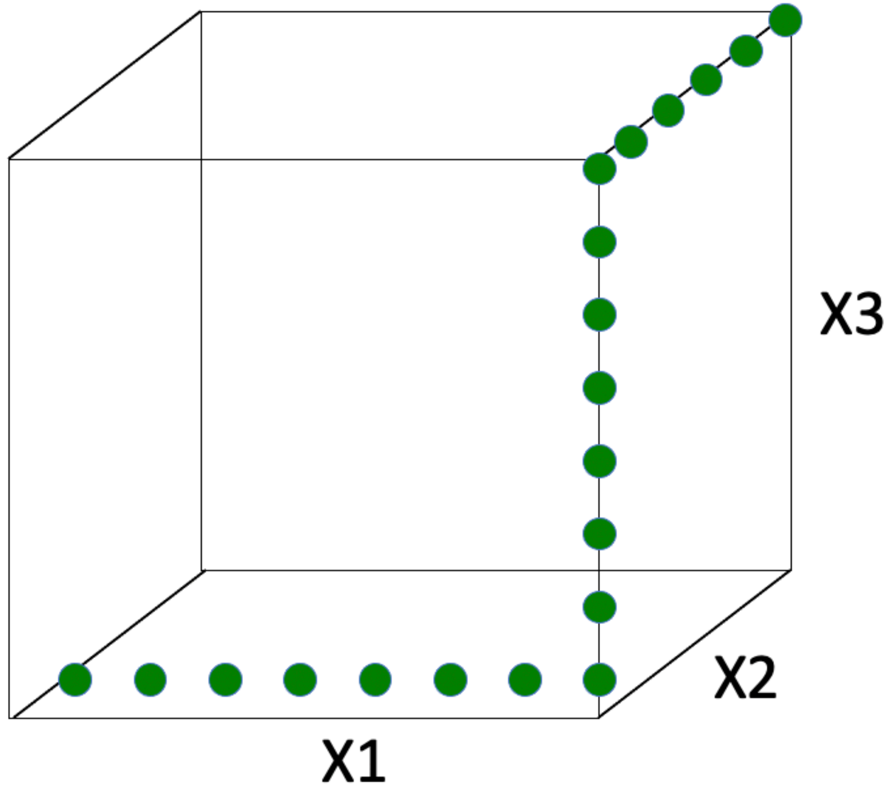
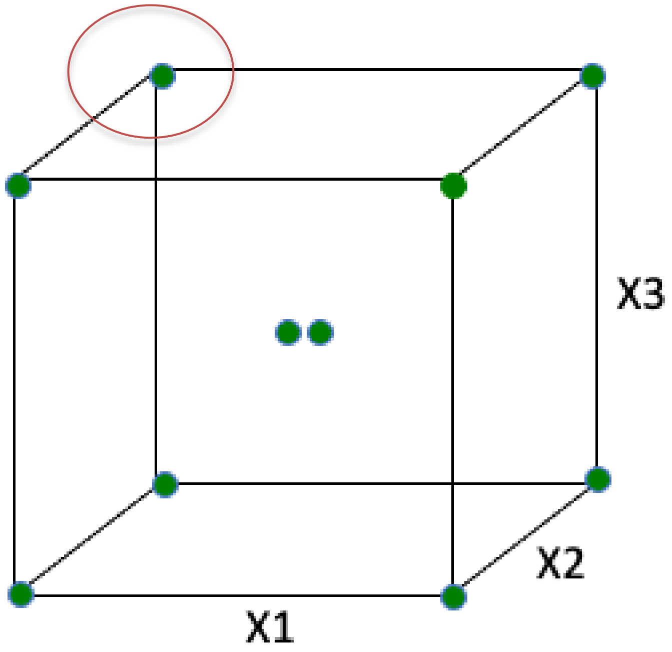
Design of Experiments not the same as One-Factor-at-a-Time

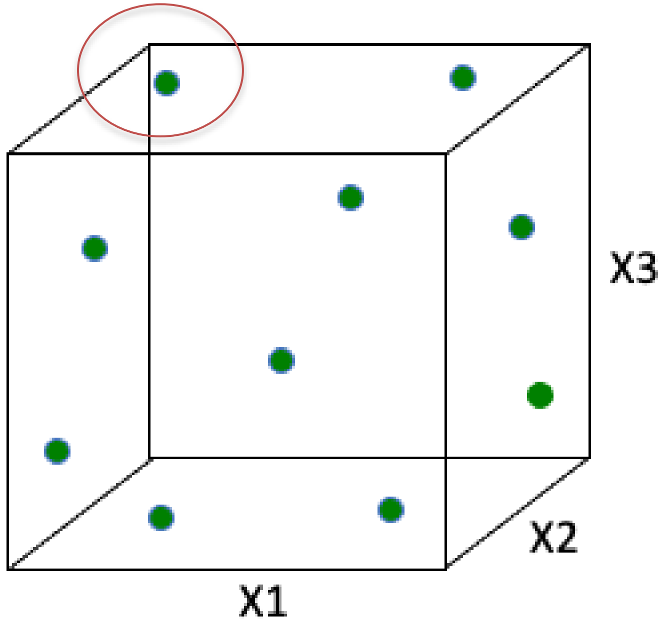
- **OFAAT strategy:**
  - Change only one input (factor) at a time
  - Hold all others constant
- **Inefficient use of budget**
- **Cannot identify interactions**
- **Not randomized**
  - Changing conditions can negatively affect the results

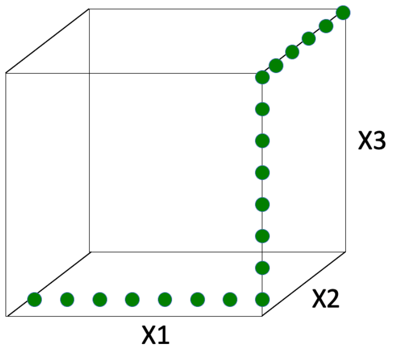


CCSI[2]
Carbon Capture Simulation for Industry Impact

DoE Avoids These Drawbacks – Is Always More Efficient







Uses **20 runs**

Two Different SDoE Approaches
Each uses **10 runs**

What Is DoE Used For?

Development

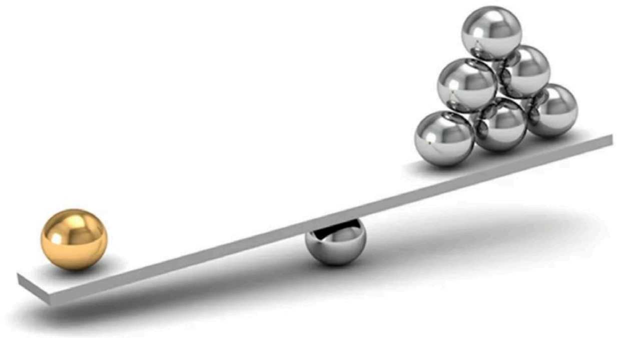
- Evaluate and compare product configurations
- Evaluate material alternatives
- Determine parameters settings to work well under variable field conditions
- Determination parameters that impact product performance

Improvement

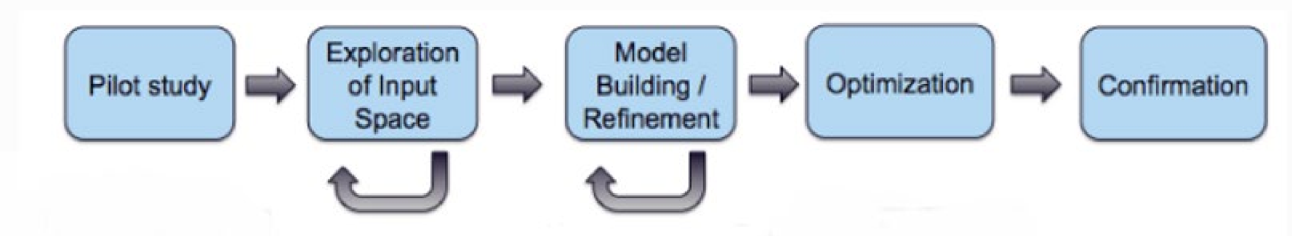
- Reduce variability
- Obtain closer conformance to target requirements
- Reduce development time
- **Reduce overall costs**

Why Use Statistically Designed Experiments?

