Piperazine Advanced Stripper (PZAS™) Front End Engineering Design (FEED)

DE-FE0031844

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2022 Carbon Management Research Project Review Meeting

Wed, 11:25

August 17, 2022

PZAS FEED outline

- Project structure and Objectives
- PZAS: a superior 2G process developed with DOE support
- Mustang Station: low energy cost, abundant space, pipeline for EOR
- Design Decisions
- Project costs: capital, annual, business case
- Design Basis and Opportunities to improve and add value
- Conclusions

The Objective: Accurate installed cost of PZAS™ on NGCC at GSEC Mustang Station

Complementary Benefits:

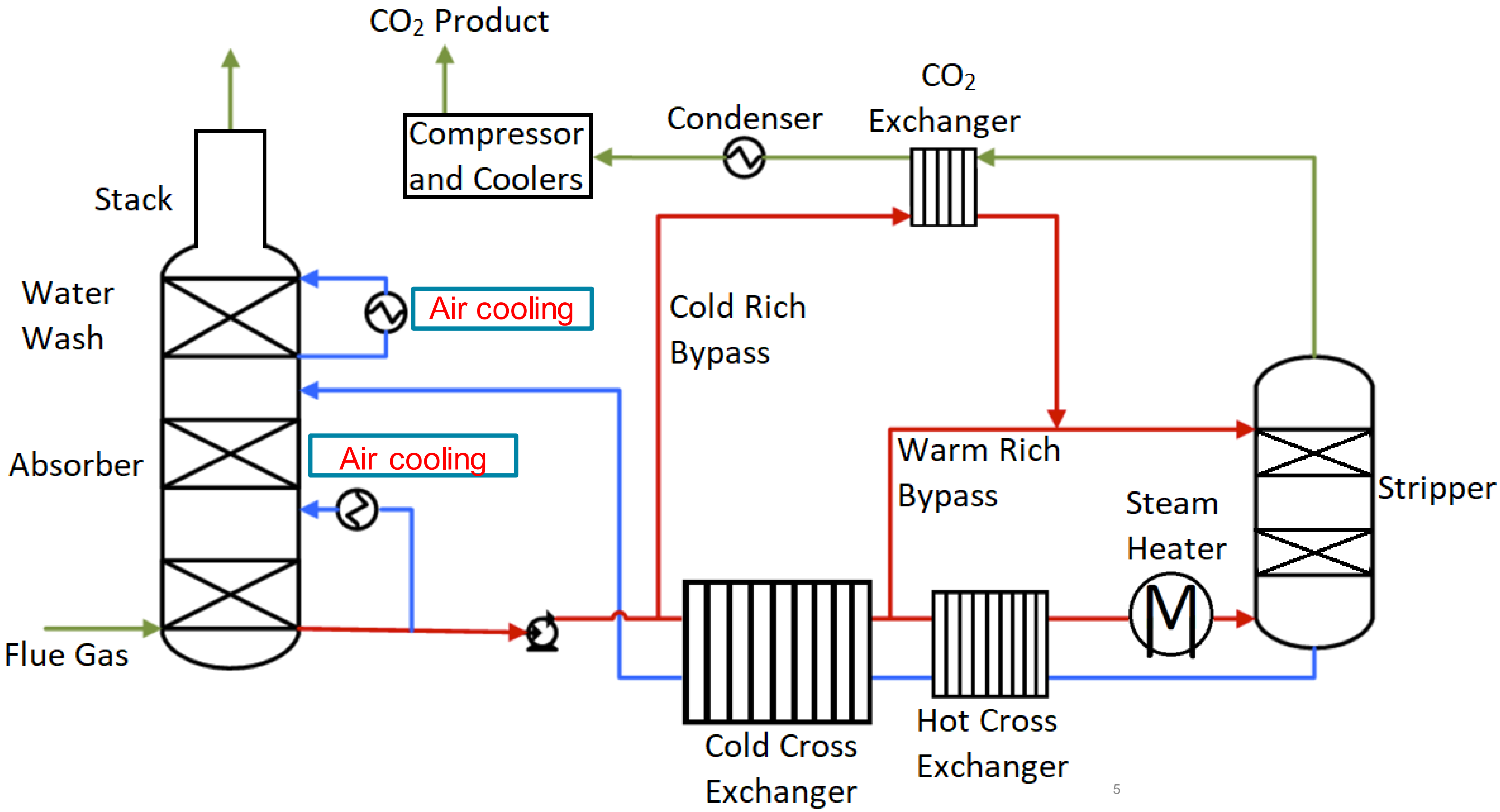
- Develop commercial project at Mustang Station
- Qualify PZAS for use on NGCC cogen
- Provide commercial cost detail
  - Optimize PZAS & other 2G capture processes
  - Guide R&D of capture technology

