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

DE-FE0013118

MTR

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2017 NETL CO_2 Capture Technology Project Review Meeting

August 24, 2017

Project Overview

- **Award name:** Bench-Scale Development of a Hybrid Membrane-Absorption CO_2 Capture Process (DE-FE0013118)
- **Project period:** 10/1/13 to 5/31/18
- **Funding:** $3.2 million DOE + $0.75 million cost share
- **DOE-NETL Project Manager:** Andy Aurelio
- **Participants:** MTR, University of Texas at Austin
- **<u>Overall goal:</u>** Evaluate a hybrid post-combustion CO_2 capture process for coal-fired power plants that combines membrane and amine absorption/stripping technology.
- **<u>Project plan:</u>** 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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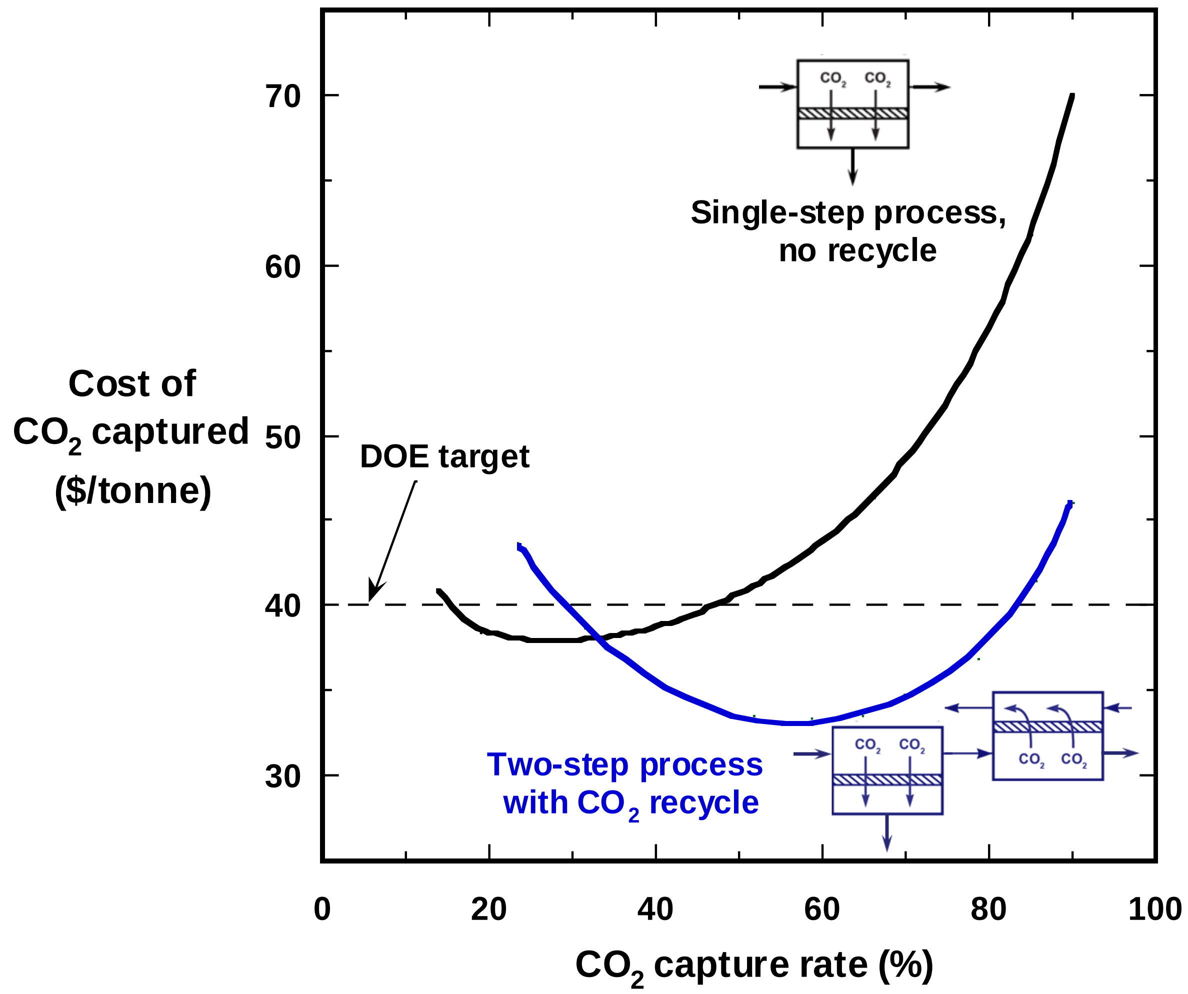
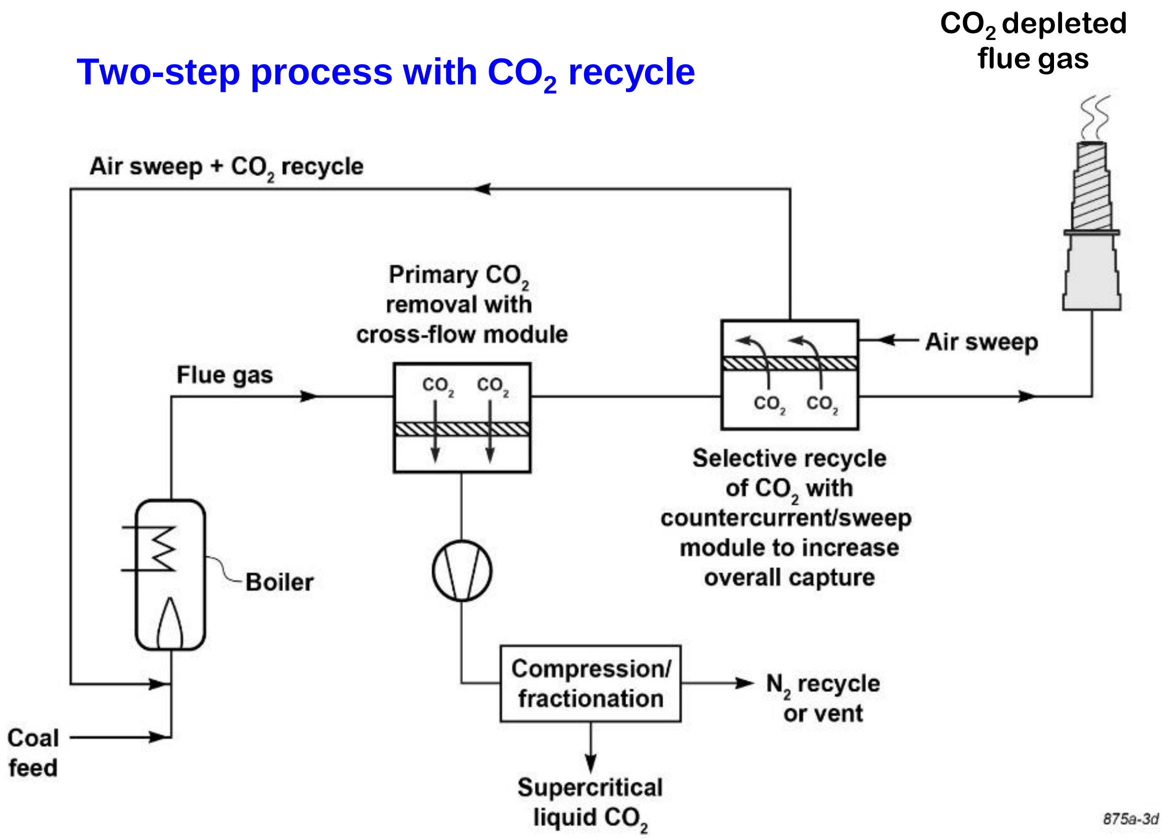
Motivation for the Hybrid Process