- **Extract maximum information with a fixed budget**
  - Produces exceptionally high-quality data
- **Can save years off pilot test schedule**
- **Proven track record from past applications**
  - Over 25% reduction in model uncertainty
  - CO_2 Capture percentage within 3-6% with 95% confidence



Notional Gantt Chart for Designing Pilot Tests



Step/Action	Total Weeks	
Determine the total time available for the experiment and the expected time required for a single experimental run	6	Week 1
Define the goals of the experiment	7	Week 1
Assess performance and maturity of system process models	14	Week 1
Identify and classify the dependent, independent intermediate, and nuisance variables	12	Week 7
Identify restrictions on the experiment	9	Week 15
Identify region of interest for experiment	8	Week 20
Determine appropriate sequential plan for SDoE	17	Week 19
Construct design(s) to be used in initial phase of the SDoE	11	Week 31
Execute SDoE: collect data from current phase, assess results, construct design(s) for next phase. Repeat to align with overall goals of experiment	7	Week 42
Collect results of SDoE, summarize key takeaways	4	Week 49

Week 1 – Week 52

Model Preparation, UQ, SDoE Setup

SDoE Execution at Pilot Test

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Carbon Capture Simulation for Industry Impact

Join us for the PSE+ Stakeholder Summit

September 18 & 19, 2024 **in** Pittsburgh, PA

[Advanced PSE Stakeholder Summit and Technical Meeting 2024 - (idaes.org)]

IDAES® Institute for the Design of Advanced Energy Systems	Multiscale Modeling & Optimization	National Energy Technology Laboratory, Berkeley Lab, Sandia National Laboratories, Carnegie Mellon, West Virginia University, University of Notre Dame, Georgia Tech
CCSI² Carbon Capture Simulation for Industry Impact	Post-combustion Carbon Capture	National Energy Technology Laboratory, Berkeley Lab, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Pacific Northwest National Laboratory, West Virginia University, University of Notre Dame, The University of Texas at Austin, UT, University of Pittsburgh
DISPATCHES Design Integration and Synthesis Platform to Advance Tightly Coupled Hybrid Energy Systems	Hybrid Energy Systems (completed)	National Energy Technology Laboratory, Sandia National Laboratories, Berkeley Lab, INL Idaho National Laboratory, NREL Transforming ENERGY, University of Notre Dame
WaterTAP	Water Desalination	National Energy Technology Laboratory, Berkeley Lab, NREL Transforming ENERGY, Oak Ridge National Laboratory
PROMMIS	Critical Mineral & Material Recovery	National Energy Technology Laboratory, Berkeley Lab, Sandia National Laboratories, Carnegie Mellon, West Virginia University, University of Notre Dame, Georgia Tech

CCSI²

Carbon Capture Simulation for Industry Impact

For more information

https://www.acceleratecarboncapture.org/

Benjamin.Omell@netl.doe.gov

Disclaimer

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Plan for CCSI² Contributions to Support of EPRI/ EEMPA Campaign

Initial Phase
- Plant start-up
- Achieve steady-state water loading

Phase 1
- Demonstrate 90% CO_2 capture for coal, natural gas flue gases
- Use designed experiments to strategically manipulate chosen variables (e.g., solvent circulation, stripper temperature)

Additional Phases
- Target high capture
- Minimize solvent regeneration energy
- Evaluate effect of solvent water content on CO_2 capture
- Investigate effect of flue gas flowrate and temperature
- Analysis of metal vs. plastic packing

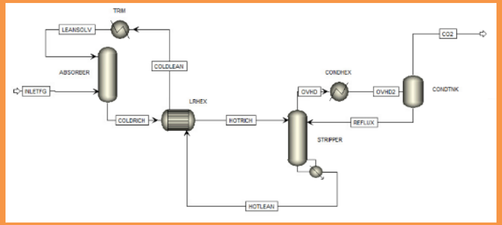
Process Model Refinement

Process Inputs

Solvent Circulation
Solvent Capacity
CO_2 Capture Target
Operating T, P

Model Parameters

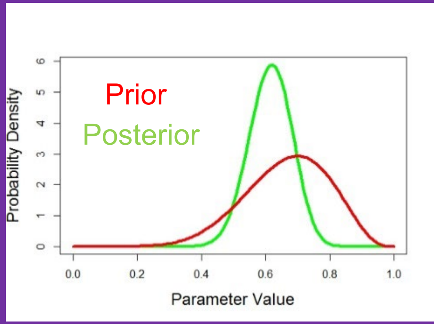
Thermodynamics
Mass Transfer
Interfacial Area
Kinetics



Process Outputs

CO_2 Capture
Specific Reboiler Duty

Stochastic Model
- Reduce risk associated with process scale-up



Sequential design of experiments (SDoE) enables direct incorporation of knowledge learned in previous stages for strategic data collection

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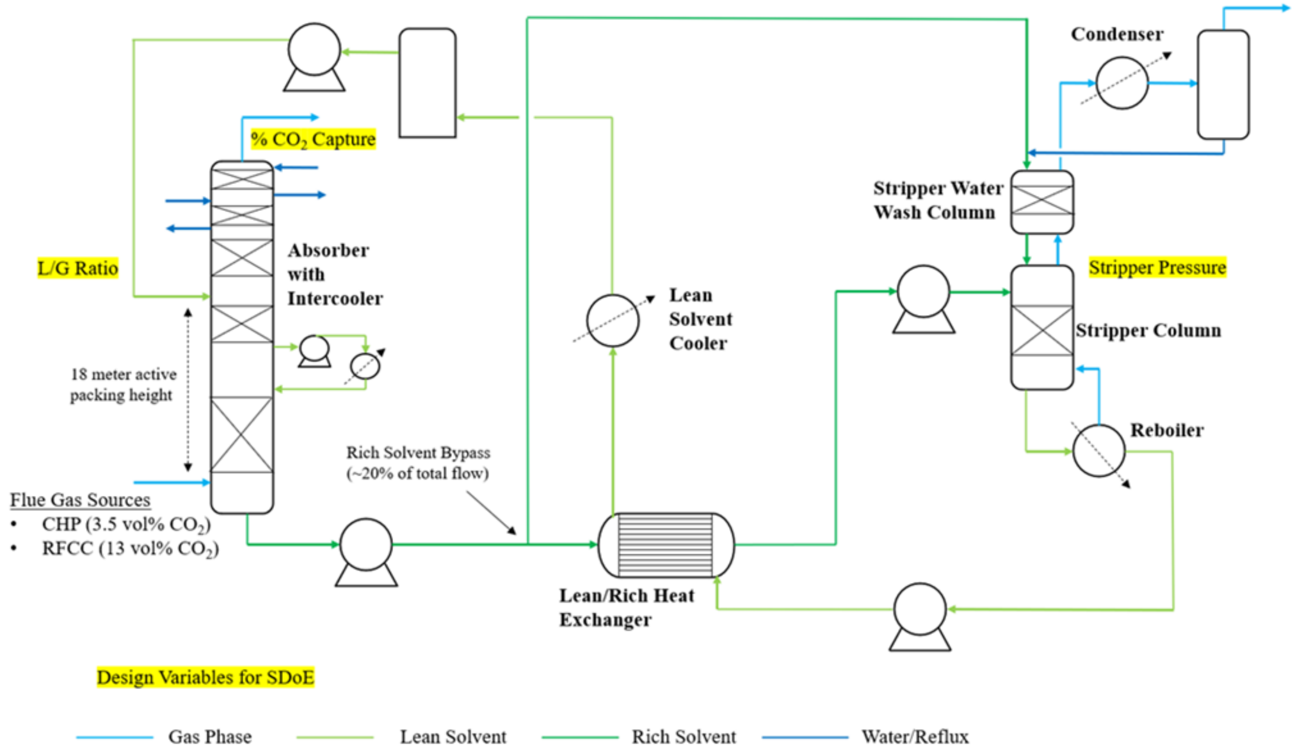
TCM Test Campaign for RTI NAS Solvent