Program Overview

- Funding ($5.3 MM)
  - 4.2 MM DOE
  - 1.1 MM cost sharing - ExxonMobil, Total, Chevron
  - [0.3 MM from Honeywell UOP outside DOE]
- Performance Period: 10/2019 – 6/2022
- Project Participants
  - Golden Spread Electric Cooperative (GSEC) – Host
  - University of Texas at Austin (UT) – Modeling/ Technology
  - Trimeric – Process Engineering
  - AECOM – EPC

- Final Report Submitted on July 29, 2022

PZAS Process



PZAS development

comprehensive research & pilot plant demonstrations

- (2000-22) Research by 49 graduate students
  - Fundamental basis & Models
- (2006-09) UT Pilot of K_2CO_3/Piperazine (PZ), DE-FC26-02NT41440
- PZAS Pilot at 12% CO_2 for coal, DE- FE0005654
  - (2010-18) UT Austin
  - (2018) NCCC
- PZAS Pilot w 4% CO_2 For NGCC (CCP4)
  - (2016-18) UT Austin
  - (2019) NCCC

PZAS pilot at NCCC with CCP4 funding

- Heat duty 2.4 GJ/t
- Stripping at 302 F/90 psia with little degradation
- 90-95% CO_2 removal with 2 x 20 ft packing
- Pump-around intercooling of hot inlet gas
- Low PZ oxidation, <0.3 kg/t CO_2
- 304 SS up to 150°C
- PZ emissions < 1 ppm

