High Purity Oxygen Generation through Modular Structured Rapid Pressure Swing Adsorption

DE-FE0032335

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National Energy Technology Laboratory
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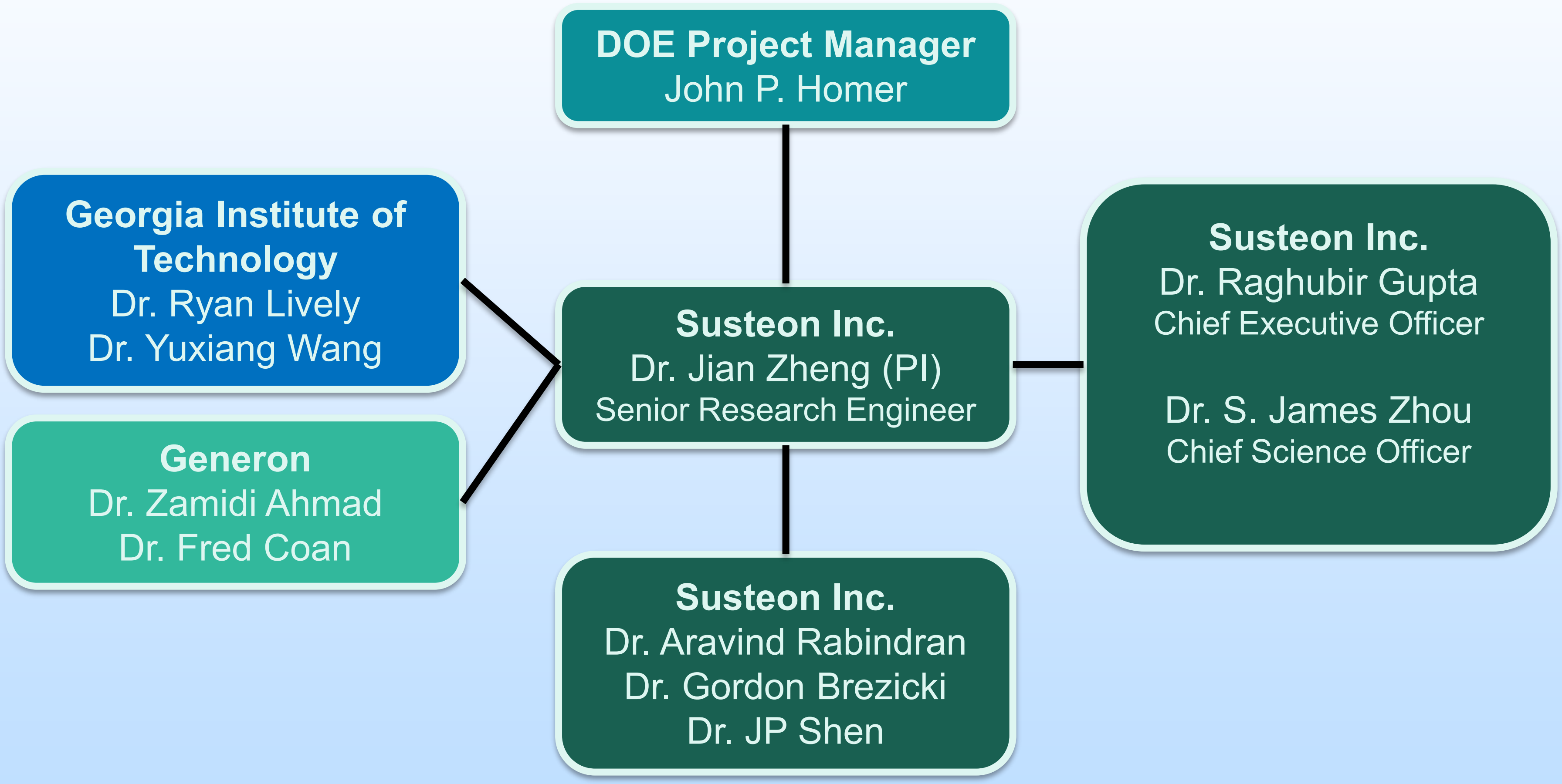
Project Overview

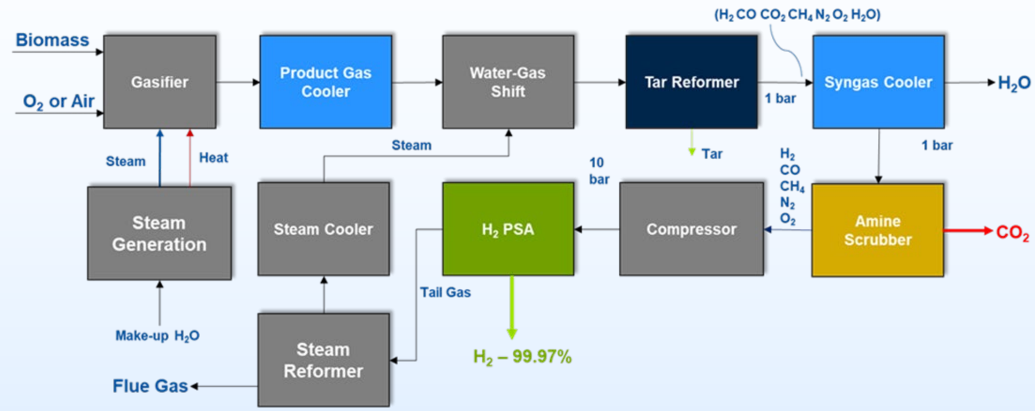
Period of Performance	10/01/2023 – 09/30/2025	
Project Funding	DOE: $1,250 K	Cost-Share: $312.5 K
Overall Project Goal	Development of a novel RPSA process for high-purity (>95%) oxygen production at <$45/ton.	
Project Participants	Susteon Inc Georgia Institute of Technology Generon	
DOE/NETL Project Manager	Mr. John P. Homer	

