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U.S. DEPARTMENT OF ENERGY

DE-FE0032215

Transformational Nano-confined Ionic Liquid Membrane for Greater than or Equal to 97 Percent Carbon Dioxide Capture from Natural Gas Combined Cycle Flue Gas

Shiguang Li, Weiwei Xu, Qiaobei Dong, Howard Meyer, *GTI Energy*
Miao Yu, Fan Wang, Dinesh Behera, *The State University of New York at Buffalo (UB)*

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GTI Energy: 80-year history of turning raw technology into practical energy solutions

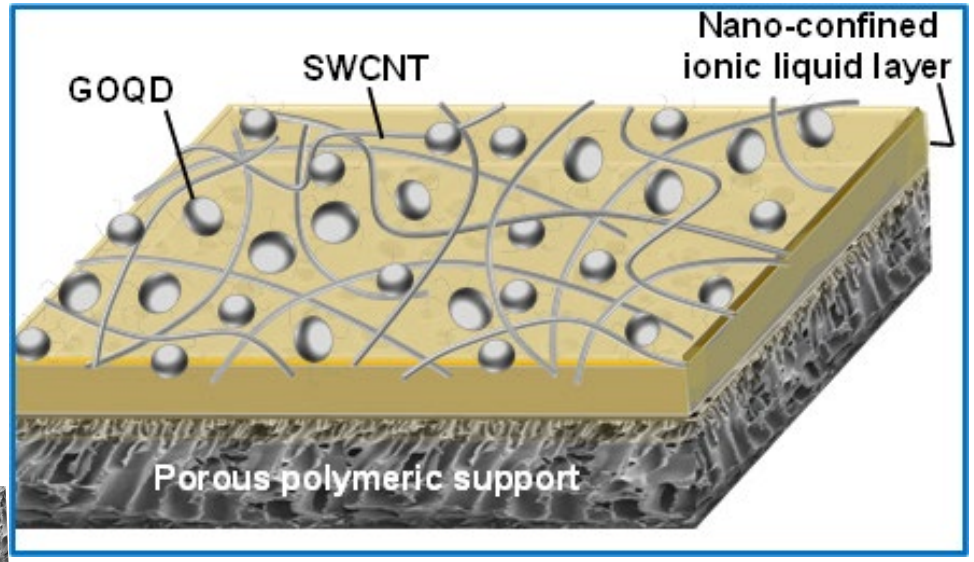
World-class facility in Chicago area

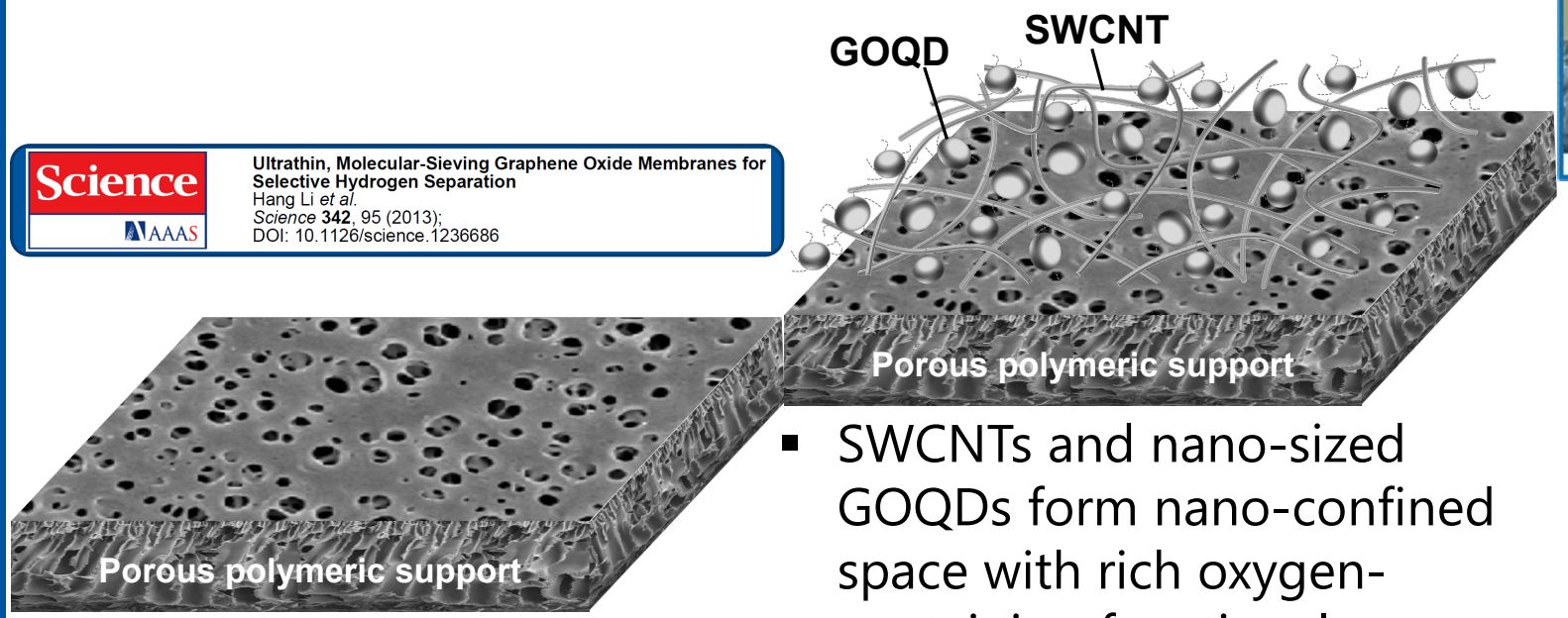
Across the entire energy value chain

CCUS is one of GTI strategic focus areas

- **Carbon conversion**
  - **FE0031909**: Membrane reactors for conversion of CO_2 to fuels/chemicals
- **Carbon capture**
  - **FE0031946**: Engineering scale facilitated transport membrane
  - **FE0031598**: Bench-scale GO-based membrane
  - **FE0032215**: Nano-confined Ionic liquid membrane
  - **FE0031630**: Solvent-based ROTA-CAP
  - **FE0031730**: Size-sieving adsorbent
- **Carbon dioxide removal (CDR)**
  - **FE0031969**: Trapped small amines in capsules
- **Carbon transport and storage**
  - **FE0032239**: CarbonSAFE Phase II

Background: from graphene oxide based membranes to nano-confined ionic liquid (NCIL) membranes





Science AAAS

Ultrathin, Molecular-Sieving Graphene Oxide Membranes for Selective Hydrogen Separation
Hang Li *et al.*
Science **342**, 95 (2013);
DOI: 10.1126/science.1236686

- SWCNTs and nano-sized GOQDs form nano-confined space with rich oxygen-containing functional groups

- Rich oxygen-containing functional groups react with amine groups of the amino acid ILs, stabilizing the ILs inside the nano-confined space
- The viscosity of the IL increases in the nano-confined space, leading a stable membrane structure with CO_2/N_2 selectivity as high as 2,000

SWCNT = single-walled carbon nanotube; GOQD = graphene oxide quantum dot; NCIL = nano-confined ionic liquid

