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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

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Net-zero Flexible Power: High Capture Rate Project Review Meeting
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GTI Energy: 80-year history of turning raw technology into practical energy solutions

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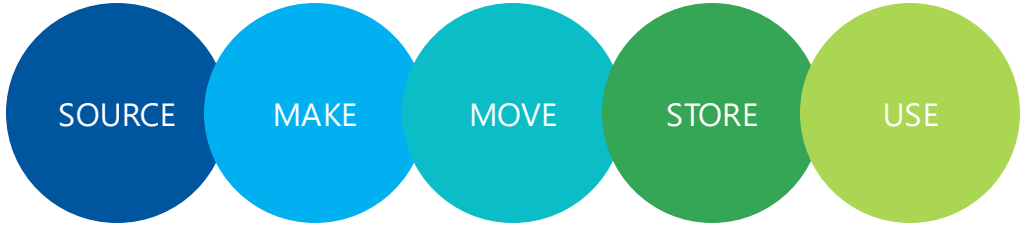
GTI Energy is a leading energy research and training organization



Across the entire energy value chain

World-class facility in Chicago area

CCUS is one of GTI strategic focus areas

- **Carbon capture**
  - **FE0031946**: 20 TPD facilitated transport membrane (FTM) for power plant application
  - **FE0032466**: 3 TPD ROTA-CAP for steel plant application
  - **FE0032463**: 3 TPD FTM for cement plant (sub to OSU)
  - **FE0031598**: Bench-scale GO-based membrane
  - **FE0032215**: Nano-confined Ionic liquid membrane
  - **FE0031730**: Size-sieving adsorbent (sub to UB)
- **Carbon conversion**
  - **FE0031909:** Membrane reactors for conversion of CO_2 to fuels/chemicals
  - **FE0032246:** Converting CO_2 to carbon-negative alternative cement (sub to WashU)
- **Carbon dioxide removal (CDR)**
  - **FE0031969**: Trapped small amines in capsules (sub to UB)
- **Carbon transport and storage**
  - **FE0032239**: CarbonSAFE Phase II

