The ARPA-E FLECCS Program

Designing CCS processes for future energy systems

Scott Litzelman, Ph.D.

Advanced Research Projects Agency-Energy (ARPA-E)

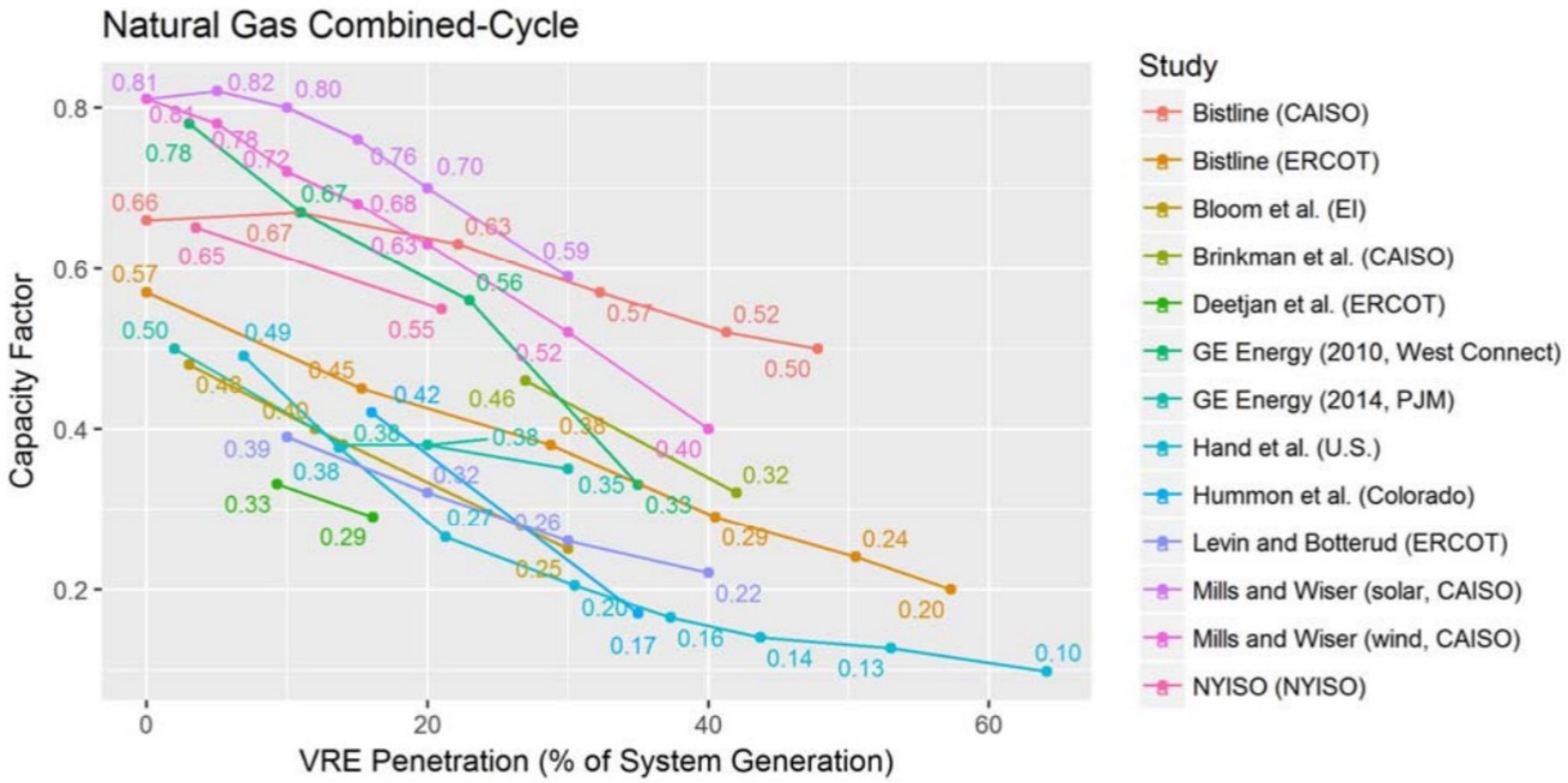
Executive Summary

- Variable renewable energy (VRE) is changing how electric grids operate
- The design and operations of CCS-equipped power plants should be reconsidered
- ARPA-E is funding FLECCS, a $45 million program, to (1) design and optimize systems and (2) build small prototypes
- Currently in Phase 1; moving to Phase 2 Spring 2022

MOTIVATION FOR FLEXIBLE CCS

CHANGING WHAT'S POSSIBLE

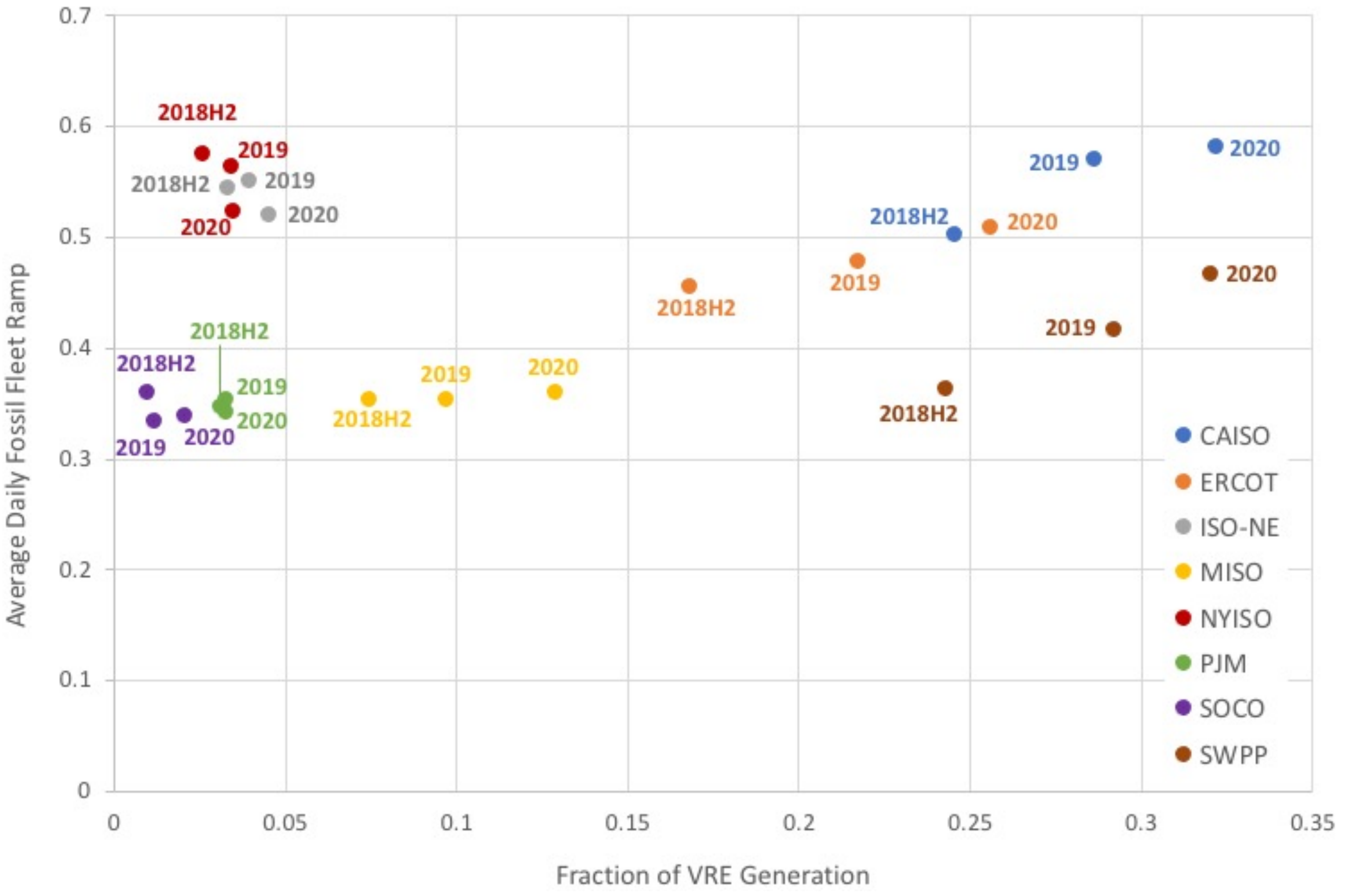
Electric power systems are changing – capacity factor



