Bench-scale Development of a Transformational Switchable-hydrophilicity Solvent-enabled Absorption Process for Energy-efficient CO_2 Capture and Fixation

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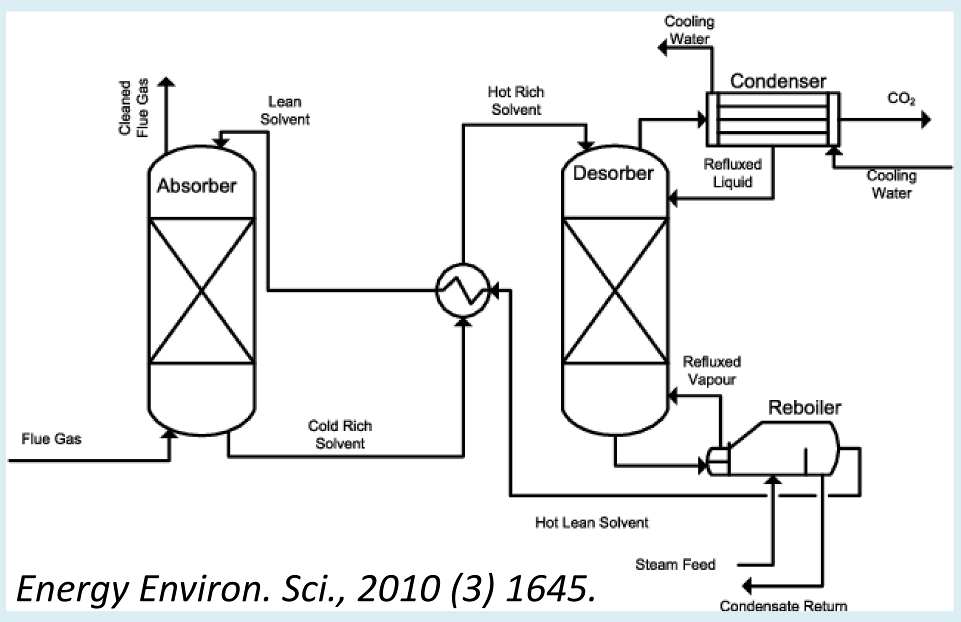
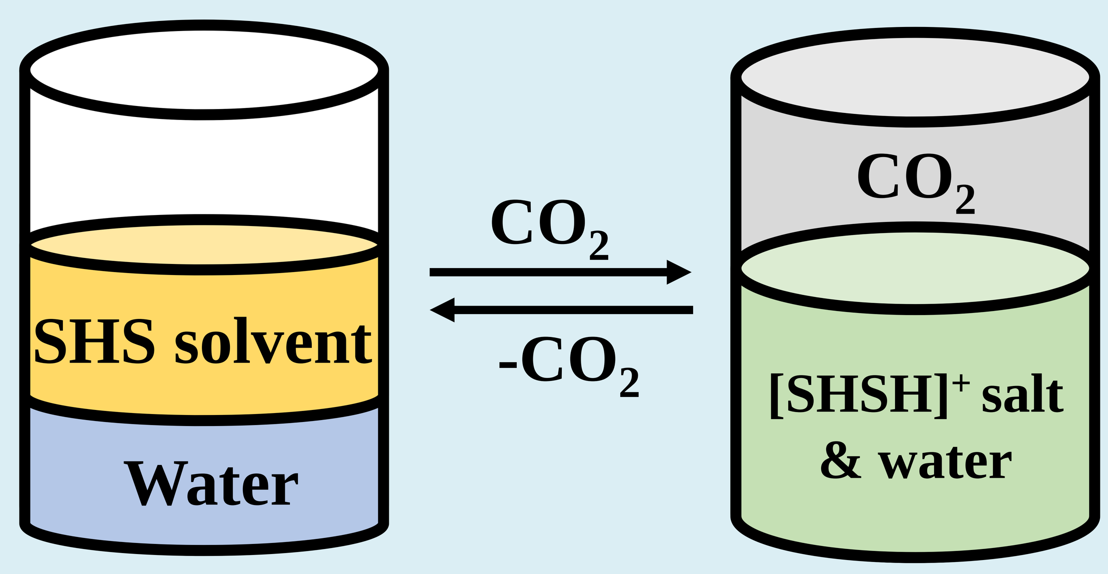
MOTIVATION

A new switchable-hydrophilicity solvent (SHS) based post-combustion CO_2 capture technology delivering both carbon capture and fixation can significantly improve the energy efficiency of CO_2 capture process



Energy Environ. Sci., 2010 (3) 1645.



