Review of Historical Membrane Workshop Results

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Membrane Technology Workshop
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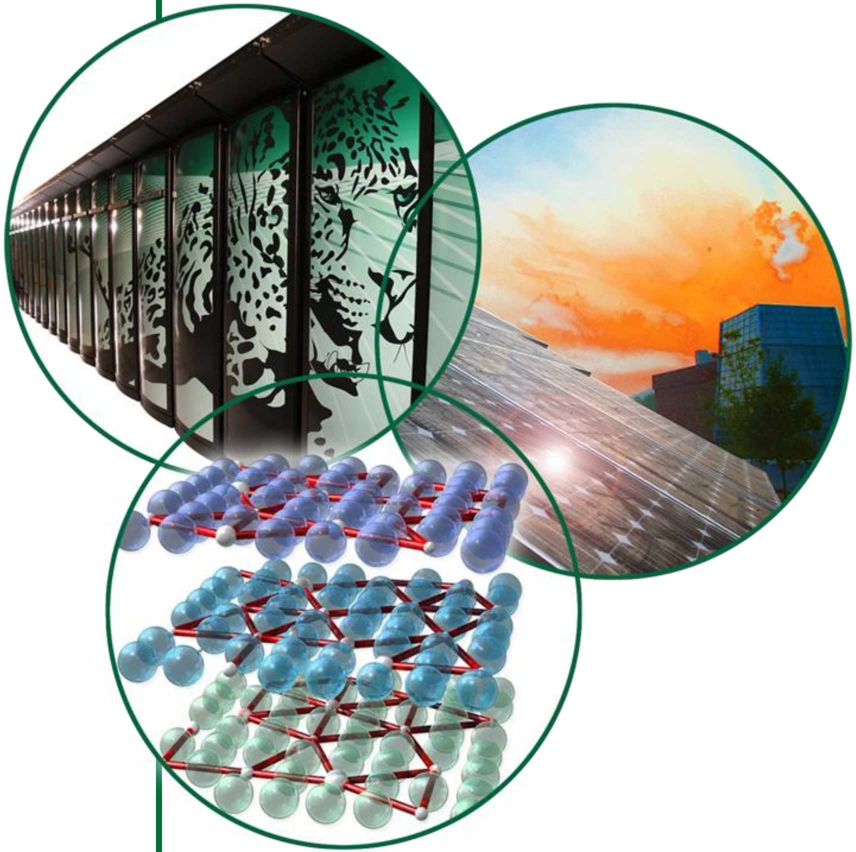

U.S. DEPARTMENT OF ENERGY

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Previous Membrane R&D Needs Studies

- Workshop reports and documents developed for DOE OIT/ITP/AMO to support the *Technology Vision2020: The Chemical Industry* (1996) as requested by the White House Office of Science and Technology Policy
  - *Separation Technologies for the IOF (1998)*
  - *Vision2020: 2000 Separations Roadmap (1999)*
  - *Materials for Separations Technologies: Energy and Emission Reduction Opportunities (2004)*
  - *Hybrid Separations/Distillation Technology: Research Opportunities for Energy and Emissions Reduction (2005)*
  - *Separation Technology R&D Needs for Hydrogen Production in the Chemical and Petrochemical Industries (2005)*
  - *Alternative, Renewable and Novel Feedstock for Producing Chemicals (2007)*
  - *Industrial Feedstock Flexibility Workshop Results (2009)*

General Status of Membrane Development for Industrial Applications

- Significant investment in membrane technology has occurred but with limited industrial implementation
  - NETL development of ceramic membranes with applications in fuel cells, H_2 separations, and O_2 separations
  - Significant R&D investment in palladium membranes for H_2 recovery
- Major high energy industrial applications covered by OIT/ITP/AMO
  - Alternatives to distillation
  - Gas separations, primarily H_2 and O_2
  - Feedstock flexibility for chemical/petroleum industry
- Membrane systems needed for many high-energy industrial applications are limited by lack of selectivity, narrow range of useful operating conditions (thermal stability and low permeation), and high costs

Major Barriers to Membrane Development for Industrial Applications

<u>Important Properties for Emerging Membrane Systems</u>

- Permeability
- Selectivity
- Durability (compaction)
- Resistance to fouling/fouling control
- Thermal stability
- Transport properties
- Defects, particularly at large scale
- Erosion/corrosion resistance
- Clean-in-place
- Advanced control systems
- Module design and scale-up
- Costs, particularly for high volume applications

Intrinsic Properties	System Properties
• selectivity • flux/capacity • fouling resistance	• boundary layer formation and control • permeate path carrying capacity • limited packing density (membrane area per module volume) • clean-in-place • limited economies-of-scale (membrane area scale linearly)