R. Wiser, Impacts of VRE on Bulk Power System Assets, Pricing, and Costs, LBL (2017)

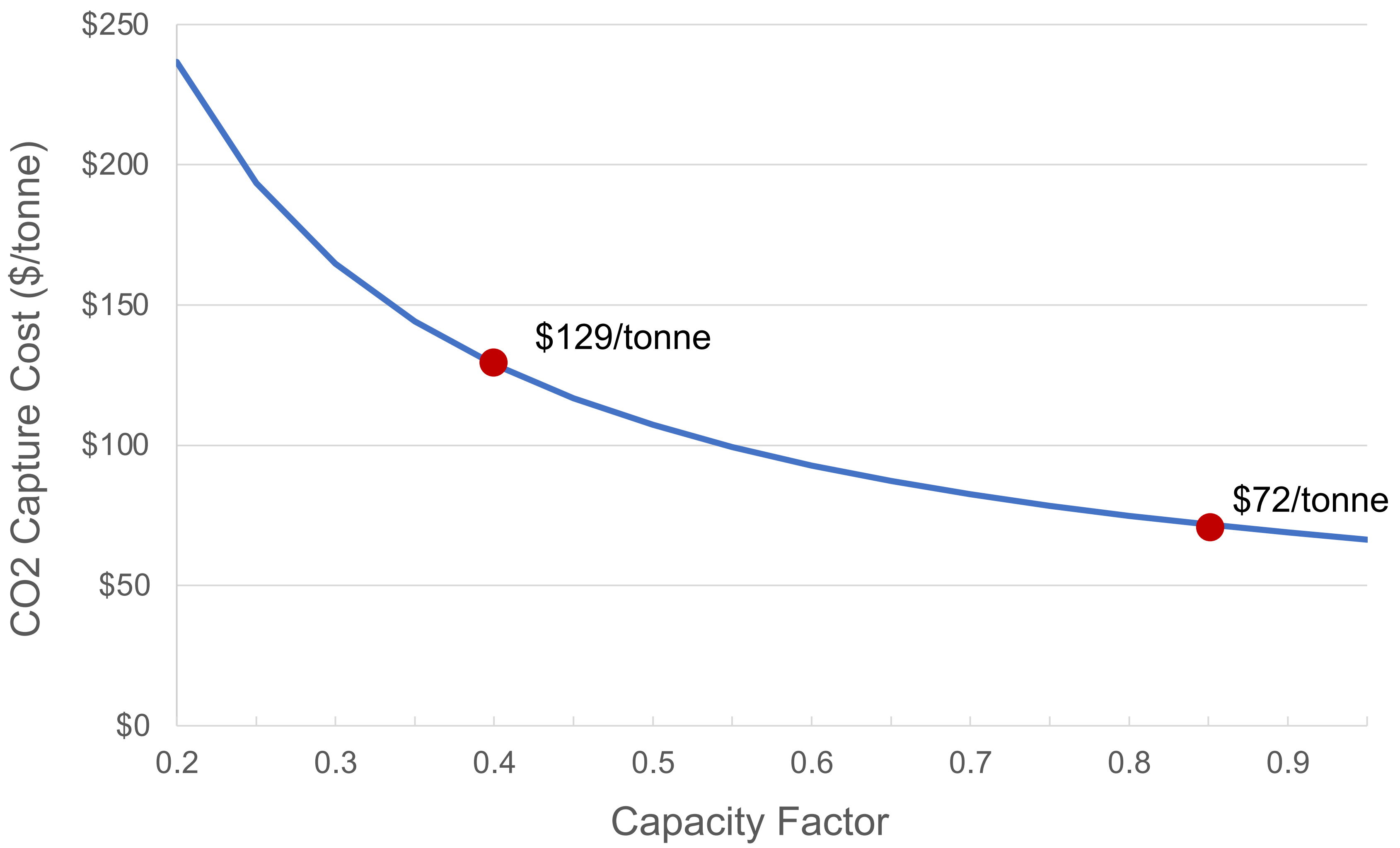
Electric power systems are changing – ramping

$$Daily\ Ramp = 1 - \frac{Min\ Generation}{Max\ Generation}$$



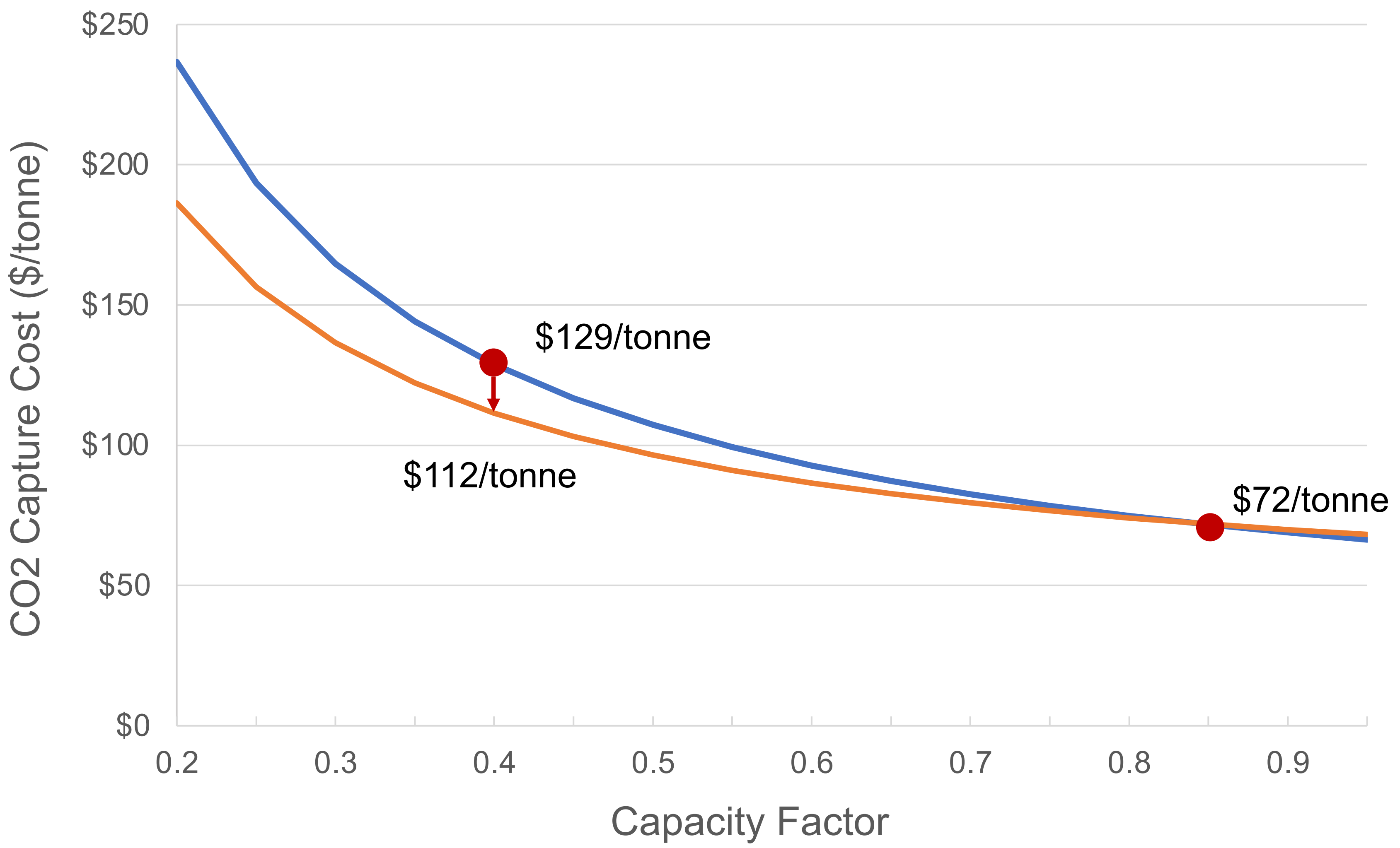
S. Litzelman, et al., Proceedings of the 15th Greenhouse Gas Control Technologies Conference (2021)

CapEx and OpEx tradeoffs



Data from NETL Cost and Performance Baseline for Fossil Energy Plants Volume 1a: Bituminous Coal (PC) and Natural Gas to Electricity, Rev. 3 (2015)

