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

DE-FE0013118

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NETL CO_2 Capture Technology Meeting
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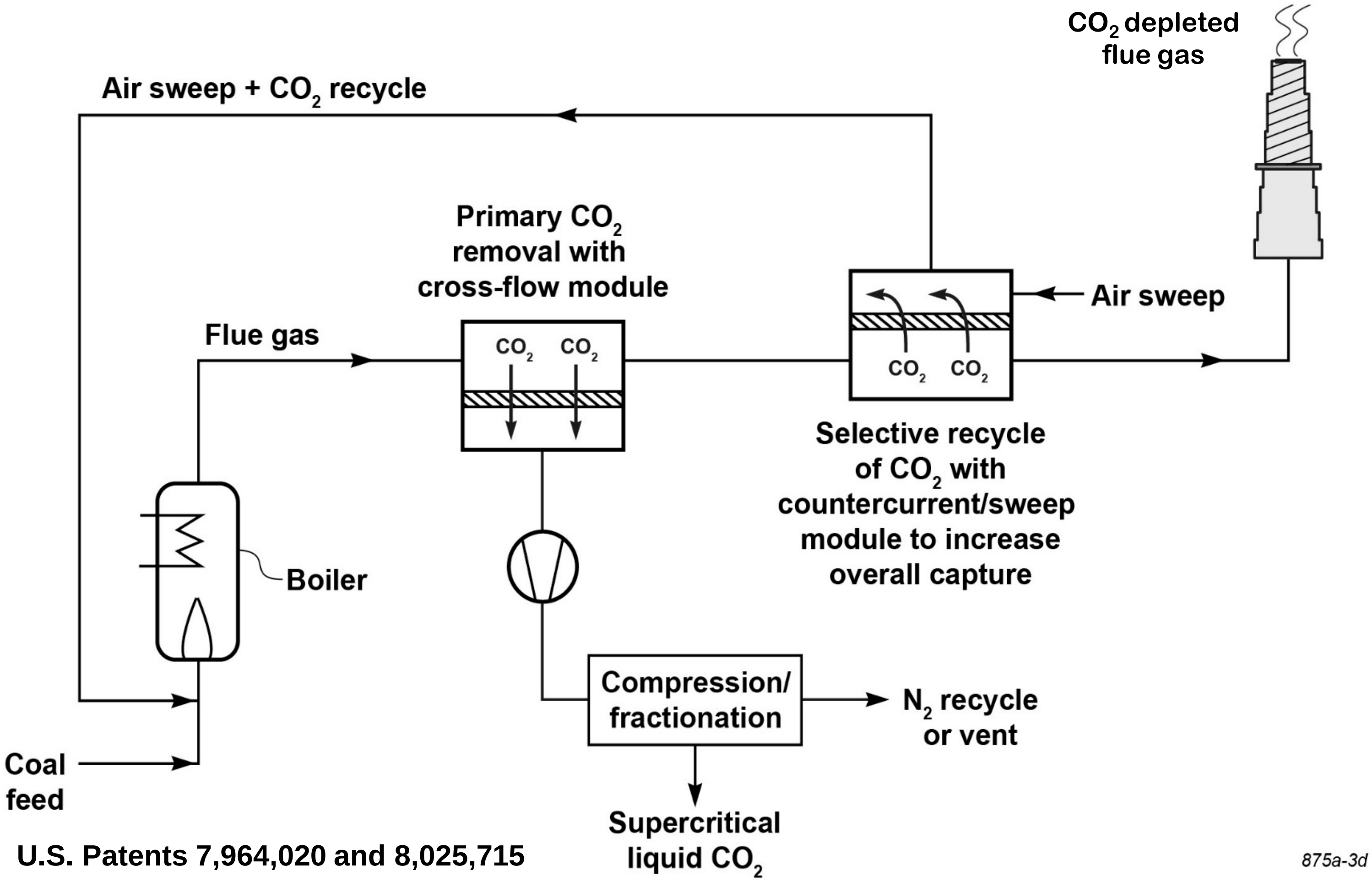
Project Overview

- **Award name:** Bench-Scale Development of a Hybrid Membrane-Absorption CO_2 Capture Process (DE-FE0013118)
- **Project period:** 10/1/13 to 9/30/17
- **Funding:** $3.2 million DOE + $0.75 million cost share
- **DOE-NETL Project Manager:** Mike Mosser
- **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 assessment for the hybrid process, and fabricate membrane modules.
  - **BP2**: Upgrade the SRP pilot plant. Conduct comprehensive parametric tests of technologies separately at MTR and UT Austin, covering full range of operating conditions expected for the hybrid design. Refine simulations and prepare for operation of the integrated membrane–absorption system.
  - **BP3**: Run full parametric test program on integrated hybrid unit at UT-Austin. Use test data to refine simulations and conduct TEA.

