2017 CAPTURE TECHNOLOGY MEETING

LAB-SCALE DEVELOPMENT OF A HYBRID CAPTURE SYSTEM WITH ADVANCED MEMBRANE, SOLVENT SYSTEM AND PROCESS INTEGRATION

DE-FE0026464

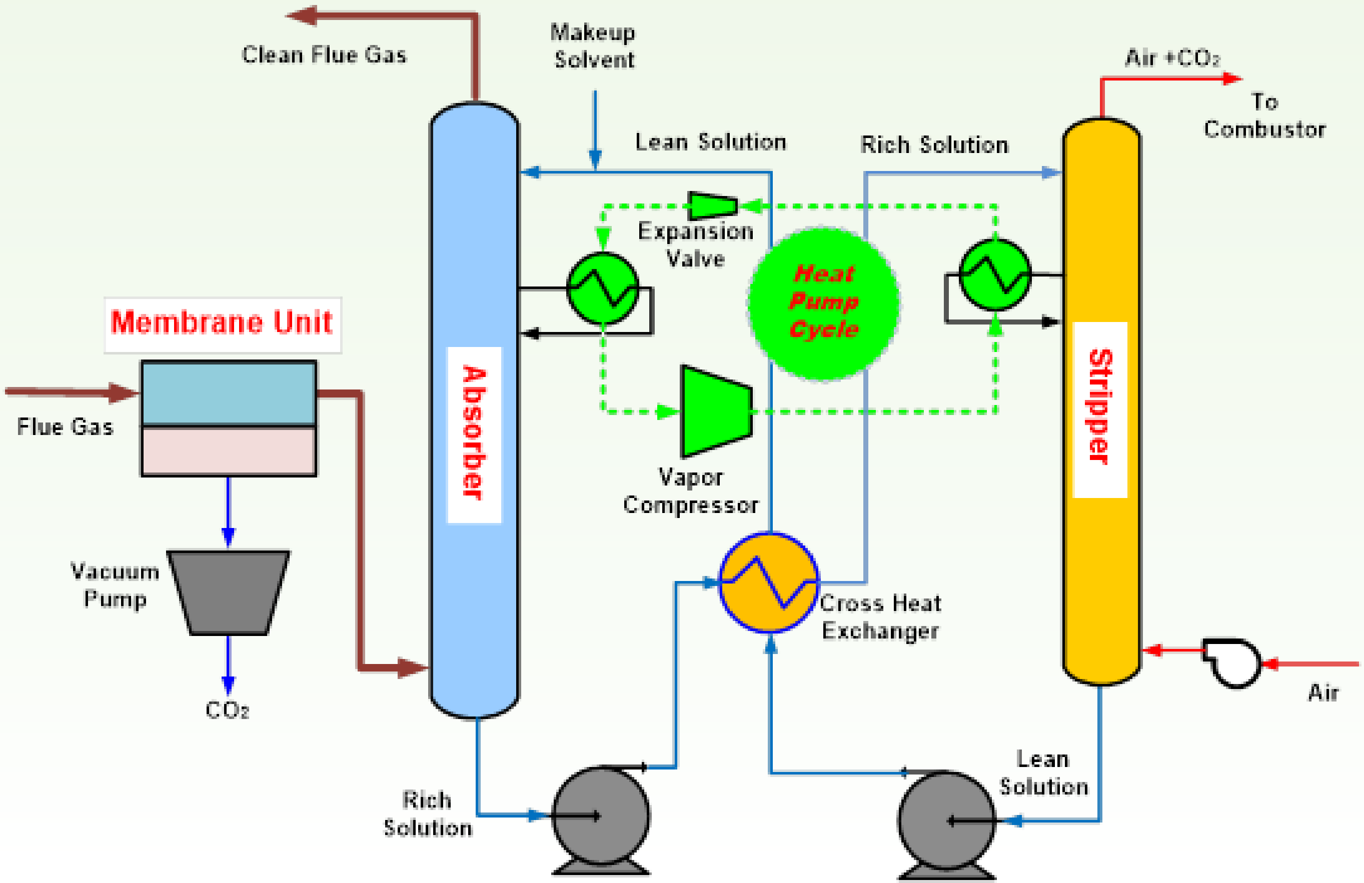
AUGUST 22, 2017

CARBON CAPTURE SCIENTIFIC LLC

Liquid Ion Solutions

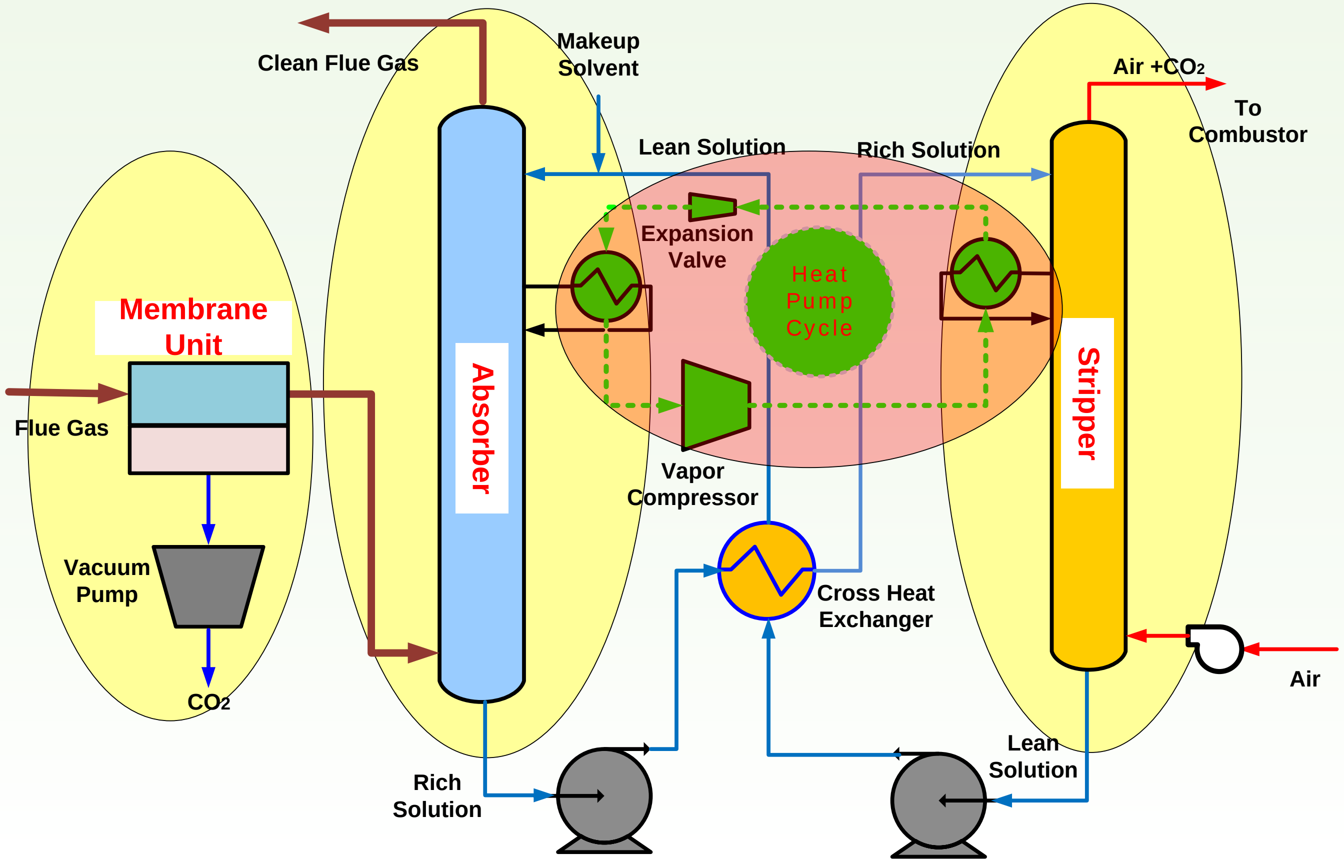
PennState

Membrane Integration



Membrane/Solvent Integrated Process

- Advantages
  - Tail-end technology which is easily used in retrofits
  - No steam extraction is required
  - Heat pump is seamlessly integrated into the cooling and heating of absorption/stripping process
  - Operating pressure of the stripper will be very flexible depending on the low quality heat
- Disadvantage
  - Capital cost could be intensive



CCS Team

Dr. Scott Chen and Dr. John Pan

- Experienced Chemical Engineer
- Strong Background in Separation Processes and Thermodynamics
- Founder of Carbon Capture Scientific, LLC

LIS Team

Prof. Hunaid Nulwala and Dr. Dave Luebke

