Grid and Process Modeling of Flexible Post-Combustion CO_2 Capture

Stuart Cohen

EPA STAR Fellow, Ph.D. Student

Thermal/Fluids Systems Division, Department of Mechanical Engineering

The University of Texas at Austin

Workshop on Operating Flexibility of Power Plants with CCS

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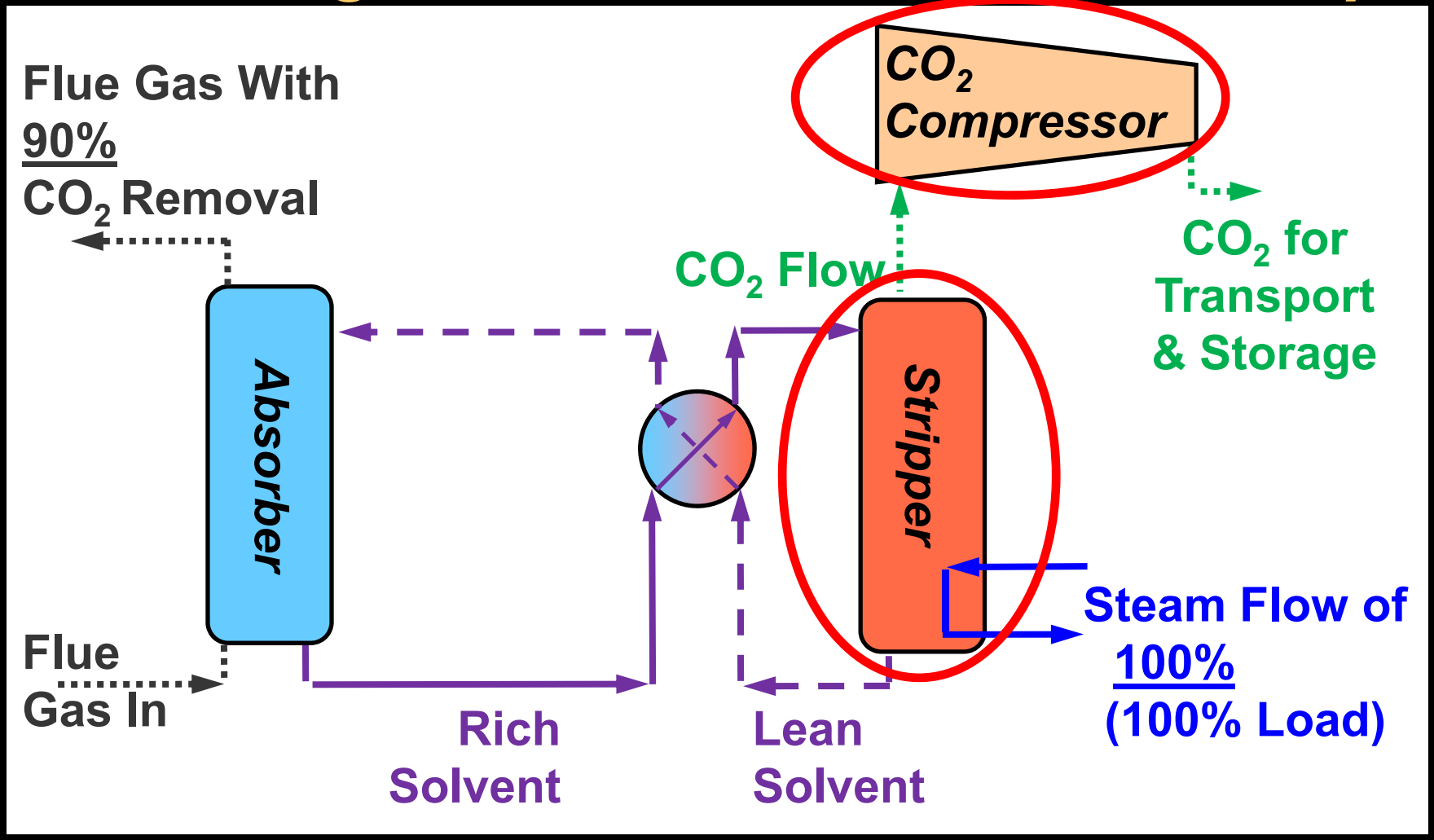
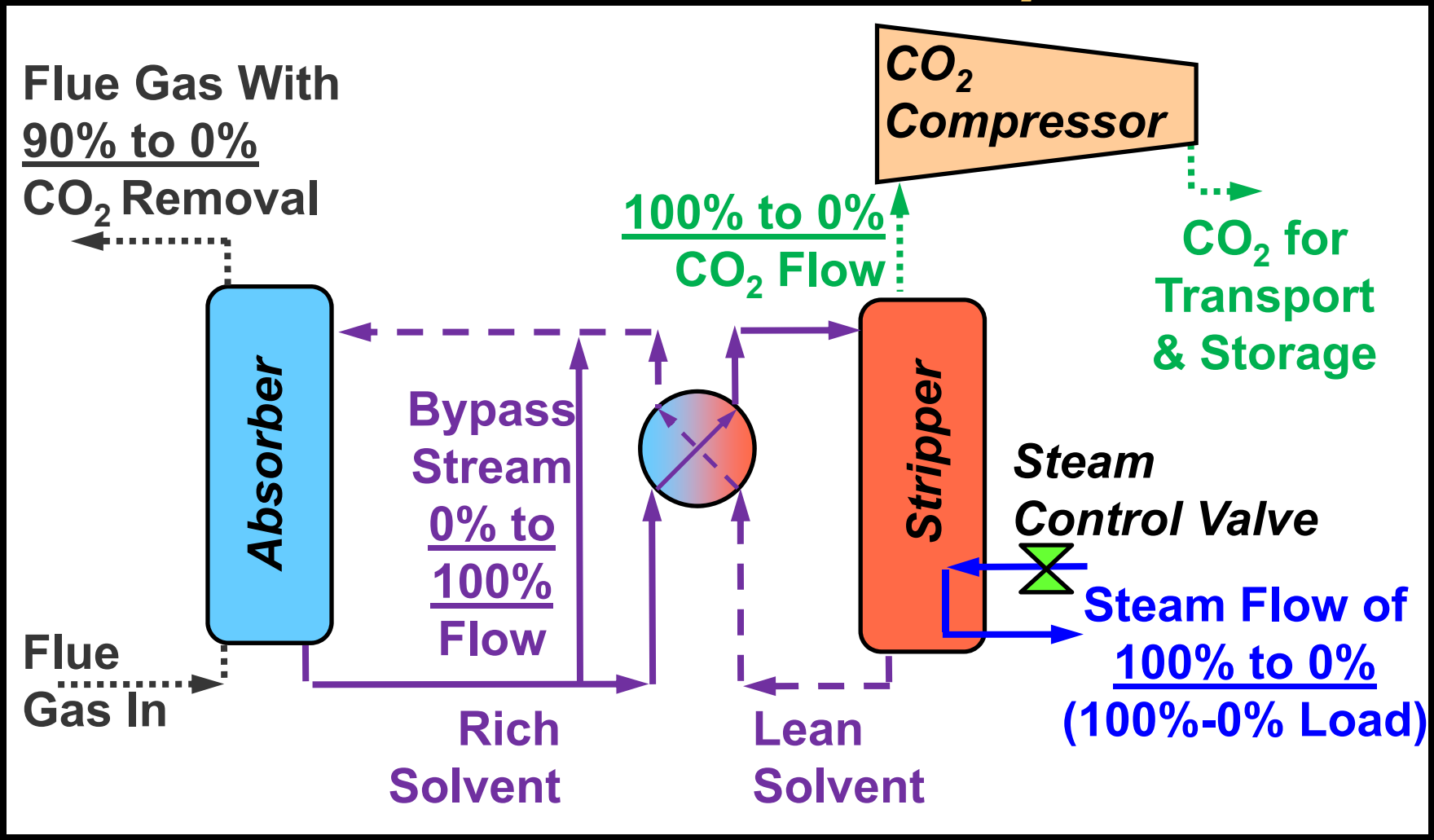
Outline

