# Bench Scale Development of a Hybrid Membrane-Absorption $CO_2$ Capture Process

# DE-FE0013118


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2018 NETL $CO_2$ Capture Technology Project Review Meeting

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# Project Overview

- **Award name:** Bench-Scale Development of a Hybrid Membrane-Absorption $CO_2$ Capture Process (DE-FE0013118)
- **Project period:** 10/1/13 to 9/30/18
- **Funding:** $3.2 million DOE + $0.75 million cost share
- **DOE-NETL Project Manager:** Andy Aurelio
- **Participants:** MTR, University of Texas at Austin
- **Overall goal:** Evaluate a hybrid post-combustion $CO_2$ capture process for coal-fired power plants that combines membrane and amine absorption/stripping technology.
- **Project plan:** The key project work organized by budget period is as follows:
  - **BP1**: Develop process simulations and initial cost assessments for the hybrid process, determine preferred hybrid configuration. Fabricate membrane modules.
  - **BP2**: Prepare the SRP pilot plant for hybrid testing. Test each capture system separately under hybrid conditions.
  - **BP3**: Conduct a parametric tests on the integrated hybrid capture system at UT-Austin's SPR Pilot Plant. Use test data to refine simulations and conduct TEA.



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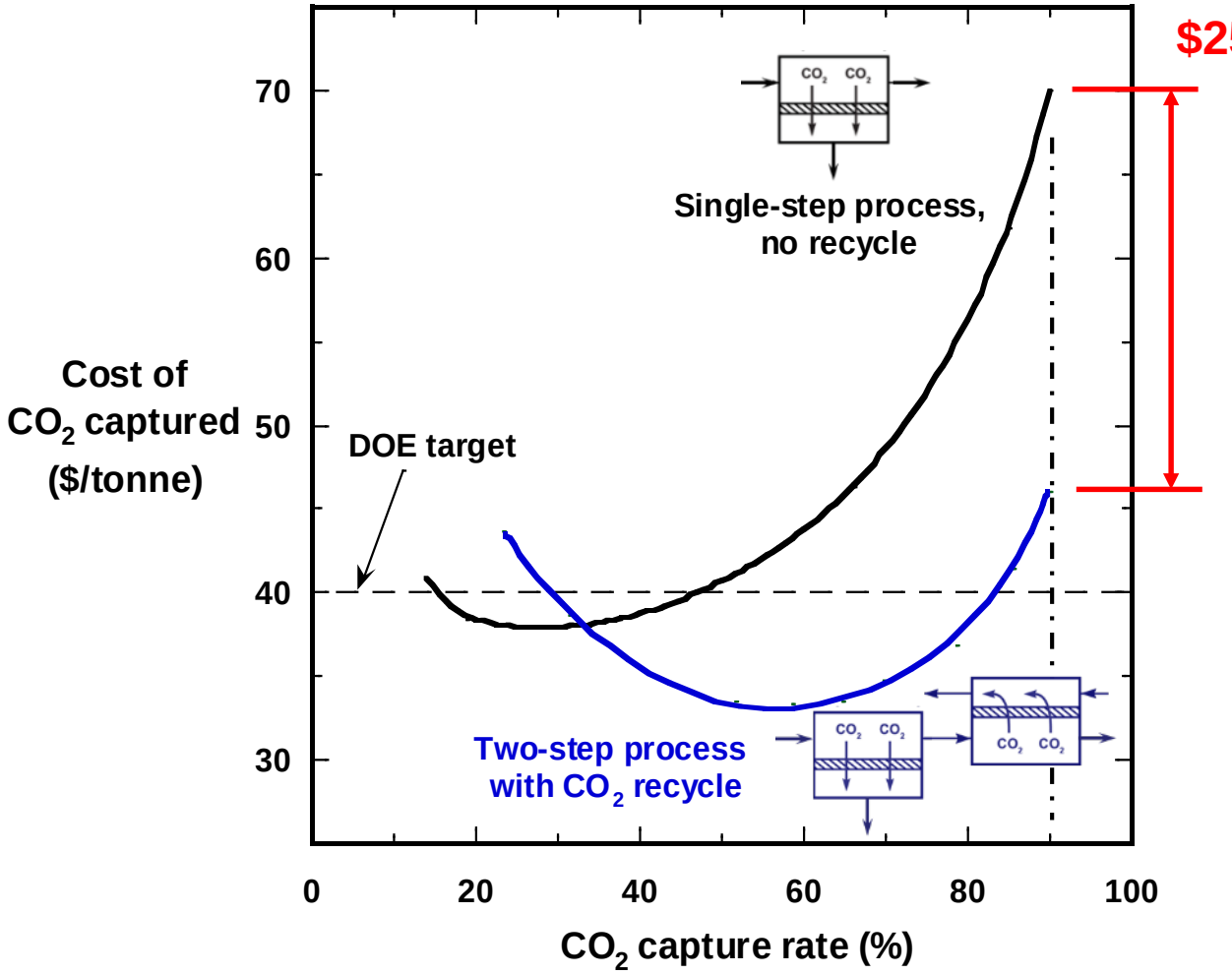
# 1) Motivation for the Hybrid Process