- Experienced Chemist with Experience in Industry, Government, and Academia
- 40+ Publications and 16+ Patents and Applications in Material Development

PSU Team

Prof. Harry Allcock and Dr. Zhongjing Li

- Leading Investigator of Phosphazene Polymers (>630 Articles in the Area)
- Renowned Chemist with Experience in Industry, Government and Academia

Project Outline

- Task 1: Project Management
- Task 2: Computer Simulation of Hybrid Process
- Task 3: Generation 0 ICE Membrane Development
- Task 4: Modification, Installation, and Testing of Absorption Column
- Task 5: Generation 1 ICE Membrane Development
- Task 6: Modification, Installation, and Testing of Air Stripper
- Task 7: Membrane Scale-up and Simulated Flue Gas Testing
- Task 8: Preliminary Techno-economic Analysis

Year 1 Year 2 Year 3

The System

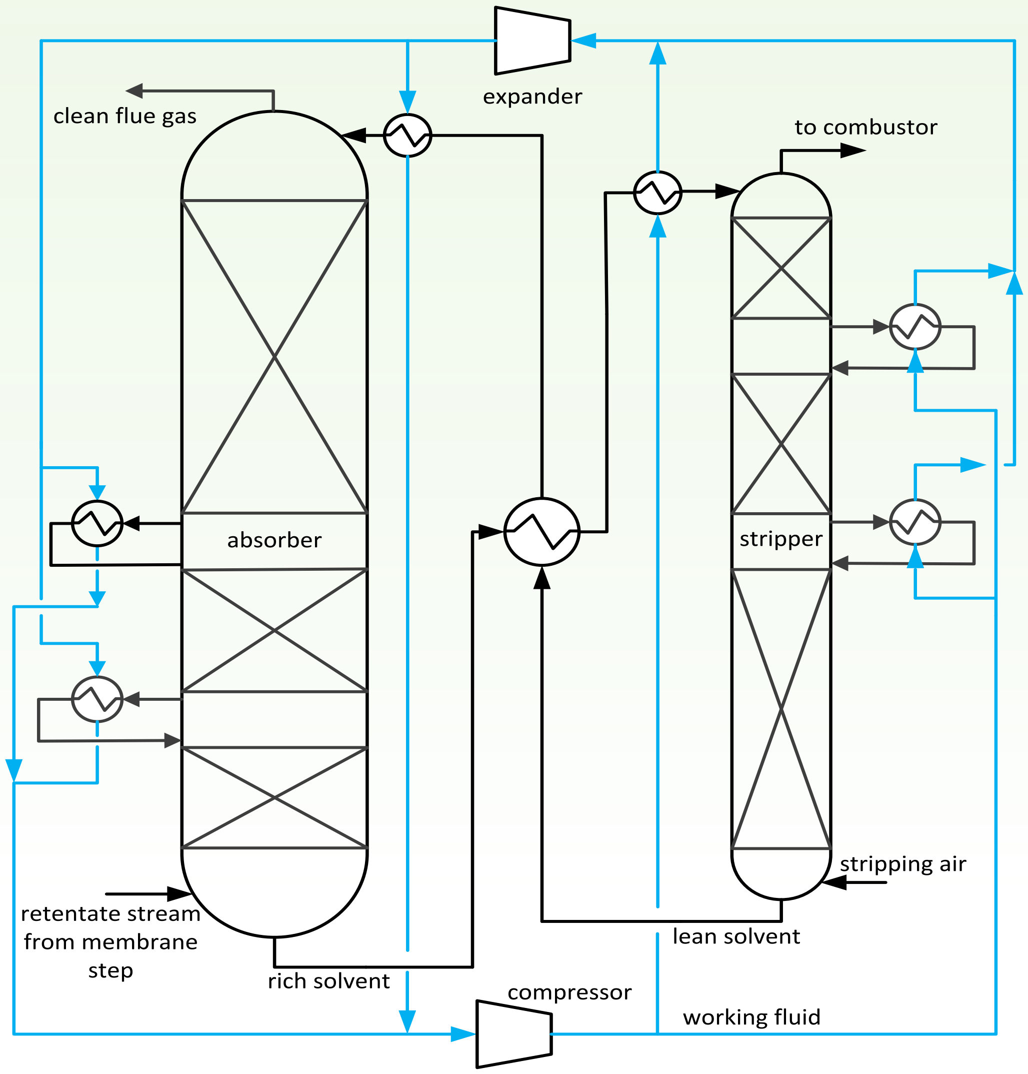
Hybrid Process Simulation

Heat duties (MW) for the absorption/stripping process (30/60^{0}C)

