Optimization and Scale-up of Molecular-Sieve Membranes with Record Air Separation Performance

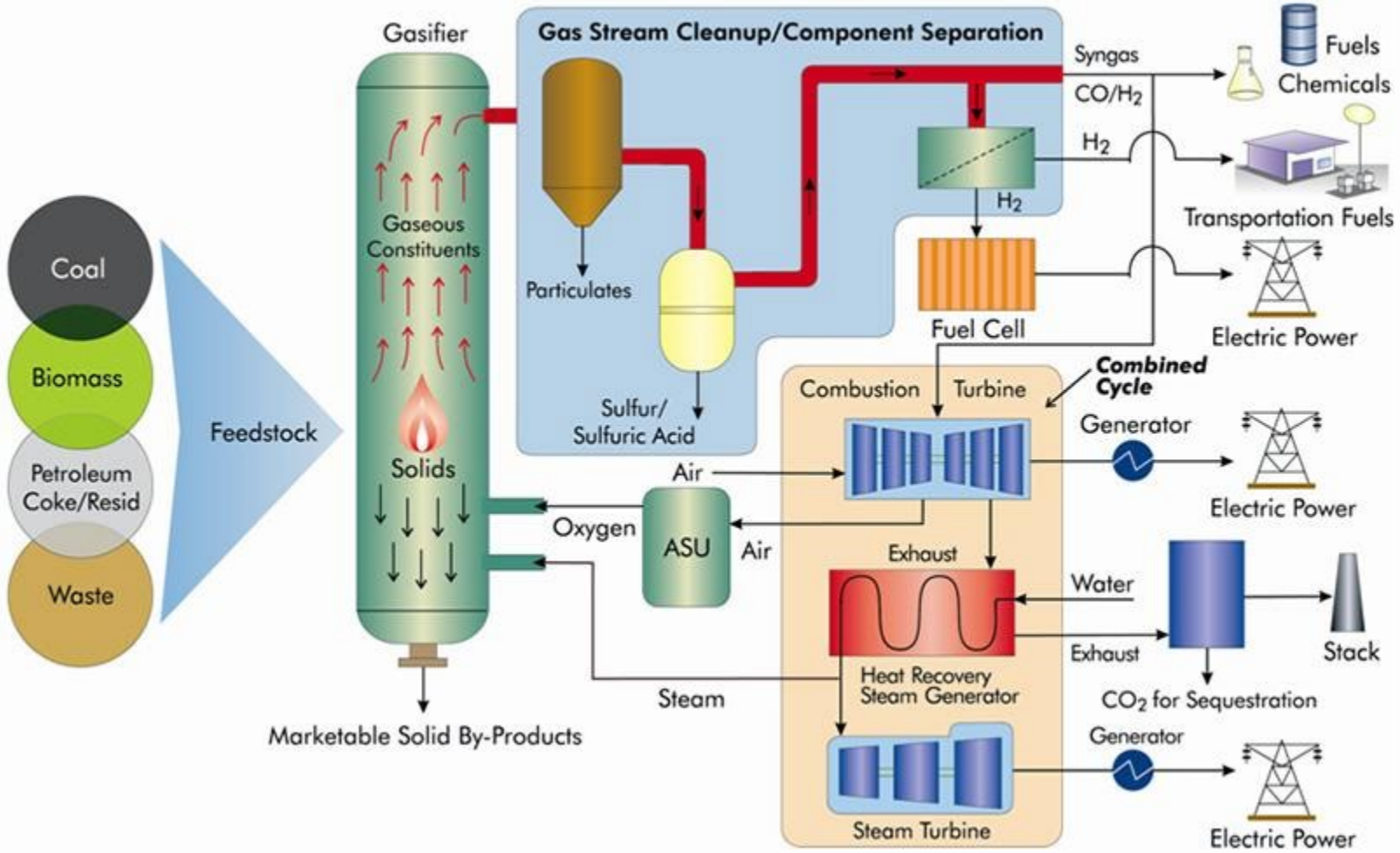
Spring FECM Project Review

Holden Lai, CTO and cofounder

OSMOSES

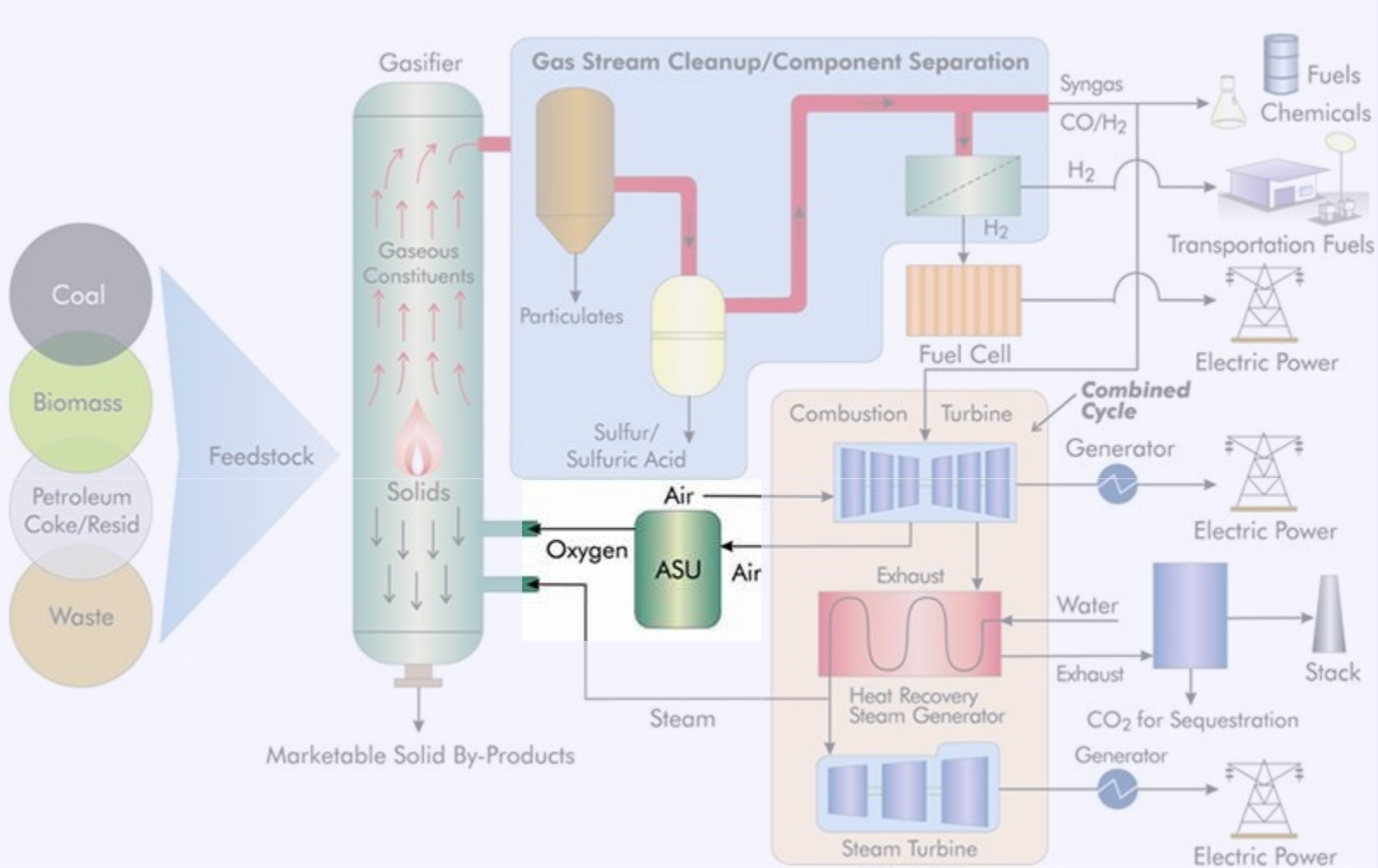
Gasification & Project Goals

The Gasification Process



From DOE NETL Website

The Gasification Process



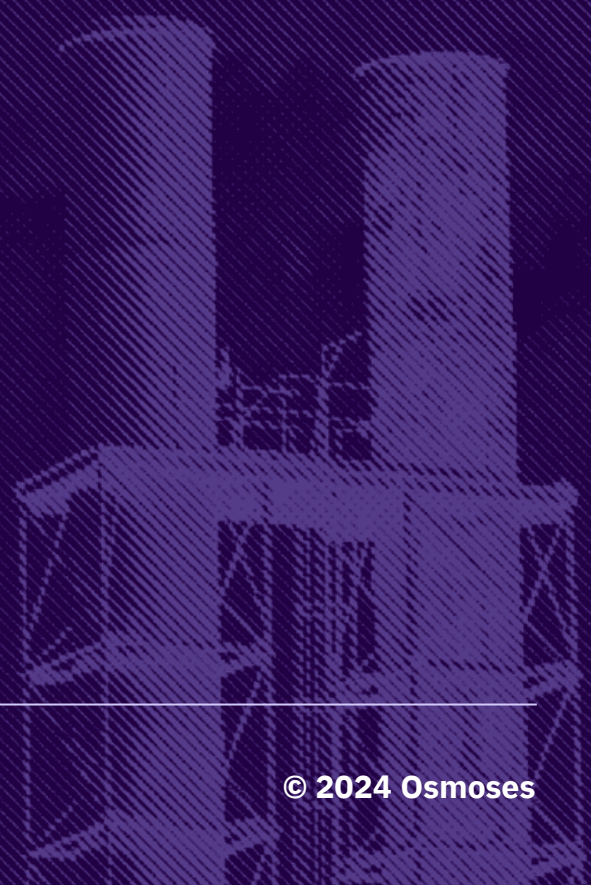
From DOE NETL Website

Project Goals

Develop a novel membrane system that can produce enriched O_2 from air for integration into modular gasification systems for low-cost H_2 production.

- Optimize polymer formulation and thin-film composites to improve membrane O_2 permeance and O_2/N_2 selectivity.
- Develop a process and technoeconomic model for using membranes systems in 5–50 MWe gasifiers to produce >99% H_2.
- Scale thin-film composite formulations to produce 100 m^2 of membrane area.
- TRL 2 -> TRL 5

