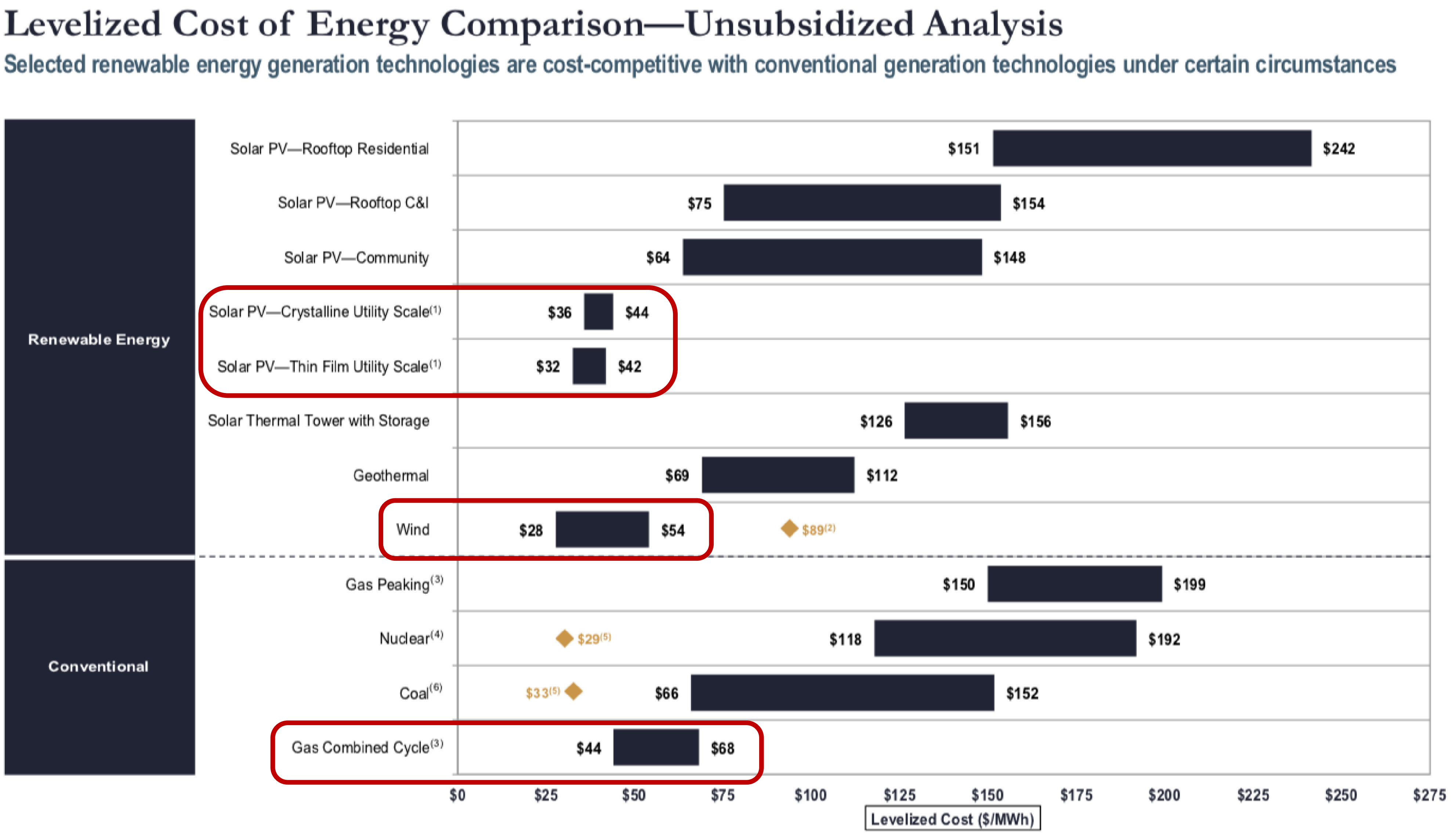
FLExible Carbon Capture and Storage (FLECCS)

Scott Litzelman, Max Tuttman (ARPA-E)