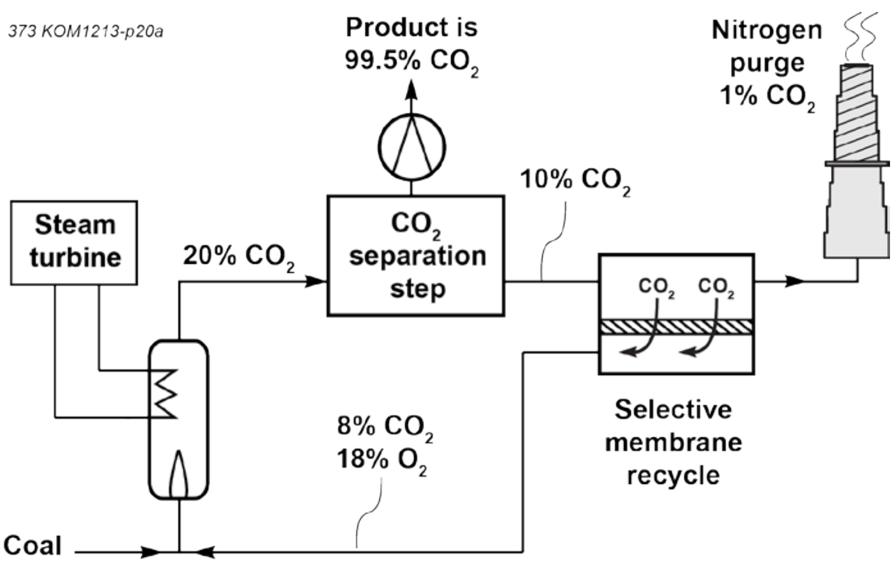
Motivation for the Hybrid Capture Process



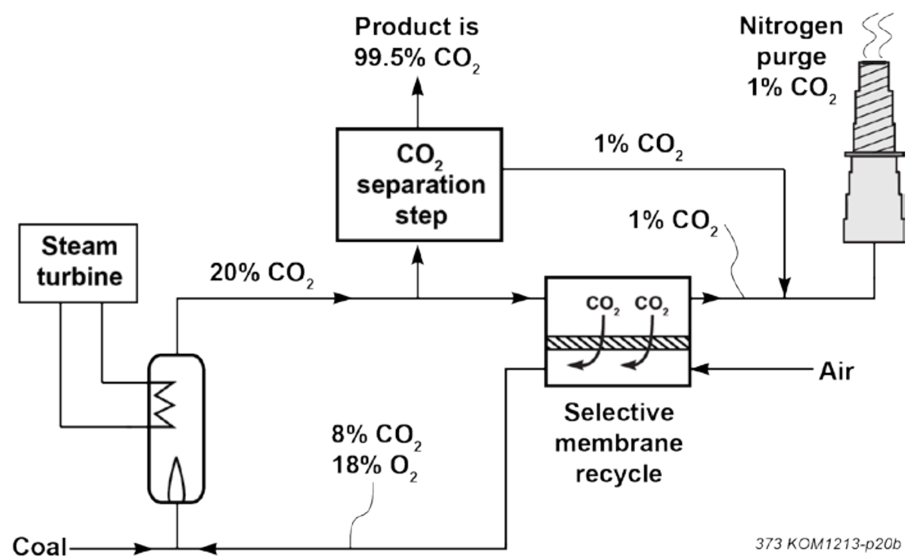
U.S. Patents 7,964,020 and 8,025,715

Two Hybrid Configurations

Hybrid-Series Arrangement



Hybrid-Parallel Arrangement



Depending on the arrangement, the selective recycle membrane can:

- Significantly increase the concentration of CO_2 in flue gas, and;
- Reduce the removal requirements for the capture unit (Series)
- Reduce the volume of gas sent to the capture unit (Parallel)

Benefits and Challenges of the Hybrid Capture Process

Benefits:

- Hybrid concept can be used with different capture technologies.
- Increases the concentration (driving force) of CO_2 in flue gas.
- Air sweep is a very efficient use of membranes.
- MTR's membrane contactor is modular and compact.