Background on Osmoses membranes

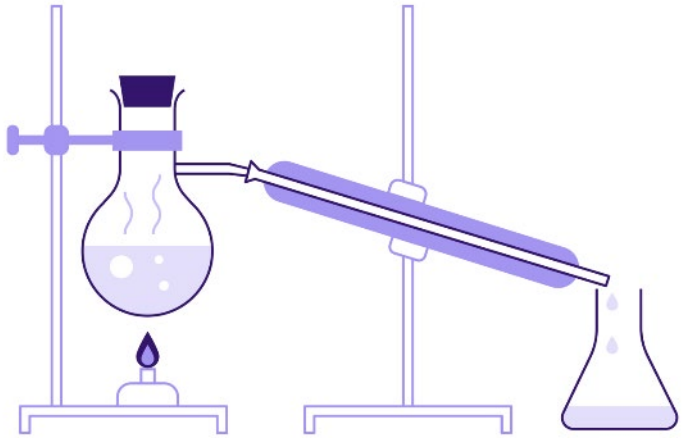


April 25, 2024

www.osmoses.com

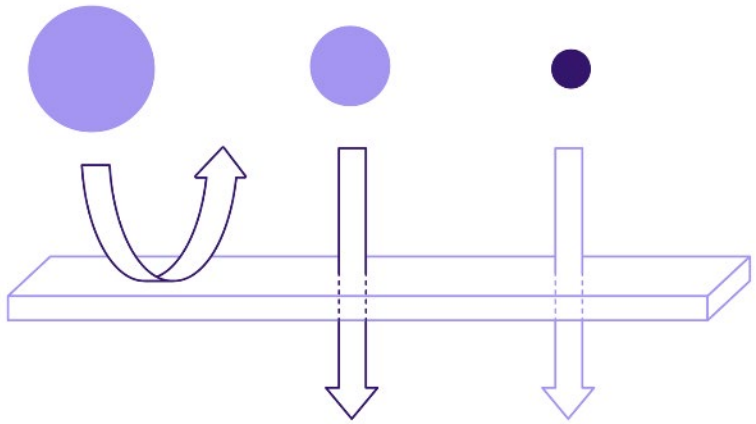
OSMOSES

Traditional separations



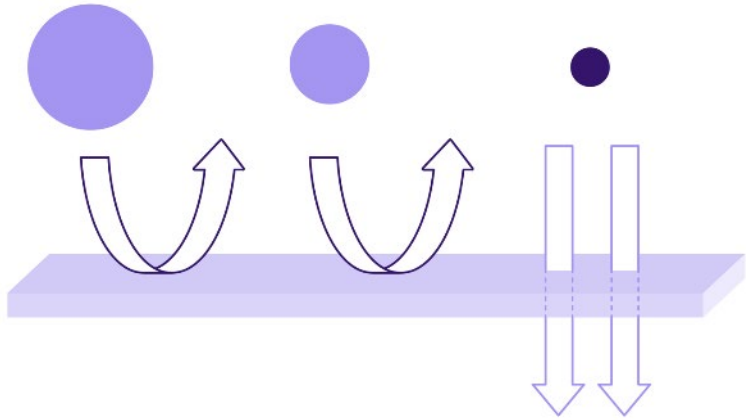
- ✗ High production costs
- ✗ High energy waste
- ✓ Effective separation