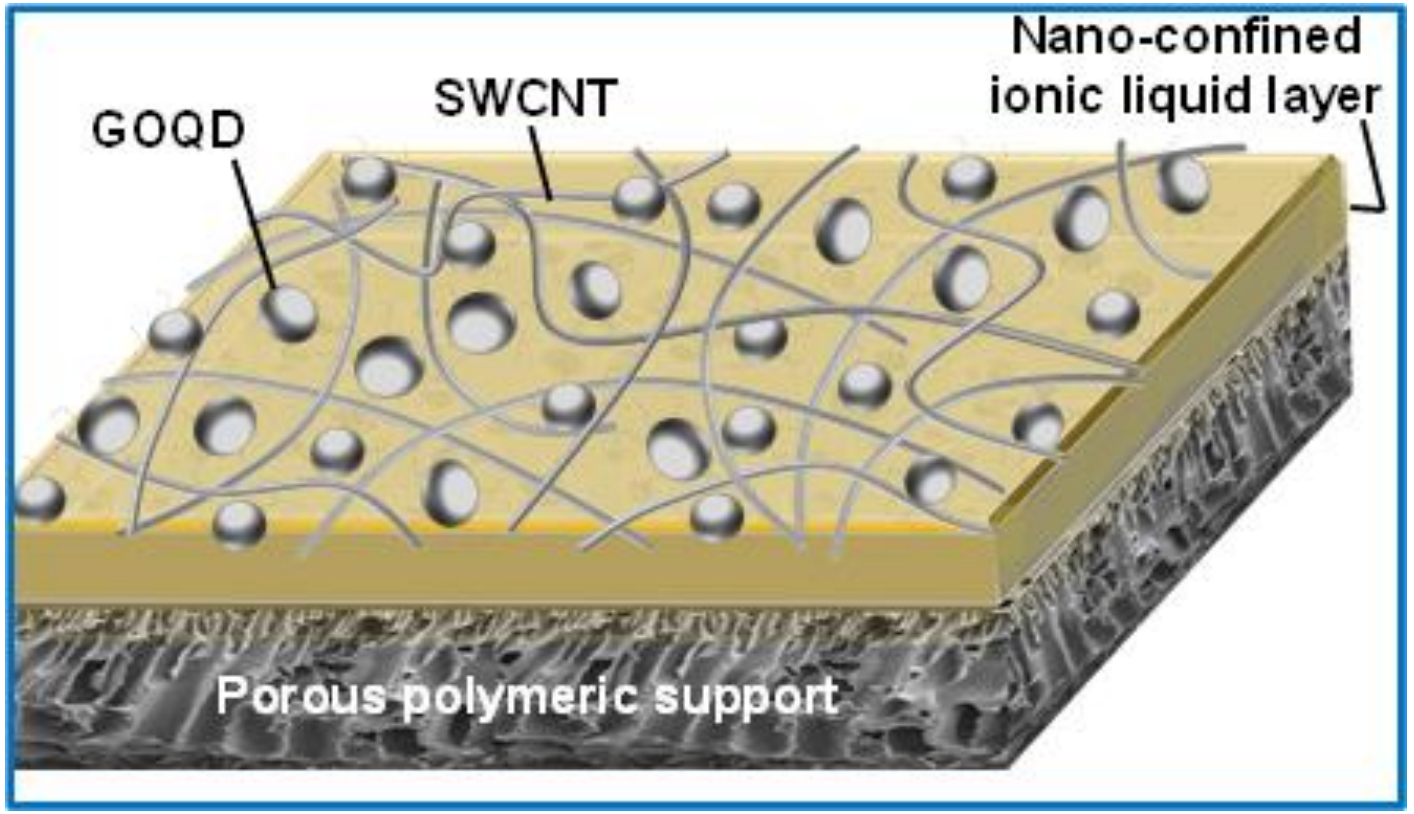
Project overview

- **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 rate
- **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

Transformational membrane structure: nano-confined Ionic Liquid (NCIL) membrane



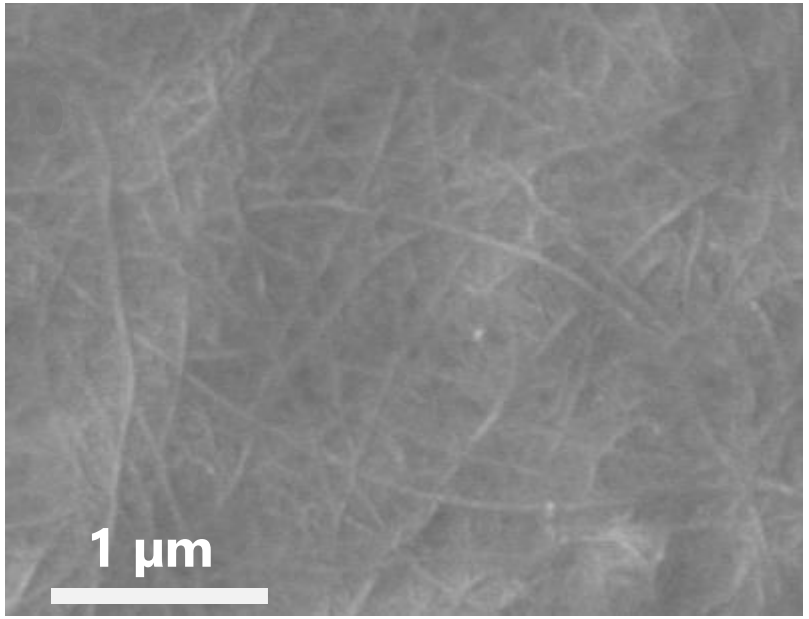
- Nano-confined space between SWCNTs, combined with nano-sized GOQDs with rich oxygen-containing functional groups, stabilizes the amino acid ILs with amine groups during membrane operations
- The enhanced viscosity of NCIL, resulting from the nano-confined space in SWCNT mesh and favorable interactions between rich functional groups on GOQDs and ILs, significantly inhibits N_2 permeation

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

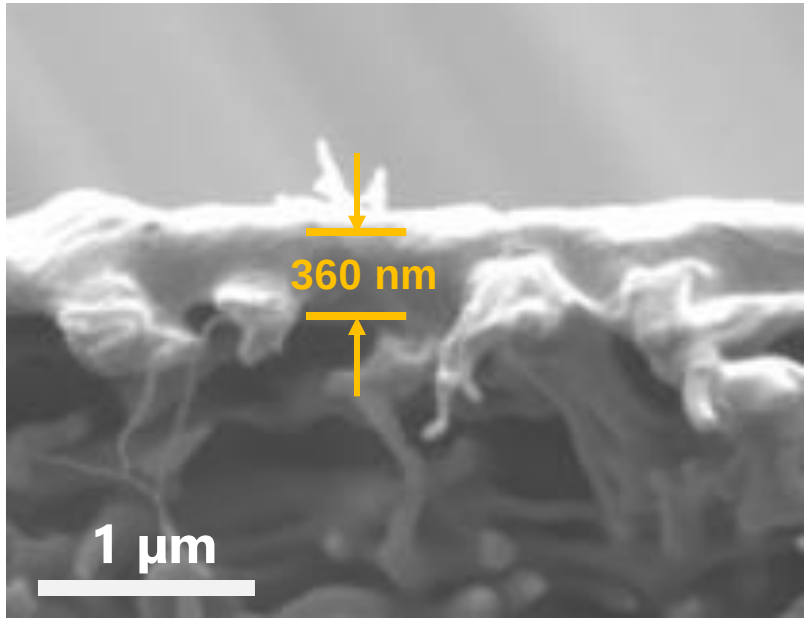
Membranes are coated on commercial polyether sulfone (PES) hollow fiber substrates

Material	Fiber ID (mm)	Module Length (cm)	Effective Length (cm)	Number of Fibers	Effective surface Area (cm^2)
PES	1.00	25	20	12	75

