Enhancement of Carbon Capture Reactor Performance

Project Number: DE-FE0032217

Performing Organization: University of Kentucky

Principal Investigator: Jesse Thompson

AOI-4: Carbon Capture R&D - Laboratory-Scale Testing of Highly-Efficient Materials or Novel Concepts for Natural Gas Combined Cycle (NGCC) Power Plants

Disclaimer

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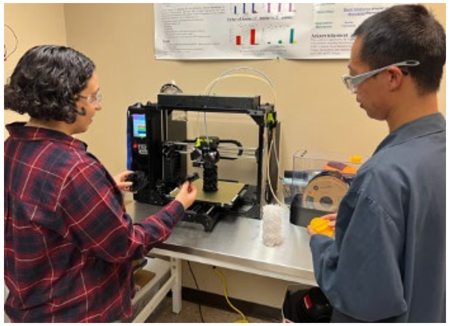
Project Overview

- Develop novel carbon capture reactor components that contribute to increased CO_2 mass transfer through increased turbulent gas-liquid interfaces and improved solvent wetting within the absorber
- Design advanced components for Natural Gas Combined Cycle (NGCC) CO_2 capture plants targeting 97% or greater carbon capture efficiency and make significant progress toward a 40% reduction in the cost of carbon capture vs. a reference NGCC plant with carbon capture.
- **Project Timeline:** 2/1/2023 - 8/31/2024
- **Funding**: Federal - $1M; CS - $250K; Total - $1.25M



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Goals

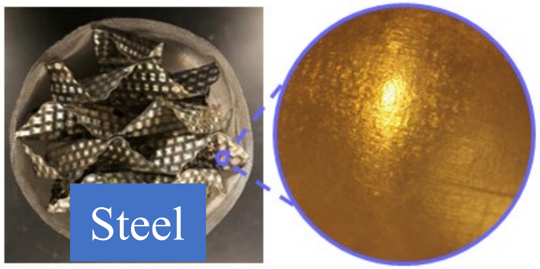
Demonstrate the ability to efficiency capture CO_2 at 90-97% or greater and make significant progress towards a 40% reduction in cost of capture versus reference NGCC power plant with carbon capture at the same carbon capture efficiency

- Reduction of heat and power requirements
  - Using water-lean solvent (WLS)

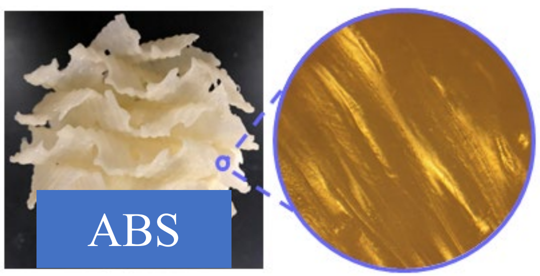
- Maximize CO_2 capture volumetric productivity to reduce the footprint and capital of carbon capture for an NGCC plant
  - Improve wetting of solvent on structured packing with water-lean solvents and use of additive manufactured (3D printed) and polymers to enhanced the surface substructure to increase liquid turbulence and mixing