Challenges:

- Very permeable/low cost membranes required.
- Hybrid partner must be able to capitalize on high CO_2 concentrations.
- The sweep stream has a derating effect on the boiler (~0.7%) derating of boiler efficiency from CO_2 recycle.
- Hybrid-parallel design requires greater removal rates (~95%) by the hybrid partner.

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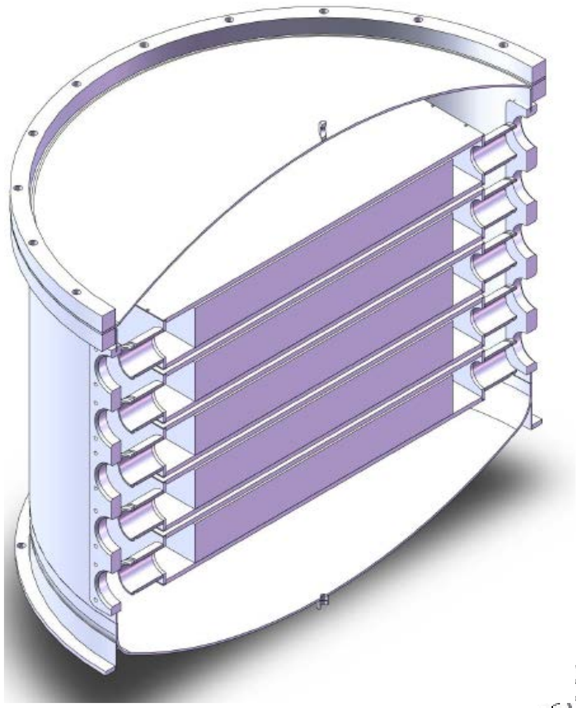
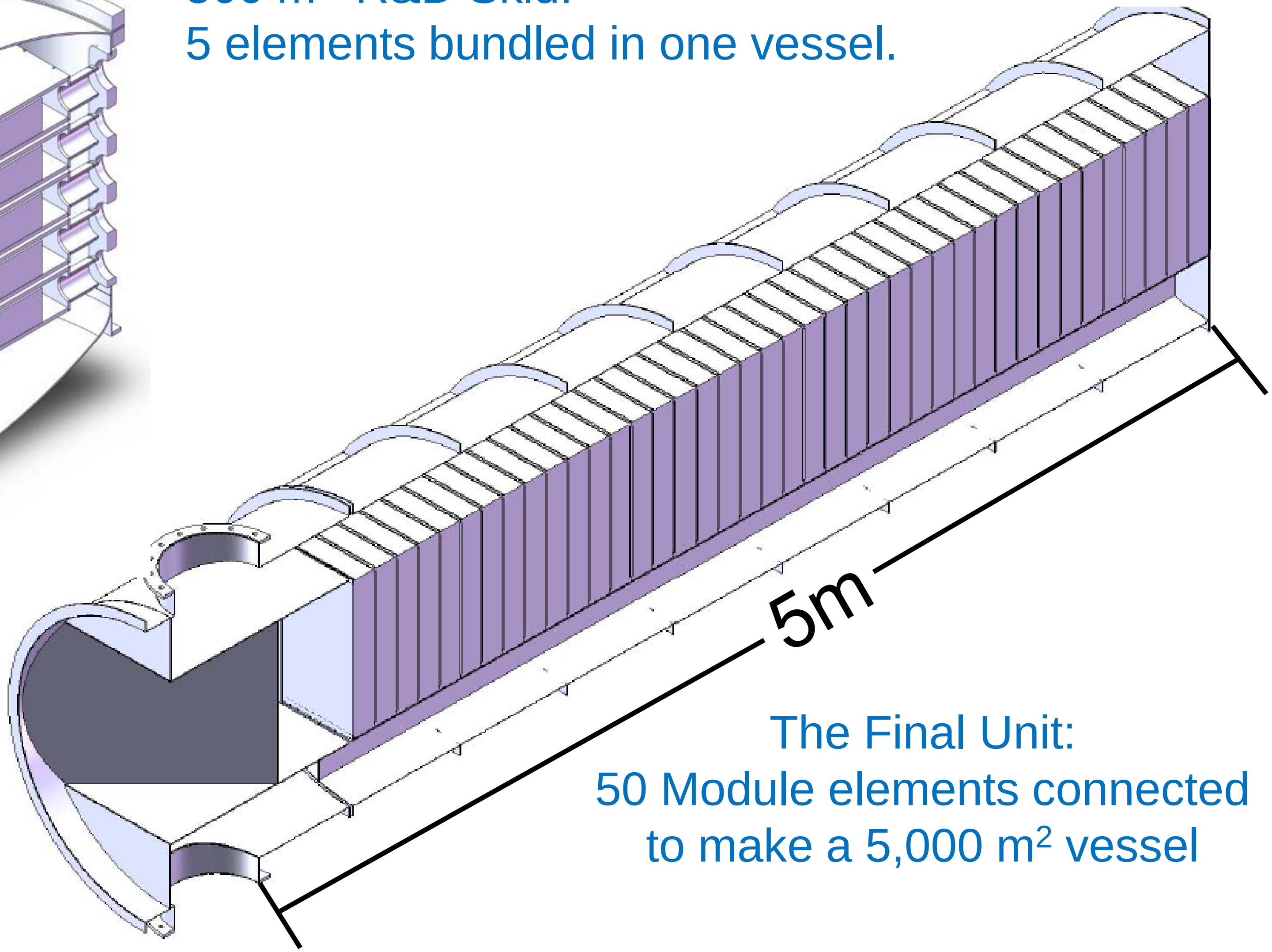
MTR Low Pressure Drop Plate-and-Frame Membrane Contactor

