ARPA-E FLExible Carbon Capture and Storage (FLECCS)

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FLECCS Program

Phase 1: 2019-2022

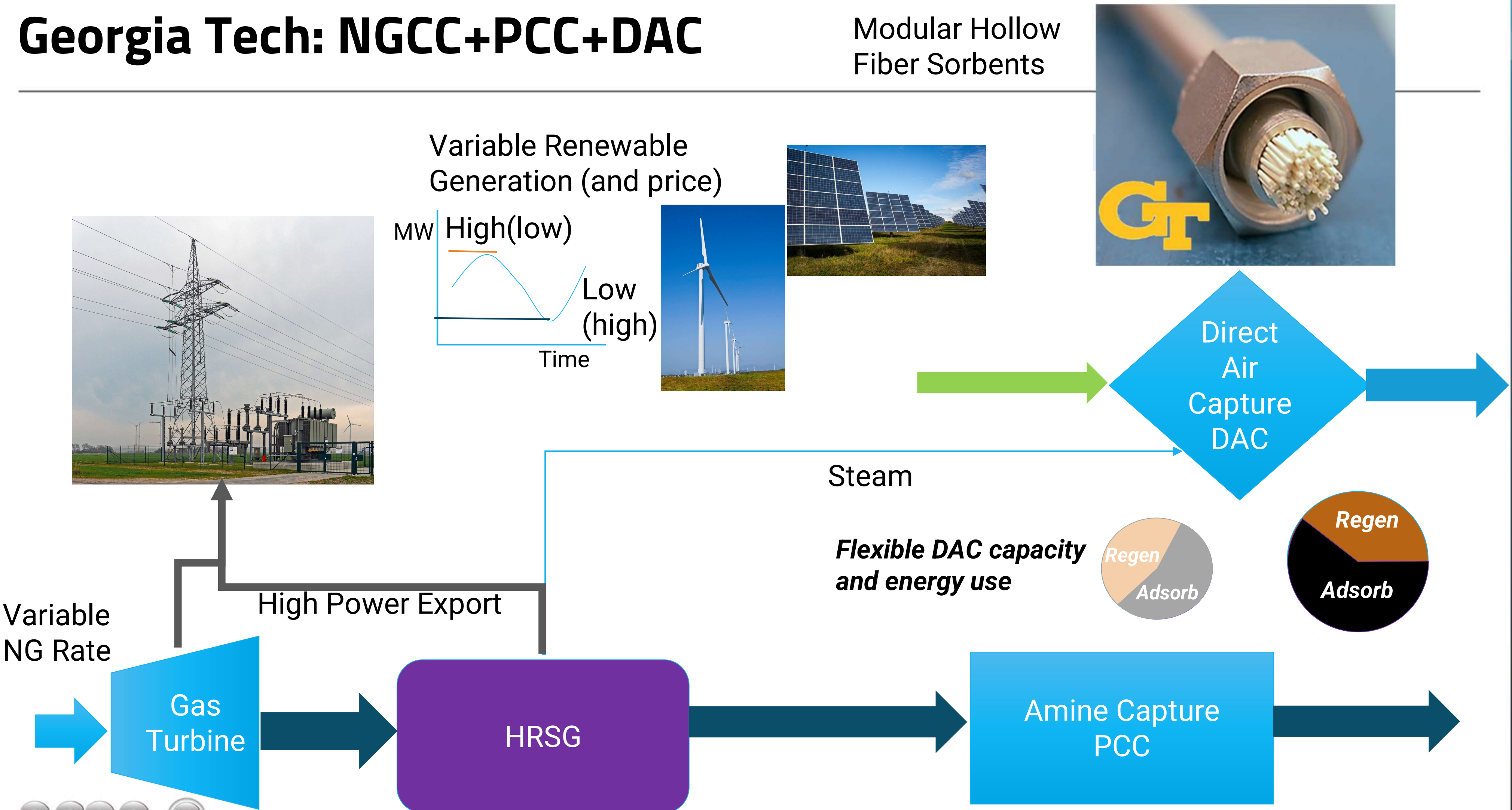
- 18 months, $11.5MM, 12 technology teams
  - Load-following carbon capture (RPB, sorbent, membranes)
  - Solvent storage
  - Thermal storage
  - O2 storage (Allam cycle)
  - H2 or DAC integration
- Modeling studies and economics based on future dispatch scenarios
- Deliverables: PFD, H&M balance, equipment list, general arrangement, TEA