CapEx and OpEx tradeoffs



20% capex reduction

5 point efficiency decrease

Data from NETL Cost and Performance Baseline for Fossil Energy Plants Volume 1a: Bituminous Coal (PC) and Natural Gas to Electricity, Rev. 3 (2015)

THE FLECCS PROGRAM

FLECCS: finding the optimal role of CCS

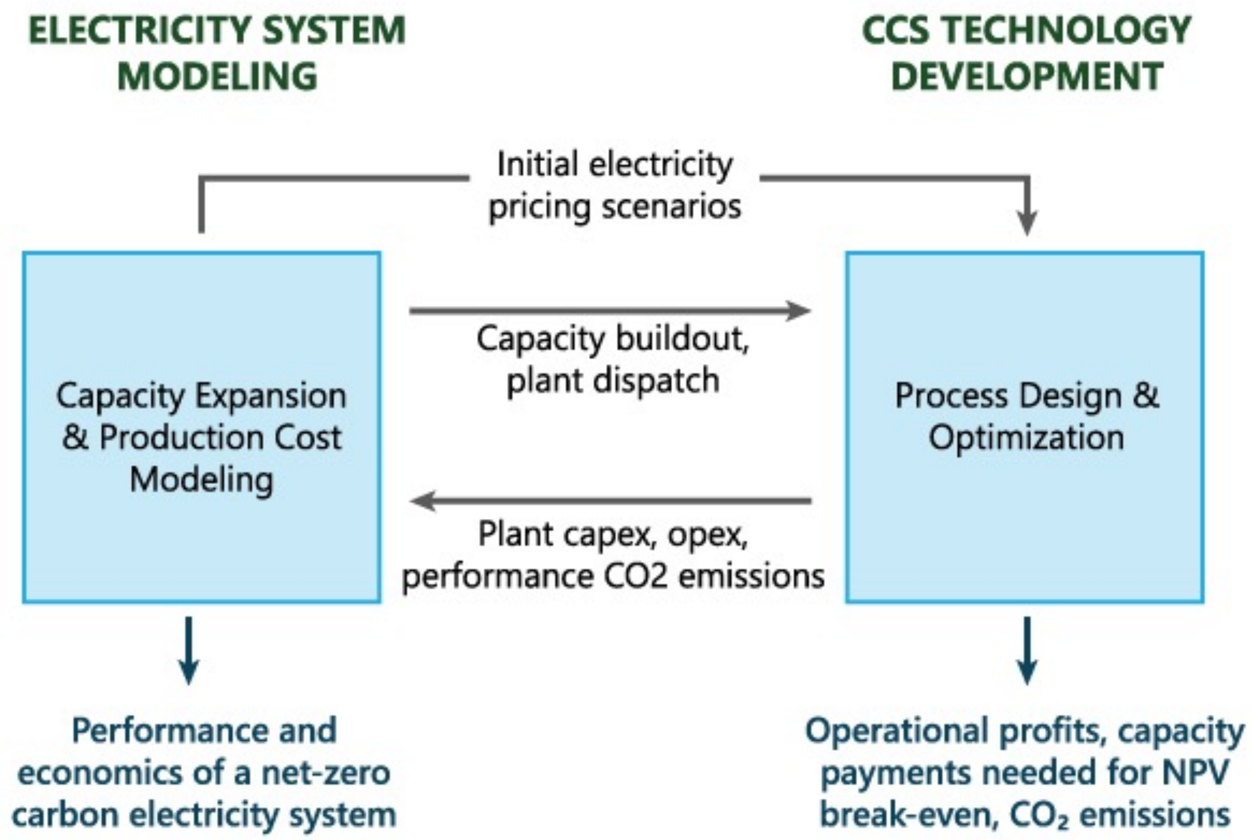
- Context: a net-zero carbon energy system with $100-300/t carbon prices (high enough for DAC to clear the market)

- Simulate electricity pricing conditions on a high-VRE grid: locational marginal prices (LMPs)

- Optimize the net present value of a CCS-equipped plant given these economic inputs

- Use capacity expansion and production cost models to assess value of a given flexible CCS approach

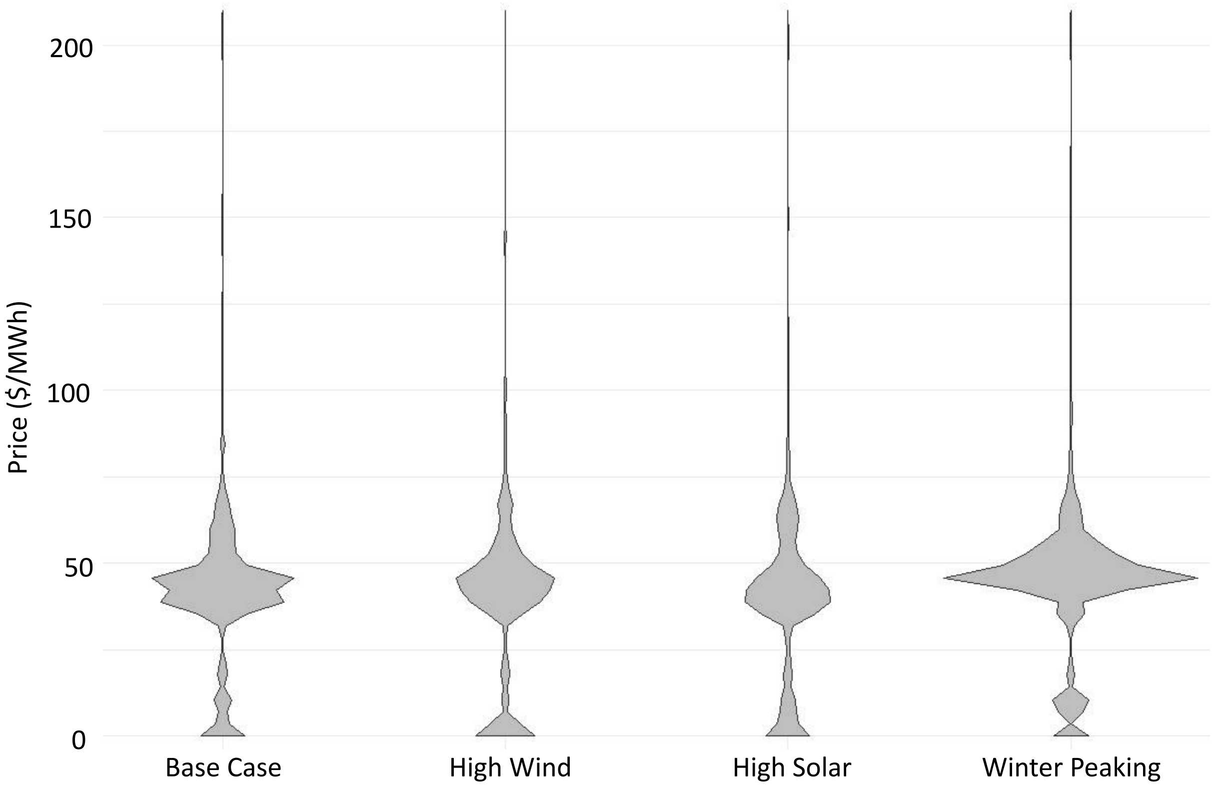
Interactions between grid modeling and tech development



