Composite Metal Membranes for Efficient Fusion Fuel Cycles

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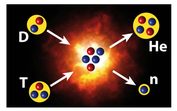
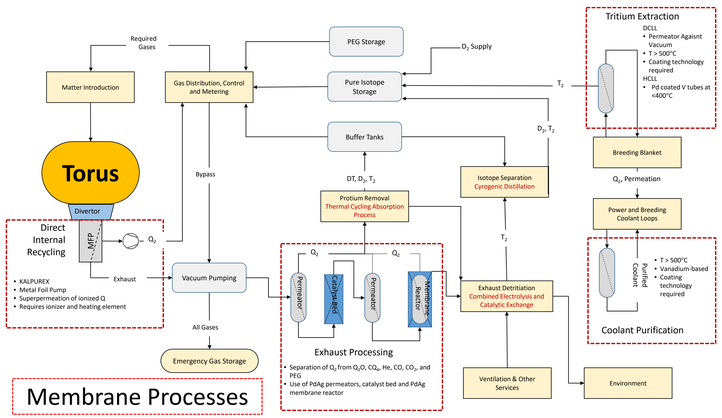
Opportunities & Challenges

Fusion Fuel Cycle

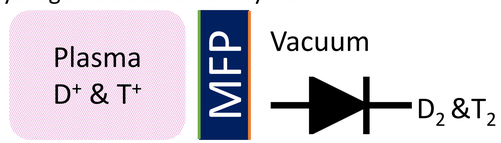
- Membranes critical throughout
- Desired: High flux, infinite selectivity
- Materials: Thermal & chemical stability





Metal Foil Pumps

- Enables direct internal recycling (DIR) reducing T inventory
- Energetic hydrogen superpermeable
- Metal foil pumps (MFP) with asymmetric coatings
- Hydrogen diodes: One way flow



Tritium Extraction from Breeder Blankets

- Molten Metals, Salts (PbLi, FLiBe)
- High temperature (400 – 800 ºC), corrosive

- Corrosion Resistant
- Mechanical Integrity

Exhaust Processing

- Removal of He, trace carbon, oxygen
- Improved efficiency over conventional CAPER process

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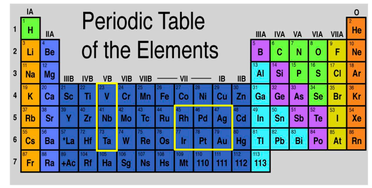
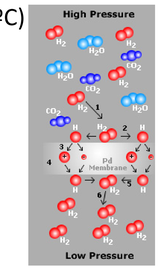
Composite Metal Membranes

Tritium Permeable Metal Membranes

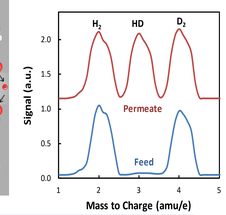
- Solution-diffusion mechanism
- High permeability, infinitely selective
- High T compatibility (300 – 1000 ºC)
- Pd alloys and BCC metals

$$J_{H_2} = \frac{\pi}{L}\left(P^n_{H2,\,feed} - P^n_{H2,\,permeate}\right)$$





Isotopic Scrambling

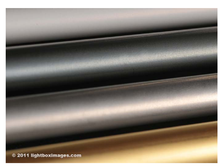


Synthesis & Performance

Palladium and Related Alloys

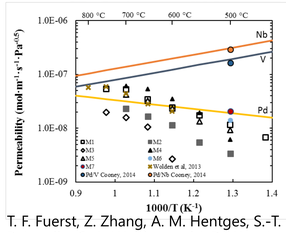
- Electroless plating: Large area, flexible geometries
- Ceramic or ceramic-coated SS supports
- Relatively expensive: 3 – 10 microns

Scalable

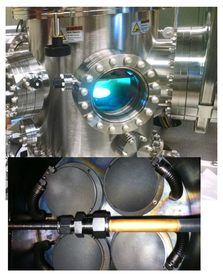


Composite BCC Metal Membranes

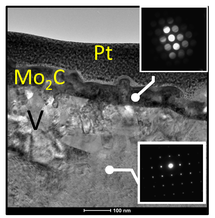
- Orders of magnitude cheaper
- Carbide catalysts (~20 nm) on metal foils
- Higher permeability than Pd!
- High temperature stable (T> 750 ºC)
- Used for isotope enrichment



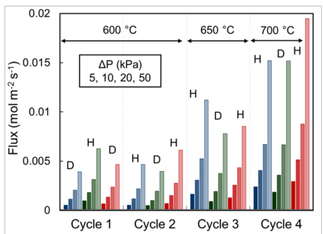
T. F. Fuerst, Z. Zhang, A. M. Hentges, S.-T. B. Lundin, C. A. Wolden and J. D. Way, *J. Membrane Sci,* **549,** 559,6 (2018).