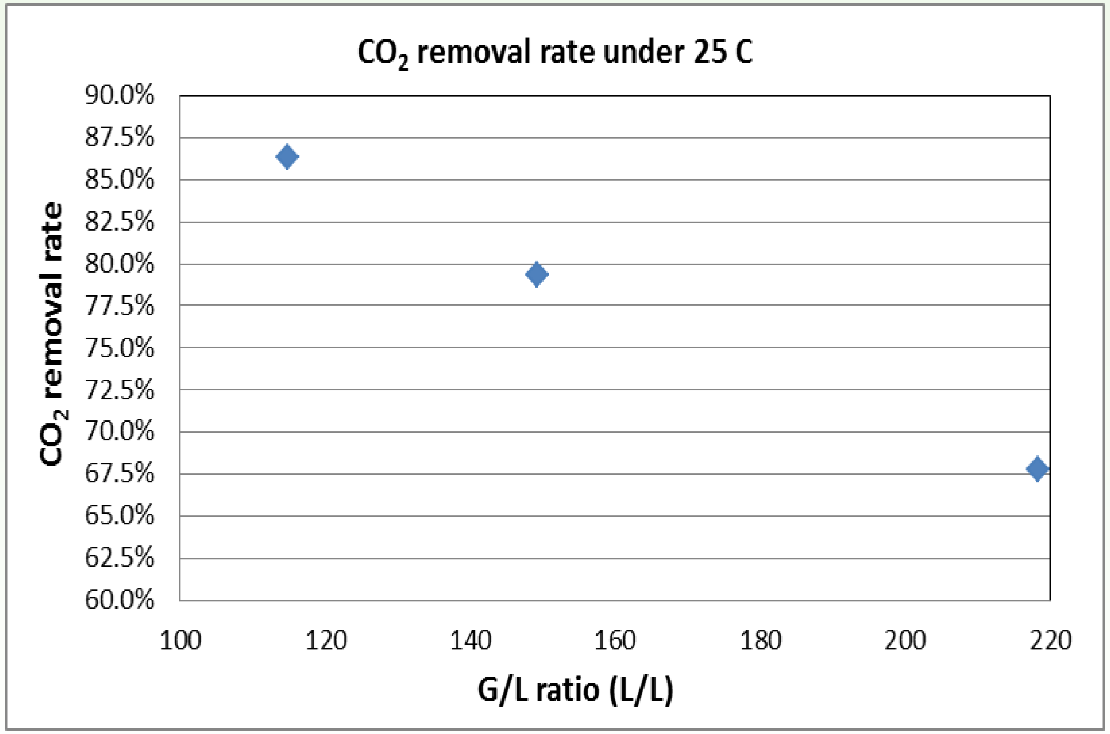
	Absorber	Stripper
top	-88.04	19.80
1st inter-stage	-52.56	77.42
2nd inter-stage	-43.48	51.35
3rd inter-stage		33.00
total	**-184.08**	**181.51**

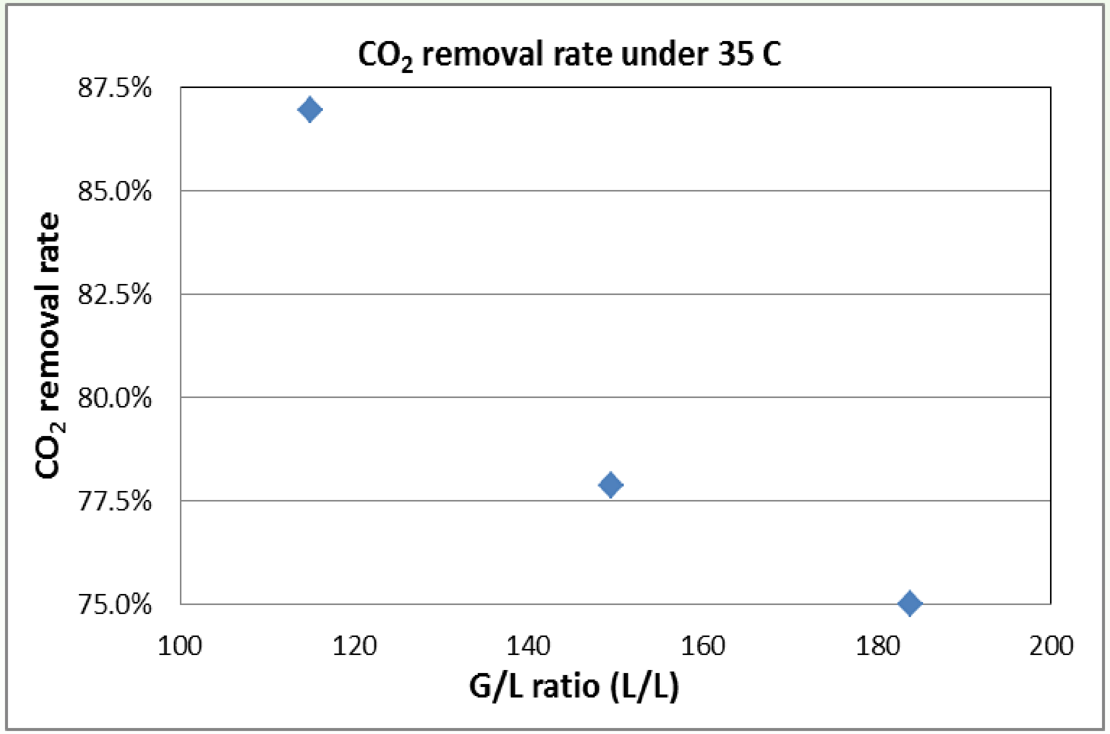
Energy Performance of the Hybrid Process

Power Item (in MWe)	Baseline Case 12	Hybrid Process
Compression	44.8	87.48
Steam Usage	139.19	0
Heat Pump Cycle	0	23.79
Membrane Unit	0	15.7
Others	20.6	20.6
total	204.6	147.57