- Flexible post-combustion absorption/stripping
- Flexibility in response to hourly electricity demand and price variations
  - Multi-year analysis
- Dynamic process modeling

CO_2 Absorption/Stripping & CO_2 Compression Uses a Large Fraction of Power Plant Output



Instead, Could Vary Steam Rate and Stripper Solvent Rate for Flexible Operation



A Thermo-economic Grid Model is Created to Examine Flexible CO_2 Capture in Response to Hourly Electricity Market Variations

INPUTS

Hourly electricity demand for day to decade-long periods

CO_2 and fuel prices

Plant performance & economic parameters

1st order dispatch & electricity market model

OUTPUTS

Hourly generation for each plant

Market electricity price

Operating profits

CO_2 emissions

Flexible CO_2 capture utilization

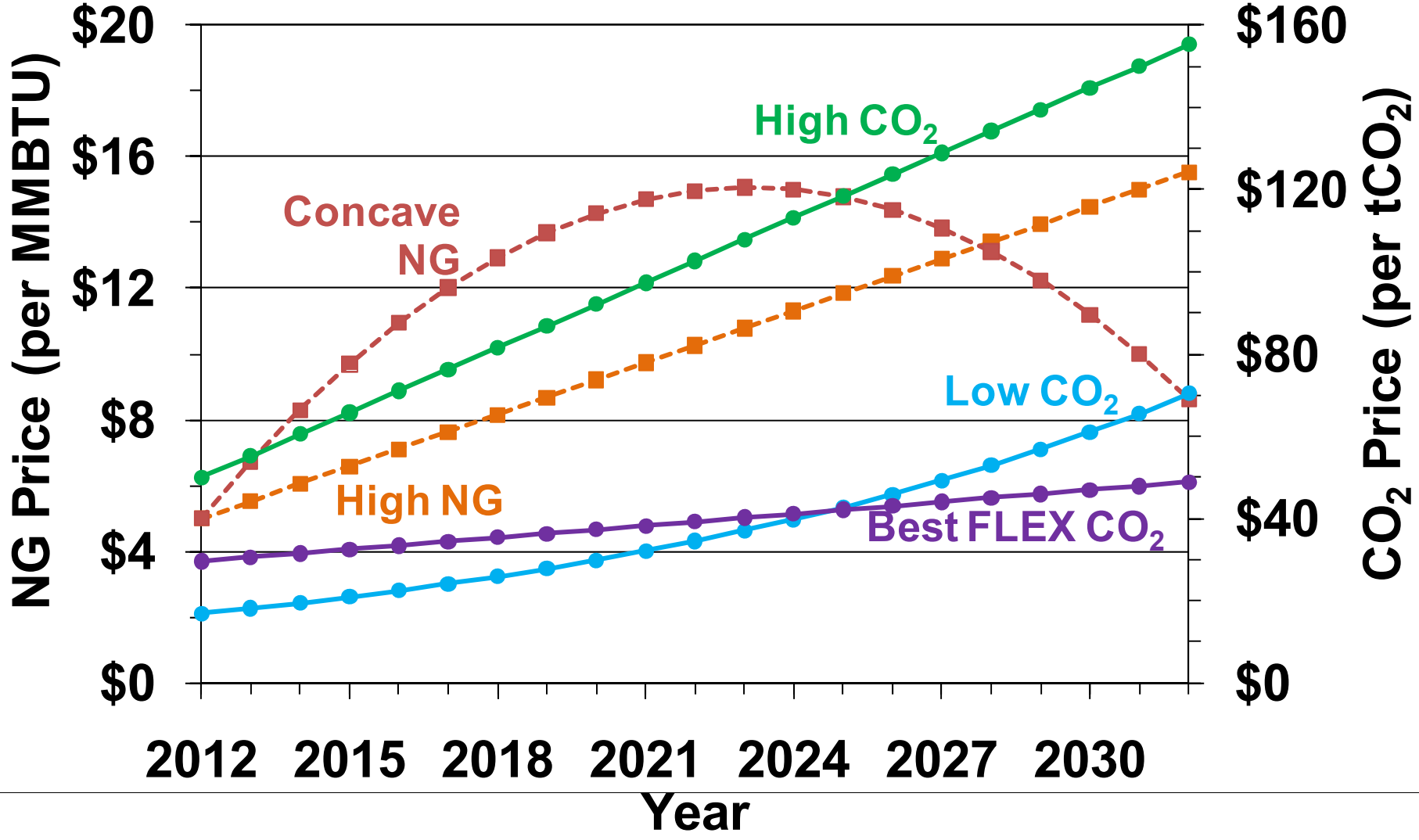
The Dynamic Model Considers Several Electric Grid Scenarios

