High Performance Solvent for Natural Gas Combined Cycle (NGCC) Flue Gas CO_2 Capture

DE-FE0032216

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Susteon

2023 Carbon Management Research Project Review Meeting
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Project Overview

Title	**High Performance for Natural Gas Combined Cycle (NGCC) Flue Gas CO_2 Capture**
Award No.	DE-FE0032216
Period of Performance	01/01/2023 – 06/31/2024
Project Funding	DOE: $1,000,000 Cost-Share: $250,000
Overall Project Goal	Development of high-performance solvent for NGCC flue gas CO_2 capture
Project Participants	Susteon Inc. and TotalEnergies
DOE/NETL Project Manager	Ms. Mariah Young

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Technology Background

Key Targets

- Fast kinetics of CO_2 absorption and desorption
- High thermal and oxidative stability
- Lower reboiler duty
- Lower environmental Impact
- Reduce CO_2 capture cost by up to 40%
- Drop-in solvent for the existing solvent-based CO_2 capture plants

Project Goals

Metric	Cansolv®	Goal
CO_2 Capture Efficiency (%)	90	>97
Specific Reboiler Duty (GJ/t-CO_2)	2.88	<2.6
Solvent Consumption Rate (kg/t-CO_2)	0.75	<0.01
Solvent Emissions (kg/t-CO_2)	3.8 x10^{-4}	< 3x10^{-4}
CAPEX	100%	67%
OPEX	100%	84%

Impact

Sustenol™ CO_2 capture process has a potential to reduce the total plant cost of 650 MW power plant by 16% and CO_2 capture costs by 40% from B31B case (NETL report-2019).

Technical Approach/Project Scope

Design of a high-performance solvent to lower the cost of NGCC CO_2 capture with specific focus on

- Novel solvent (SUSTENOL™) with higher ***CO_2 working capacity***
- Greater than ***40% reduction*** in the energy required for solvent regeneration
- ***Fast kinetics*** of CO_2 absorption and desorption to reduce the equipment size
- Drastic increase in solvent lifetime/stability due to **high** thermal and ***oxidative stability***
- Lower environmental impact

Project schedule

- SUSTENOL™ – synthesized and physical and chemical properties measured
- Successful design and optimization of a contactor bench-scale module (Absorber and Desorber)
- Updated preliminary technoeconomic assessment (TEA)

Project success criteria

- SRD (Specific Reboiler Duty) ≤ 2.2 GJ/tonne CO_2
- SUSTENOL™ can reach ≥ 97% CO_2 capture from NGCC flue gas at >95% purity and at L/Gs ≤ 1(kg/kg)
- Demonstrate significant progress towards a 40% reduction in cost of capture versus a reference NGCC power plant with carbon capture at 97% carbon capture efficiency (B31B case, NETL Report-2019)

Our Approach for Reduction of Regeneration Energy

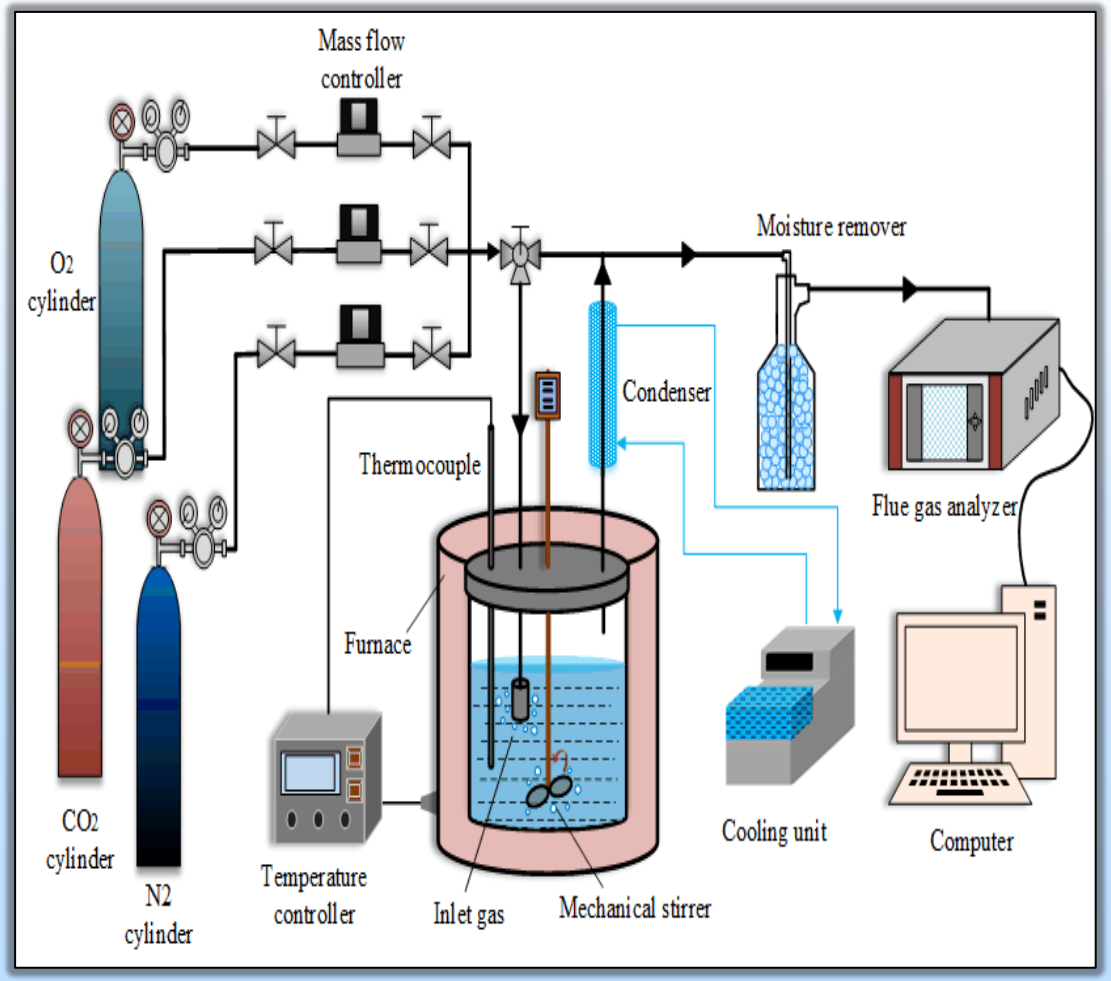
Comparison of SRD of Aqueous MEA, CANSOLV® and SUSTENOL™

Solvent	C_p [J/g K]	ΔH_{abs} [kJ/mol]	ΔH_{vap} [kJ/mol]	x_{solv} [mol solvent/mol solution]	$\Delta\alpha$ [mol CO_2/ mol solvent]	Specific Reboiler Duty [GJ/t-CO_2]
MEA	3.75	85	40	0.11	0.18	3.88
CANSOLV®	Estimated from DOE Baseline Case B31B Steam Flow Rate to the Reboiler					2.83
SUSTENOL™	**2.3**	**66**	**40**	**0.14**	**0.5**	**2.2**

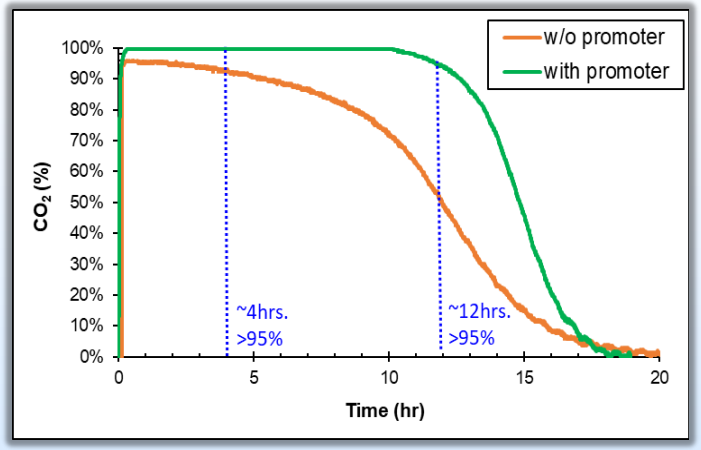
- Higher absorption rates with doubled CO_2 working capacity *(Column Testing & Vapor-Liquid Equilibrium)*
- Lower heat capacity due to lower water-content *(Reaction Calorimeter)*
- Lower reaction energy required for solvent *(Reaction Calorimeter)*
- Lower ratio of (P_{H2O}/P_{CO2}) at the top of stripper *(Column testing & Vapor-Liquid Equilibrium)*
- Addition of ppm quantities of promoter to amine solvents has been demonstrated to significantly enhance the CO_2 adsorption and desorption rates *(previous NCCC-PSTU testing campaign with coal/NGCC flue gas using 30wt% MEA)*