Organization Chart



Technology Background – High Purity H_2

- DOE/NETL is targeting clean H_2 production through biomass/waste gasification, with ultimate cost goal of ≤ \$1/kg H_2



- High-purity oxygen allows higher H_2 productivity

Syngas composition for air and oxygen fed gasification of biomass

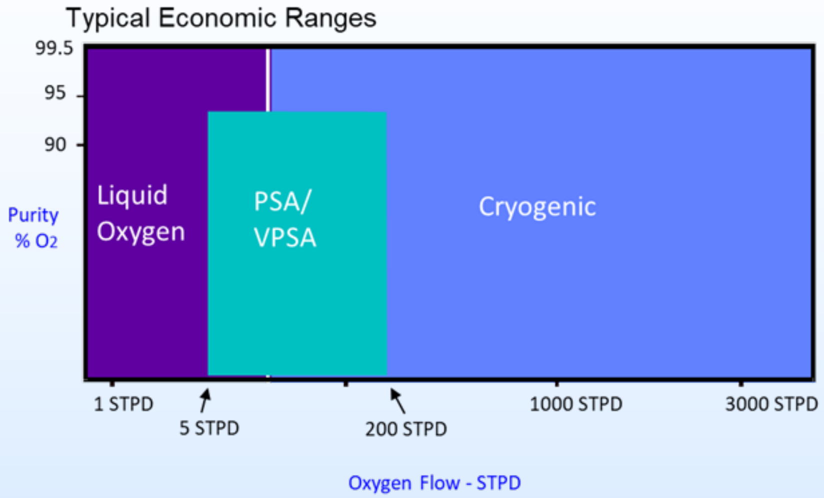
PSA Inlet Syngas Conc.	Oxygen Conc. %		
	21 v%	96%	100 v%
H_2	28.9%	82.1%	85.3%
CO	2.24%	2.47%	2.22%
CO_2	0.03%	0.01%	0.01%
CH_4	3.38%	11.24%	10.10%
N_2	65.0%	4.14%	2.42%
LHV, MJ/Nm^3	4.09	9.34	9.61
Biomass feed, kg/hr	33,393	33,393	33,393
PSA H_2 Recovery	49%	80%	87%
H_2 Product Rate, kg/hr	862	1431	1500

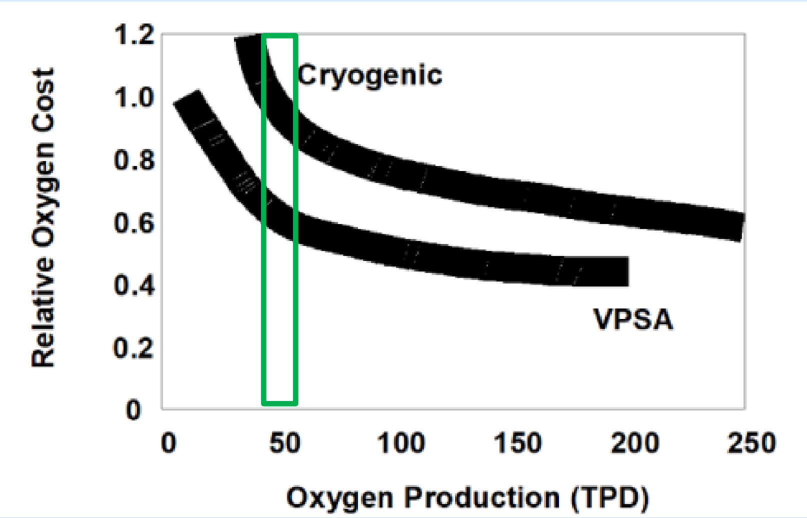
- Critical to produce high-purity (>95%) oxygen at low cost

Wang, Z. et al.; *Fuel* **2015**, *150*, 386

High Purity O_2 through Commercial ASU

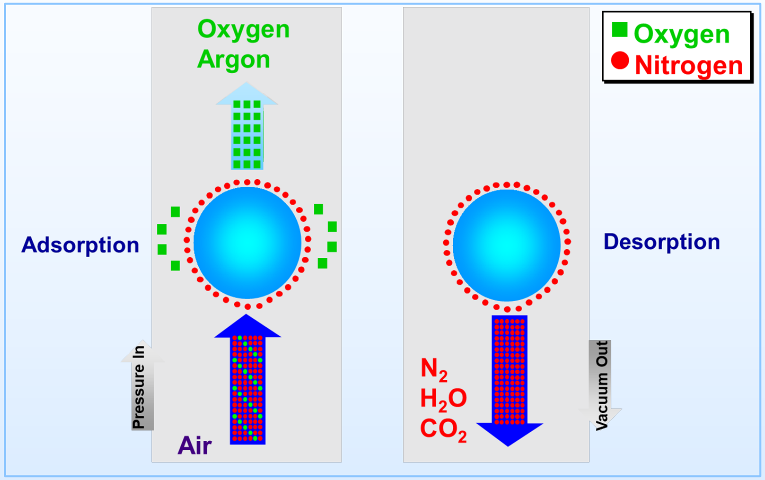
- Flexible and modular 5 MW biomass gasification systems typically require 50 ton/day (TPD) of oxygen
- DOE Requirement for O_2
  - > 95% purity, < $45-50/ton
- Cryogenic air separation unit (ASU) does not meet the requirement
  - Can produce 99+% pure O_2
  - Typical Size: 1000 – 4000 TPD
  - Oxygen costs: $33/ton to $70/ton, depending on scale and site
  - Does not scale down cost-effectively below 200 ton/day