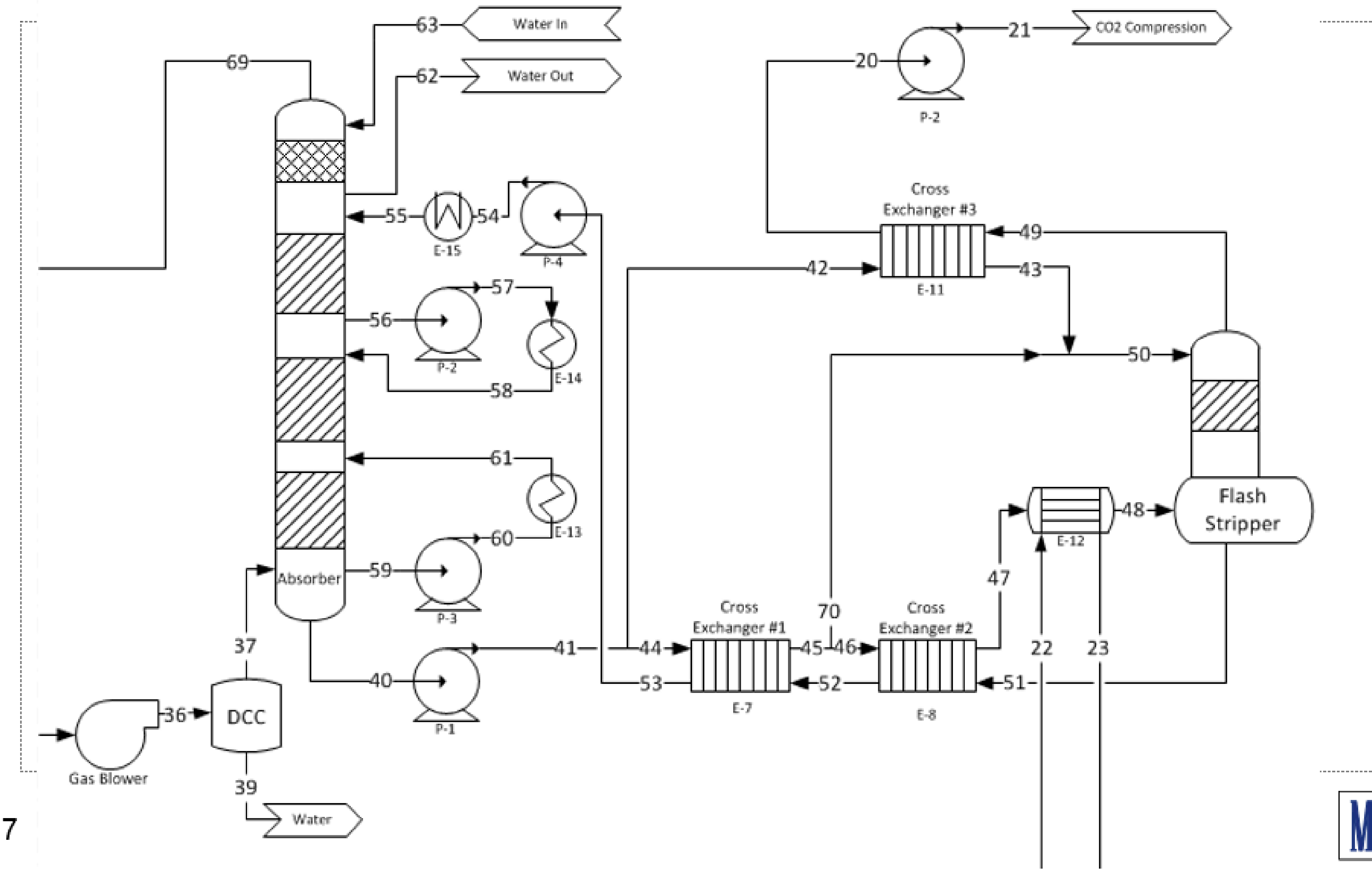


500 m^2 R&D Skid:
5 elements bundled in one vessel.



The Final Unit:
50 Module elements connected to make a 5,000 m^2 vessel