Host Site - Mustang Station

Golden Spread Electric Cooperative

Denver City, TX

Southwest Power Pool

Greatest wind penetration of U.S. IPO's

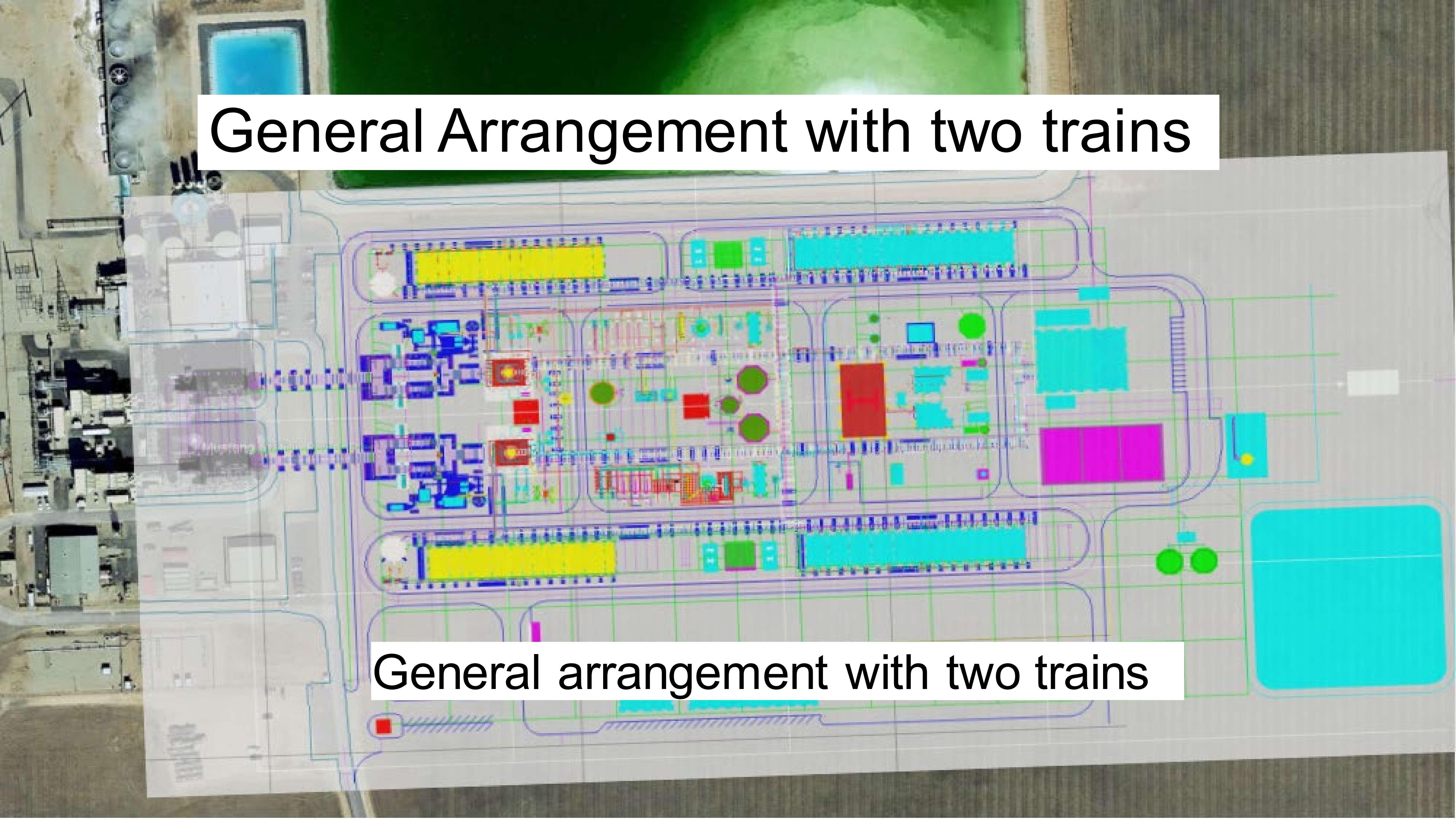
460 MW NGCC

2 GT/1 ST

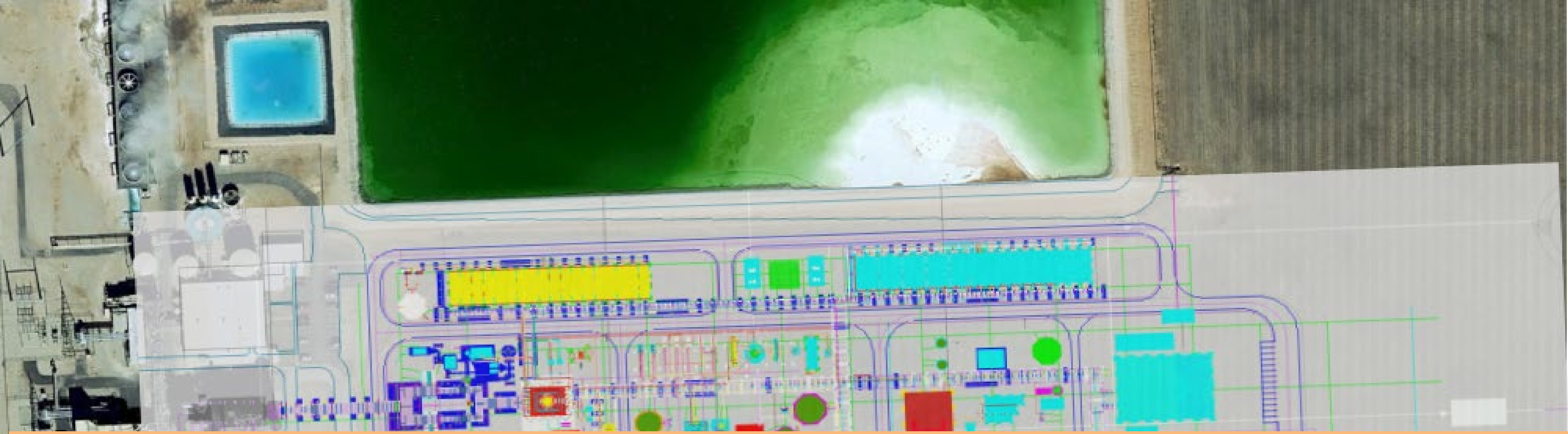
Changing perspective on the Mustang site