Phase 2: 2022-2025

- 36 months, $33MM, 5 technology teams
- Lab to large pilot demonstrations focused on carbon capture system
  - All above deliverables
  - Investigate controls and system-level integration
- Princeton modeling future dispatch scenarios

CHANGING WHAT'S POSSIBLE

Georgia Tech: NGCC+PCC+DAC



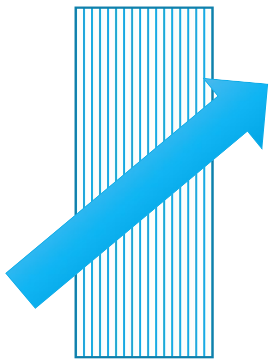
CHANGING WHAT'S POSSIBLE

FLECCS 2/Stage 2: Proposed Asahi Japan Scope

Fabricate DAC Modular Hollow Fibers

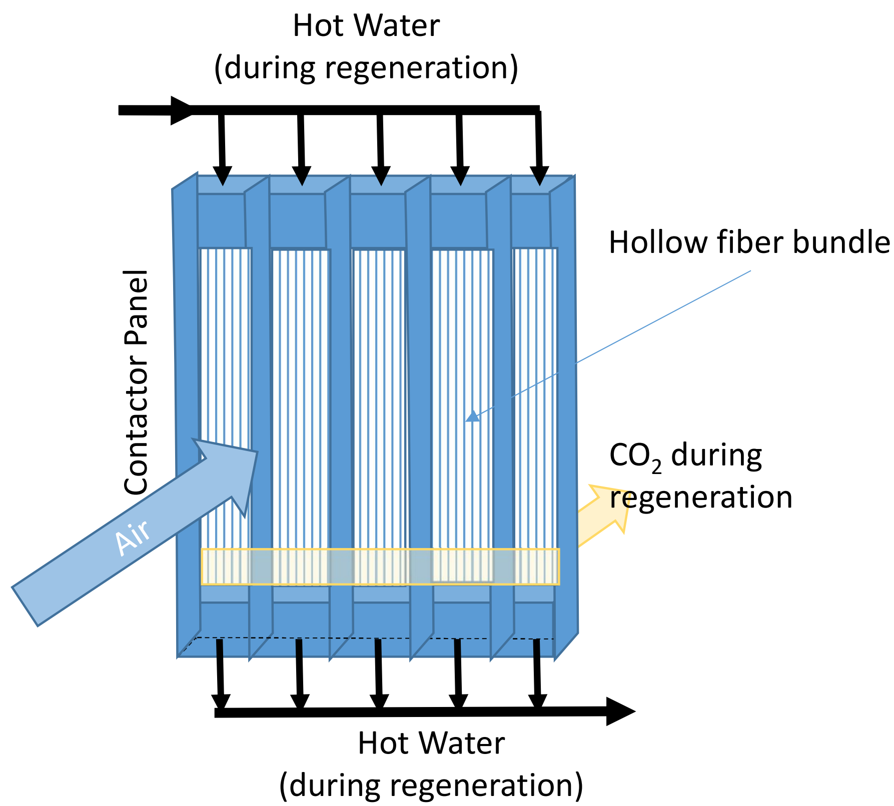
- Scale up fiber bundle size
- Scale up number of fiber bundles