Membrane surface



Membrane cross section



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

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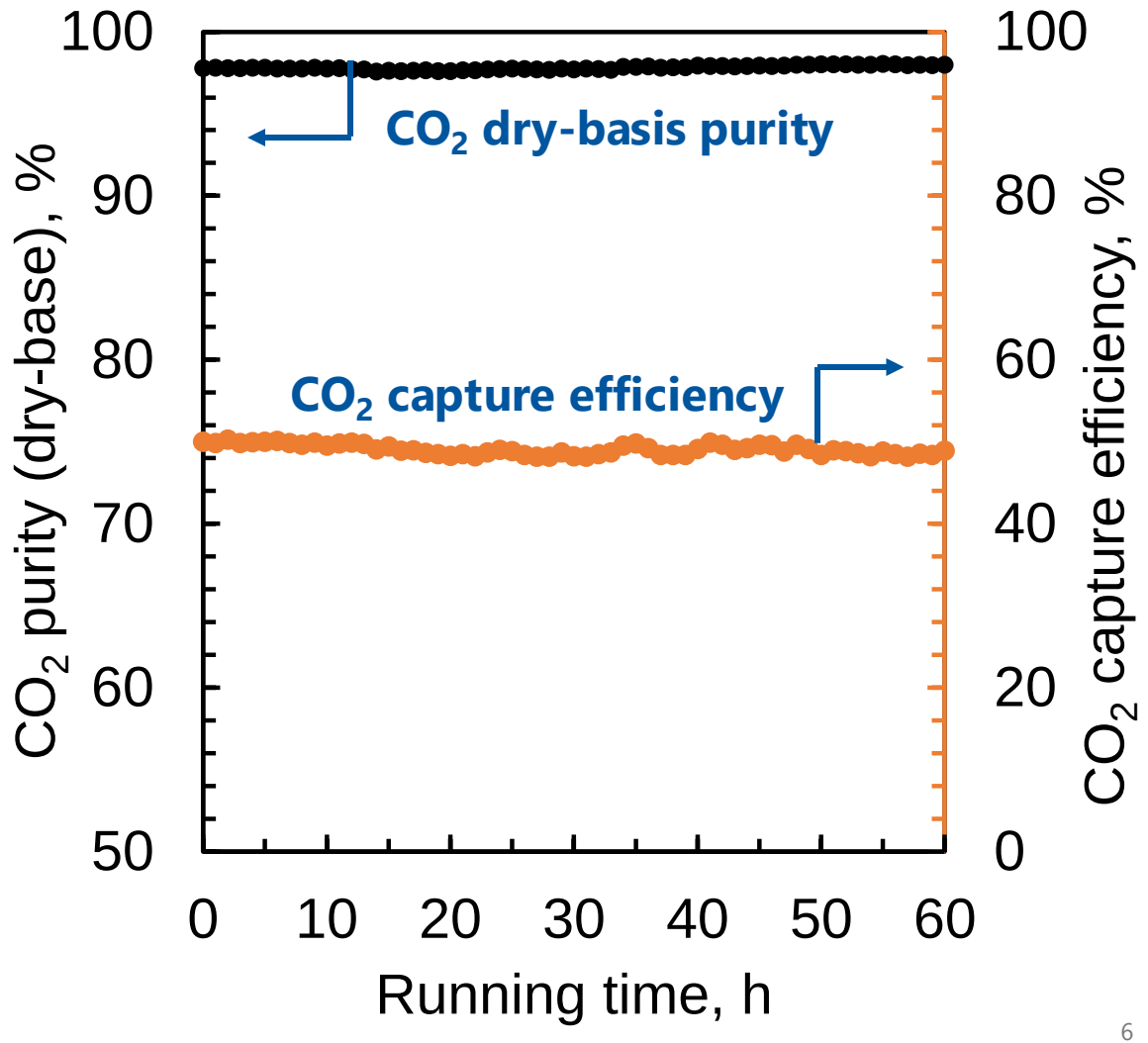
Testing conditions