Traditional membranes



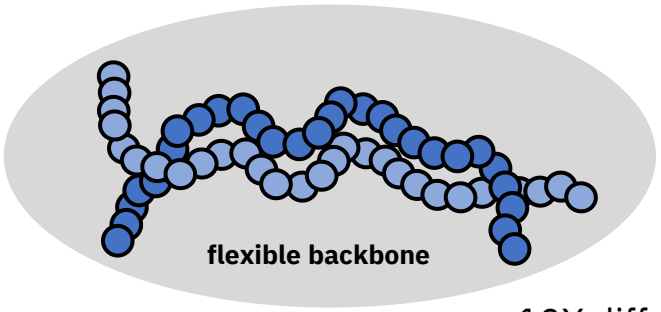
- ✗ Medium production costs
- ✓ Low energy consumption
- ✗ Poor separation

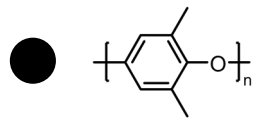
Osmoses membranes



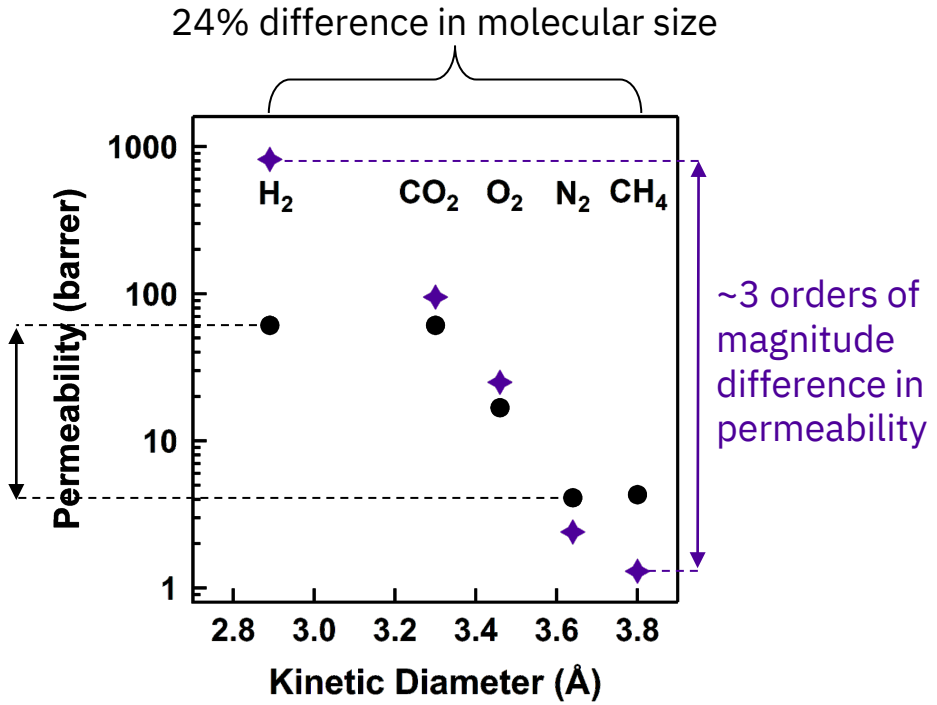
- ✓ Low production costs
- ✓ Low energy consumption
- ✓ Exceptional separation