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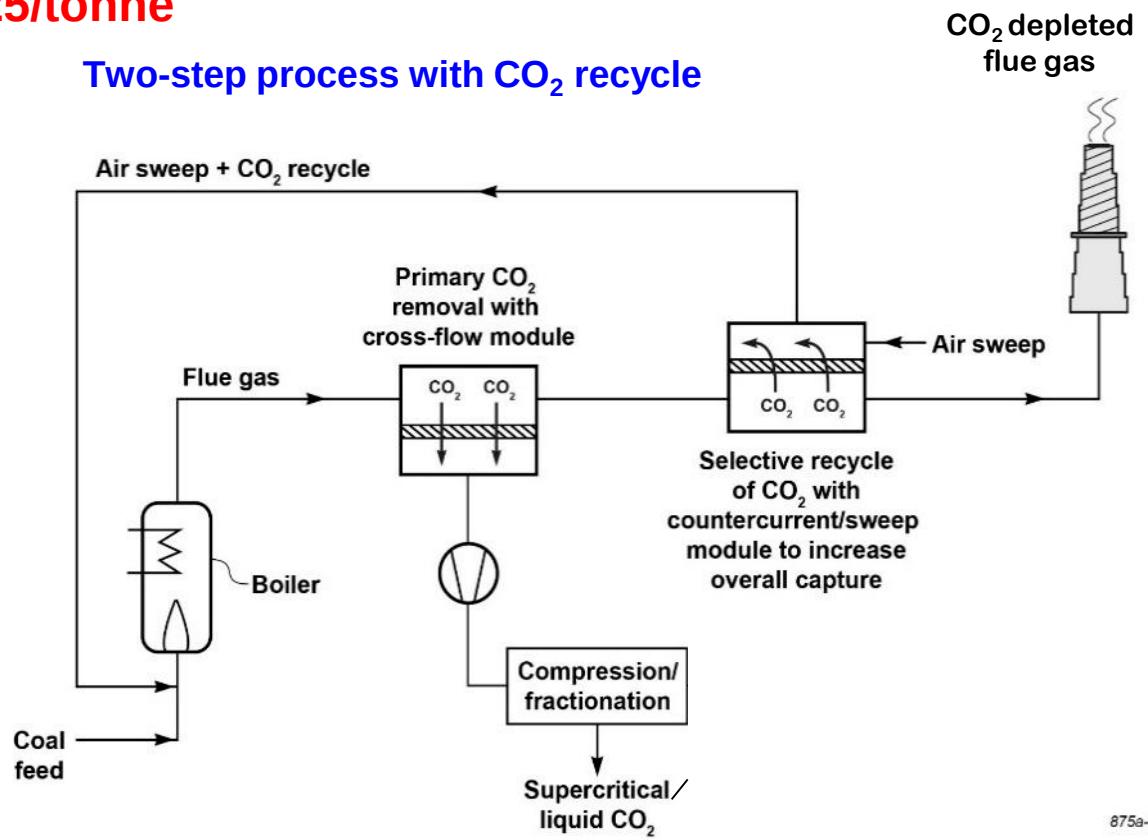
**Two-step process with $CO_2$ recycle**




U.S. Patents 7,964,020 and 8,025,715

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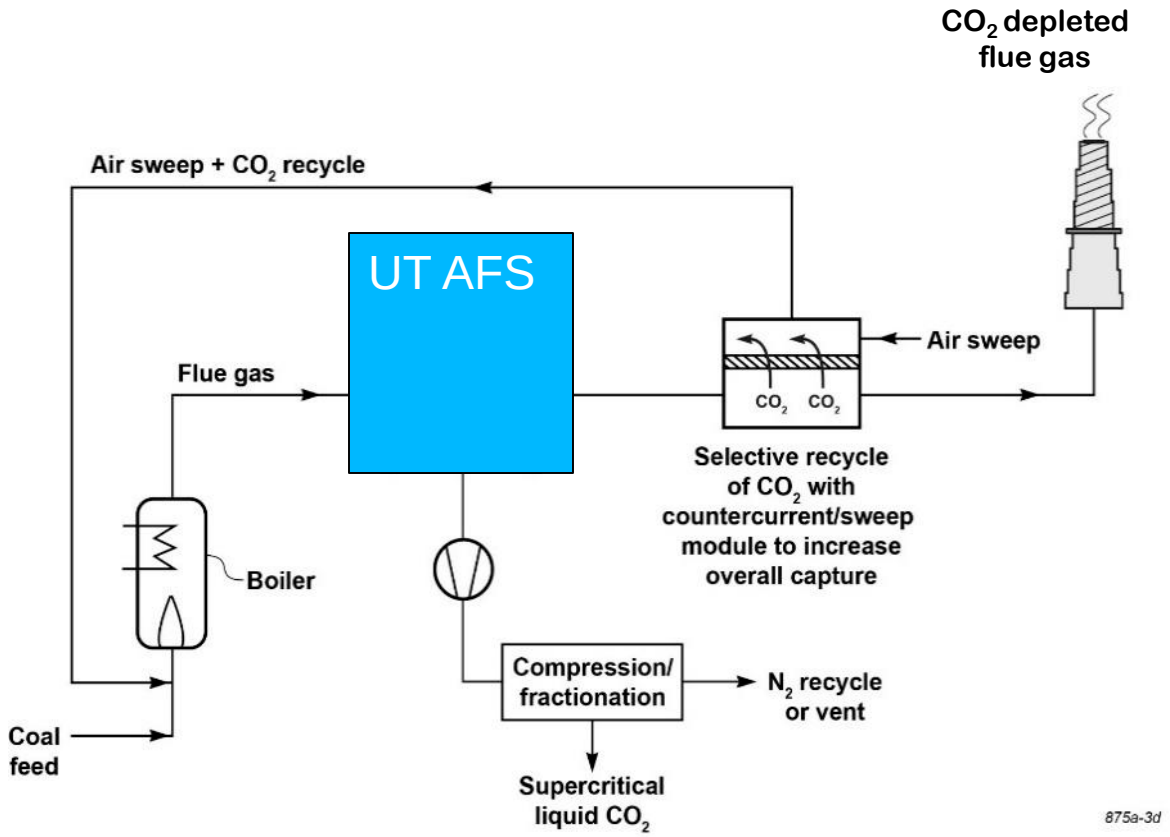
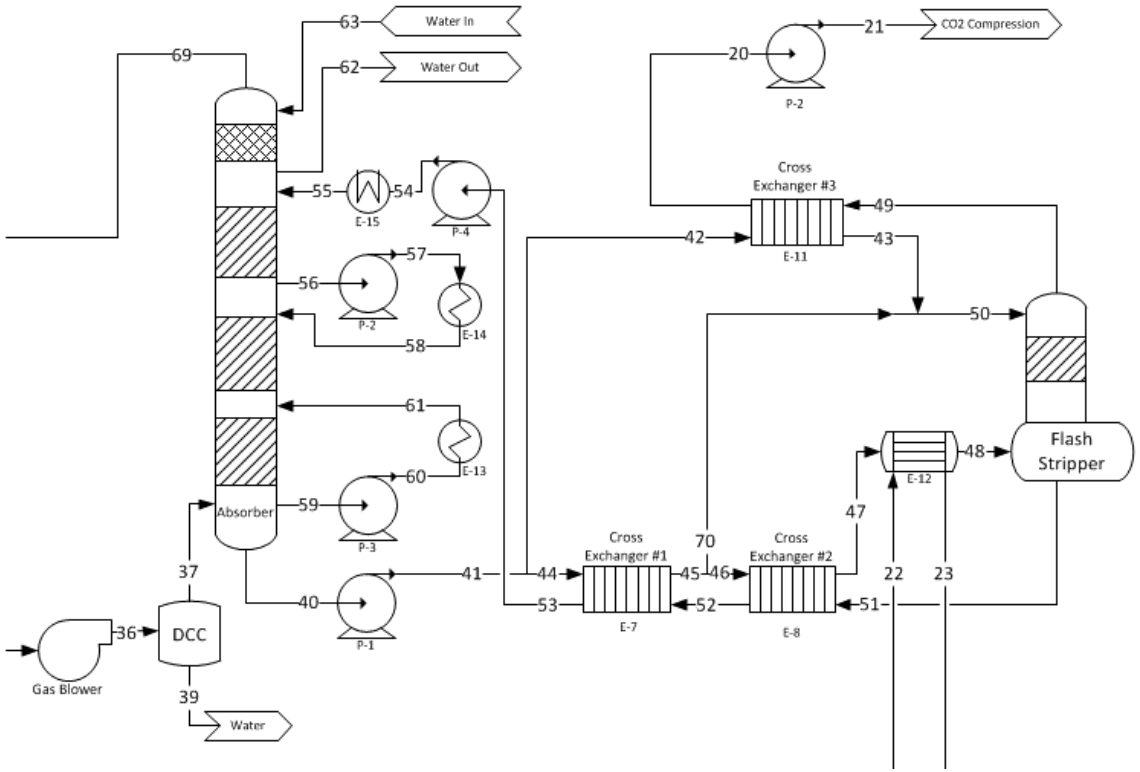
# 1) Optimization of UT Austin's AFS Capture Process