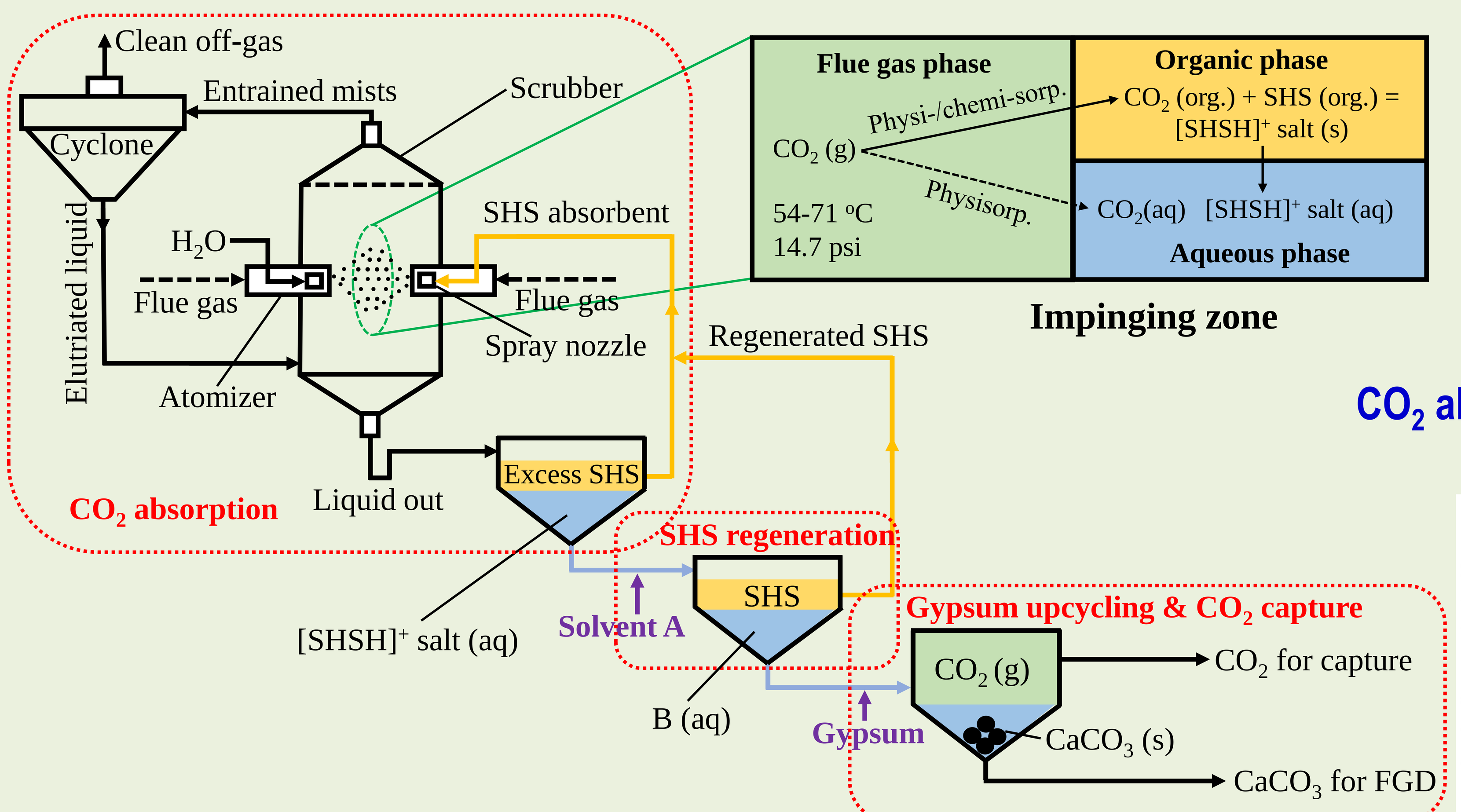
GRAND CHALLENGES FOR CCS WITH CONVENTIONAL AMINE ABSORBENTS