~100 Fibers



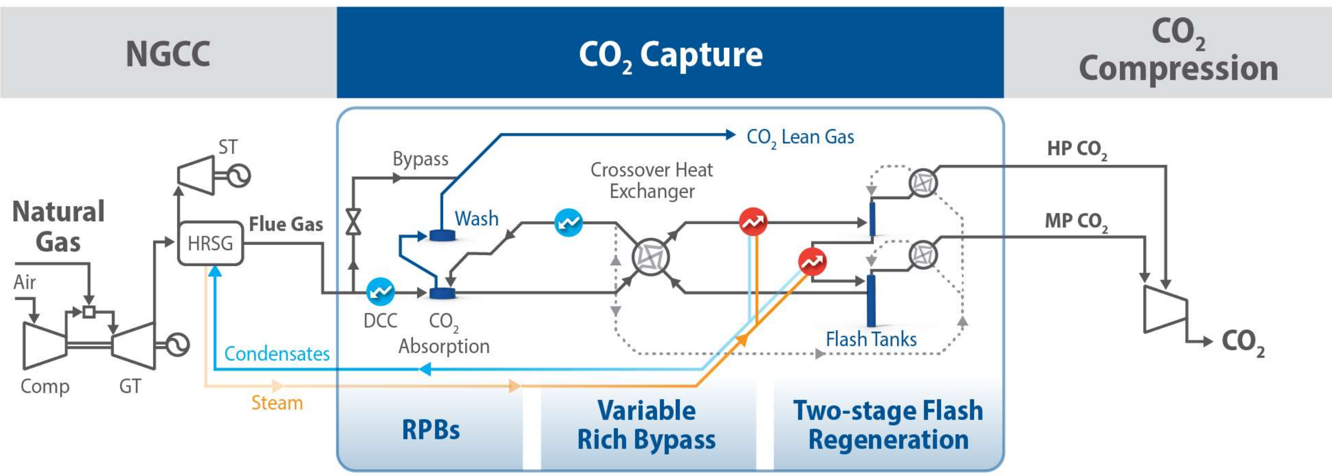
~ 1000 fiber bundle

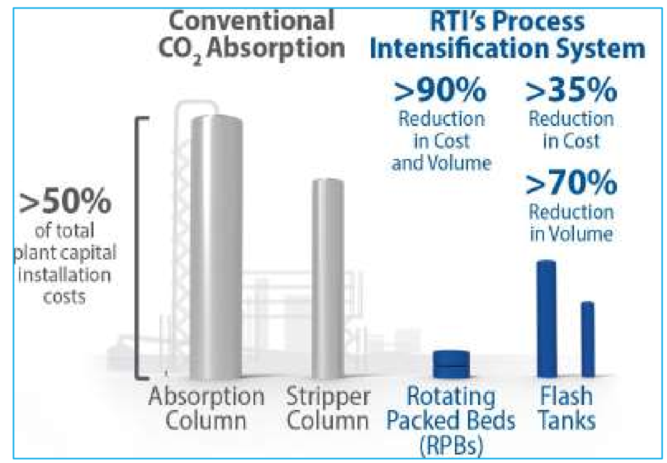
Fabricate Contactor "Panels"



~ 10 x 10000 fiber bundle/contactor panel

RTI/Mojonnier (Rotating Packed Bed)





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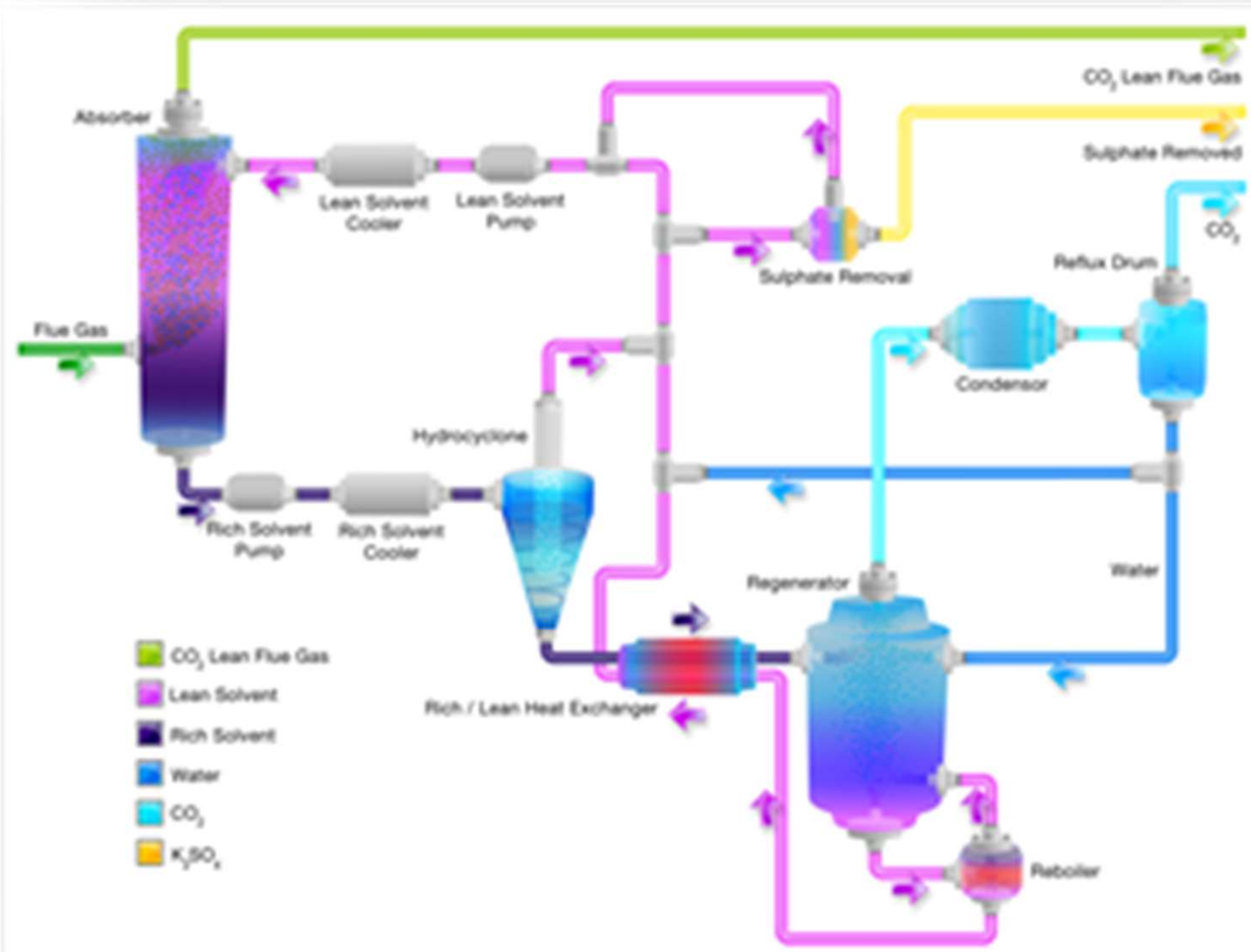
8 Rivers/KC8: Potassium Carbonate Solution