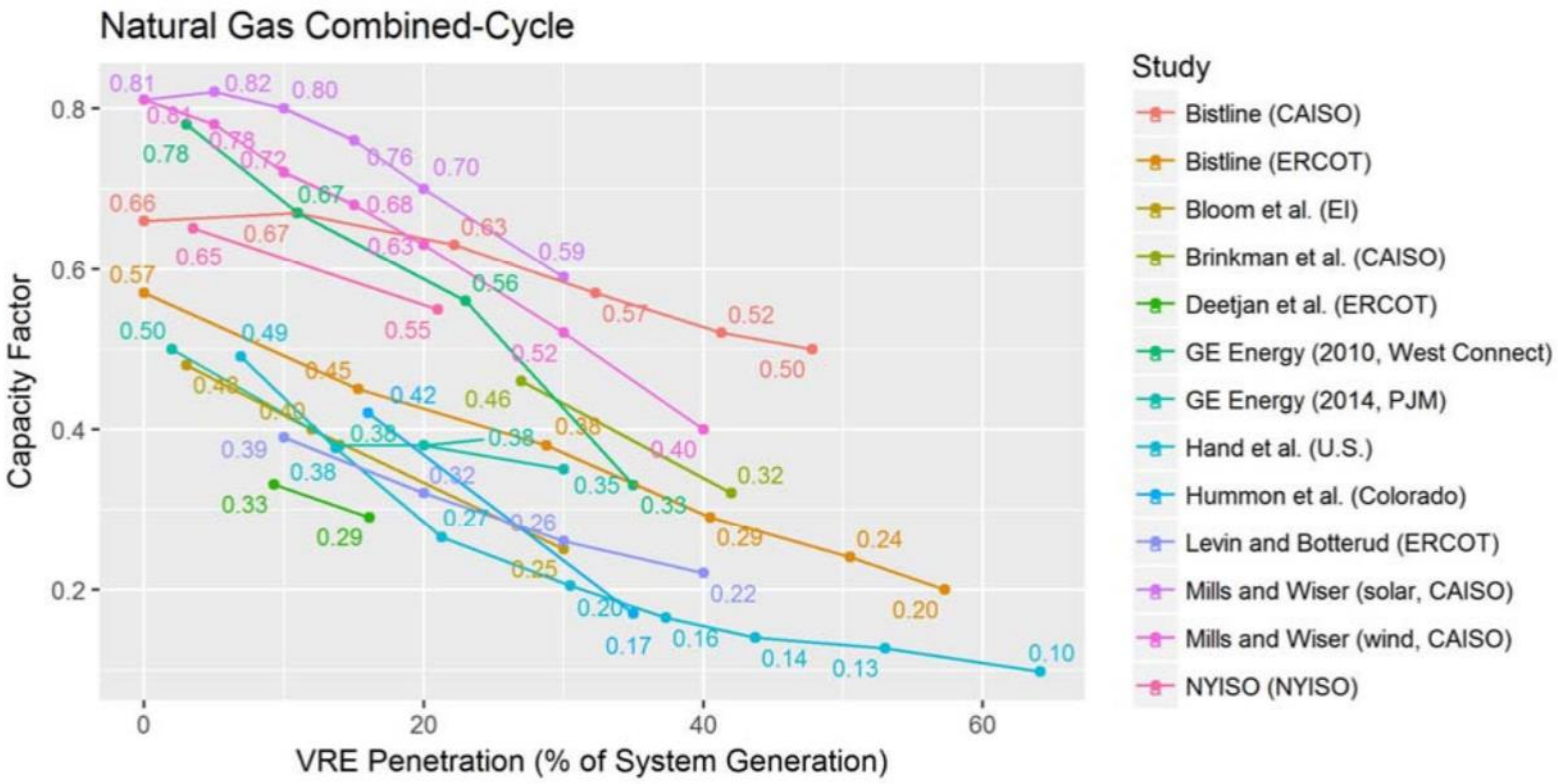
Maruthi Devarakonda, Dora Lopez, Max Lyubovsky (Booz Allen Hamilton)

Ray Duthu (QS-2)