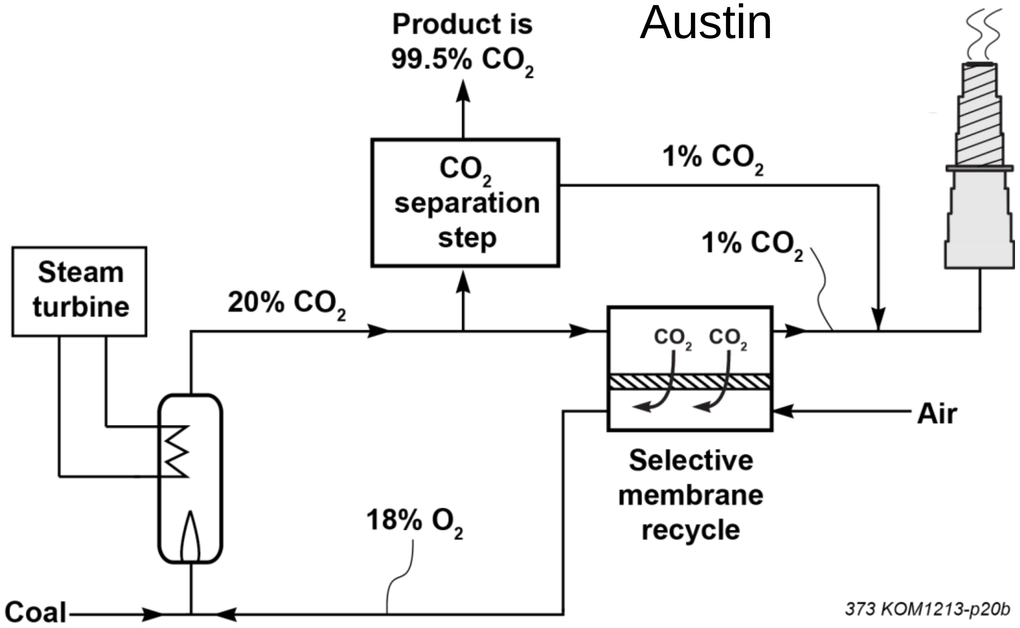




U.S. Patents 7,964,020 and 8,025,715

Hybrid Parallel Configuration

Pilot plant testing at UT Austin



Integrated Boiler Testing at B&W
(FE-0026414)

Benefits:

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

Challenges:

- The sweep stream impacts boiler performance; ~0.75% efficiency derating.
- Hybrid partner must be able to capitalize on higher CO_2 concentrations.
- Overall, hybrid systems increase operational complexity.

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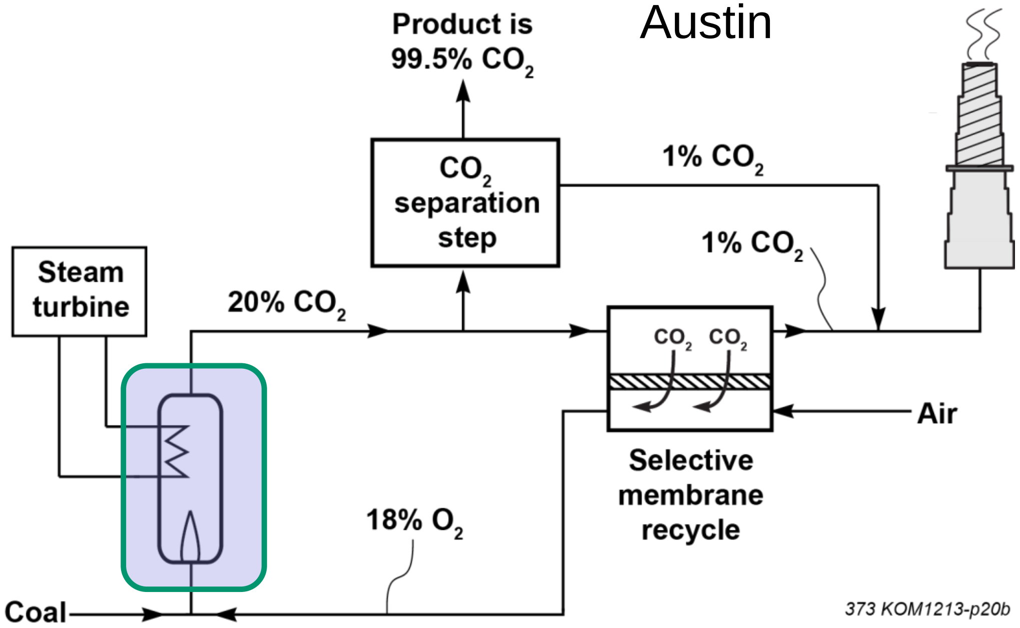

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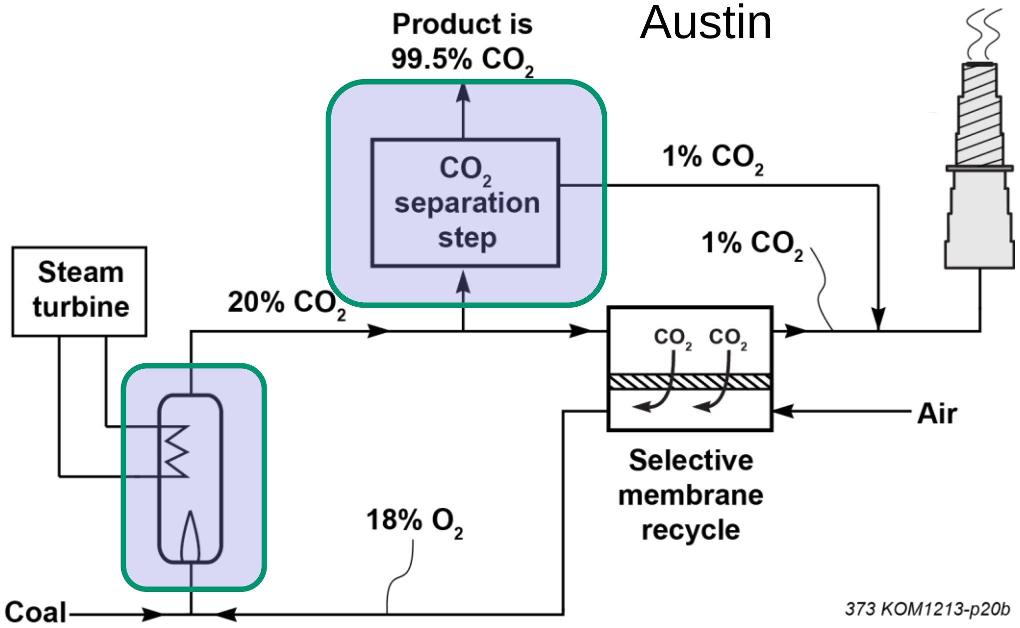

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Sample Results from B&W Integrated Tests (FE-0026414)

Membrane-Boiler Test Results

- 5 weeks of testing on natural gas, Powder River Basin (PRB), and Eastern Bituminous coal
- 90% capture and a variety of partial capture conditions were achieved
- Boiler flame was stable allowing a full battery of stream conditions and boiler efficiency measurements to be conducted

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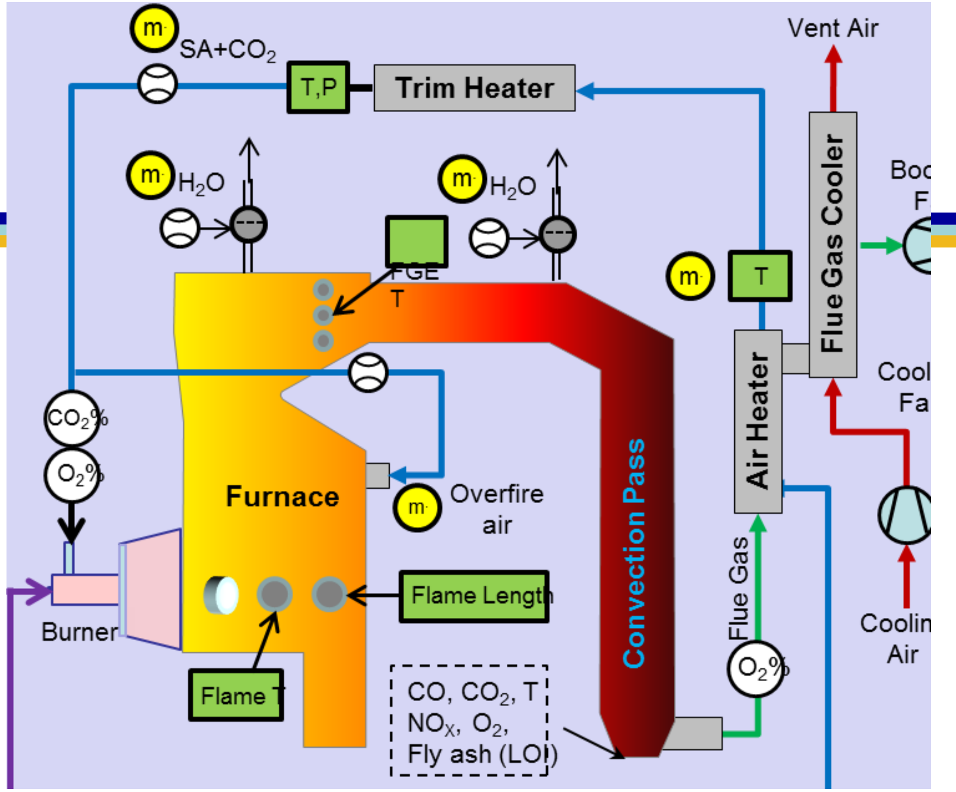
Boiler Impacts from B&W Tests
(FE-0026414)



