Teesside University

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Academic Background

Chemical Engineering

Post Doc Yeungnam University, South Korea (2014-15)

PhD Univeriti Teknologi Peronas, Malaysia (2009-13)

MS Otto-von Guricke University, Magdeburg, Germany (2004-07)

BSc (Engg) University of the Punjab, Pakistan (2000-04)

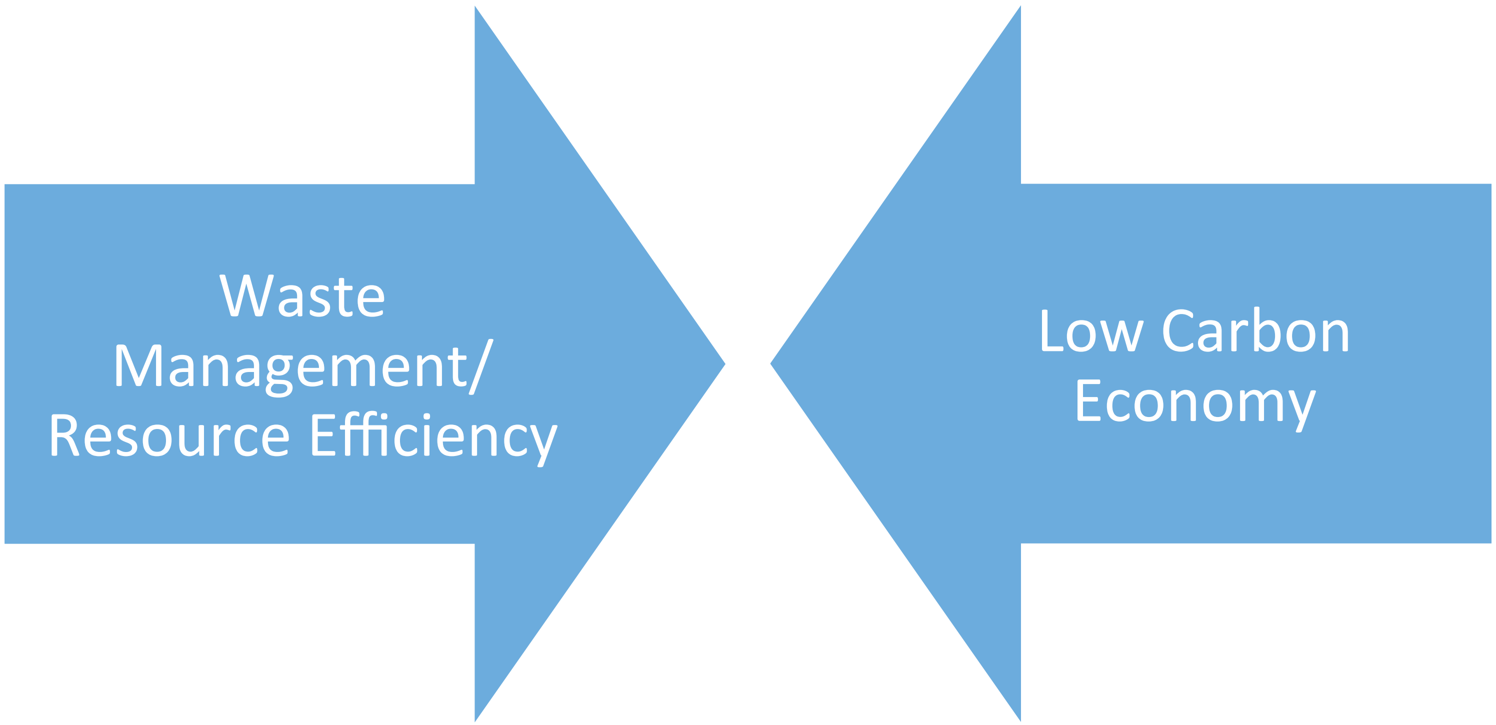
Track Record

Over 20 peer-reviewed journal articles, over 15 conference contributions, 1 Patent filed, 2 Gold medals and1 silver medal in innovation exhibitions