Screening of promoters for CO_2 Absorption Rate and CO_2 Capture Efficiency

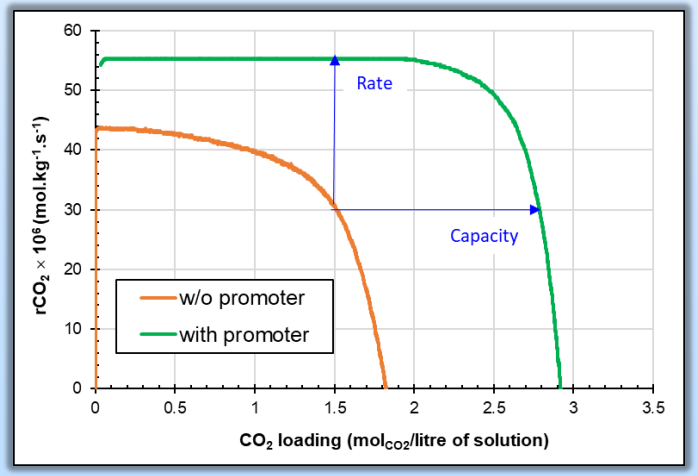
CO_2 Breakthrough Set-up for screening



CO_2 capture efficiency enhancement in 30wt% MEA



CO_2 capture rate and capacity enhancement in 30wt% MEA



Screening of promoter for CO_2 Absorption Rate and CO_2 Capture Efficiency

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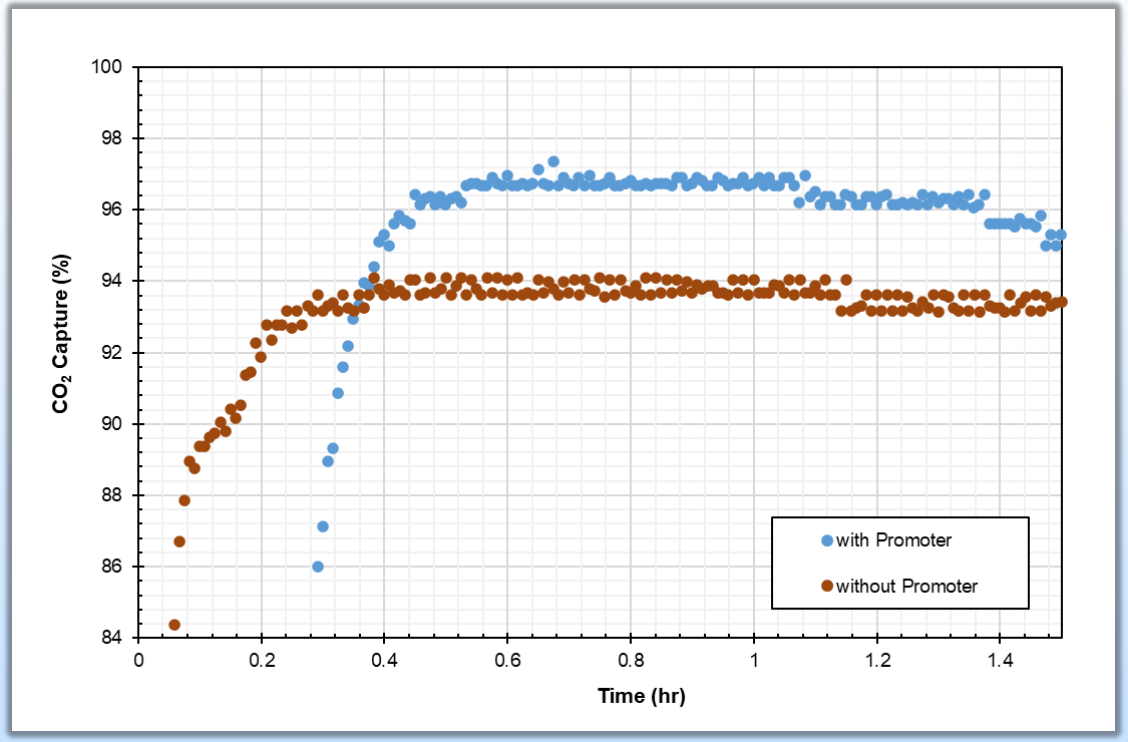
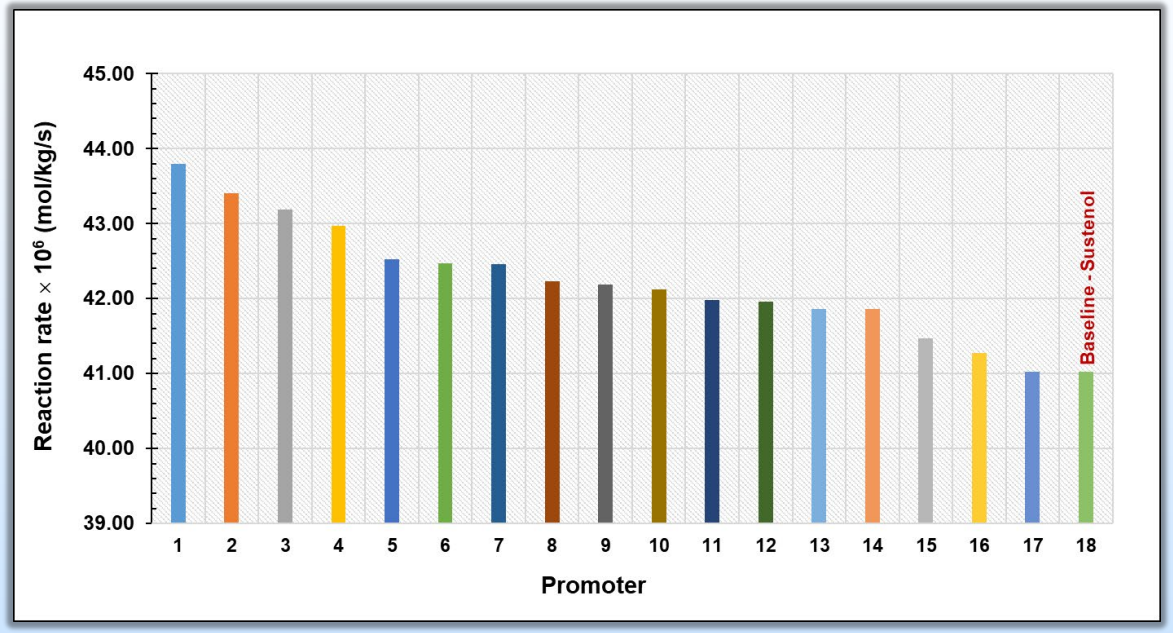


Promoter screening based on reaction rate

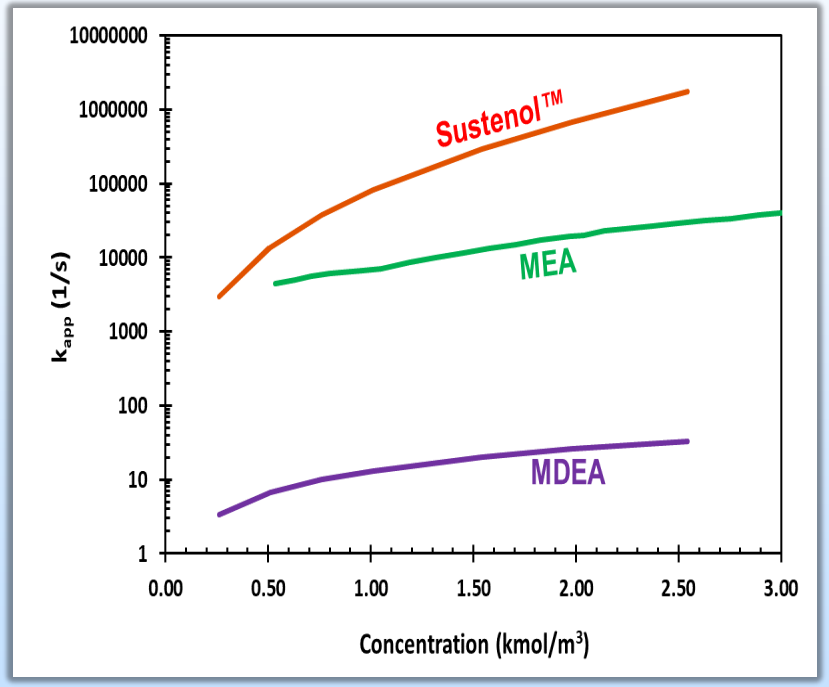


KPI	Without Promoter	With Promoter
Maximum CO_2 capture (%)	94	96
Maximum CO_2 captured (wt.%)	9.06	9.21
Maximum rate (mol/kg/sec) × 10^6	40.67	45.30
Average reaction rate (mol/kg/sec × 10^6, >90% capture)	40.26	43.80