Absorber Testing

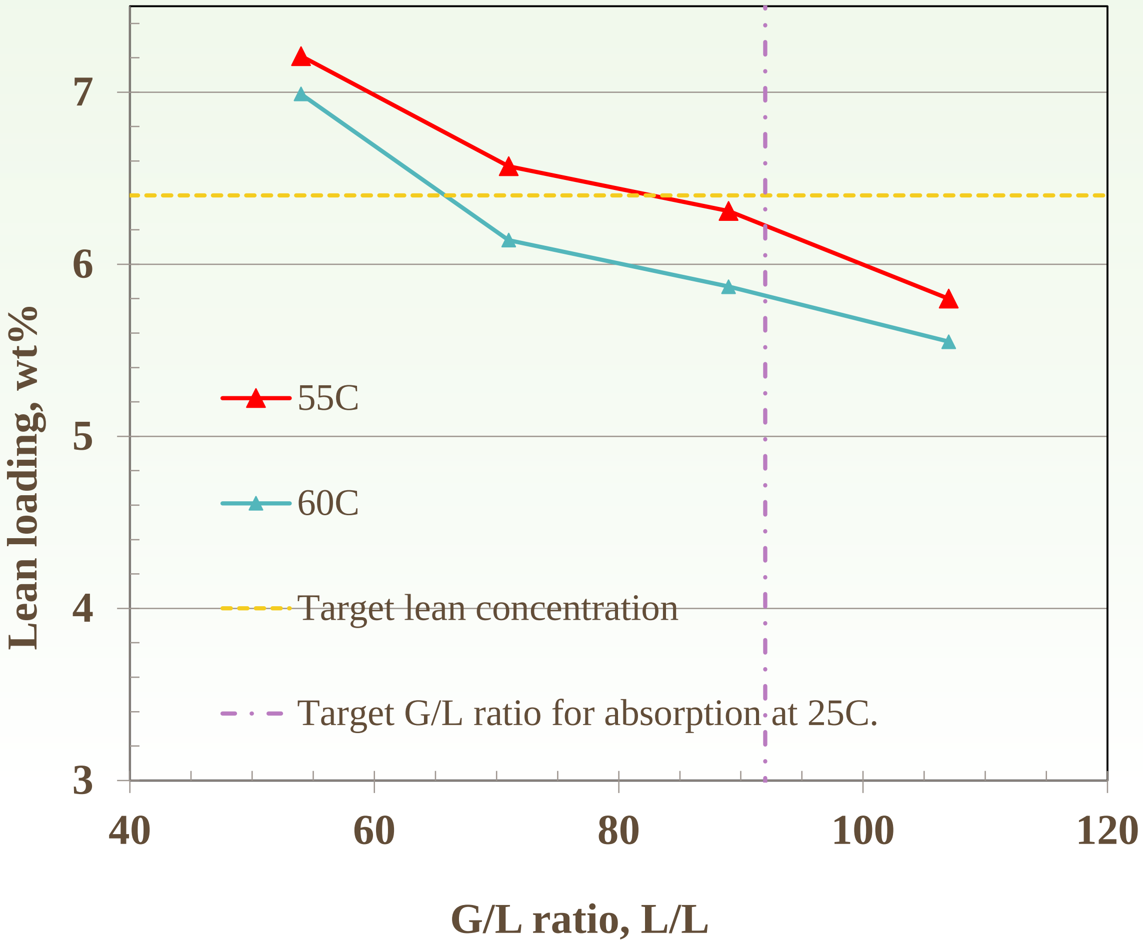


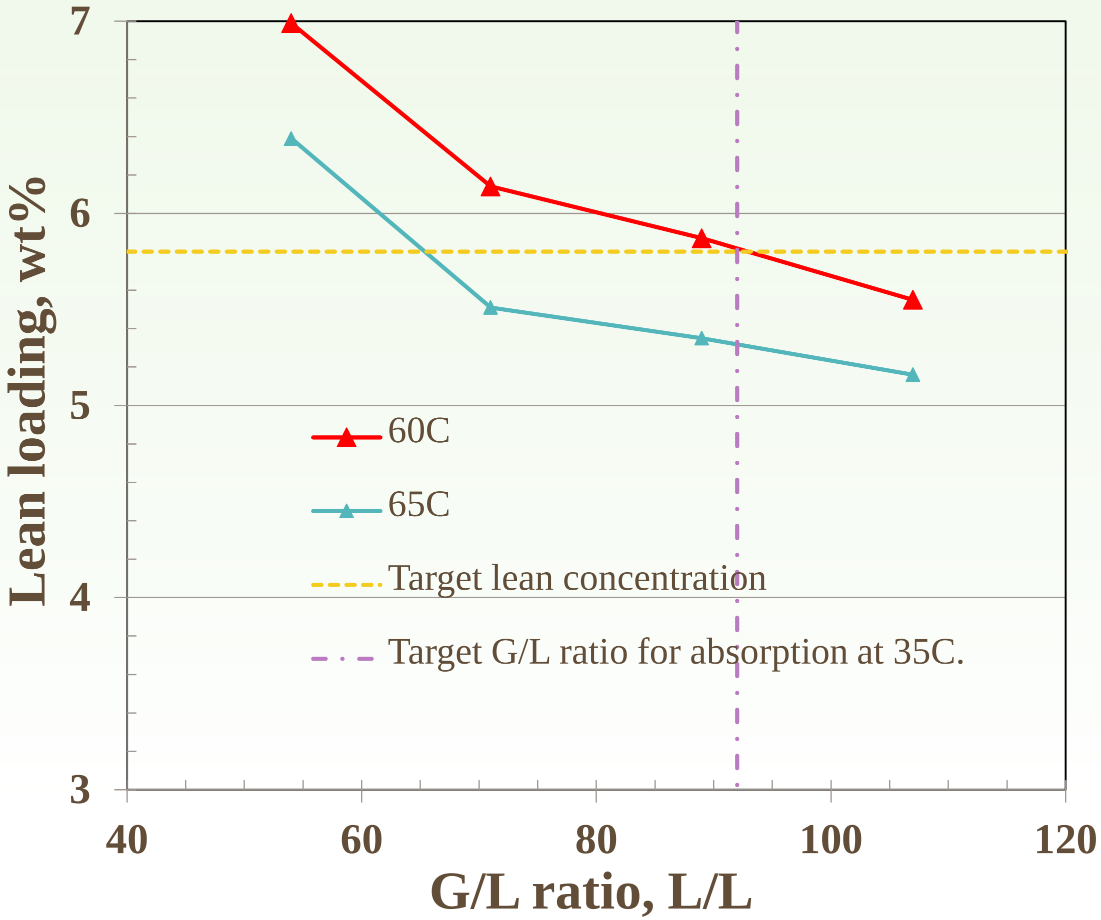


Lean loading: 6.4 wt%

Lean loading: 5.8 wt%

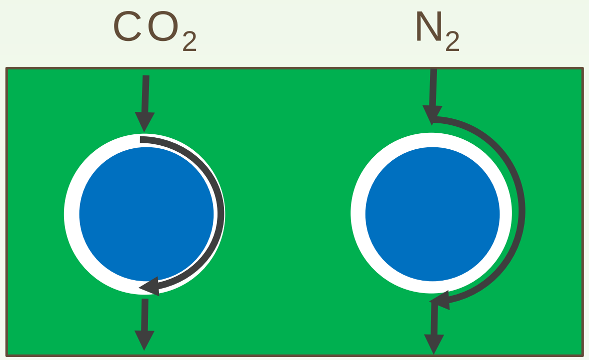
Stripper Testing





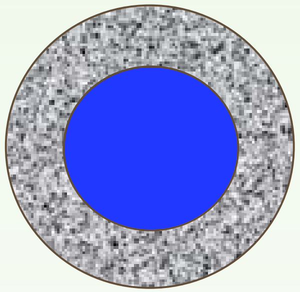
The Membrane

Plan of Attack for Mixed Matrix Membranes



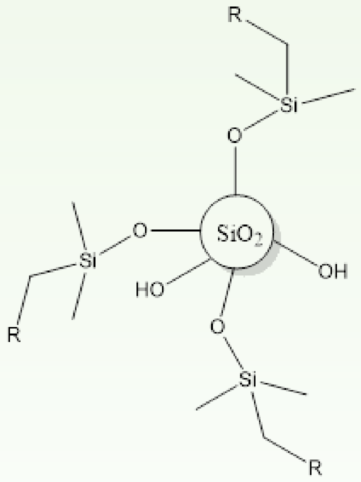
- Use simple nanoparticle fillers
- Surface modify the particles to improve interactions with CO_2 and the polymer
- Employ an advanced polymer with good compatibility and CO_2 transport properties
- Create a membrane in which diffusion phenomena are determined by interactions with the particle and polymer surface