Research Interests

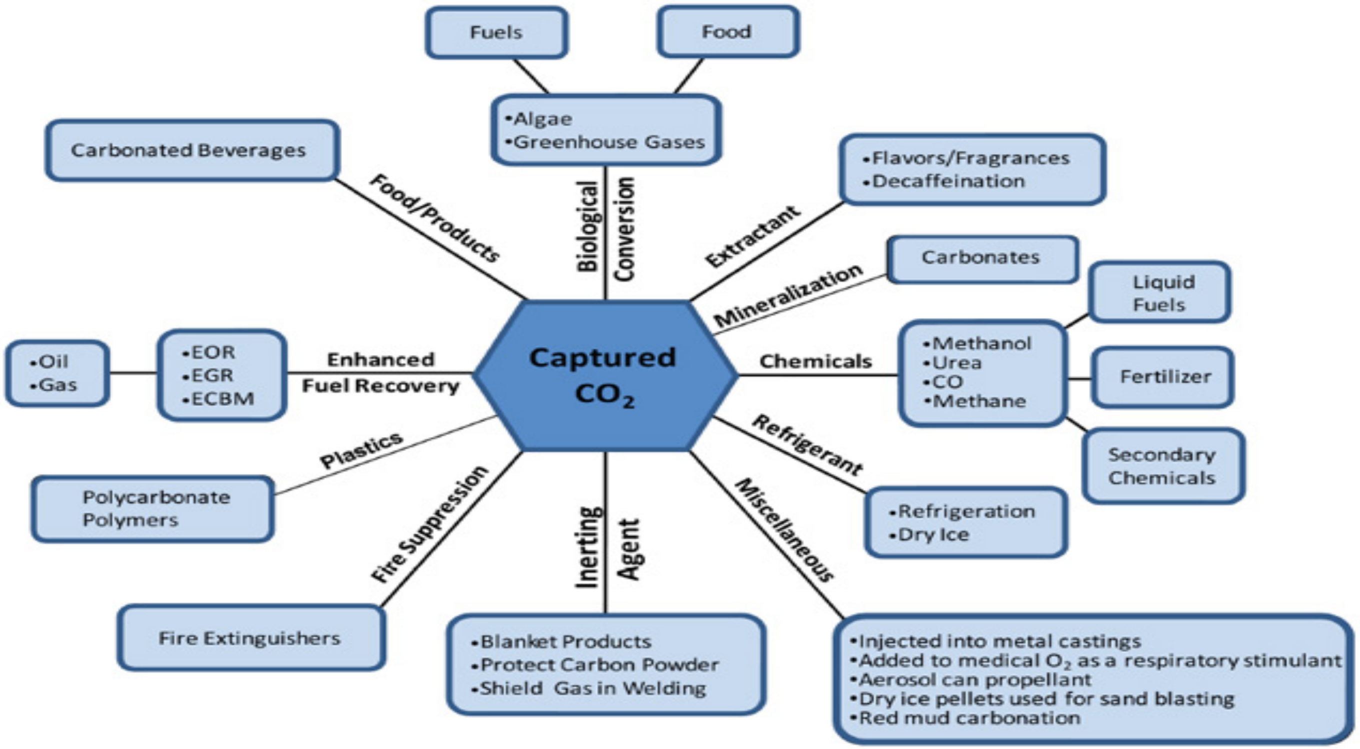
Carbon capture
Environment and Energy
Membrane Technology
Process Modelling and Simulation

Alignment of My Research Area and Workshop Topic



CO_2 can be resource rather than waste

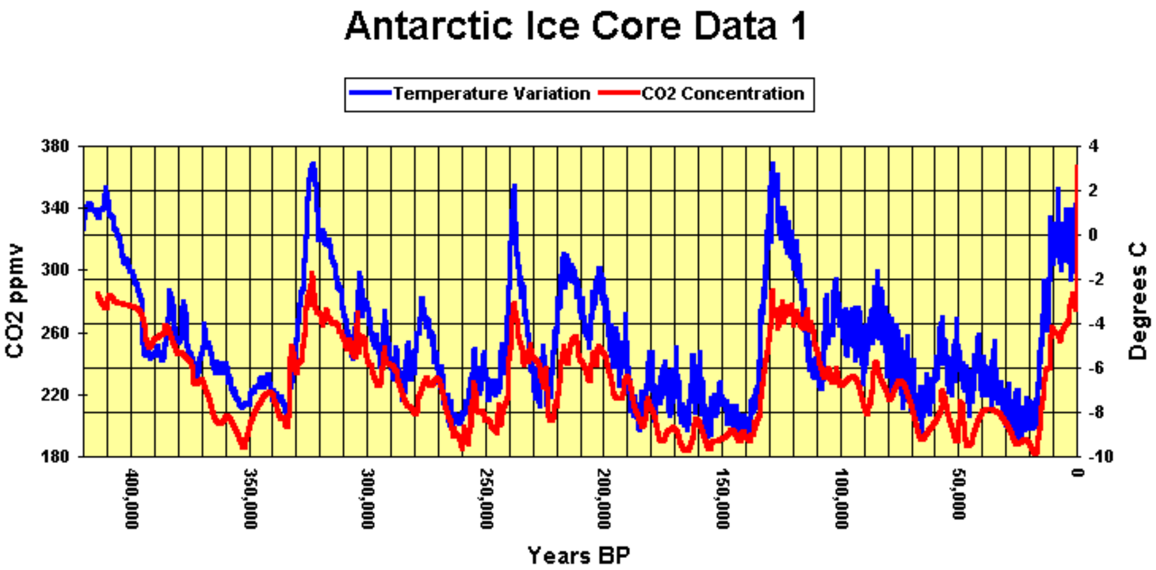
How CO_2 Can be Resource



Ref: Carbon Dioxide Can Be A Resource Rather Than A Waste Product, The Energy Collective, Feb. 2014