Exceptional size-selectivity in Osmoses polymers

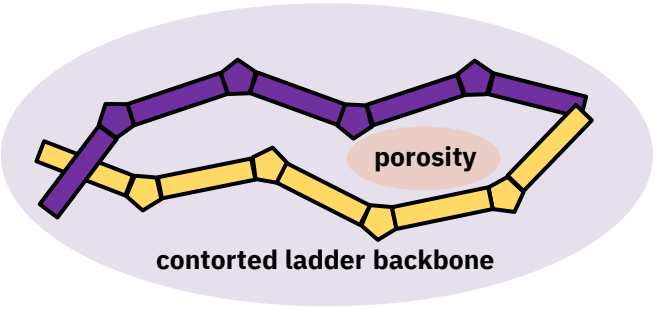


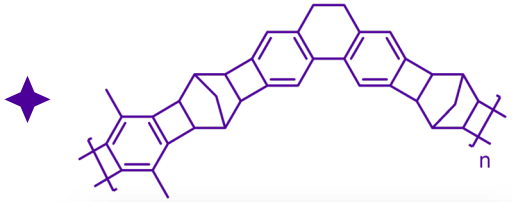


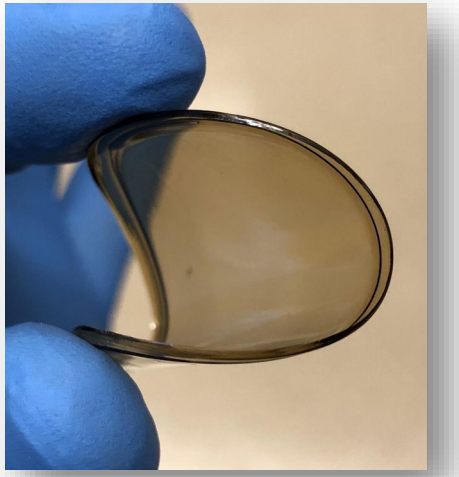
~10X difference in permeability



~3 orders of magnitude difference in permeability







Commercializing breakthrough science

OSMOSES

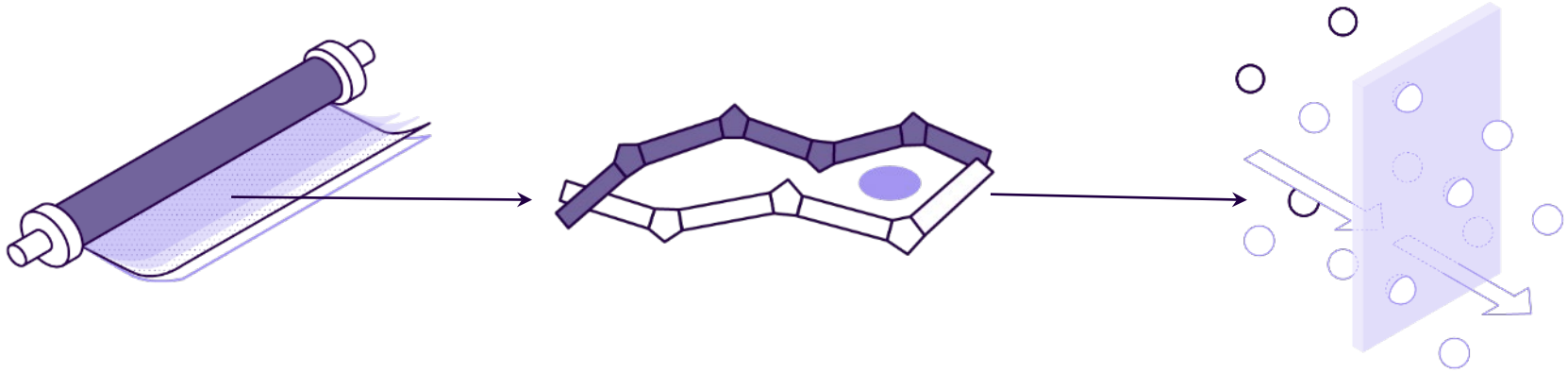
RESEARCH

Science JOURNALS AAAS

MEMBRANES

Hydrocarbon ladder polymers with ultrahigh permselectivity for membrane gas separations