Membrane Fabrication and Optimization



5-10 nm Silica

Nano-particle Selection



Nano-particle Modification

Membrane Film Fabrication

The Polymer

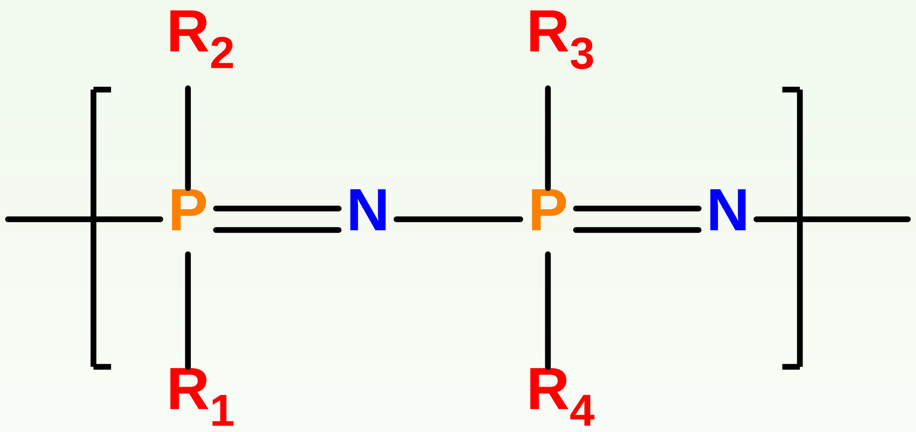
The Ideal Polymer?

Processability/
Mechanical Properties

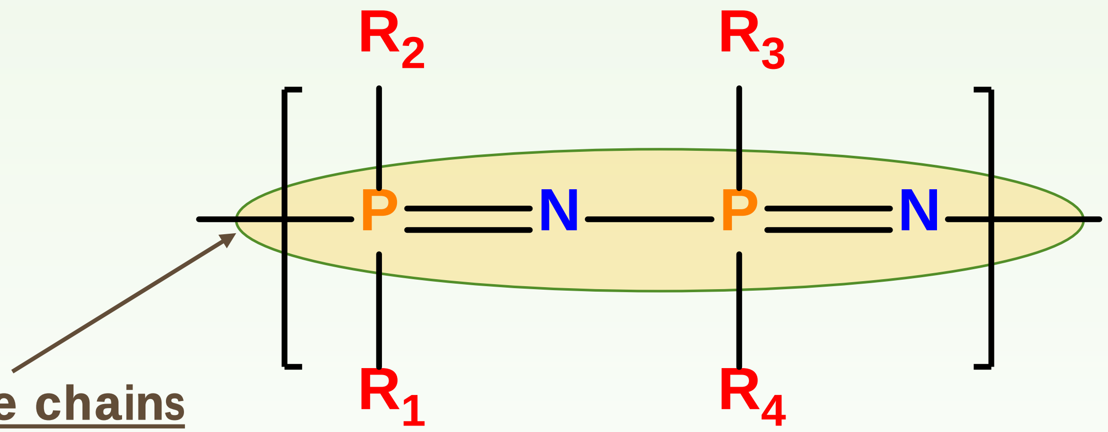
Chemical and
Environmental
Stability

Gas Separation Performance

What's so great about polyphosphazenes?

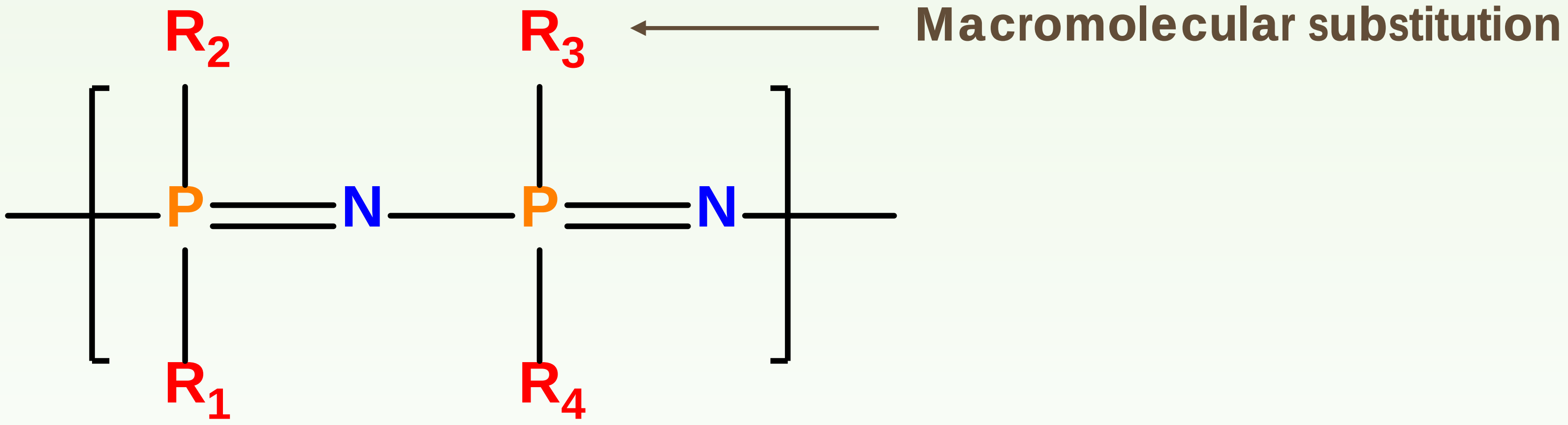


What's so great about polyphosphazenes?



Ultra Flexible chains
High chain mobility
Improved gas solubility and diffusion

What's so great about polyphosphazenes?



