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

DE-FE0031844

Gary T. Rochelle, Principal Investigator

Department of Chemical Engineering, The University of Texas at Austin

Krista Hill, NETL Project Manager

2022 Carbon Management Research Project Review Meeting

Wed, 11:25

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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:

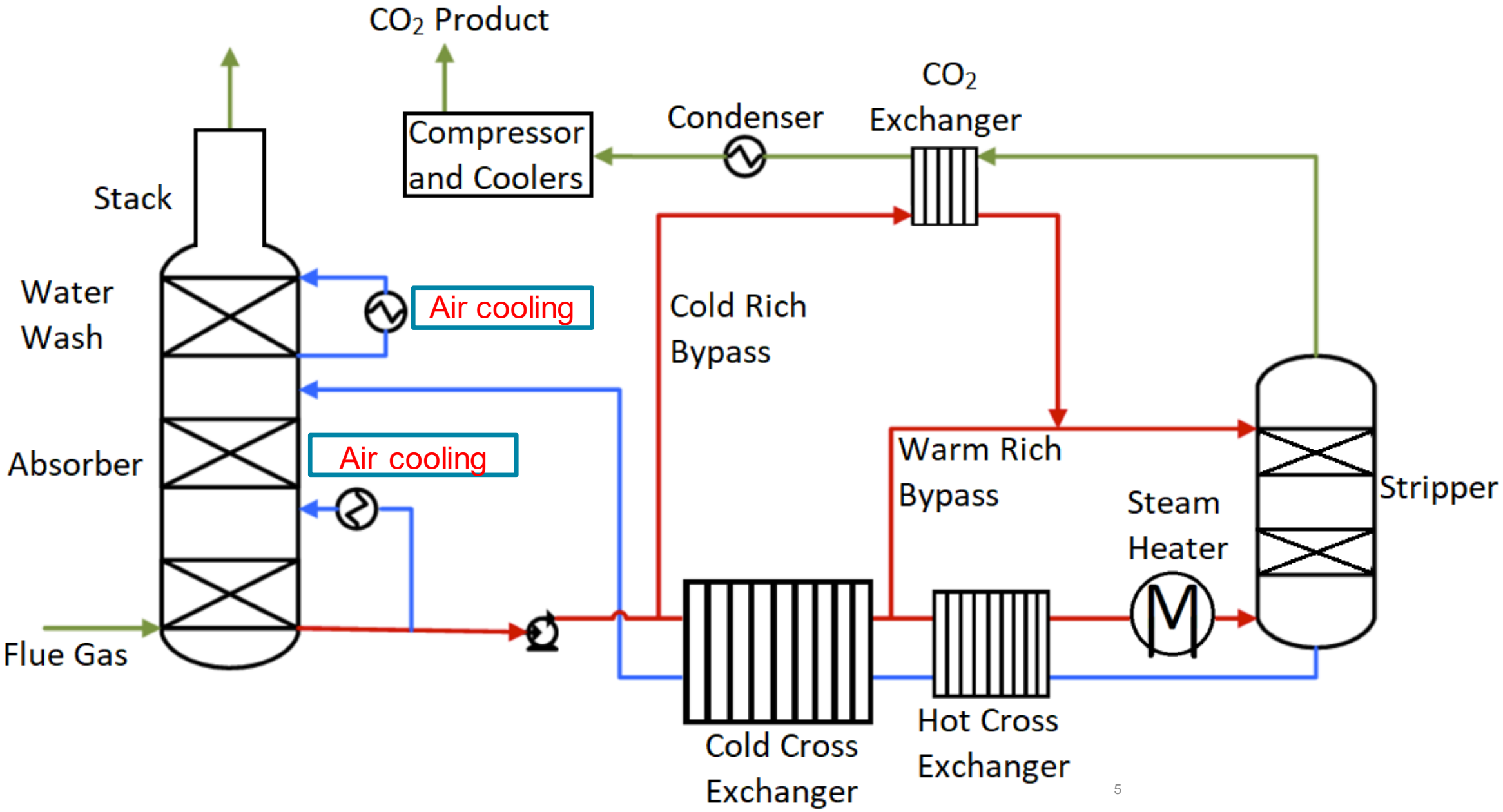
- Develop commercial project at Mustang Station
- Qualify PZAS for use on NGCC cogen
- Provide commercial cost detail
  - Optimize PZAS & other 2G capture processes
  - Guide R&D of capture technology

