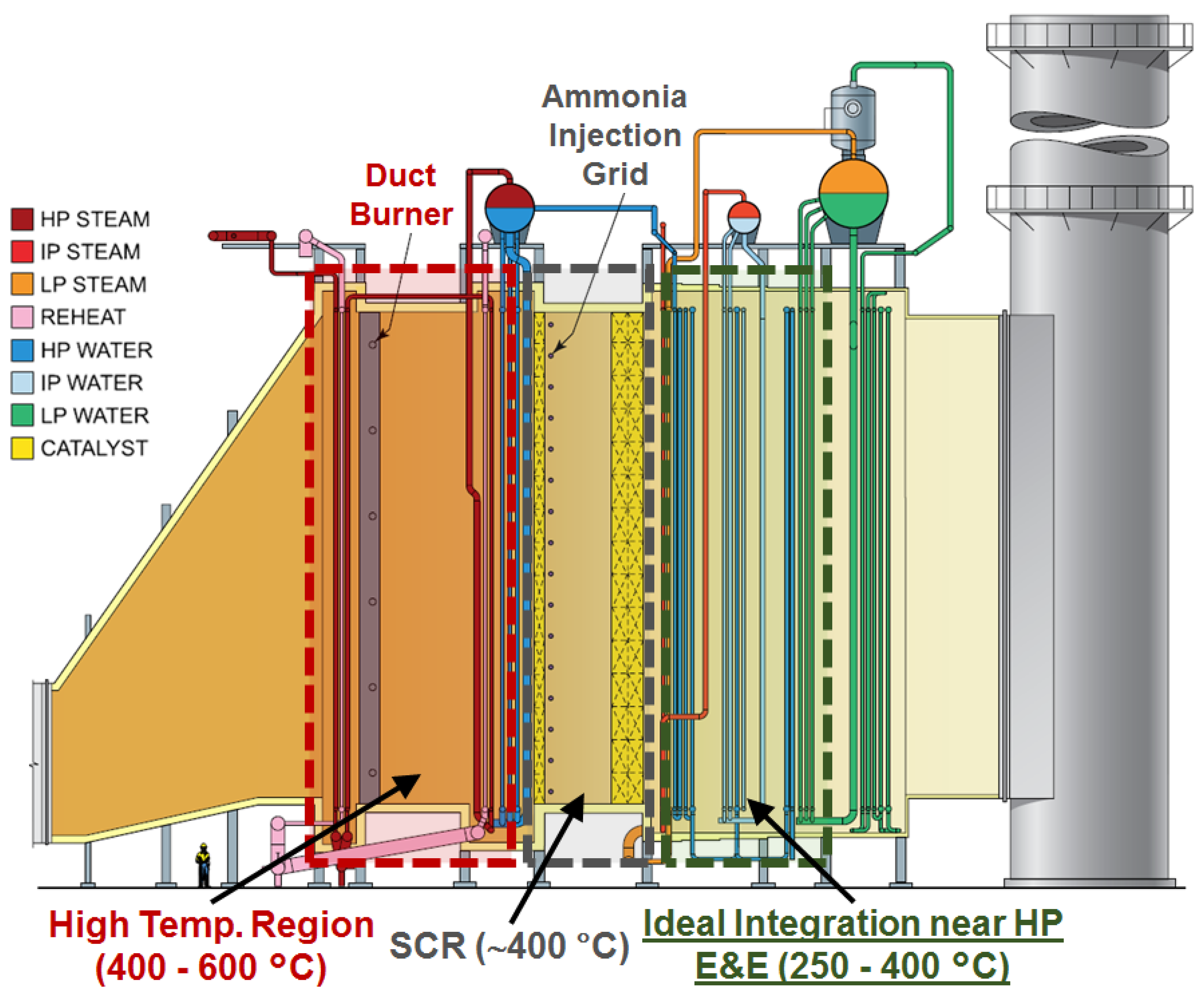
Passive CO_2 Separation Membranes for Hot Flue Gases