Fossil w/o CCS has higher LCOE than utility-scale wind and solar



The capacity factor of thermal generators is decreasing

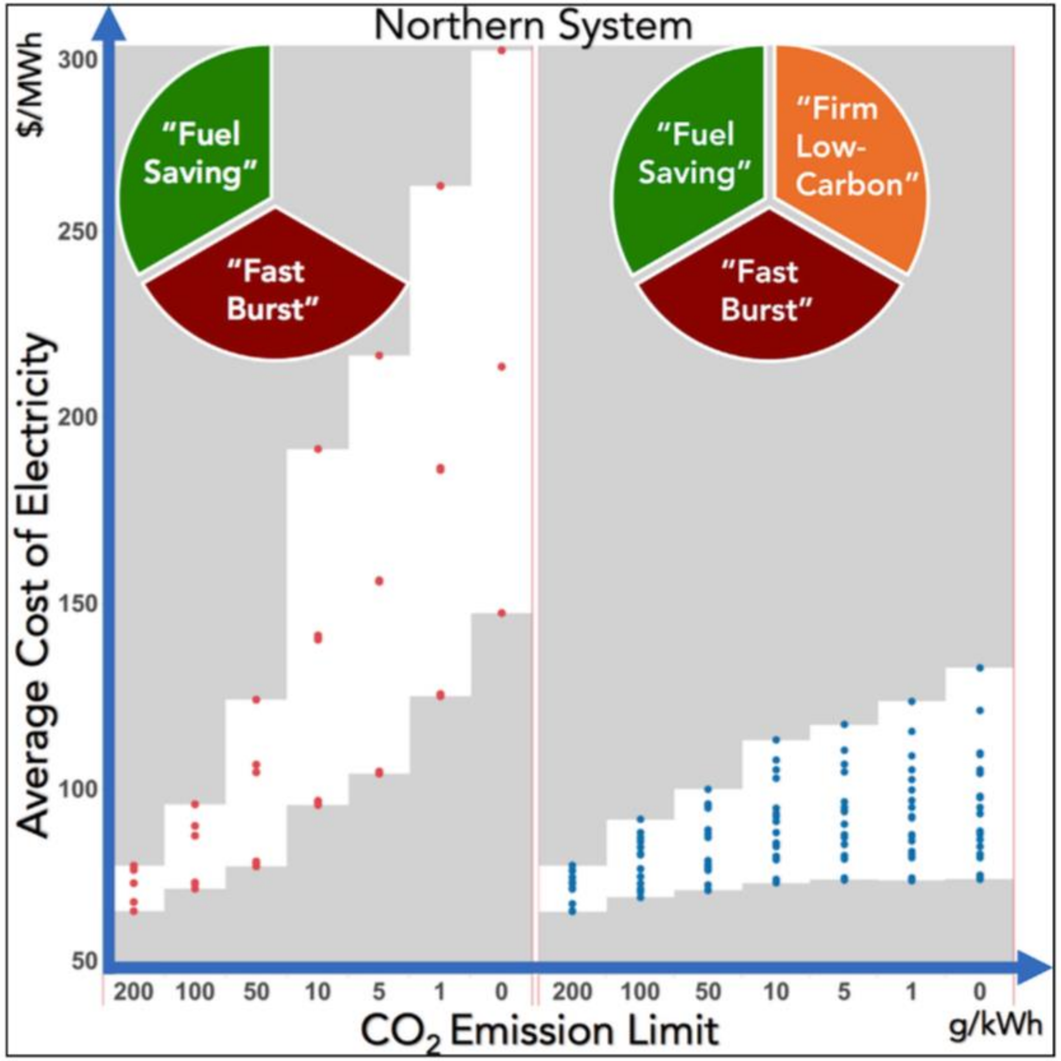


R. Wiser, Impacts of VRE on Bulk Power System Assets, Pricing, and Costs, LBL (2017)

Outline

- **The motivation behind FLECCS**
- Overview of the FLECCS program
- A few comments about DAC

Good news for CCS: cheaper path to net-zero carbon



Technology examples

- Solar, wind
- Storage, demand response
- Nuclear, CCS, geothermal

"Firm low-carbon" resources like CCS and nuclear lower the cost of deep decarbonization by 10-62%

CHANGING WHAT'S POSSIBLE

Sepulveda, et al., *Joule* 2, 1–18 (2018)

FLECCS: finding the value in CCS and its role in the grid

Context: vision for future grid

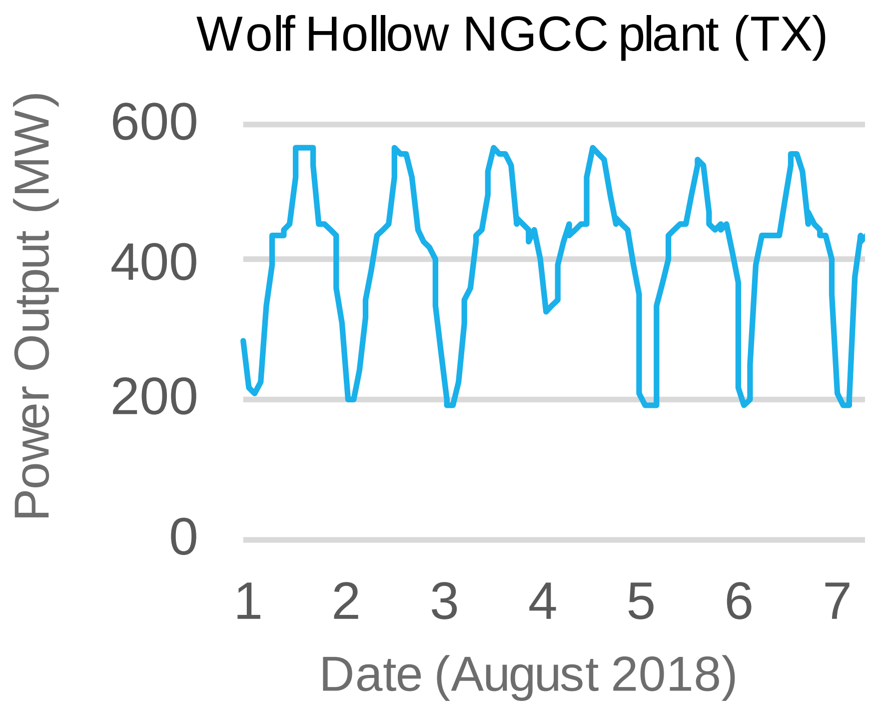
- Net-zero carbon
- Carbon pricing high enough for DAC to clear the market
- Need to model at the system level
- Using locational marginal prices (LMP) to simulate high variable renewable energy (VRE) grid

Design and operational implications

- Decreasing plant capacity factors
- Capex/efficiency tradeoffs
- Optimal CO_2 capture rate
- Variations in capture and/or heat rate

VREs are already changing power plant operations

Power plants are operating dynamically in response to electricity price fluctuations…



…which changes how CCS systems should be designed and operated

- Ex: responsive capture systems that quickly start, ramp, turndown, and shut down
- Or, buffering capabilities (e.g. thermal storage) so plant can run at steady-state but selectively export electricity to the grid
- Integrate with direct air capture (DAC) to optimize point-source CCS utilization and cost