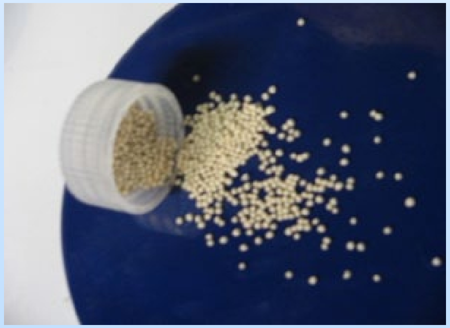




O_2 Production through Commercial VPSA

- Commercial VPSA is based on LiX zeolite beads
  - Can only produce ~90% purity O_2 (due to presence of 1% Ar in air)
  - Typical size: 5 – 250 TPD
  - Oxygen cost $50/ton to $80/ton
  - Power consumption contributes to ~ 50% of O_2 production cost with **high △P**
  - Poor operational reliability





LiX bound with dense clay

This project:

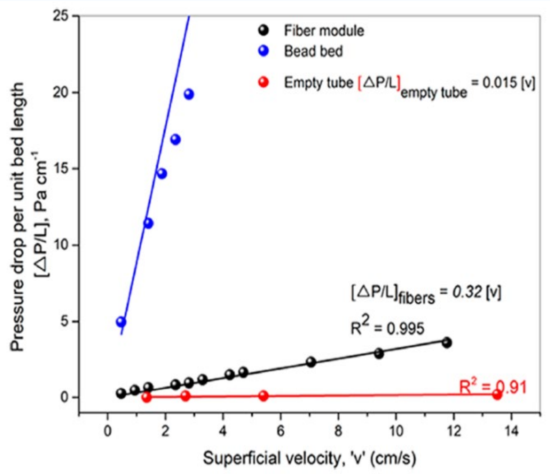
Fiber-adsorbents

LiX bound in porous polymer

Technical Approach Step#1 – Fiber RPSA

Fabricate zeolite adsorbent in fiber form

- Reduce the pressure drop, attrition, and dusting of the current beaded bed system by using **fibrous-structured** adsorbent
  - Order of magnitude lower △P
- Reduce the bed size factor (BSF) by employing rapid cycles in PSA using fiber structured beds
  - >30% lower BSF (equivalent to higher throughput)
- Maximize adsorption capacity and rate through optimized fiber manufacturing with suitable polymer binder

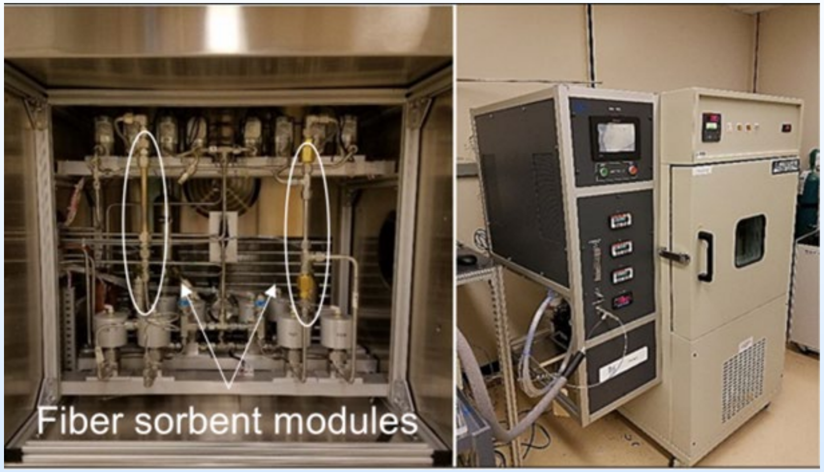


Sujan, A. R. et al.; *Ind. Eng. Chem. Res.* **2018**, *57*, 11757.

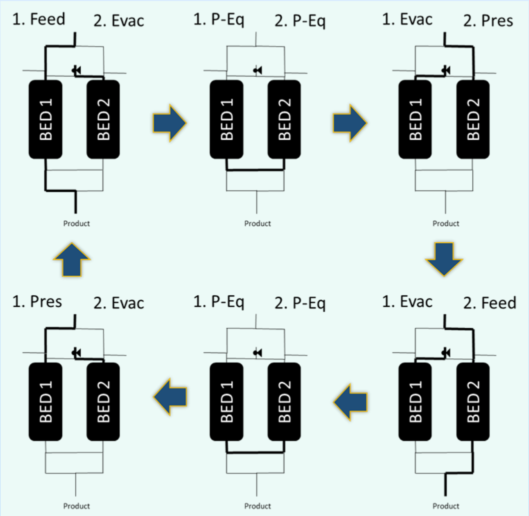
Performances	Typical Beads	Target Fibers
Bed Size Factor - BSF (lb of adsorber/ton O_2/day)	600	400
Recovery (%)	55	65
Spec Power (kWh/ton)	250	210

Preliminary Lab Fiber RPSA Testing

- Fully automated rapid cycles (< 20 seconds)
- Two-bed system operates at cyclic steady-state