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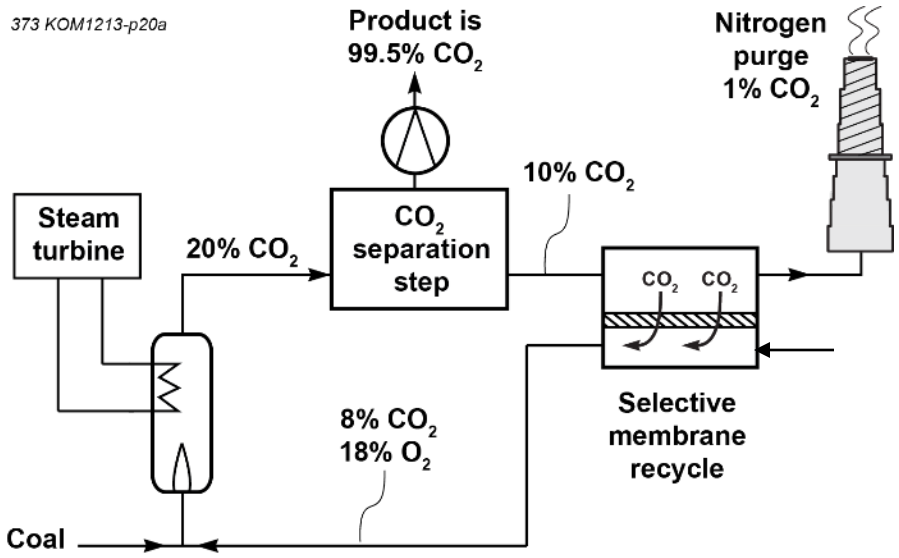
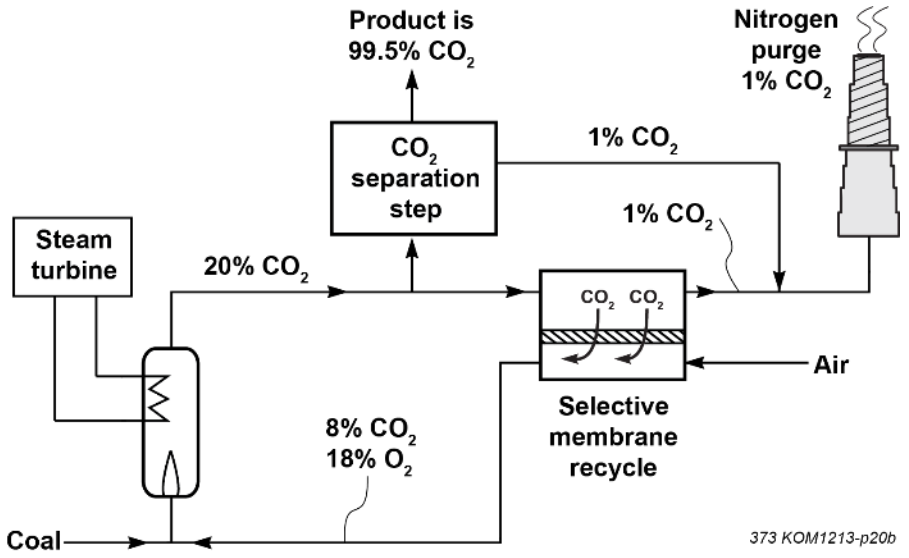
# 2) Example Hybrid Capture Systems