	Proposal, May 2019	FEED Report, July 2022
Space	Excellent	Spread out, but still good
CO_2 Disposal	Existing pipeline with EOR	Existing pipeline to storage site
Cooling	Available cooling tower & water	No water; air cooling required
Steam supply	Extract from existing turbine	Gas-fired boiler
Fuel cost	$2/MMBtu w pipeline access	$8/MMBtu
CO_2 design rate	126 t/hr	190 t/hr
Electricity cost	Wholesale LMP = $20/MWh	Retail? = $100/MWh
Load Factor	>52%, higher with good CO_2 value and low fuel cost	<52%, Lower with higher fuel cost & more renewables
Financing	<5% with Non-profit	10% IRR with private capital
Capital cost	$270 million	$725 million

General Arrangement with two trains



General arrangement with two trains



- Each train treats all flue gas from 1 GT and one new gas boiler
  - Turndown to match Mustang Station operation
  - Sequenced, isolated maintenance
  - Off-site fabrication of some large equipment (strippers)
  - Sequenced construction
  - Reasonable absorber size

Other Design Decisions

- 90% CO_2 removal at median ambient T
- Air cooling
  - Absorber intercooling
  - Water wash with 24-hour water balance in summer
- One package boiler for each train to provide steam for stripping
  - Boiler flue gas treated in absorber
- Moderate energy requirement by design (3.0 GJ/t CO_2)
  - 5 plate-and-frame exchangers per train
  - (2.5 GJ/t could be obtained with 10 exchangers/train)
- One 3-stage reciprocating compressor for each train
  - Air intercooling

Project Costs and Business Case

Total Overnight Cost

	Cost, $Million
Total Direct Cost	384
Total Indirect Cost	93
Engineering	37
Insurance, Taxes, Bonds & Permits	19
Contingency	105
Contractor Overhead & Profit	60
Project Total Cost	**698**
Owner's Cost	27
Total Overnight Cost	**725**

Direct costs (total DC = $384 million)

	Cost, $M	% of total	Potential Savings
Air Cooling Systems	90.0	23	Use water
Absorber	37.0	10	Use Carbon Steel
CO_2 Compression	24.2	6	
Ductwork, Dampers, Fans	21.6	5.6	Shorten ductwork
Solvent Reclaiming	19.6	5.1	Revisit
Stripper, CO_2 Conditioning	17.4	4.5	
Steam Generation	14.1	3.7	Use steam extraction
Solvent Heat Exchangers	9.5	2.5	Use more exchangers
Solvent Storage	6.5	1.7	