- 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.

		w/ recycle	w/out recycle
FEGT	(°C)	1,179	1,259
Convection Pass Exit Temperature	(°C)	397	380
Air Heater Exit Temperature (Flue Gas)	(°C)	217	210
Membrane Secondary Air Ratio		**53%**	**0%**
Furnace Absorption	(MW)	0.52	0.66
Convection Pass Absorption	(MW)	0.96	0.91
Convection Pass Outlet Heat Flux	(MW)	0.50	0.43
Total Heat Absorption	(MW)	1.62	1.68
Air Heater Absorption	(MW)	0.19	0.16
Air Heater Outlet Heat Flux (Flue Gas)	(MW)	0.31	0.27

University of Texas at Austin: SRP Pilot Plant

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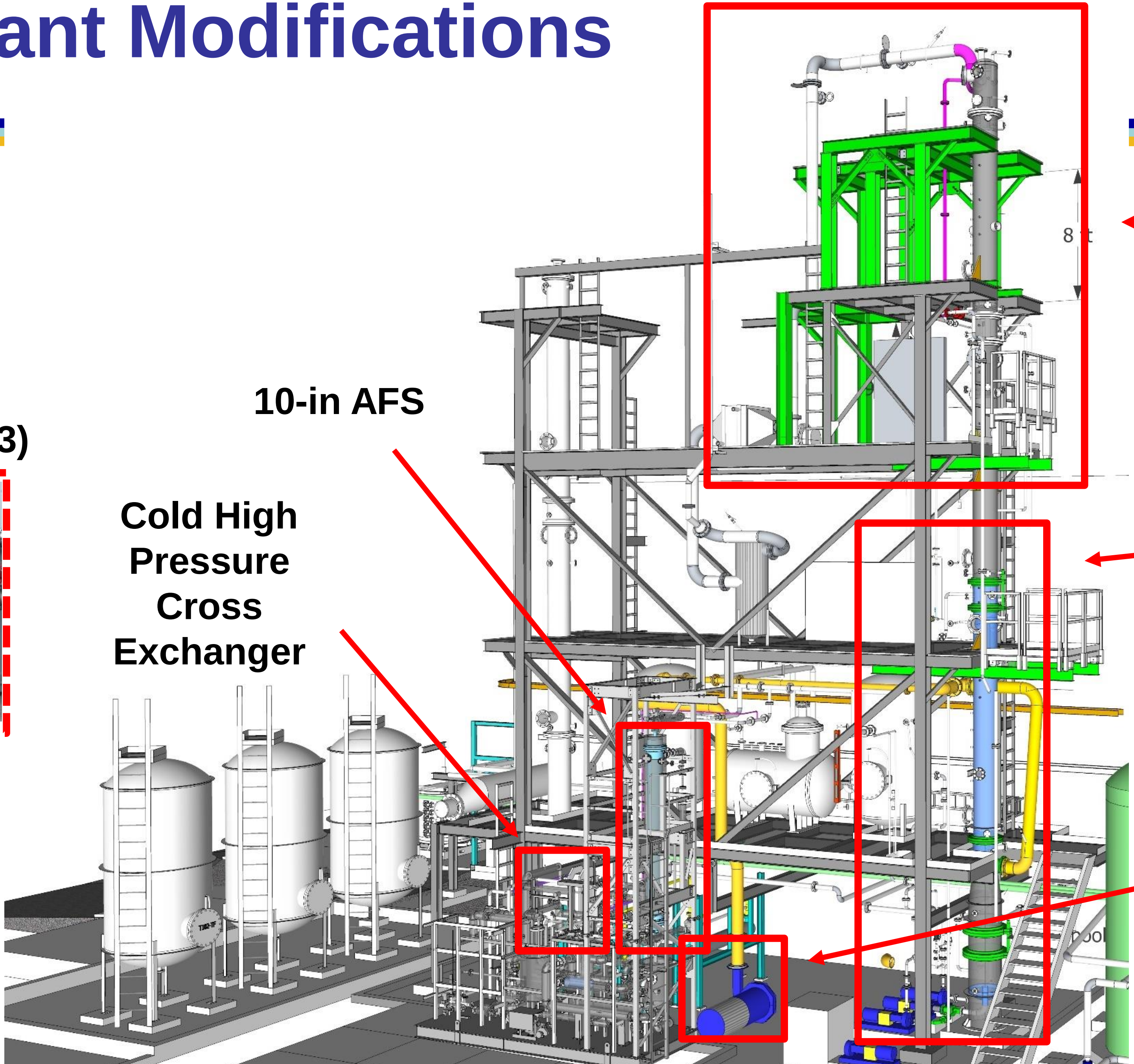
Pilot Plant Modifications

MTR Skid (BP3)

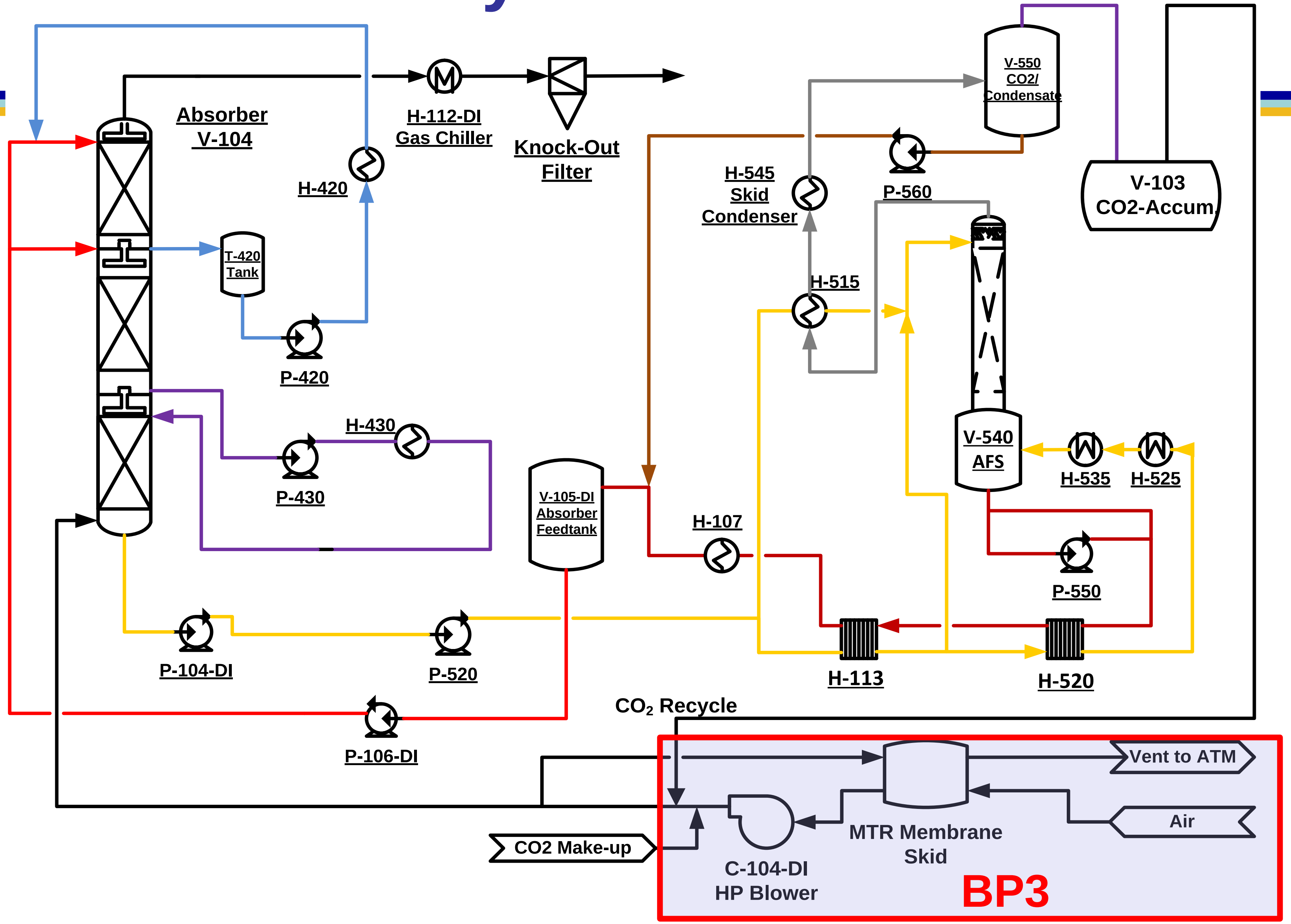


Structure modification

Absorber Column Ext & Intercooling skids

HP Blower (BP3)