- Leveraged SDoE to guide NAS test campaign at TCM → focused on demonstrating high levels of CO_2 capture with low solvent emissions and regeneration energy requirement
- CCSI[2] team contributed separate designed experiments for gas-fired combined heat and power (CHP) [3.7 vol% CO_2] and residual fluidized catalytic cracker (RFCC) [13.5 vol% CO_2] flue gas sources
- Each designed experiment includes a series of test matrices with 12-22 proposed operating conditions for flexibility in design size



Design factors:

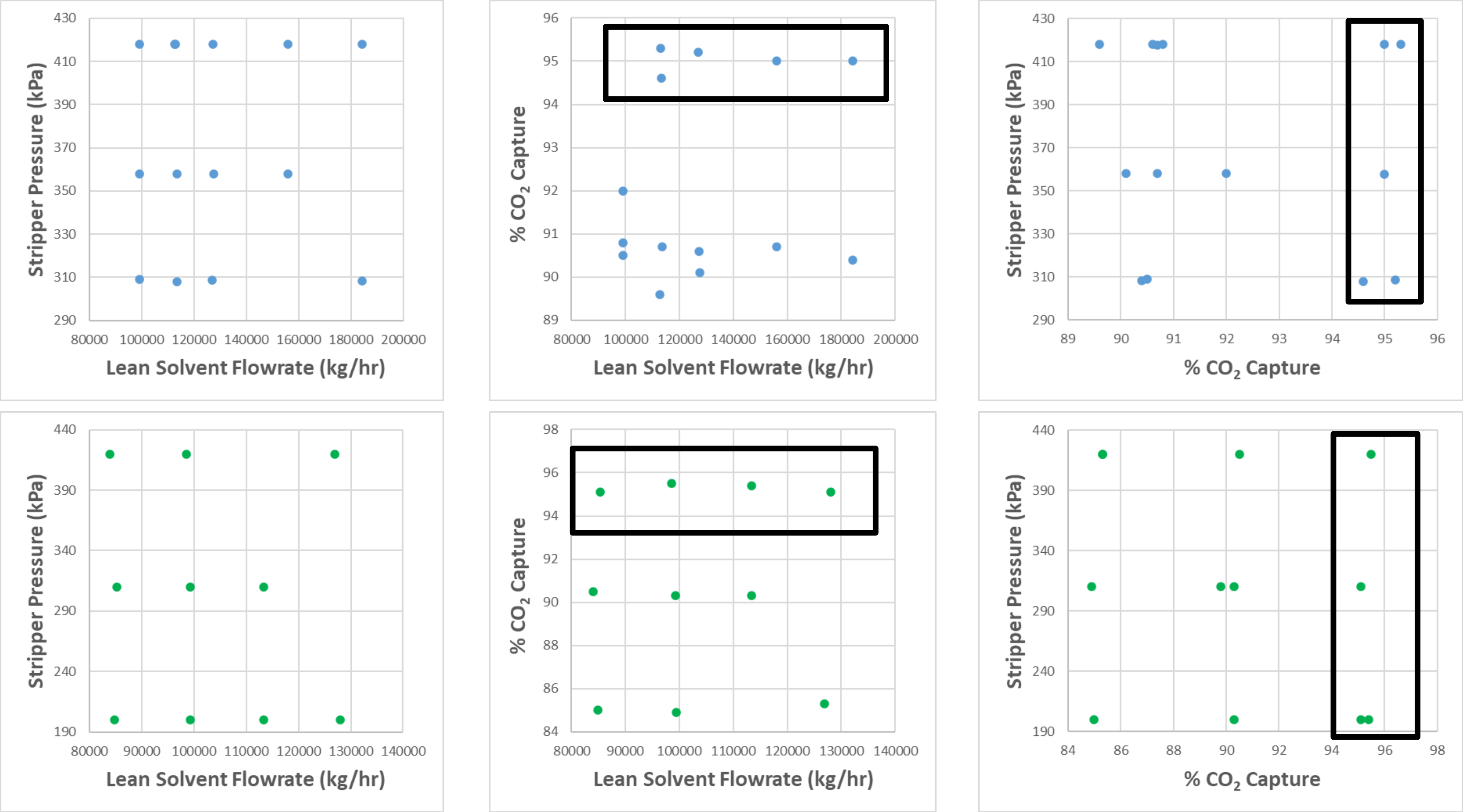
CO_2 Capture: 85 – 95%

Absorber L/G Ratio: 2.5 – 6.5 kg/kg

Stripper Pressure: 0.9 – 3.2 barg

SDoE Results – Data Collection at TCM

Data sets generated for SDoE demonstrate good coverage of operation space:



Characterization of parameter interactions through DoE → demonstrates multiple pathways to high capture levels based on the trade-off between solvent circulation and CO_2 capacity

● Coal-based flue gas

● NGCC flue gas

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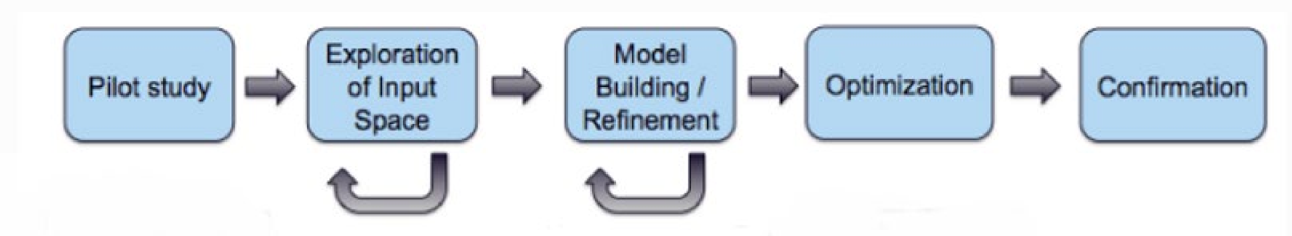
Sequential Design of Experiments (SDoE)

- **<u>Design of experiments (DOE)</u>** is a powerful tool for accelerating learning by targeting maximally useful input combinations to match experiment goals
- **<u>Sequential design of experiments (SDoE)</u>** allows for incorporation of information from an experiment as it is being run, by updating selection criteria based on new information
- Specific algorithms can be tailored to match experimental goals. Options available in the CCSI Toolset include:
  - Uniform Space Filling (USF)
  - Non-Uniform Space Filling (NUSF)
  - Input-Response Space Filling (IRSF)
  - Robust Optimality-Based Design of Experiments (ODoE)
- Recommended to run experiments in phases to take advantage of SDoE capabilities and customize test designs to meet expected project outcomes

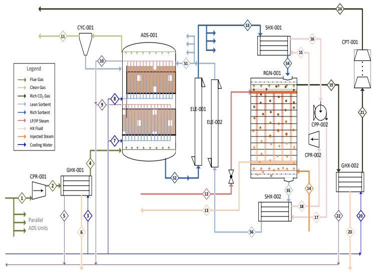


<u>Detailed discussion on SDoE</u>:

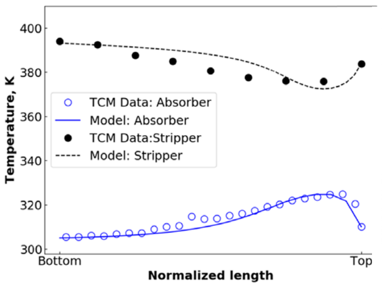
Technical Risk Reduction: Sequential Design of Experiments and Uncertainty Quantification (Abby Nachtsheim – LANL)
Thursday (8/31/2023) @ 9:30 AM during Point Source Carbon Capture Breakout Session

Stochastic Equation-Oriented Modeling and/or "Black Box" Simulations

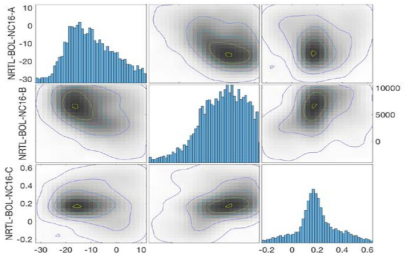
High Fidelity Process Modeling



Model Validation

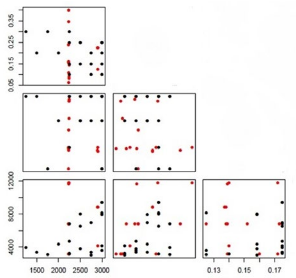


Uncertainty Quantification

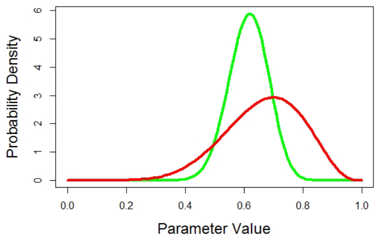


UQ Guides SDoE to Optimize Data Value, Maximize Learning

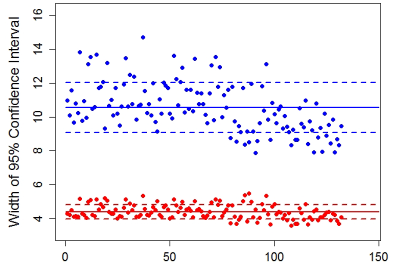
Optimize Experimental Design



Refine Model Parameters

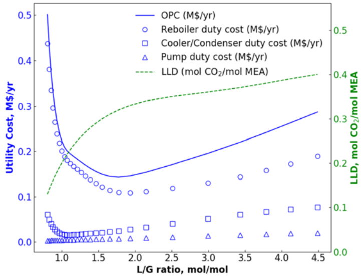


Maximizing Learning

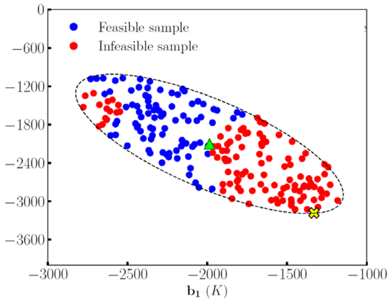


Framework for Robust-Optimal Design and Operation

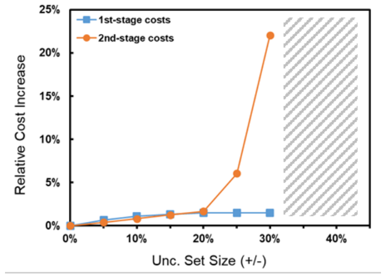
Process Optimization



More Robust Optimal Designs



Quantify Price of Robustness



- **Uncertainty Quantification (UQ)** provides a modeling framework for characterizing epistemic uncertainty - essential for understanding scale-up risk
- **Sequential Design of Experiments (SDoE)** techniques enable reduction of uncertainty through strategic collection of process data to maximize learning from pilot test campaigns
- **Robust Optimization (RO)** framework quantifies cost of accommodating uncertainty in designs ensured to meet performance targets (with a chosen confidence level)

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CCSI² – Modeling, Optimization and Technical Risk Reduction

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Multi-lab modeling initiative to support carbon capture technology development

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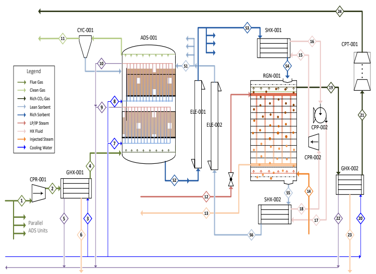
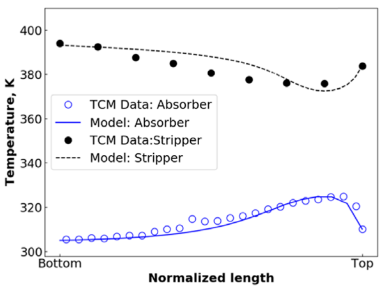
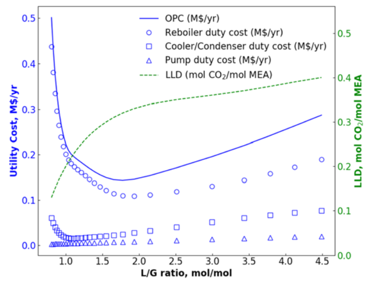
High Fidelity Process Modeling