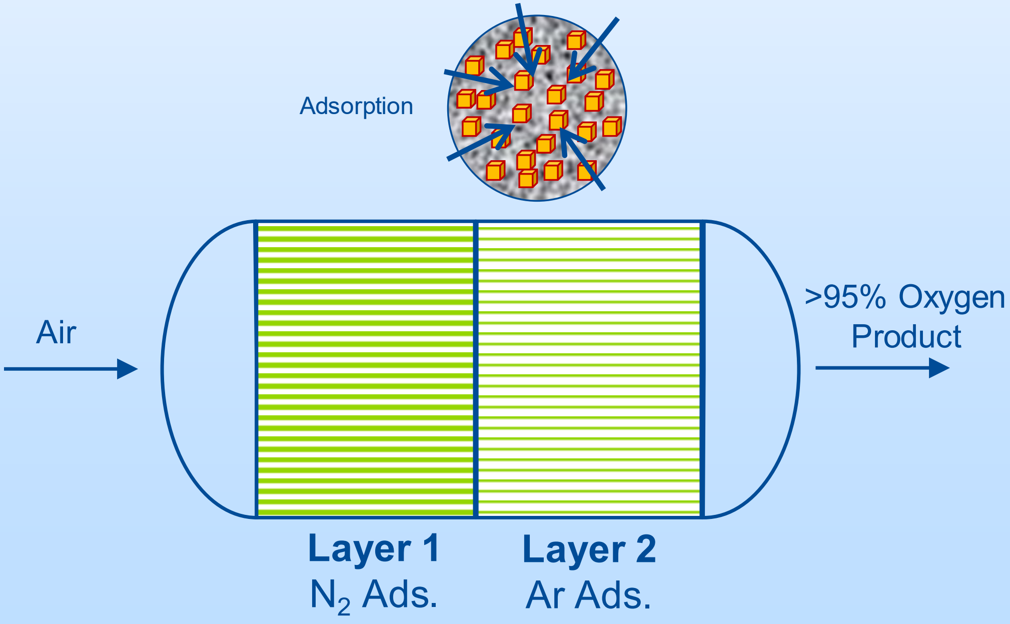


Feed Gas	O_2 Target	O_2 Purity Achieved	Bed Size Factor (lb/TPD)	O_2 Recovery
Dry Air	> 90%	90.2%	360	67.4%



Technical Approach Step#2 – High Purity O_2 through 2-Layer Fiber RPSA

- **Introduce a 2nd-layer adsorbent, also in fiber form, specifically for Ar-removal as further purification of ~90% → 95+% O_2**
  - Explored AgX zeolite as the known Ar-selective adsorbent
  - Novel carbon molecular sieve (CMS) showed surprisingly good Ar-selectivity
    - CMS can be made from readily available cellulose

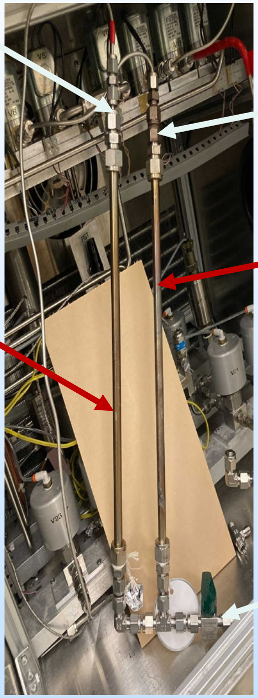


Preliminary 2nd-Layer RPSA Testing

Module Type	Feed Gas *	Pressure Gas **	O_2 Target	O_2 Purity Actual	Bed Size Factor (lb/TPD)	O_2 Rec.
LiX+AgX	SG	SG	> 95%	93.5%	--	--
LiX+CMS	SG	SG	> 95%	94.8%	111	59.0%
AgX	SG	O_2	> 95%	**96.9%**	68	67.4%
CMS	SG	O_2	> 95%	**96.4%**	25	80.9%
LiX+CMS	SG	O_2	> 95%	**98.4%**	141	58.3%

*SG: 90% O_2, 6% N_2, 4% Ar

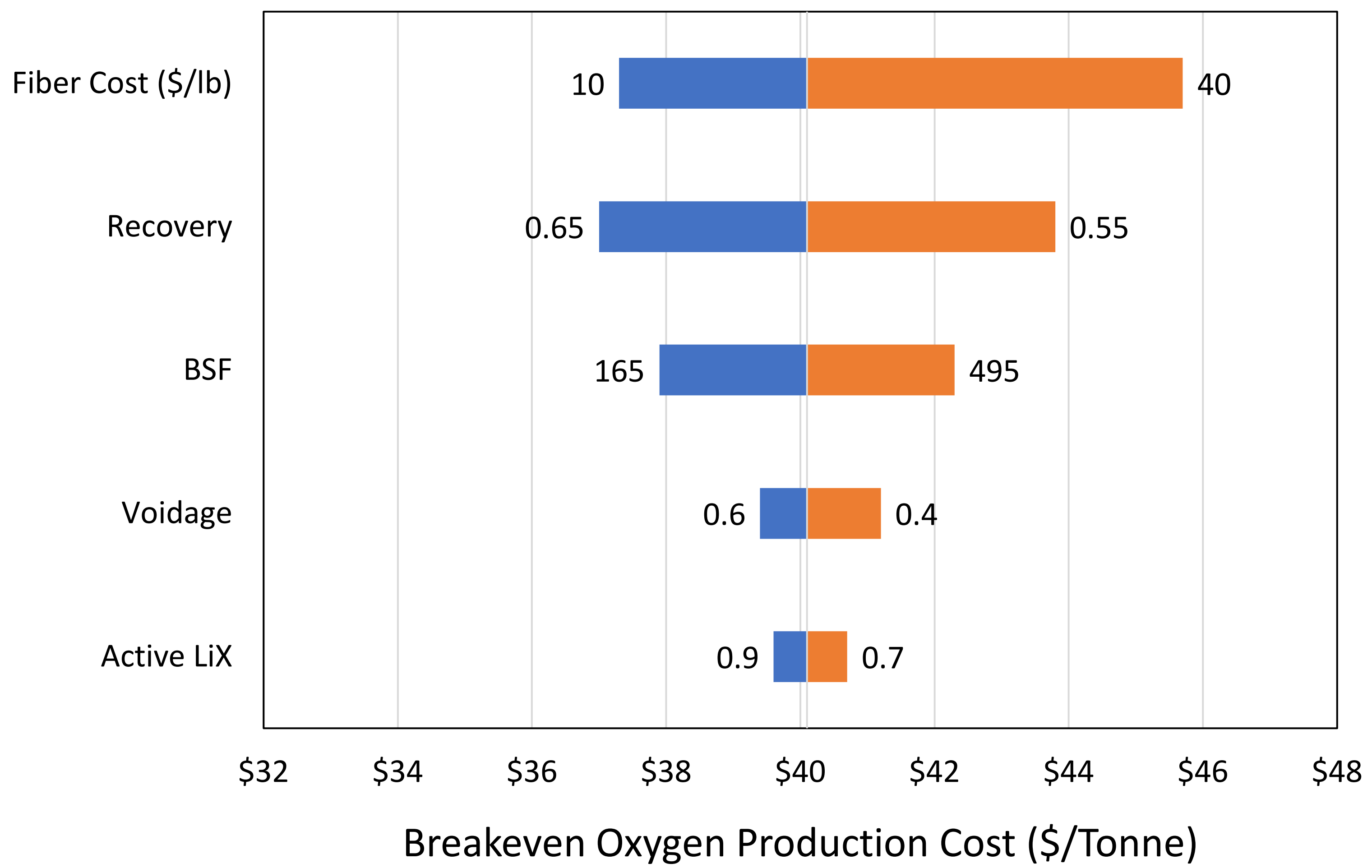
**Pure O_2 pressurization to help counter lab system void