Motivation for Carbon Capture Technology

Climate Change



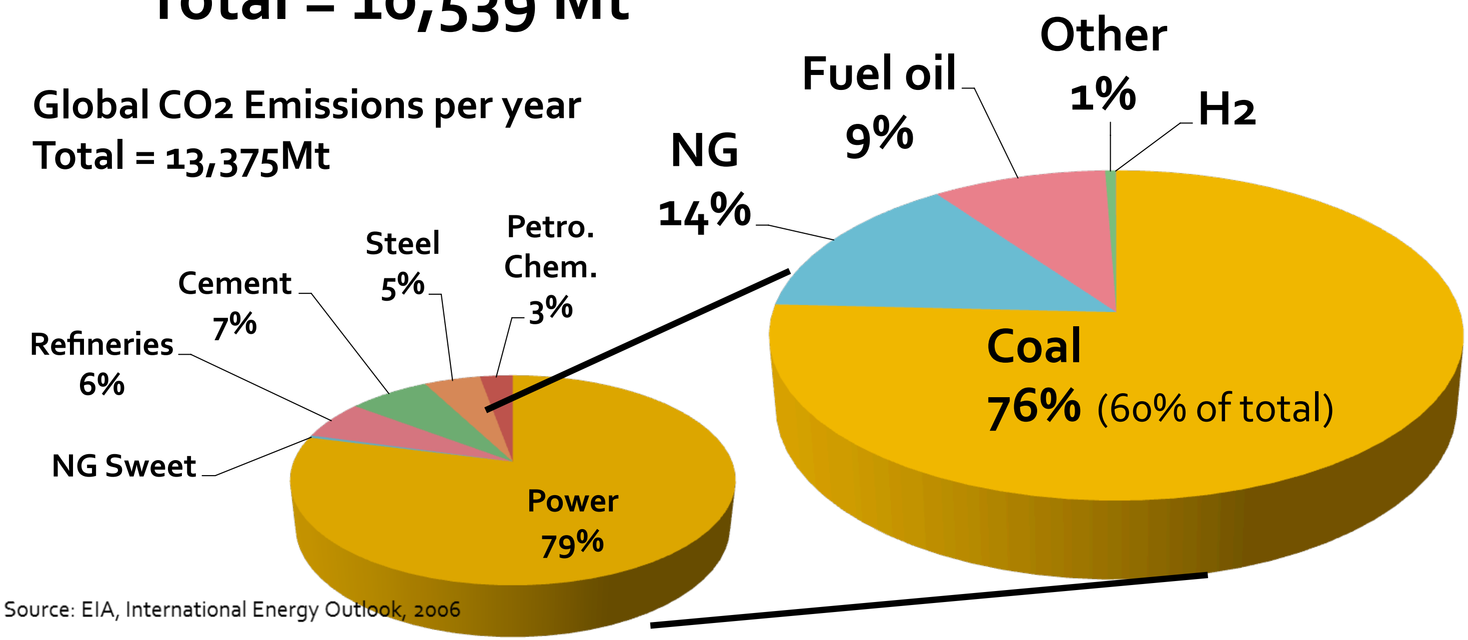
Source: Petit et. al. , Nature, 2000

Motivation for CCS Technology

Energy Profile

Global Carbon Dioxide Emissions from Power Generation per year

Total = 10,539 Mt



Carbon Capture Options

Technologies Overview

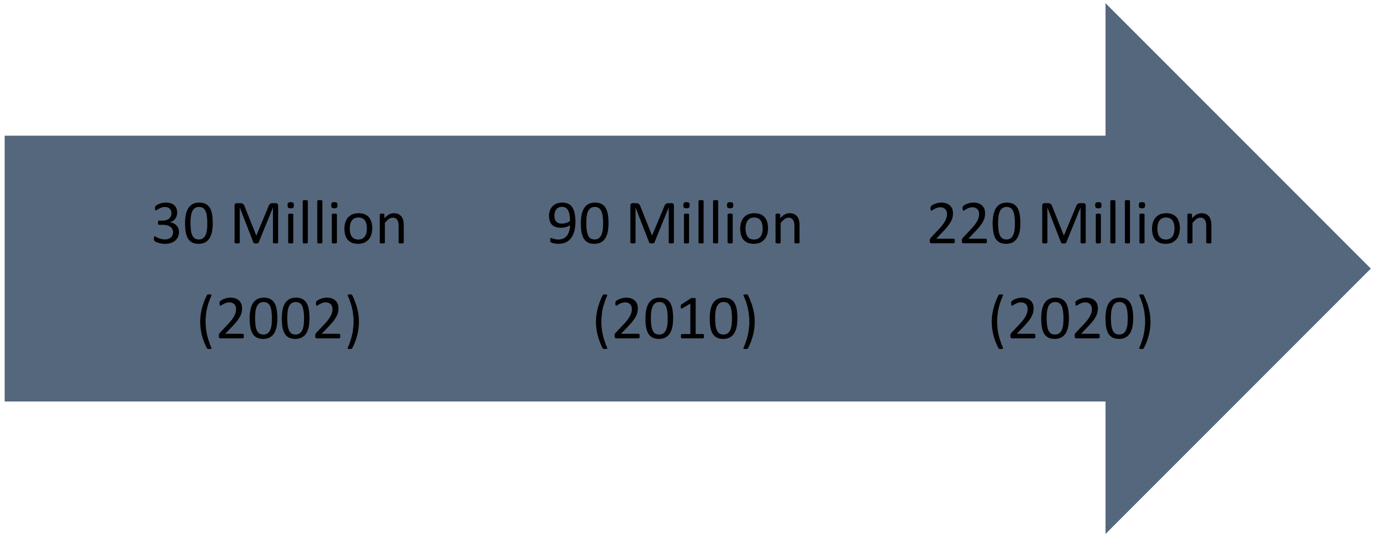
- Systems
  - Pre-combustion
  - Post-combustion
  - Oxy-fuel combustion