Solvent Characterization

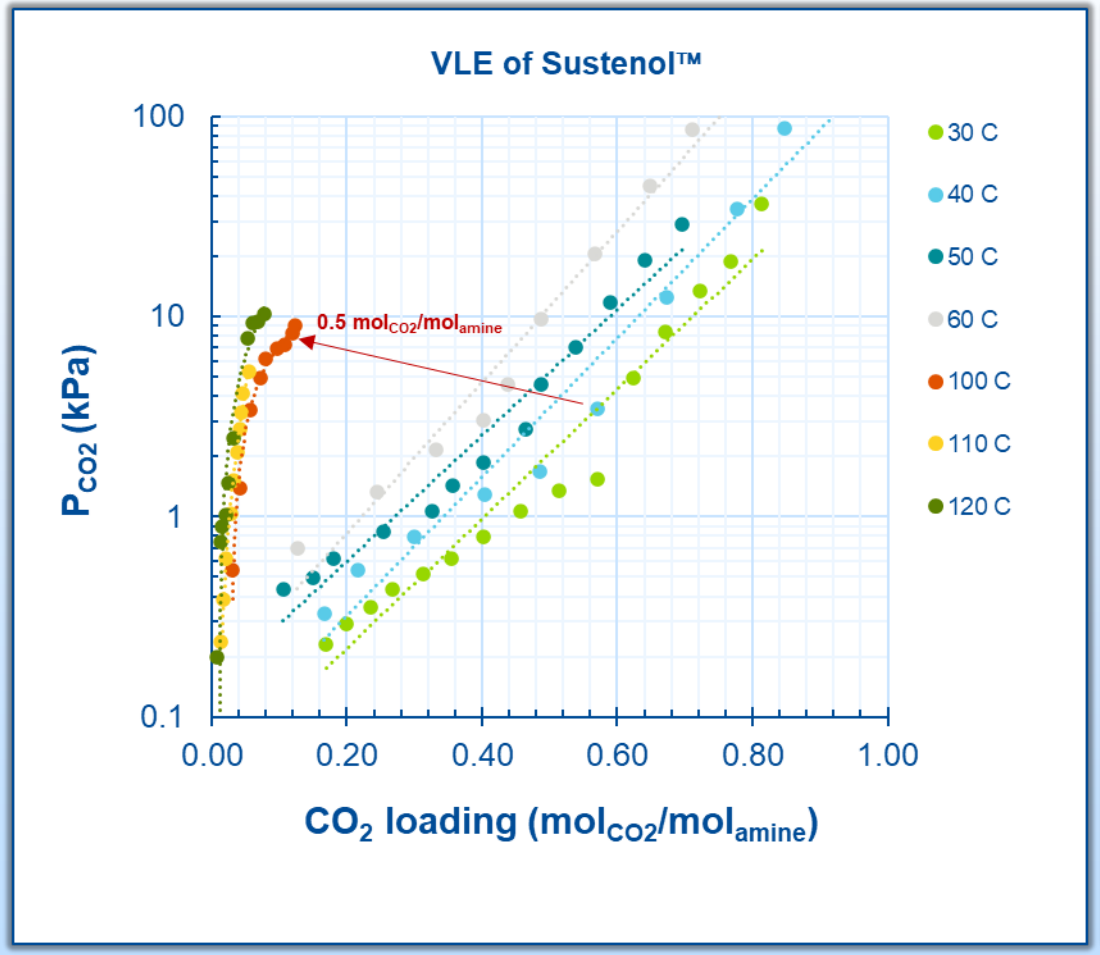
Sl.	Characterization	Conditions	Verified	Measured
			30wt% MEA	Sustenol
1	VLE (Absorption)	30- 60°C	×	✓
2	VLE (Regeneration)	100- 130°C	×	✓
3	Density - Fresh	25- 75°C	×	✓
4	Viscosity - Fresh	25- 75°C	×	✓
5	ST - Fresh	25- 75°C	×	✓
6	VP	RT- 150°C	×	✓
7	Density - Carbonated	30- 60°C	×	✓
8	Viscosity - Carbonated	30- 60°C	×	✓
9	ST- Carbonated	30- 60°C	×	✓
10	Kinetics (flux-vs P-CO_2)	30-60°C	×	✓