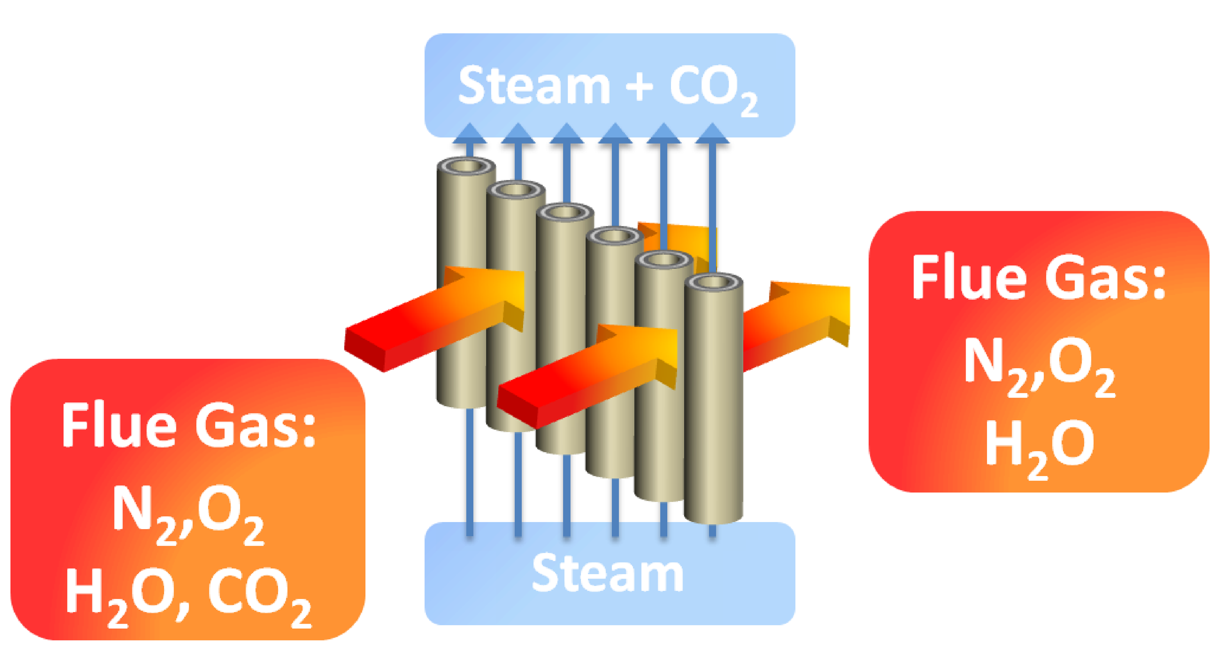
Matthew Merrill, PhD
Luna Innovations
www.lunainc.com
434-220-2512
merrillm@lunainc.com

Integrating passive separation membranes into heat recovery steam generators (HRSG) and boilers to enable greater CO_2 capture energy efficiency.

Avoiding the High Energy Costs of Conventional CO_2 Capture



- The gas separation process functions more like a fuel cell than a conventional membrane.
- Stable operation in previously unattainable temperatures, pressures, and environments.
- Conventional dual phase membranes cannot operate below 650 °C because of limitations in solid oxide ion conduction.
- These membranes can be applied separate air for oxy-fuel combustion and gasification.



The Problem: The theoretical minimum energy penalty for carbon capture (3.5%) is about 10 times smaller than the applied energy penalty (25 – 40%) with conventional technology for coal. (J.R. Long, Angewandte Chemie 2010)

- The Carnot inefficiencies of temperature and/or pressure sorption technologies are too high.
- The energy costs of flue gas compression or applied vacuums in conventional separation membrane approaches are too high.

The Need: The applied energy penalty of CO_2 capture needs to be reduced to enable cost effective CO_2 capture, use, and sequestration (CCUS).

- Incremental energy efficiency improvements of existing technologies will be insufficient and a new approach is needed.
- A new technology should enable fossil fuel power plants and other, large scale sources of flue gas to be retrofitted for CCUS.