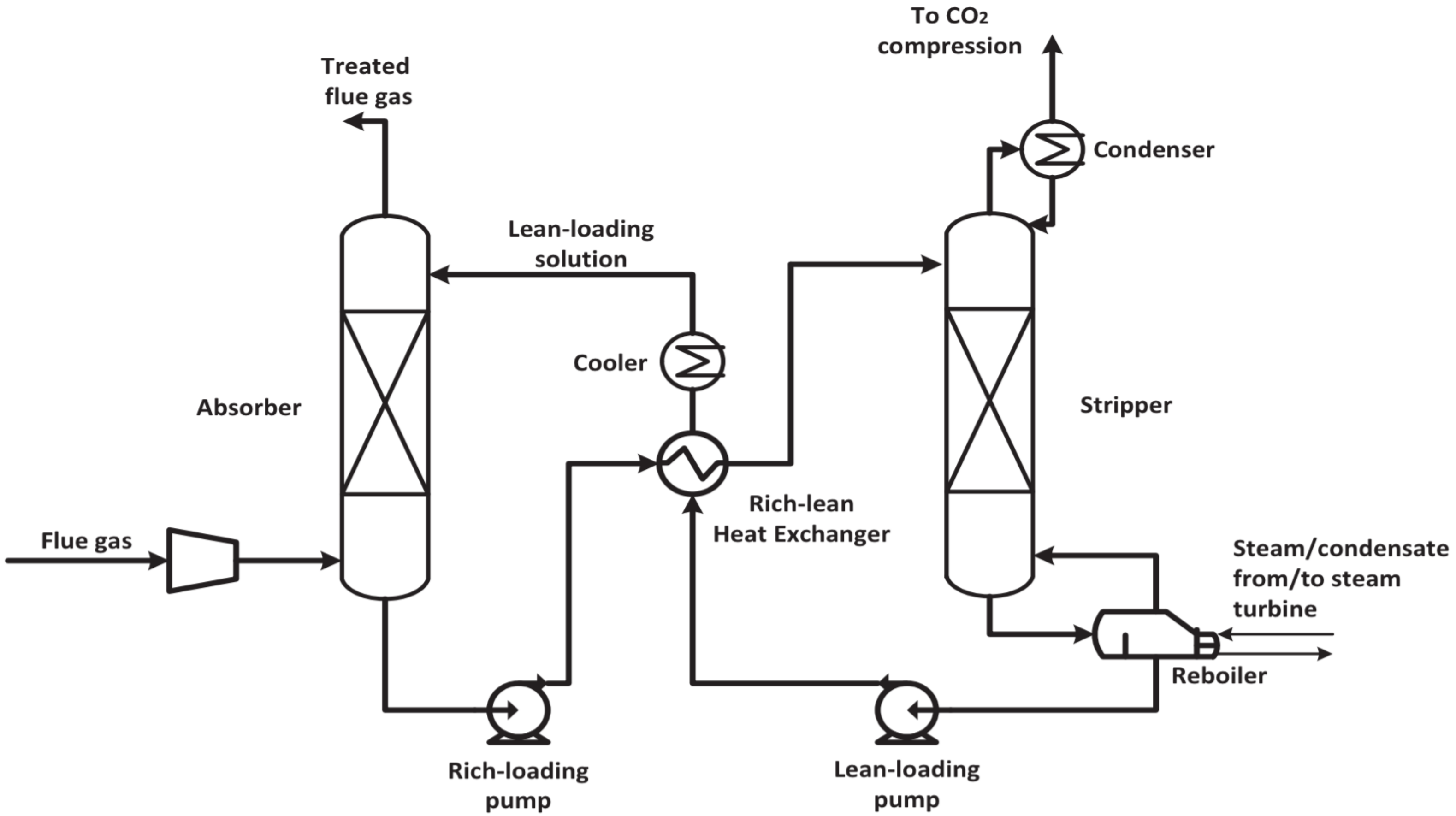
https://ampd.epa.gov/ampd/

Can CCS be flexible? To some extent, sure

Citation	Source of plant data
P. Tait, et al., Int'l J. Greenhouse Gas Contr. 48, 216-233 (2016)	Sulzer Chemtech pilot plant, Switzerland
J. Gaspar, et al., Energy Procedia 86, 205-214 (2016)	Esbjerg pilot plant, Denmark
P. Tait, et al., Int'l J. Greenhouse Gas Contr. 71, 253-277 (2016)	UKCCSRC PACT pilot plant, UK
M. Bui, et al., Int'l J. Greenhouse Gas Contr. 79, 134-153 (2018)	UKCCSRC PACT pilot plant, UK

Broad conclusions: lots of parameters to optimize, but capture plant can load follow and handle a range of plant operation schemes

Why increasing dynamics is hard for CCS



CCS parameters affected by variable power plant output

- CO_2 lean solvent loading
- CO_2 removal %
- T and P in absorber, regenerator
- L/G ratio in the absorber
- Liquid residence time