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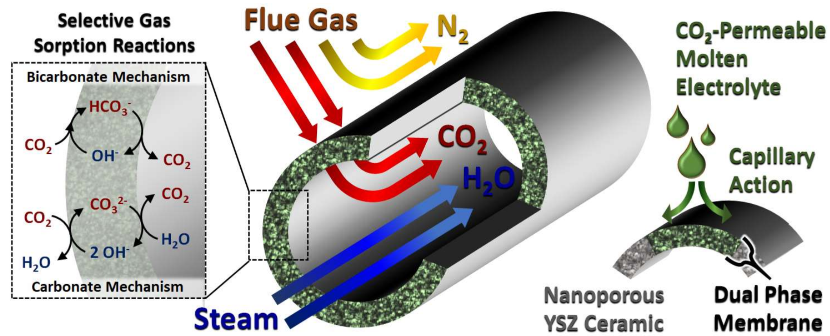
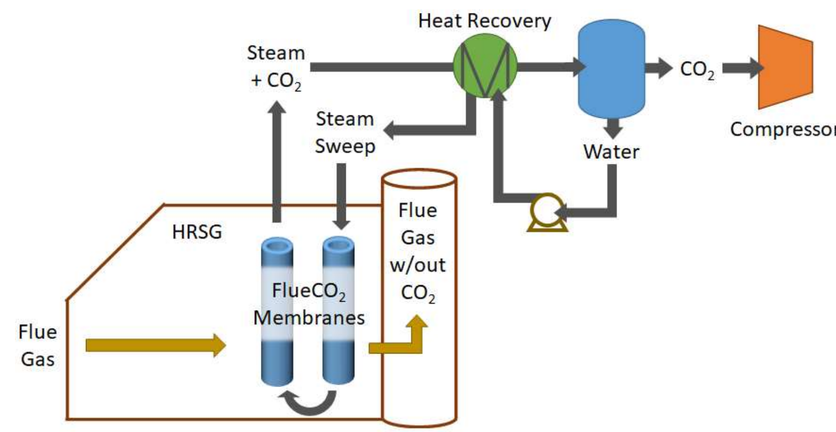
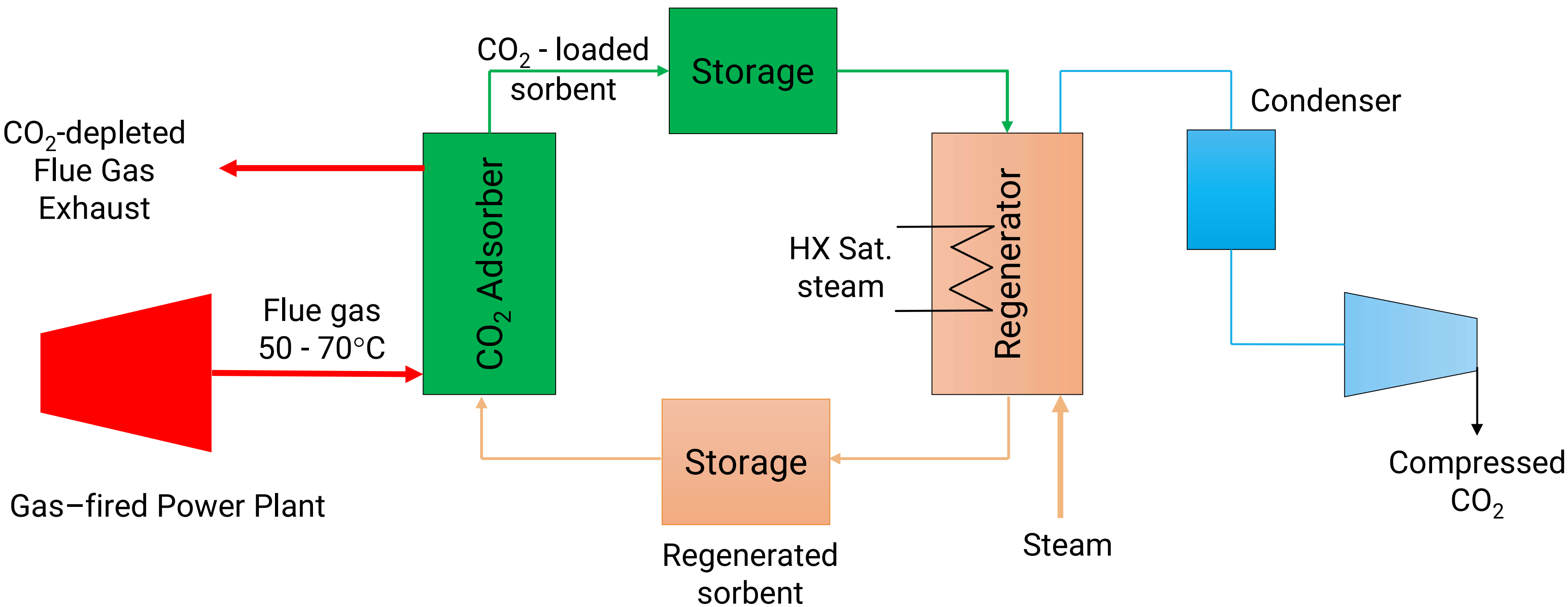
Luna/Saint Gobain/Nooter: Active Transport Membrane