**Hybrid-Series Arrangement**




**Hybrid-Parallel Arrangement**




Depending on the arrangement, the selective recycle membrane can:

- Increase the concentration of $CO_2$ in flue gas, and;
- Reduce the removal requirements for the capture unit (Series; OpEx savings)
- Reduce the volume of gas sent to the capture unit (Parallel; CapEx savings)

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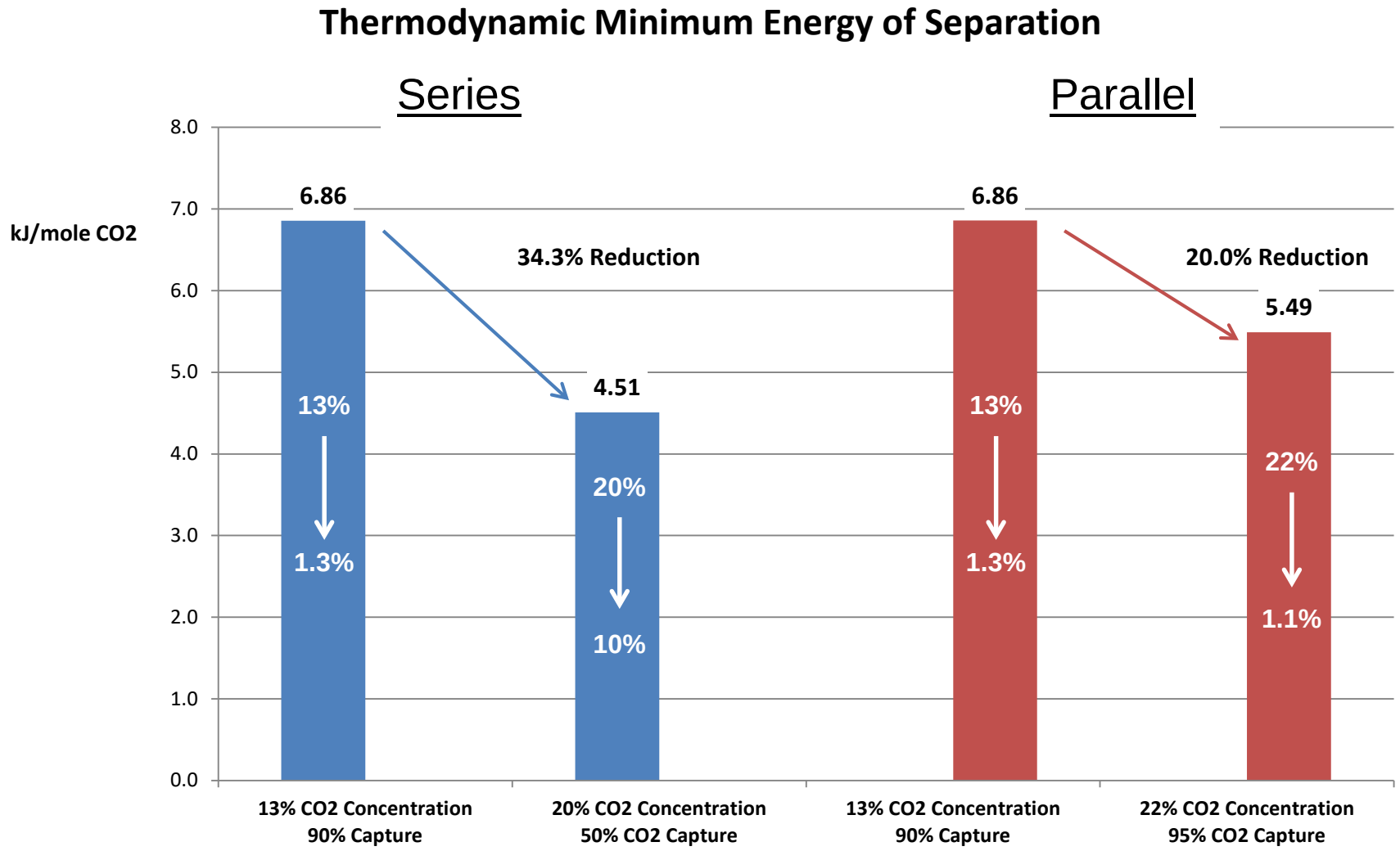
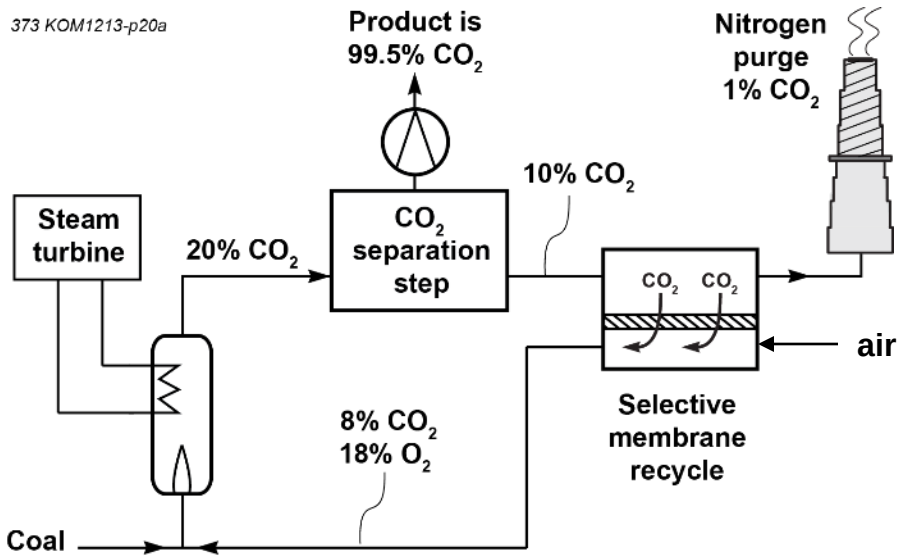
# 2) Minimum Energy of Separation for the Hybrid Partner