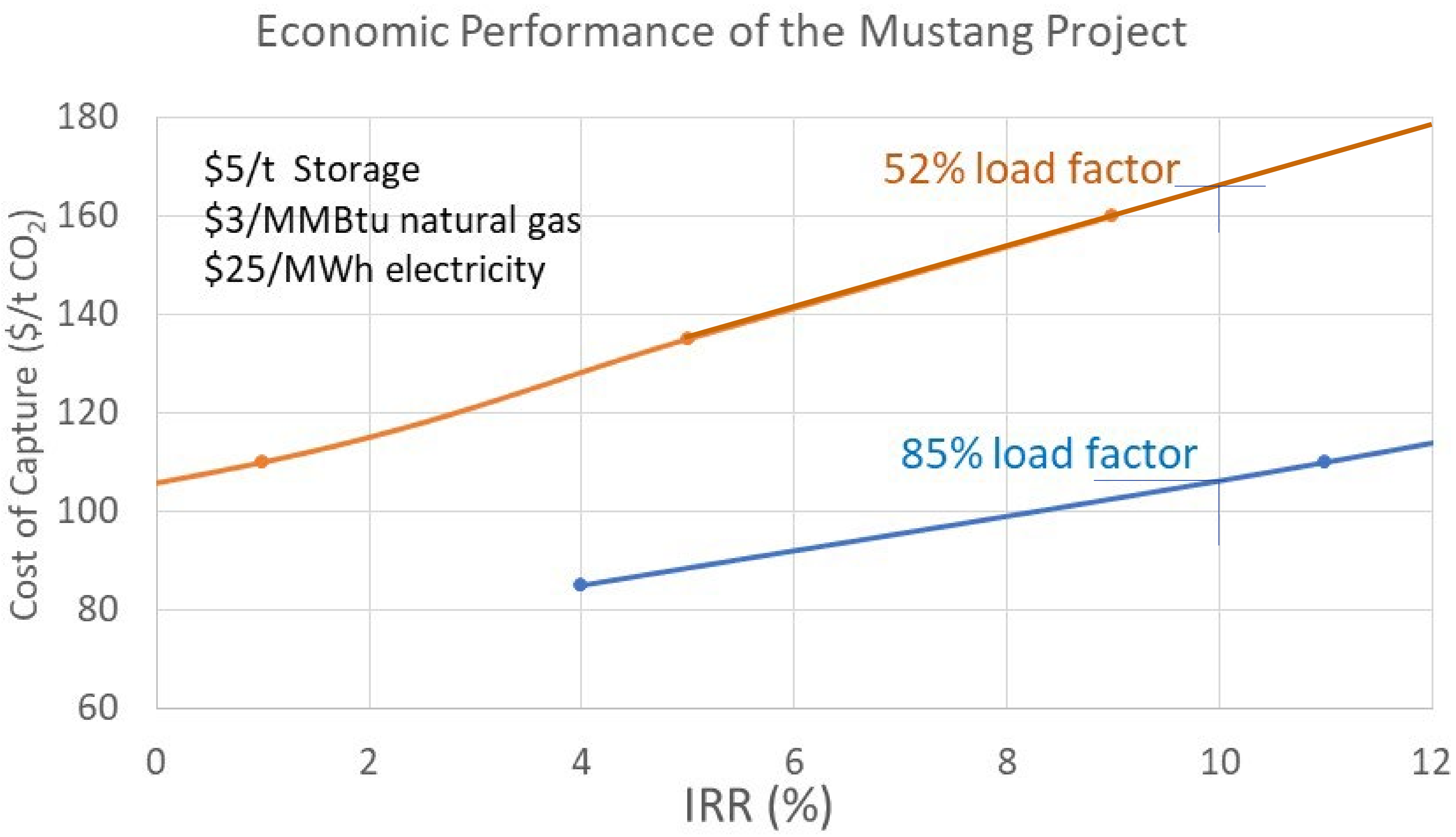
Annual Variable Operating Costs @ 52% LF	$21.5 MM
Natural Gas (417 MMBtu/hr) @$3/MMBtu 15 % increase in total NGCC fuel rate [Use more exchangers to reduce heat duty] [Extract Steam from existing turbine]	9.5
CO_2 Tariff for transport and storage ($5/t)	4.3
Electricity (33 MW) @$25/MWh 7 % decrease in net power from NGCC [Replace Air Cooling with Cooling Water]	3.8
Piperazine solvent	2.0
Other (Caustic, Water, TEG, N2, waste)	1.9

Annual Fixed Operating Costs	$32.6 MM
Property Taxes and Insurance (Year 1) @ 2.5% [Negotiate for local tax break]	18.2
Maintenance Labor & Material	9.9
Operating Labor	3.3
Admin & Support Labor	1.2

Net Cash Flow at base case conditions

52% Load Factor, $3/MMBtu, $25/MWh

	$million
Income from 45Q @ $85/t	64
Fixed annual costs	-32.6
Variable annual costs	-21.5
Net Cash Flow	+9.9