SRP Pilot Plant Hybrid Flowsheet



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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^{o}C, 150^{o}C

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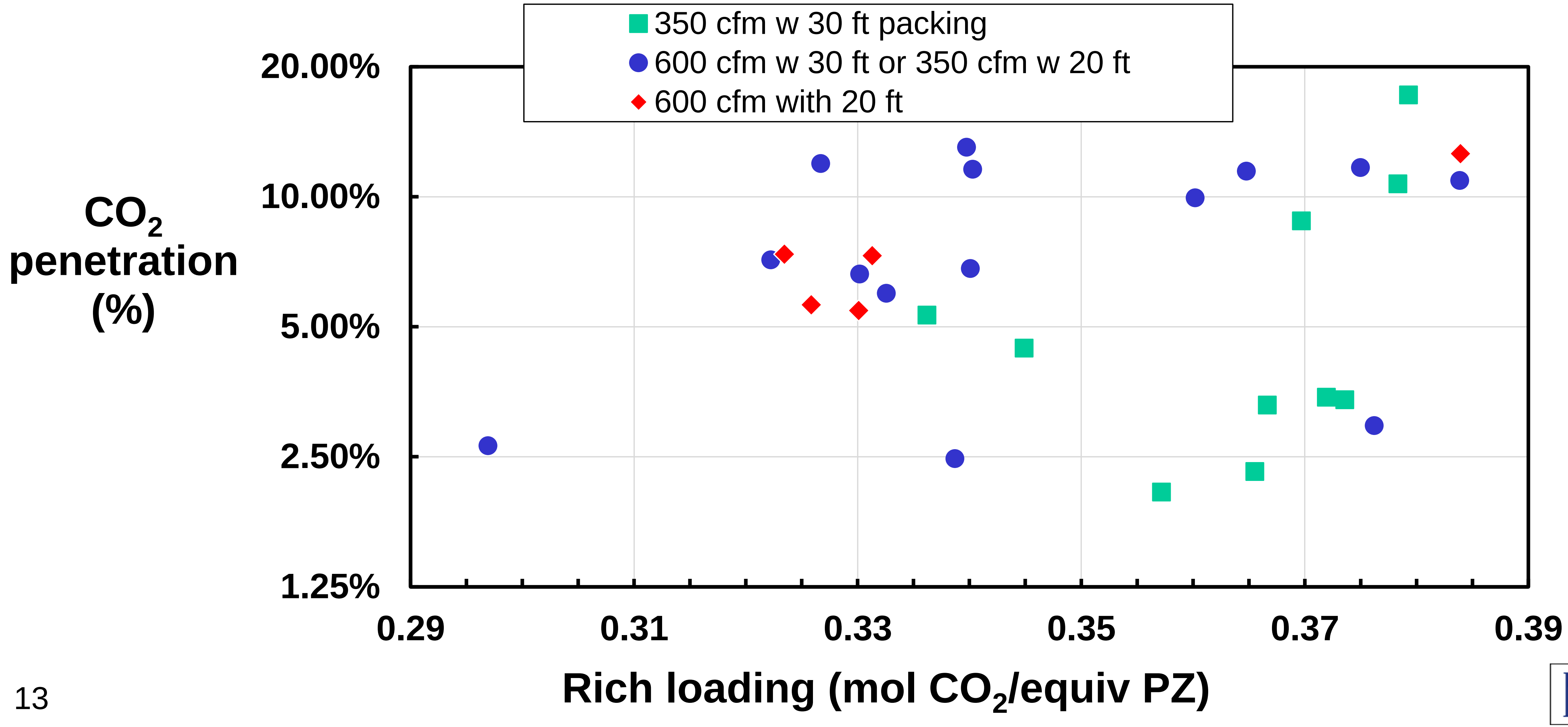
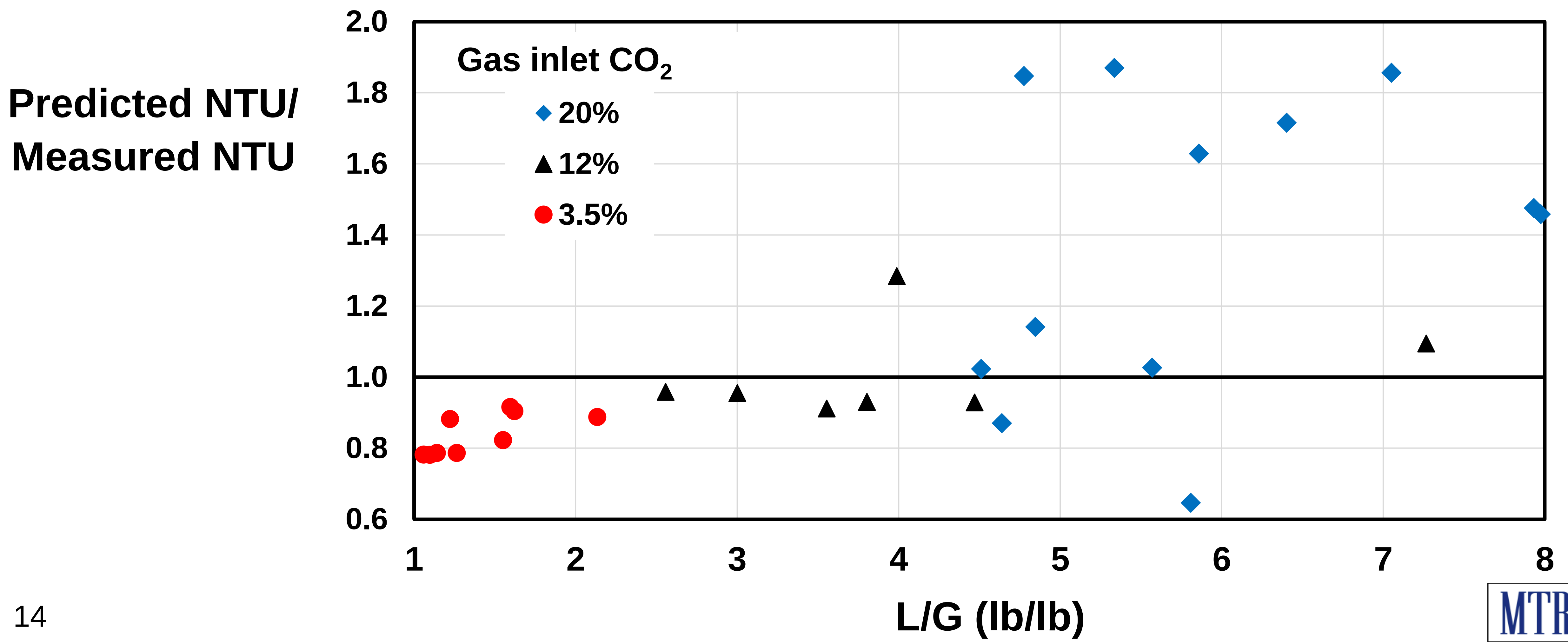
Absorber Performance