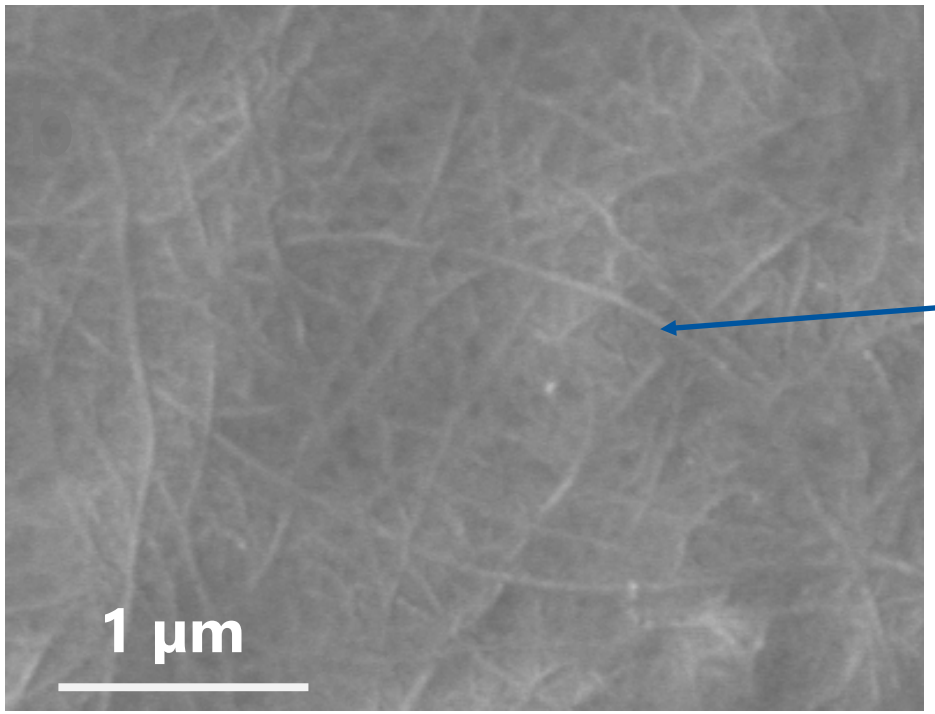
Project overview

- **Performance period**: 3/1/2023-8/31/2024
- **Total funding**: $1,250,000 (DOE: $1,000,000, cost share: $250,000)
- **Objectives**: Develop a transformational membrane technology capturing CO_2 from NGCC flue gas, and demonstrate significant progress towards a 40% reduction in the cost of CO_2 capture versus a reference NGCC power plant for the same carbon capture efficiency
- **Team**:

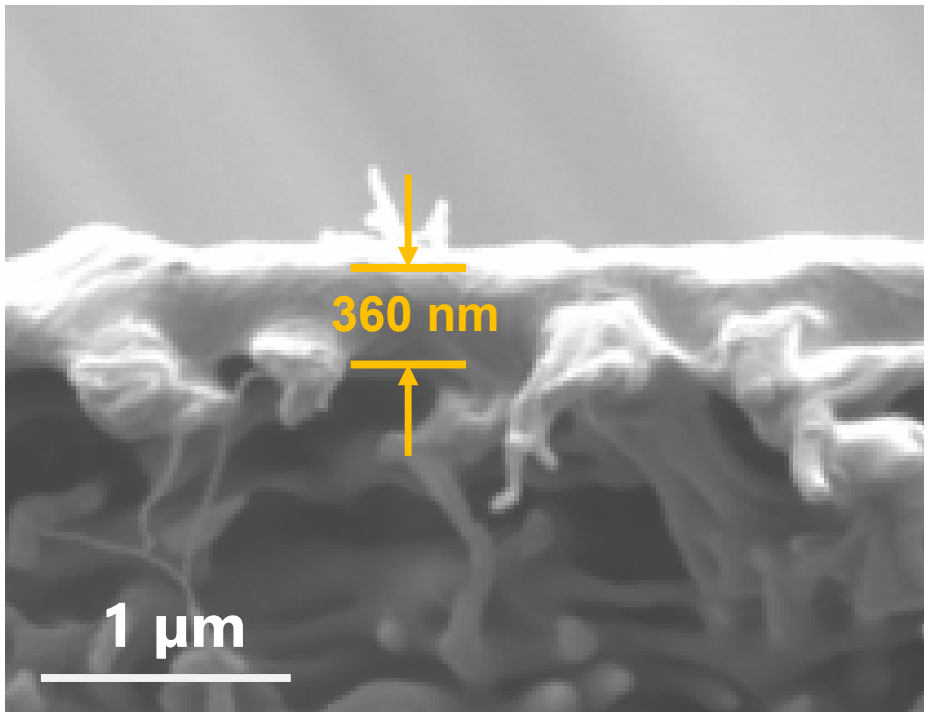
Member	Roles
GTI ENERGY	• Lead on project management and planning • Lead on stability tests, and membrane process modeling • Lead on detailed TEA
UB	• Lead on membrane development • Supporting techno-economic analysis

NGCC = natural gas combined cycle; TEA = Techno-economic analysis

Membranes are coated on commercial PES hollow fiber substrates



Membrane surface SEM



Membrane cross section SEM

PES = polyether sulfone; SWCNT = single-walled carbon nanotube

Tests with simulated NGCC flue gas: good stability, dry-basis CO_2 purity as high as 98 vol%