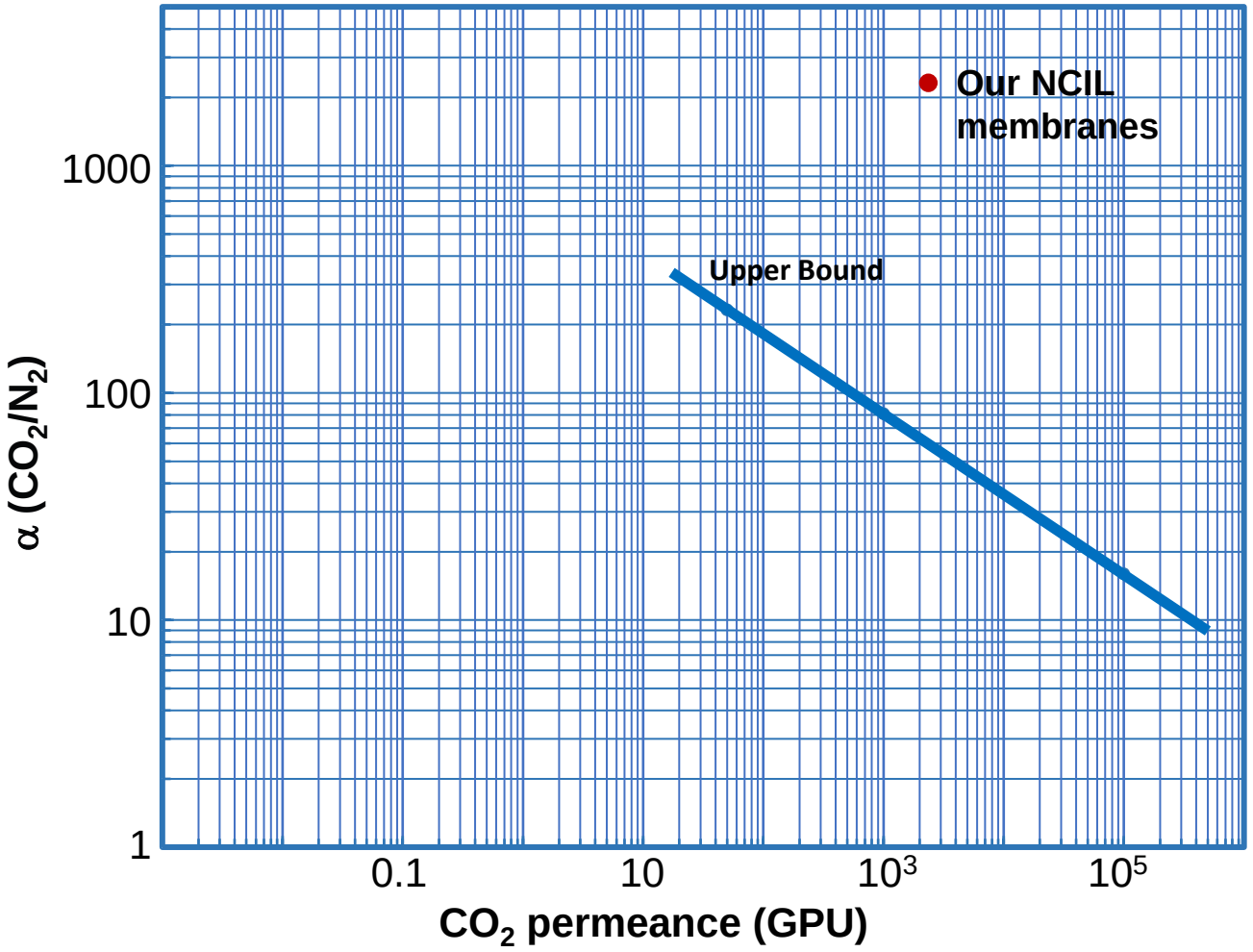
Membrane area, cm^2	75
Temperature, °C	70
Feed CO_2 concentration, vol%	4.2
Feed pressure, bara	1.0
Permeate pressure, bara	0.15

Testing results

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



Where do NCIL membranes fall on the Robeson plots?



- Selectivity significantly higher than membranes reported in the literature

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

Note: Polymer data points (red): 100 nm membrane thickness assumed

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

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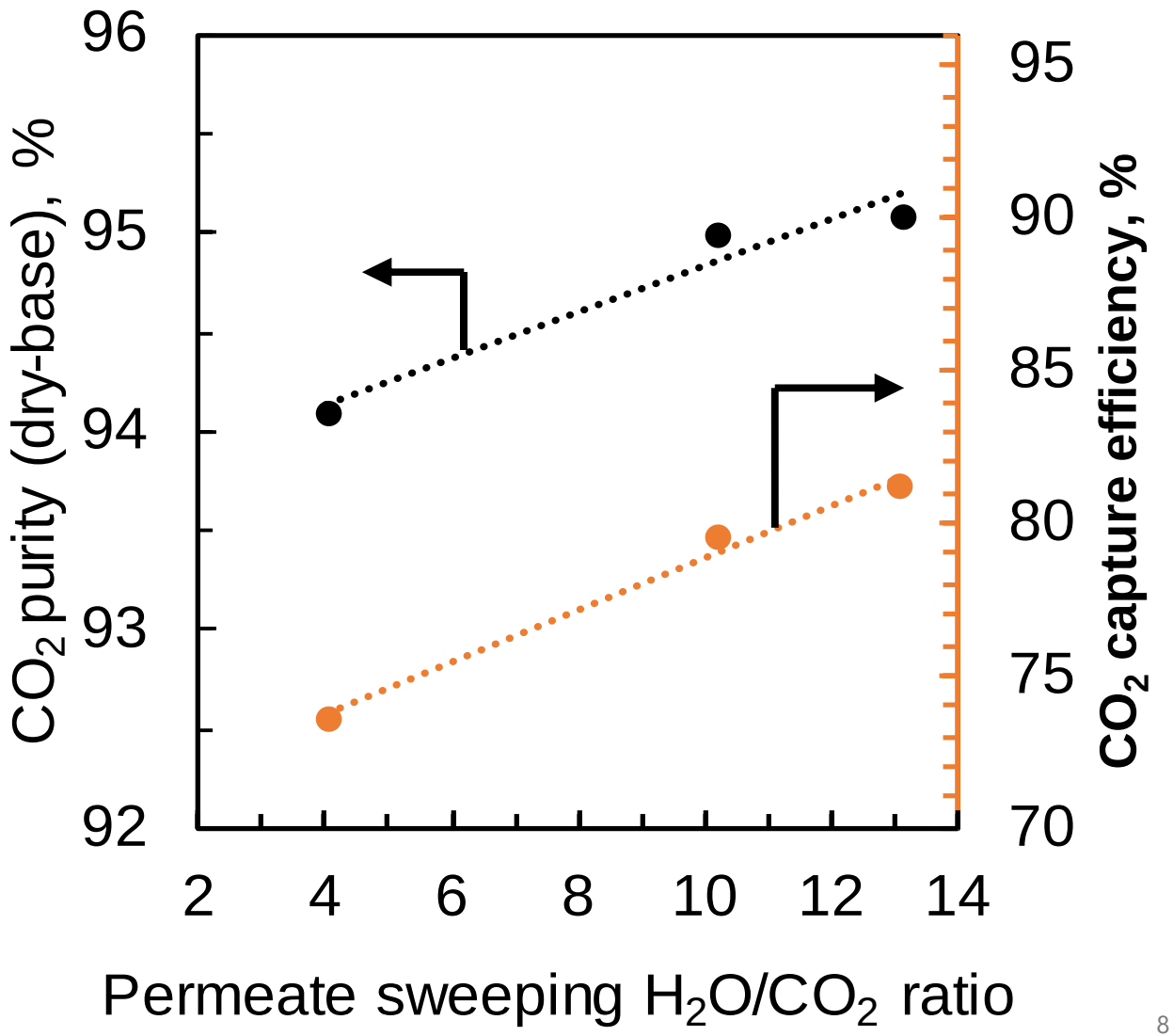
Testing conditions