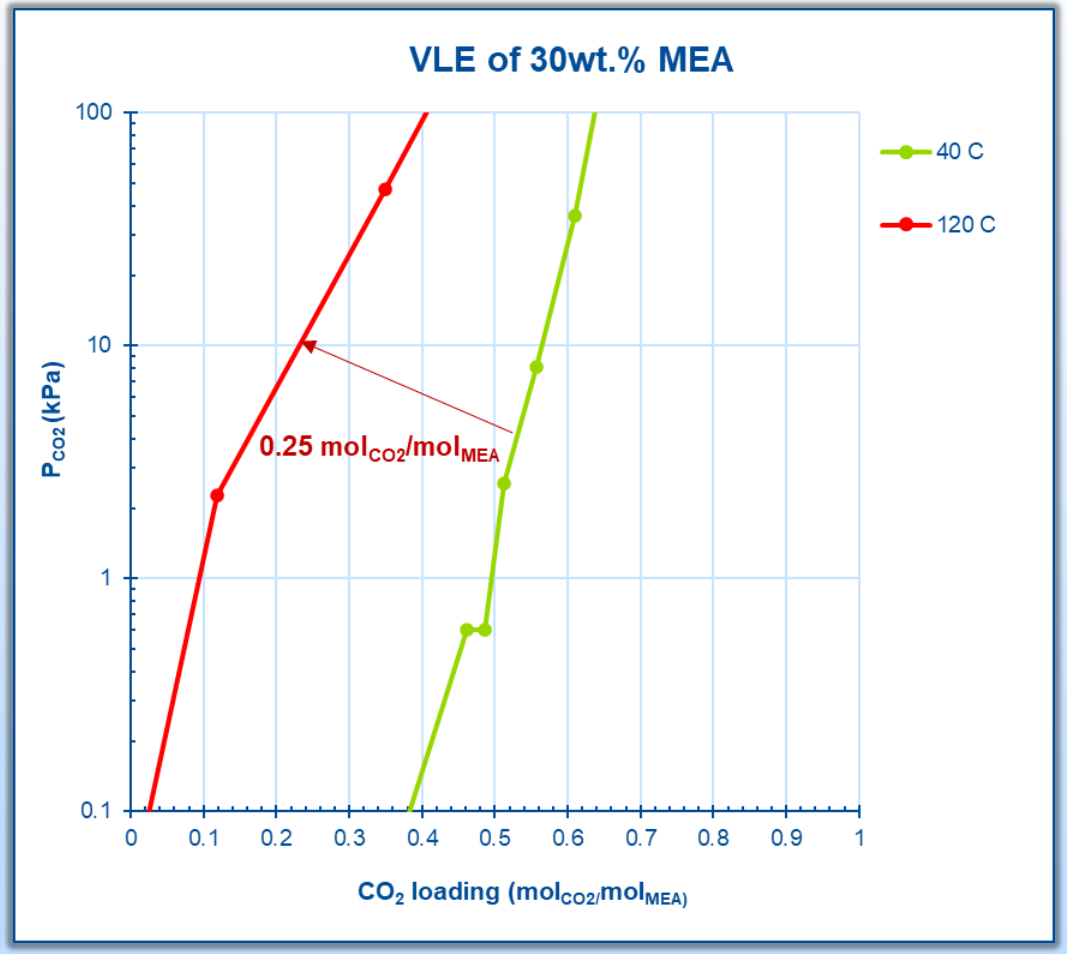
2 order higher reaction rate than MEA



Solvent Characterization

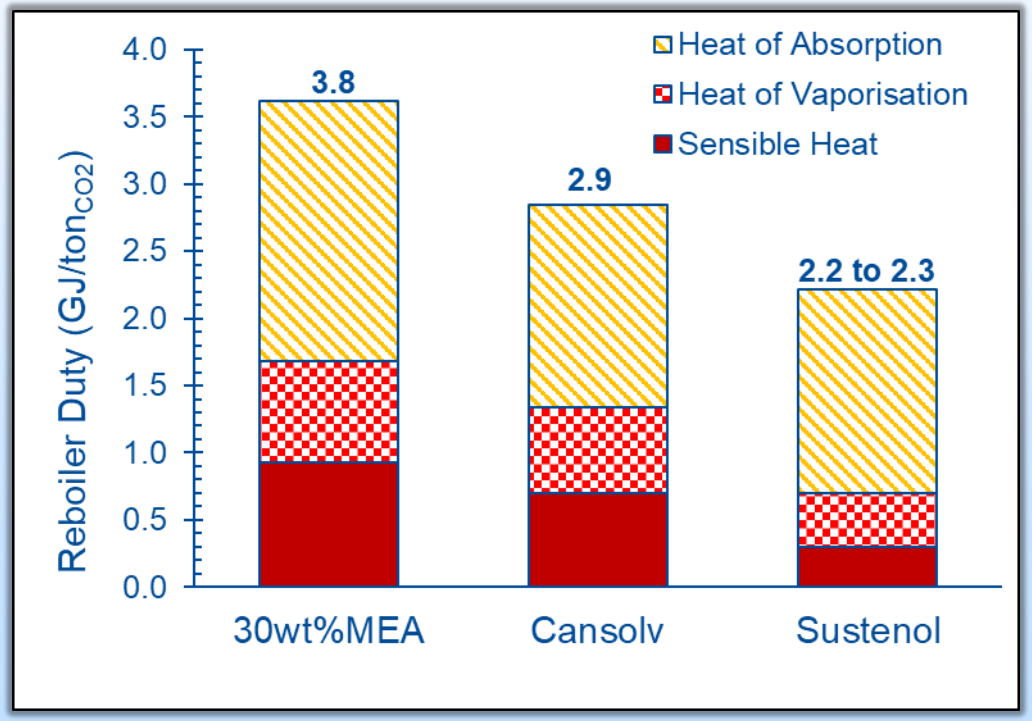
VLE shows double the capacity that of MEA





Solvent Characterization

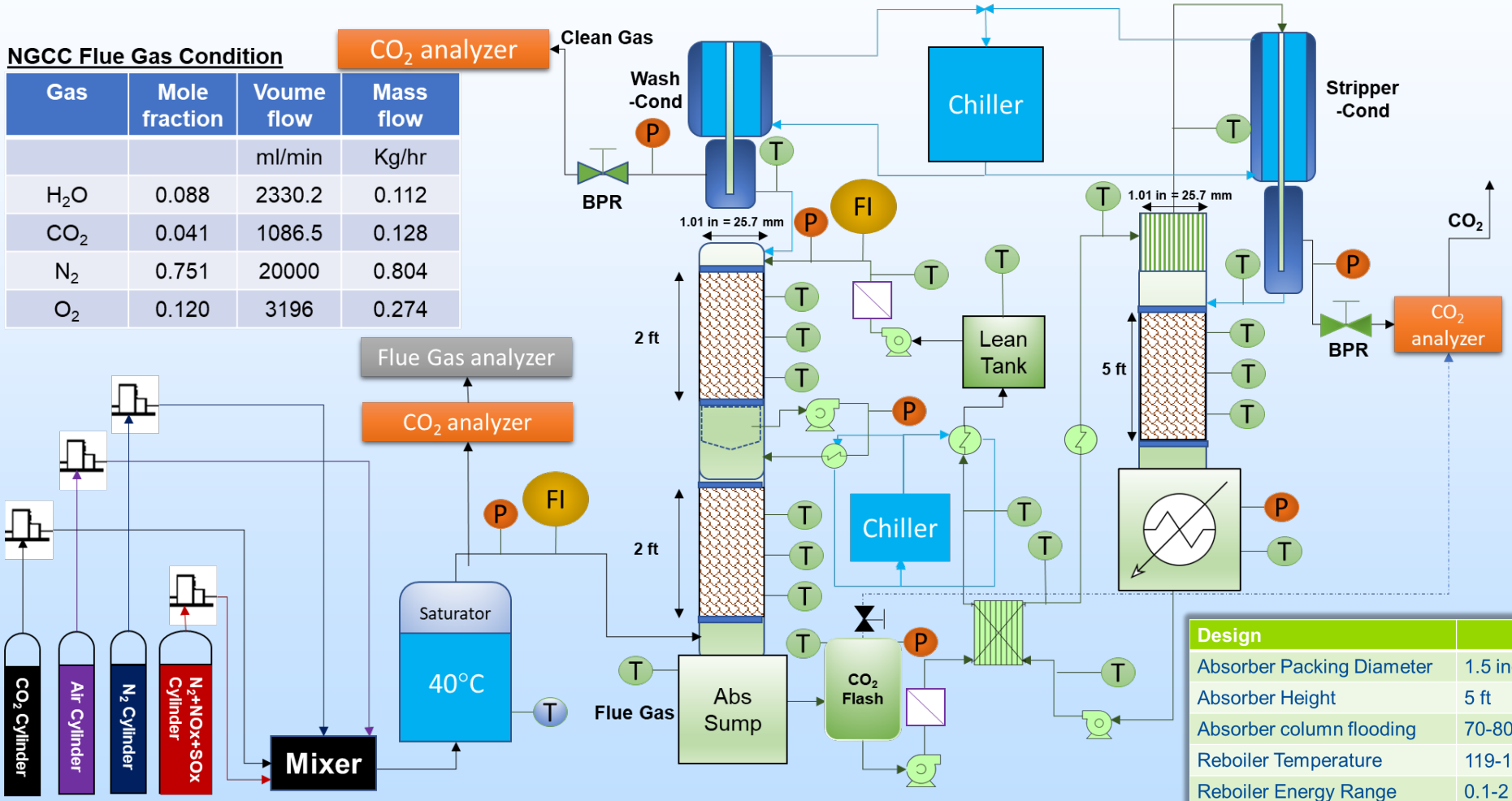
- Preliminary analysis shows that the solvent has reboiler duty of 2.2-2.3 GJ/tonneCO_2
- Higher density
- Viscosity in the desired range for column operation
- Lower surface tension than Cansolv® (better wettability)
- Lower heat capacity than Cansolv®
- Lower heat of vaporization than Cansolv®