UT Austin's Advanced Flash Stripper



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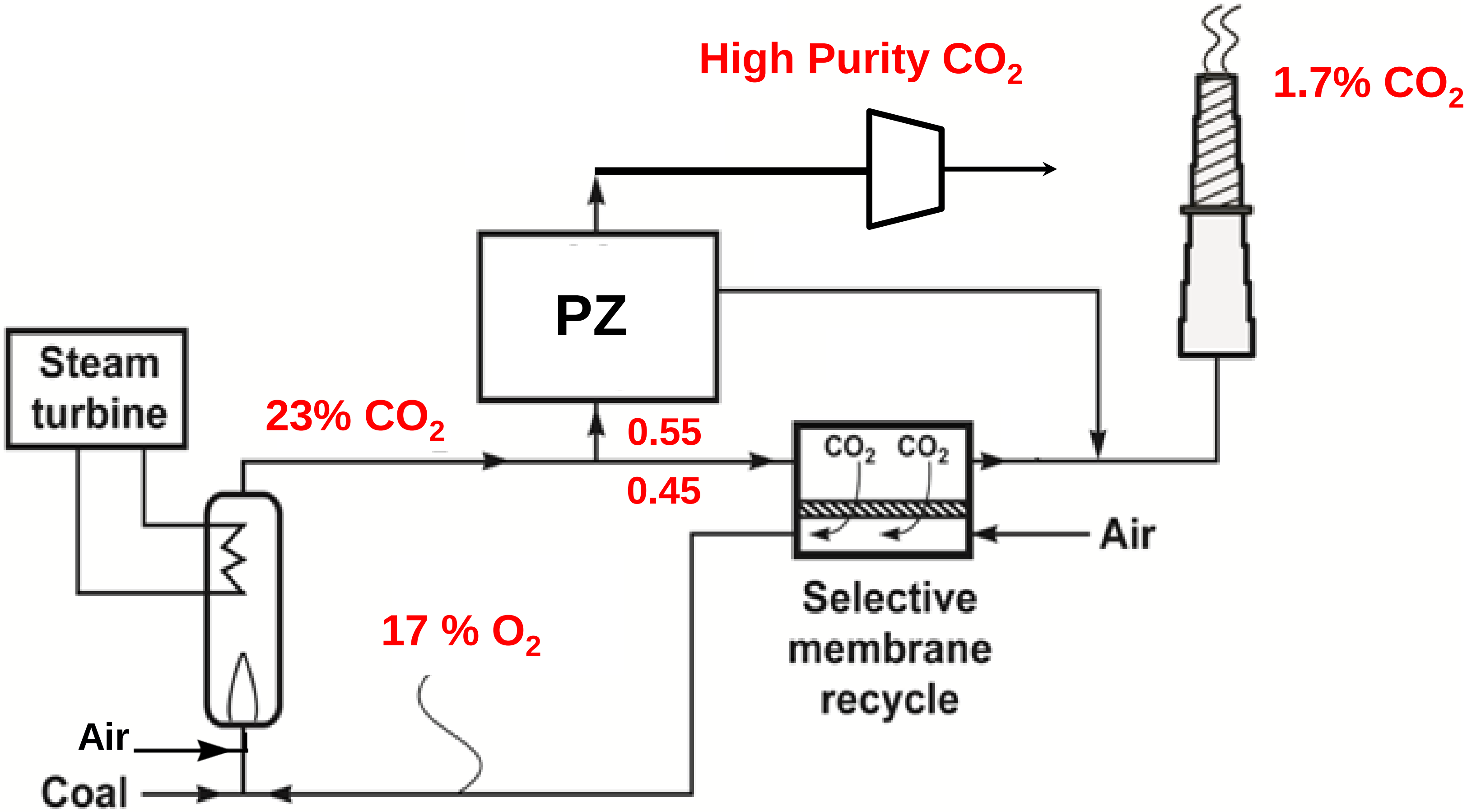
Process Model Parameters