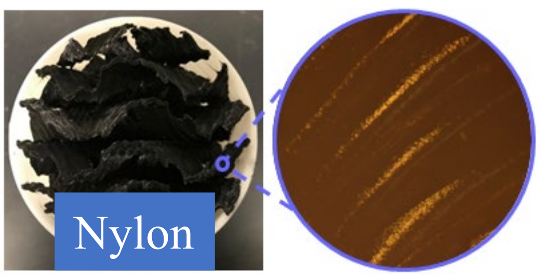
Absorber Packing

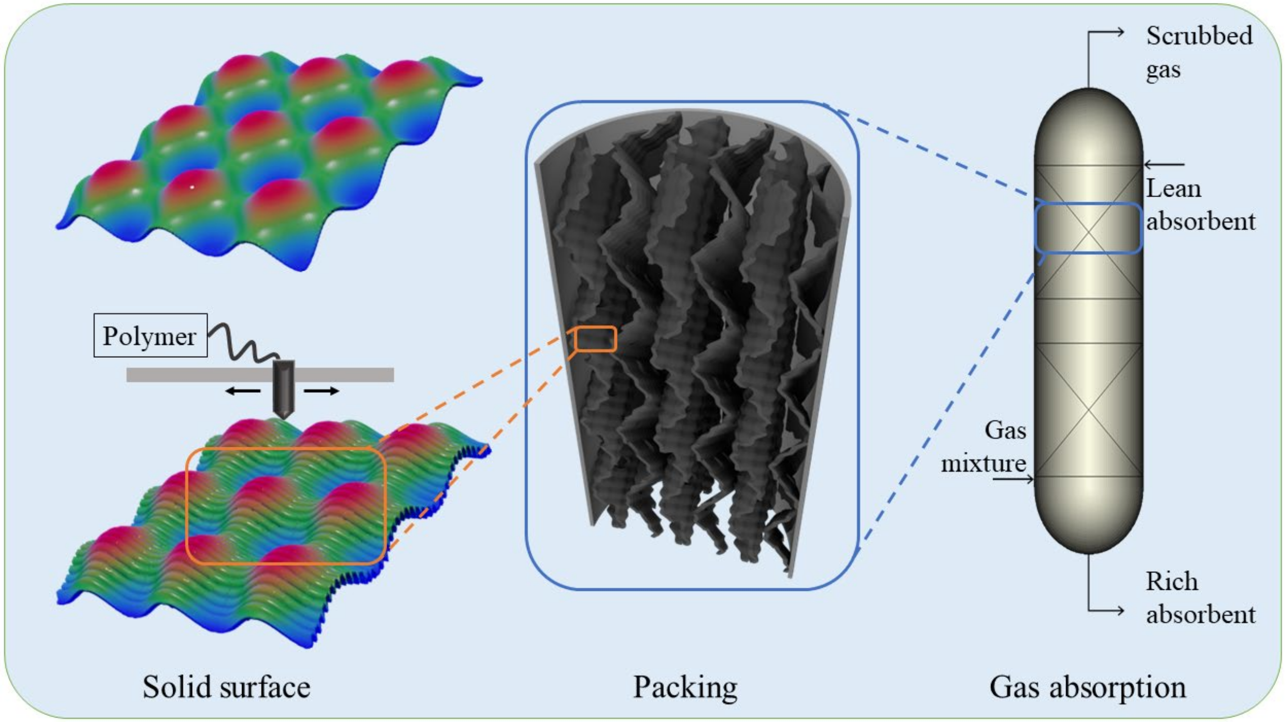
Commercial Packing



3D Printed Polymer



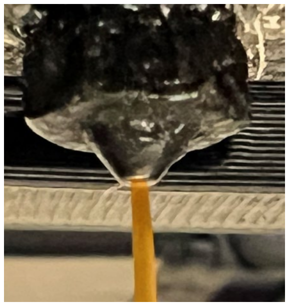


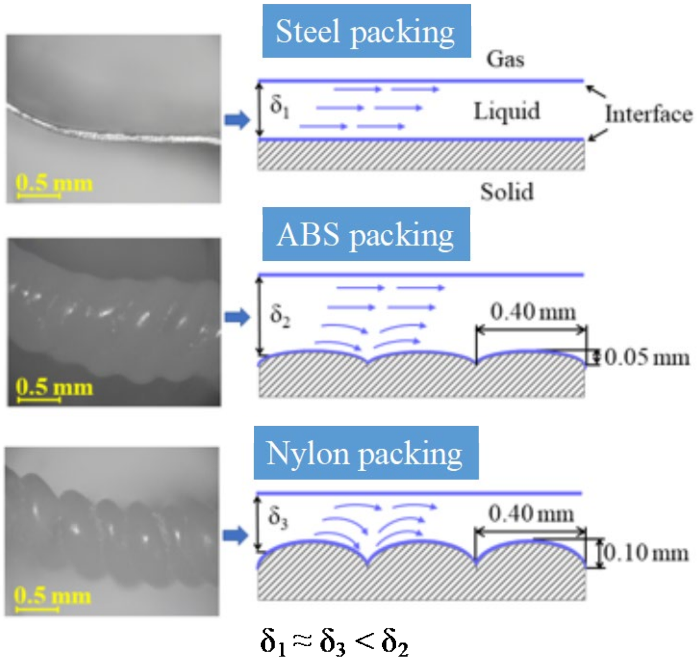


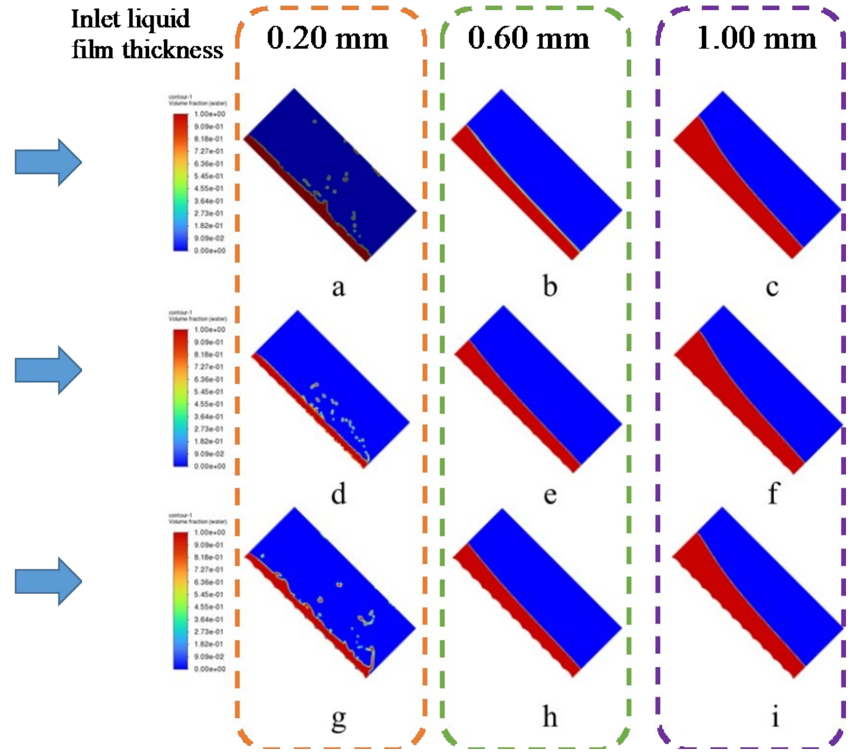
3D printed and polymer packing can be easily modified to have an additional surface sub-texture that further improves liquid turbulence on the surface translating to improved CO_2 capture rates