Y. Wang, et. al, Energy Procedia, 650-666 (2017)
M. Bui, et. al, Computers and Chem. Eng., 61, 245-265 (2014)

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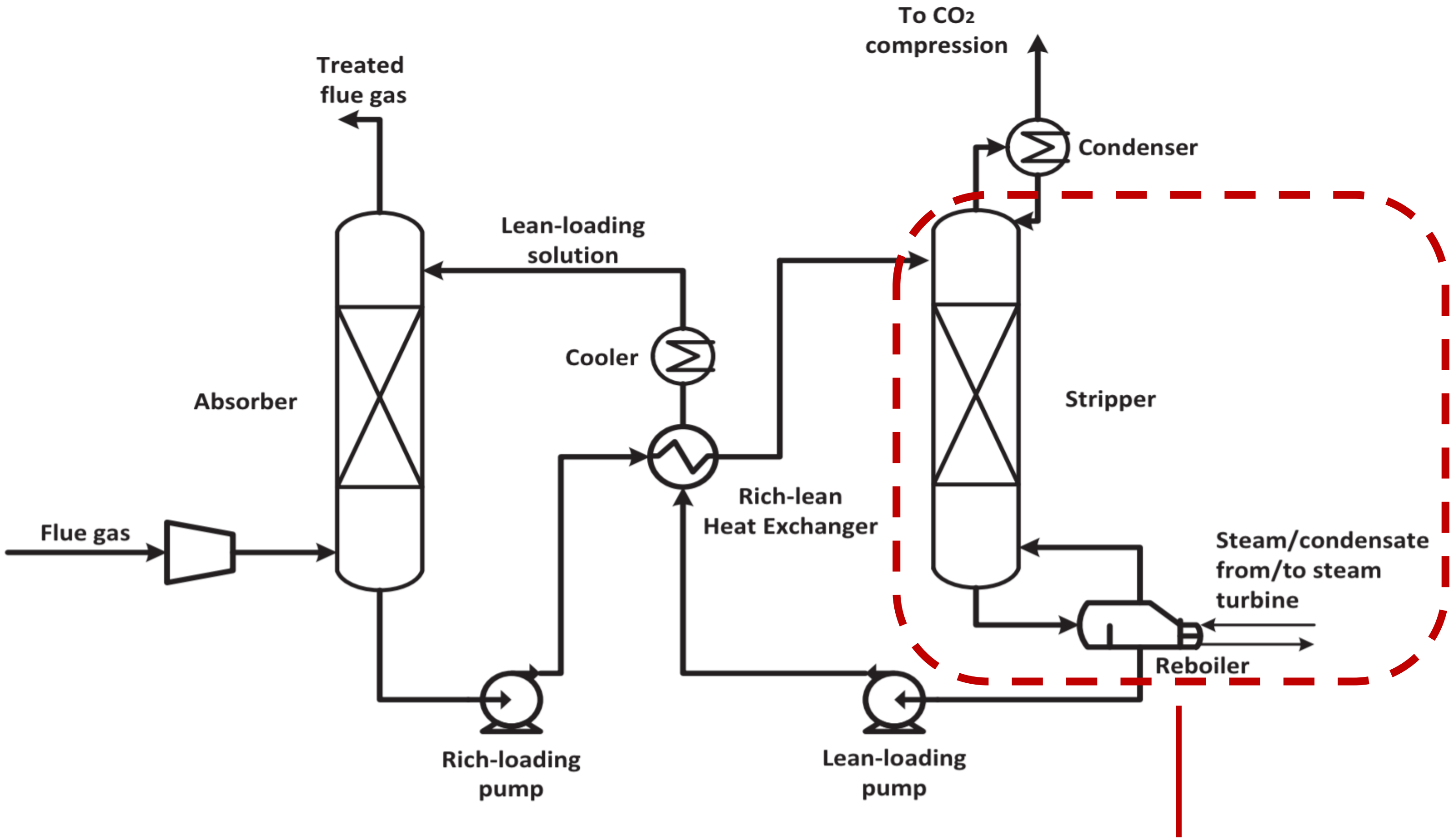

CCS parameters affected by variable power plant output

- CO_2 lean solvent loading
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Example: deep turndown causes liquid maldistribution in regenerator and increases reboiler duty by 50%

Y. Wang, et. al, Energy Procedia, 650-666 (2017)

M. Bui, et. al, Computers and Chem. Eng., 61, 245-265 (2014)

Grid modeling 101

Capacity Expansion

Goal: Simulate generation and transmission capacity investment to evaluate generation mix and/or policy impacts in the mid- to long-term

Inputs: future electricity demand, fuel prices, scenario assumptions, technology cost and performance…

Outputs: Annual generation, generation and transmission capacity builds/retirements, system LCOE, emissions, fuel consumption…

Examples: Regional Energy Deployment System (ReEDS), National Energy Modeling System (NEMS), GenX (Princeton), Resource Planning Model (RPM)