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 and flue gas flowed in the same direction)	



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

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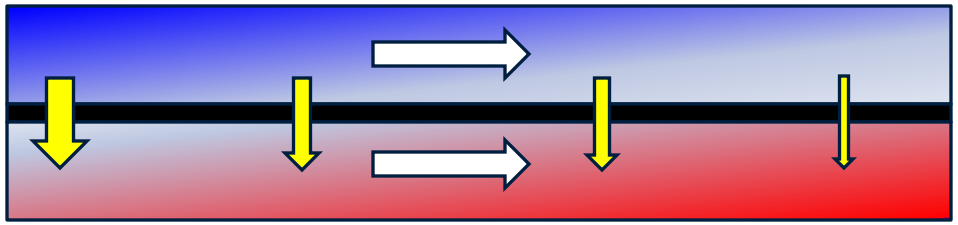
Co-current flow

~ 4% CO_2

Membrane

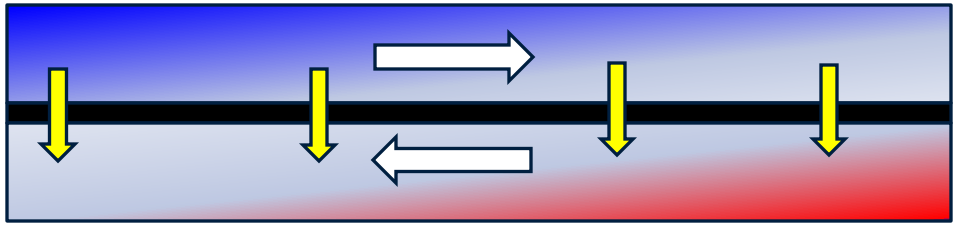


~ 100% H_2O vapor

Counter-current flow

~ 4% CO_2

Membrane



~ 100% H_2O vapor

Testing conditions

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

Results

CO_2 capture efficiency	97.6%
CO_2 dry-basis purity, vol%	96.6%

Highly H_2O-selective membranes have been successfully developed to recover H_2O vapor