Based on results from DE-FE0031661
Xiao et al., Chemical Engineering Science 267 (2023) 118320

CFD-Modeling of Surface Mixing

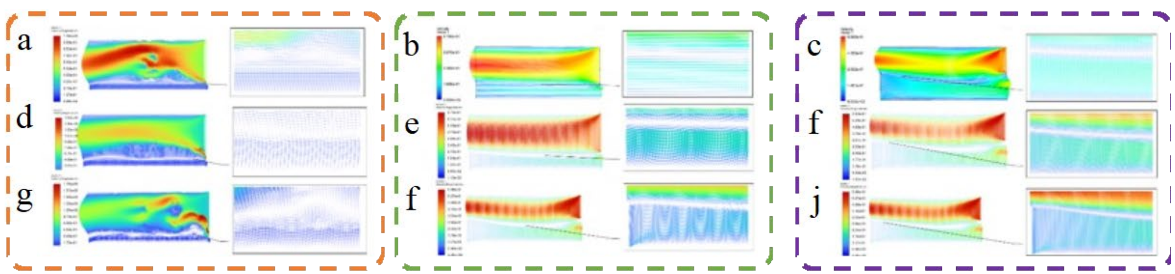






- **Surface texture amplitude**
- **Liquid film thickness**

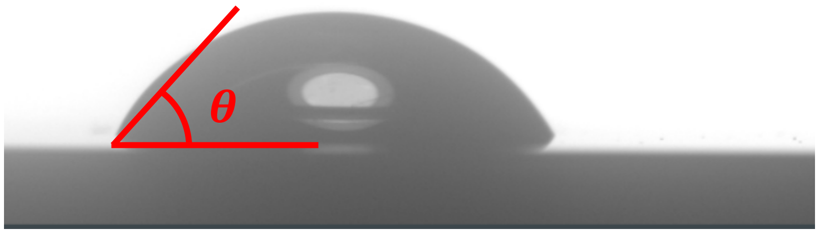
Local mixing within the liquid



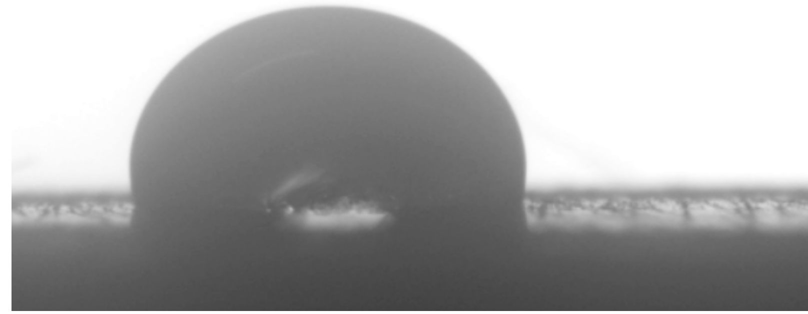
Solvent Wetting - Contact Angle

The wetting (CA) of an aqueous amine solvent (AAS) is typically in the 30-60° range depending on the solvent and CO_2 loading