- Power plant performance based on NETL Case #11.
- Fixed coal input rate; fixed CO_2 generation rate.
- Total system CO_2 capture rate is 90% for all cases.
- Membrane: CO_2 2,000 GPU; CO_2/N_2 selectivity 50.
- Pressure drop for feed and sweep side = 0.2 bar (2.9 psi)
- O_2 concentration in combustion air entering the boiler is 17% (for new build applications).
- Membrane is modeled in ChemCAD, PZ Capture Plant in Aspen (UT Austin's Independence model).

Modeling the Hybrid Parallel System



- 90% Capture Rate for the Entire System
- Absorption process removes 95% CO_2 from partial stream

Absorber Design Conditions

Two Solvents Evaluated

- 5 m PZ & 5 m PZ/5 m MDEA

Two CO_2 Removal Rates

- 95% & 99% (in Absorber); 90% total

Two Bounding Economic Scenarios

- 1.1 L/L_{min} (Higher CapEx, Lower OpEx)
- 1.3 L/L_{min} (Lower CapEx, Higher OpEx)

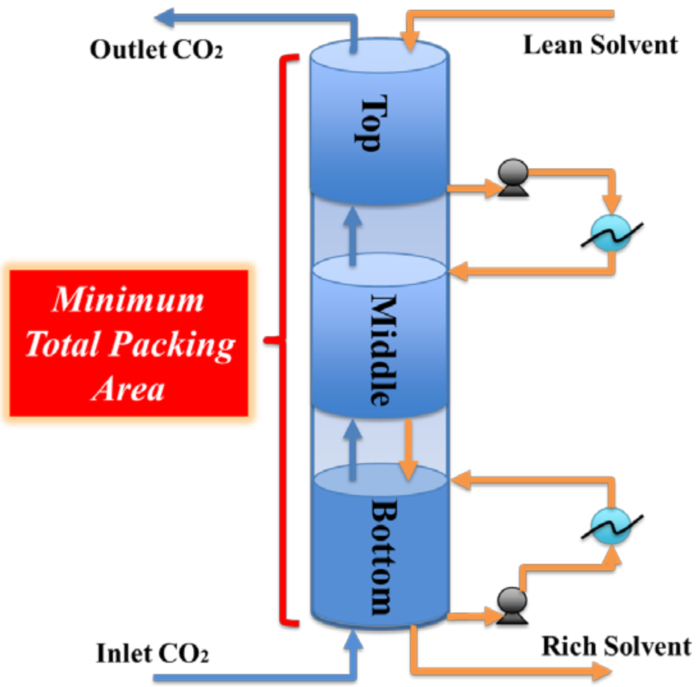
A Wide Range of Lean Loadings

- Over-stripping LLDG, Normal LLDG

Multiple Intercooling (IC) Configurations

- In-and-out IC & Pump-around IC

Objective is to minimize packing area



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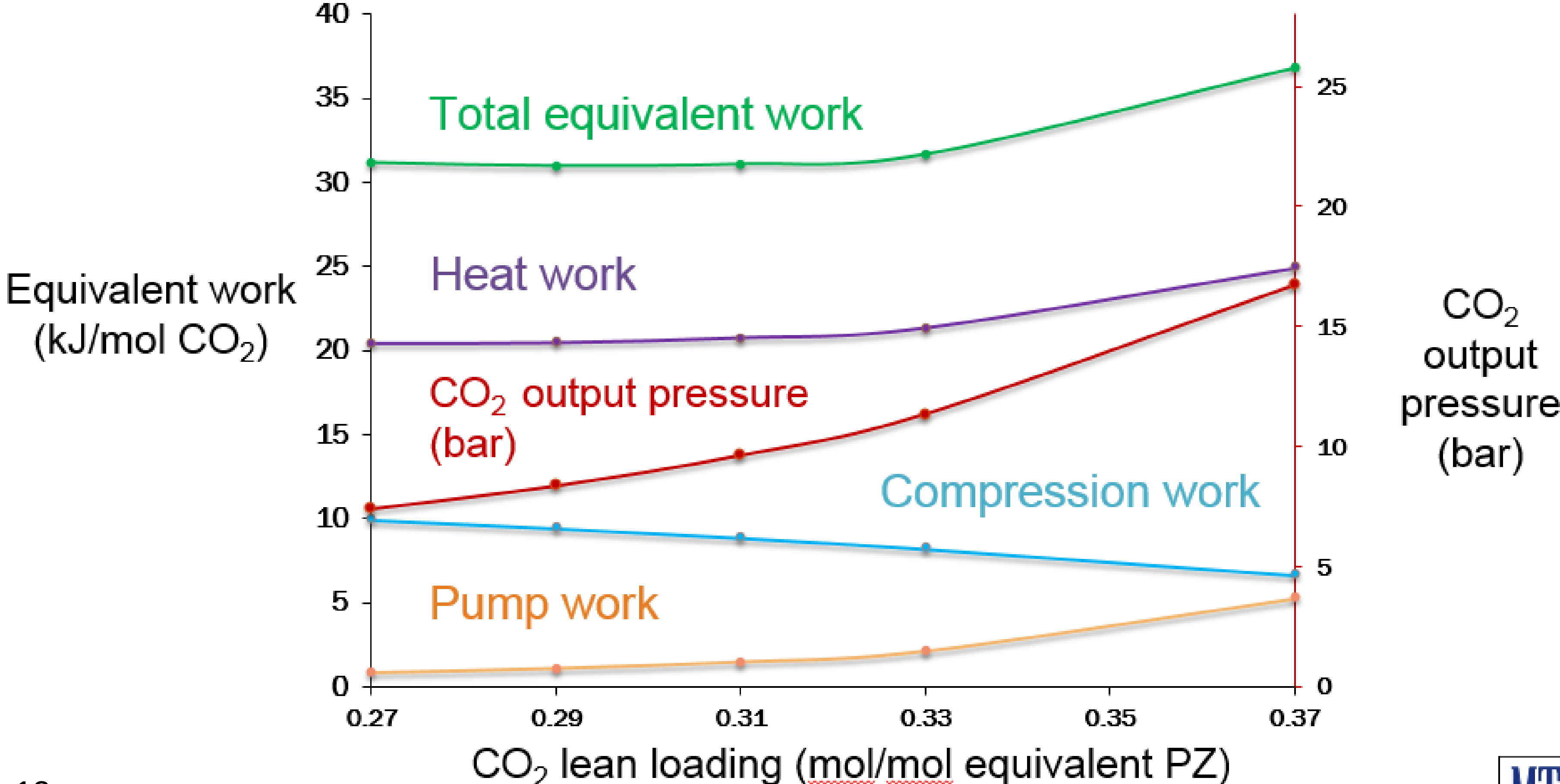
Stripper Model Conditions

- Stripping temperature set to amine thermal degradation rate of 2% / week of amine degradation.
  - T_{strip} 150 °C for 5 m PZ, 120 °C for 5 m PZ / 5 m MDEA
- For each rich loading, for a range of lean loadings:
  - Cold rich bypass and warm rich bypass stream were optimized. cold and rich warm bypass streams were optimized for a range .
- A minimum equivalent work (W_{eq}) was calculated.