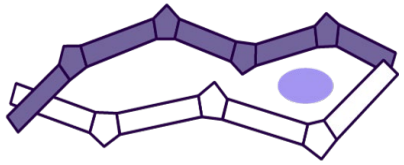
Holden W. H. Lai[1]†, Francesco M. Benedetti[2]†, Jun Myun Ahn[1]‡, Ashley M. Robinson[1], Yingge Wang[3], Ingo Pinnau[3], Zachary P. Smith[2]*, Yan Xia[1]*



US patent US9,708,443 B2
PCT patent WO2021/101659 A2
PCT patent PCT/US23/34879
PCT patent PCT/US24/13947

THE ENGINE · ENERGY CAPITAL VENTURES · Fine Structure VENTURES · orbia ventures · arpa·e · U.S. DEPARTMENT OF ENERGY · MASSACHUSETTS CLEAN ENERGY CENTER · Activate · NSF

Detailed technology description

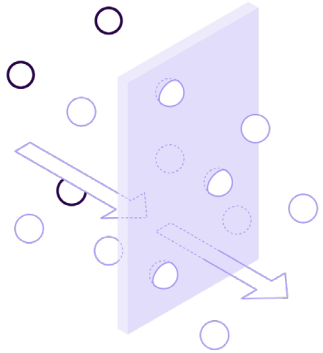


Osmoses membranes consist of a novel polymer with:

Size Selectivity: a result of gas-size pores generated from inefficient polymer packing

Thermal Stability: chemically stable up to 250°C

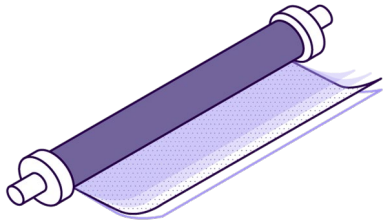
Chemical Resistance: nonreactive in the presence of water, H_2S, and other contaminants



Osmoses membranes have been proven to perform well under:

High pressure: External tests demonstrated high CO_2/CH_4 selectivity at 60 bar.

Aggressive contaminants: High CO_2/CH_4 selectivity in the presence of C_3 hydrocarbons and H_2S



Work is underway to build membrane modules using Osmoses materials.