Rich - AAS on Stainless Steel

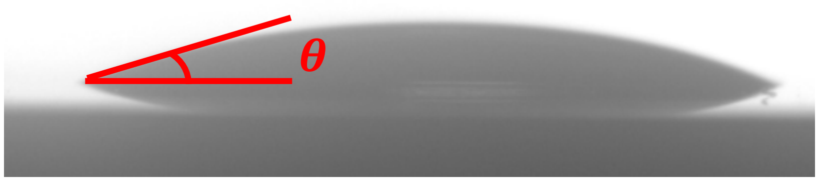


Rich - AAS on Nylon



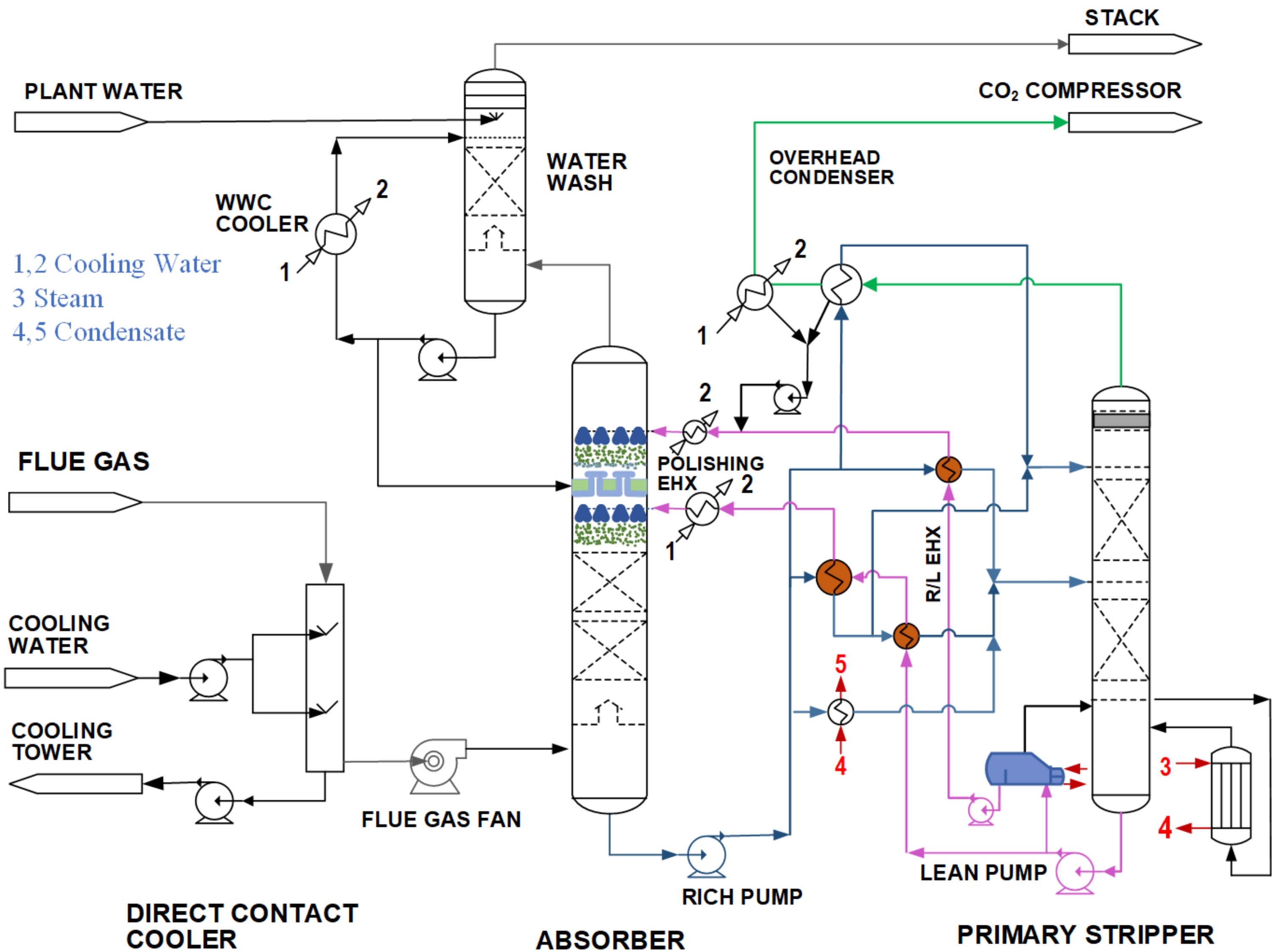
Water-lean solvents (WLS) can have CAs in the 10-20° range, depending on CO_2 loading, but have similar CAs on steel and polymer surfaces

WLS on Stainless Steel



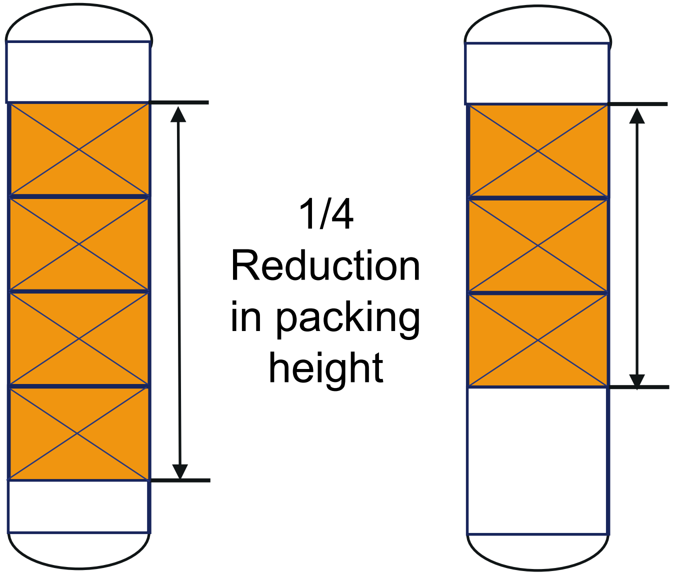
WLS on Nylon

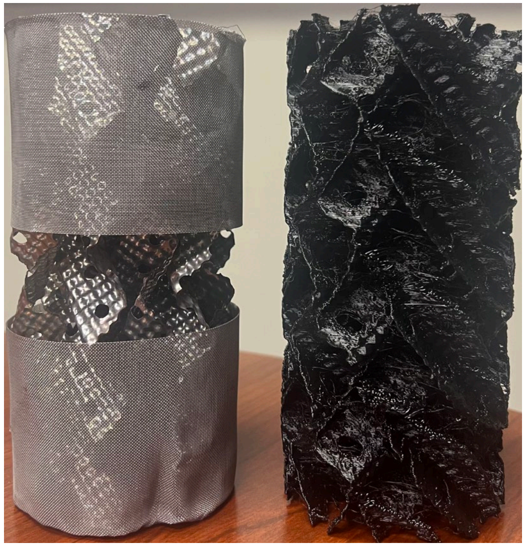
UK NGCC Process



Initial TEA Estimates

Assuming a ¼ reduction in the packing height through process intensification and enhancement in CO_2 mass transfer, and using a lower cost material (polymer), can result in a significant (52%) reduction in the construction cost of the absorber.