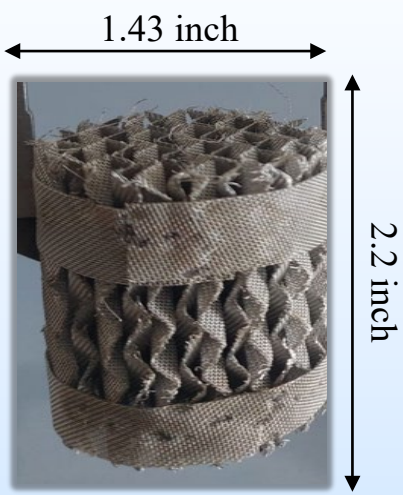


Bench-Scale Test System

NGCC Flue Gas Condition

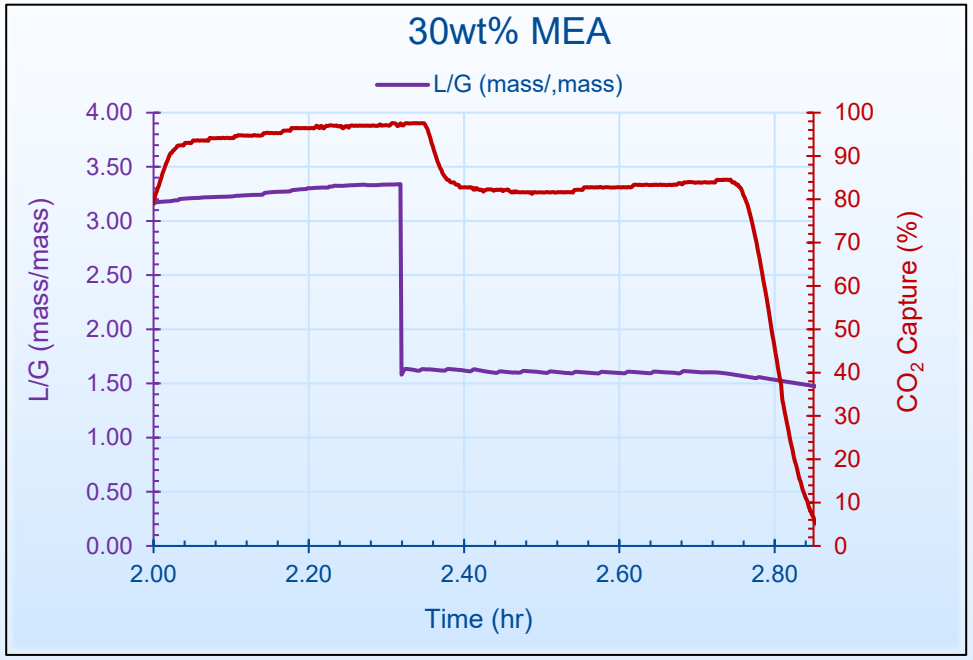
Gas	Mole fraction	Voume flow	Mass flow
		ml/min	Kg/hr
H_2O	0.088	2330.2	0.112
CO_2	0.041	1086.5	0.128
N_2	0.751	20000	0.804
O_2	0.120	3196	0.274

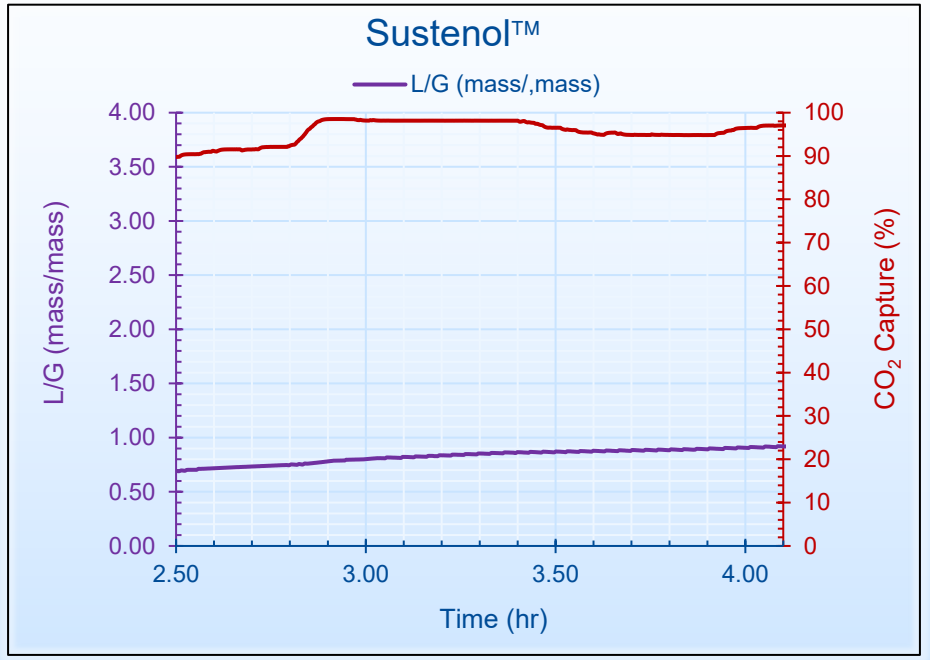




Design	
Absorber Packing Diameter	1.5 inch
Absorber Height	5 ft
Absorber column flooding	70-80%
Reboiler Temperature	119-120°C
Reboiler Energy Range	0.1-2 kW

Bench-Scale Test Results





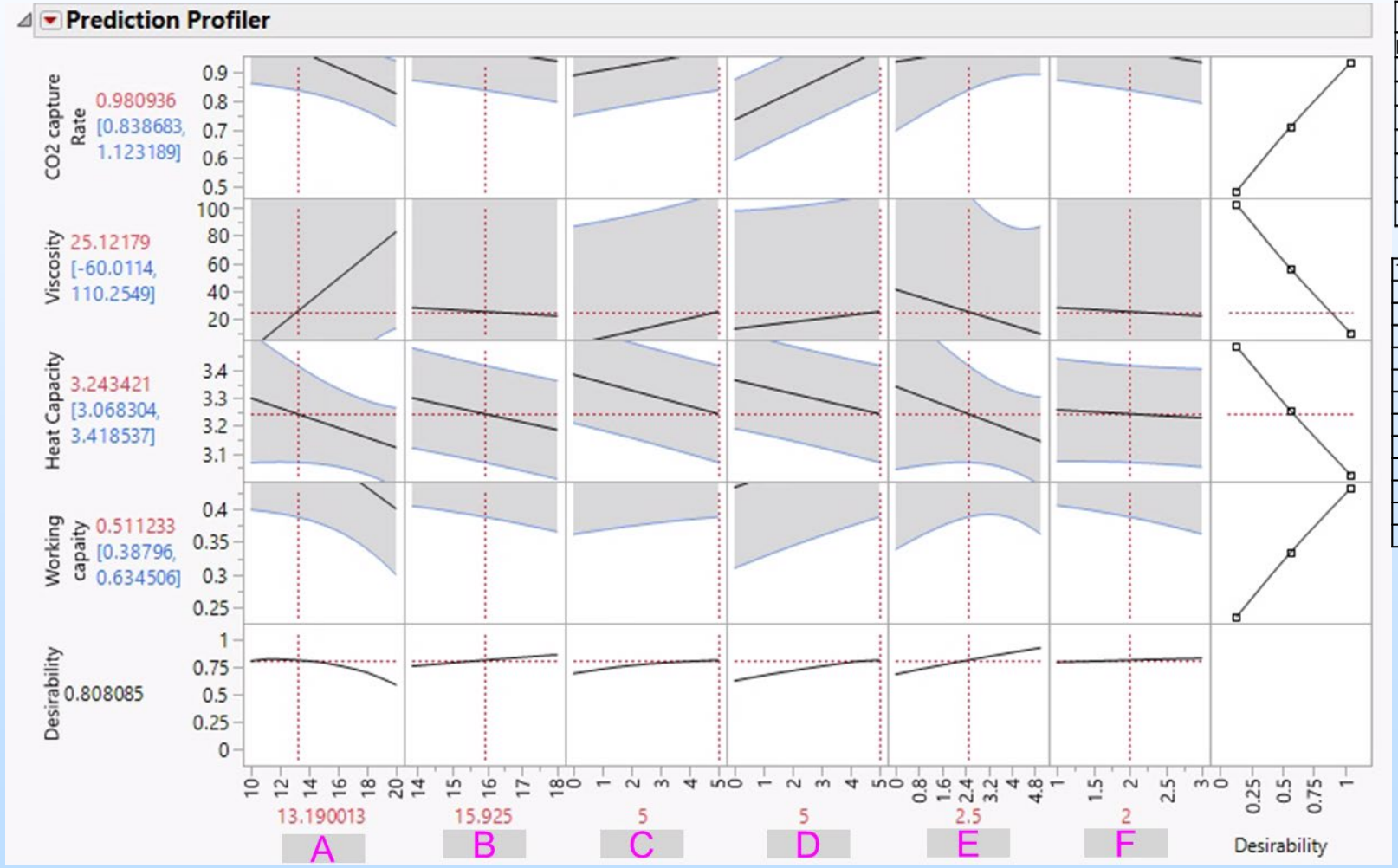
- One batch of 2000 kg of solvent was produced by a commercial manufacturer.
- A sample from this batch was tested in our bench-scale test unit.
- Results were compared with 30wt% MEA

<u>At the same condition in the tested packing</u>

- 30wt% MEA needs L/G = 3.5 to reach >97%
- Sustenol™ needs L/G = 1.7 to reach >97%

Solvent Screening
(Design of Experiments)

DoE-(Plackett-Burman 12 run)