- Novel membrane "pumps" CO2 from low concentration in flue gas to high concentration in bore
- Luna optimizing key molten electrolyte coating
- Saint Gobain optimizing ceramic support tubes
- Nooter optimizing HRSG retrofit





Envergex/UND/Barr: Sorbent Injection



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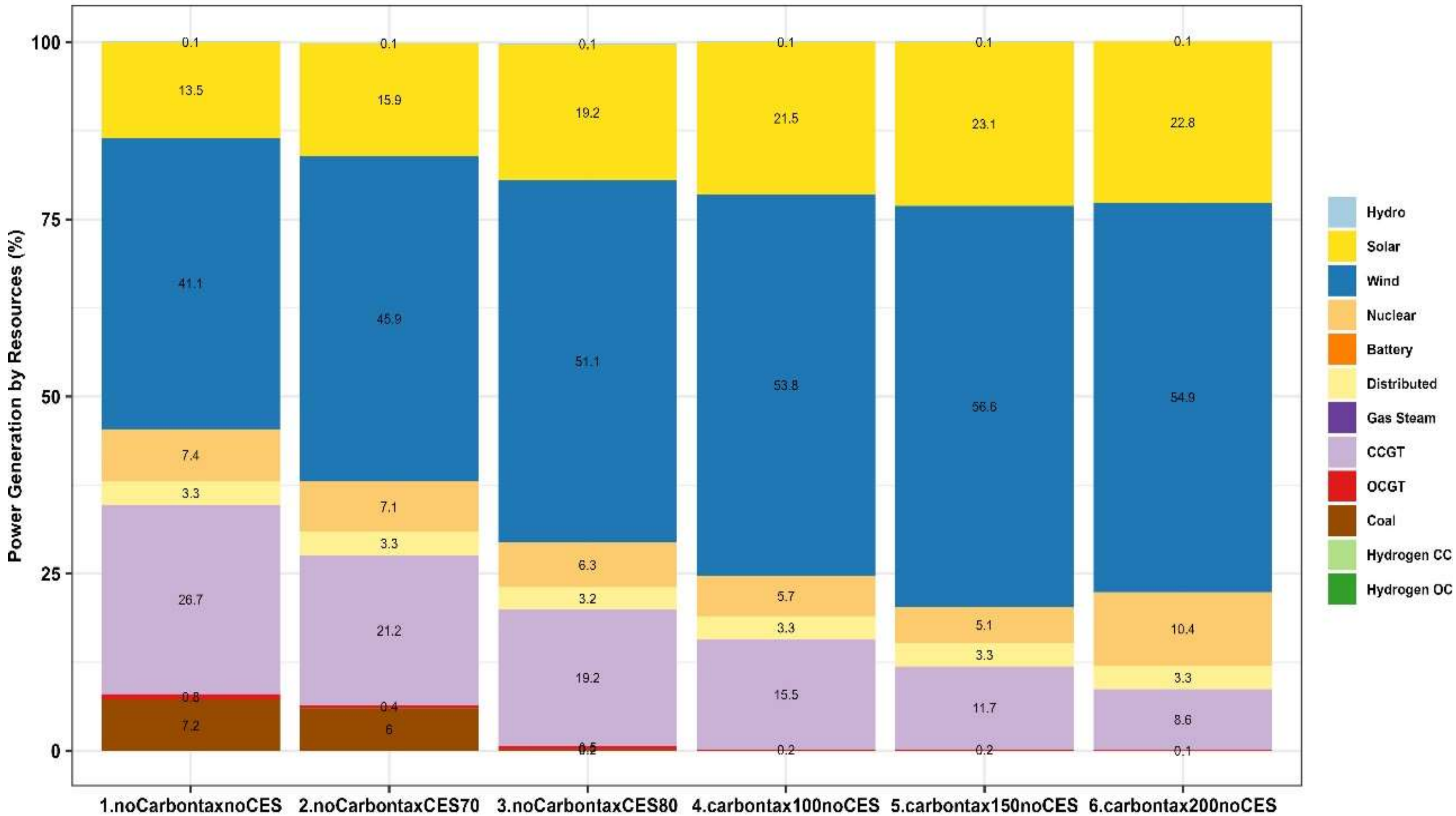
Princeton: Future Grid Dispatch and Pricing