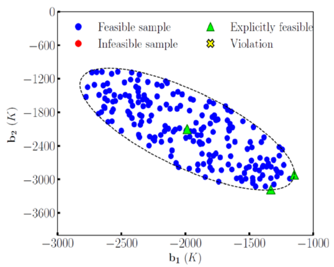
Model Validation



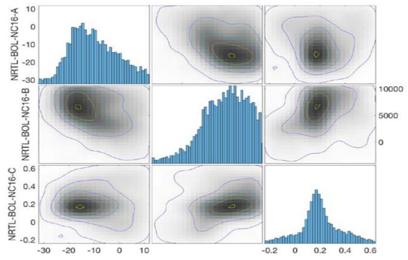
Process Optimization



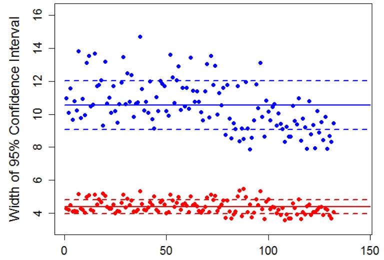
Robust Design

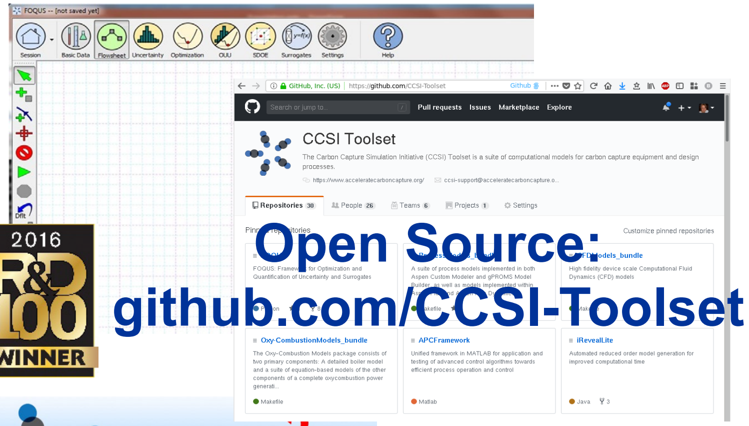


Uncertainty Quantification



Maximizing Learning





Open Source: github.com/CCSI-Toolset

IDAES
Institute for the Design of Advanced Energy Systems

Open Source: github.com/IDAES/idaes-pse

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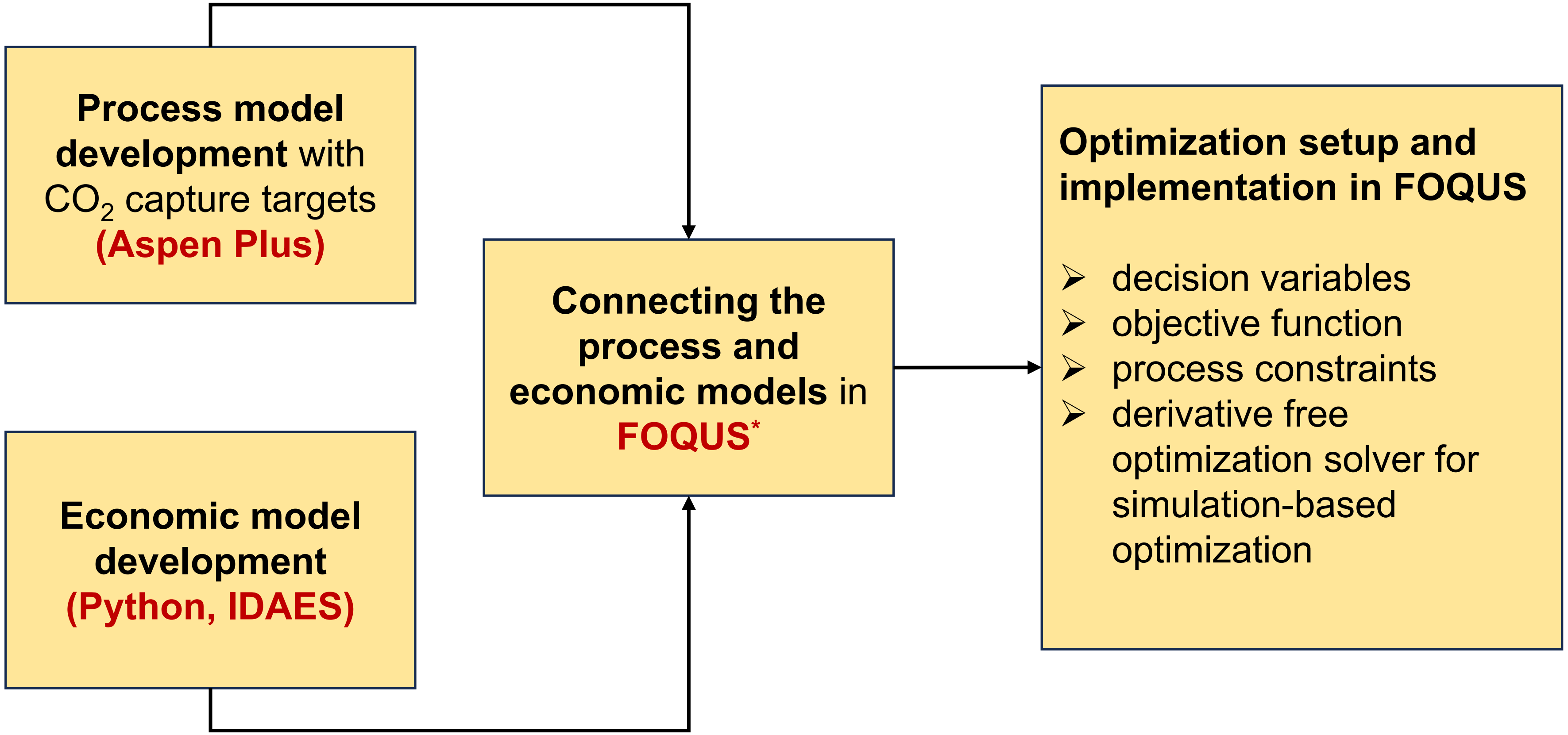
Objective

- Understand high capture process variables important for optimization
- Characterize optimal capture costs and their rate of increase as capture demands rise
- Assess usefulness of pilot data for model validation
- Quantify effects of model uncertainty
- Explore means to accommodate uncertainty

CCSI² Techno-Economic Optimization Framework

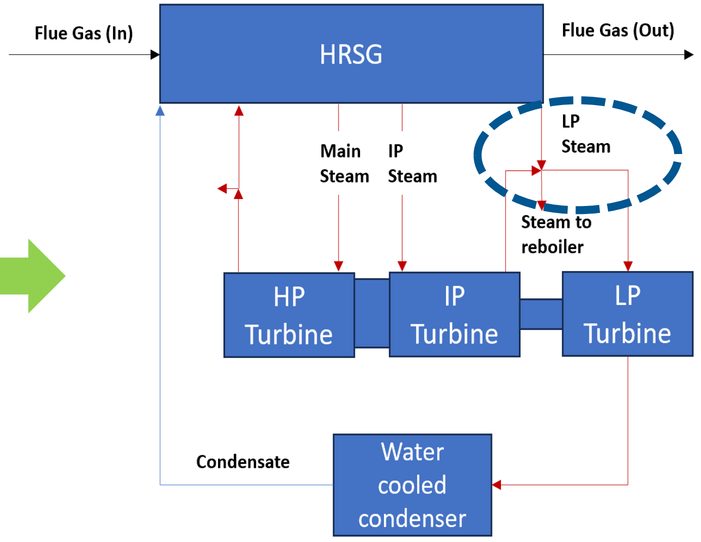


*** Framework for Optimization and Quantification of Uncertainty and Surrogates**
Open Source: github.com/CCSI-Toolset/FOQUS

Optimization Cases

Case Name	CO_2 Capture Solvent	Steam Source for solvent regeneration	CO_2 Capture Levels (%)
SE	MEA	Steam extraction from NGCC steam cycle	Discrete levels between 90% – 99.8%
AB		Natural gas fired auxiliary boiler	

Steam extracted from the IP/LP steam turbine crossover



Auxiliary boiler: No steam extraction from the NGCC steam cycle

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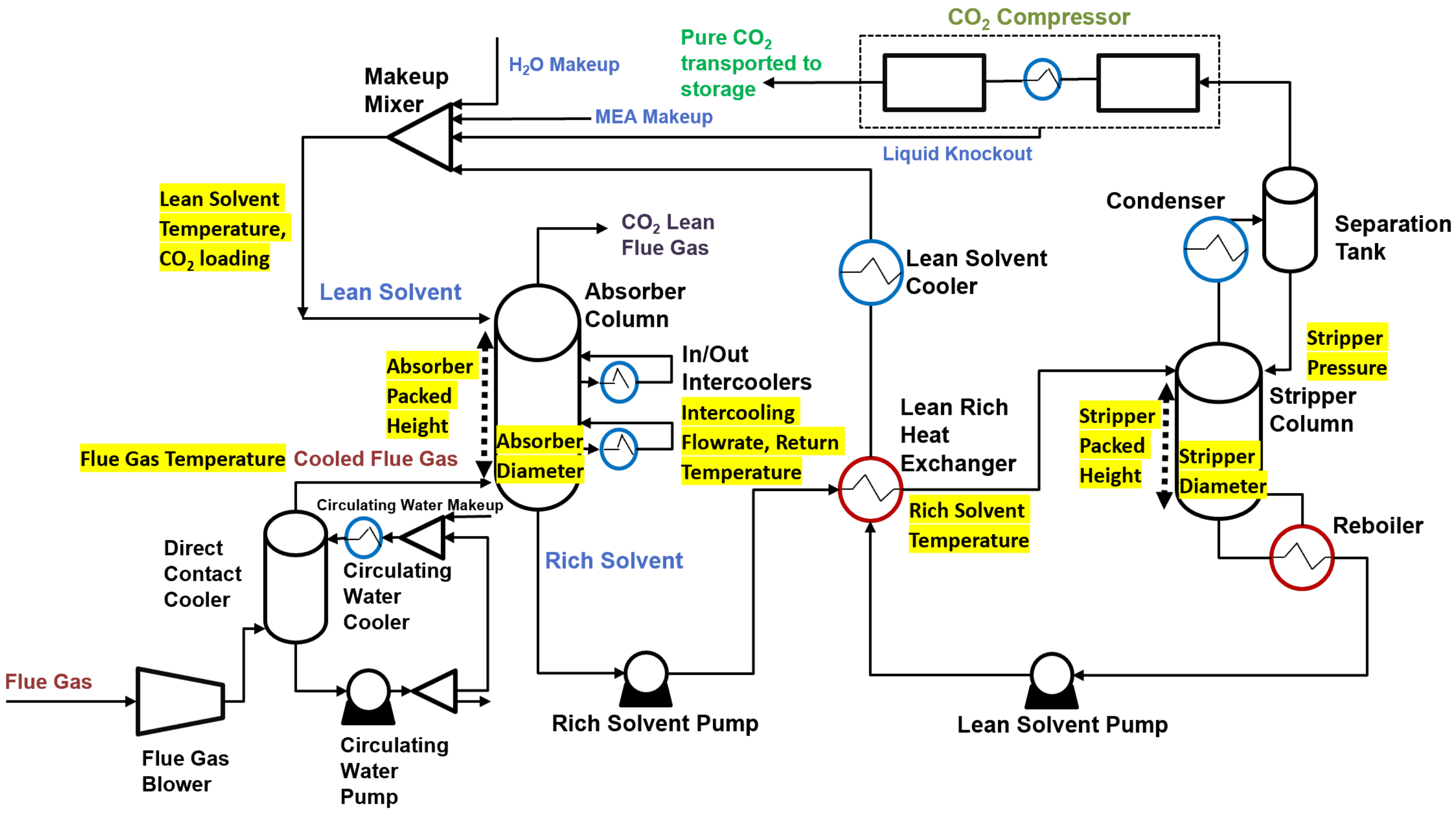
SE: MEA with steam extraction
AB: MEA with auxiliary boiler