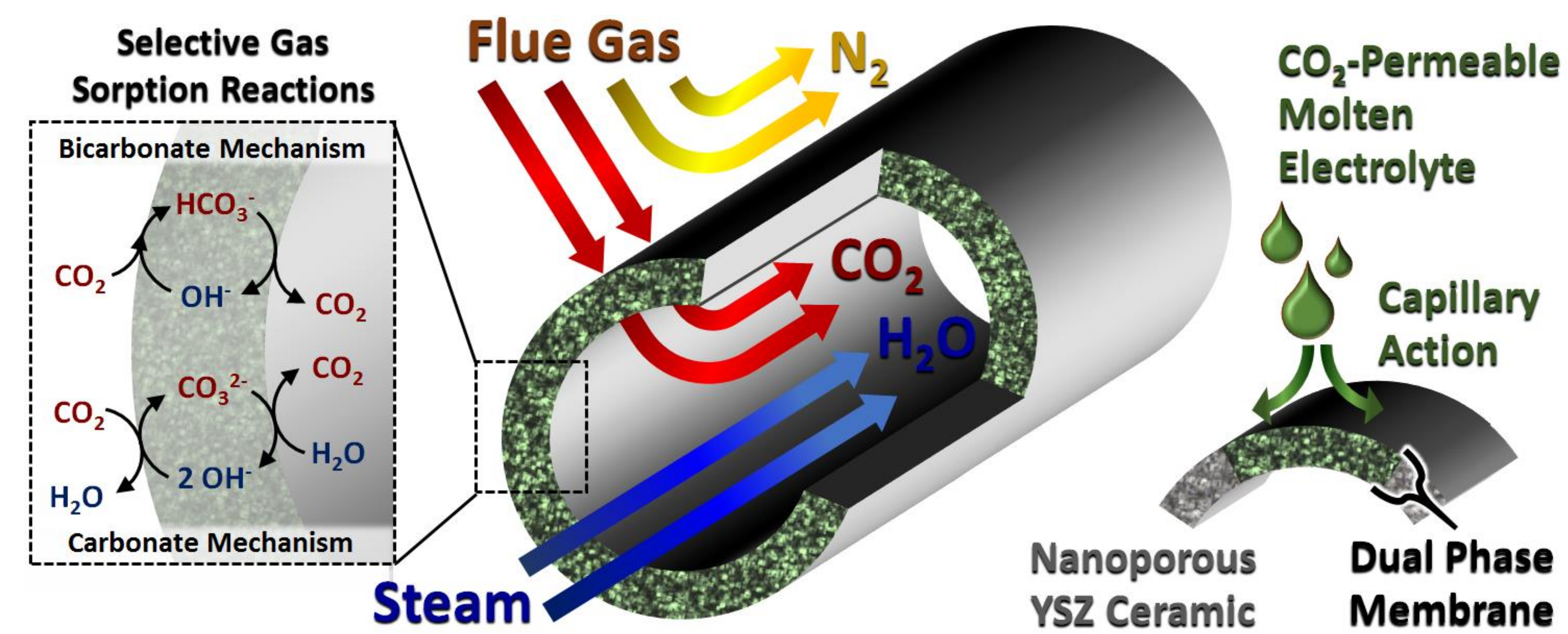
The Solution: ***The difference in $H_2O_{(g)}$ partial pressure between the low pressure steam and the flue gas can be used as the energy input for CO_2 separation and achieve substantial improvements in overall energy efficiency.***

- ***Develop a membrane that can operate within a HRSG in the target range of 250 – 400 °C.***
- ***Modular integration into existing infrastructure with inexpensive materials.***
- ***Use a fraction of the low pressure steam available in a Nooter/Eriksen HRSG. The separated CO_2 is reclaimed from the steam sweep upon condensation of $H_2O_{(g)}$ back to water.***

The Phase II SBIR Program: Develop the best dual phase membrane technology into a module for incorporation into HRSGs.

- Luna is leading the development of the overall design, operation, and commercialization of the membranes, modules, and CO_2 capture approach.
- Nooter/Eriksen is the largest supplier of HRSG technology and is contributing to the integration plan and energy analysis.
- The Lawrence Livermore National Laboratory is developing advanced manufacturing capabilities for membrane production.
- The University of Illinois, Chicago is supporting Luna with additional high temperature membrane testing and expertise.