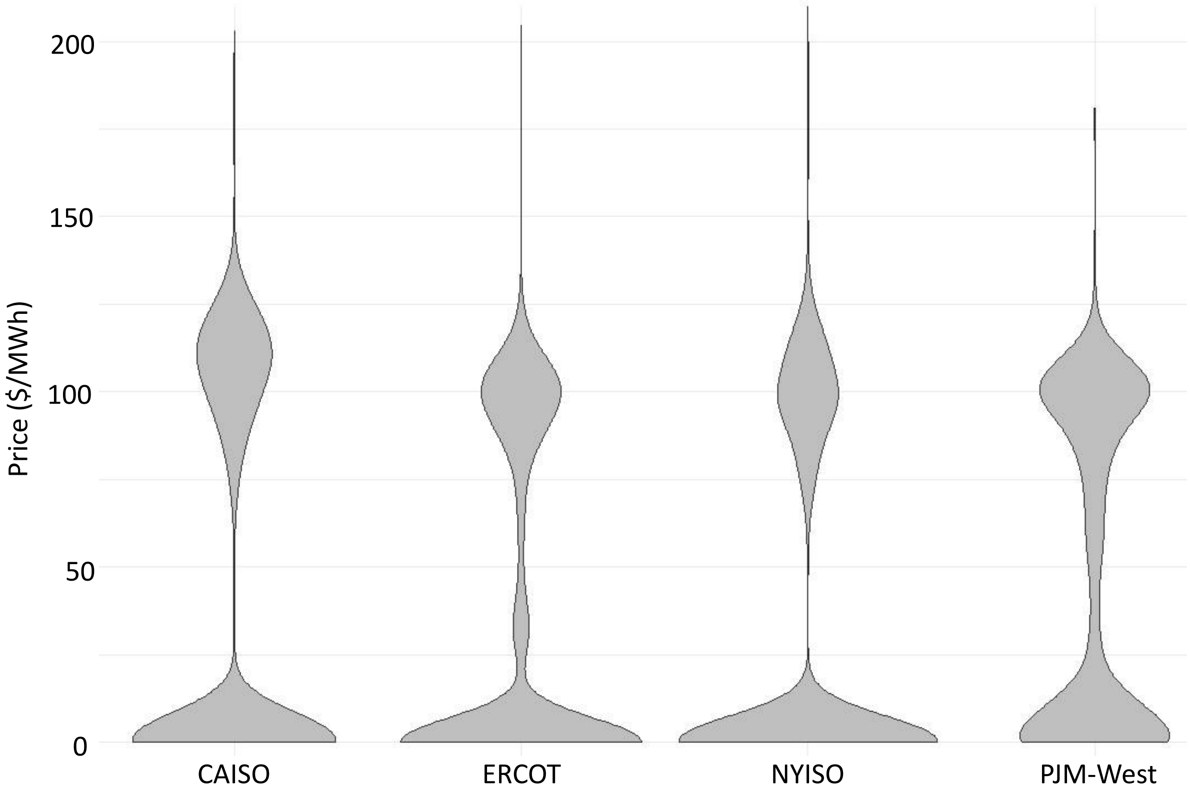
CHANGING WHAT'S POSSIBLE

Example of electricity pricing projections

Princeton University GenX model: $60/tonne CO_2



NREL ReEDS/PLEXOS: $150/tonne CO_2

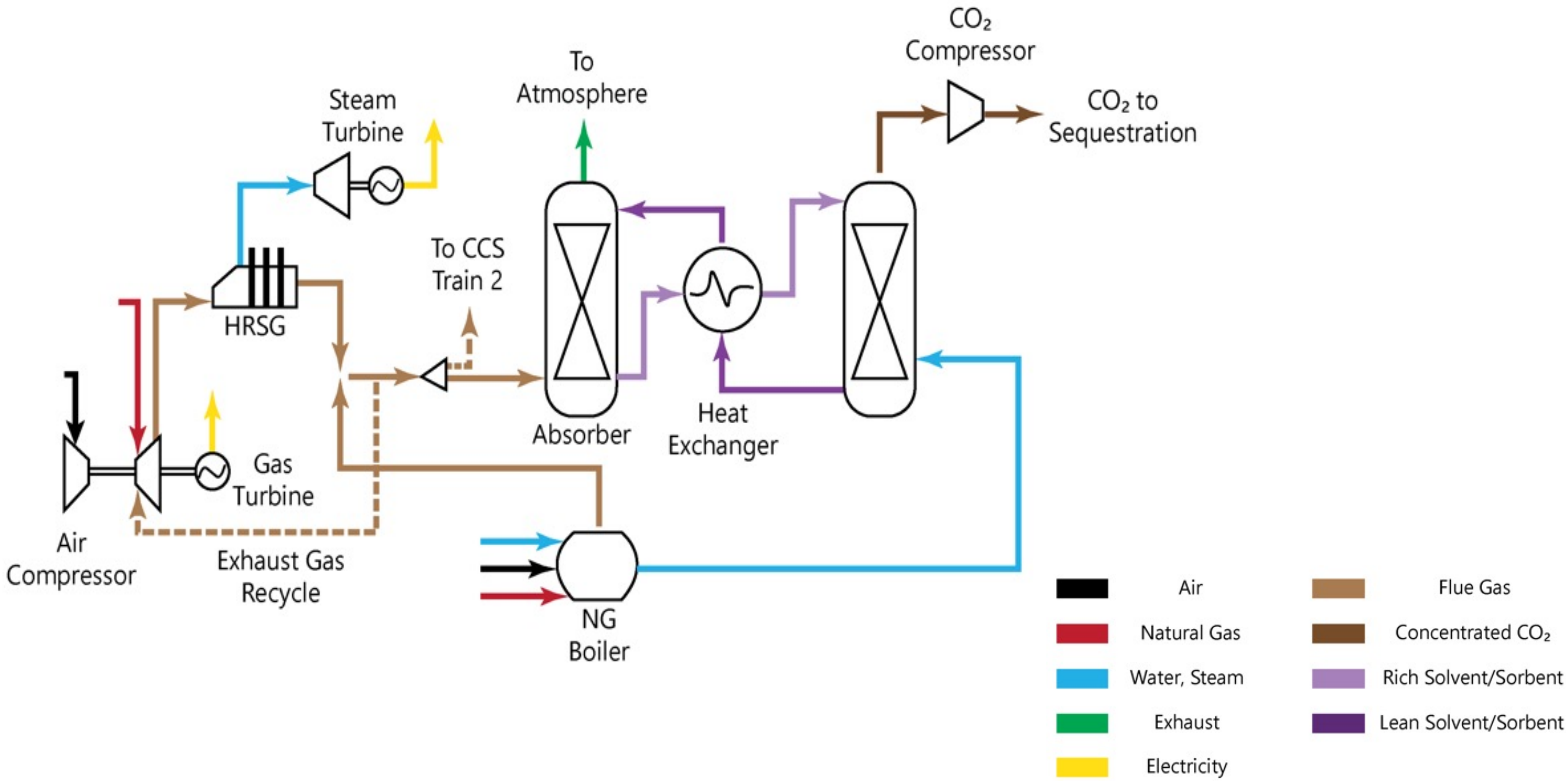


S. Litzelman, et al., Proceedings of the 15th Greenhouse Gas Control Technologies Conference (2021)

FLECCS technology teams

Flexible solvents, sorbents, membranes	Flexibility via thermal or chemical storage	Flexibility via DAC integration
RTI International, Susteon	Colorado State University	Georgia Tech
LUNA, 8 Rivers Capital, LLC	Southwest Research Institute	Massachusetts Institute of Technology
Envergex	GE Research	University of Pittsburgh
	Linde	

Potential solution: load-following CCS



S. Litzelman, et al., Proceedings of the 15th Greenhouse Gas Control Technologies Conference (2021)

Description of Technology and Strategy for NPV Optimization

Susteon

Description of Technology

- Structured solid adsorbents with **very high surface areas** and **low pressure drop**
- 60-second cycle times
- Fast startup and shutdown as well as fast cycle allow CCS plant to follow power plant operation
- Actual NGCC power plant data from LADWP for model validation

Strategy for NPV Optimization

- Clustering algorithms to sort LMP data into representative days
- CAPEX and OPEX correlations
- Identify decision variables – design and operating variables
- Solve for best design given identified scenarios (i.e. different LMP clusters)

$$\max_{d,u} NPV = \sum_{s\in S} w_s f(Revenue - Capital\ Cost - Operating\ Cost)$$

d – design (stage 1) variable
u – operating (stage 2) variable
w_s – weight for scenario s

$$\sum LMP_t * Power_t$$

- LMP signal from ARPA-E
- Scenarios will be considered independently

$$\sum \begin{matrix} TSA(design\ variables) + \\ CO_2\ compression\ (design\ variables) \end{matrix}$$