Energy Performance of High CO_2 Rich Loading (0.43) for 5 m PZ

$$W_{EQ} = W_{pump} + W_{comp} + 90\% \frac{T_{reb} + \Delta T - 313K}{T_{reb} + \Delta T} Q_{reb}$$

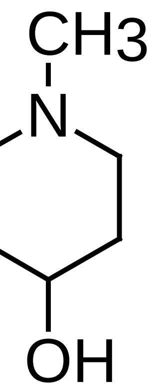


Modeling Results

- Challenges:
  - 5 m PZ has low capacity, high circulation rate, high heat exchanger costs.
  - PZ VLE curves sharply at rich loading – unable to take full advantage of 23% CO_2.
- MDEA/PZ is stripping pressure is limited to ~ 3 bar, due to low (120 C) stripping temperature.
- 5 m MDEA / 5 m PZ purchased equipment cost is 15% lower than for 5 m PZ.

High Capacity, Thermally Stable Solvent

- High capacity – >0.6 mol CO_2/mol alk.
- Fast reaction rates
- Low degradation – <2% per week, 150C
- Low volatility – < AMP
- Low viscosity – <5 cP; ~<200 MW
- Low cost – inexpensive precursors and simple synthesis.



4-hydroxy-1-methylpiperdine (HMPD)

- 2m PZ/3m HMPM is preferred blend concentration

Key Findings

- Hybrid concept can achieve up to 24% CO_2 concentration in the flue gas.
- The Hybrid-Parallel is the preferred configuration.
- High lean loading leads to high solvent circulation rates, which increased mass and heat transfer surface areas, thereby increasing equipment cost.
- 5 m PZ at 23% CO_2 concentration shows marginally higher rich loadings compared to 13% CO_2 . A higher capacity solvent would take advantage of the high inlet CO_2 concentration.
- A high capacity, thermally stable amine is best suited for the hybrid conditions.

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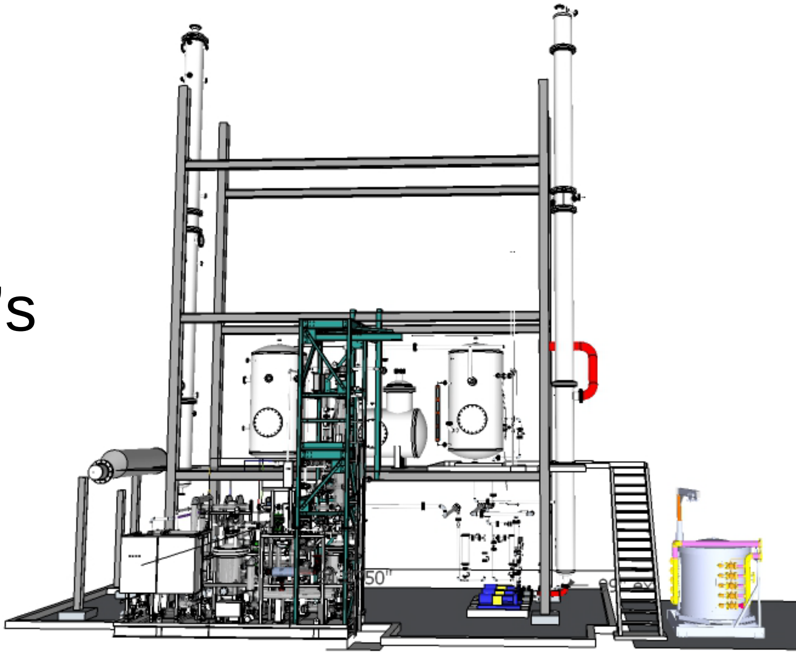
Next Steps

Budget Period 2

- Develop initial TEA based on modeling results
- Modify SRP with the addition of a third 10' section of packing and water wash section.
- Independent testing of systems

Budget Period 3

- Test hybrid concept at UT Austin's 0.1 MW SRP Pilot Plant
- Updated TEA with test results



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Hybrid Project Team

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