Additonal LiX packed in a few 2nd-layer dual-modules to adjust N_2 removal.

- This approach provides a pathway to produce >95% purity O_2
- Critical to manufacture high-performance fiber adsorbents at **low-cost**

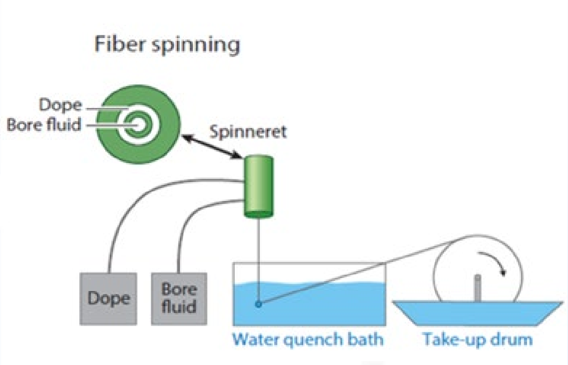
O_2 Cost Sensitivity Analysis - LiX



LiX-Polymer Fiber Spinning Process

Criteria for Suitable Polymer Binder

- Good binding strength with minimum amount
- High thermal stability up to 350°C
- High porosity to allow high gas adsorption
- Cheap and readily available



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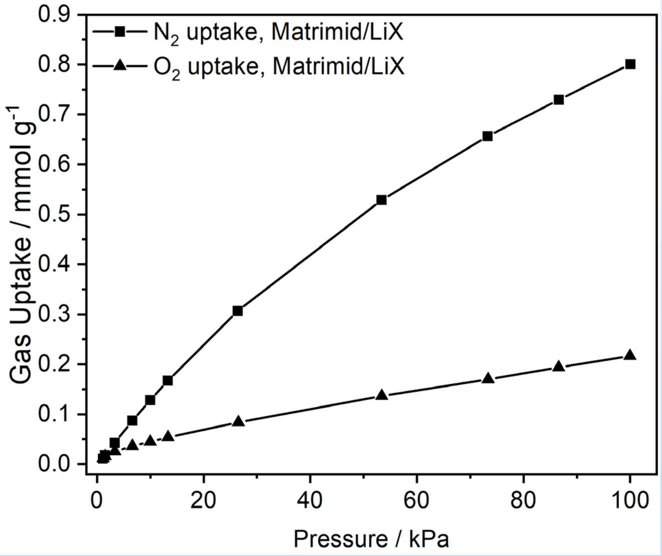
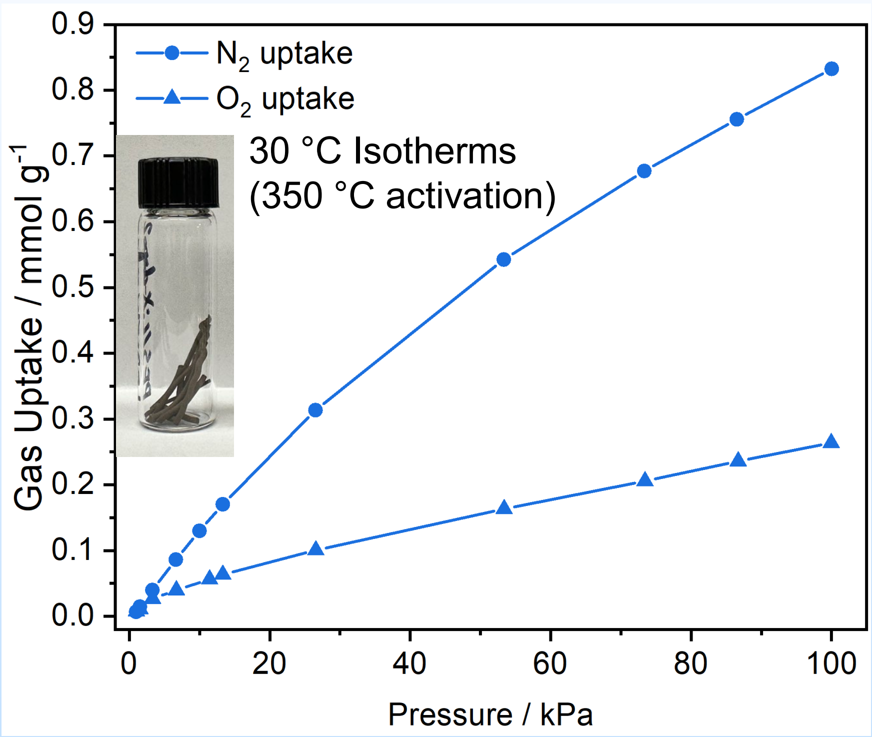