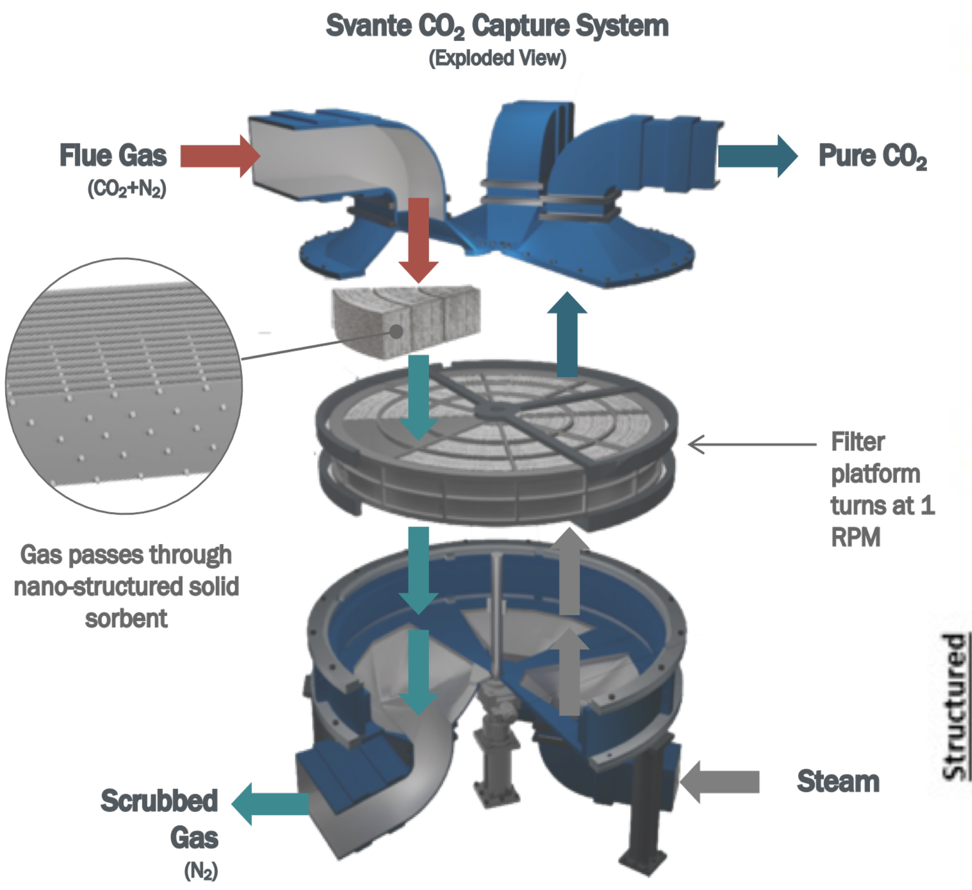
- Capital costs only for capture system
- Capital cost for modifications (steam extraction)

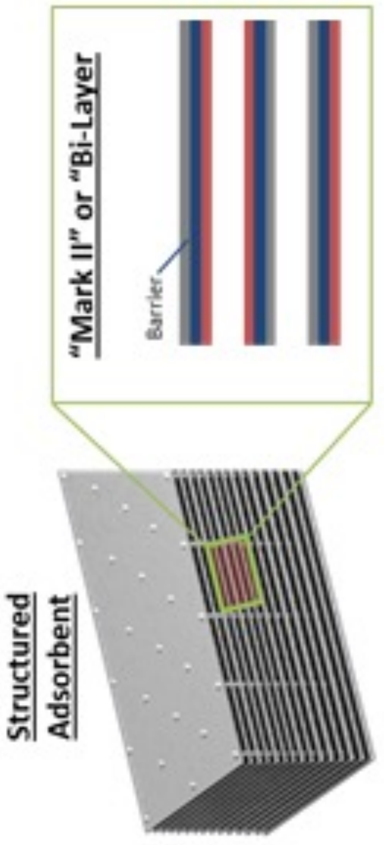
$$\sum \begin{matrix} NGCC(operating\ variables) + \\ TSA\ (operating\ variables) \\ + CO_2\ compression(operating\ variables) \end{matrix}$$

- Operating cost for NGCC and capture system

Carbon Capture Technology for Fossil Power Plants

Susteon



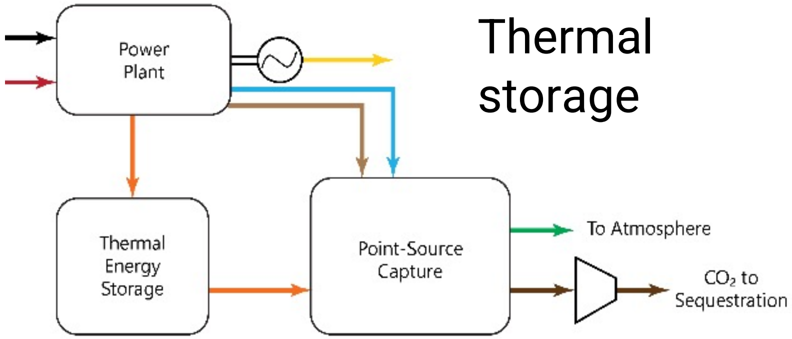


- Using novel structured adsorbents with fast TSA cycles for quick start/stop/turndown and load following
- CO_2 capture process and compression models integrated with power plant models
- Validation of process models using plant operating data and NPV optimization

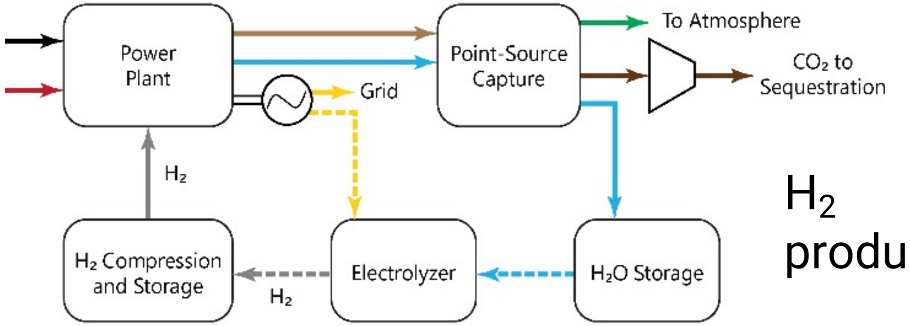
Project Goals

Metric	SOA	Goal
CCS Plant Technology	Cansolv	Fast Cycle TSA
CCS System Capital Cost	$779/kW	$549/kW
Cost of CO_2 captured	$82/Tonne	$48/Tonne
Flexibility Enabler	Not Flexible	High turndown ratio, fast cycle time