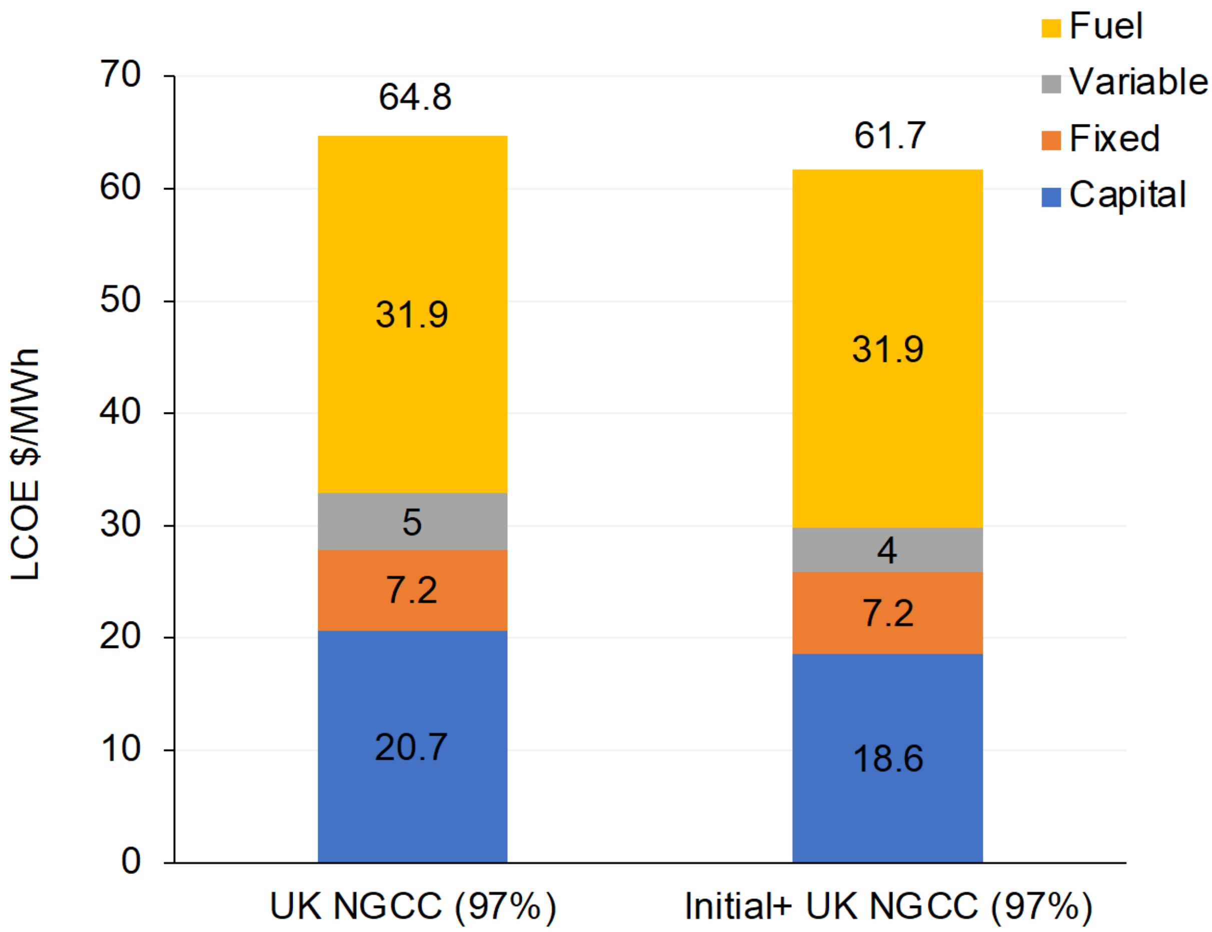




	Case1 - MP 250Y	Case 2 - Polymer Packing
Packing Height (ft)	40	30
Tower Diameter (ft)	25	25
Shell Height (ft)	80.00	70.00
Shell/Packing Ratio	2.00	2.33
Total Shell Cost ($)	$178,708.00	$164,461.00
Packing Volume (ft3)	19,635	14,726
Unit Cost for Packing ($/m3)	$4,012.00	$2,407.20
Unit Cost for Packing ($/ft3)	$113.61	$68.16
Total Packing Cost	$2,230,669	$1,003,801
Total Column Cost	$2,409,377	$1,168,262
Cost Reduction		52%