Dual Phase Membranes for Post-Combustion CO_2 Capture



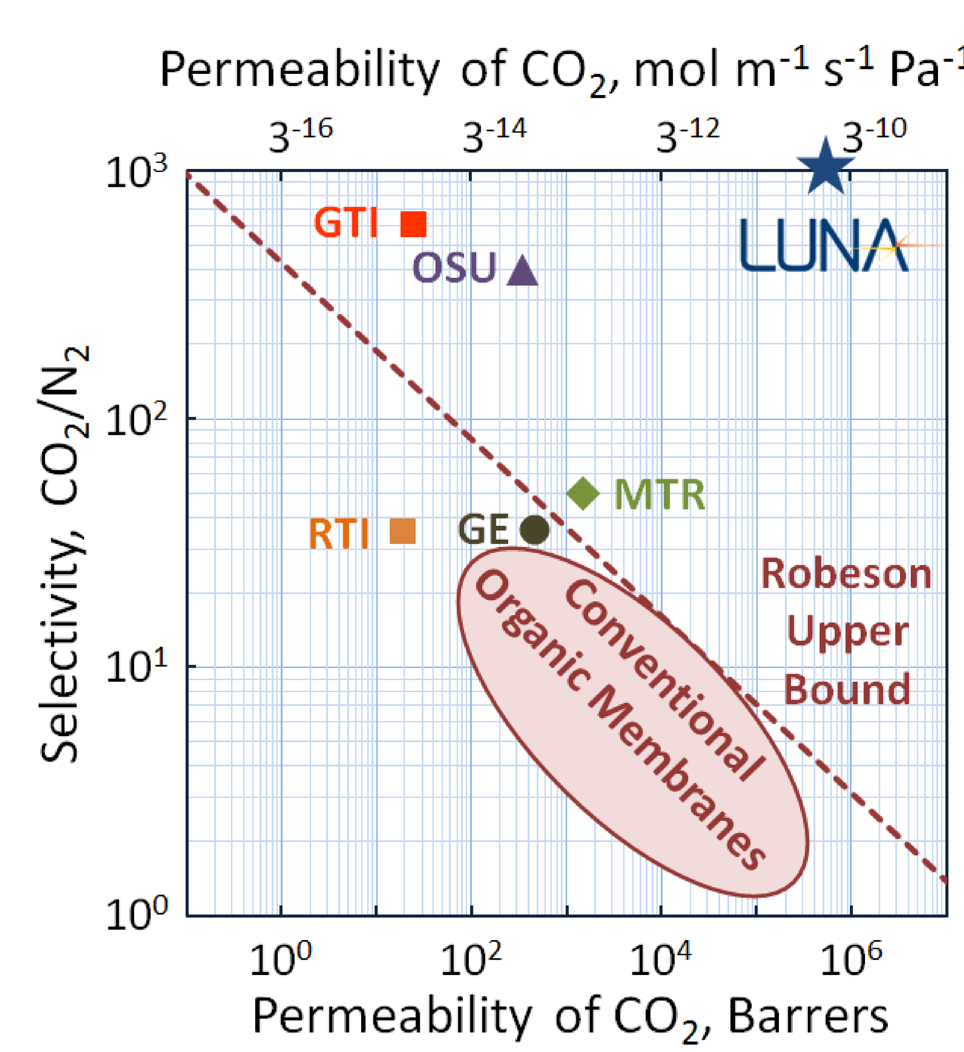
Dual Phase Membrane: The non-volatile liquid phase is retained in the nanoporous solid phase with capillary pressures up to 100 ATM.

The Liquid Phase: A molten electrolyte is used to selectively and reversibly sorb and transport gases as ions. All mass transport is conducted within the liquid phase for rapid permeation through the fastest ion conductors in the HRSG temperature range of 200 – 700 °C.

The Solid Phase: The solid phase is an inert, high strength ceramic that forms thin membranes capable of withstanding high pressures.

The Performance: ***The combination of selectivity and permeability exceeds those of competitive technologies and meets the performance requirements expected for post-combustion CO_2 capture (Ramasubramanian, J. Membrane Science 2012).***

Operational Conditions: The inorganic, oxidation resistant membranes enable separation in previously unattainable conditions that include 200 – 700 °C and 0.1 – 10 ATM.



- **Dual phase membranes are not limited by the physics governing Robeson's Upper Bound.**
- **CO_2 flux does not slow down at lower CO_2 partial pressures due to the separation mechanism.**
- **The separation chemistry is also adaptable to O_2, NH_3, HCl, Cl_2, and NO_2 for other industrial applications.**

- **OSU**: Ohio State University, 2017 NETL Continuation Application Status Meeting
- **MTR**: Membrane Technology and Research, NETL Advanced CO_2 Capture R&D Program Technology Update May 2013
- **RTI**: Research Triangle Institute, 2013 NETL Advanced CO_2 Capture R&D Program Technology Update
- **GE**: General Electric, 2013 NETL Advanced CO_2 Capture R&D Program Technology Update
- **GTI**: Gas Technology Institute, 2017 NETL BP1 Review Meeting

Acknowledgments

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