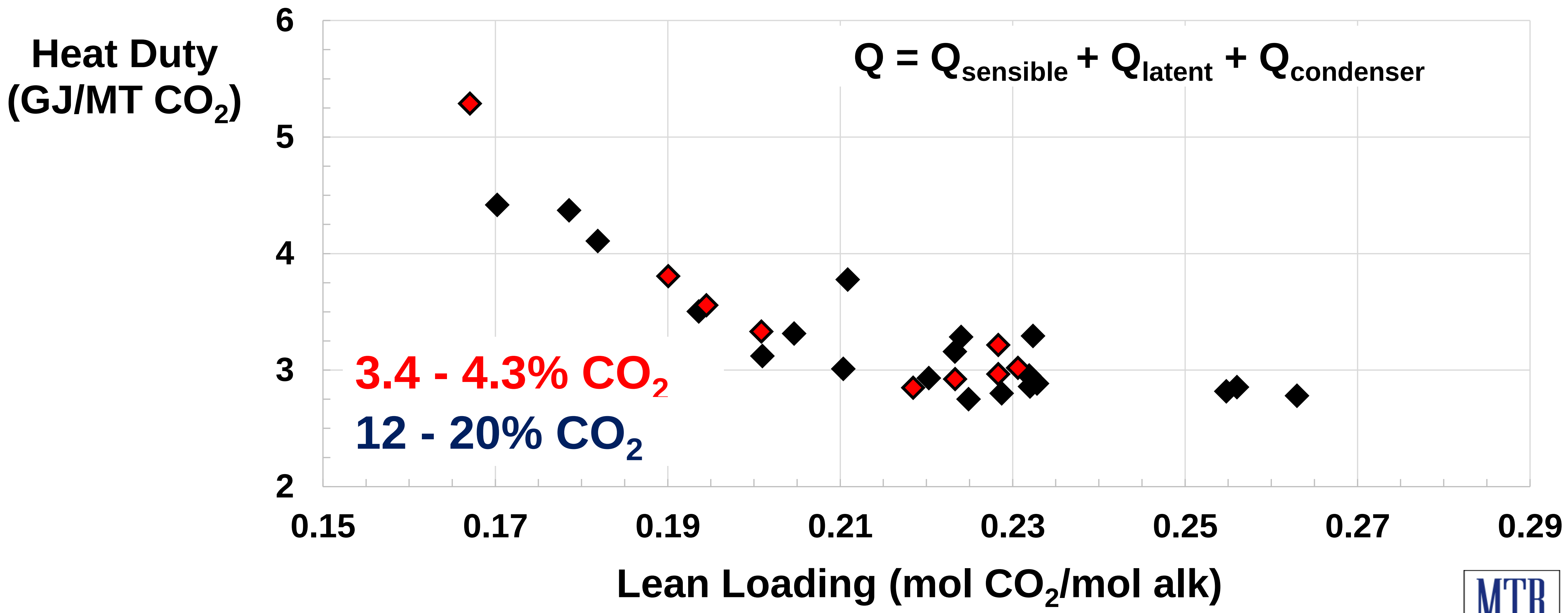
Aspen Plus® Model Predictions of CO_2 Removal by Independence

Failure at high L/G probably due to liquid distribution

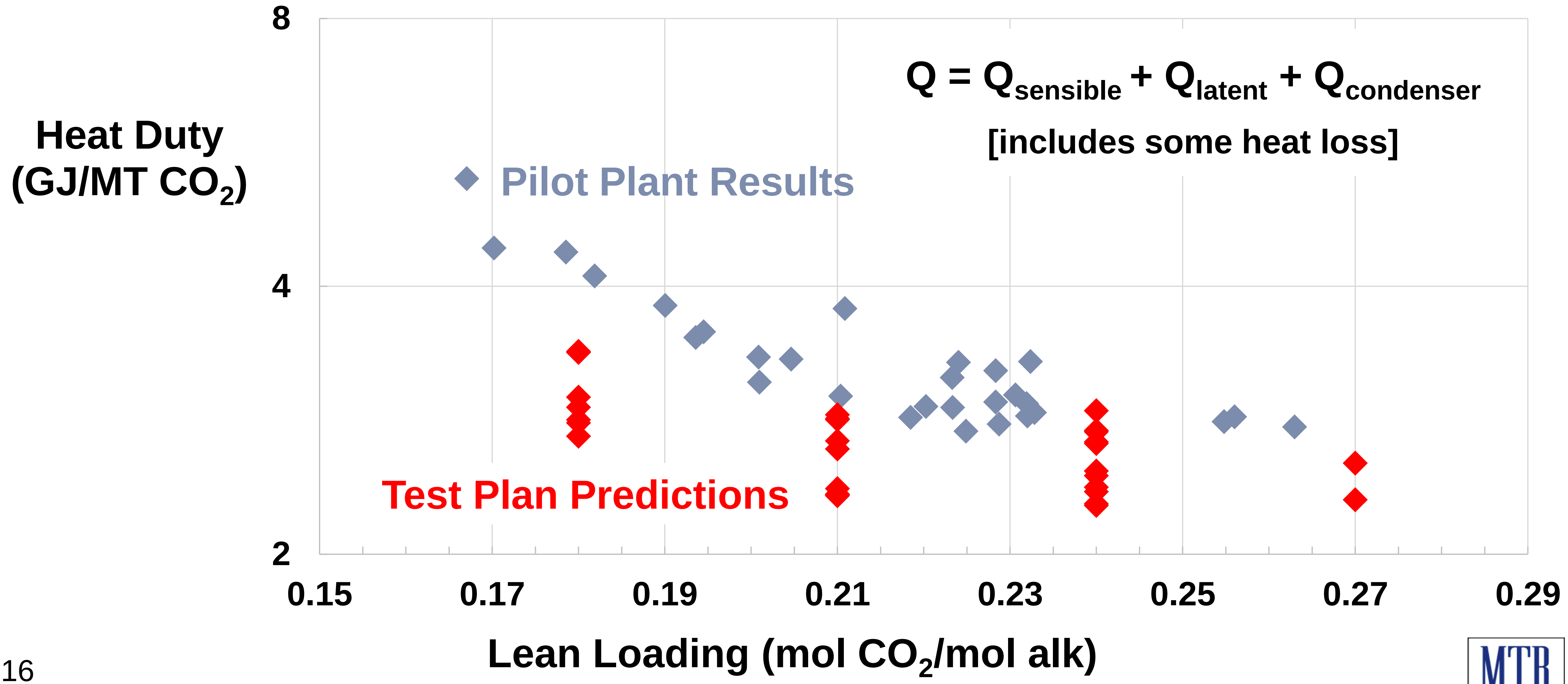


Heat Duty is Independent of CO_2 Concentration

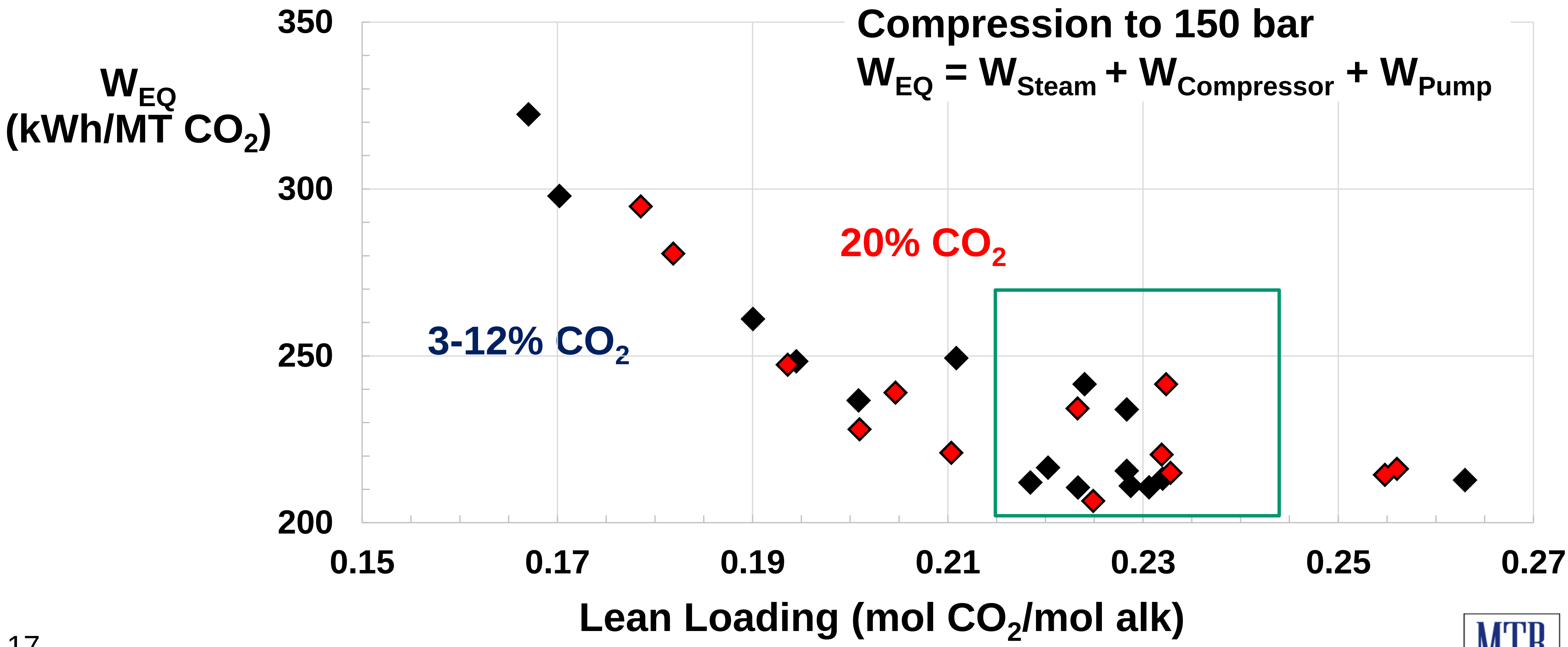
Minimum heat duty at 0.22-0.26 lean loading still includes some heat loss.