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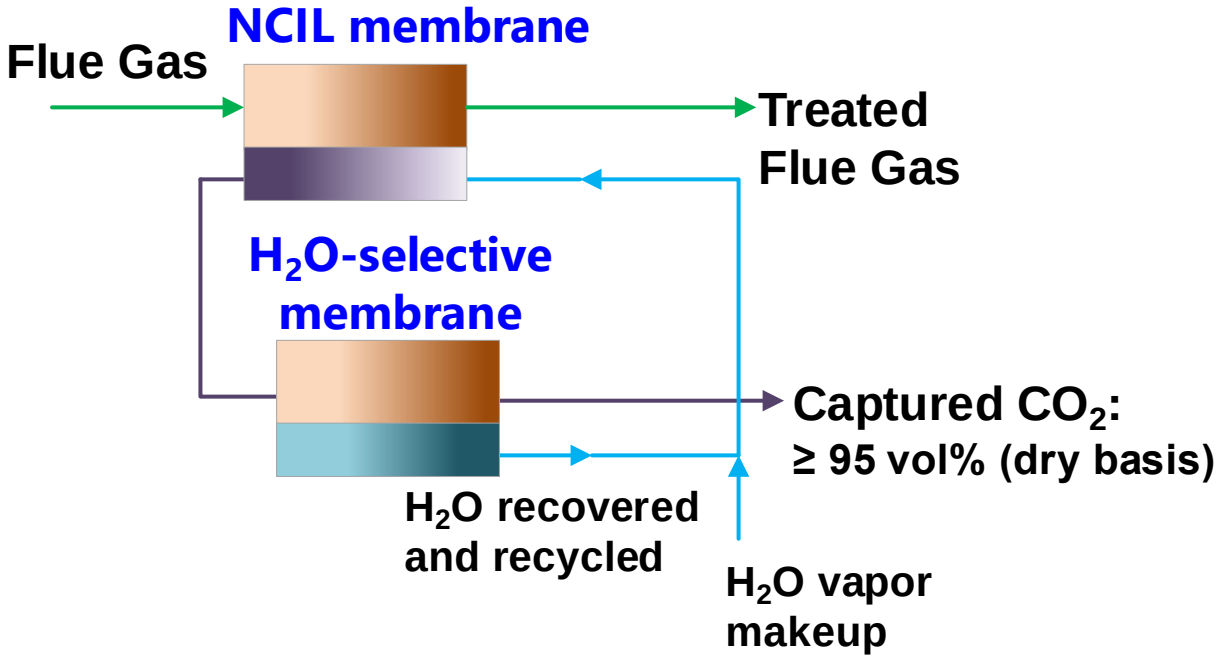
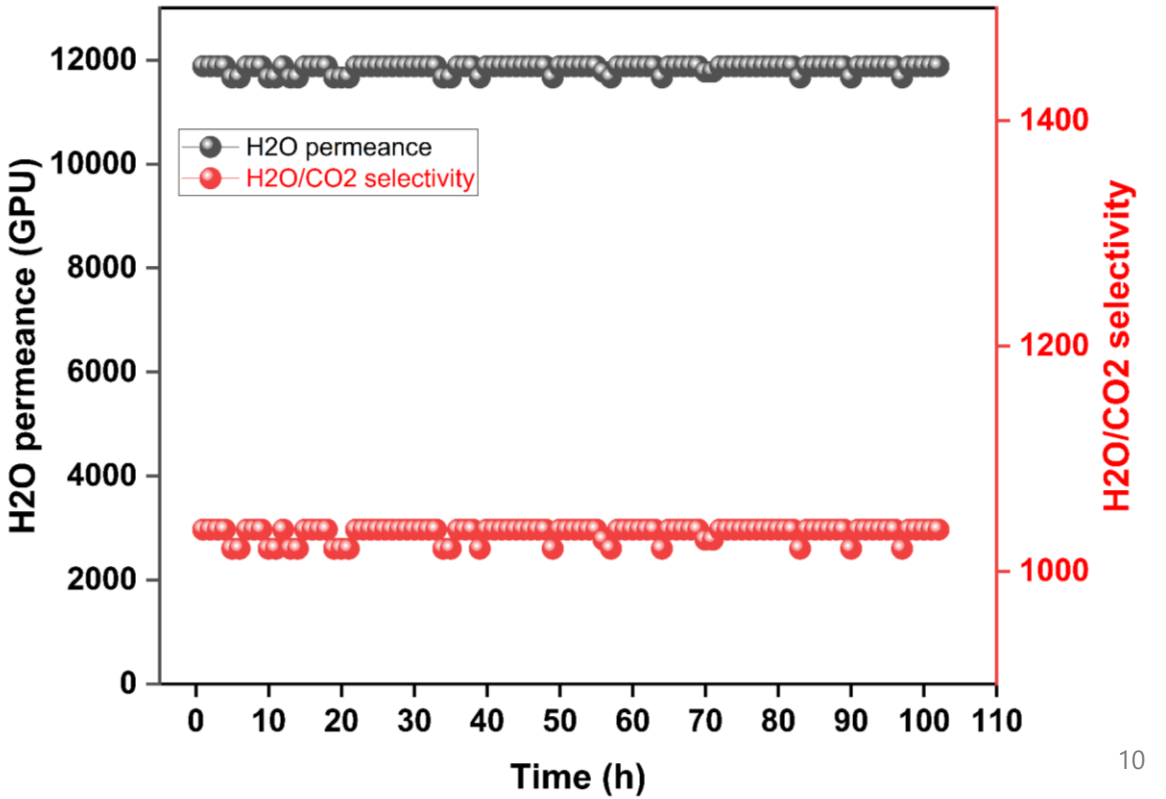
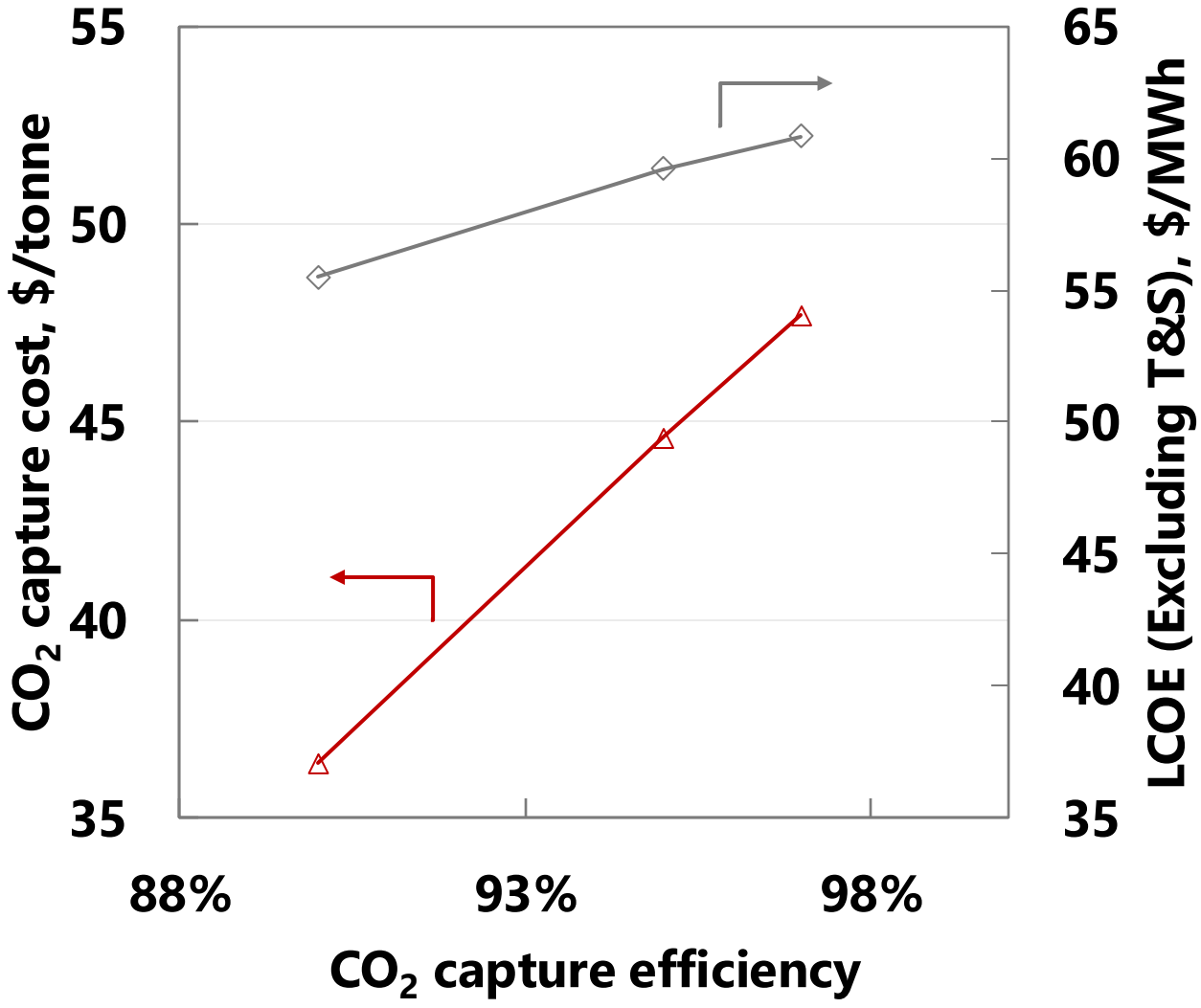
A highly H_2O-selective membrane was designed to recover majority of the H_2O vapor, which is then recycled to the inlet of the permeate side of the NCIL membrane