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

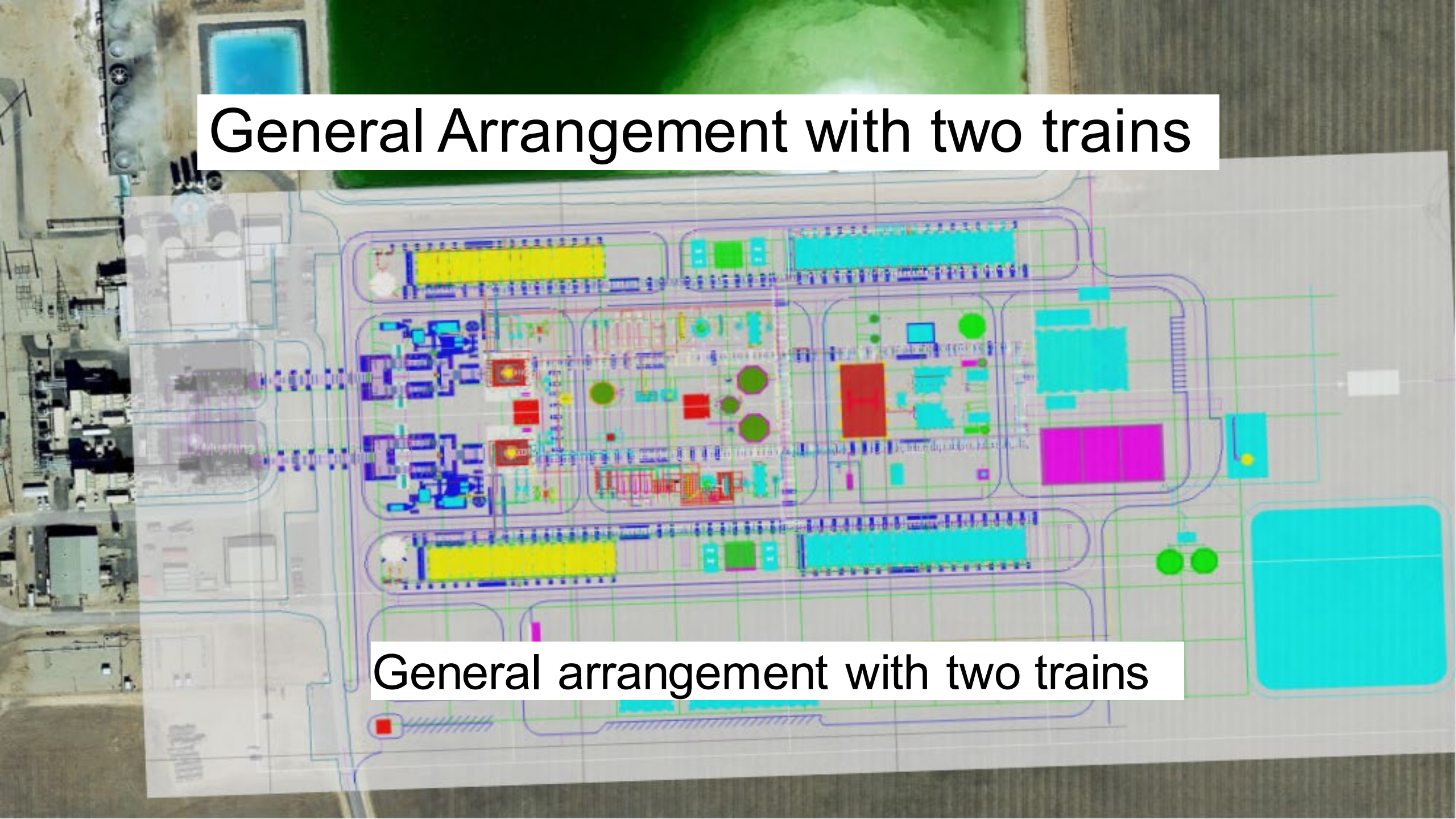
460 MW NGCC

2 GT/1 ST

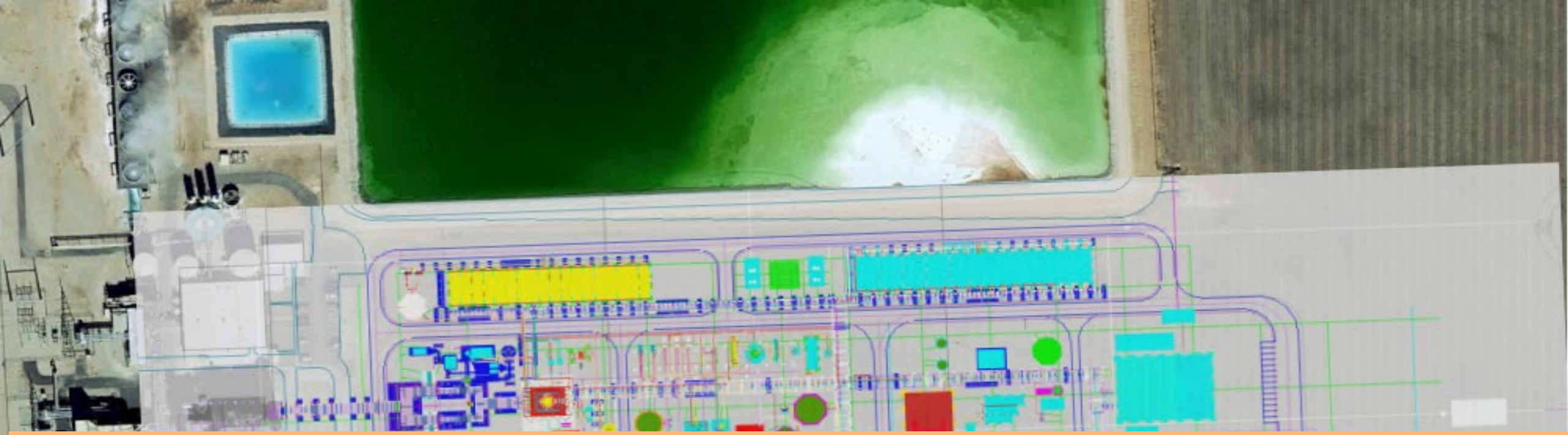
Changing perspective on the Mustang site

	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	

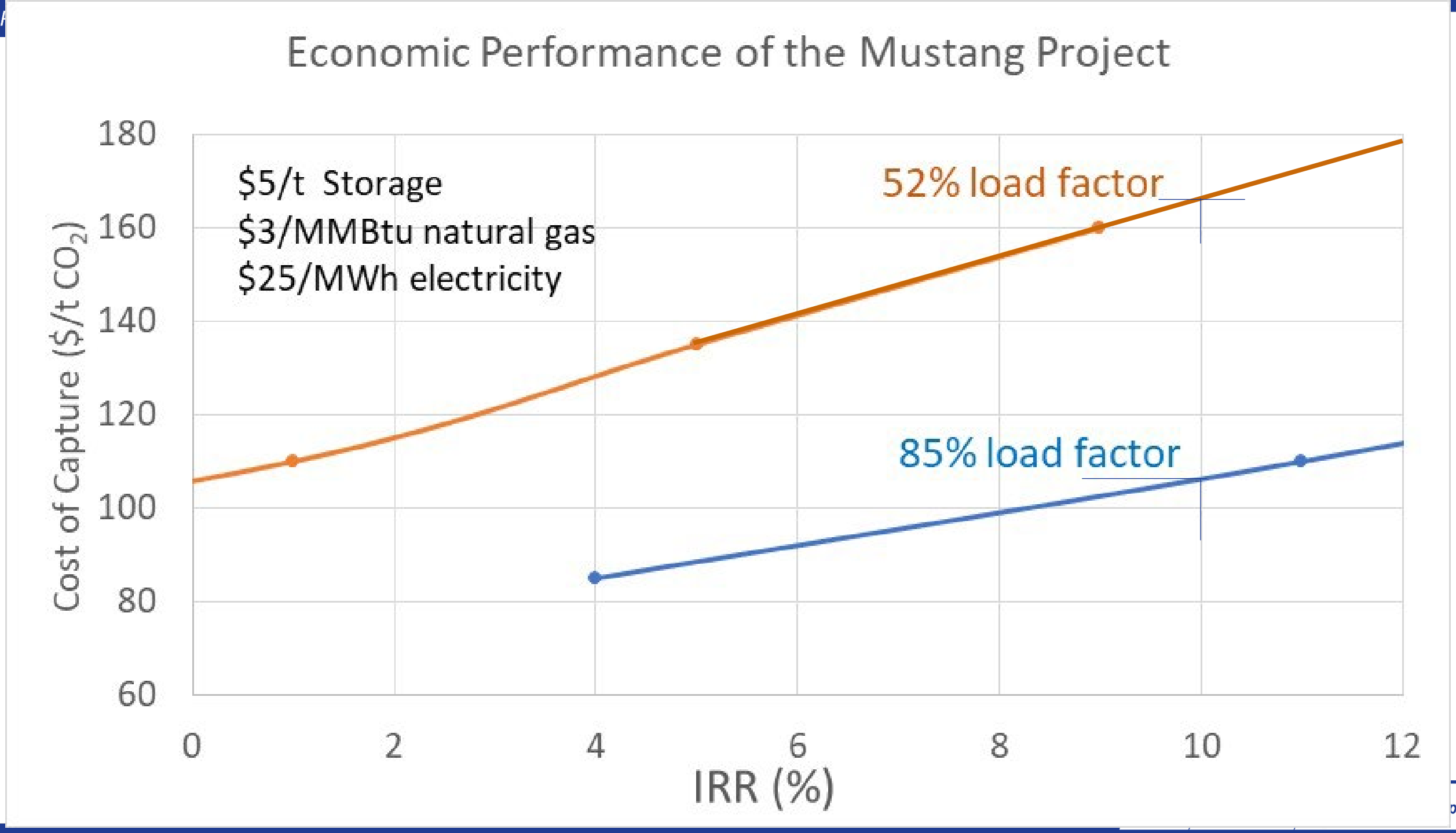
Annual Variable Operating Costs @ 52% LF	$21.5 MM
Natural Gas (417 MMBtu/hr) @$3/MMBtu 15 % increase in total NGCC fuel rate [Use more exchangers to reduce heat duty] [Extract Steam from existing turbine]	9.5
CO_2 Tariff for transport and storage ($5/t)	4.3
Electricity (33 MW) @$25/MWh 7 % decrease in 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)
180
160
140
120
100
80
60
0
2
4
6
8
10
12
IRR (%)