Economic Performance of the Mustang Project
$5/t Storage
$3/MMBtu natural gas
$25/MWh electricity
52% load factor
85% load factor
Cost of Capture ($/t CO₂)
IRR (%)
180
160
140
120
100
80
60
0
2
4
6
8
10
12

Takeaways

– Completed FEED
  - Defines a technically feasible design for Mustang
  - Capital cost of $725 million
  - Cost of capture for 10% IRR is $105/t CO_2 (w $3/MMBtu, 85% LF)

– Major opportunities for enhanced performance and reduced cost
  - Steam extraction from the existing steam turbine
  - Additional absorber packing to get > 97% CO_2 removal, approaching C neutral
  - Additional exchanger area to reduce natural gas consumption

– Detailed, public FEED provides basis for an NGCC or Cogen demo
  - Ideal site: cooling water, steam extraction, low renewables, high load factor

Future work

- Further development at Mustang is not expected
- Honeywell UOP design/marketing to all applications & sites with proprietary knowhow
- Honeywell actively developing opportunities for a potential FOA for demonstration
- UT Modeling to make public use of FEED results – funded by CCSI2, TxCMP, et al.
  - Optimize operations at GSEC with the existing design
  - Optimize design at GSEC with estimates for improvements
  - Develop & optimize design for NGCC at other sites, including stakeholder sites
    - NGCC at ideal conditions - cooling water, steam extraction, low renewables, high load factor
    - CoGen
  - Develop and optimize designs of PZAS for other applications

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Acknowledgements

This work was performed with funding from the U.S. Department of Energy under Co-operative Agreement DE-FE0031844. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Additional funding was received as cost-sharing from ExxonMobil, Chevron, and TotalEnergies.

The authors are grateful to Golden Spread Electric Cooperative for providing the site for this study.

Other Contributors

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TRIMERIC Corp Andrew Sexton, Katherine Dombrowski, Duane Myers, Michael Marsh, Brad Piggott, Rosalind Jones

Kronos Management, LLC: Jeff Lee

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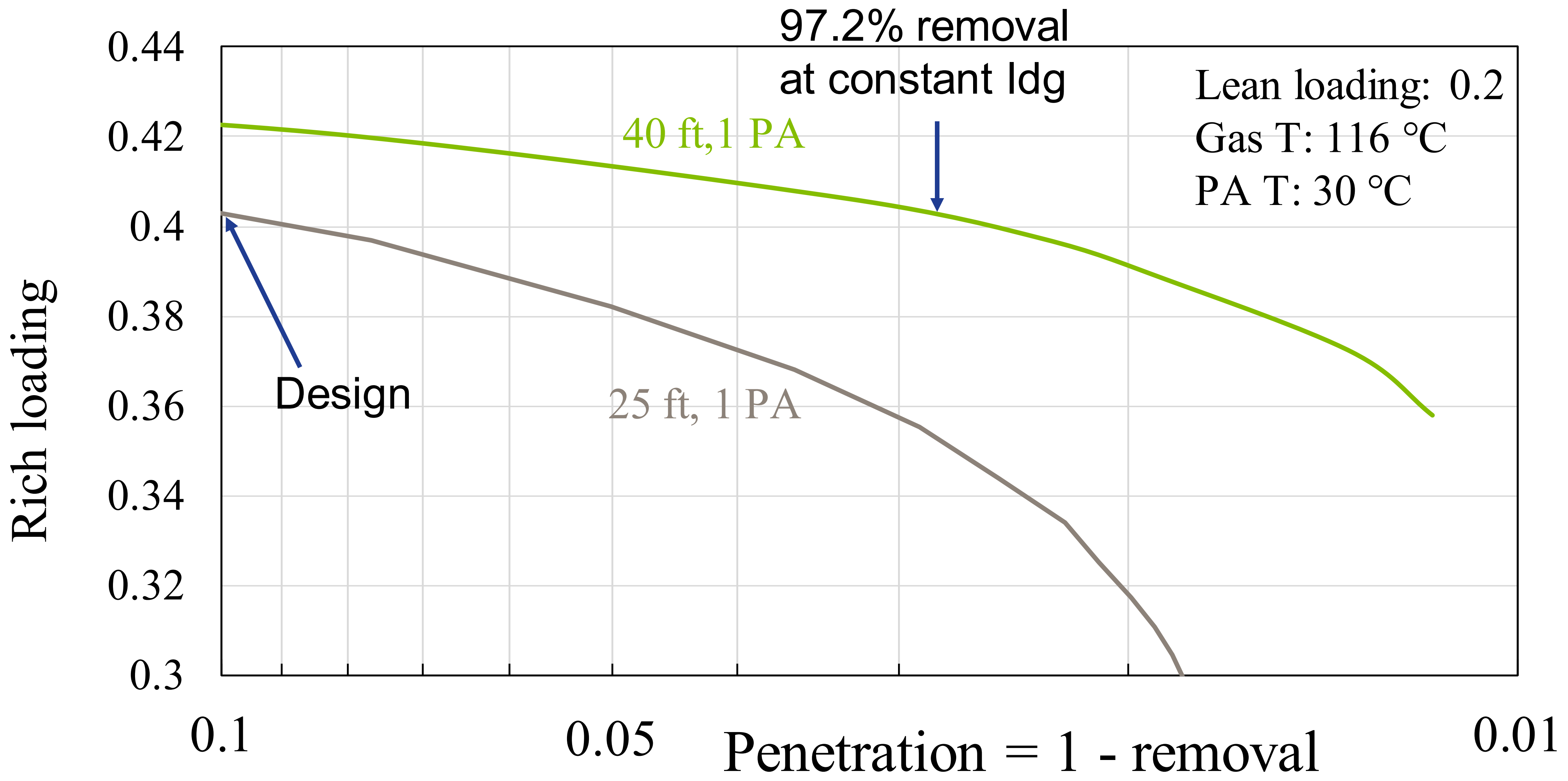
High Removal with PZAS at Mustang