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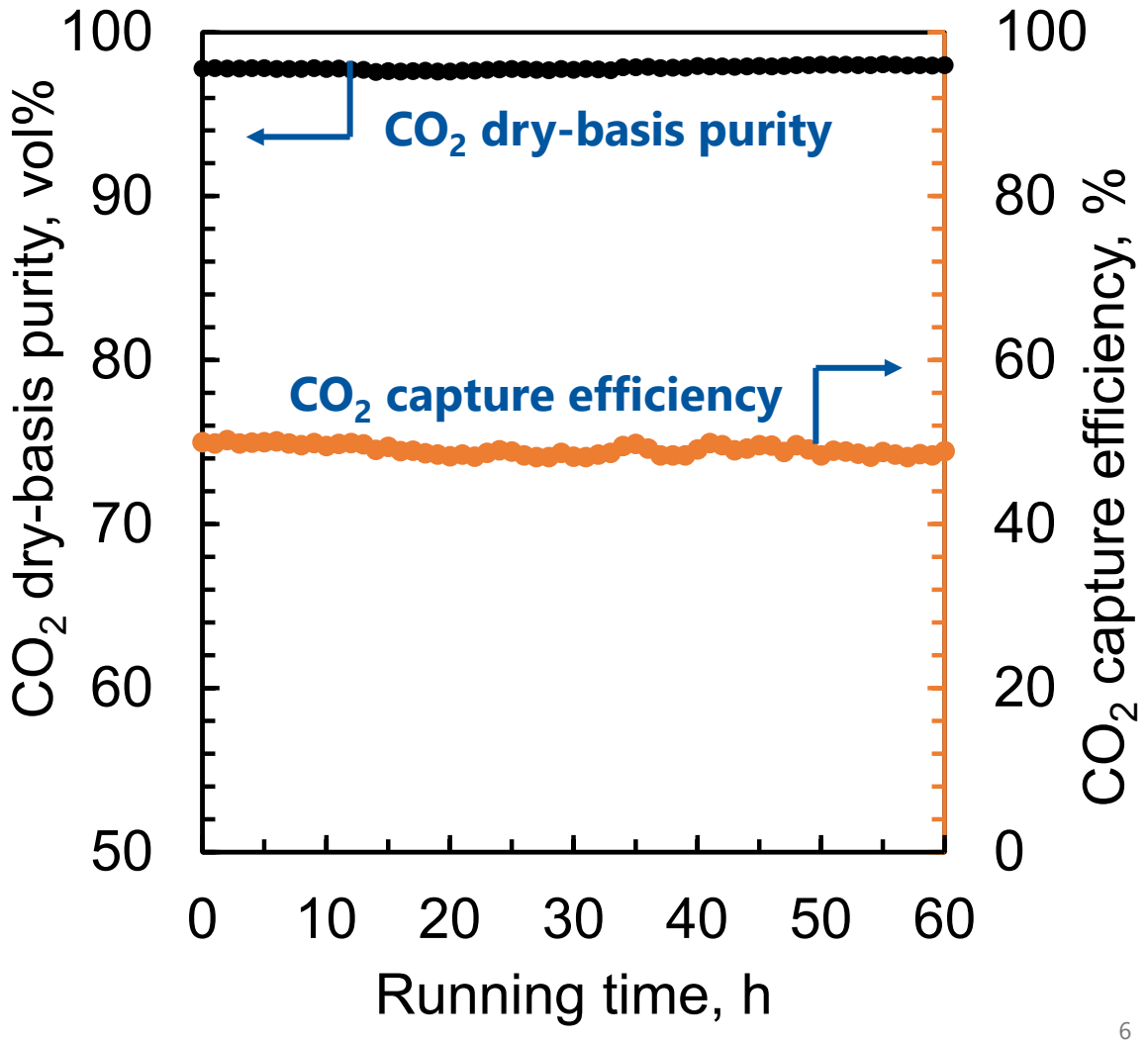
Testing conditions

Membrane area, cm^2	75
Temperature, °C	70
Feed CO_2 concentration, vol%	4.2
Feed pressure, bara	1.0
Permeate pressure, bara	0.15