Scenario	CO_2 Capture Installed?	Flexible CO_2 Capture Operation?	CO_2 Capture at Partial-Load When?
BAU (no capture)	No	n/a	n/a
CCS Base (inflexible capture)	Yes	No	Never
FLEX Op Costs	Yes	Yes	When operating costs are less at partial-capture load
FLEX Profit	Yes	Yes	When operating profits are greater at partial-capture load

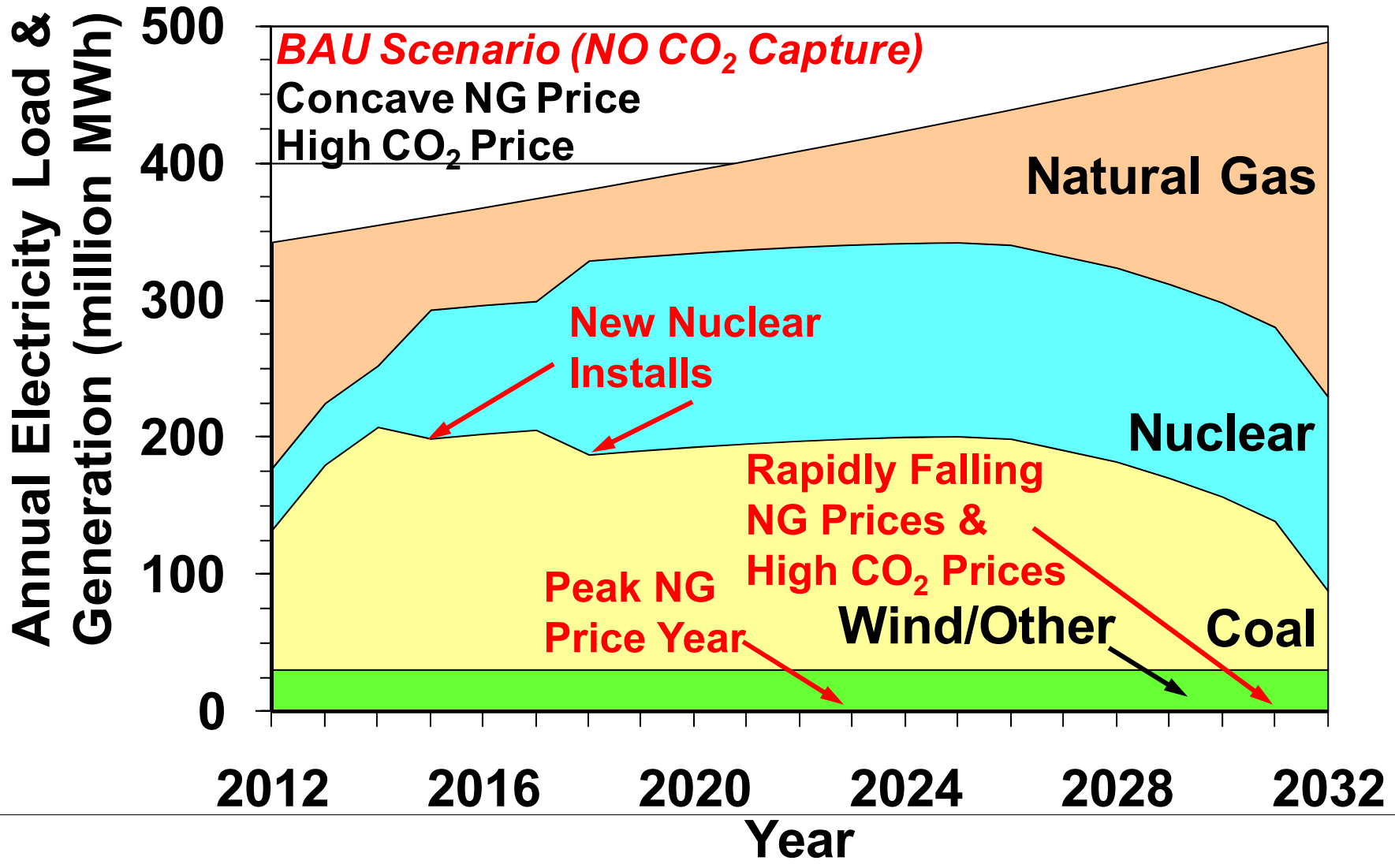
The Model Has Recently Been Adapted for Multi-Year Analysis of Dynamic Grid Behavior in ERCOT (TX grid)