Production Cost

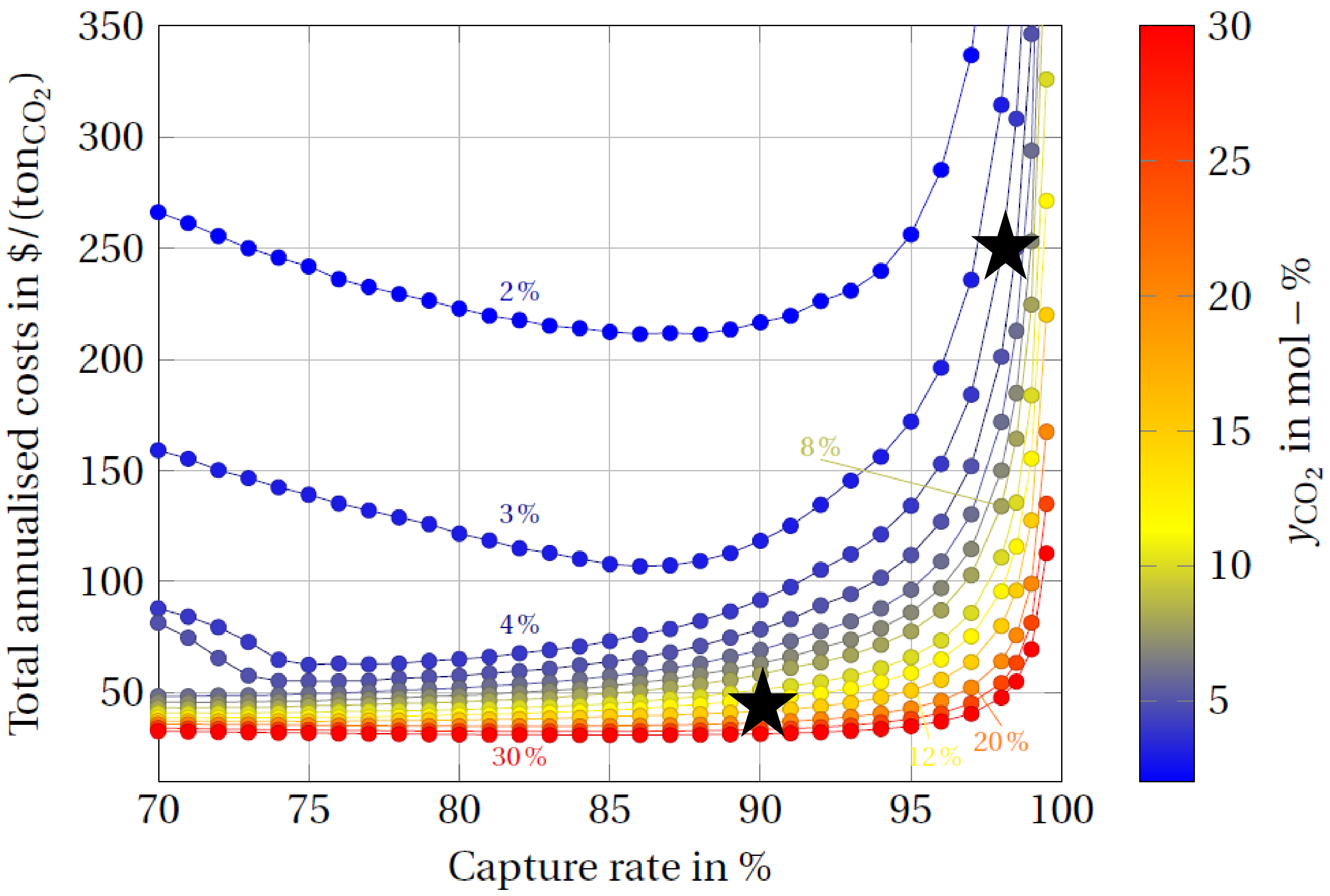
Goal: Optimize multi-interval (typically hourly) balance of generation and load constrained by transmission and generator operational limits

Inputs: Time series of nodal demand, fuel prices, transmission constraints, generator cost functions, generator operational constraints…

Outputs: Time series of generation and transmission setpoints that serve load at an optimized objective (typically minimum cost or maximum market surplus)

Examples: PLEXOS

Cost as a function of concentration & capture rate



Brandl, *et al*, Int J GHG Control, 2019

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FLECCS program structure

Phase 1
12 teams, 15 mo., $11.5M

Design and optimize responsive CCS processes for flexible power plants

Engineering design review, economic evaluation, review of cost sensitivities, technical uncertainties

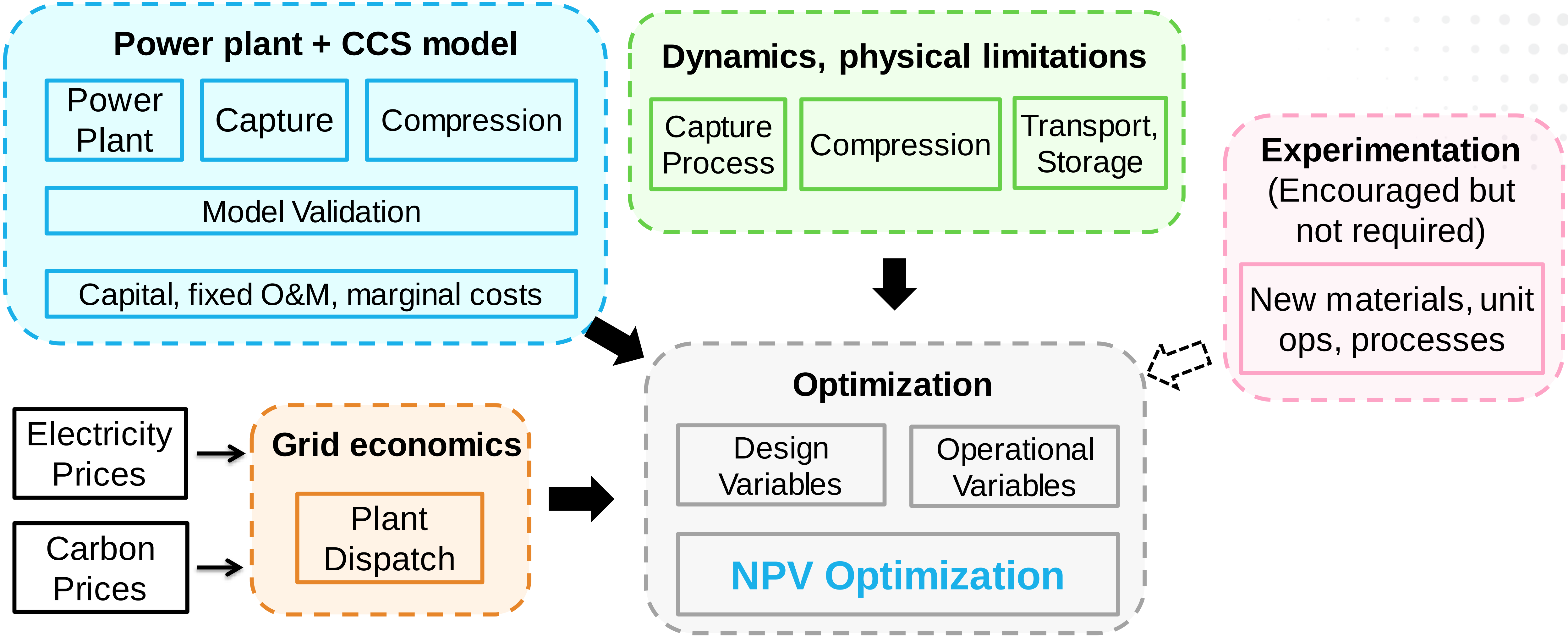
Build CCS- and DAC-specific grid models to assess system impact