Scenarios:

- Supply/demand
- “Competition”
- Grid constriants
- Tax
- CO2 incentives
- ISO



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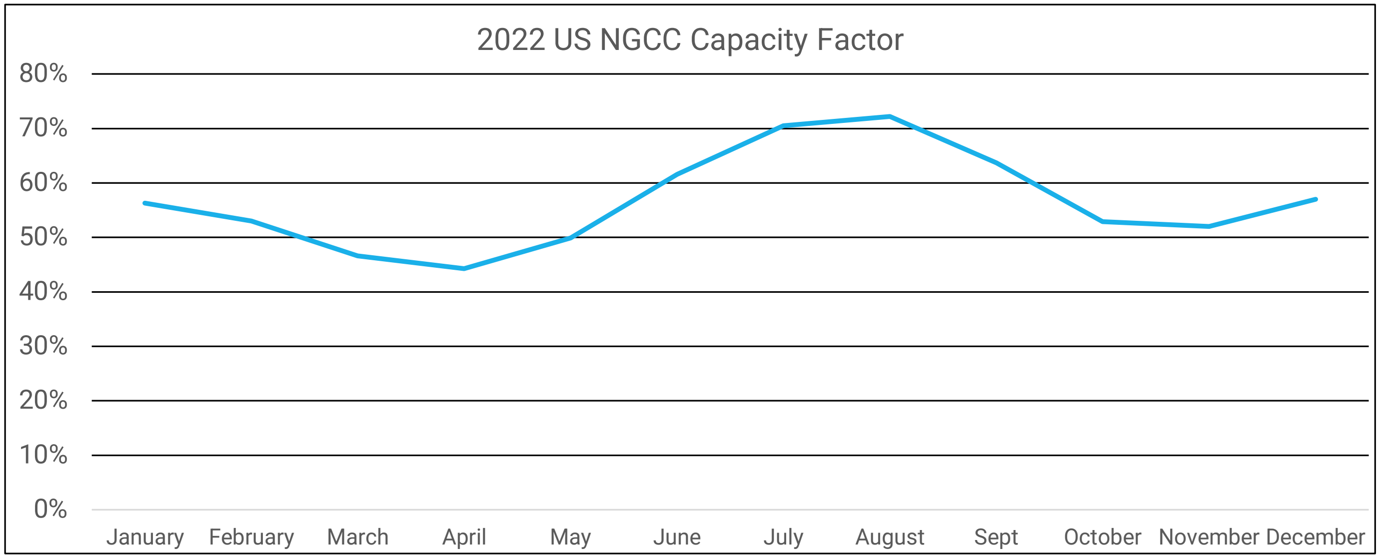
“Flexible Operations” – Matching NGCC and CO_2 systems

- “In 2019, the average number of starts for combined cycle plants was 39 per year. Just three years later, it's likely to hit 70, and the average could break 100 by 2023.”