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

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Other Contributors

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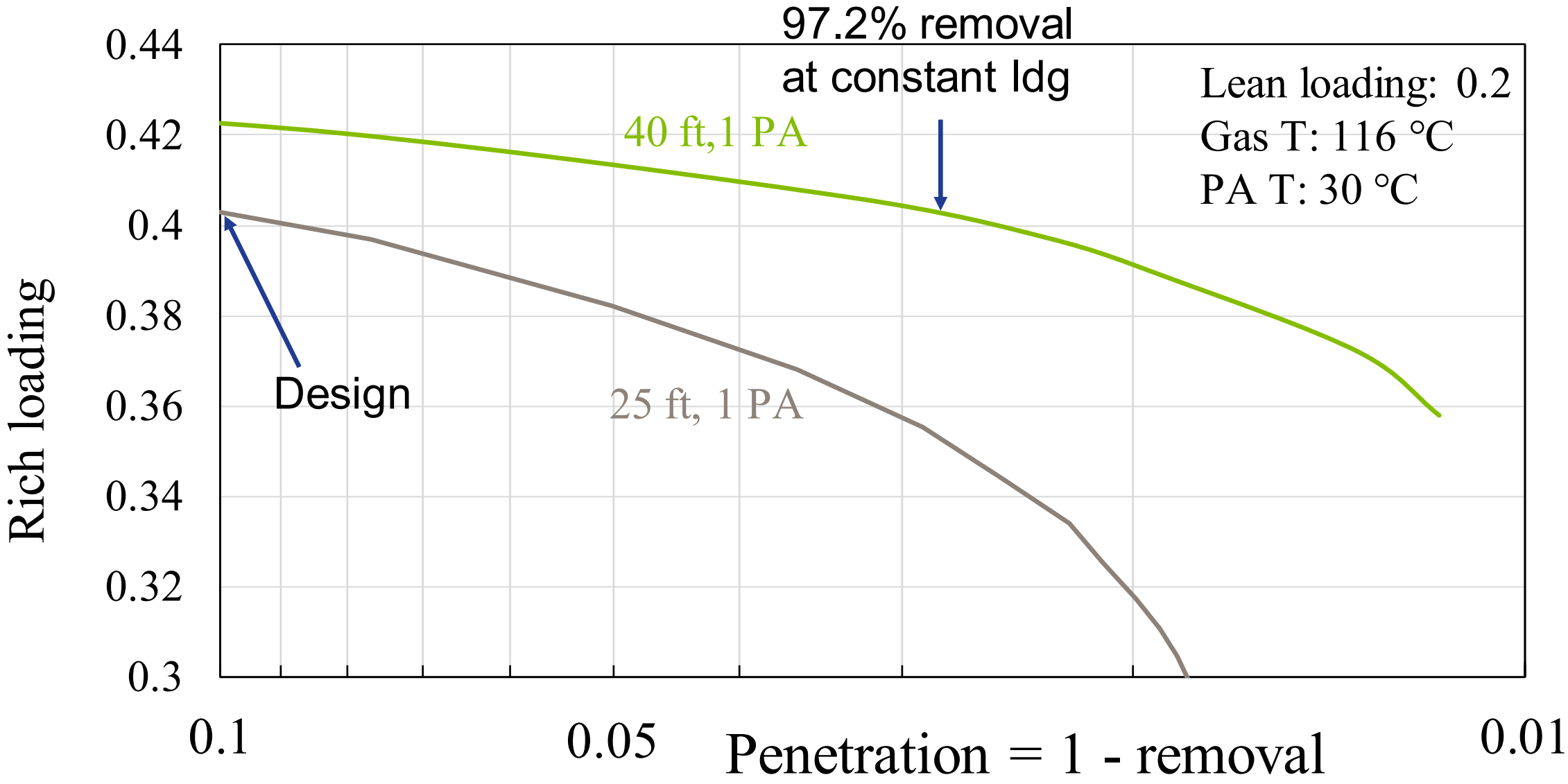
AECOM