- Fast amine solvent loss rate due to thermal and oxidative degradation
- High energy penalty for rich solvent regeneration
- Conventional carbon emissions mitigation technologies generally suffer up to 40% or more of the energy output of a coal-fired power plant

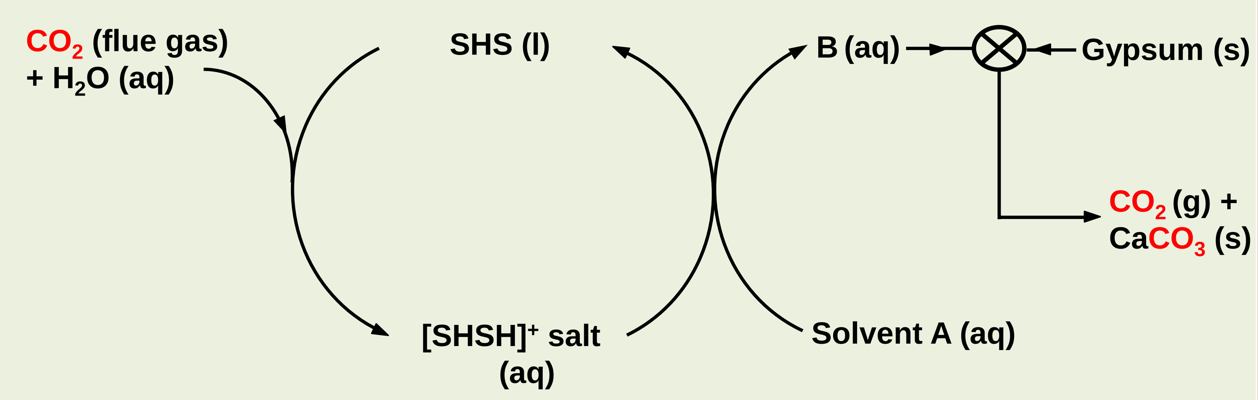
OVERALL OBJECTIVES

- Design an integrated carbon capture process to improve energy efficiency
- Build a gas-liquid impinging scrubber with fast interfacial mass transfer rate
- Regenerate rich solvent at ambient or mild temperature
- Offer a sustainable approach to effective waste valorization

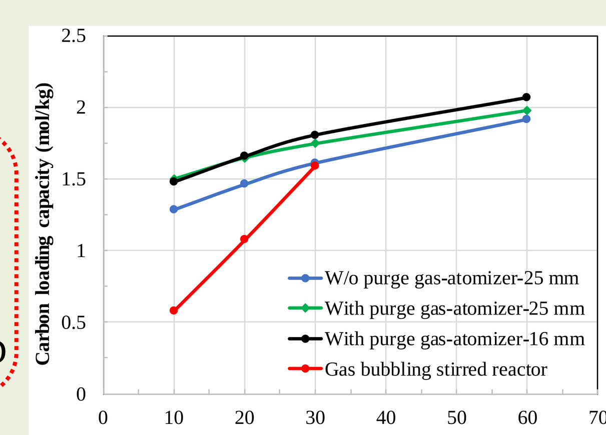
CARBON CAPTURE AND CONCURRENT GYPSUM WASTE UPCYCLING