Based on results from DE-FE0031661

Initial TEA Estimates

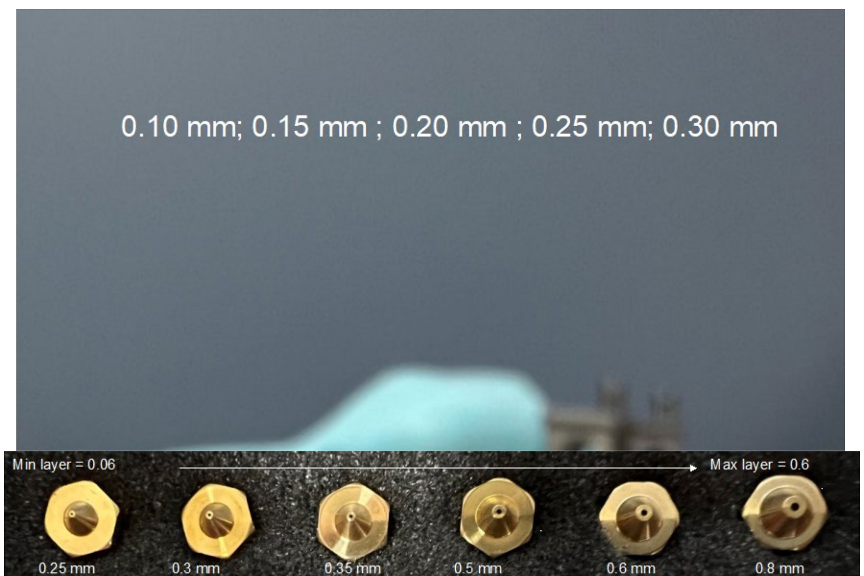


(Very) preliminary estimates for NGCC with the UK WLS process and enhanced packing shows a potential reduction in the levelized cost of electricity from reductions in the absorber column height and related components

Technical Tasks

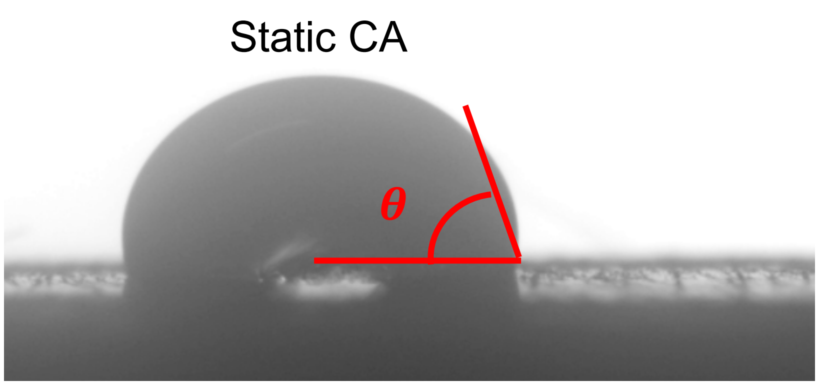
Verify stability of polymers vs WLS → Create different patterns, geometries, configuration using 3D printer speeds , temperatures → Test packing designs for CO_2 mass transfer enhancement in bench scale mini-absorber → Collect process data for incorporation into TMP, TEA, State Point Data Table

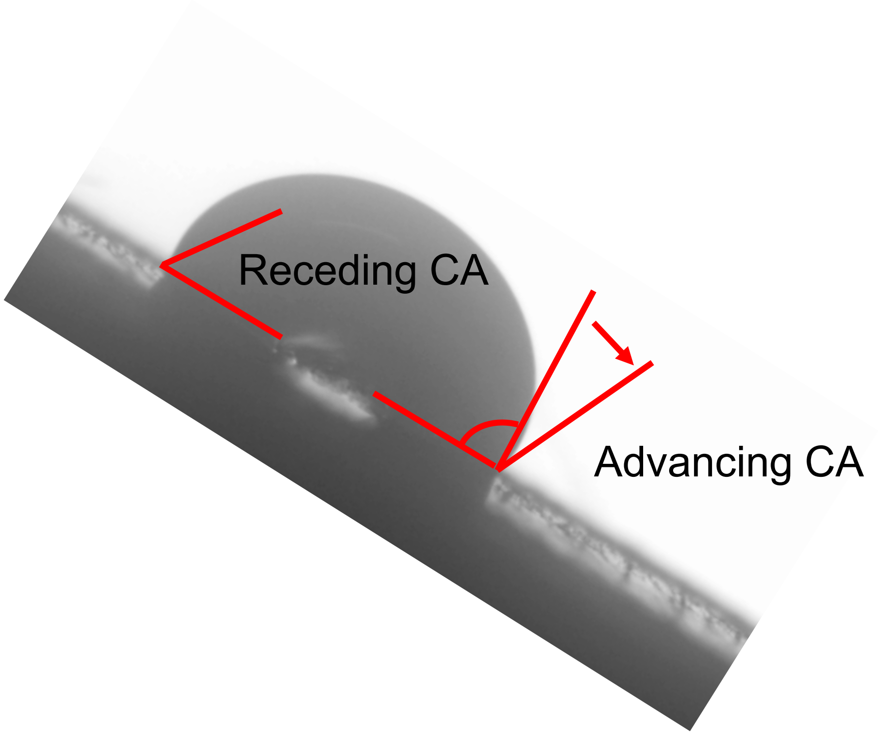
Design and Fabrication of Absorber Reactor Components