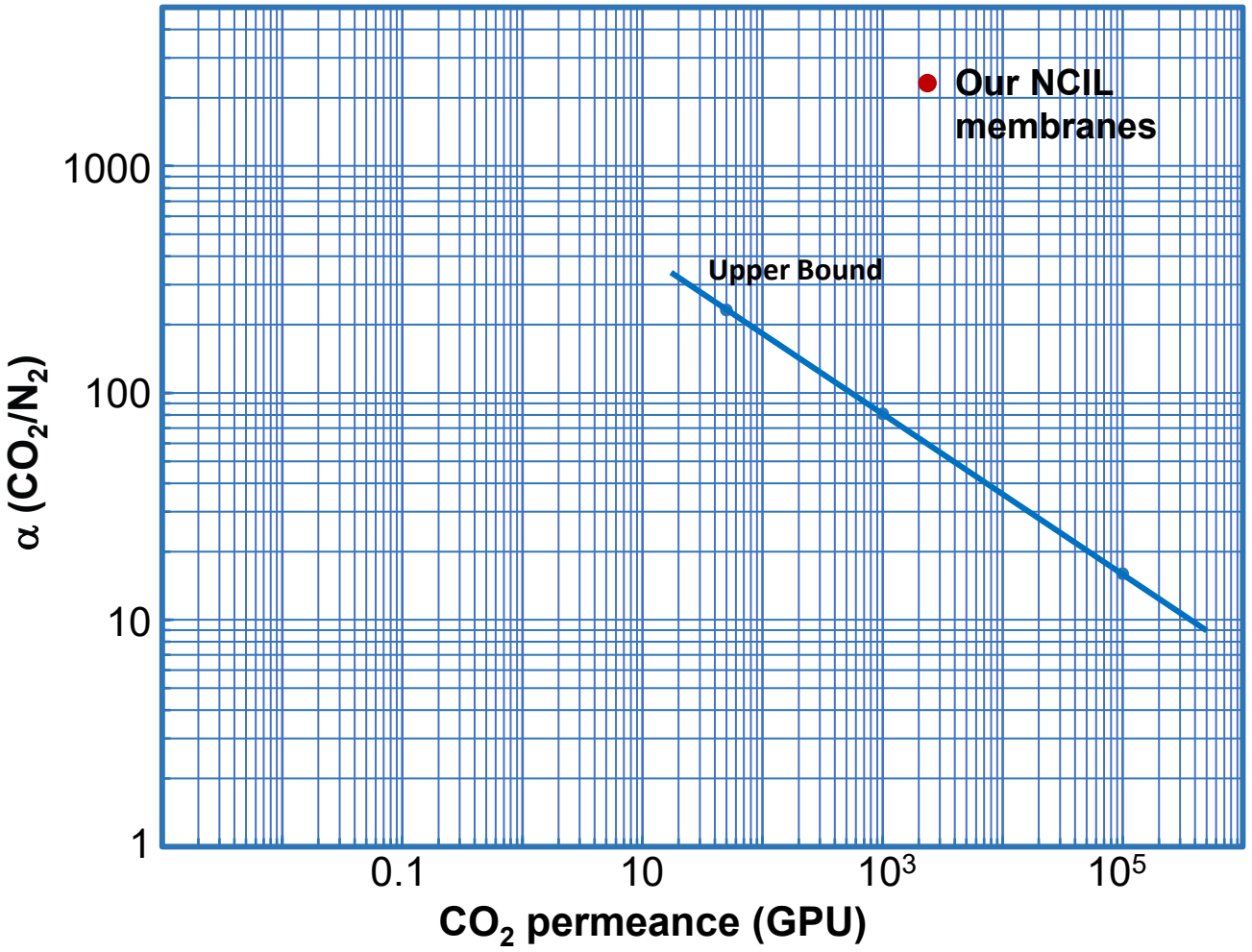
Testing results

CO_2 dry-basis purity, vol%	CO_2 capture efficiency, %	CO_2 permeance, GPU	CO_2/N_2 selectivity
98.0	50	2,400	2,100



NGCC = natural gas combined cycle

Where do NCIL membranes fall on the Robeson plots?