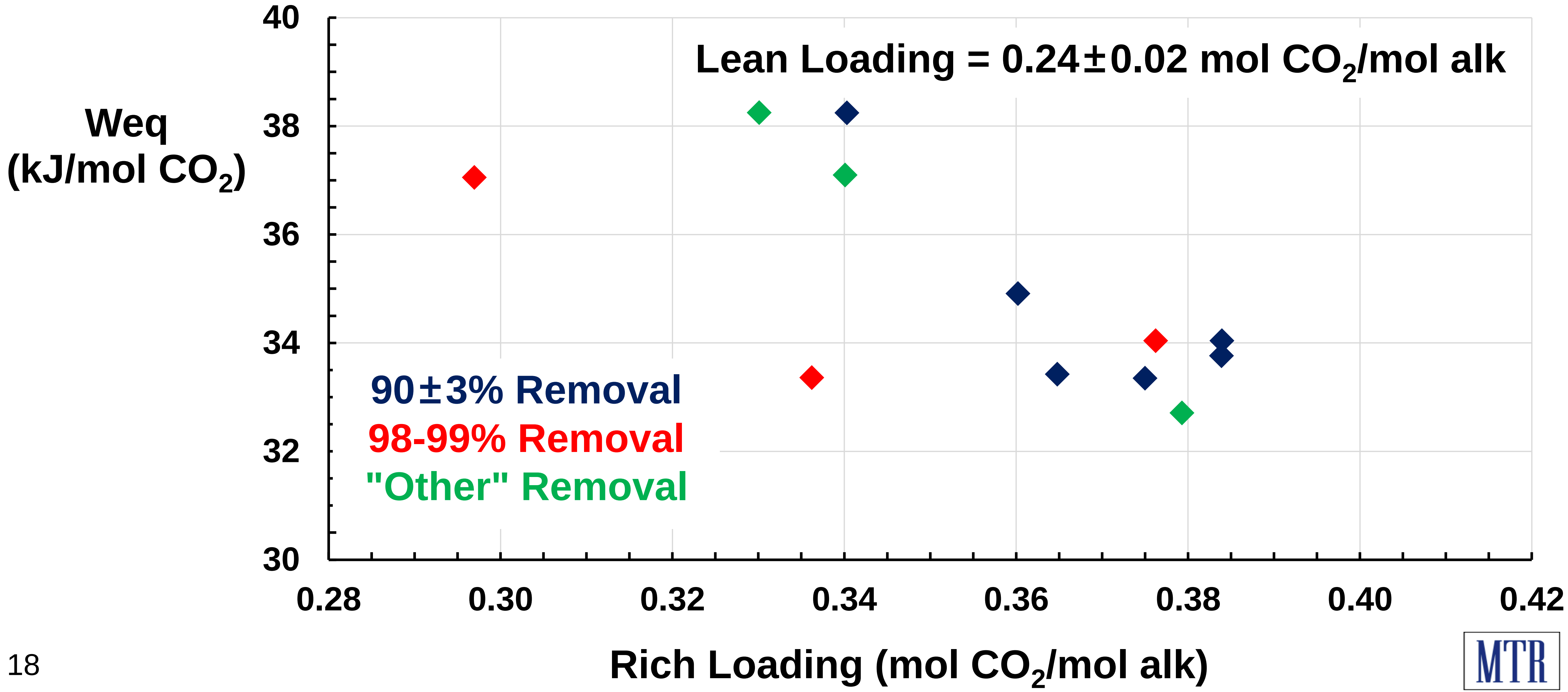
Initial Modeling Under Predicts Measured Heat Duty



Total Equivalent Work (including some heat loss)



Weq Near Optimum Depends on Rich Loading



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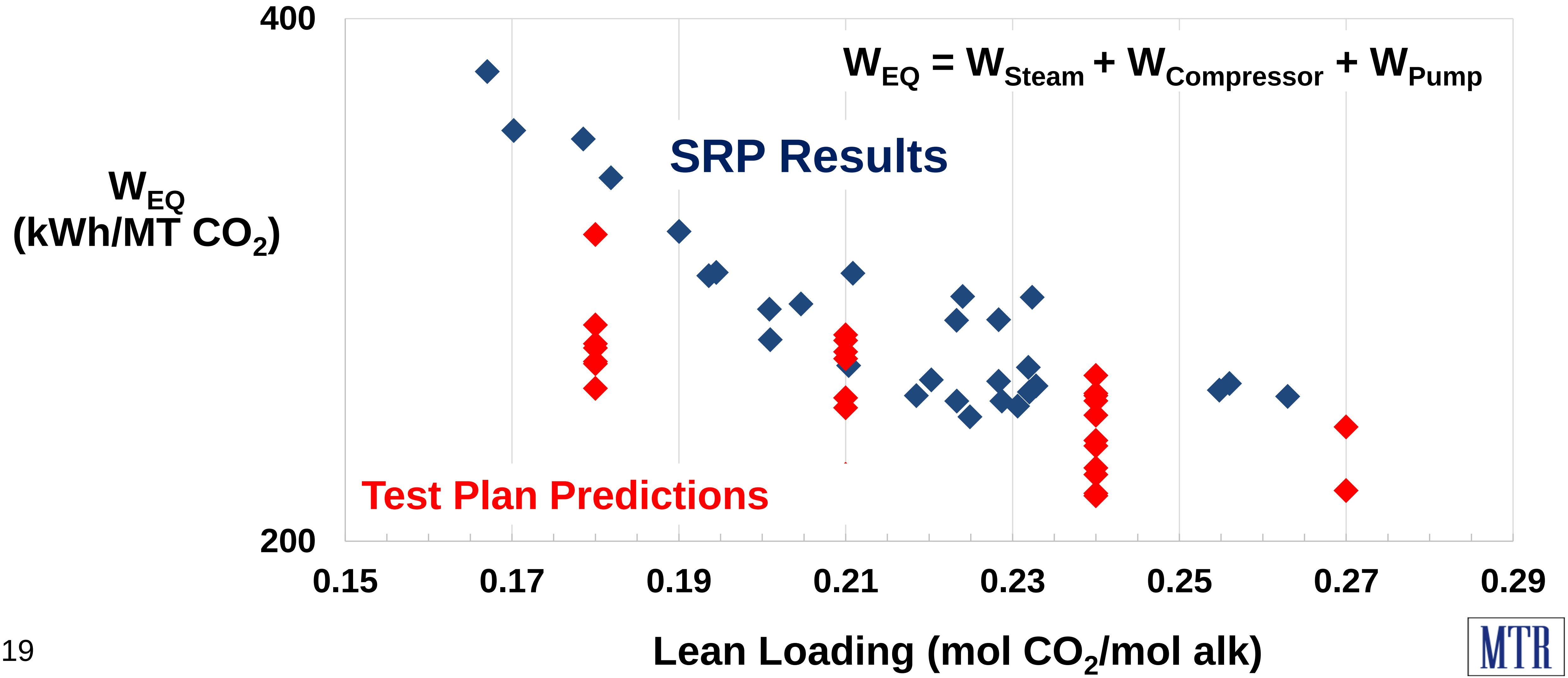
Initial Model Under Predicts Equivalent Work