- Separation technologies
  - Solvents – aqueous amines and salts
  - Membranes – polymeric
  - Solid sorbents – zeolite, activated carbon
  - Cryogenic processes
  - Chemical Looping (Calcium looping)

Advantages of Membrane Separation

- High Efficiency
- Low Energy Requirements
- Ease of Operation
- Mechanically Robust
- Low Capital and Operating Cost
- Environmental Friendly

Projected Growth in Membrane Market Demand (USD)



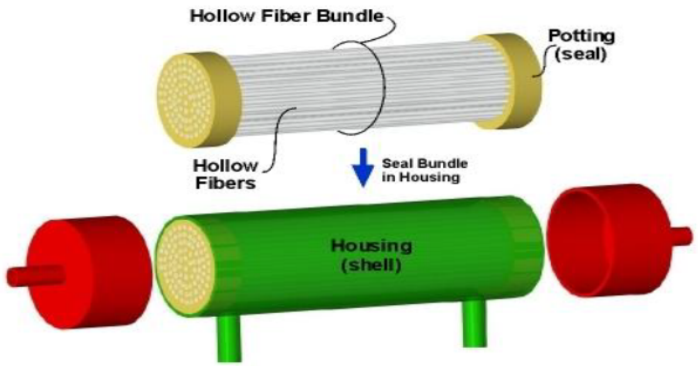
Reference:
R. W. Baker, "Future Directions of Membrane Gas Separation Technology," *Industrial & Engineering Chemistry Research,* vol. 41, pp. 1393-1411, 2002.

Classification and Selection of Membrane Module

	Tubular Module	**Plate and Frame Module**	**Spiral Wound Module**	**Capillary Module**	**Hollow Fiber Module**
Manufacturing cost (USD/m^2)	50-200	100-300	30-100	20-100	5-20
Packing density(m^2/m^3)	Low	Low	Moderate	Moderate	High
Resistance to Fouling	Very good	Good	Moderate	Good	Poor
Parasitic pressure drops	Low	Moderate	Moderate	Moderate	High
Suitable for High pressure operation	Can be done with difficulty	Can be done with difficulty	Yes	No	Yes
Limitations to Specific Type of Membranes	No	No	No	Yes	Yes

Hollow Fiber Membrane Module

- Hollow fiber membrane module is employed by more than 80 percent gas separation facilities in industry
- Cost effective and Highest packing density in comparison to other modules.
- Extremely fine polymeric tubes having diameter of 50-200 micron
- Hollow fiber membrane module will normally contain tens of thousands of parallel fibers potted at both ends in epoxy tube sheets



Ref: J. P. Montaya., *Membrane Gas Exchange*. 2010, Available: http://permselect.com/files/Using_Membranes_for_Gas_Exchange.pdf

Membrane Module Development

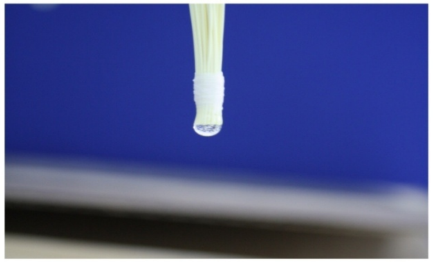
Membrane Properties:
Polyimide (Matrimid)
Inner diameter of fibers: 250 µm

Outer diameter of fibers: 400 µm
Length of fibers: 28 cm
Number of fibers: 5, 15, 20, 30, 50