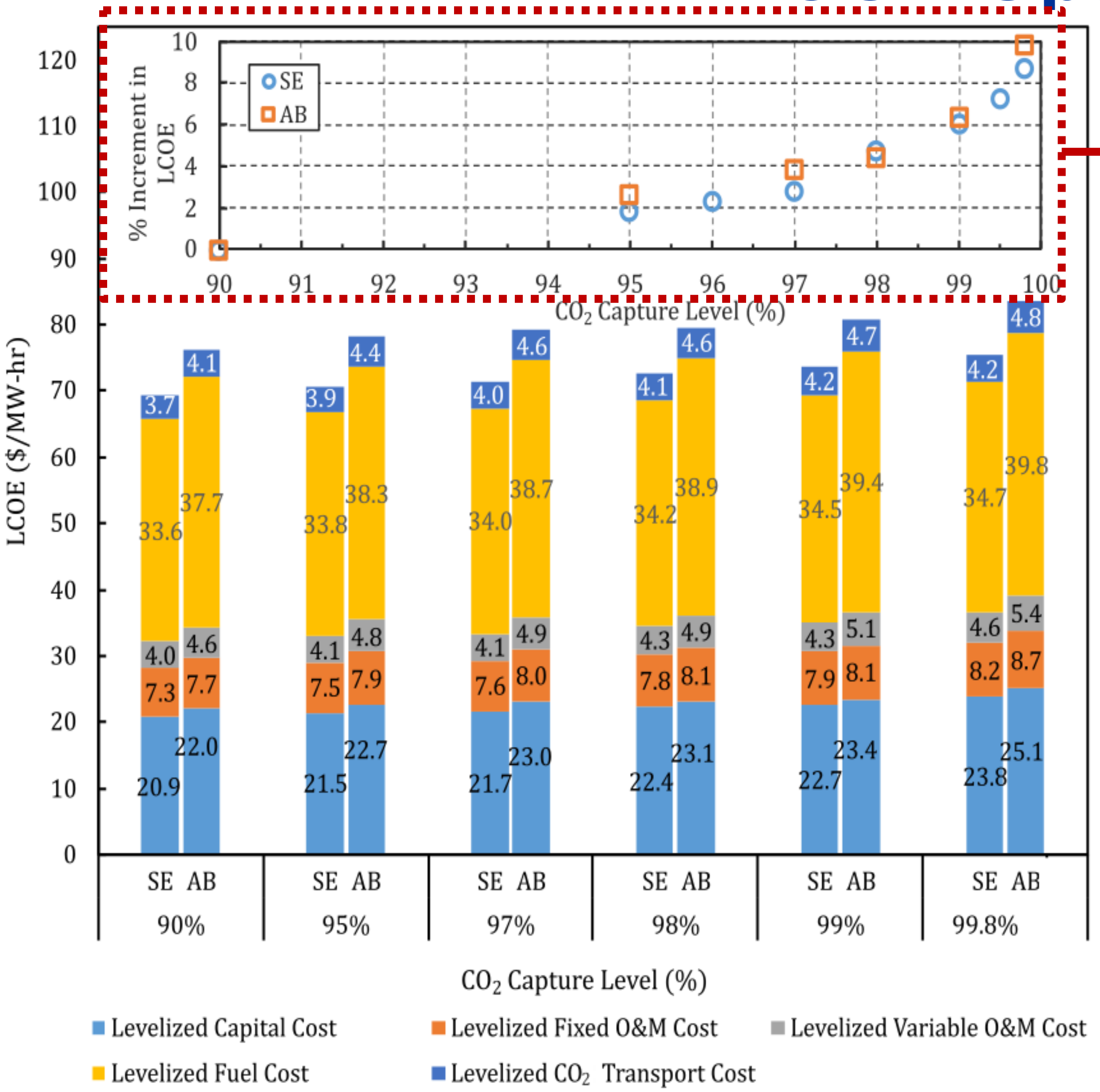
Optimization Decision Variables

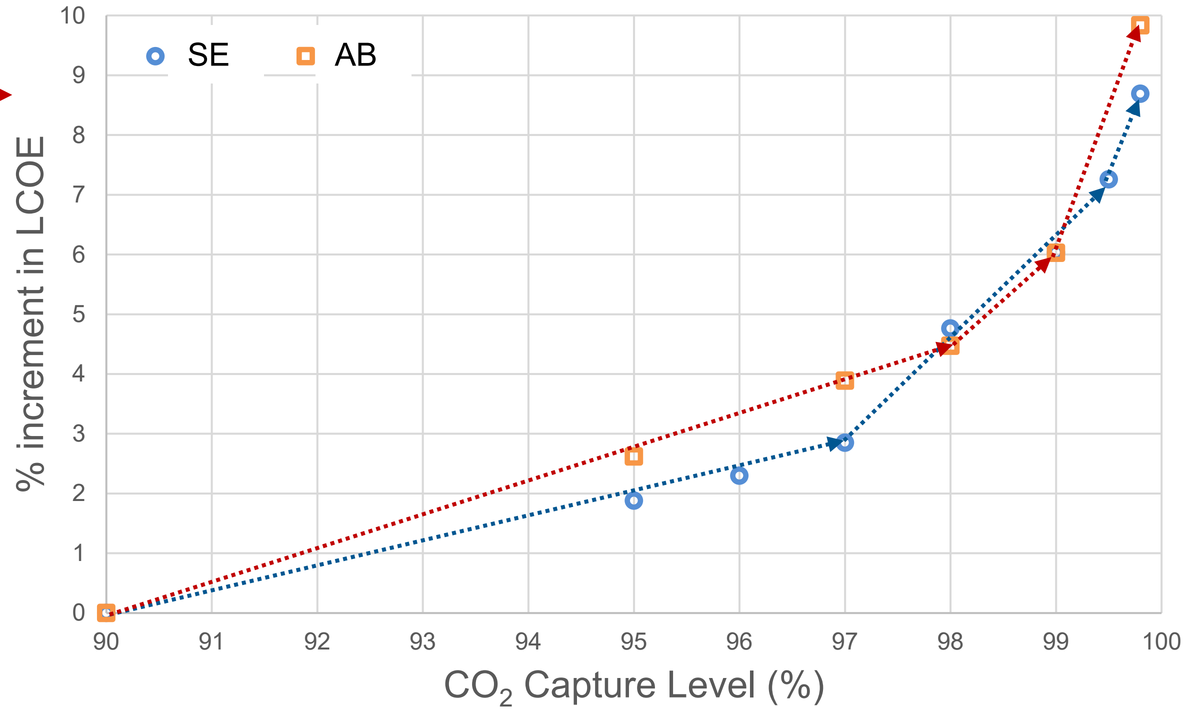


Decision Variables for Optimization Problem

Variable	Unit	Range
Absorber Diameter	meter	12 - 20
Absorber Height	meter	20 - 45
Lean CO_2 Loading	$\frac{\text{mol } CO_2}{\text{mol MEA}}$	0.1 - 0.25
Intercooler #1 Temperature	°C	25 - 45
Intercooler #2 Temperature	°C	25 - 45
Intercooler # 1 flow fraction	$\frac{\text{mass flow IC\#1}}{\text{mass flow lean solvent}}$	1e-5 - 1
Intercooler # 2 flow fraction	$\frac{\text{mass flow IC\#2}}{\text{mass flow lean solvent}}$	1e-5 - 1
Lean Solvent Temperature	°C	25 - 45
Rich Solvent Temperature (Lean/Rich HEX Exit)	°C	90 - 115
Stripper Height	meter	4 - 15
Stripper Diameter	meter	3 - 10
Stripper Pressure	kPa	170 - 230
FG Temperature	°C	25 - 45

LCOE Optimization Results





- A sharp increase is observed beyond 97% capture for the SE case and 98% capture for the AB case.
- Across the capture levels and between the steam sources, the cost contribution of the LCOE components does not vary significantly.

SE: MEA with steam extraction
AB: MEA with auxiliary boiler

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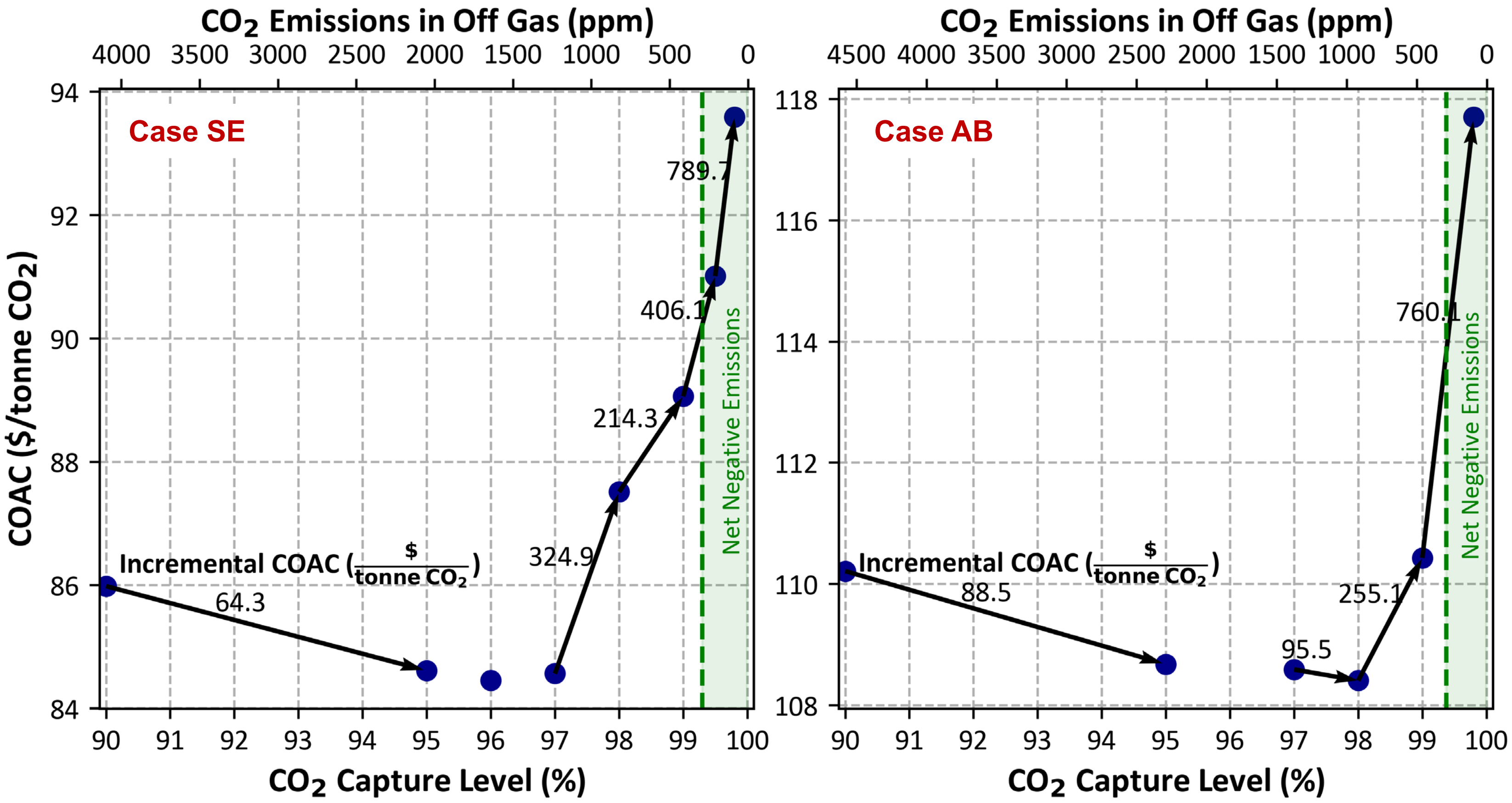
Optimum Cost of Avoided Carbon (COAC)



- COAC has an optimal value near 96% capture.
- Incremental COAC is the change in LCOE wrt the change in CO_2 footprint

$$\Delta COAC[i + \Delta i] = \frac{LCOE[i+\Delta i] - LCOE[i]}{\frac{CO_2\ Emissions[i]}{Plant\ Net\ Power[i]} - \frac{CO_2\ Emissions[i+\Delta i]}{Plant\ Net\ Power[i+\Delta i]}}$$

- Incremental COAC between capture levels increases exponentially above 97% and 98% CO_2 capture for case SE, and AB respectively

SE: MEA with steam extraction
AB: MEA with auxiliary boiler

Conclusions

- CCSI Toolset provides useful framework for optimizing numerous designs through **coupling of costing models and process models**
- **Inflection point** in cost of capture occurs past 98% for MEA
- **Designs can fail** with expected realizations of uncertain parameters
- **Recourse strategies** can handle much of the uncertainty, but **require insights gained via computational analyses**
- Full techno-economic modeling frameworks support the **test data generation of highest value**

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Acknowledgements

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Norma Kuehn (*)
Alex Zoelle (*)
Mike Matuszewski (*)