2 teams, $1.4M

Phase 2
6-7 teams, 3 yrs., $30.8M

Build new components, unit ops, and small systems

Phase 1 – focus on process design



CHANGING WHAT'S POSSIBLE

FLECCS awardees

Flexible solvents, sorbents, membranes

RTI INTERNATIONAL

Susteon

LUNA

8 RIVERS
8 Rivers Capital, LLC

Envergex
Sparking Innovations

Flexibility via thermal or chemical storage

Colorado State University

SwRI
SOUTHWEST RESEARCH INSTITUTE

GE Research

Linde

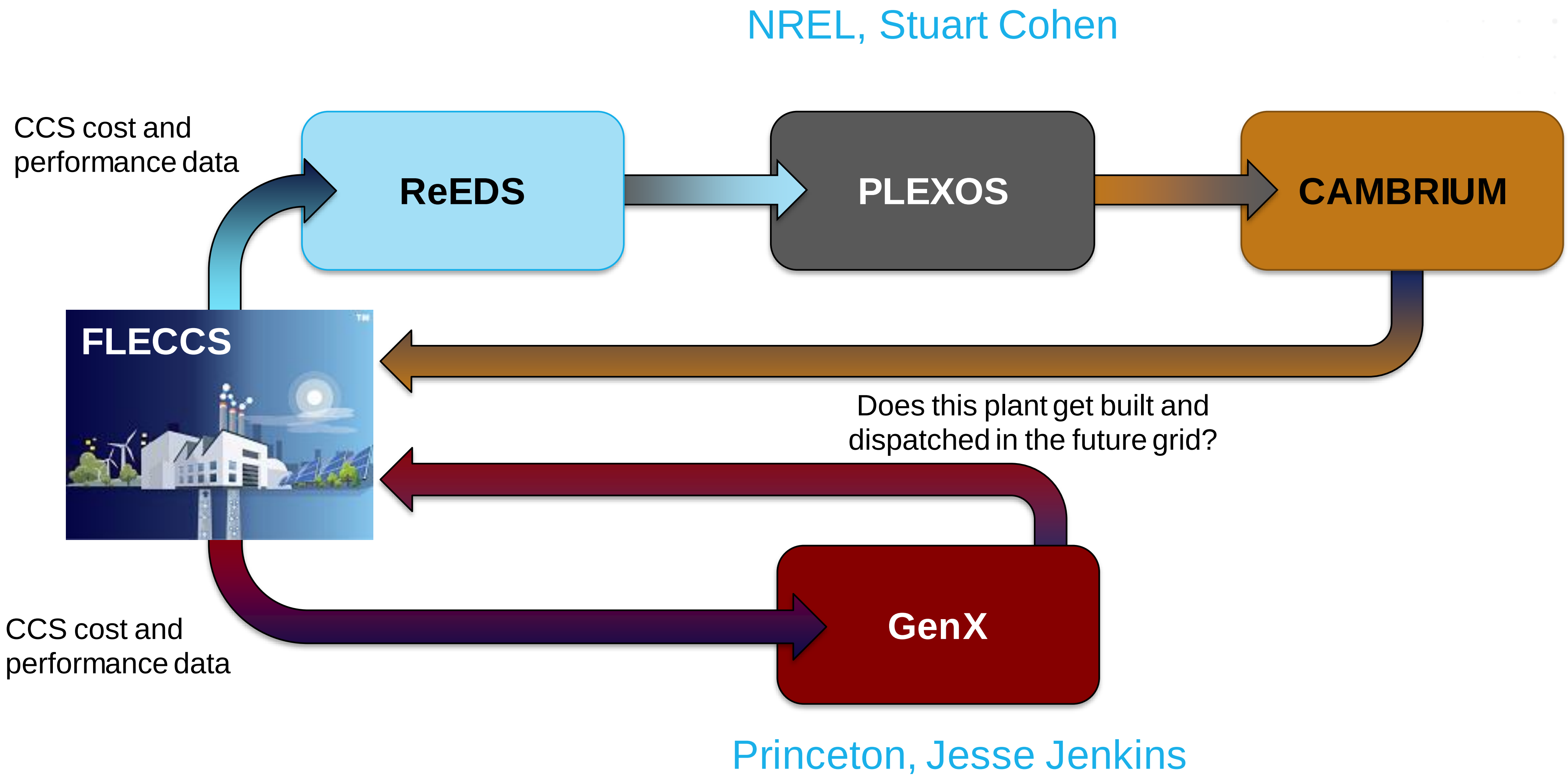
Flexibility via DAC integration

Georgia Tech

Massachusetts Institute of Technology

University of Pittsburgh

Interactions between technology and modeling teams



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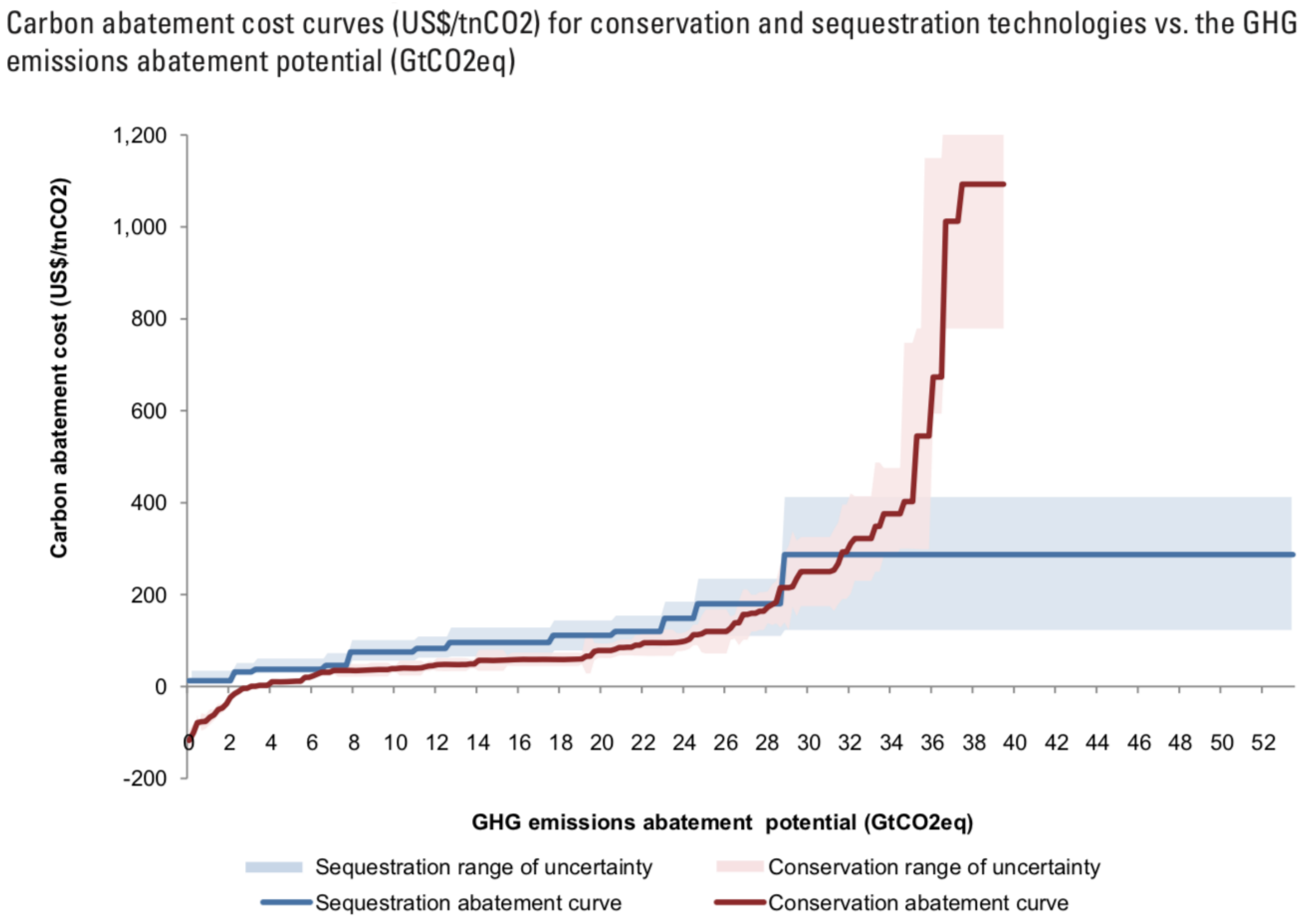
DAC offsets are cheaper than some forms of abatement



Source: Goldman Sachs, Carbonomics, December 2019.

DAC: lots of capacity, lots of energy needed

DAC Capacity — The U.S. will need 1-3 Gt of DAC capacity to achieve a net-zero carbon economy

Energy Needed — Varies, but on the order of 13.8 EJ (13 quads) heat and 3 EJ (2.8 quads) electricity (<u>delivered</u>)

Renewable Capacity — At 35% capacity factor, 270 GW of dedicated renewable capacity needed (current capacity: 157 GW)

Bottom Line — DAC will become its own sector of the economy

ARPA-E DAC projects

OPEN18: ASU

Create hollow fiber membranes that transport H_2O and CO_2

SEED: Verdox

Electroswing: sorbent captures and releases CO2 based on redox state

FLECCS: GT, MIT, Pitt

Integration between NGCC and DAC systems (lime, sorbent DAC)

Current FOA

New materials, passive air contactors, mineralization, electrochemical approaches, other ideas…

Wednesday 1:45 pm DAC panel: Dr. Zara L'Heureux (ARPA-E Fellow)

Summary

- As VREs proliferate, conventional power plants will be operated in a more dynamic manner. This will affect the design and operation of CCS systems.
- FLECCS is a 4½ year, $44M program to design, optimize, and build small prototypes of CCS systems that enable power plants to be responsive to grid conditions.
- FLECCS is using a market-based framework and is technology agnostic.
- Coordinating closely with FE and NETL.
- Increasing amount of focus on DAC, as well as other negative emissions like direct ocean capture, bio-approaches, etc.