(a) Cutting fibers according to required size


(b) Fiber bundle preparation

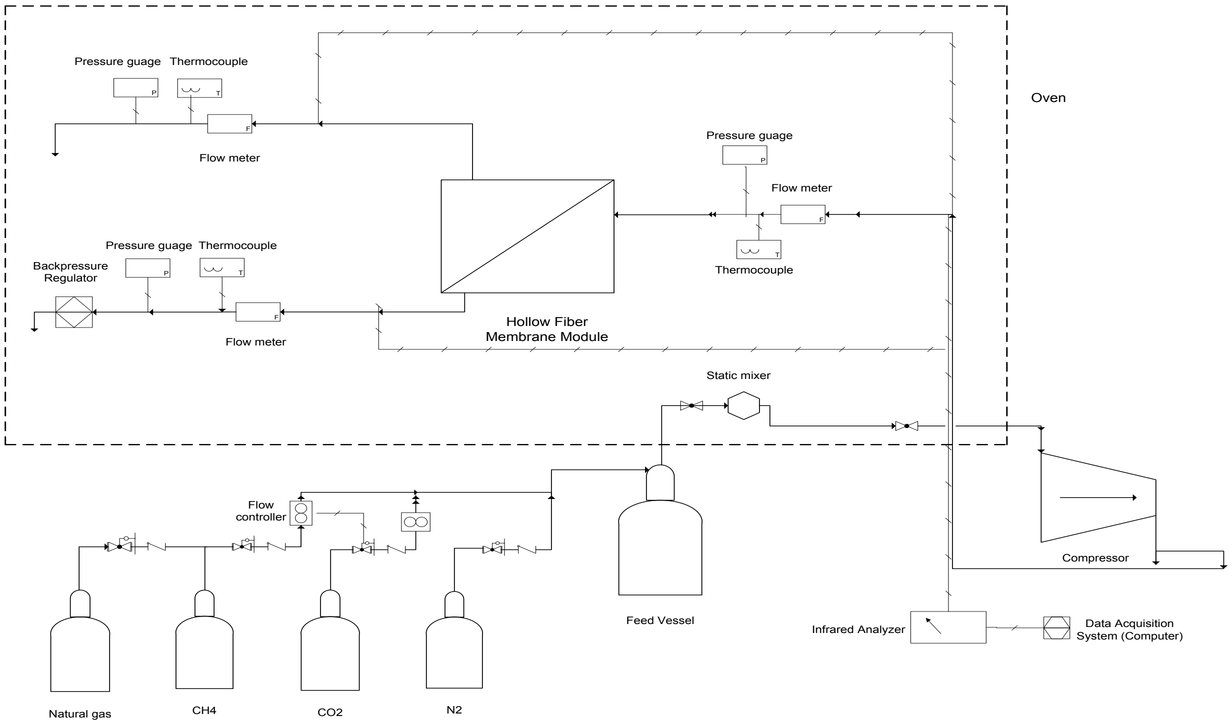

(c) Epoxy for tube sheets


(d) Sealed end of the fiber bundle

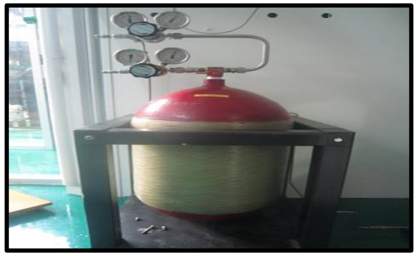

(e) Housing of fiber bundle in the shell


(f) Hollow fiber module ready to be installed

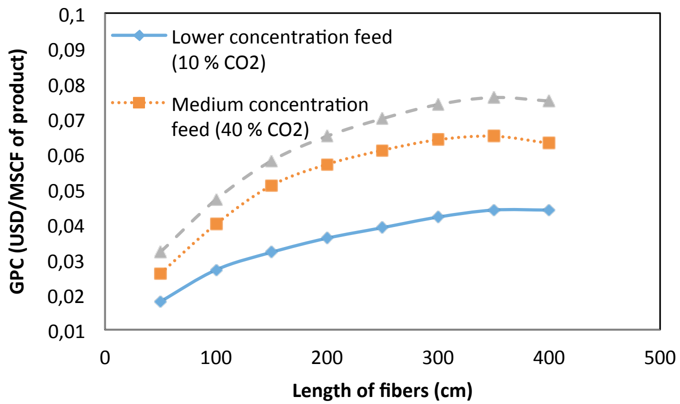
Flow sheet of Gas Permeation Testing Unit