D. A. Cooney, J. D. Way and C. A. Wolden, *Int. J. Hydrogen Energy* **39,** 19009-19017 (2014).



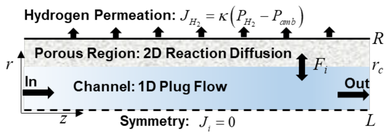
S. K. Gade, S. J. Chmelka, S. Parks, J. D. Way and C. A. Wolden, *Adv. Mater.* **23,** 3585 (2011)



T. F. Fuerst, C. N. Taylor, M. Shimada, J. D. Way and C. A. Wolden, , *JVST A* **37,** 021501 (2019).

Catalytic Membrane Reactors

Reactor Construction & Model

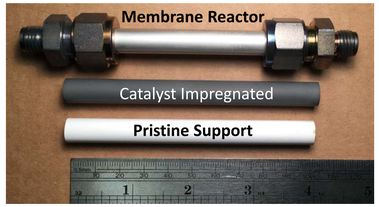


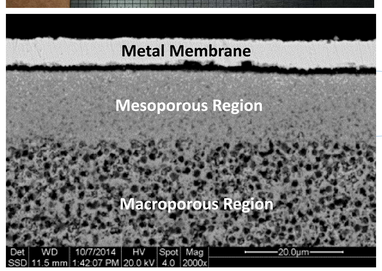
$$\frac{d}{L} << ReSc << \frac{L}{d}$$

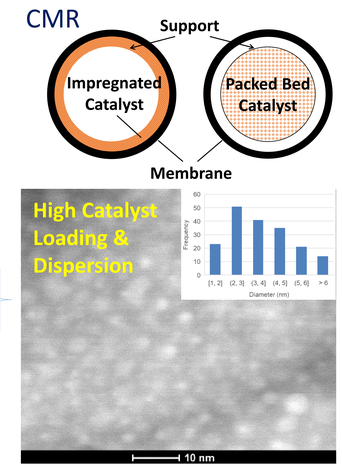
$$\frac{\partial(\rho_i u)}{\partial z} = F_c \nu_i r - F_m W_i J_i$$

$$\nabla(D_i \nabla C_i) = \nu_i k C_{NH_3}$$

- Reduced catalysts loadings (10X), operating temperature >200 ºC .
- Significantly enhance recovery of hydrogen
- Validated reactor model for design, scale-up

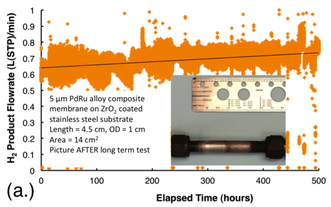


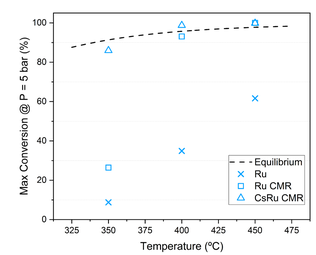




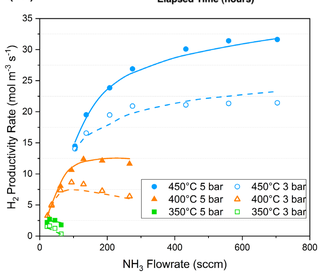
Systems Examined

- Steam Methane Reforming (SMR): $CH_4 + 2H_2O \rightarrow 4H_2 + CO_2$
- Water Gas Shift (WGS): $CO + H_2O \rightarrow H_2 + CO_2$
- Ammonia Reforming: $2NH_3 \rightarrow 3H_2 + N_2$





Z. Zhang, S. Liguori, T. F. Fuerst, J. D. Way and C. A. Wolden, *ACS Sustainable Chemistry & Engineering* **7,** 5975 (2019).



H. W. Abu El Hawa, S.-T. B. Lundin, N. S. Patki and J. D Way, *Int. J. Hydrogen Energy* **41,** 10193-10201 (2016).