Potential solution: storage as a buffer

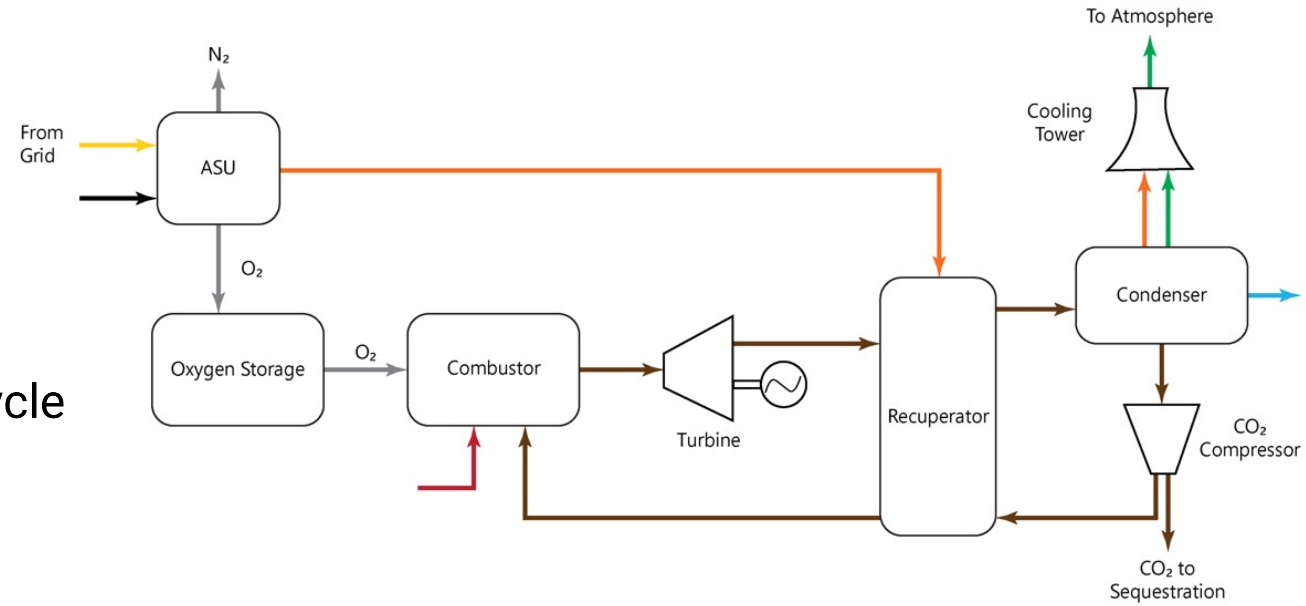


Thermal storage



H_2 production

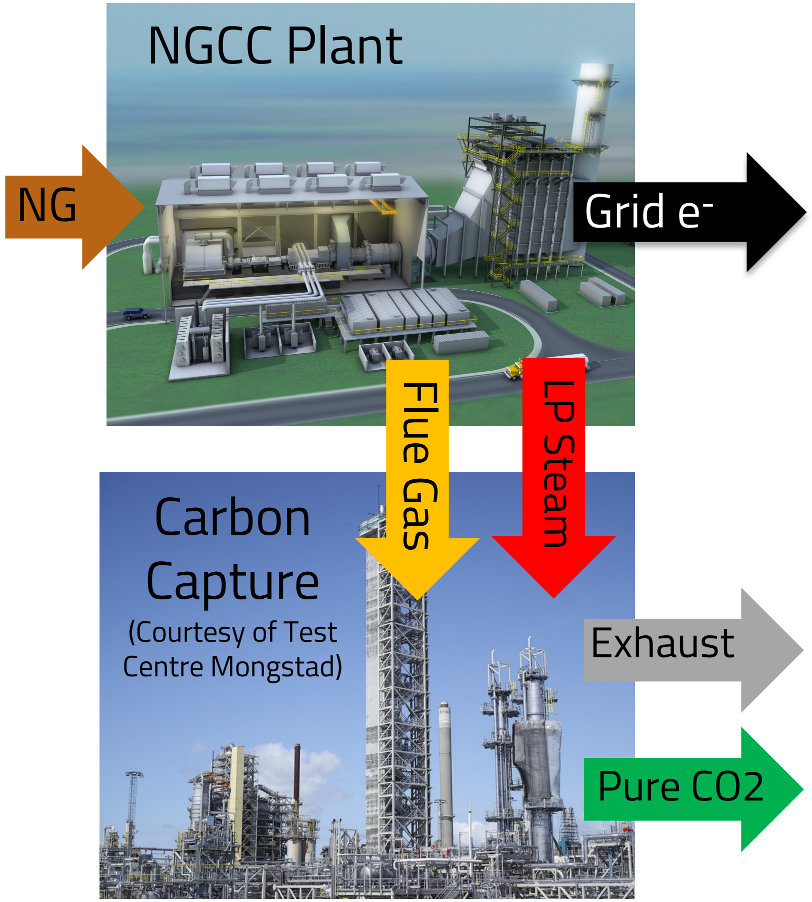
O_2 storage for Allam-Fetvedt cycle



Air	Water, Steam	Flue Gas	Electricity	Heat
Natural Gas	Exhaust	Concentrated CO_2	Other Streams	---------- only active during low LMP times

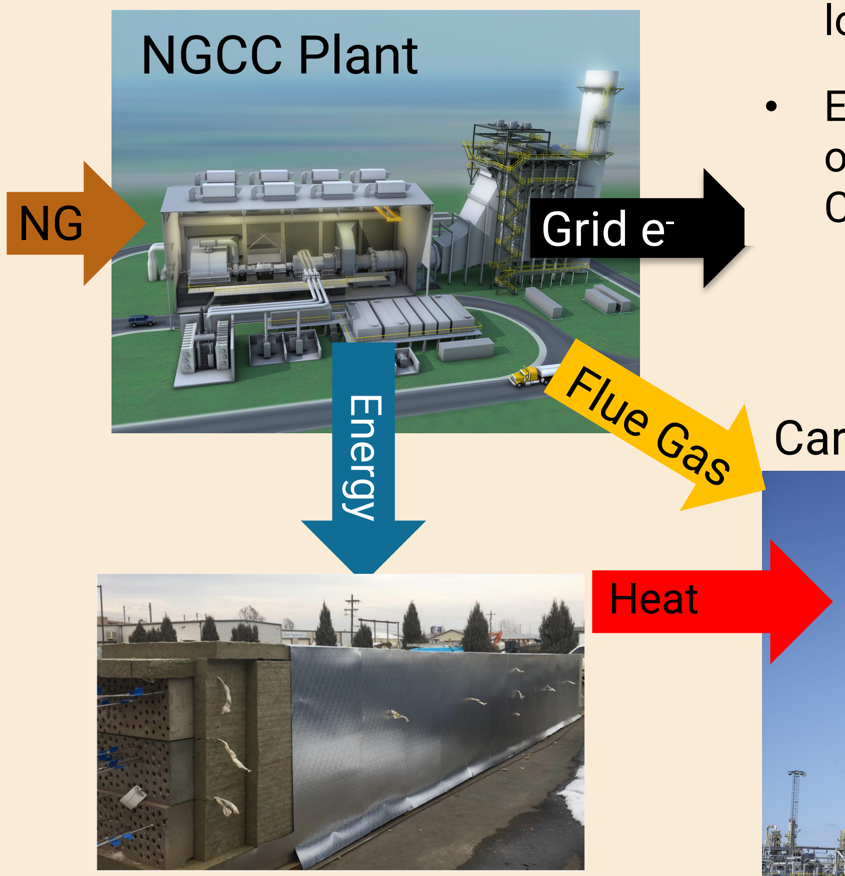
CSU: pumped thermal storage integration

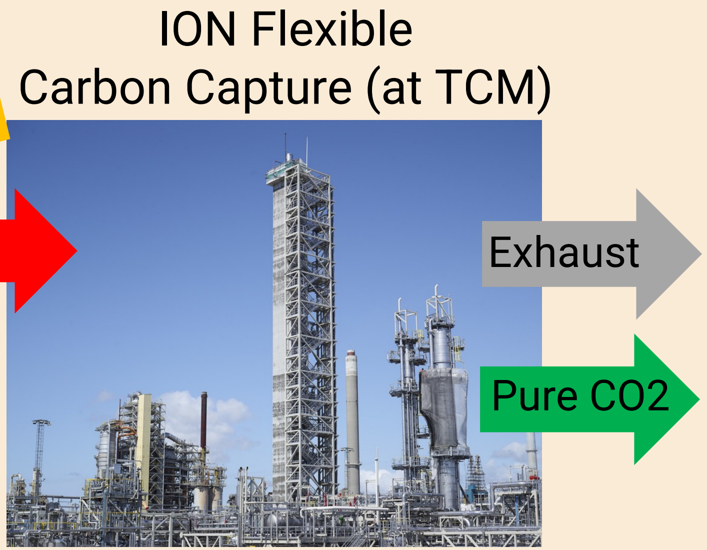
State of the Art



Solution

- Energy storage/utilization at low/high demand
- Enables NGCC capacity factor optimization while capturing 95% CO_2





Concept

Project Team

GE Research

Expert in power plant design, simulation, and economic analysis

8RIVERS

8 Rivers Services

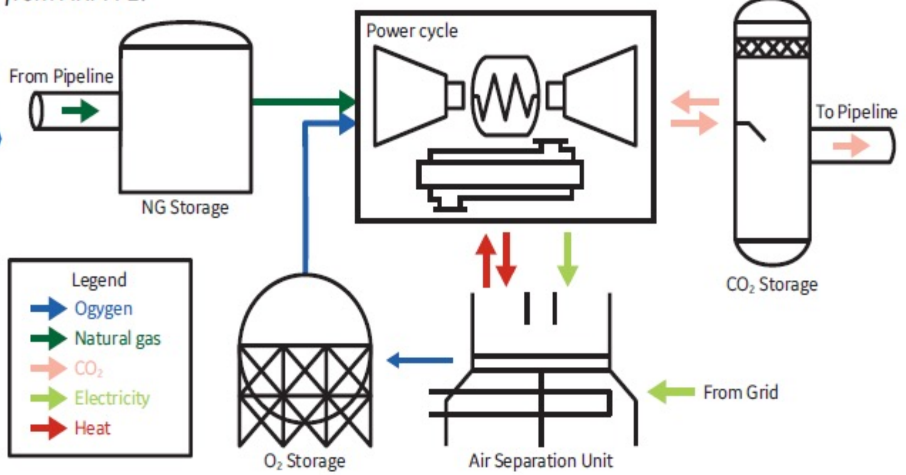
Expert in oxy-combustion power plants

Relevant Prior Work

GE Research has designed numerous gas turbines and developed complex optimization scenarios for power plants. 8 Rivers has developed and piloted a 50MWt oxy-combustion plant with carbon capture.