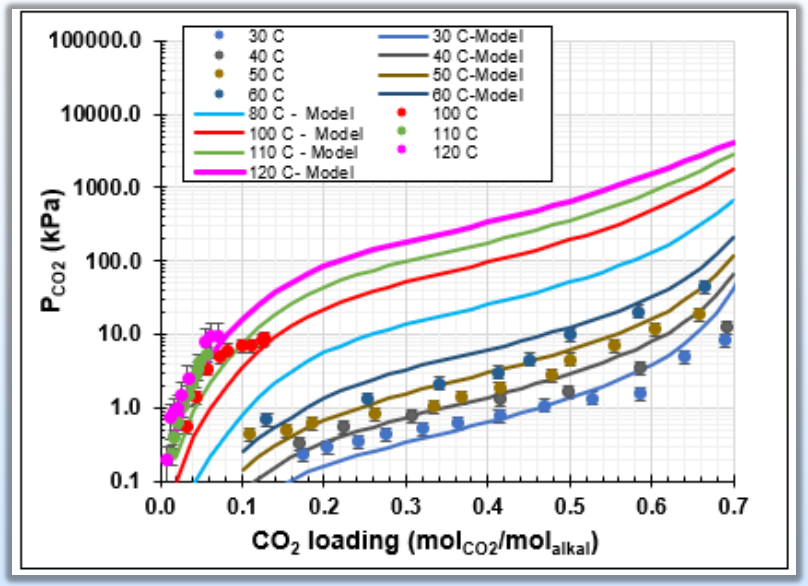
Design of Experiments						
Factor	Factor Name		Level 1	Low(-)	Level 2	High(+)
1	A		45		60	
2	B		17.84		25	
3	C		4.54		10	
4	D		10		22	
5	E		0		5	
6	F		0		5	
7	G		1000		7000	

Trials	A	B	C	D	E	F	G	Interactions	Responses
1	60	25	4.54	22	5	5	1000	1	
2	45	25	10	10	5	5	7000	1	
3	60	17.84	10	22	0	5	7000	1	
4	45	25	4.54	22	5	0	7000	-1	
5	45	17.84	10	10	5	5	1000	1	
6	45	17.84	4.54	22	0	5	7000	1	
7	60	17.84	4.54	10	5	0	7000	1	
8	60	25	4.54	10	0	5	1000	1	
9	60	25	10	10	0	0	7000	-1	
10	45	25	10	22	0	0	1000	1	
11	60	17.84	10	22	5	0	1000	-1	
12	45	17.84	4.54	10	0	0	1000	-1	

Design of experiments testing to identify optimum conditions.

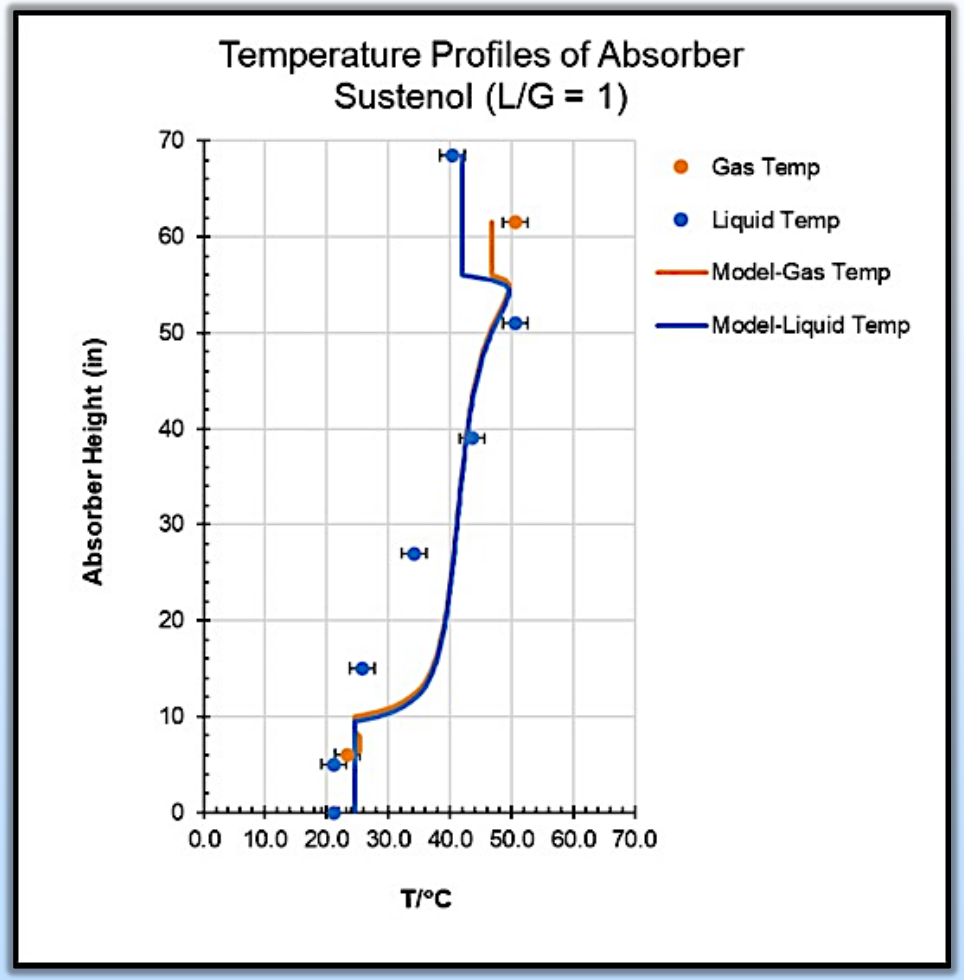
Process Modeling

VLE Prediction



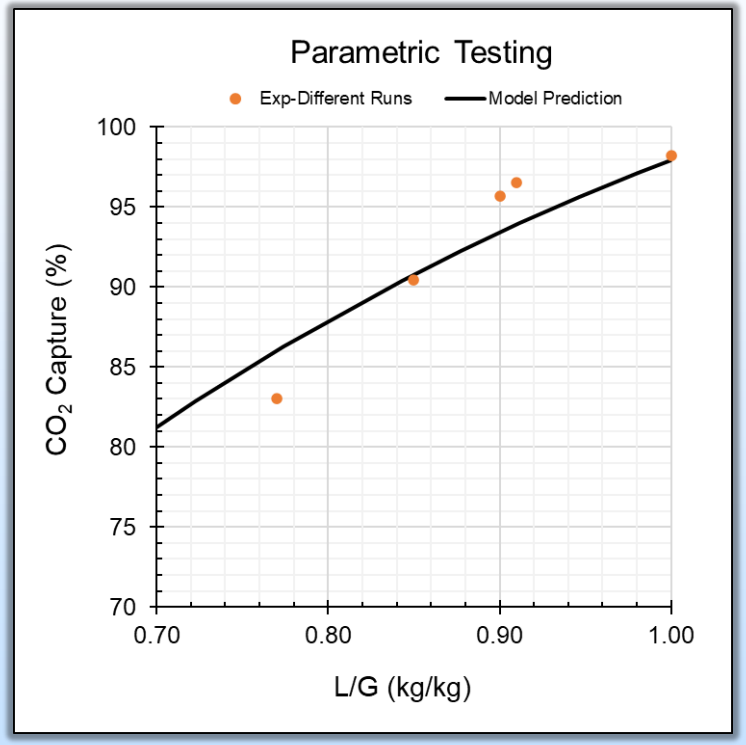
CO_2 balance (Gas & Liquid)

Parameters	Exp	Model
L/G	1	1
CO2 Capture (%)	95.7	95.3
CO2 loading (mol_{CO2}/mol_{alk})	0.398	0.350
Lean viscosity (cP)	8	3.1
Rich viscosity (cP)	22	20.8