- Selectivity significantly higher than other membranes

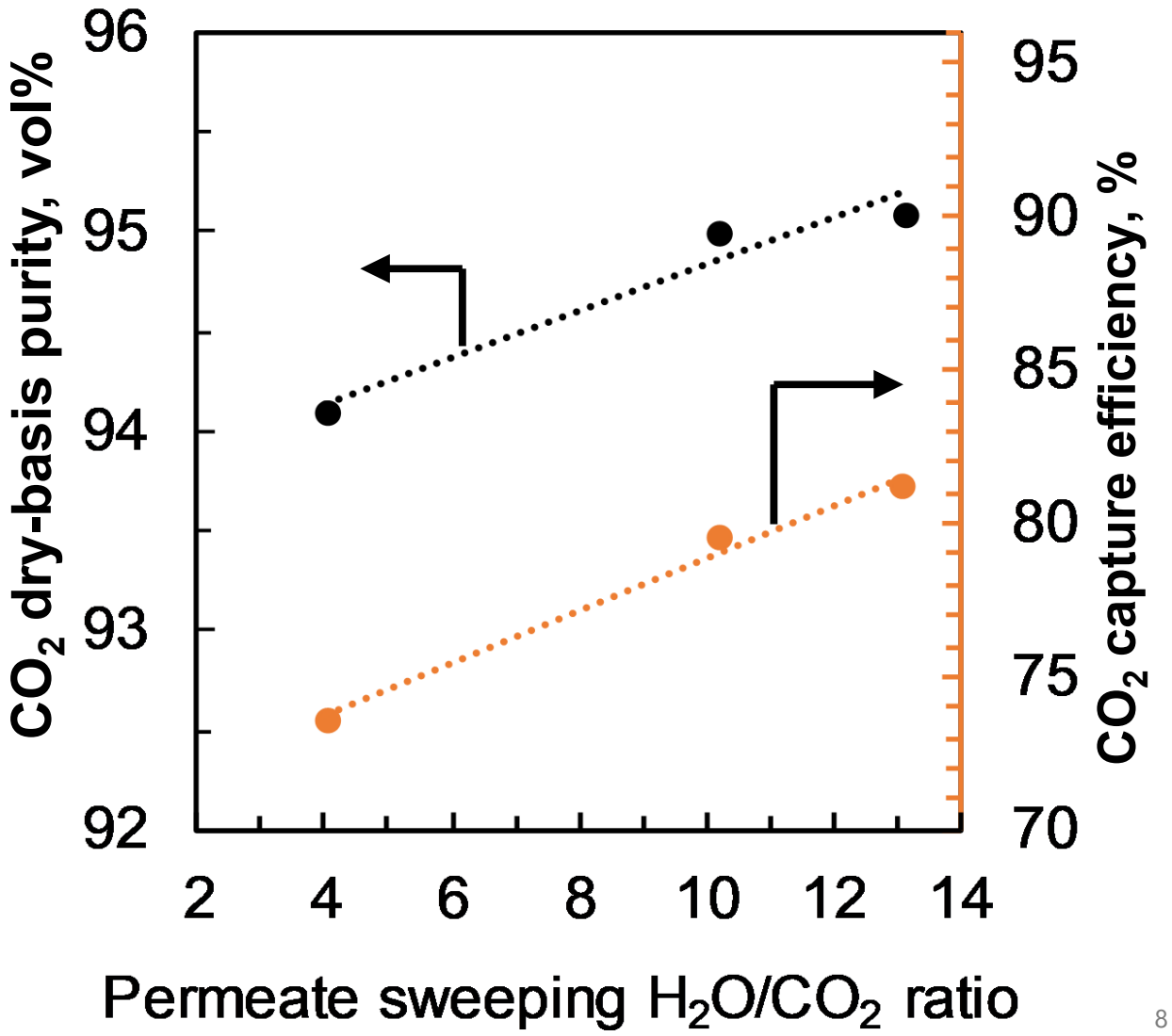
Robeson, J. Membrane Sci. ***2008****, Vol. 320, p390*

Note: 0.1 μm membrane thickness assumed for polymers

To use the high selectivity to the greatest extent, water vapor sweep is applied in the permeate side

Testing conditions

Membrane area, cm^2	75
Temperature, °C	70
Feed pressure, bara	1.0
Permeate pressure, bara	0.15
Feed composition, vol%	
CO_2	4.5%
Water	13.0%
N_2	82.5%
Flow arrangement: **co-current flow** mode (H_2O vapor sweep and flue gas flowed in the same direction)	