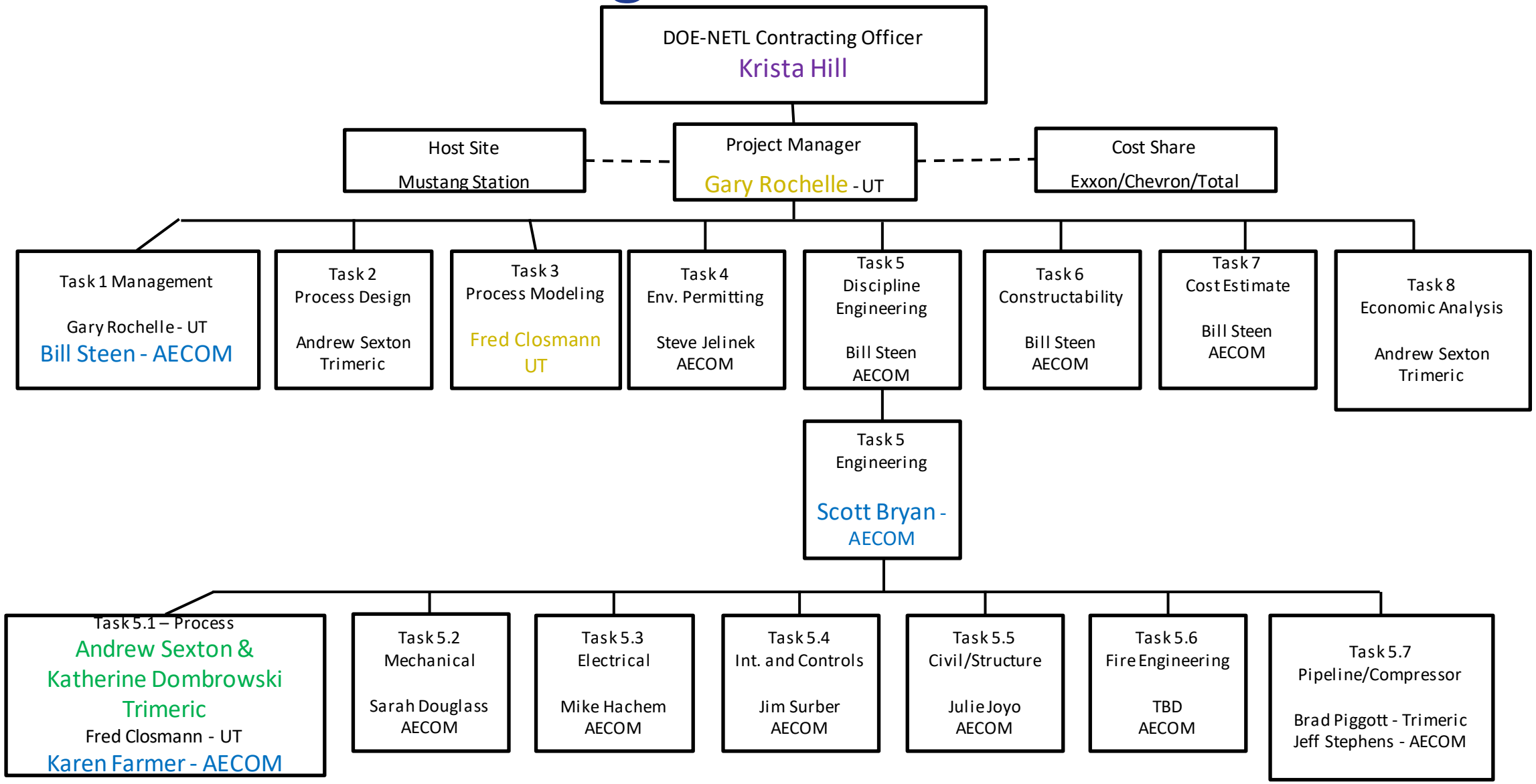
High Removal with PZAS at Mustang



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

Organizational Chart



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