- 8 of 15 current and all new ERCOT pulverized coal-based plants are considered for CO_2 capture
- For flexible CO_2 capture scenarios
  - Choose between 20% and 100% load
  - Energy use per tCO_2 nearly the same at each operating point, but greater emissions at 20% load (venting)
- Electricity demand increases 1.8%/yr
- Current grid planning documents used to estimate future ERCOT power plant fleet
  - 2 large nuclear installations in 2015, 2018

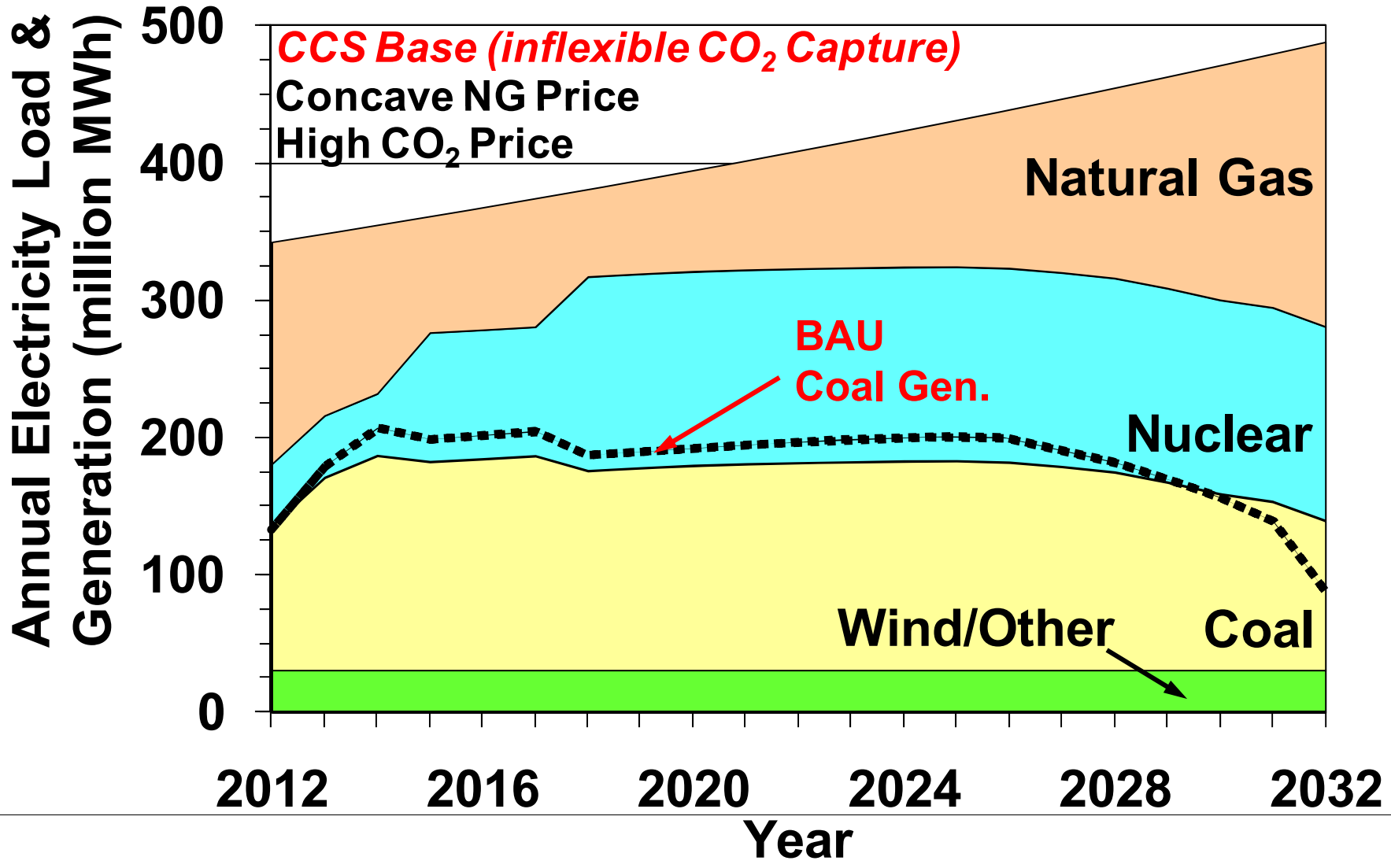
Several Gas/CO_2 Price Paths are Used to Investigate a Variety of Market Scenarios