A counter-current flow mode enables CO_2 capture rate as high as 97%

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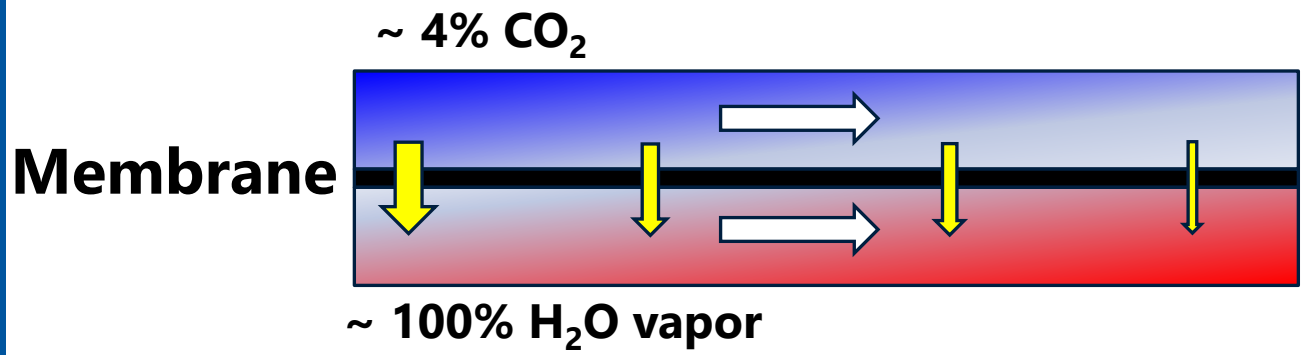
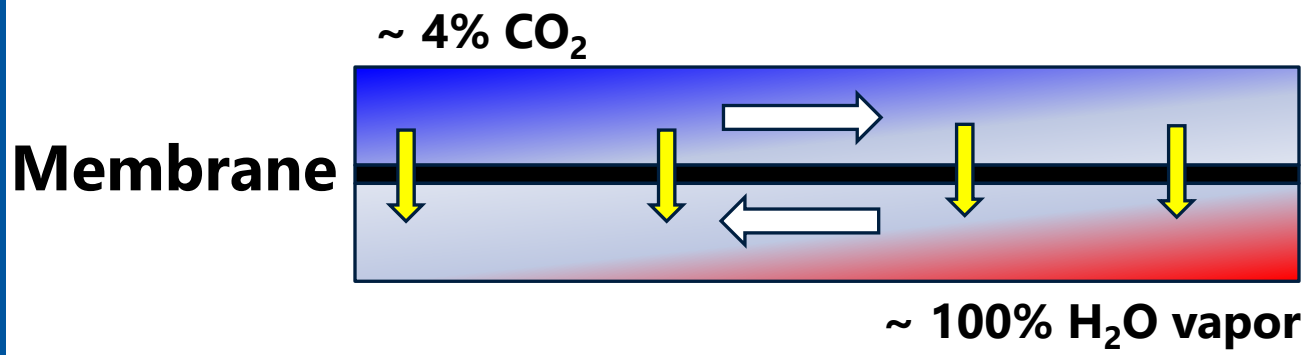
Co-current flow



Counter-current flow



Testing conditions

Membrane area, cm^2	75
Temperature, °C	70
Feed pressure, bara	1.0
Permeate pressure, bara	0.10
H_2O/CO_2 ratio	16: 1
Feed composition, vol%	
CO_2	5.4%
Water	9.6%
N_2	85%
Flow arrangement: count-current flow	