15 ~~12~~-month, $900,000 project to model a low-cost, flexible oxy-combustion power plant with carbon capture

Program Objective: *Model the highest NPV for an integrated oxy-combustion plant given the pricing information and CO_2 cost of $100, $200, and $300/t CO_2 from ARPA-E.*



Technical Approach

Determine what policies and investments need to be implemented to drive investment by industry in flexible carbon capture. Develop a thermodynamic and economic model of the integrated plant.

Technical Challenges

Optimize the NPV of the plant by varying design and operational parameters.

Project Deliverables

Plant performance and cost information for the capacity expansion model, with the goal of getting as close to the DOE aggressive target of LCOE of $75/MWh.

Project Benefits

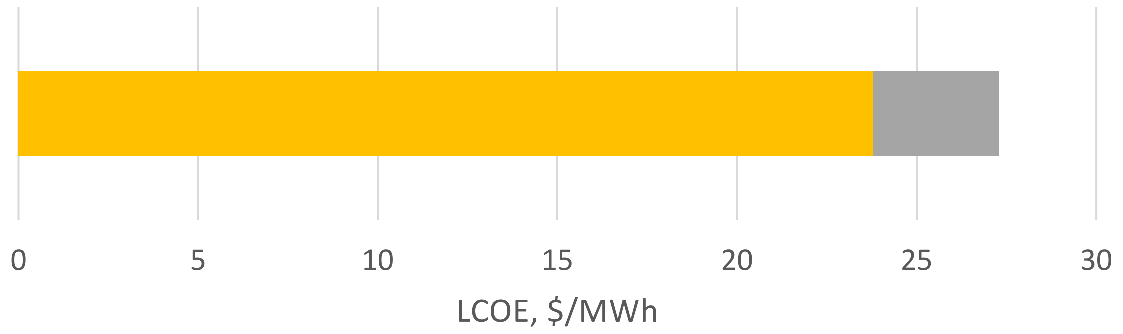
This technology has the potential to provide the flexibility of a gas plant with near-zero CO_2 emissions. The combination of tight thermal integration across the plant and gas buffering will allow this oxy-fueled system to provide flexible, near-zero CO_2 electricity, at a competitive price.

Figure 1. Summary of the proposed Flexible Oxy-fuel Combustion for High-Penetration Variable Renewables project.

"The information, data, or work presented herein was funded in part by the Advanced Research Projects Agency-Energy (ARPA-E), U.S. Department of Energy, under Award Number DE-AR0001304. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."

Early dispatch modeling … idealized

Marginal cost



Fuel Cost

$23.78/MWh

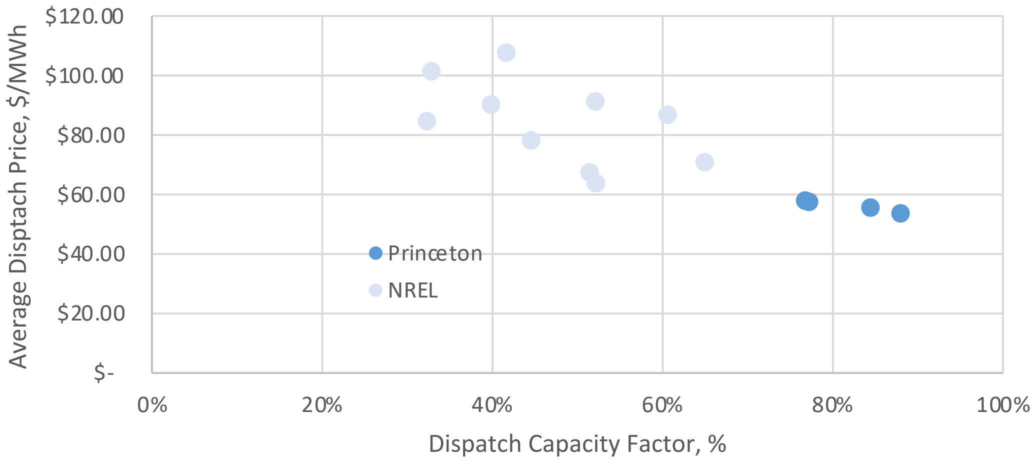
Variable O&M

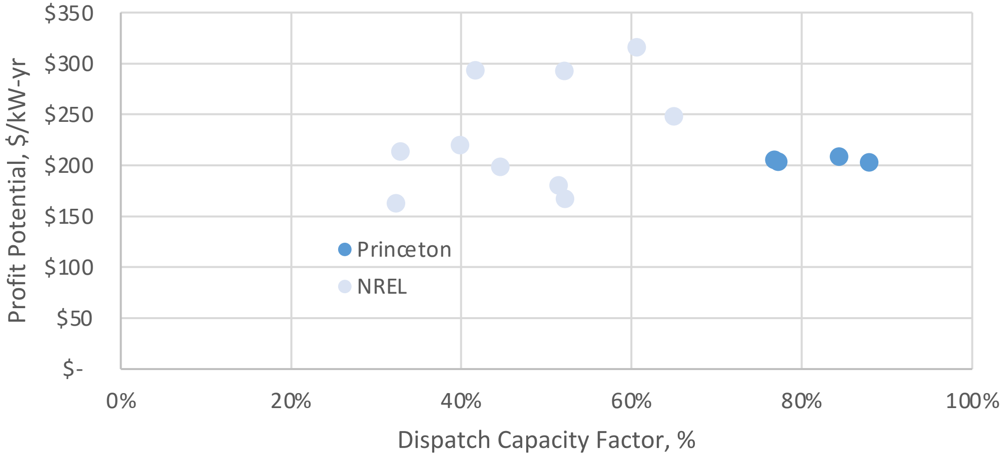
$3.50/MWh

$$\frac{6{,}132\ Btu_{LHV}}{kWh} * \frac{\$3.50}{mmBtu_{HHV}} * \frac{1.108\ HHV}{LHV}$$