Coal-Based Generation Drops Substantially with High CO_2 and Low NG Prices

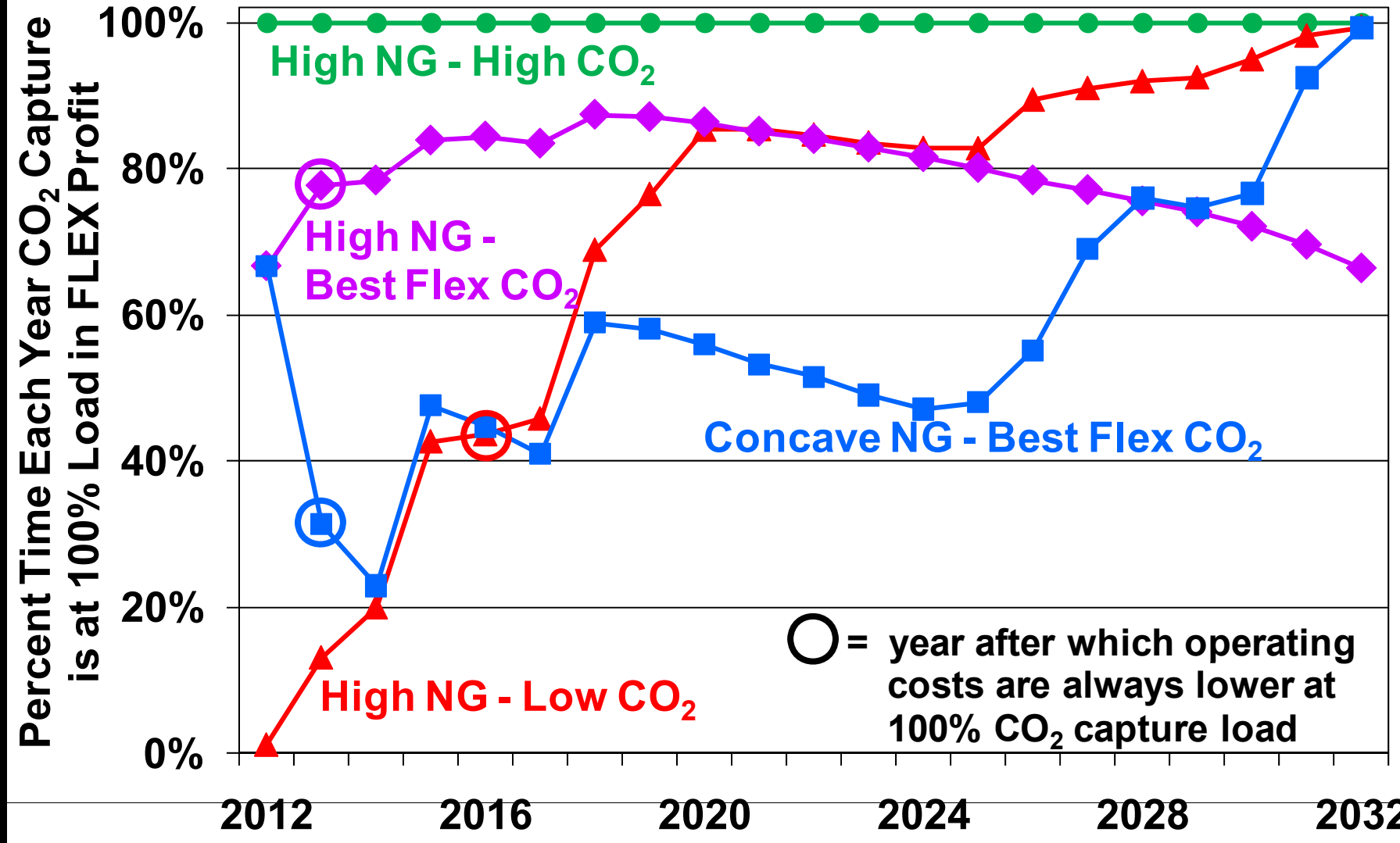


CO_2 Capture Allows Greater Coal-Based Generation in Later Years

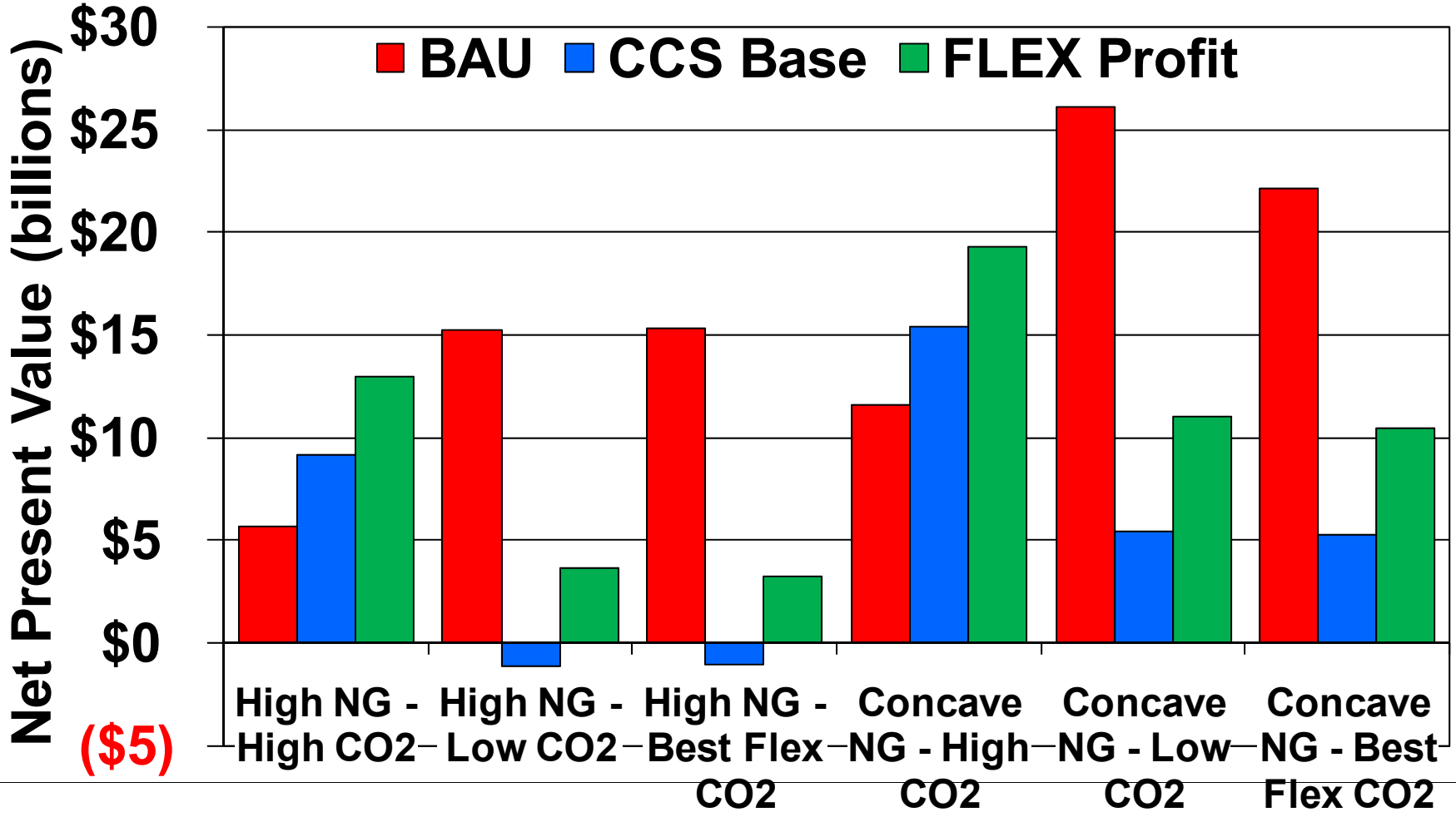


Preliminary Data

Utilization of Flexible CO_2 Capture is Highly Dependent on Fuel and CO_2 Prices