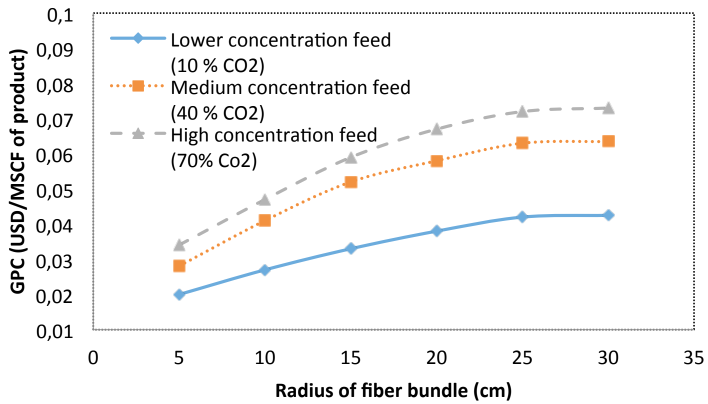


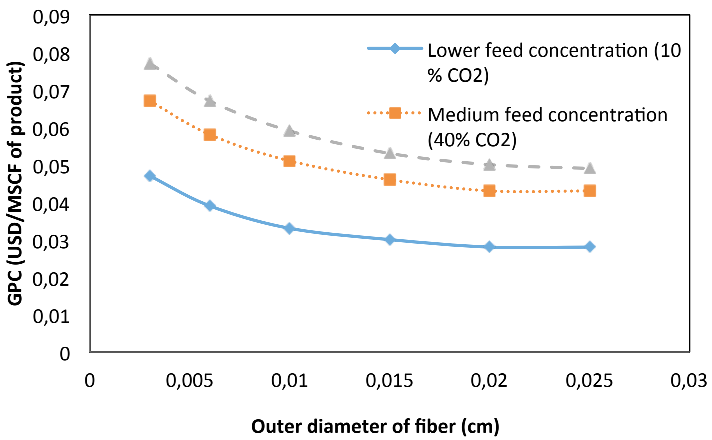
Gas Permeation Testing Unit (CO_2 from Natural Gas)

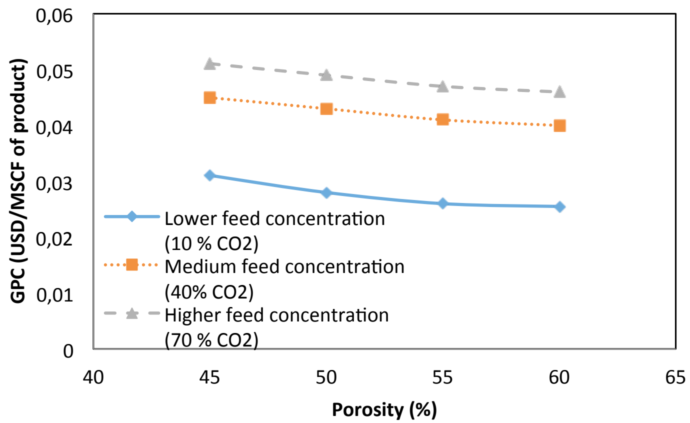


Example of Research Findings (Effect of Module Characteristics on Gas Processing Cost)