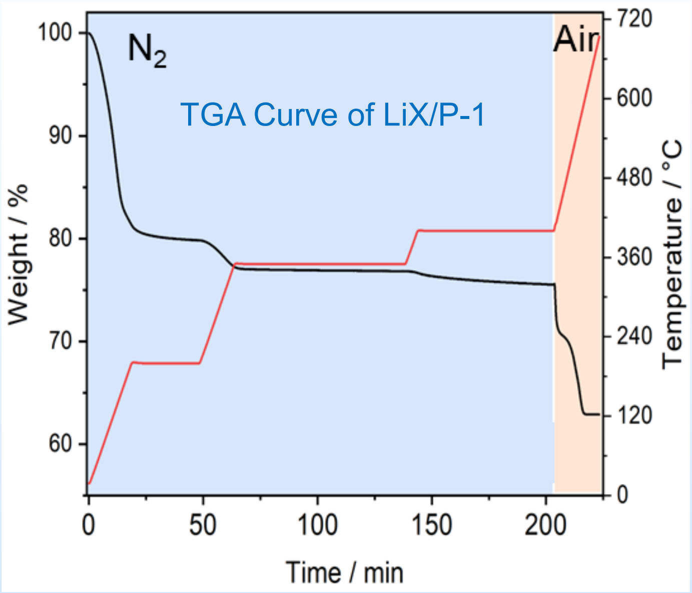
- Matrimid proven to be effective polymer binder
- Matrimid ~ \$300/lb, results in high O_2 cost

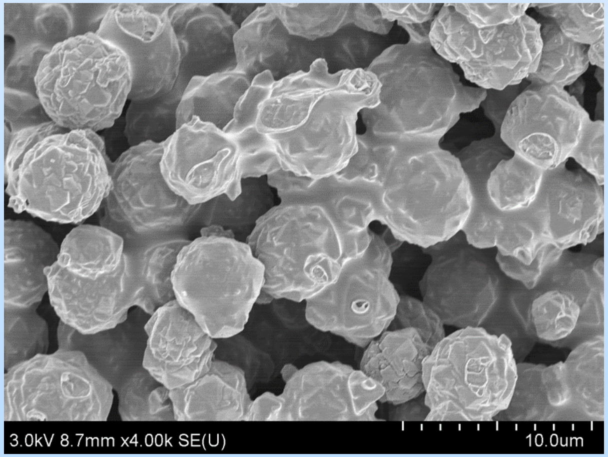
LiX Fiber with Cheap Polymer P-1

P-1, T_g ~ 230 °C



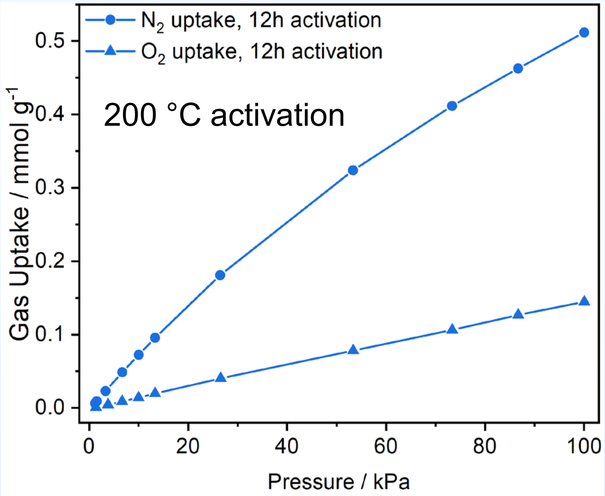
- LiX/P-1 performs equivalent to LiX/Matrimid