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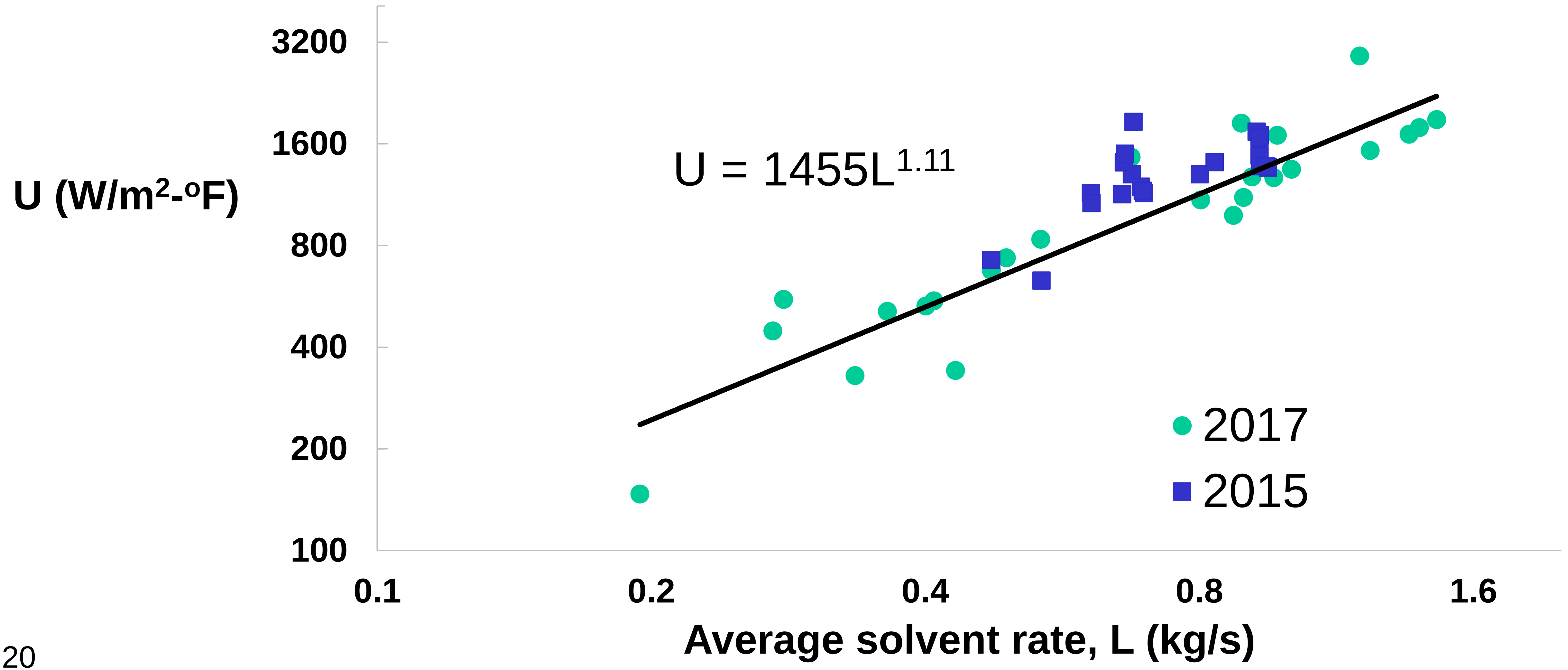
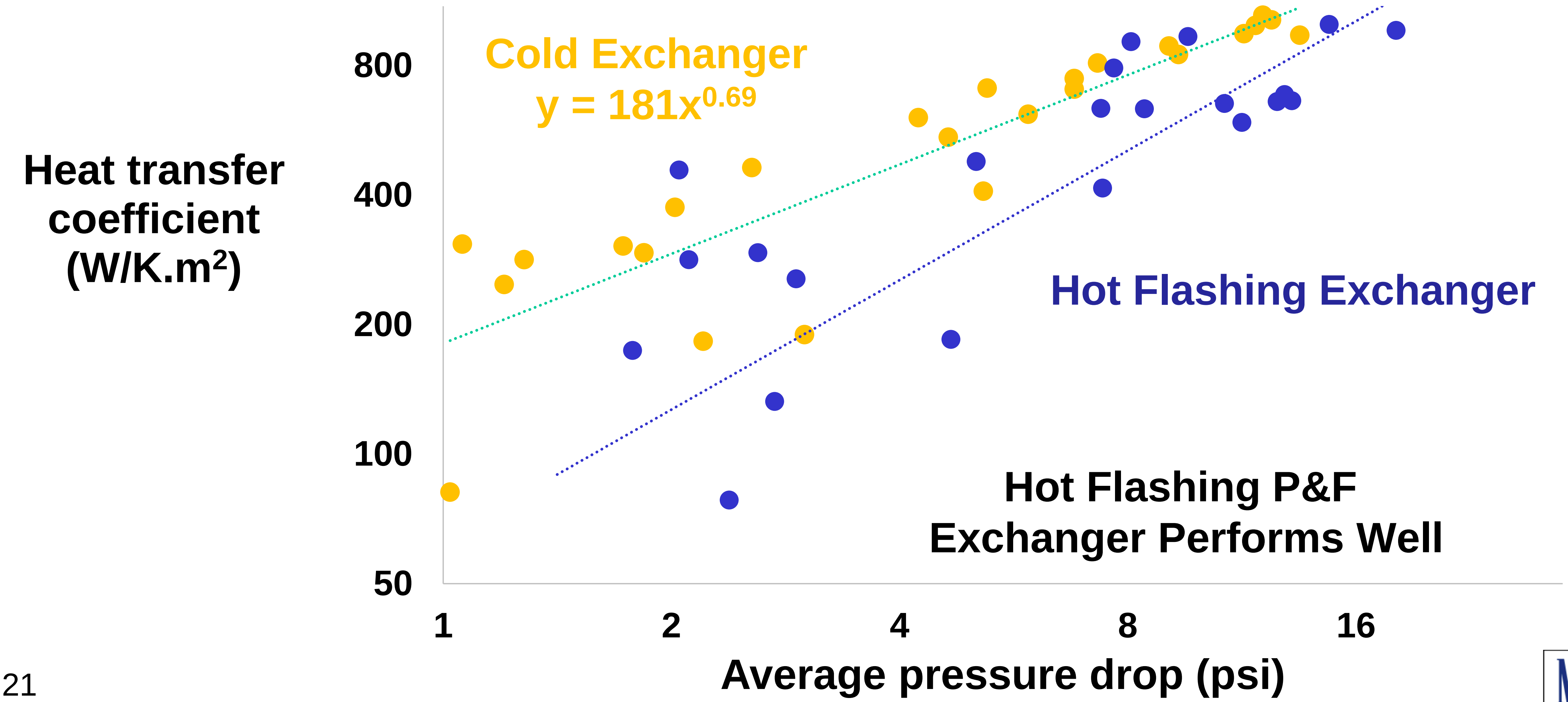
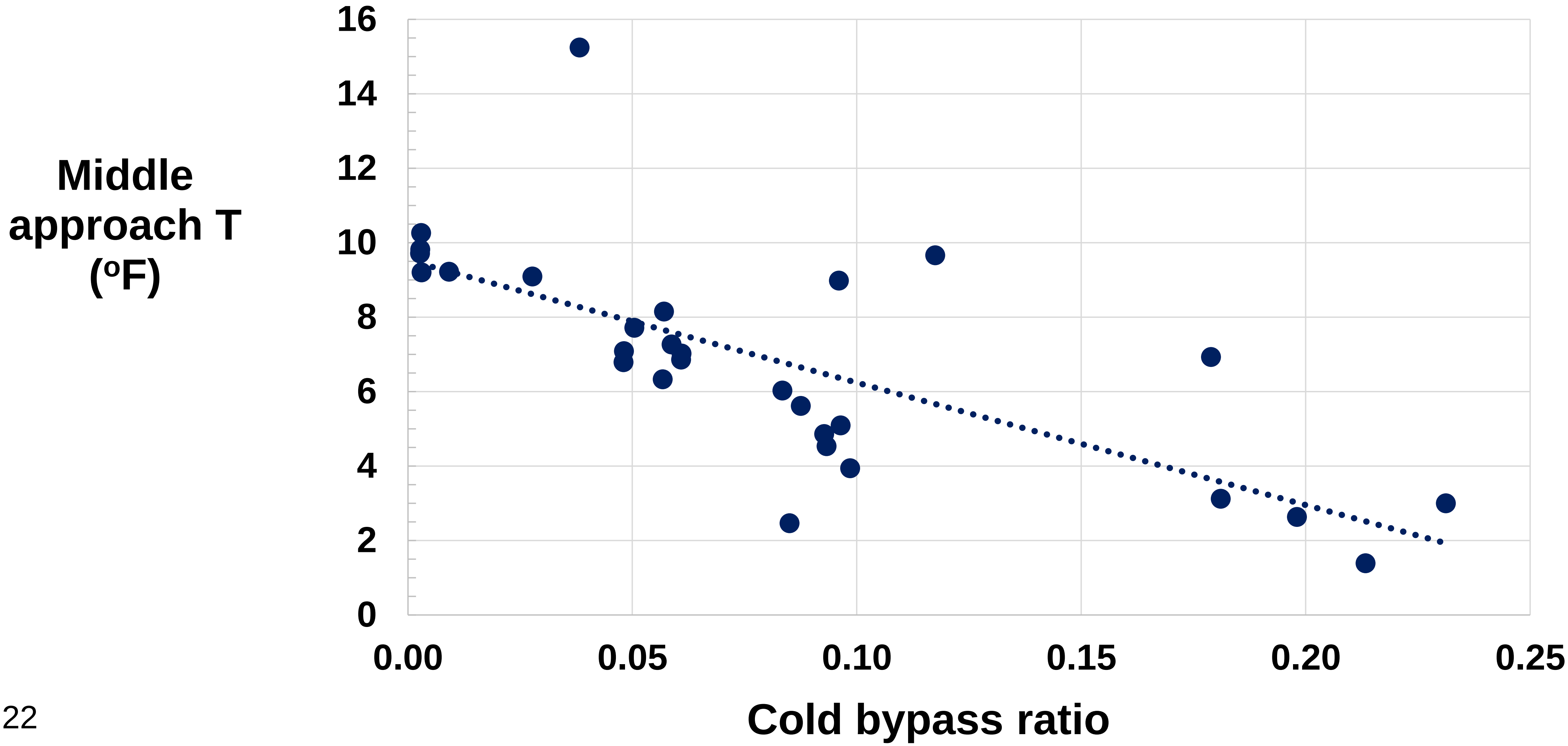
Performance of Cold Cross Exchanger