Bench Testing of Absorber Components

Dynamic Contact Angle

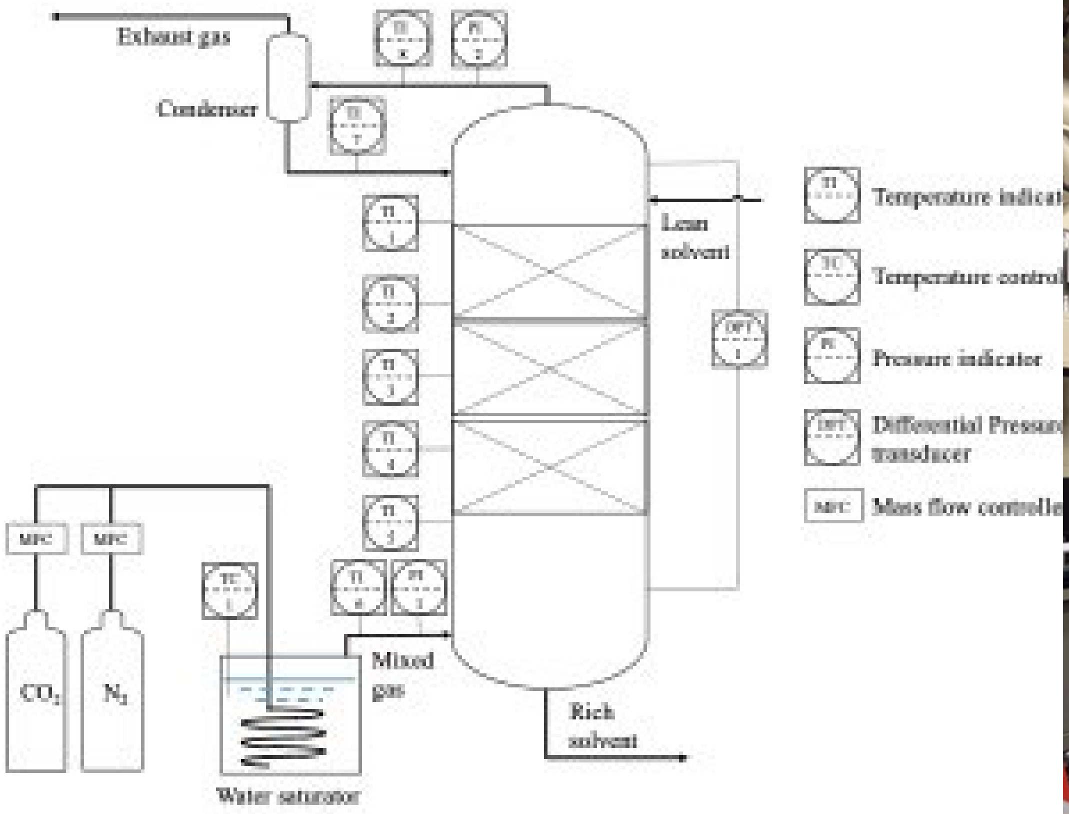




Static Contact Angle (CA) measures the bulk repulsive/attractive interactions between the surface and solvent, whereas the Dynamic Contact Angle replicates the downward flow of the solvent on the packing and better describes the actual wetting profile on the packing

CO_2 Capture System

UK 3" CO_2 Capture Evaluation System w/ Simulated NGCC (~4% CO_2)



Milestones and Deliverables

Task Number	Title	Planned Completion Date	Actual Completion Date	Verification Method
1	Updated Project Management Plan	2/28/2023	2/24/2023	PMP File
1	Kickoff Meeting	3/31/2023	3/13/2023	Presentation File
1	Subcontracts Established	4/30/2023	5/26/2023	Written Verification
1	Initial Technology Maturation Plan	4/30/2023	4/26/2023	Appended to Quarterly Report
1	Final Technology Maturation Plan	5/31/2024		Appended to Quarterly Report
1	State Point Data Table Revision	5/31/2024		Appended to Quarterly Report
2	Identification of polymer that is stable for 5000 hr in the water-lean solvent at absorber temperatures of > 50 °C	11/30/2023		Written Verification
2	Production of 72” height of 3” diameter packing for installation into UK mini-scrubber	11/30/2023		Written Verification
3	Absorber components capable of > 20% increase in CO_2 mass transfer from bench-scale testing	5/31/2024		Written Verification
4	Initial Techno-Economic Analysis (TEA)	7/31/2023		TEA Report
4	Final Techno-Economic Analysis	5/31/2024		TEA Report