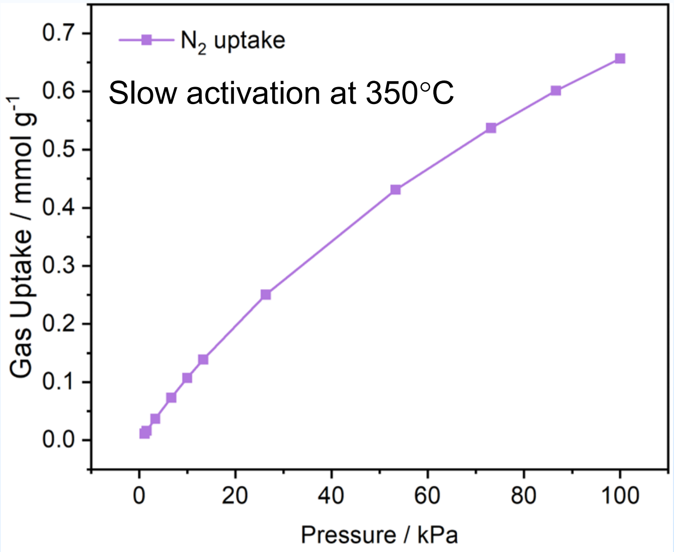


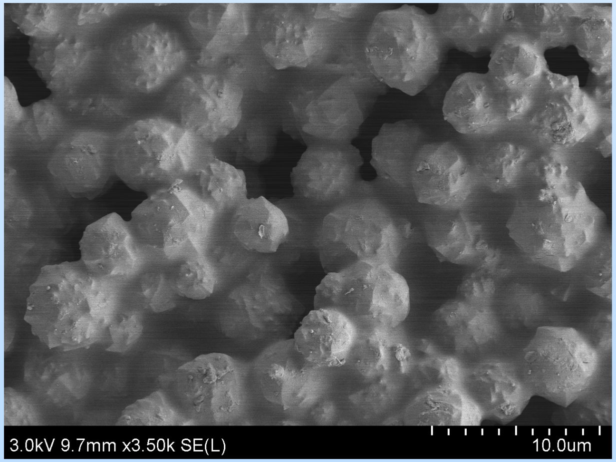


LiX Fiber with Cheap Polymer P-2

P-2, T_g ~ 210 °C





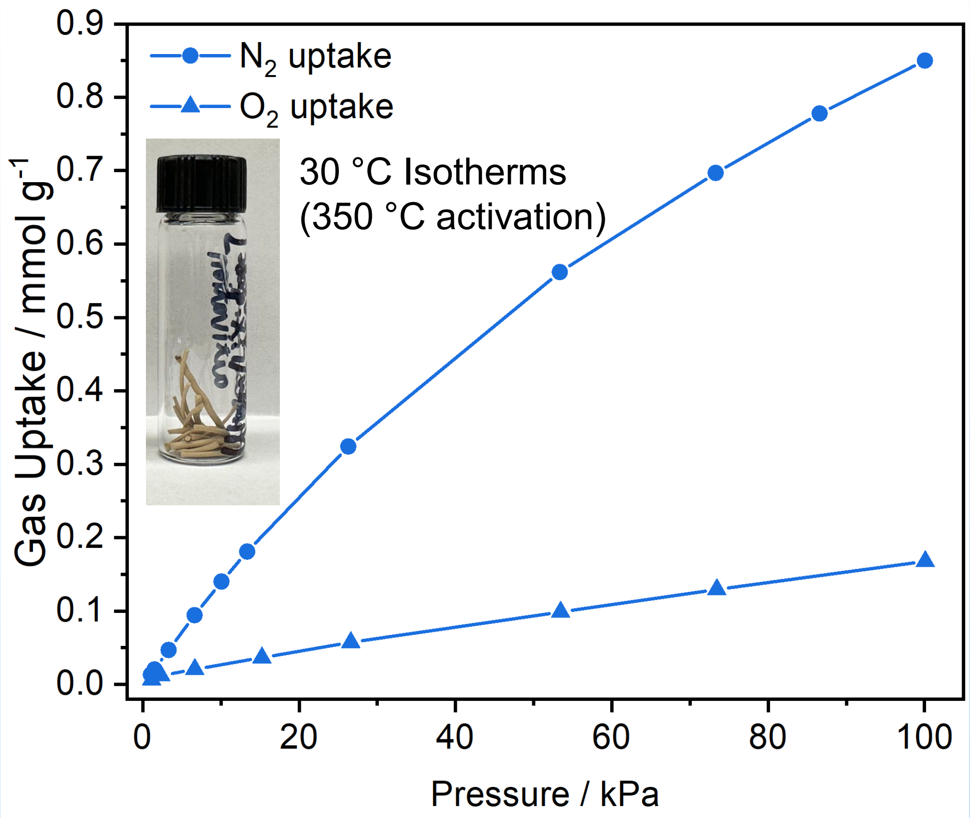


- LiX/P-2 underperforms, even after initial cross-linking attempt

LiX Fiber with Hybrid Polymers

- Form LiX fiber w/ hybrid polymer binders: P-2 + Matrimid
- Change ratio of P-2 : Matrimid