(*) NETL Support Contractor

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Disclaimer

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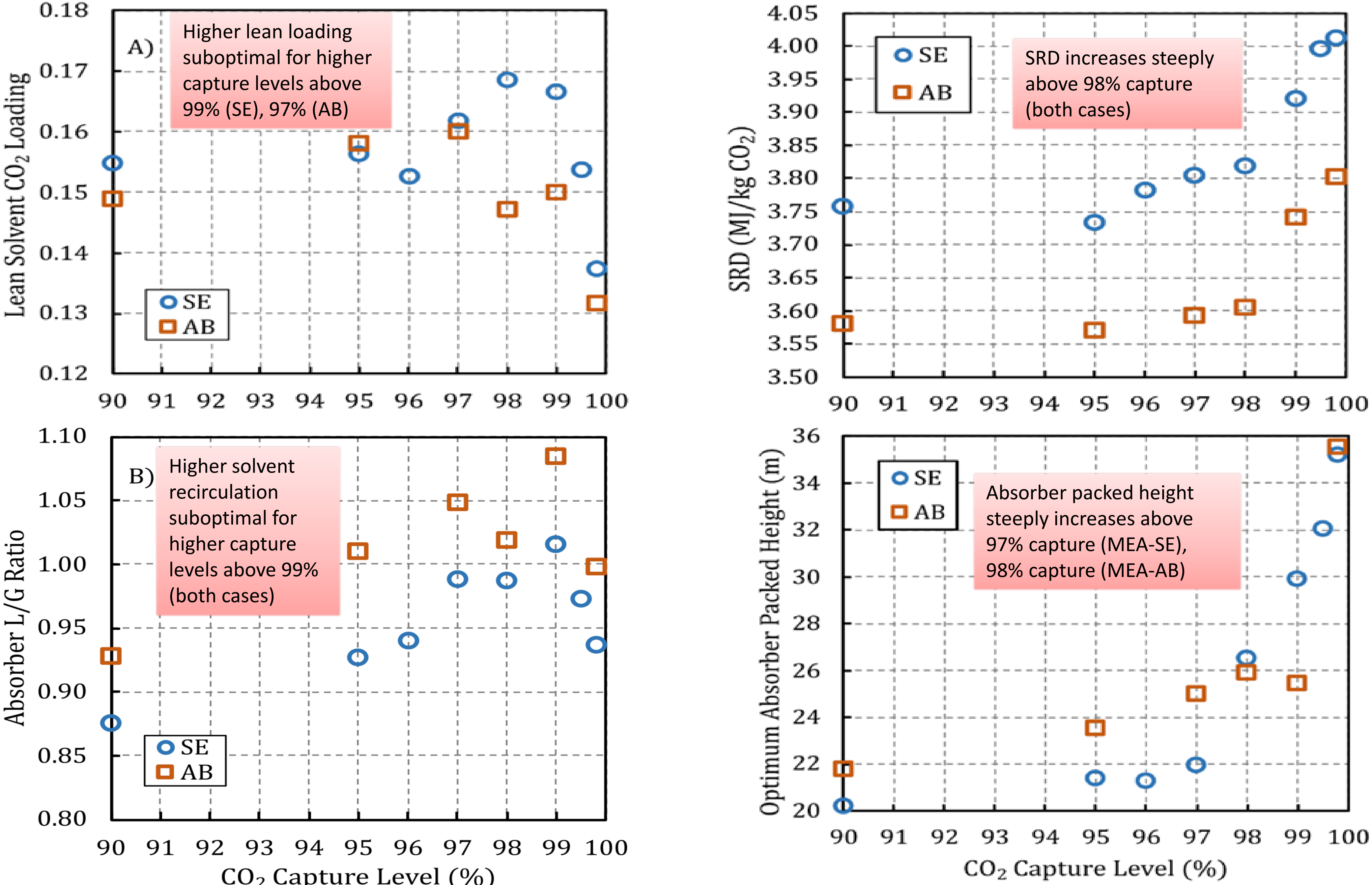
Optimum Design and Operation of CCS Unit – Case Comparison

SE: MEA with steam extraction

AB: MEA with auxiliary boiler



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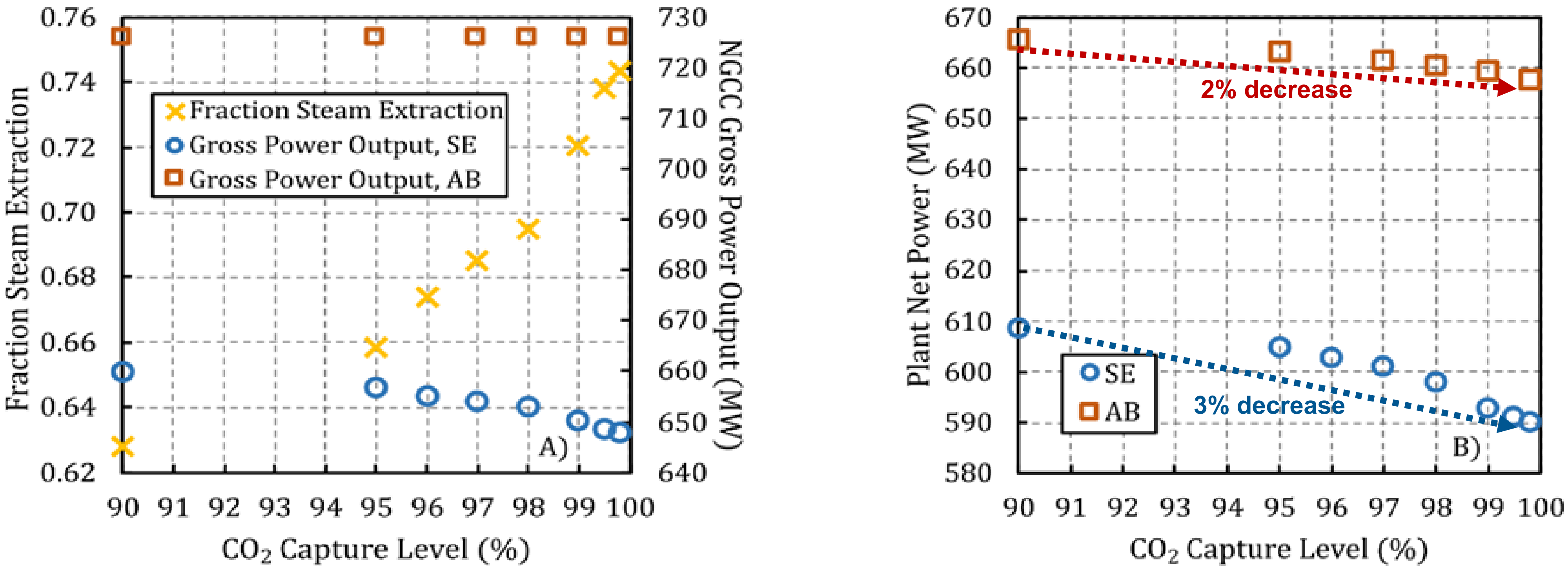
Performance of NGCC at Optimum CCS Conditions



- Optimum steam extraction in the SE case increases by 17% across the capture levels – NGCC Gross Power reduces by 1.8%.
- No steam extraction in the AB case – NGCC Gross Power remains constant—72 MW (on average) higher than SE.
- NGCC Net Power reduces in both cases across capture levels (combined effect of steam extraction and increasing auxiliary load).

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SE: MEA with steam extraction
AB: MEA with auxiliary boiler

Economic Model: NGCC Solvent-based CCS System

- Developed in Python using the IDAES Costing Framework[1]
- **Key Inputs:**
  - **Resources and Chemicals:** Natural gas flowrate, solvent initial fill and makeup rate, etc.
  - **Design Conditions:** Absorber and stripper column size, heat exchanger surface area
  - **Operating Conditions:** Flue gas flowrate, solvent circulation rate, CO_2 capture rate
  - **Performance Indicators:** Heat exchanger duties; power requirement for blowers, pumps, and compressors
- **Key Outputs:** Economic Evaluation Metrics
  - **Total Plant Cost (Million $):** NGCC plant, CCS equipment, and full system
  - **Levelized Cost of Electricity ($/MW-hr):** Amount of revenue required per net megawatt-hour during the power plant's operational life to meet all capital and operational costs[2]
  - **Cost of CO_2 Captured ($/tonne CO_2):** Minimum CO_2 plant gate sales price that will incentivize carbon capture relative to a defined reference non-capture plant[2]
  - **Cost of CO_2 Avoided (COAC) ($/tonne CO_2):** Minimum CO_2 emissions price that will incentivize carbon capture relative to a defined reference non-capture plant[2]

[1] IDAES online documentation: https://idaes-pse.readthedocs.io/en/latest/index.html
[2] National Energy Technology Laboratory, "Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity Revision 4a," US DOE, Pittsburgh, PA, 2022.