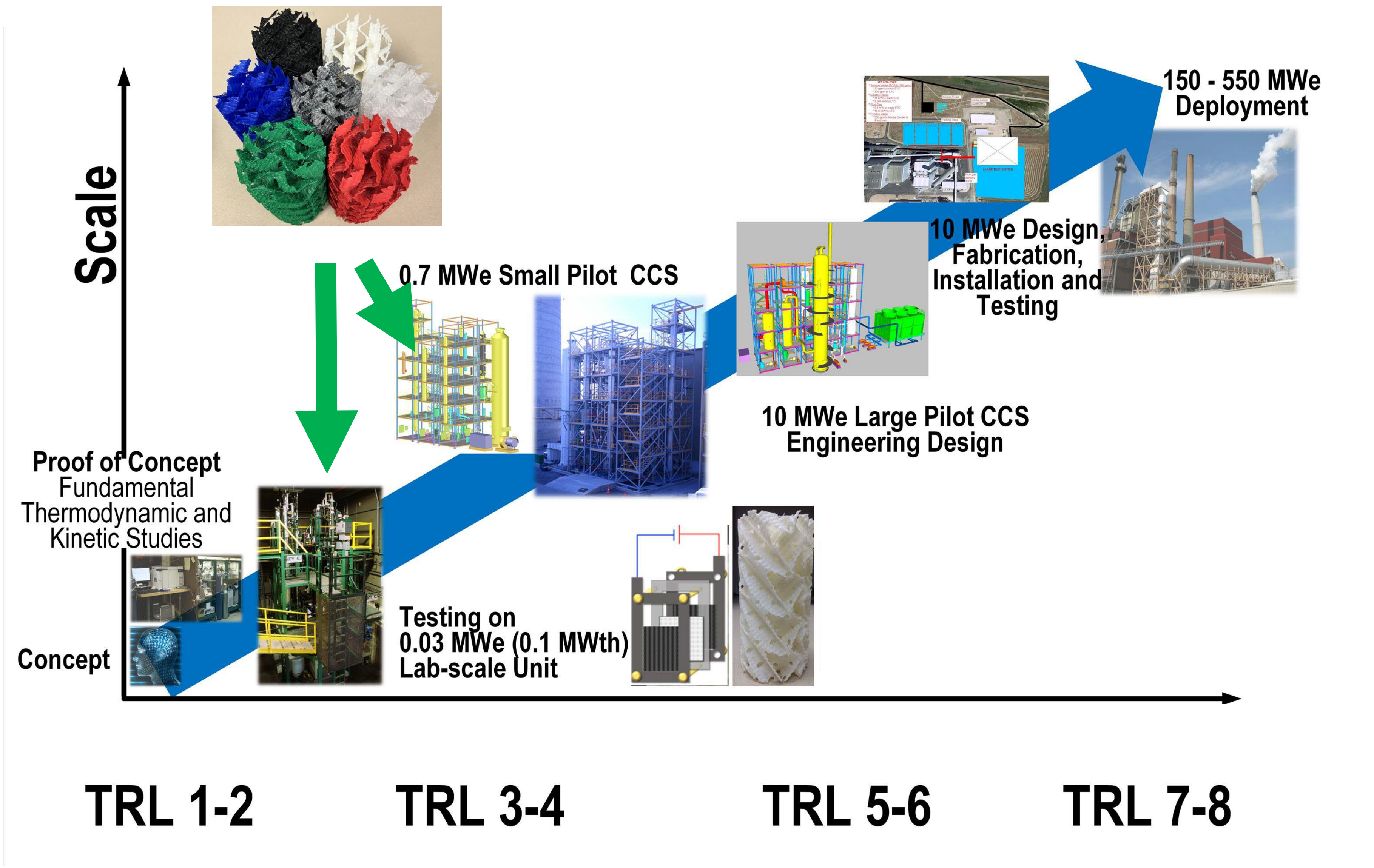
Success Criteria

Task #	Due Date	Success Criteria (Task #)
2	11/30/2023	Fabrication of Polymer Packing: Packing prototype with 10% increase in solvent wetting as measured by dynamic contact angle
3	5/31/2024	Testing of Absorber Components: A completed test for the absorber components to achieve the target >20% mass transfer enhancement
1,4	5/31/2024	Collection of experimental data for update of TMP, State Point Data Table and TEA
4	5/31/2024	TEA: Demonstrate 97% capture efficiency and significant progress toward a 40% reduction in the cost of carbon capture vs. a reference NGCC plant with carbon capture.

Project Schedule

					Federal FY 22/23 - 23/24						
Task Number and Name	Length (months)	Start	End	Leader	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1. Project Management and Planning	19	2/1/23	8/31/24	UK CAER							
1.1 Project Management Plan	19	2/1/23	7/31/24								
1.2 Technology Maturation Plan	19	2/1/23	7/31/24								
1.3 State Point Data Table	16	2/1/23	5/31/24								
M1:Updated Project Management Plan	1		2/28/23		☆						
M2:Kickoff Meeting	2		3/31/23		☆						
M3:Establish Subcontracts	3		4/30/23			☆					
M4: Initial Technology Maturation Plan (TMP)	3		4/30/23			☆					
M5: Final Technology Maturation Plan (TMP)	16		5/31/24							☆	
M6: State Point Data Table	16		5/31/24							☆	
2. Design and Fabrication of Absorber Reactor Components	10	2/1/23	11/30/23	UK CAER							
2.1 Physical Property Measurements of WLS co-solvents	3	2/1/23	4/30/23								
2.2 Polymeric material stability	9	2/1/23	10/31/23								
2.3 Component Design Specifications	6	2/1/23	7/31/23								
2.4 Fabrication of Absorber Reactor Components	4	8/1/23	11/30/23								
2.5 Dynamic contact angle measurements	7	5/1/23	11/30/23								
M7: Identification of polymer that is stable for 5000 hrs in the WLS at absorber temperatures of > 50 °C			10/31/23					☆			
M8: Production of components for installation into UK mini-scrubber			11/30/23					☆			
3. Bench testing of Absorber Components	9	12/1/23	8/31/24	UK CAER							
3.1 Modification of CO2 mini-absorber	1	12/1/23	12/31/23								
3.2 Testing of Absorber Components	5	1/1/24	5/31/24								
3.3 Solvent and Component Degradation	8	1/1/24	8/31/24								
M9: Absorber components capable of > 20% increase in CO2 mass transfer from bench-scale testing			5/31/24							☆	
4. Techno-Economic Assessment with Technology Gap Analysis	19	2/1/23	8/31/24	EPRI							
M10: Issue initial TEA			7/31/23				☆				
M11: Issue Final TEA Report			5/31/24							☆	

Technology Development



Acknowledgements

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