- LiX loading ~ 80 wt%, Total polymer: 20 wt%
- P-2 : Matrimid = 50 : 50

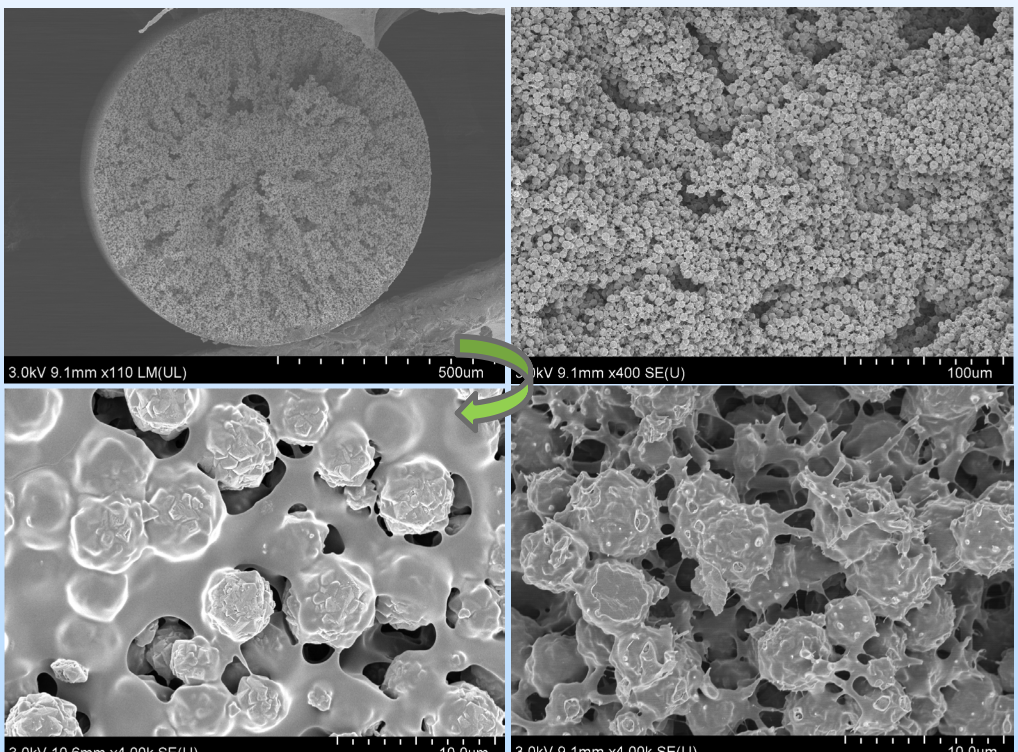


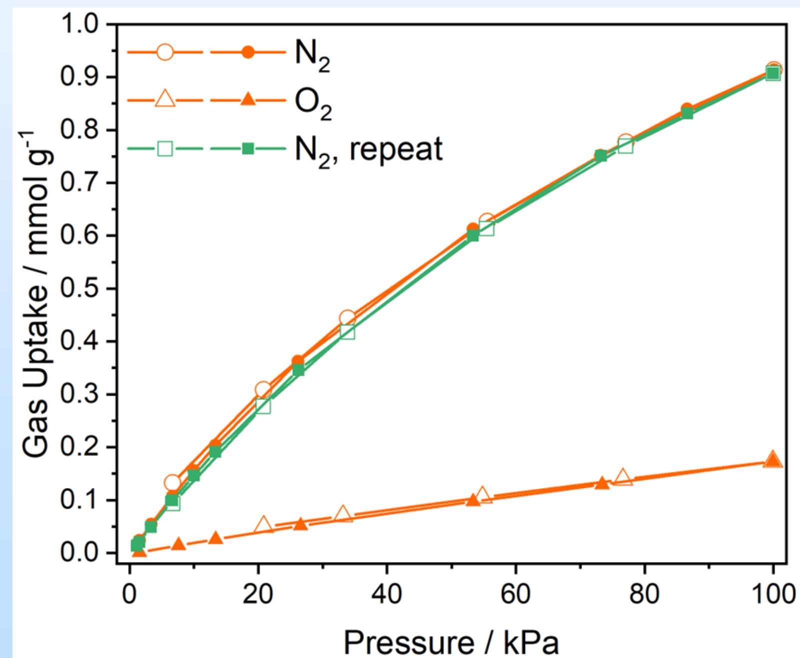
LiX/(P-2 + Matrimid) performs better than LiX/Matrimid

LiX Fiber with Improved & Cheap Hybrid Polymers

- Total polymer content in the fibers: 15 wt%
- Matrimid content in polymers: 10 wt%
- N_2 uptake in LiX can be tuned/maintained with little amount of Matrimid blending

Hybrid polyimides achieve high performance with minimum cost penalty





Summary

- Multiple LiX-polymer fibers were successfully prepared in the lab with LiX ≥ 80 wt%.
- Both LiX/P-1 and LiX/(P-2 + Matrimid) fibers show promising N_2 uptakes and thermal stability.
- Hybrid polymer binders with small addition of Matrimid improves performance, with potential to significantly reduce the overall fiber cost.

Future Work

- Fabricate continuous LiX fiber at production scale and perform detailed characterization
- Conduct RPSA testing with improved fiber bundles
- Demonstrate 2-layer design with LiX fibers and CMS
- Perform process design and TEA

Project Schedule

Project Timeline			Months from Project Start Date																							
	Start Date	End Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Task 1.0 - Project Management and Planning																										
Subtask 1.1 Project Management Plan	10/1/2023	9/30/2025																								
Subtask 1.2 Technology Maturation Plan	10/1/2023	12/30/2023																								
Subtask 1.3 Diversity, Equity, Inclusion and Accessibility (DEIA) Plan	10/1/2023	12/30/2023																								
Milestone 1: Initial TMP within 90 days of Project Start		12/30/2023			★																					
Milestone 2: Update DEIA Plan within 90 days of Project Start		12/30/2023			★																					
Task 2.0 – Fiber Structured Adsorbent Optimization																										
Subtask 2.1: Optimization of the Fiber Structured Adsorbent Formulation	10/10/2023	1/31/2024																								
Subtask 2.2: Optimization of the Fiber Packing and Lab RPSA Test Conditions	11/10/2023	6/30/2024																								
Subtask 2.3: Synthesis of Selected Fiber Structured Adsorbents for Prototype Testing	1/10/2024	9/30/2024																								
Task 3.0 – Design and Fabrication of Modular RPSA Prototype System																										
Subtask 3.1. Complete Detailed Design Specifications, P&ID, Control Specifications	4/10/2024	7/30/2024																								
Subtask 3.2. RPSA System Design	4/10/2024	7/30/2024																								
Subtask 3.3. Process Hazard Analysis, Instrument List, and Equipment and Fabricator	6/1/2024	12/31/2024																								
Subtask 3.4. Equipment procurement, component fabrication, prototype installation	6/1/2024	12/31/2024																								
Task 4.0 – Prototype Unit Commissioning and Testing																										
Subtask 4.1. Prototype Unit Commissioning and PSSR	10/1/2024	2/28/2025																								
Subtask 4.2. Parametric Testing with Integrated Prototype Unit	10/1/2024	3/30/2025																								
Subtask 4.3. Extended Testing with RPSA Prototype Unit	10/1/2024	6/30/2025																								
Milestone 3: > 95% O_2 purity with > 100 hours of RPSA cycles		6/30/2025																					★			
Task 5 - Process Design and Analysis																										
Task 5 – Process Design and Analysis	2/1/2025	6/30/2025																								
Task 6 - Techno-Economic and Life Cycle Analysis																										
Subtask 6.1 – Process Model Update	3/1/2025	6/30/2025																								
Subtask 6.2 – Techno-Economic Analysis (TEA)	5/1/2025	9/30/2025																								
Milestone 4: Final TEA/TMP within 90 days of Project Compeletion		9/30/2025																								★

Acknowledgement

- DOE NETL
  - DOE SBIR
- Program Manager
  - John Homer

- THANKS FOR YOUR ATTENTION

SUSTEON