- **Cost threshold defining desired dispatch**

Idealized dispatch … On/off based on marginal cost only

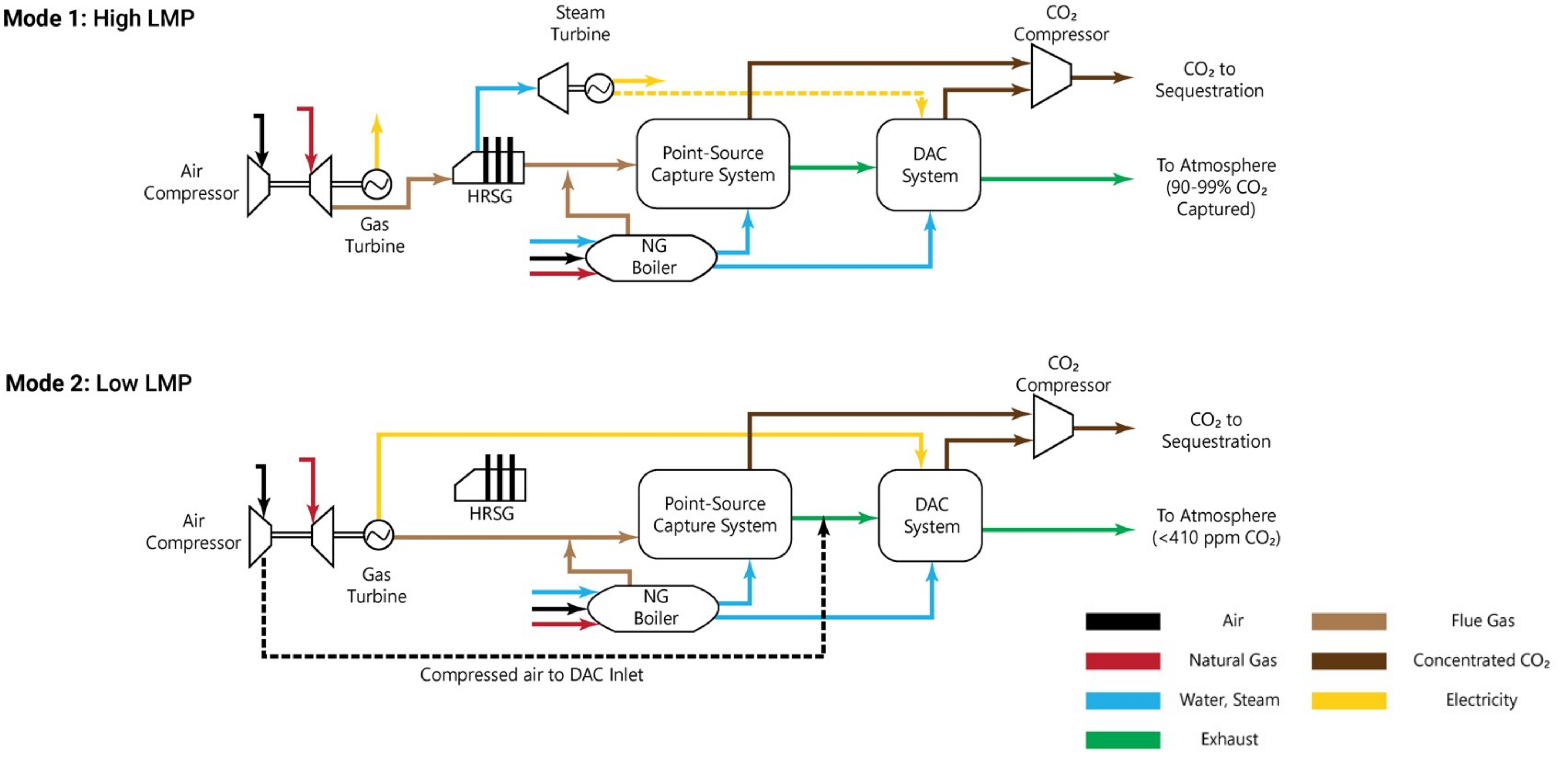




Although CF's varies from 32% to 88% … profit potential closer

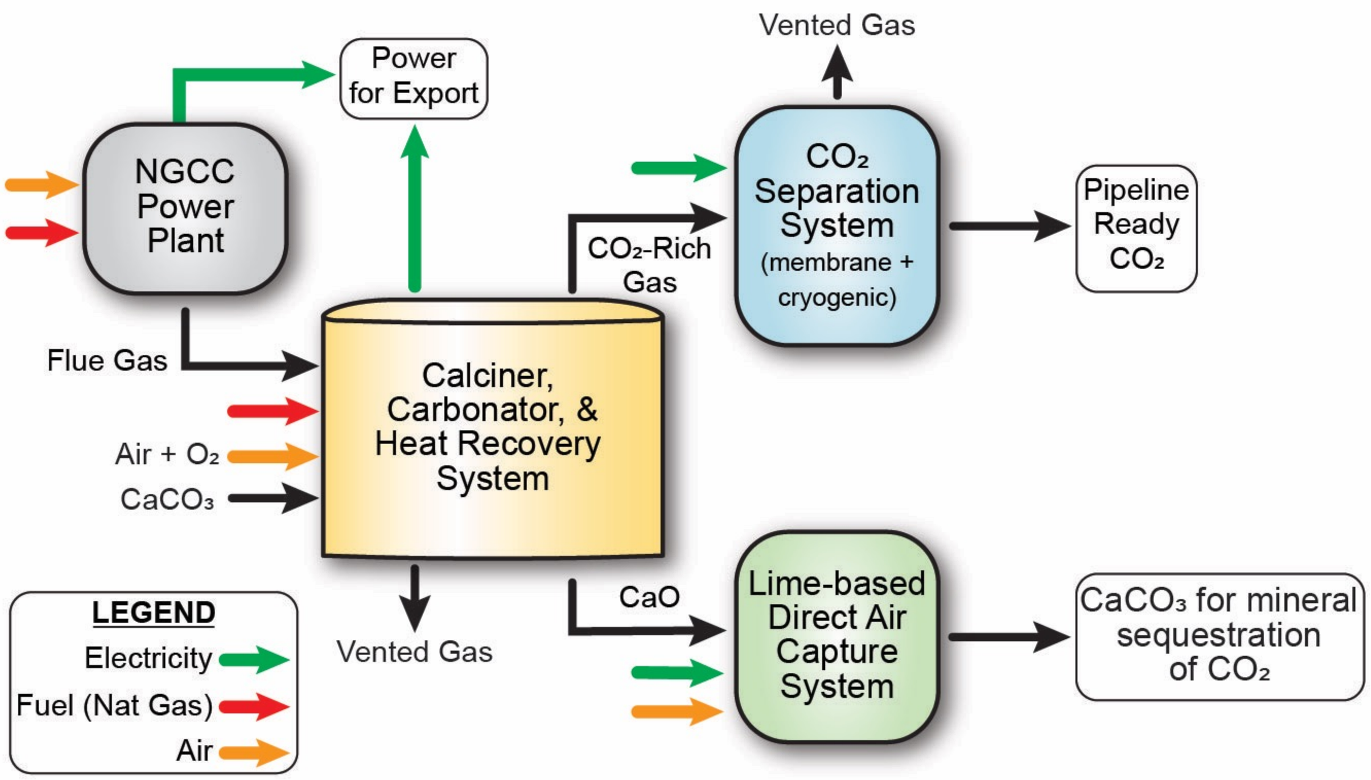
"The information, data, or work presented herein was funded in part by the Advanced Research Projects Agency-Energy (ARPA-E), U.S. Department of Energy, under Award Number DE-AR0001304. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."

Potential solution: direct air capture integration



S. Litzelman, et al., Proceedings of the 15th Greenhouse Gas Control Technologies Conference (2021)

FLECCS Concept: integrate plant flue gas CO_2 capture with lime-based direct air capture (DAC)



The Team

MITei

Howard Herzog, Dharik Mallapragada, Emre Gençer, Edward Graham, Moataz Sheha

8 RIVERS

Philip Cross, James Custer, Adam Goff, Ian Cormier

About the process

Implements patent-pending technologies from 8 Rivers
- Lime-based direct air capture (DAC)
- Calciner and carbonator process (Carbon8)

Key features:
- High (>30 vol%) CO_2 concentration of calciner exhaust makes electricity-based downstream separation/purification practical
- Potential for net negative emissions power generation
- Process does not impact power plant flexibility

Flexible operation and optimization strategy

Flexibility enablers

CO_2 separation system is electrically-driven and not thermally integrated with the power plant

Units still operate at reduced or zero power plant loadings

- Process adjusts to varying flue gas (e.g.,$CaCO_3$ feed is varied)
- Fresh $CaCO_3$ calcined, producing CaO for DAC and a CO_2 rich stream for separation and sequestration
- Process units operate even when power plant is idle

Optimization Strategy (MIT)

Detailed steady-state process simulation

Vary power plant loading levels; identify key design variables

Dynamic modeling

Identify ramp rate constraints; assess impact of equipment size on transient behavior

Reduced order models

Computationally efficient surrogate models to characterize unit ops

Costing

Size and cost the plant using Aspen economic analyzer supplemented with vendor info

Integrated design and optimization

Optimize design and operation of power plant concept to maximize NPV for different electricity and CO_2 price scenarios

A timeline of FLECCS Phase 1

Note: broad distribution of project start times (for some, 2020)

Start	Model, costing methodology	Initial T2M plan	System models validated	First analysis by modeling teams	Phase 2 Decisions
Feb.	May	Aug.	Nov.	Feb.	May

← 2021 → ← 2022 →

Summary

- The design and operations CCS-equipped power plants should be reconsidered in light of increasing VRE penetrations

- Electricity system models can help quantify value

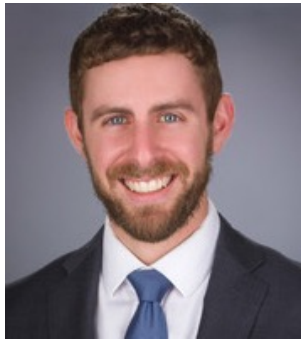
- We have hypotheses as to CCS systems that add value, but must quantify

- FLECCS is a two-phase program to identify most promising concepts and start building prototypes

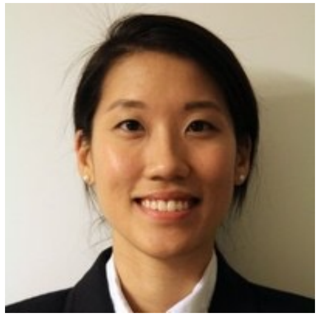
Acknowledgements

Programmatic Support
Alexis Amos
Erin Gilley

Tech-to-Market
Max Tuttman



Technical Support



Elena Chung

Maruthi Devarakonda

Ray Duthu

Max Lyubovsky