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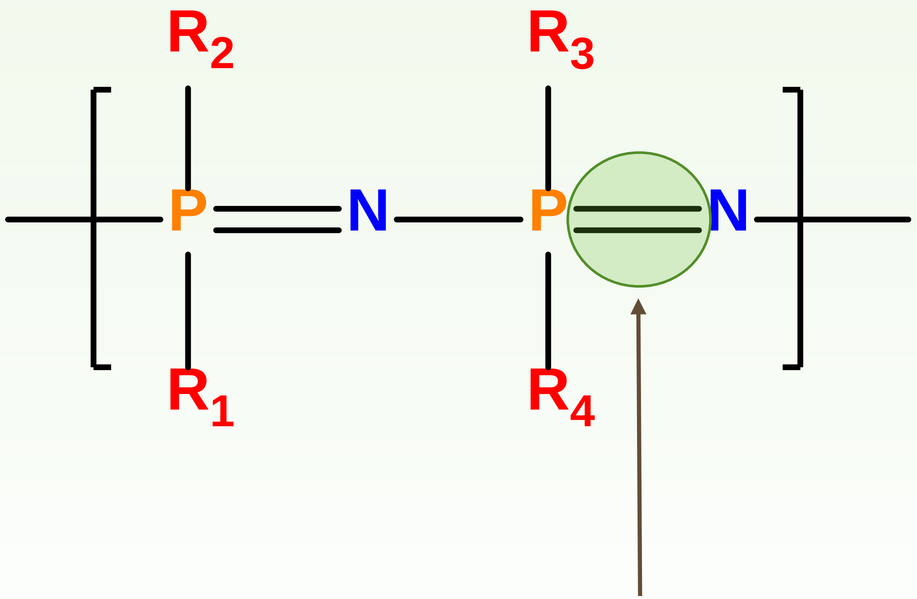
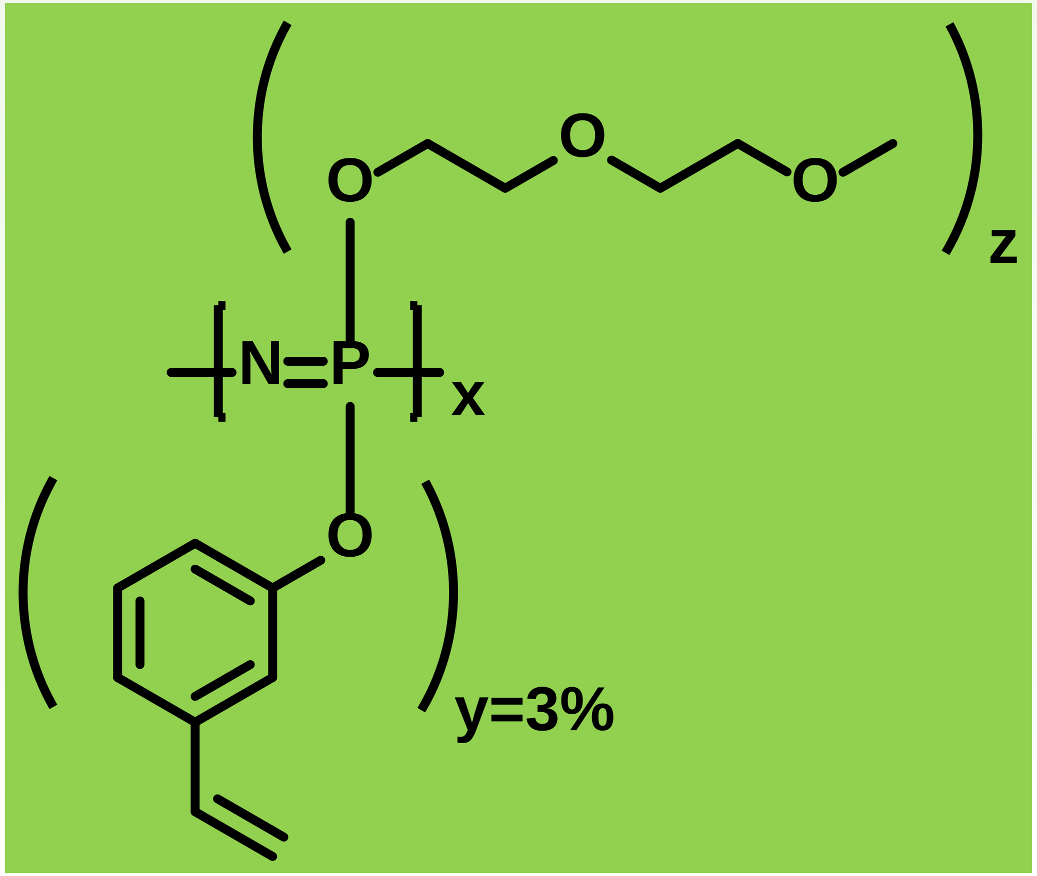


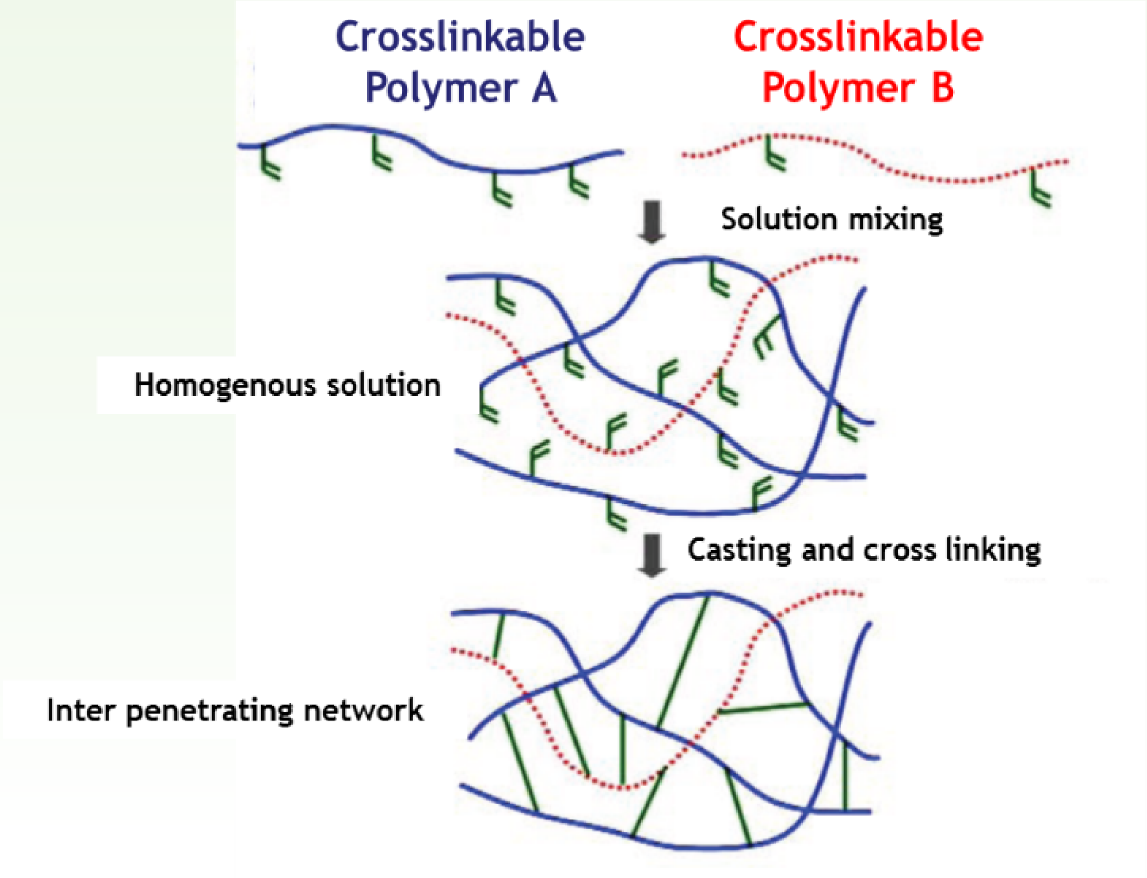
Excellent chemical and thermal stability