Roadmap to **commercialization**

Grow the team
Scale up membranes

Build prototype modules
Partner with companies

Pilot with customers

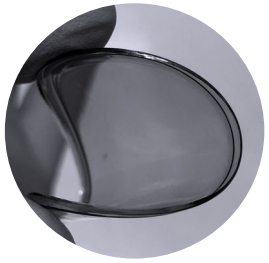
Commercialize solutions

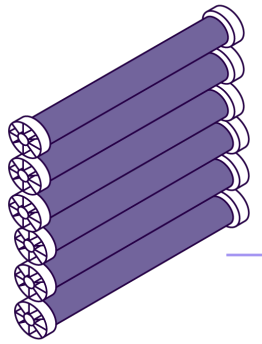
2022

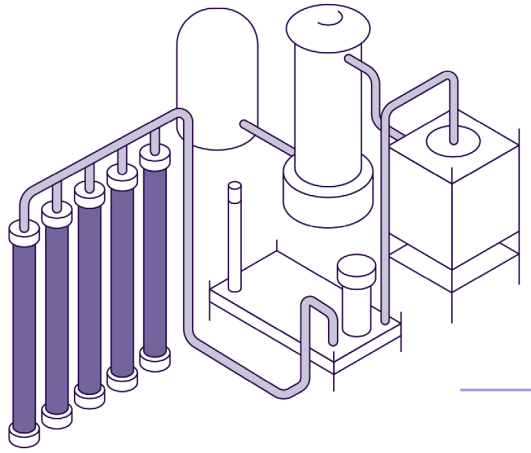
2023

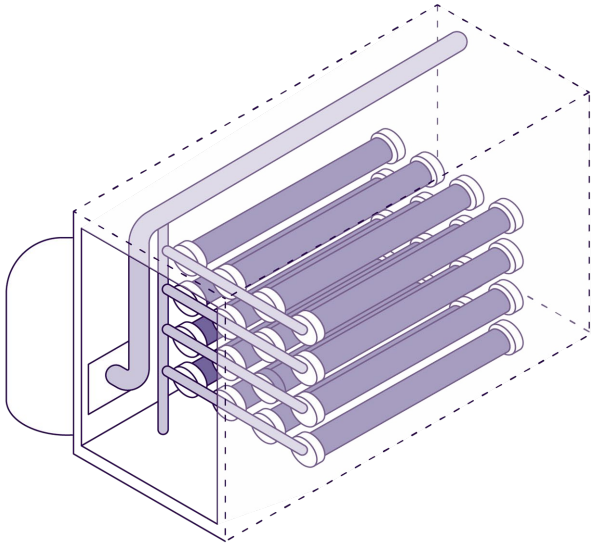
2025 -

2027 -









Specific plan to achieve project objectives, timeline

Demonstrate feasibility

- Scale up the best polymers (Subtask 2.3).
- Evaluate temperature and pressure effects on separation performance (Task 3)
- Long-term, continuous testing (Task 4.1).
- Make a 100 m2 of membrane (Task 4.2).
- Technoeconomic analysis (Task 5).

Task 5

- **Task 5.02 Process Model**
  - Biomass and Waste Gasification
  - U-GAS (Fluidized bed) and R-GAS (Entrained flow)
  - Compare performance with ASU vs Osmoses Membrane Separation
- **Task 5.03 Model Cost and Efficiency differences**
  - Cases from 5.02
  - Class 5 Cost Estimates for the four models

Tasks timeline

Task/Subtask/Milestone Name	Project Year 1 (2024)				Project Year 2 (2025)			
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Task 1.0 Project Management Plan								
Subtask 2.1 – Synthesize polymers for thin-film composite membrane formation								
Milestone A. Confirm synthesis of 5 different polymers at 250-mg scale	♦ (Mar. 31, 2024)							
Subtask 2.2 – Produce thin-film composite membranes using polymers synthesized in Subtask 2.1								
Milestone B. Report permeance and selectivity results for each thin-film composite membrane		♦ (Jun. 31, 2024)						
Subtask 2.3 – Scale up of the best polymers								
Milestone C. Confirm synthesis of 3 different polymers at 5-g scale				♦ (Dec. 31, 2024)				

Tasks timeline

Task/Subtask/Milestone Name	Project Year 1 (2024)				Project Year 2 (2025)			
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Task 3 – Evaluate temperature and pressure dependence of the thin-film composite membranes for air separation								
Milestone D. Report the permeance and selectivity of membranes at different temperatures and pressures					♦ (Mar. 31, 2025)			
Subtask 4.1 – Evaluate performance of top performing TFC for up to 1,000 h to determine aging rates and performance								
Milestone E. Report performance and aging rates of top performing TFC						♦ (Jun. 31, 2024)		
Subtask 4.2 – Scale TFCs to 100 m2 through in-house manufacturing to evaluate quality control and performance								
Milestone F. Make 100 m2 of TFC polymer and report performance of multiple samples for quality control								♦ (Dec. 31, 2025)