Carbon capture and fixation are accomplished by three key steps



CO_2 absorption capacity is doubled due to this unique cycle design



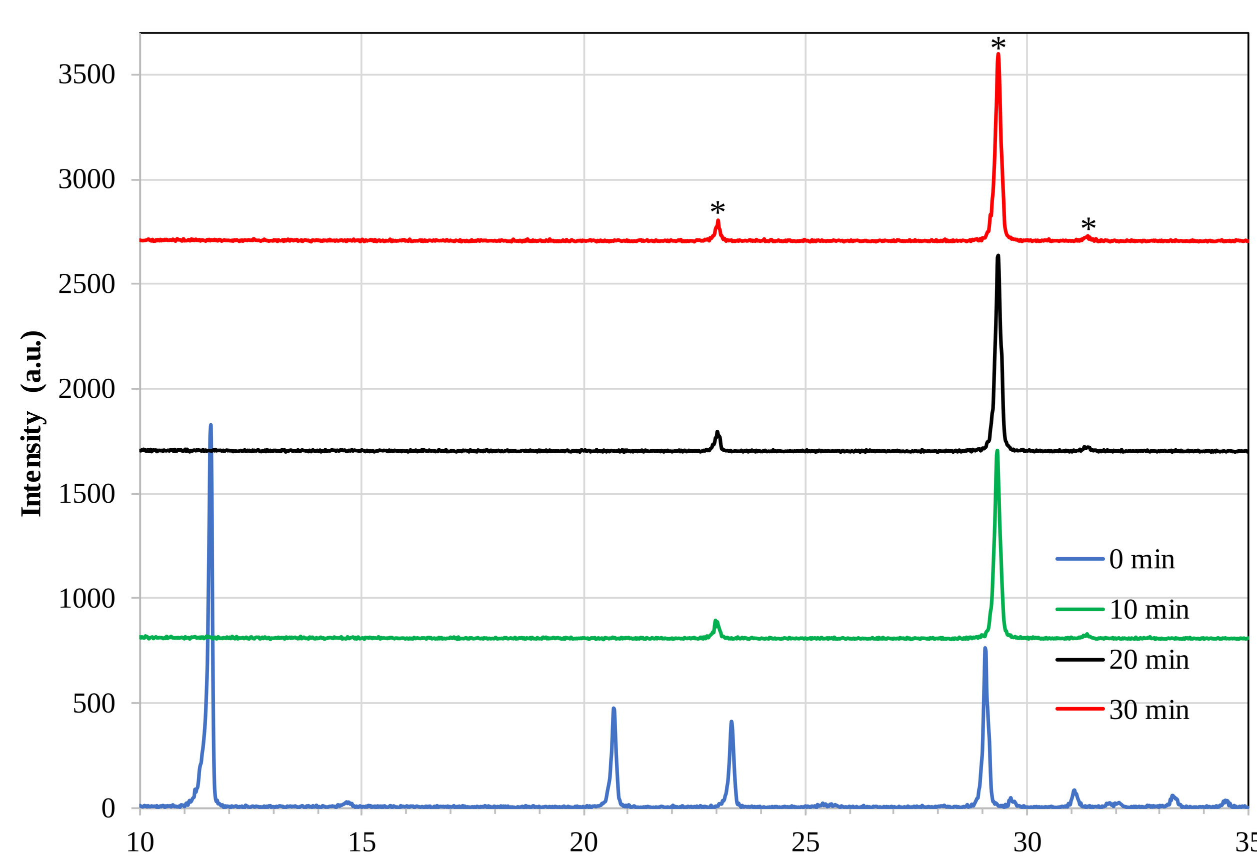
- Greatly broadeded accessibility window for biphasic solvent selection
- Fast CO_2 absorption kinetics by way of new scrubber
- Purge gas streams enhance CO_2 absorption rate to some extent
- Inter-tip spacing has a little effect on CO_2 absorption kinetics
- No frothing issues during reactions