Assumes 98% $CO_2$ Product Purity. Does not consider $CO_2$ compression.

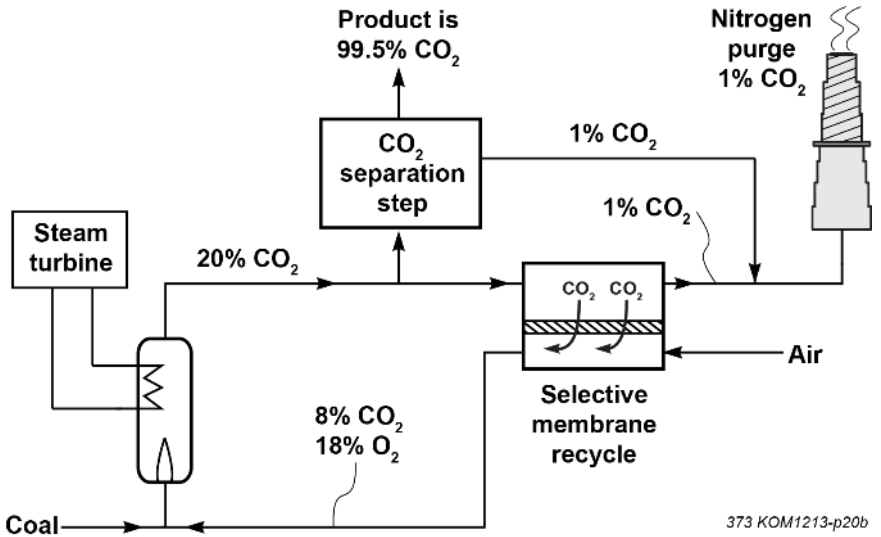
# 2) Hybrid-Series Modeling Results

- The **Hybrid Series** Configuration:
  - Minimum $O_2$ concentration in the combustion air (18% retrofit) limits the $CO_2$ concentration in the flue gas to ~17%
  - The sweep ratio in the membrane contactor is only ~50% as much as the Hybrid Parallel case.
  - To take advantage of the higher $CO_2$ concentration, PZ needs to be over stripped (0.18 mol $CO_2$/mol alk). and there is little opportunity to gain benefit at low capture rates (~60%).



# 2) Hybrid-Parallel Modeling Results

- The **Hybrid Parallel** Configuration:
  - Readily achieved 20% $CO_2$ concentration in the flue gas.
  - Requires less membrane area (vs. Series)
  - 5 m PZ able to achieve the required high capture rates – 95 to 98%+
  - Initial cost study showed significantly lower capture costs for the Hybrid-Parallel vs. Hybrid-Series.