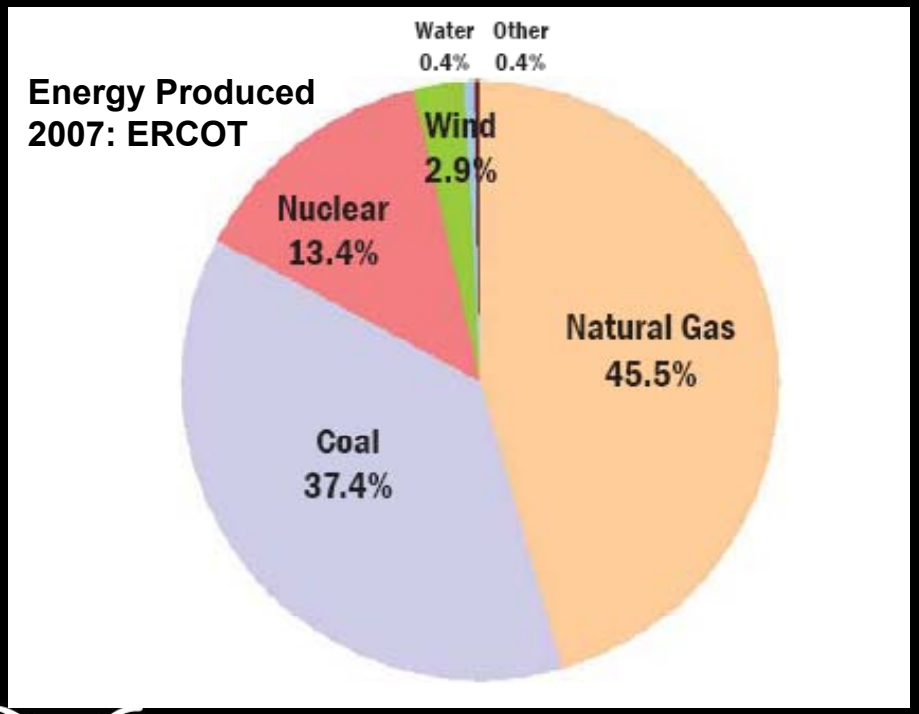
Flexibility Greatly Improves Lifetime NPV Across Capture Plants with $3000/kW Replacement Capacity Cost

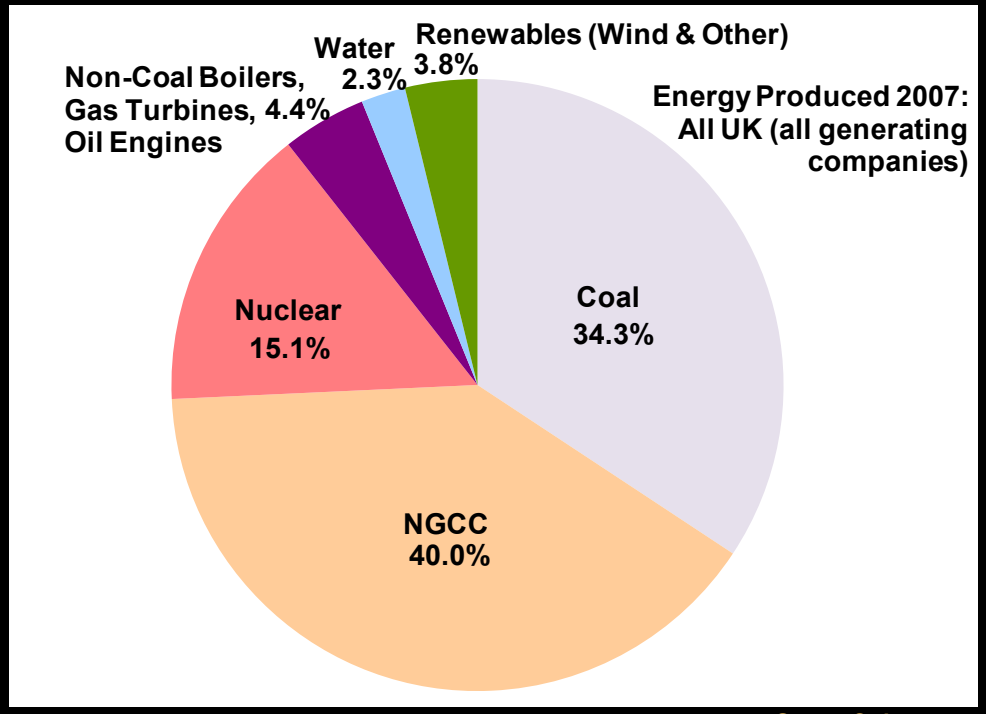


The Model is Also Being Used to Compare & Contrast the ERCOT and GB Electric Grids