KEY INNOVATIONS

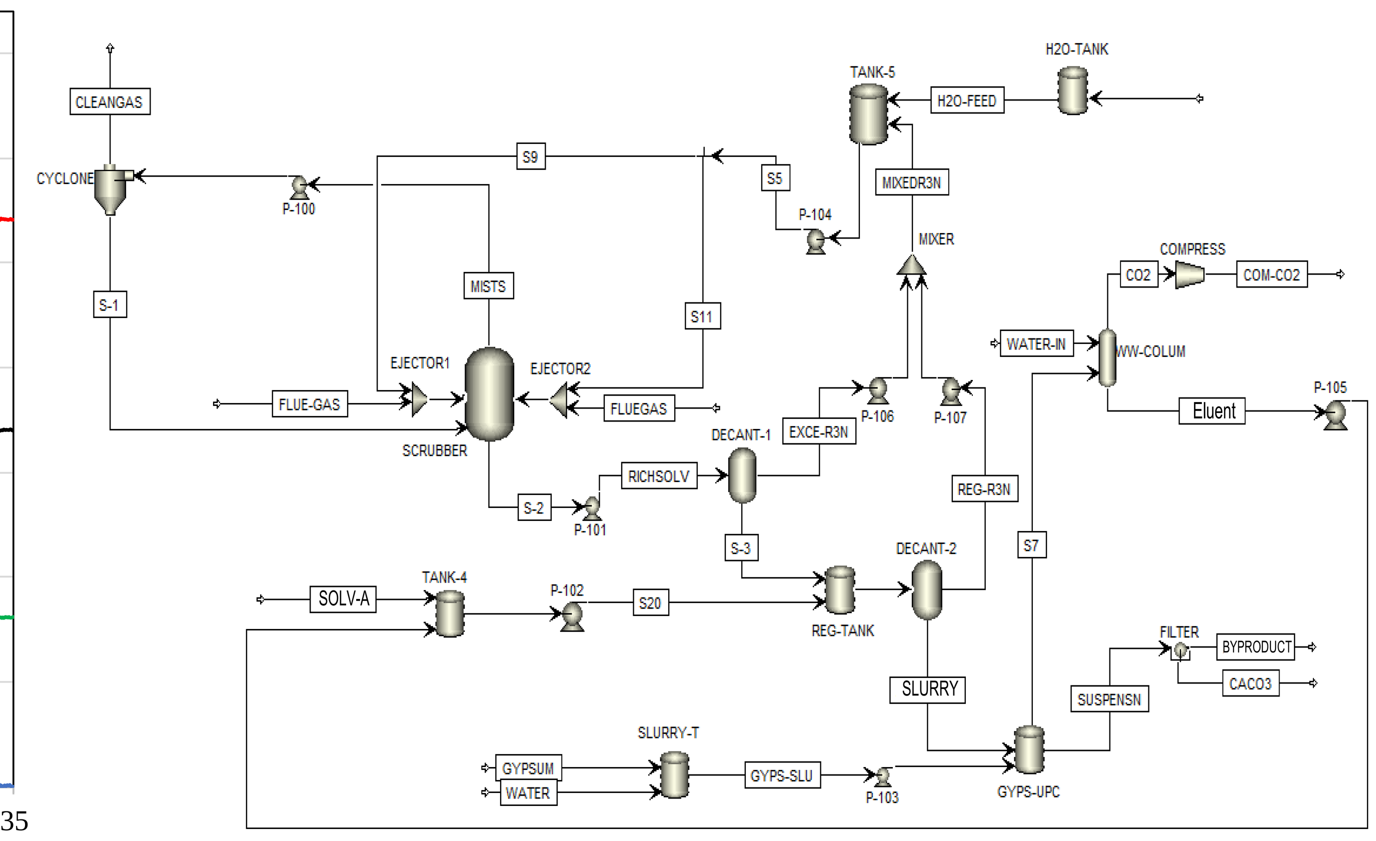
- **Absorption reaction/extraction coupling to break up chemical equilibrium limitations**
- **Low *T* rich solvent regeneration to mitigate solvent makeup rate, equipment corrosion, and energy consumption**
- **Gypsum waste upcycling to limestone sorbent to enable direct use of low-grade coal**
- **Innovative design and integration of sub-systems to deliver energy-efficient carbon management process**

Regenerant	Regeneration Temp. (°C)	Regeneration time (min)	ER (%)
A1	40	10	83.33
	50	10	85.71
	65	10	88.00
	65	52	88.10
A2	R.T.	10	95.23
	65	45	100.00
A3	40	20	No LLPS
	50	10	87.00
	65	10	90.72
	65	30	94.00

- ✓ Spontaneous liquid-liquid phase separation (LLPS) promotes a deep regenerability of rich solvents under mild operating conditions
- ✓ Final equilibrium recovery (ER) of lipophilic SHSs is roughly independent of initial carbon loading of rich solvents