Our recently developed H_2O-selective membrane showed high H_2O permeance, high H_2O/CO_2 selectivity, and good stability at design conditions (70°C) during 100-h continuous testing



Initial TEA indicates CO_2 capture cost of $47.7/tonne at 97% capture (23% reduction versus reference case)



Technology	CO_2 capture cost at 97% capture, $/tonne
DOE Baseline Case B31B.97 *	61.8
NCIL membrane process	47.7

Impacts and issues regarding emissions changes in flexible operation or at high capture rates?

- None from the membrane side

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

Challenges to maintain high capture rates and mitigation strategies

1) Stability of the NCIL membrane at NGCC flue gas condition

- B31B.97 stream table shows NGCC flue gas temperature is 101°C – challenging for membrane technology

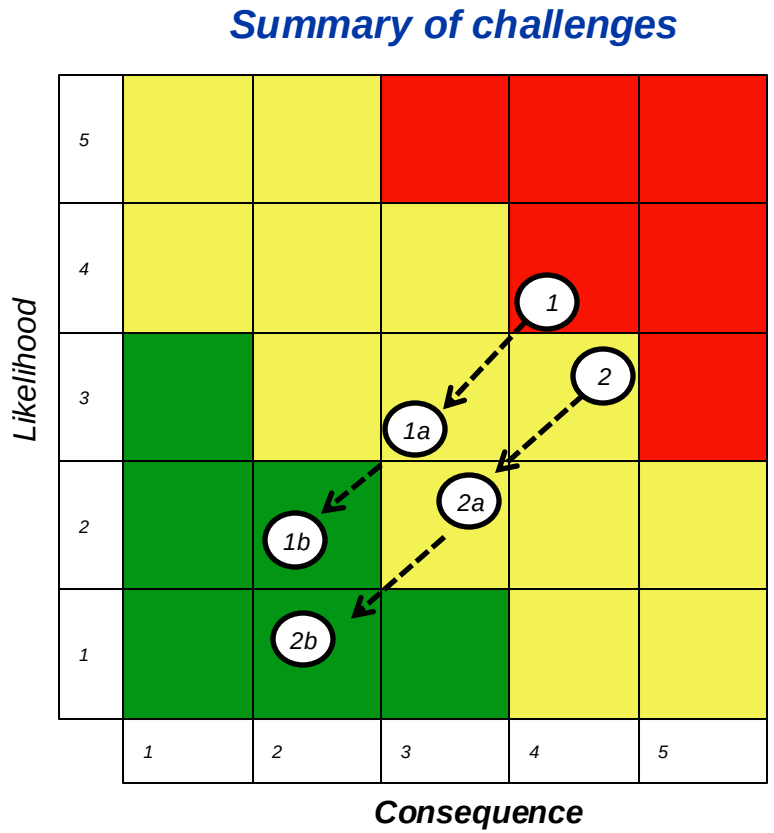
Mitigation (R&D needs):