  Power Magazine, Aug 1, 2022

- NGCCs may ramp up/down while operating



https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_07_a

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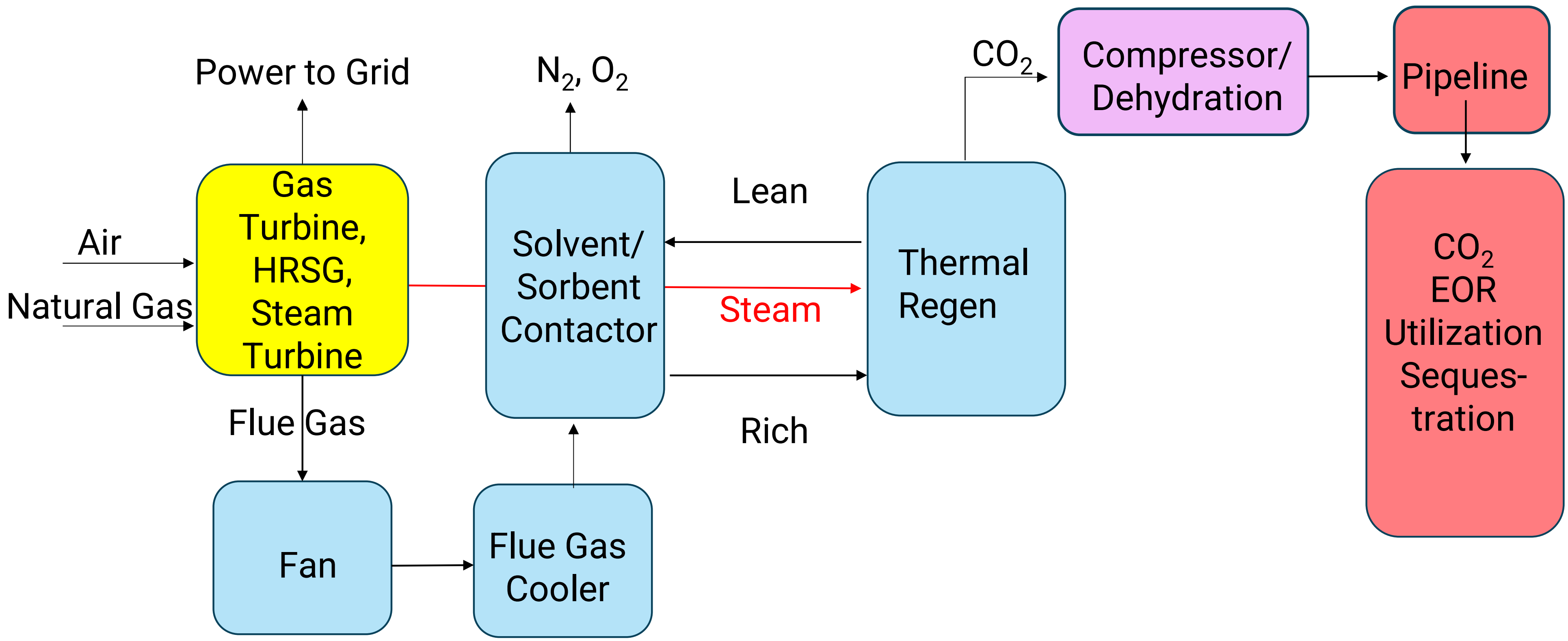
Generic NGCC/CCS Flowsheet



Functional Challenges

- Flue Gas Cooling
  - Solvents and sorbent prefer lower flue gas temperature
- Flue Gas Pressure drop
  - Backpressure on gas turbine/HRSG
  - Need to get flue gas out the stack with possibly zero buoyancy
- Steam
  - NGCC steam turbines do not have steam extraction ports
  - Regen steam requirements may pull too much steam from steam turbine range
- Space
  - Area CCS system ~ area to NGCC plant or larger