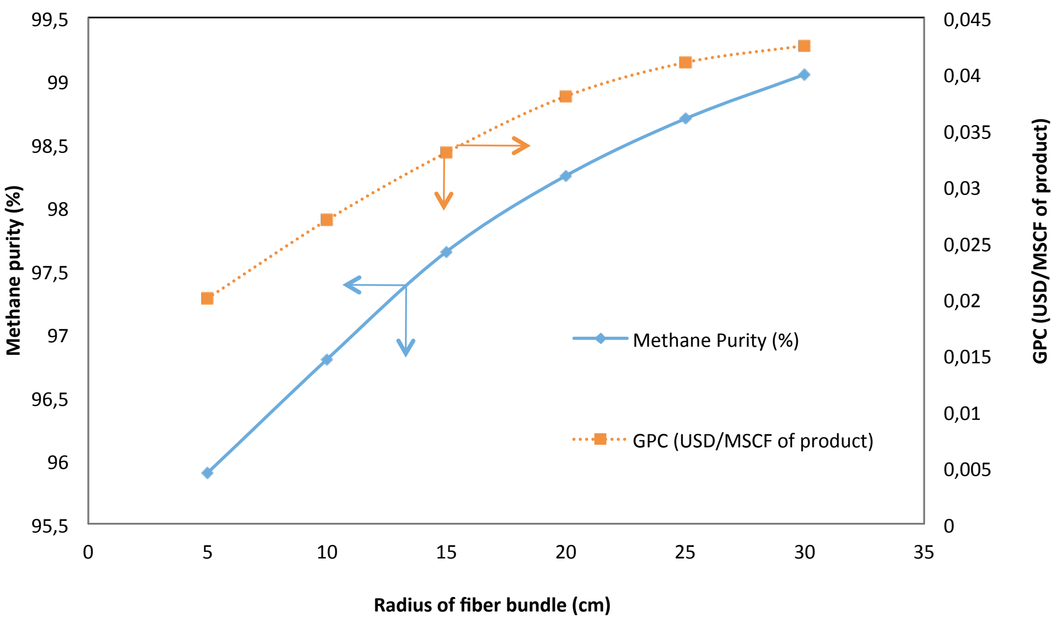




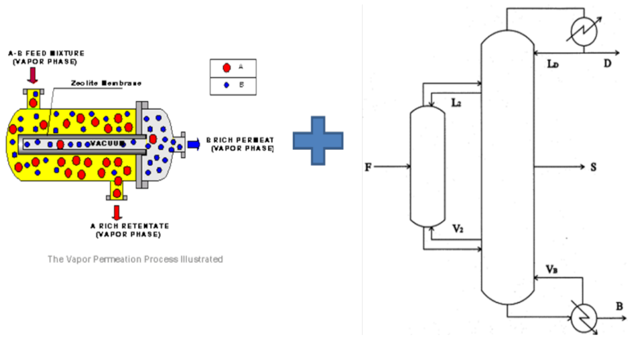




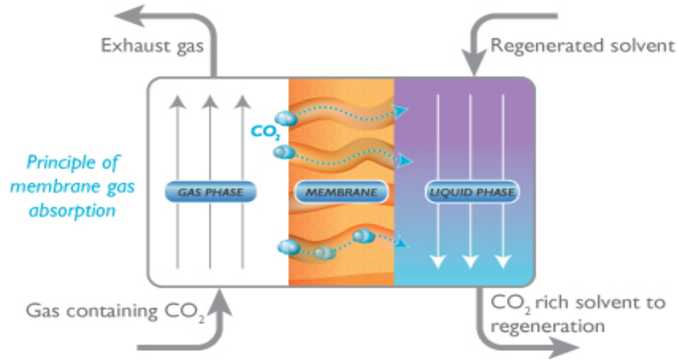
Comparison of Process Performance and Economics



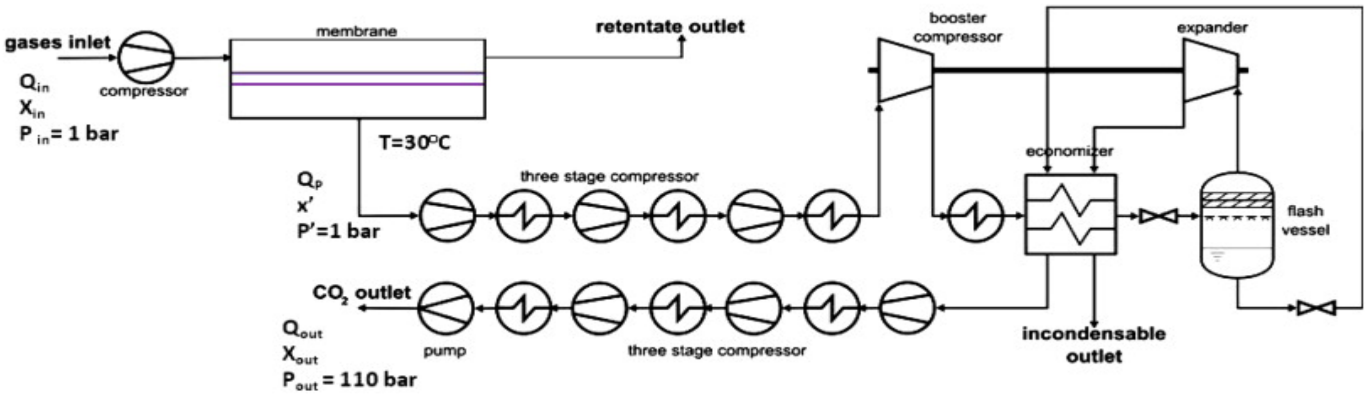
Hybrid Membrane Processes



Hybrid membrane/distillation process



Hybrid membrane/absorption process



Hybrid membrane/cryogenic process

Current Project:
Process Intensification
Hydrogen on Teesside/North East England

- **BACKGROUND**

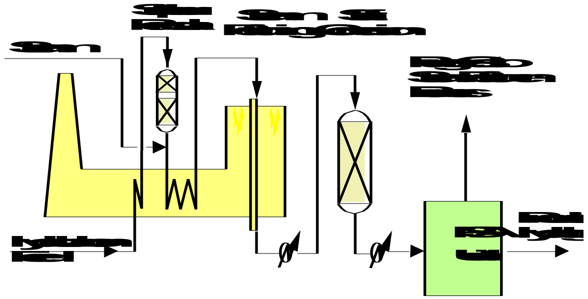
The North East is a world leader in the large scale manufacture of hydrogen, producing more than 50% of the UK's total in Tees Valley. A recent study outlines opportunities to increase this further reaffirming the region's position as the third largest hydrogen economy behind London and Aberdeen.

Tees Valley and North East Hydrogen Economic Study
Final Report
16th October 2014

Global Trends (from World Health Organization)

- The global urban population is expected to grow by approximately 1.7% per year between 2015 and 2030.
- Currently >80% of people living in urban areas that monitor air pollution are exposed to air quality levels that exceed WHO limits.
- According to the latest urban air quality database, 98% of cities in low- and middle income countries with more than 100 000 inhabitants do not meet WHO air quality guidelines.

Making Hydrogen on Teesside



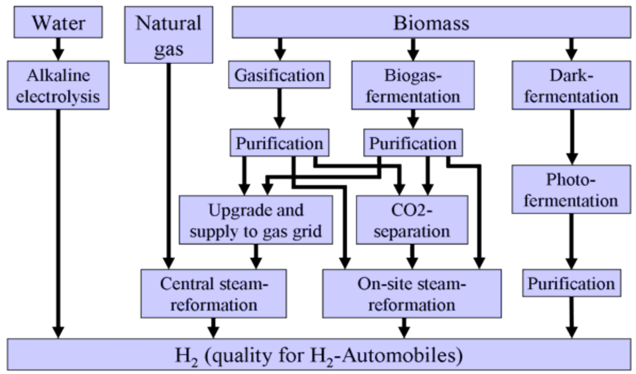
$C_nH_m + n\ H_2O \Rightarrow n\ CO + ((n+m)/2)\ H_2$

$CH_4 + H_2O \Leftrightarrow CO + 3\ H_2$

$CO + H_2O \Leftrightarrow CO_2 + H_2$

Although hydrogen from natural gas is certainly a viable near-term option, it is not viewed by DOE as a long-term solution because it does not help solve the green house gas (GHG) or energy security issues. BUT…………………………………… .