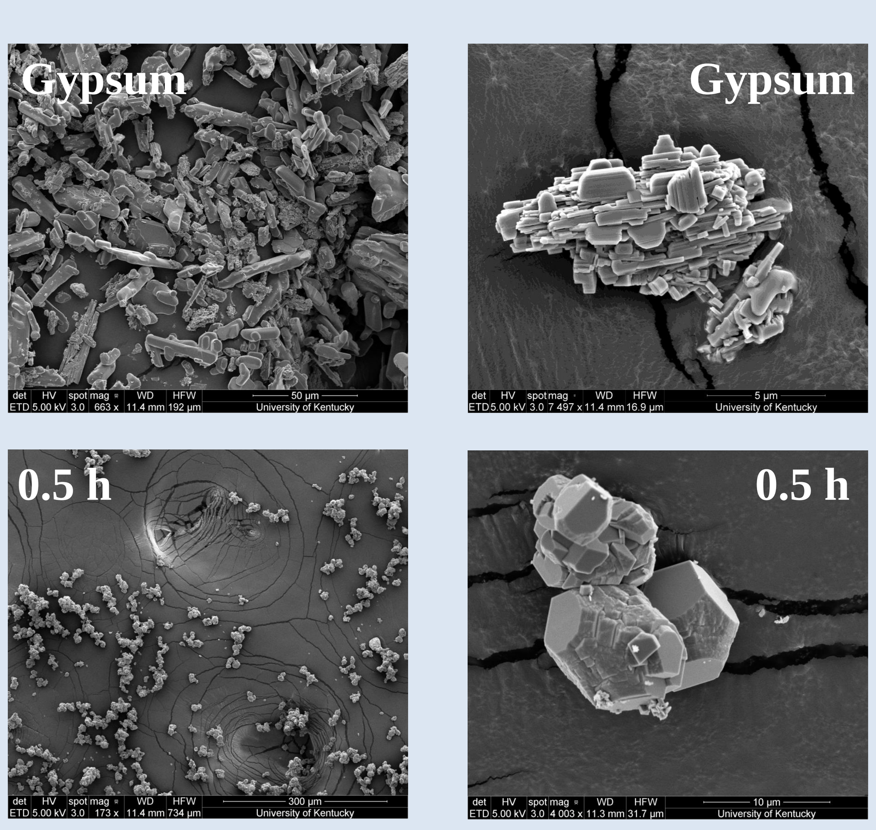


Gypsum conversion to limestone at 40 °C (0 min: gypsum, *: calcite, and limestone yield: ~100%)



Process flow diagram (PFD) of the whole carbon capture and fixation process used for the TEA

GYPSUM UPCYCLING TO LIMESTONE



Rod-like gypsums are fully transformed into well-faceted calcite crystals within 30 min of reaction time under mild synthesis conditions

CARBON CAPTURE PERFORMANCE METRICS

Metrics	Values
CO_2 loading capacity at 40 °C	≥ 2 mol/kg
Overall cyclic CO_2-equivalent loading capacity	≥ 1.8 mol/kg
CO_2 absorption time	≤ 10 min
ER of rich solvents at T ≤ 65 °C	≥ 95%
Regeneration reaction time	≤ 10 min
Gypsum waste purity	≥ 95%
Gypsum conversion efficiency	≥ 95%
Gypsum carbonation time at T ≤ 65 °C	≤ 10 min
Limestone purity	≥ 95%
CO_2 removal efficiency	≥ 90%
Final CO_2 purity in vapor phase	≥ 95%
Increase in cost of electricity generation	≤ 35%
Overall CO_2 capture cost	~$30/tonne

FUTURE WORK

- Upgrade the whole evaluation apparatus to reach its full bench-scale potential
- Design and assemble the atomizers to enable an overall solvent flowrate on a GPM scale
- A 2nd-generation scrubber will be built and commissioned in-house with novel packing materials in place
- CO_2 absorption kinetics and overall CO_2 cyclic loading capacity will be further enhanced
- Seamlessly integrate the key three-unit operations to enable a continuous operational process
- More exhaustive TEA of this carbon capture technology will be undertaken

ACKNOWLEDGEMENTS

This project is financially supported by the DOE SBIR/STTR Programs (DE-SC0022734) with Mariah I. Young as the PM, and by the KY Cabinet for Economic Development (2022-002-006). The authors would also like to thank LG&E and KU Energy, LLC for its help and support.