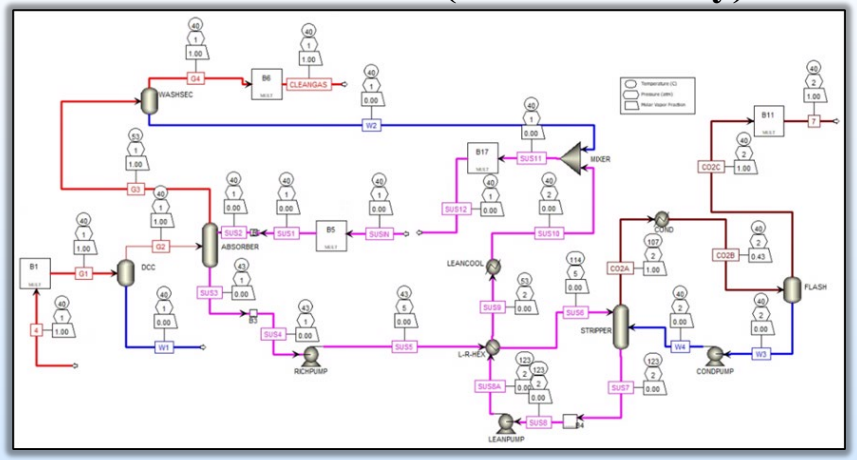
Process Modeling

>95% Capture at L/G = 0.85-1

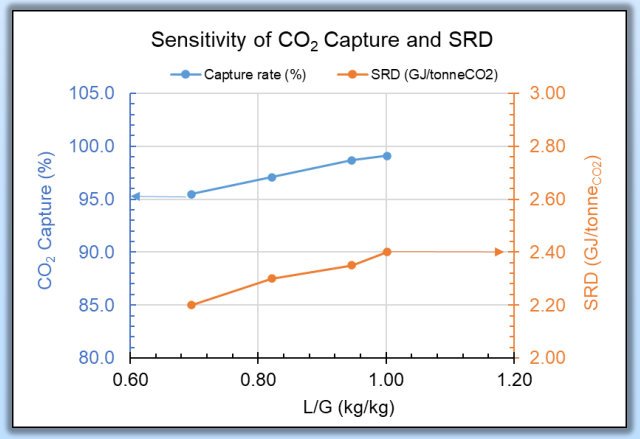


Model predicts the temperature profiles and CO_2 capture performance of bench-scale unit. Scaled-up process model used to predict the specific reboiler duty.

Scaled-up Process model to commercial scale (6000 tonne/day)

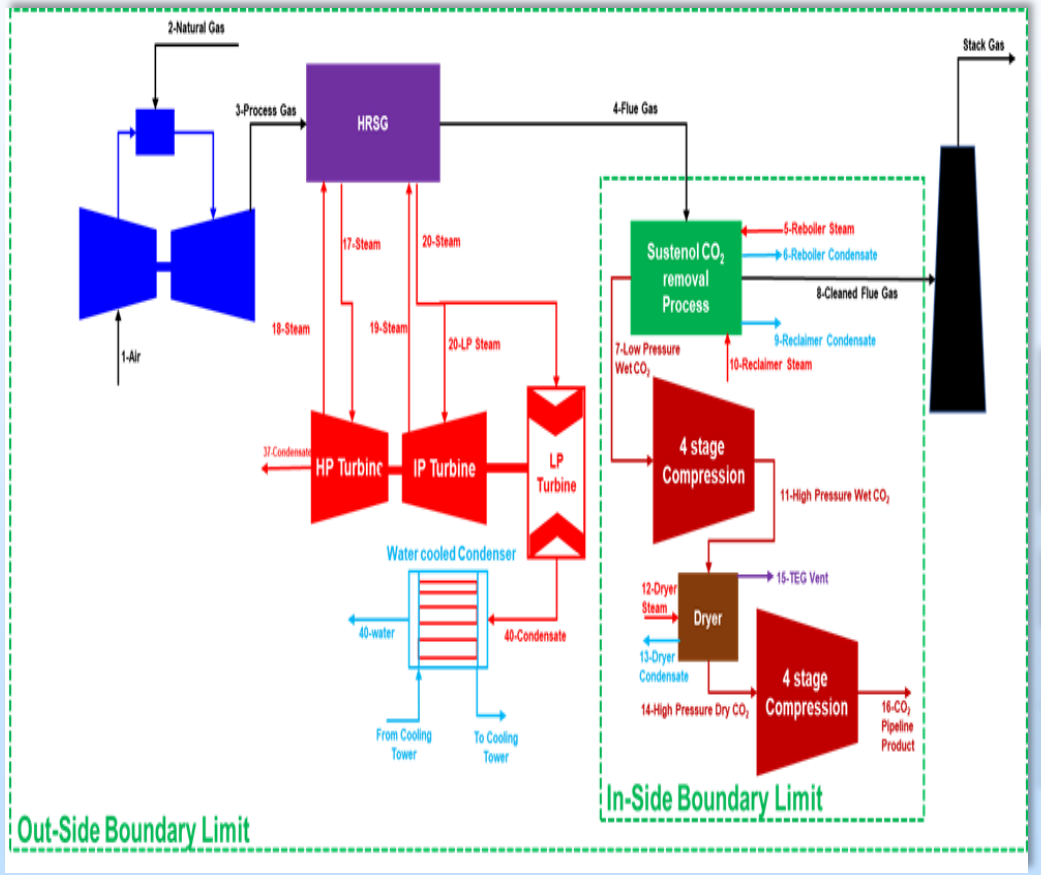


SRD varied from 2.2 to 2.4 GJ/tonneCO_2



Initial TEA

Simple Process Flow Diagram



Power Performance

Power Summary	B31B.97-NETL-CANSOLV®	B31B.97-Susteon-Sustenol™
Total Gross Power, MWe	687	687
Total Auxiliaries, MWe	50562	35441
Net Power, MWe	636.4	651.6

CO_2 Capture cost comparison

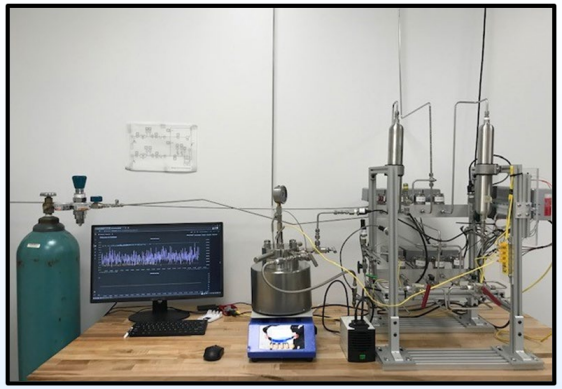
Cost Distributions	Unit	CANSOLV®			Sustenol ™
		NETL	Susteon	IECM	Susteon
Add CCS cost	**$/MWh**	**22.80**	**22.86**	**22.82**	**17.24**
Capture Plant		**NETL**	**Susteon**	**IECM**	**Susteon**
CO_2 Avoided Cost	$/tonne$CO_2$	**80.28**	**80.46**	**80.29**	**63.47**
CO_2 Capture Cost	$/tonne$CO_2$	**60.09**	**60.14**	**60.25**	**45.45**

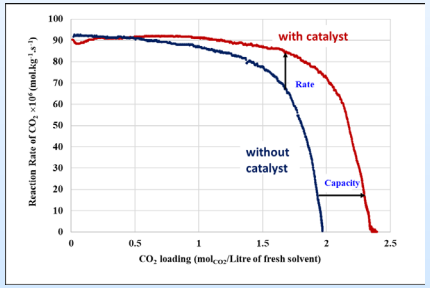
Pathway to 30% reduction in CO_2 capture cost (42$/tonne$CO_2$) is in progress.

Plans for Future Testing/Development/ Commercialization

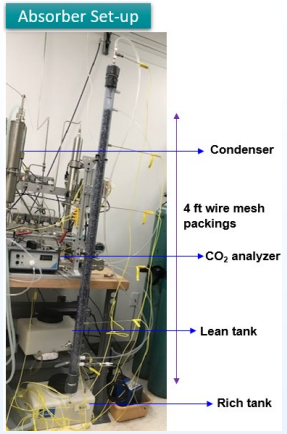
- Comprehensive characterization of solvent
- Building a scale-up unit:
  Height - 18 ft and Diameter – 4.2 inch
- Thermal and oxidative stability testing
- Emission and waterwash evaluation
- Bulk solvent production and quality control testing
- Engineering scale testing at NCCC-PSTU (0.5 MWe) with the optimized solvent (parametric and long-term testing)
- Process model development and validation
- Pre-FEED for technology demonstration
- Technology licensing

Plans for Commercialization





Breakthrough set-up (TRL 1-2)



4 feet packing height (TRL 2-3)

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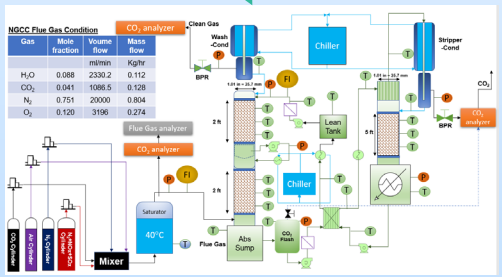
Bench-Scale Test Unit **(2023)**