Results

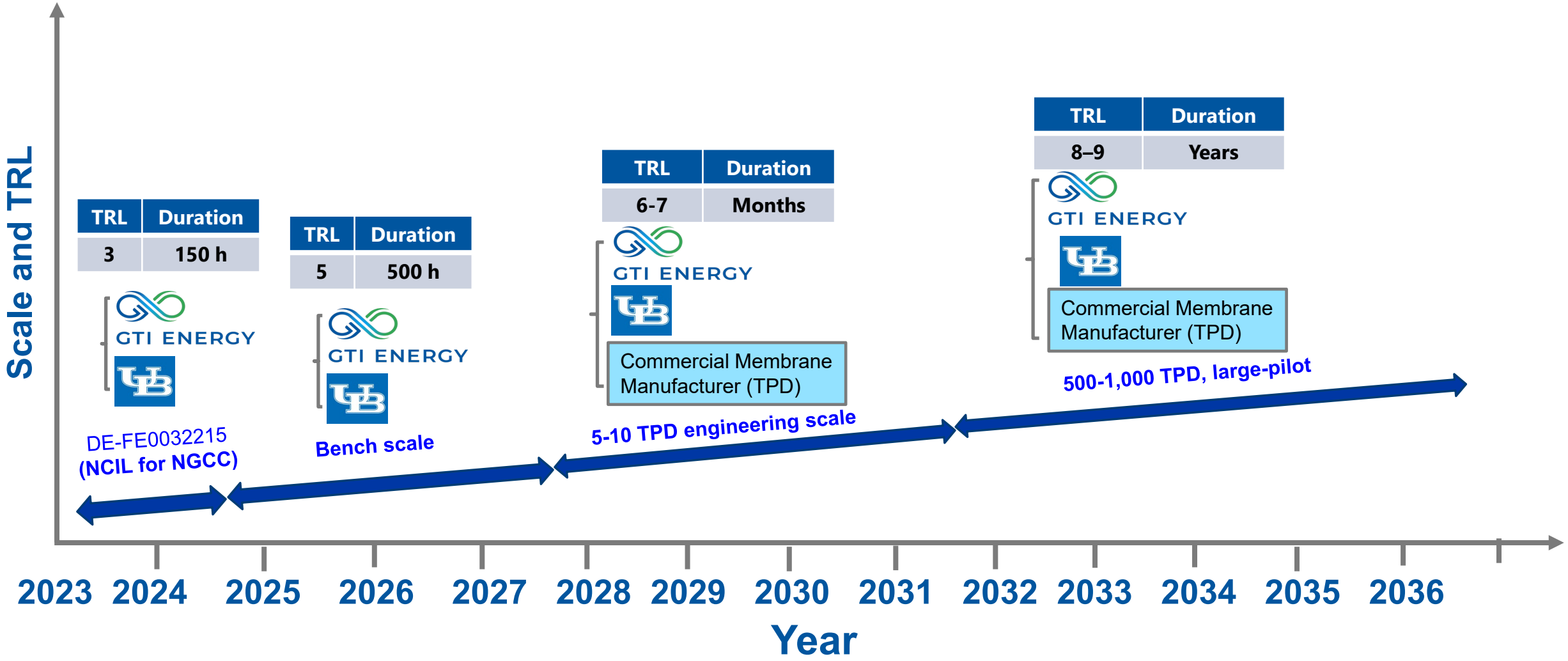
CO_2 capture rate	97.6%
CO_2 dry-basis purity	96.6 vol%

Initial TEA indicates CO_2 capture cost of $44.6/tonne of CO_2 captured at 95% capture

Technology	CO_2 capture efficiency	CO_2 capture cost, $/tonne
DOE Baseline Case B31B.95 [1]	95%	59.9
NCIL membrane process	95%	44.6

1. DOE Report 2023/4320 (Revision 4A, issued on Oct. 14, 2022)

Envisioned technology development path



TRL = Technology readiness level

Summary

- GTI Energy and UB are developing a transformational process based on nano-confined ionic liquid membranes for capturing ≥97% CO_2 from NGCC flue gas
- Membrane showed CO_2 permeance as high as 2,400 GPU with a CO_2/N_2 selectivity of 2,100 for typical NGCC flue gas
- When water vapor sweep is applied in the permeate side, >95% CO_2 dry-basis purity and >97% CO_2 capture rate were achieved with single stage
- Initial TEA indicates CO_2 capture cost of $44.6/tonne of CO_2 captured at 95% capture, which is a 26% reduction versus DOE's reference case B31B.95 ($59.9/tonne of CO_2 captured) from a NGCC power plant

Acknowledgements

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- DOE NETL: Andrew O'Palko and Dan Hancu

Disclaimer

Appendix – Organization Chart