Mismatch of Component Dynamics

Component	Cold start-full load	Warm start-full load	ramp rate	Operating range	Comments
Gas turbine/ steam turbine/ HRSG *	< 1 hr (GT) 2-3 hours (HRSG, ST)	0.5 – 2 hours	10%-15%/minute	20-100%	F, H Class
ID Fan(s)/ Damper(s)	?	?	?	?	Multiple fans?
Flue Gas Cooler	?	?	?	?	Gas/liquid distribution
Absorber	12-24 hours	2-10 hours	5%-50%/hr	50(?)-100%	24 hours for large CCS and NG amines
Regen	12-24 hours	?	?	50(?)-100%	ST impact? Offline regen?
CO_2 compressors	2+ hours	?	?	?	Need multiple units
CO_2 dehydration	?	?	?	?	Columns/flash
CO_2 pipeline	?	?	?	?	Supercritical CO_2

* https://www.epa.gov/system/files/documents/2023-05/TSD%20-%20Efficient%20Generation%20Combustion%20Turbine.pdf

System-level challenges (some may be beyond FLECCS)

- Operations
  - Mis-match in system dynamics
  - Maintaining CO_2 purity through transients (start-ups, load swings, shut-downs)
  - Managing power derate
  - Matching steam supply/demand through load cycle
  - Purge times

- Unknown dynamics for the “other” components
  - Fans/dampers/flue gas hydraulics, esp if multiple units
  - CO2 compressors/dehydration
  - Rapid flowrate changes may challenge CO_2 pipeline and downstream sequestration

- System Optimization for Load Following
  - Part load; short runs; offline for extended periods, esp. during shoulder months
  - Solvent storage?
  - Multiple trains to load follow?
  - Exhaust gas recycle?
  - Run at loss to maximize revenue?

Issues – CO_2 Pipelines

- Pipeline Contracts specify composition and “rateable” flow
  - Composition
    - Almost all US and global experience is with CO2 from sources without free oxygen. May contain H2S and NH3.
    - Flue gas will have O2. May contain SO2/HSO3, NO2, possibly HCl
    - Uncertainty in water phase diagram for supercritical CO2
    - Water drop-out/acid/O2 may cause pitting corrosion
  - Flow
    - Pipeline contracts usually require “rateable” or constant flow
    - Power plants and other sources may have variable flow, frequent stops/starts
    - Supercritical CO2 is incompressible. Flow/pressure fluctuations may cause problems
- CO_2 pipeline permitting uncertainty

Example CO2 Pipeline Spec – Northern Lights

Northern Lights

Liquid CO_2 (LCO2) Quality Specifications

Component	Unit	Limit for CO_2 Cargo within Reference Conditions[1]
Carbon Dioxide (CO_2)	mol-%	Balance (Minimum 99.81%)
Water (H_2O)	ppm-mol	≤ 30
Oxygen (O_2)	ppm-mol	≤ 10
Sulphur Oxides (SO_x)	ppm-mol	≤ 10
Nitrogen Oxides (NOx)	ppm-mol	≤ 1.5
Hydrogen Sulfide (H_2S)	ppm-mol	≤ 9
Amine	ppm-mol	≤ 10
Ammonia (NH_3)	ppm-mol	≤ 10
Formaldehyde (CH_2O)	ppm-mol	≤ 20
Acetaldehyde (CH_3CHO)	ppm-mol	≤ 20
Mercury (Hg)	ppm-mol	≤ 0.0003
Carbon Monoxide (CO)	ppm-mol	≤ 100
Hydrogen (H_2)	ppm-mol	≤ 50

Original CO_2 spec

Updated component (Nitrogen Oxides (NOx))

Updated component (Mercury (Hg))

[Northern-Lights-GS-co2-Spec2024.pdf (norlights.com)](https://norlights.com)

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Recommendations

- CO_2 specs are a system-level issue
  - At a minimum, start measuring and reporting key trace species (O2, SO2, NO2, HCl, H2O, other)

- Need input from all stakeholders in the CO2 chain. Many DOE offices engaging.
  - Flue gas source (composition, flow)
  - Carbon capture technology vendor (quality of CO2, esp during transients)
  - CO2 compressor/CO2 "polishing" (esp H2O)
  - Pipeline operator (PRCI)
  - CO2 "end game"
    - CCS
    - EOR
    - CO2 utilization

Summary

- CCS retrofit to NGCC plants is hard, esp due to intermittent operation
  - Steady state operation of components is not sufficient for assessing how these system will work

- Unsteady-state operations may result in off-spec CO2 during transients
  - Capture rates need to address disposition of potentially off-spec CO2

- FLECCS evaluating novel carbon capture systems
  - Will likely tee up more issues than it will resolve

- Recommend DOE coordinate information sharing for system-level issues
  - Need collaboration among power plant operators, CCS process developers, component OEMs, pipeline operators, and EOR/CO2 utilization/sequestration stakeholders to define critical design cases