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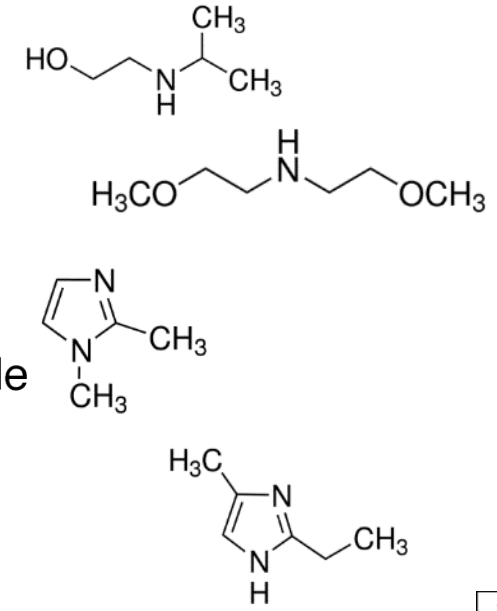
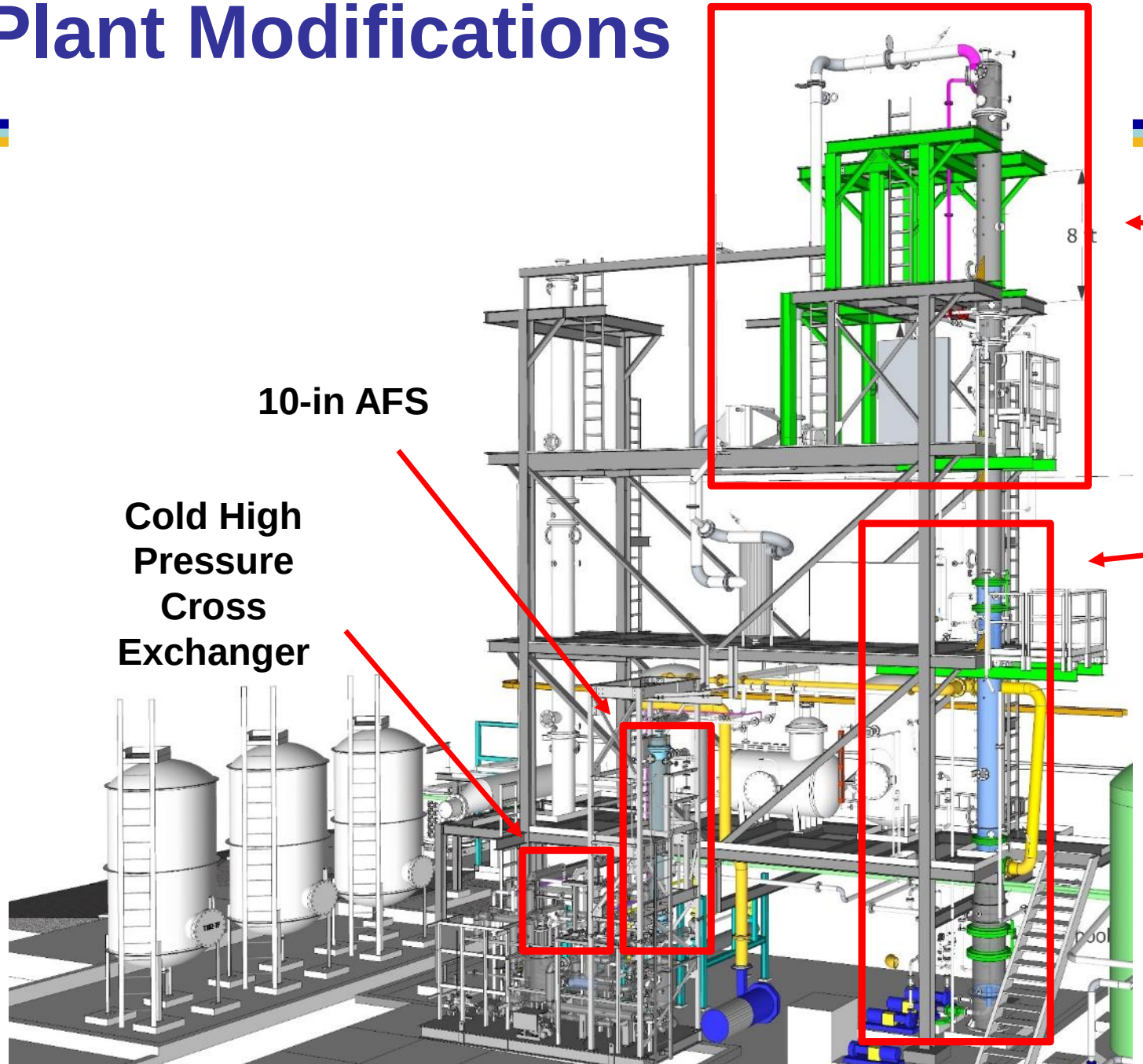
# 3) Evaluation of thermally stable tertiary amine blends

- Under C2P3 sponsorship, UT Austin examined numerous PZ blends, screening for:
  - Absorption rate -- Viscosity
  - Solvent solubility -- Availability and Cost
- Candidate solvents:
  - 2-(isopropylamino)ethanol (IPAE)
  - bis(2-methoxyethyl)amine (BMEA)
  - 1,2-dimethylimidazole (1,2-DM-IMI)
  - 2-piperidinoethanol (2PDE)
  - 2-ethyl-imidzaole (2E-IMI)
  - 2-ethyl,4-methyl-imidizaole (2E-4M-IMI)
- Modeled 2 m PZ / 3 m HMPD (4-hydroxymethyl, 1-piperidine)



# 4) Pilot Plant Modifications



# 4) Simulated Hybrid Test Conditions

- 29 conditions with 5 m (30 wt%) piperazine (PZ)
- Inlet $CO_2$: 12 & 20% (DOE/MTR), 4% (CCP4)
- Solvent rate: 3 – 24 gpm with 350 or 600 cfm air
- Lean loading: 0.18 – 0.27 mol $CO_2$/equivalent PZ
- Rich loading: 0.30 – 0.38
- 84 to 99% $CO_2$ removal
- Two absorber configurations
  - 3 x 10-ft solvent
  - 2 x 10-ft solvent, 1 x 10-ft water wash
- Stripper Temp: 135°C, 150°C



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# 4) Conclusions from Simulated Hybrid Test Campaign

- Absorber & stripper performed well with 20% $CO_2$
- Absorber performance predicted acceptably by “Independence”
  - Absorber model is most accurate for 4% and 12% $CO_2$
  - Additional analysis needed for 20% $CO_2$
  - Liquid distribution is poor at high L/G
- Energy requirement independent of inlet $CO_2$
  - Nominal smallest $W_{eq}$ = 215 kWh/t at 0.23 lean loading
- Exchangers provide 4-8 $^{o}$F pinch with 5 to 10% cold bypass