- **Both "island" electricity systems with competitive wholesale electricity markets**

	ERCOT	All UK
Capacity in 2008 (MW)	72,820	84,880
Demand in 2007 (TWh)	307	373

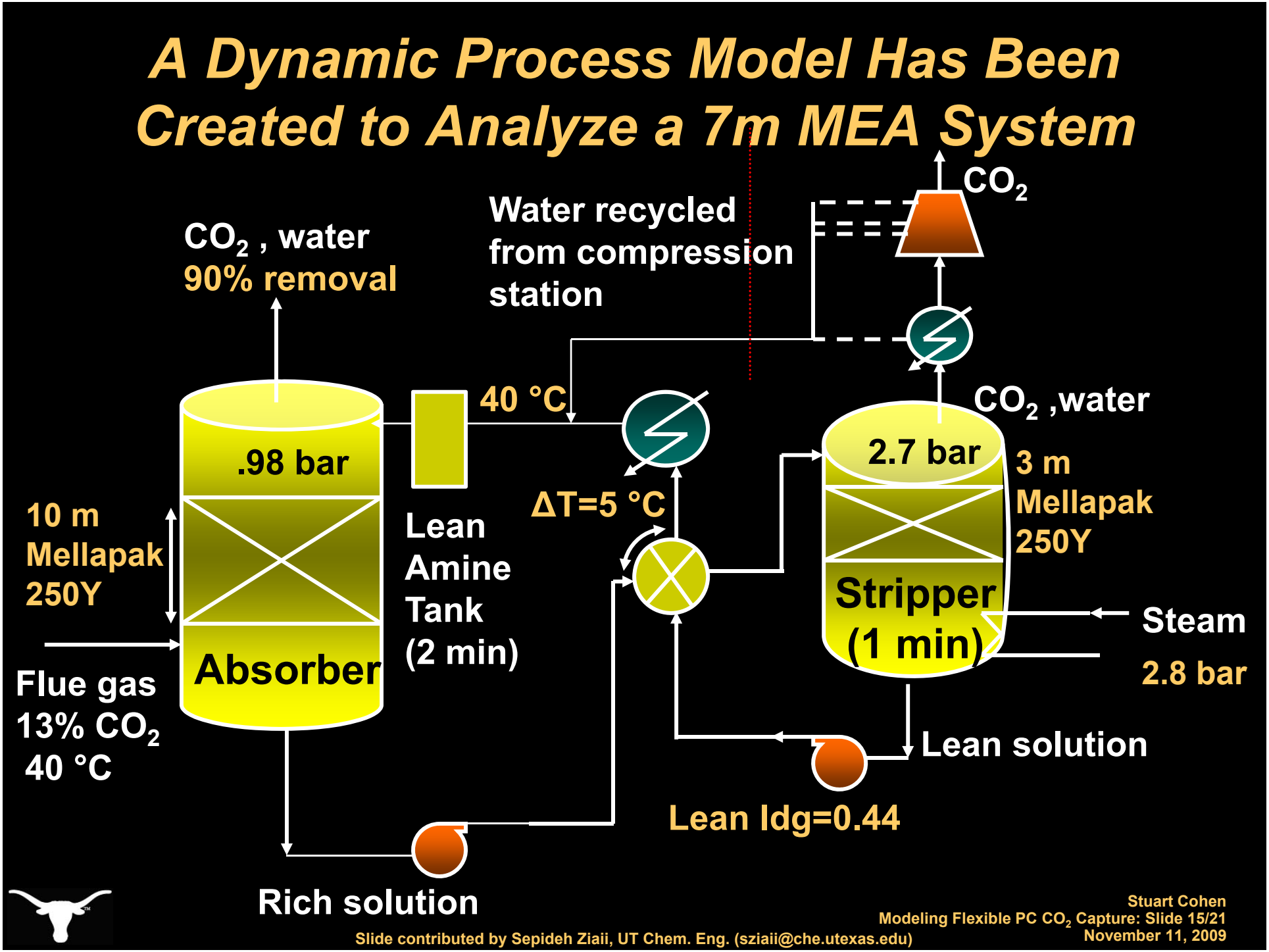




Grid Modeling Conclusions: Flexible CO_2 Capture May Improve Plant Economics

- A model of hourly grid behavior is used to study flexible capture for multi-year time periods and various electric grids
- CO_2 capture has a minor effect on electricity prices relative to fuel and CO_2 prices
- The CO_2 price required for full-load operation is much lower than that required for investment
  - If CO_2 prices remain high after CO_2 capture installation, flexibility does not affect operation in energy markets
  - If fuel and CO_2 prices allow similar operating costs across CO_2 capture operating range, flexibility may improve annual operating profits by $10s-$100s millions
  - Operation of flexible capture is a complex function of fuel and CO_2 prices, operating costs, and the plant fleet
  - Flexibility is a hedge against CO_2 and fuel price volatility
- Regardless of operating economics, NPV is greater for flexible systems when accounting for replacement capacity