C-C =607Δ*Hf* kJ/mol vs. P-N =617 Δ*Hf* kJ/mol

Selected Polymer



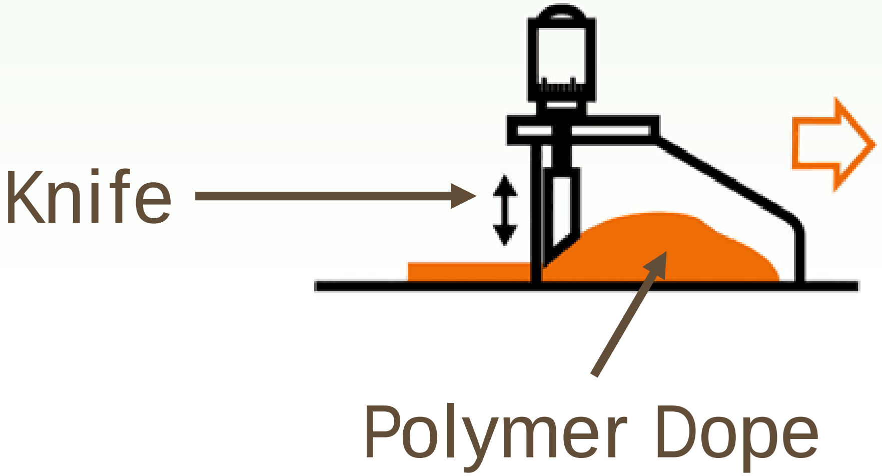
Polymer

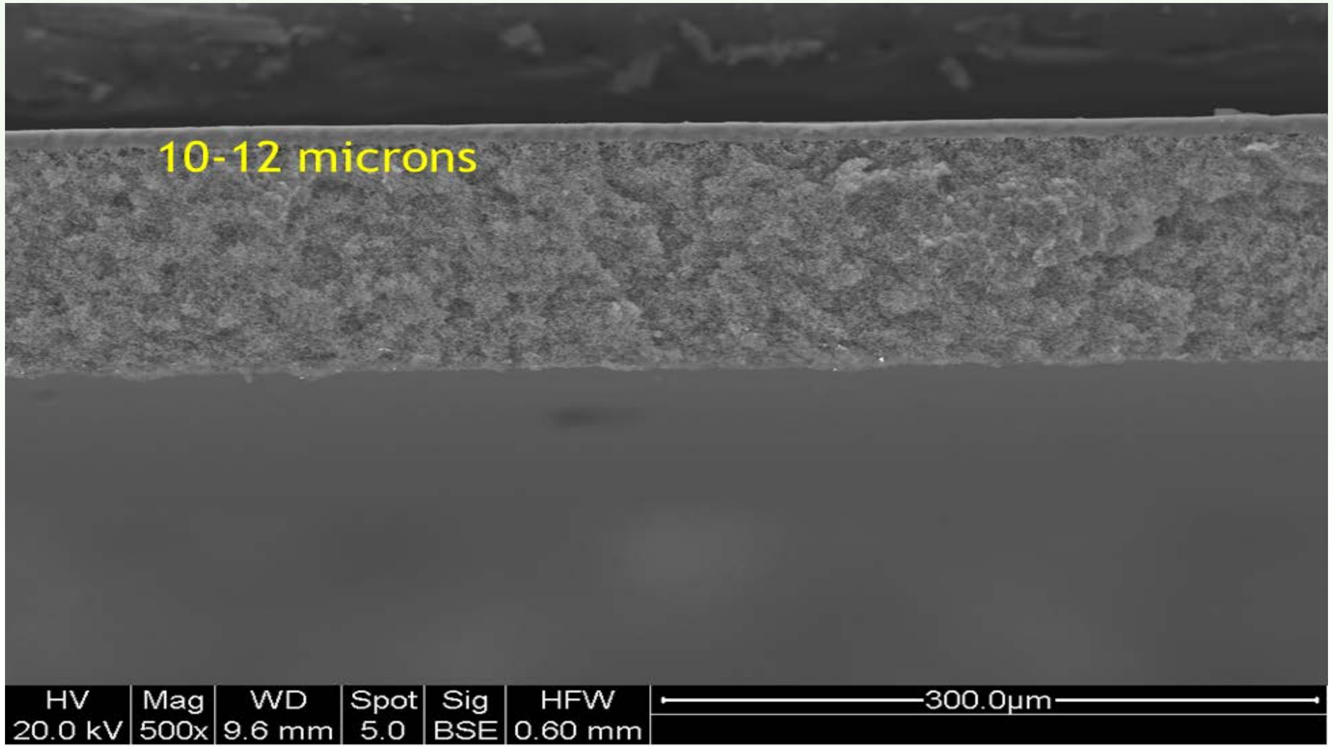


Crosslinking Approach

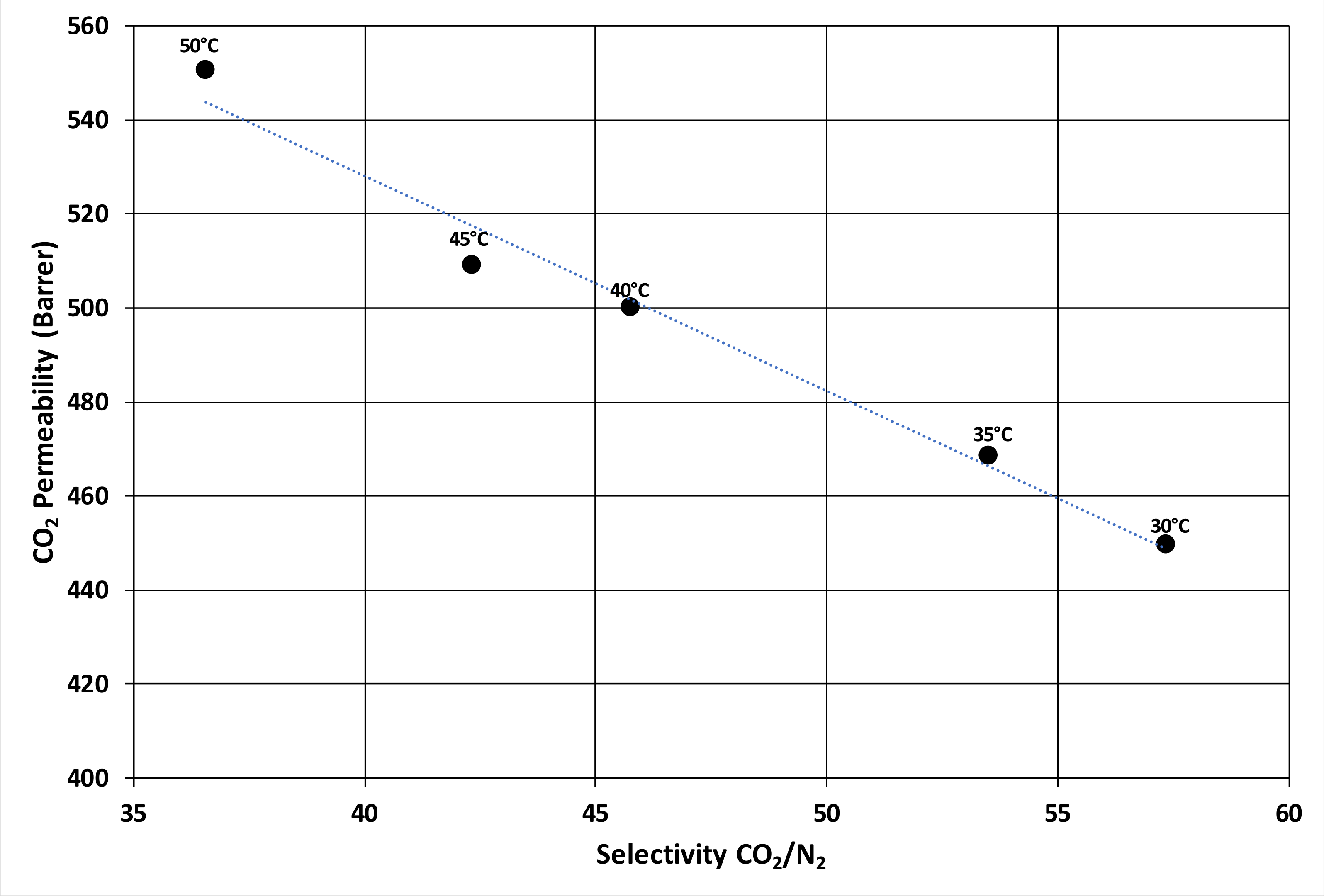
Fabrication and Testing

Knife Casting on Porous Support





Generation 0 Membrane (Neat Polymer)

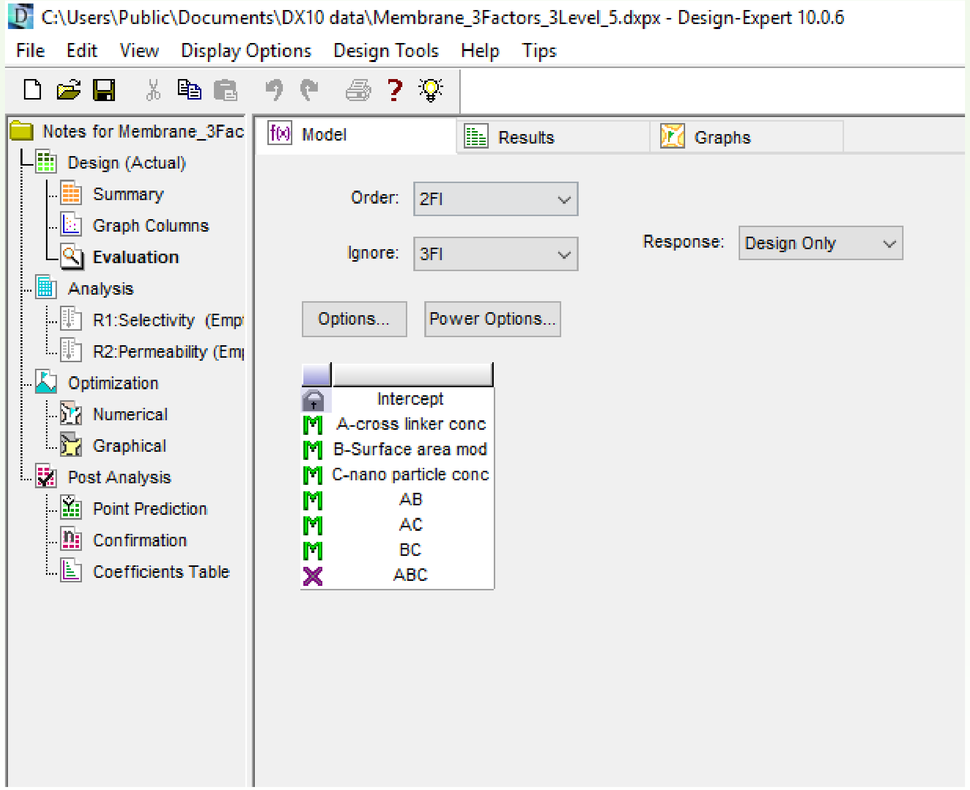


Generation 1 Membrane (Mixed Matrix)

%wt. Loading of Nanoparticles	Characterization	Membrane Results	
		Permeability	Selectivity
30% Unmodified Particles	Non-Homogenous Films	N/A	N/A
10% Modified Particles	SEM, TGA, DSC, Membrane Testing	659	41
20% Modified Particles	Membrane Testing	675-1025	20-33
40% Modified Particles	SEM, TGA, DSC, Membrane testing	1609	44
60% Modified Particles	Membrane testing	250-400	25-30

Design of Experiments Matrix

- Further optimization of membrane composition Design of Experiments
  - Surface modification of the nanoparticles
  - Concentration of nanoparticles
  - Degree of crosslinking
- 30 compositions examined.



Using statistical tools to optimize membrane composition

Next Steps

- Complete optimization of membranes.
- Test membranes in simulated flue gas.
- Fabricate membranes as sub-micron films.
- Complete preliminary economic analysis.

Acknowledgement

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Questions?