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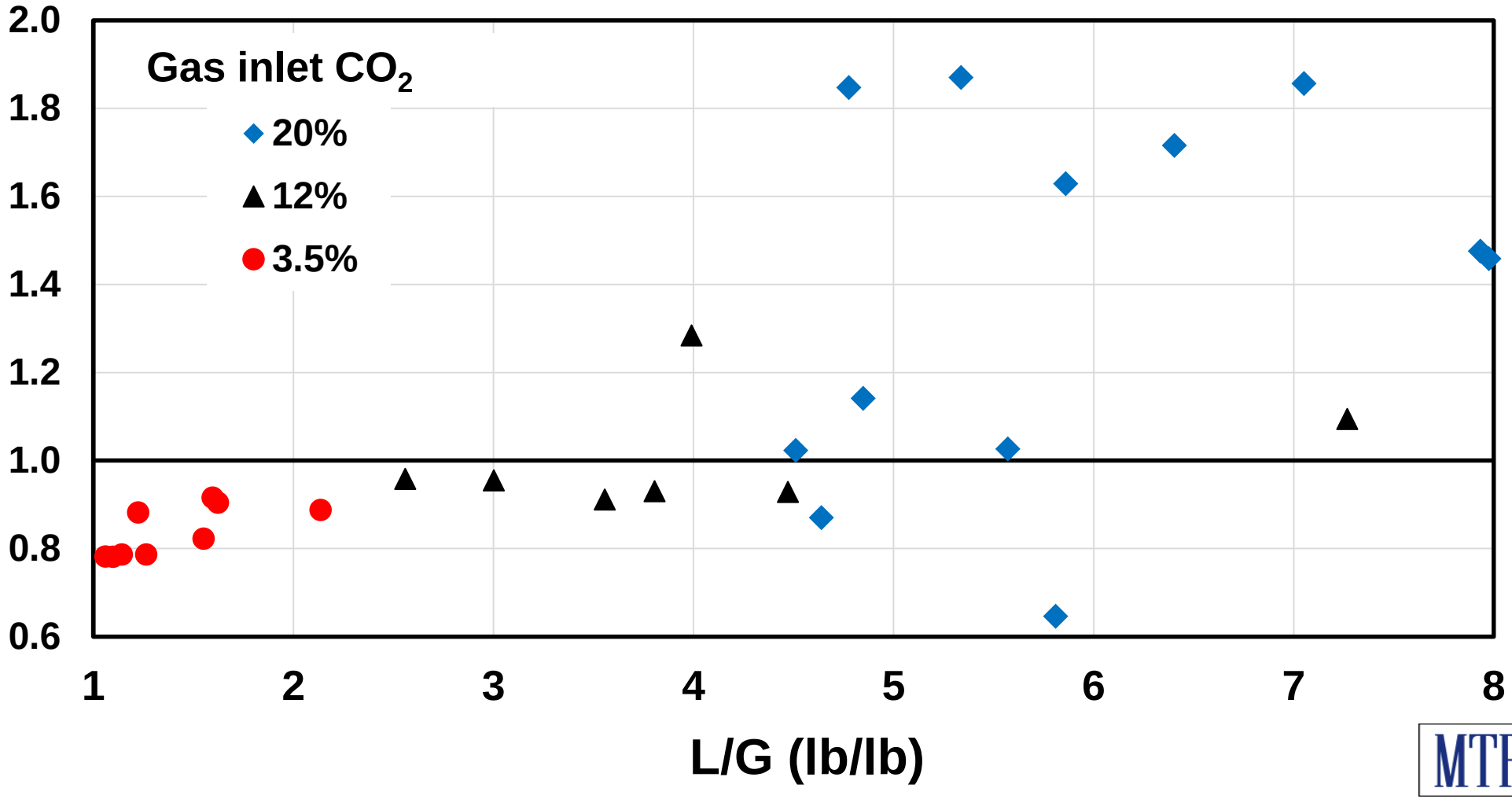
# 4) Aspen Plus® Model Predictions of $CO_2$ Removal by Independence

**Failure at high L/G probably due to liquid distribution**




Trough distributors were sized for 7 to 17 GPM but the absorber in several 20% CO2 runs was operated up to 24 GPM.



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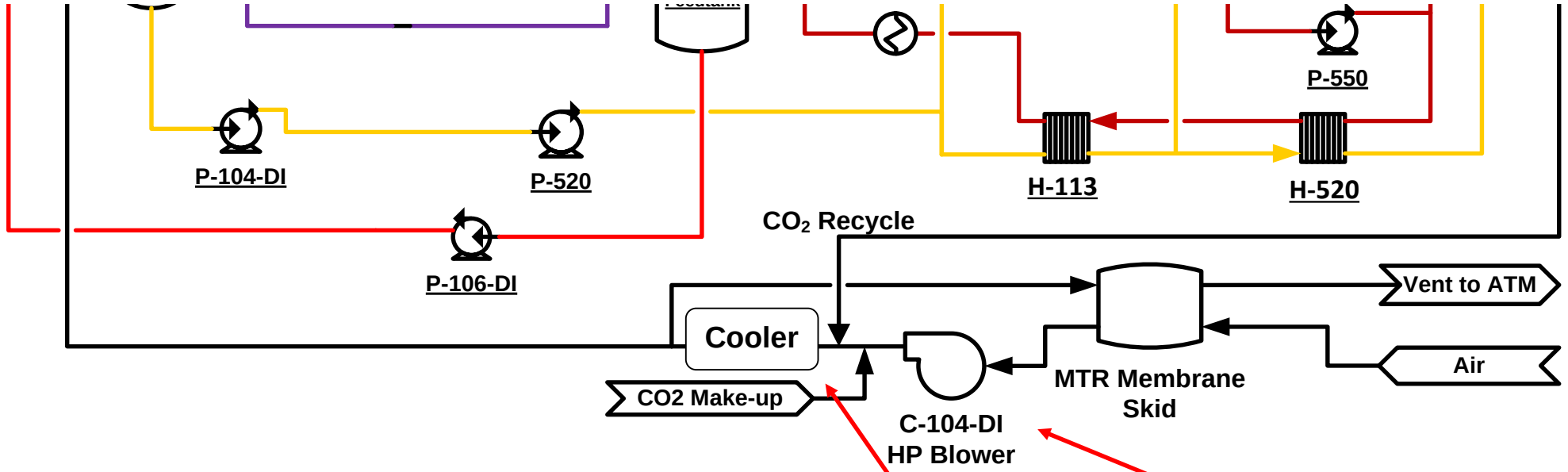
# #5 Pilot Plant Lessons Learned – managing P and T