- 1a: Optimize operation conditions including cooling flue gas down to 70–90 °C
- 1b: Further optimize membrane structure

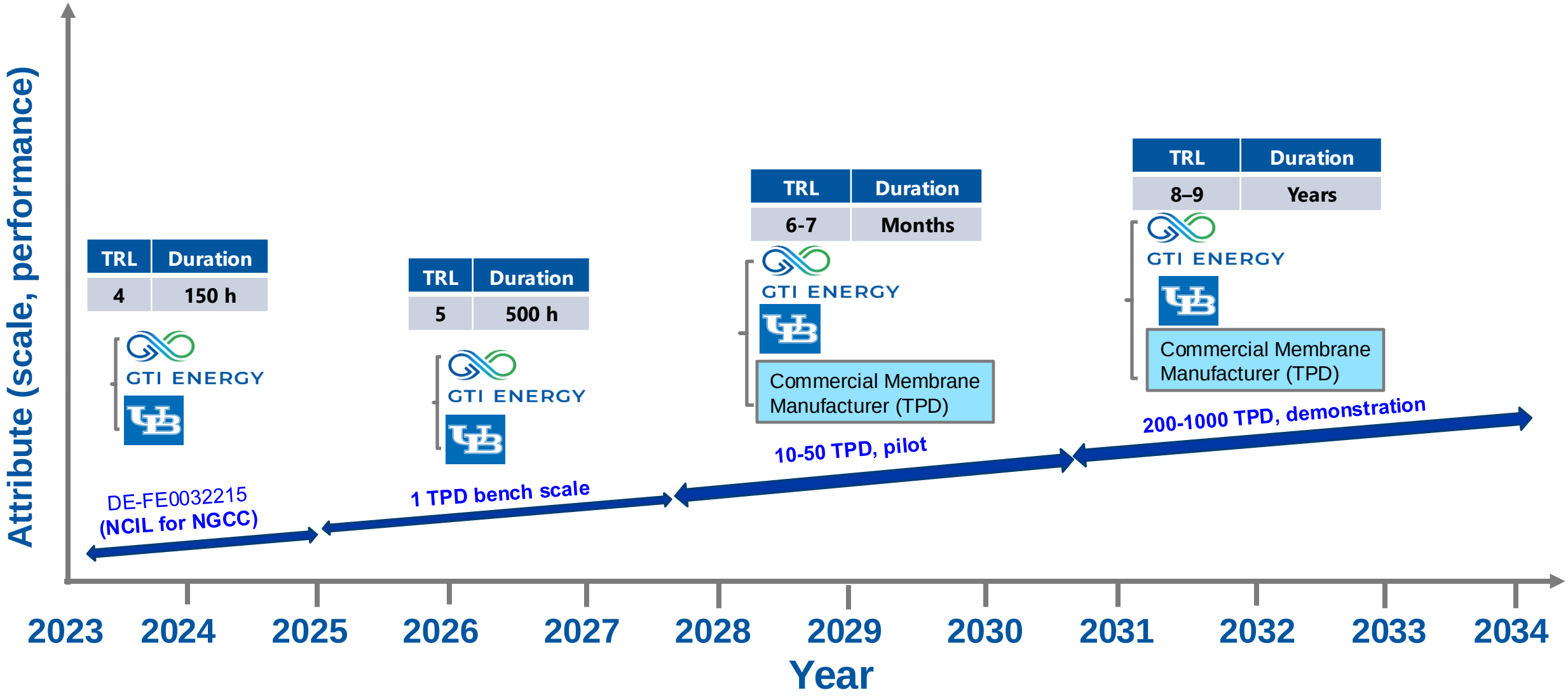
2) Cost of the process not in line with expected outcome

Mitigation (R&D needs):

- 2a: Improve separation performance of the membranes
- 2b: Improve process design and equipment selection



Envisioned technology development path



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-base purity and >97% CO_2 capture rate were achieved with single stage
- Highly H_2O-selective membranes successfully developed to recover H_2O vapor
- Initial TEA indicates CO_2 capture cost of $47.7/tonne at 97% capture, which is a 23% reduction versus DOE's reference case B31B.97 from a NGCC power plant

Acknowledgements

- Financial and technical support

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