Mechanical Properties	Organic	Inorganic
• pressure	compaction	
• temperature	compaction, rate of chemical attack	rate of chemical attack
• pH	hydrolysis, rate of chemical attack	rate of chemical attack
• microbes	biological attack and fouling	biological fouling
• solvents	compaction, swelling, dissolution	dissolution
• mechanical stress/shock	rupture	rupture/fracture
• thermal stress/shock	rupture	rupture/fracture
• colloids	irreversible sorption	irreversible sorption

Membrane Systems for Distillation Applications

Status

- Systems lack selectivity, have narrow range of operating conditions, and have high costs
- Higher selectivity/flux membranes that can withstand high temperatures (80 – 1,200 °F); aggressive chemicals and organic mixtures with molecular sieving capabilities are needed
  - Organic membranes are not likely to withstand high distillation temperatures. Inorganic materials or inorganic/polymer composites have the highest potential, and hybrid systems may be easier to implement than total replacement of distillation equipment
- New module configuration designs, fouling control, and advanced control systems are needed to increase efficiency and reduce costs.
- Membranes are likely to be most successful in “clean” applications, i.e. gas recovery

General R&D Opportunity Areas

- Pilot plant demonstrations of existing materials in specific applications
- Model Predictive Control (MPC) for membrane process
- Material compatibility studies for entire systems (not just membrane materials)
- Improved membrane chemical stability
- Better scaling to reduce costs

Membrane Systems for Distillation Applications continued

R&D Opportunities for Specific Membrane Systems

- Inorganic metal membranes
  - Refinement of the fabrication process to reduce defects in large scale membranes
  - Durability and reliability testing of the membranes
  - Erosion and corrosion resistance of membranes under long-term test conditions
  - Development of thin inorganic membrane films which will exhibit high fluxes
- Ceramic membranes
  - Develop materials that can operate with high selectivity and flux (a challenge for separation of large molecules and similar size molecules)

High Potential Application Areas

- Azeotrope breaking (CO_2 / C_2H_6 separation)
- Pre-concentrator for distillation
- Bulk gas separations for low-temperature streams where existing polymers could be applicable
- Vent gas recovery for refining and olefin/paraffin separations
- Desalination/reverse osmosis for phosphoric acid and caustic applications

Membranes for Gas Separations

Status

- Systems lack selectivity, have narrow range of operating conditions, and have high costs
- Most promising membrane systems for these applications are microporous metal and ceramic membranes

R&D Opportunities for Specific Membrane Materials

- Microporous metal and ceramic membranes
  - Refinement of fabrication process to reduce defects in large scale membranes
  - Development of higher flux/high temperature membranes
  - Development of metal oxide membrane materials capable of operation at <1100°F
  - Improved thermal mechanical performance

Membranes for Gas Separations continued

General R&D Opportunity Areas

- High temperature membranes that are selective only to O_2 or H_2
- Low temperature O_2 selective membranes with permeance >100 x 10^{-8} mole(s·m^2·Pa)
- High integrity H_2 selective mixed matrix membranes
- Organic-inorganic hybrid membrane materials
- Improved H_2 selective inorganic microporous membranes

High Potential Energy Savings Application Areas

- H_2 recovery in petroleum refining processes, such as catalytic cracking and hydroforming
- O_2 enrichment for oxygen-fueled furnaces (reducing the mass of nitrogen by 50%)

Membrane Systems for Feedstock Flexibility Applications

Status

- Workshops have focused on feedstock flexibility for the chemical and petroleum industries: alternative bio-based feedstocks, alternative fossil-based feedstocks, and improvements in efficiency for conventional feedstocks
- Membranes are needed that can withstand processing conditions (temperatures, pH, chemicals); can cope with fouling; can selectively separate desired materials from dilute solutions; have improved permeance, selectivity, reduced costs, chemical resistance; are defect free at large scale; and have proven performance at scale

General R&D Opportunity Areas

- Design better molecule configuration in membranes for fouling abatement
- Develop facilitated transport membranes to separate like molecules
- Develop membrane adsorbent materials (ionic liquids, olid polymeric)
- Develop smart membranes and separations systems for low concentration / high value products

Membrane Systems for Feedstock Flexibility continued

<u>R&D Opportunities for Specific Systems</u>

- Membranes to support bio-based feedstocks
  - Membranes to increase alcohol yield, separate salts, and purify solvents
  - Scalable, low-cost commercially available membranes
  - Membranes that withstand the bio-processing conditions (temperatures, pH, chemicals), can cope with bio-system fouling, and can selectively separate desired materials from dilute solutions
- Membranes to support alternative fossil-fuel feedstocks
  - Improved air separations
- Membranes to support improvements in conventional feedstocks
  - Replace conventional distillation
  - Improved gas separations

Summary from Previous Workshops

- Significant investment in membrane technology has occurred but with limited industrial implementation
- The major R&D needs are for improved selectivity, range of useful operating conditions, defect-free scale-up for large volume systems, module configuration designs, fouling control, advanced control systems, and lower costs
  - Inorganic materials or inorganic/polymer composites have the highest potential for success for many of these applications
- Research programs should focus on these technical areas for the most promising high energy applications