Chronology of PZAS FEED

– August 19, 2019	– Proposal accepted for contract negotiation
– January 22, 2020	– Meeting with GSEC in Amarillo
– November 3	– Process Design Package
– March 14, 2021	– Draft Equipment List
– October 28	– Model Review
– November 18	– Completion of Capital Cost Estimate
– March 31, 2022	– Draft FEED Report

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Organizational Chart

- **DOE-NETL Contracting Officer** — Krista Hill
  - **Project Manager** — Gary Rochelle - UT
    - Host Site — Mustang Station
    - Cost Share — Exxon/Chevron/Total
    - Task 1 Management — Gary Rochelle - UT; Bill Steen - AECOM
    - Task 2 Process Design — Andrew Sexton, Trimeric
    - Task 3 Process Modeling — Fred Closmann, UT
    - Task 4 Env. Permitting — Steve Jelinek, AECOM
    - Task 5 Discipline Engineering — Bill Steen, AECOM
      - Task 5 Engineering — Scott Bryan - AECOM
        - Task 5.1 – Process — Andrew Sexton & Katherine Dombrowski, Trimeric; Fred Closmann - UT; Karen Farmer - AECOM
        - Task 5.2 Mechanical — Sarah Douglass, AECOM
        - Task 5.3 Electrical — Mike Hachem, AECOM
        - Task 5.4 Int. and Controls — Jim Surber, AECOM
        - Task 5.5 Civil/Structure — Julie Joyo, AECOM
        - Task 5.6 Fire Engineering — TBD, AECOM
        - Task 5.7 Pipeline/Compressor — Brad Piggott - Trimeric; Jeff Stephens - AECOM
    - Task 6 Constructability — Bill Steen, AECOM
    - Task 7 Cost Estimate — Bill Steen, AECOM
    - Task 8 Economic Analysis — Andrew Sexton, Trimeric

Opportunities and Constraints at Mustang Station

- Ideal ample space at the site
- Competitively priced natural gas
- CO_2 Pipeline & EOR + potential storage
- Summer Ambient T (cool nights, hot days)
- Cooling water not available for capture system
- Competitive power grid (SPP) with renewables

  Greatest wind penetration of U.S. IPO’s