Pilot-Scale Test Unit **(2024)**

15 feet packing height (TRL 4-5)



Engineering-Scale Test Unit **(2025-2026)**

View of 0.5-MW PSTU

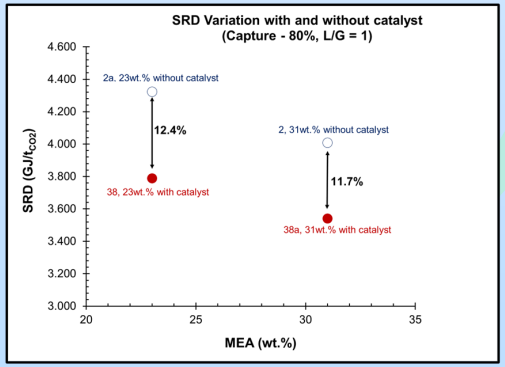
NCCC PSTU Unit 60 feet packing height (TRL 6)

Proof of solvent concept **(2022)**

Proof of promoter concept **(2021)**

View of 0.5-MW PSTU

NCCC PSTU Unit 60 feet packing height (TRL 6)



Experimental : Runs 2 & 38
Normalized Model: Runs 2a & 38a

Summary and Conclusions

- Highly efficient solvent composition identified for NGCC flue gas
- Promoters were identified to enhance absorption/desorption rates and solvent working capacity.
- Solvent was produced at 2,000 kg scale.
- Comprehensive solvent characterization was completed.
- Testing in bench-scale-scale test unit undergoing.
- Process model was developed and validated with initial bench-scale data.
- SRD of the highly efficient solvent was found to be 2.2 GJ/tonneCO_2.
- Preliminary TEA showed a CO_2 capture cost of \$45.50/tonneCO_2.
- A technology pathway was developed to meet DOE target of >30% cost reduction compared to Cansolv® (NETL Report-2022).

Acknowledgement

Financial and Technical Support

- Department of Energy (DOE/NETL)
- DOE Project Manager: Ms. Mariah Young

- TotalEnergies

Acknowledgement
This material is based upon work supported by the Department of Energy under Award Number DE-FE0032216.

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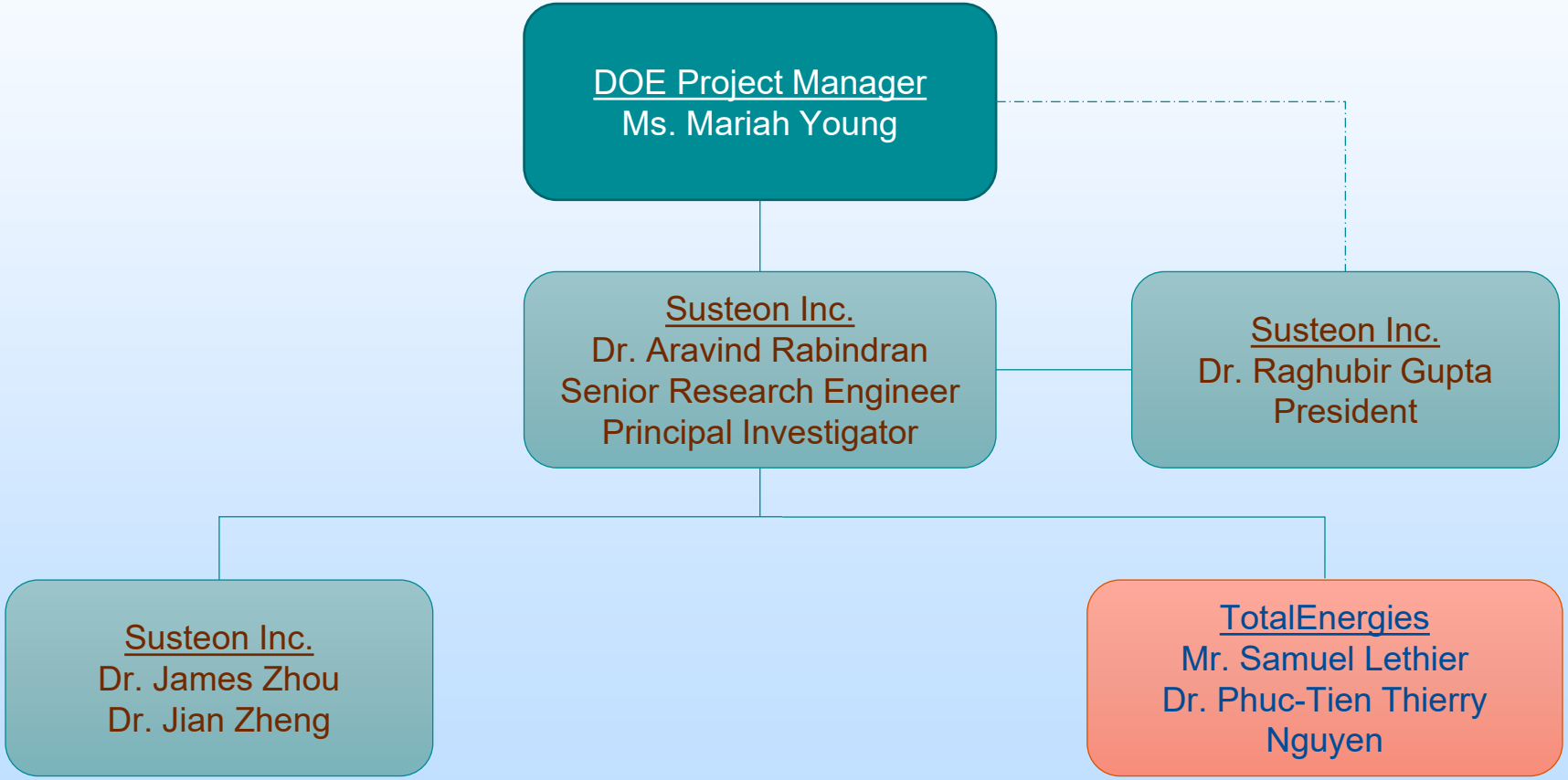
Organization Chart



Gantt Chart

Project Timeline	Start Date	End Date	Months from Project Start Date
			1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Task 1.0 - Project Management and Planning	**1/1/2023**	**6/30/2024**	
Milestone 1: Revised Project Management Plan	1/1/2023	1/24/2023	
Milestone 2: Kickoff meeting	1/1/2023	1/31/2023	
Milestone 3: Initial Technology Maturation Plan	1/1/2023	3/31/2023	
Milestone 10: Final Technology Maturation Plan	5/1/2024	6/30/2024	
Task 2.0 – Synthesis and characterization of catalyzed solvent	**2/1/2023**	**7/30/2023**	
Milestone 4: Solvent synthesized and its physical and chemical properties measured	2/1/2023	7/30/2023	
Task 3.0 – Laboratory-scale test system upgrade and commissioning	**2/1/2023**	**5/31/2023**	
Milestone 5: Successful design and optimization of contactor module	2/1/2023	5/31/2023	
Task 4.0 – Solvent screening and CO2 capture performance evaluation	**6/1/2023**	**1/31/2024**	
Milestone6: Successful CO_2 Capture performance testing demonstrating working capacity increase and regeneration energy reduction	6/1/2023	1/31/2024	
Task 5.0 – Solvent formulation optimization and down selection	**8/1/2023**	**3/31/2024**	
Milestone7: Solvent formulation optimized for CO_2 capacity with capture rate > 97%	8/1/2023	3/31/2024	
Milestone 8: Update State Point Table	8/1/2023	3/31/2024	
Task 6.0 – Process modeling	**8/1/2023**	**3/31/2024**	
Milestone 9: Successful process design and model development using the optimized solvent formulation test data	8/1/2024	3/31/2024	
Task 7. Final TEA & Process design Work	**1/1/2023**	**3/31/2024**	
Milestone 3: Initial TEA	1/1/2023	6/30/2023	
Milestone 10: High-fidelity TEA to assess the cost of capture of the proposed technology compared to SOTA	1/1/2024	3/31/2024	
Milestone 11: Final Report & Process deisgn	1/1/2024	6/30/2024	