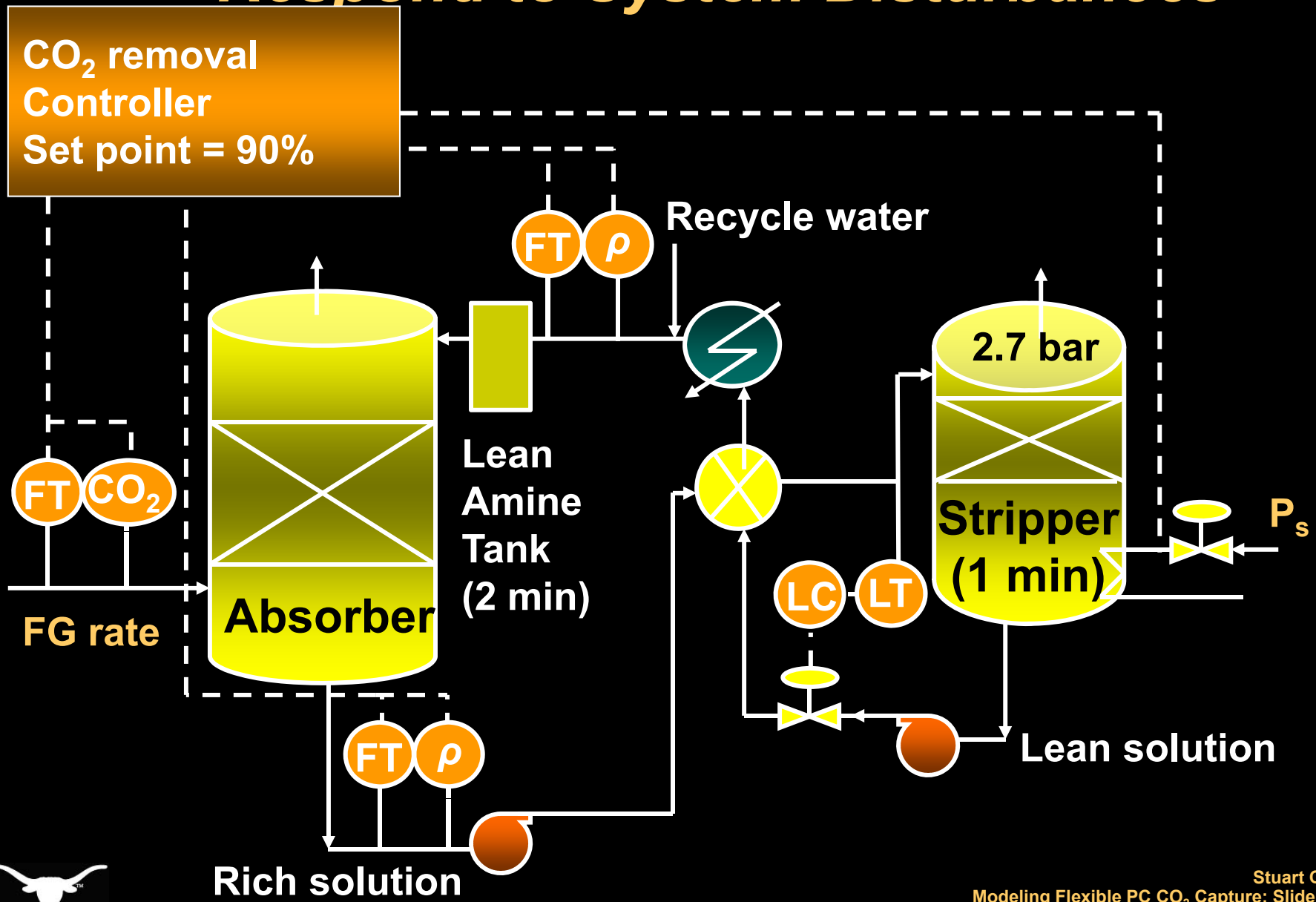
A Dynamic Process Model Has Been Created to Analyze a 7m MEA System



Open-Loop Analysis Shows Effects of ±5 % Step Changes to Steam P and Flue Gas Rate

- Step changes to each parameter are made separately
- New steady state is achieved in under 30 min
- Response time governed interactions between column process conditions
- Changes disrupt steady state of water balance, but not significantly enough to require real-time control
- Liquid level in the stripper sump should be controlled to meet the required min/max
- ~1% change in reboiler duty with ± 5% step changes
- Up to -70% ramp in 30s will converge

Closed Loop CO_2 Removal Control Can Respond to System Disturbances



Closed-Loop Control Maintains CO_2 Removal at the Expense of System Response Time and Energy Performance

- The control loops are tuned based on different tuning methods (Ziegler-Nichols, IMC, IAE,ISE,ITAE)
- CO_2 removal controller can track the set point and reject disturbances. Fastest tuning parameters achieve S.S. in ~40 min after ± 5% disturbances
- The system responds slower than open loop system due to tight control on CO_2 removal
- This strategy is not able to maintain optimal energy performance because the lean loading is not controlled at the optimum value

Slide contributed by Sepideh Ziaii, UT Chem. Eng. (sziaii@che.utexas.edu)

Future Work

- Analyze the feasibility and implications of using solar thermal energy for solvent stripping
- Find optimal operation of a flexible system that uses solvent storage to maintain continuous high CO_2 removal
- Model flexible CO_2 capture in ancillary service markets, particularly for complementing intermittent renewable generation

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Questions?

Stuart Cohen

EPA STAR Fellow, Ph.D. Student
Thermal/Fluids Systems Division
Mechanical Engineering

The University of Texas at Austin
stuart.cohen@mail.utexas.edu
http://www.webberenergygroup.com
http://www.che.utexas.edu/rochelle_group