Pressure Drop Enhances Exchanger Performance



Cold Bypass Reduces Loss of Sensible Heat



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Piperazine Management Results and Observations

- Precipitation minimized by 5 m PZ (only one incident)
  - Instrument air loss + chilled water to IC = precipitation
  - Melted at 80^{o}C with heat gun
- Foaming Unexpected
  - Moderate unexpected absorber pressure drop at high gas flow rate
  - Reduced with the addition of antifoam
- Oxidation is acceptable
  - NH_3 emissions of 3 to 10 ppm, could still be reduced
- Aerosol requires high SO_3
  - PZ emissions doubled with 10 -100 ppm SO_3
- Corrosion of CS could be acceptable for stripper shell
  - 175 (SS), 325 (CS) mm/yr in hot lean PZ

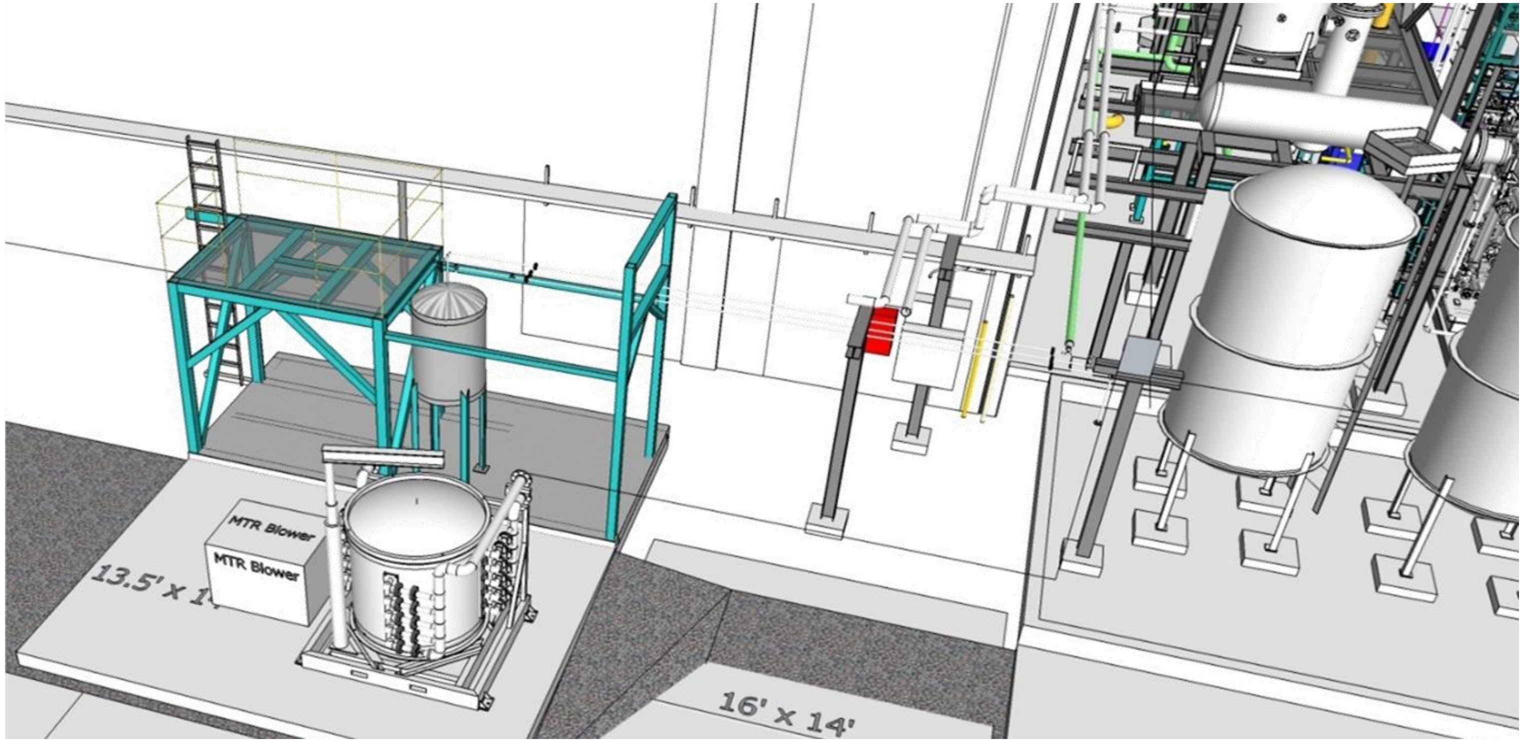
Conclusions from Simulated Hybrid Test Campaign

- 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
  - Liquid distribution is poor at high L/G
- Energy requirement independent of inlet CO_2
  - Heat loss needs more analysis
  - 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
- Hot flashing P&F exchanger provides reliable heat transfer

Next Steps

Budget Period 3

- Integrate MTR's plate-and-frame skid with UT Austin's SRP Pilot Plant
- Perform integrated testing campaign under hybrid-parallel conditions
- Develop TEA based on test results, final project report



Hybrid Project Team

- **DOE-NETL:**
  - Andy Aurelio (Federal Project Manager)
- **MTR:**
  - Brice Freeman (PI)
  - Richard Baker (Technical Advisor)
  - Pingjiao “Annie” Hao (Sr. Research Scientist)
  - Jay Kniep (Research Manager)
  - Tim Merkel (Dir. R&D)
- **U. Texas - Austin:**
  - Gary Rochelle (co-PI)
  - Eric Chen (Research Associate)
  - Frank Seibert (Sr. Research Engineer)
  - Darshan Sachde (Graduate Student)
  - Brent Sherman (Graduate Student)
  - Yue Zhang (Graduate Student)
  - Junyuan Ding (Graduate Student)