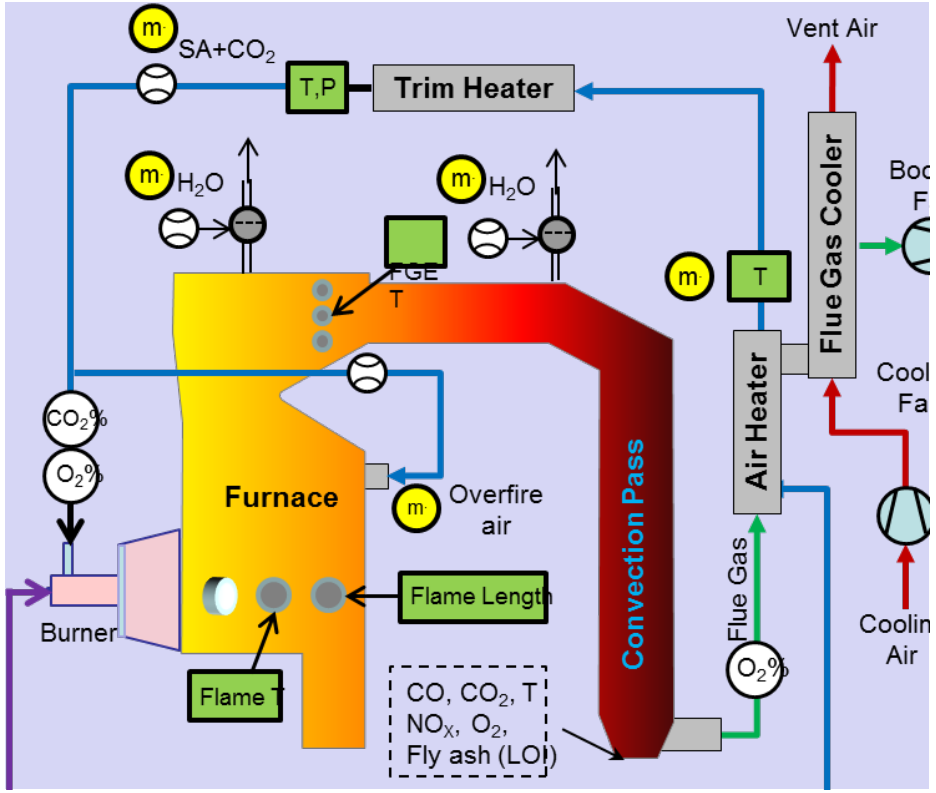

- Existing SRP fan upgraded to a blower
- Blower is performing double duty (through membrane sweep and feed)
- Small inefficient blowers drive up gas temperature
- Flue gas cooler added to cool flue gas

**Flue Gas Cooler**

**Atlas Copco Blower**

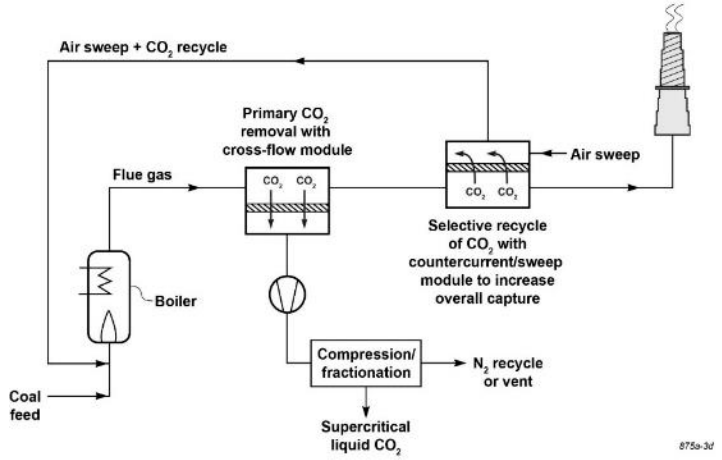
# #6 Boiler Impacts from B&W Tests (FE-0026414)

- Furnace heat absorption is lower (FEGT)
- Convection pass heat absorption is higher due to improved heat transfer coefficients.
- Convection pass outlet heat flux is higher
- Air heater heat absorption is higher
- Air heater flue gas outlet heat flux is higher
- Total heat absorption is slightly reduced
- Validated earlier derating assumption; 0.75% at 18% $O_2$ in inlet secondary air.



# Observations and Lessons Learned (1 of 3)

- A Hybrid capture system is not a simple combination of two capture technologies.
- The “hybrid partner” must be optimized for the hybrid conditions and be able to capitalize on the preferred capture conditions.
- Hybrid-Parallel is superior to Hybrid-Series configuration.
- The impacts of selective recycle on boiler performance are known and validated via testing (FE-0026414)
- MTR and UT Austin thoroughly explored options for process optimization.



# Observations and Lessons Learned (2 of 3)

- MTR and UT Austin are able to accurately predict capture performance in hybrid conditions.

- The cost of capture from the hybrid system is not materially less than what is possible from the 5 m AFS capture process.

# Observations and Lessons Learned (2 of 3)

- For hybrid's to be a compelling capture technology option, the lower cost-of-capture must reconcile:
  - operationally, hybrid system are more complex
  - likely to have larger footprints
  - a potentially longer and more complex retrofit/installation

- Areas yet to be studied:
  - Hybrid-Series with adsorption, cryo
  - Hybrid-Parallel with slightly reduced capture rate (85%)

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# Final Step: Integrated Testing of the Hybrid Capture System at UT Austin's SRP Pilot Plant

**MTR's Plate-and-Frame Membrane Skid**

# Acknowledgment

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# Hybrid Project Team

- **DOE-NETL:**
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