Tasks timeline

Task/Subtask/Milestone Name	Project Year 1 (2024)				Project Year 2 (2025)			
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Subtask 5.1 (GTI) – Design a process model for biomass and waste conversion to reach 99% H2 based on optimized Osmoses membranes								
Milestone G. (GTI) Report a process model for H2 production using Osmoses membranes								♦ (Dec. 31, 2025)
Subtask 5.2 – Calculate optimized membrane areas and costs ($/ton O2) required for 5–50 MWe equivalent gasifier applications								
Milestone H. Report required membrane area and cost for optimized O2 delivery to 5–50 MWe gasifiers								♦ (Dec. 31, 2025)
Subtask 5.3 (GTI) – Model cost and efficiency differences for Osmoses membranes compared to state-of-the-art air separation and other oxygen production methods								
Milestone I. (GTI) Report cost and efficiency differences for Osmoses membranes compared to state-of-the-art air separation and other oxygen production methods								♦ (Dec. 31, 2025)

Diversity, equity, inclusion, and accessibility (DEIA) plan

April 25, 2024

www.osmoses.com

Mission Statement

You belong at Osmoses!

We are committed to an environment that provides a workplace of belonging, acceptance and safety for everyone! We appreciate, value, and embrace the unique differences of our team members, business associates, candidates and stakeholders.

Why? Because we believe it is powerful to embed diversity in all aspects of our business – it is at the core of our culture. Osmoses' responsibility and dedication towards our DEIB principles ensures an equitable workplace with a diverse, dynamic team of professionals. This is fundamental to our mission to develop and commercialize environmentally safe, innovative technology that can create a future where cleaner and more sustainable industrial processes become the norm.

Project Goals

- **Goal 1:** Define DEIA milestones and track DEIA data within the organization on a yearly basis. **Due: Apr 17, 2024**. **In Progress**
- **Goal 2:** Develop a DEI mission statement, and allocate organizational resources to DEIA activities. **Due: Apr 17, 2024**. **Complete**
- **Goal 3:** Implement DEI training and ensure that the training is effective among employees. **Due**: **Dec 31, 2024**. **In Progress**
- **Goal 4:** Develop a formalized annual performance appraisal strategy for existing employees. **Due: Dec 31, 2024. In Progress**
- **Goal 5:** *On retention* - Refine benefits, policies, resources, and initiatives to improve well-being and address the needs of employees across career stages and personal family circumstances. **Due**: **Feb 28, 2025**. **In Progress**
- **Goal 6:** *On recruitment* - Identify the best way to collect information from job applicants to get accurate recruitment data and perform unbiased hiring. Including, collaborating with, and contracting with persons from URM groups. **Due May 31, 2025**. **In Progress**
- **Goal 7:** Increase engagement with minority owned businesses on vendor or sub-contracting jobs. **Due**: **Aug 31, 2025. In Progress**
- **Goal 8:** Create educational opportunities for underserved communities where our project team could share their expertise on topics that the communities are interested in. **Due: Dec 31, 2025**. **In Progress**

Project Plan Milestones

Goal 1: Milestones

- Collaborating with third parties regarding training, initiatives, tracking and reporting back. Evaluating effectiveness of efforts.
- Mapping definitive roadmap to meet objectives of our plan

Goal 2: Mission

- Mission statement complete.
- Collaborating with Third Parties on Training efforts aligned with budget.

Goal 3: Training

- Justworks trainings assigned.
- Additional hands-on workshops in creation

Goal 4: Performance Appraisal

- Performance evaluation strategy in development.
- Identifying outside resources to review and provide feedback

Goal 5: Retention

- Crafting new polices and refining existing with a holistic lens.Reviewing total rewards program to expand or refine package.
- Affording platform to enable and encourage consistent personal and professional development through PDP program

Goal 6: Recruitment

- Crafting refreshed recruiting strategy, initial screening forms, evaluation and selection criteria, broader candidate outreach.
- Seeking ATS to track applicants/ created new method to track in interim.

Goal 7: External engagement

- Creating a source list of minority owned businesses on vendor or sub-contracting jobs.
- Collaborating with internal and external resources to establish unbiased criteria for selection and use of vendors

Goal 8: Education

- Fostering relationships to afford opportunities for underserved communities to visit Osmoses, tour our lab/space and learn.
- Seeking opportunities to reach underserved communities/schools to speak/train or introduce science opportunities and paths

Optimization and Scale-up of Molecular-Sieve Membranes with Record Air Separation Performance

Holden Lai
Co-Founder and CTO
info@osmoses.com

OSMOSES