Chicken and Egg, Investor and Consumer



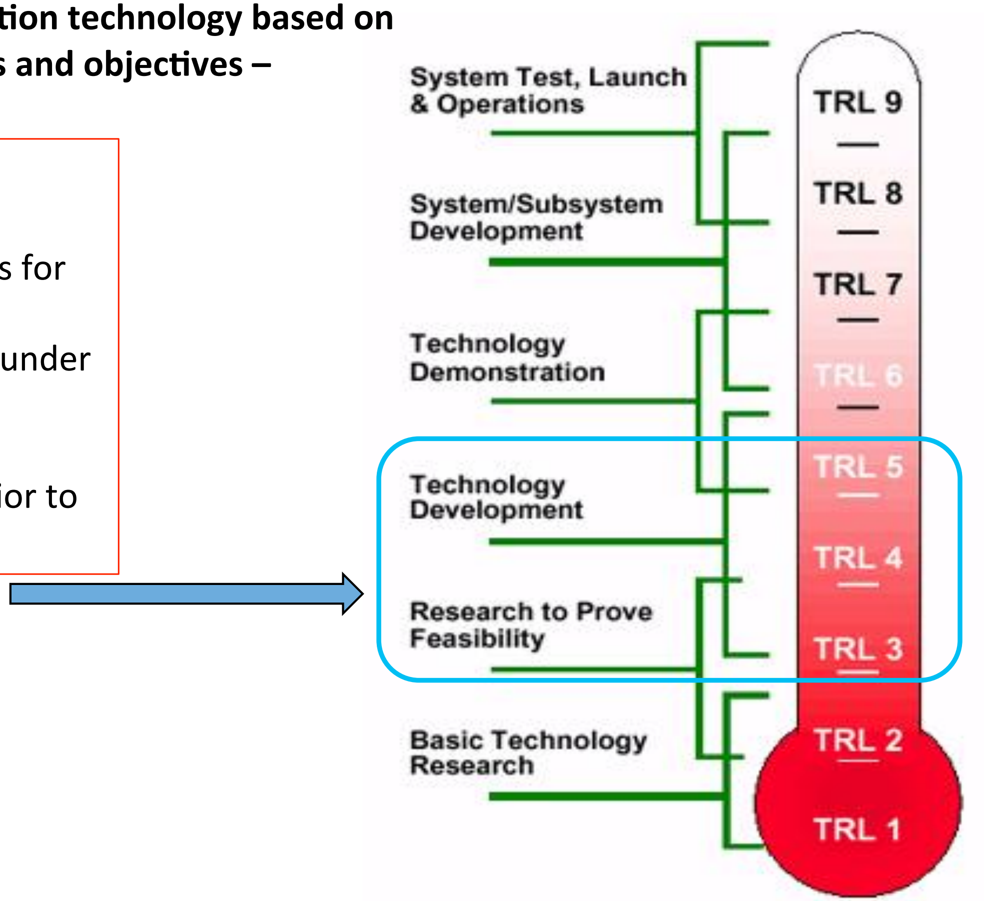
What is Process Intensification

- Lower Cost (CAPEX – OPEX)
- Smaller size
- Higher Efficiency
- Safer Design
- Better shape
- Combined process components
- Sustainable development

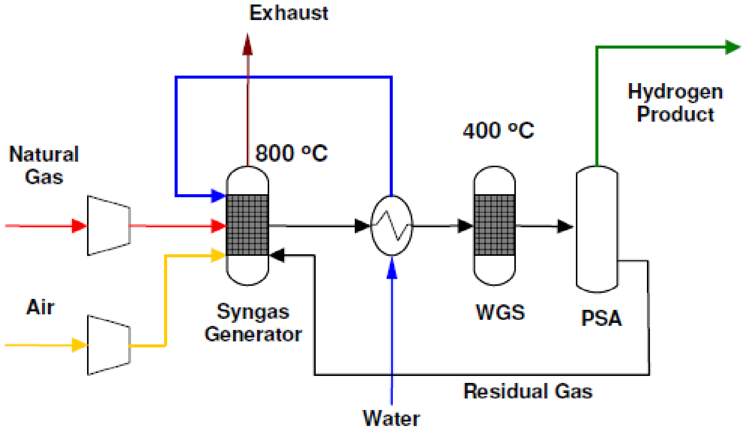
Current Project:
To develop an innovative Hydrogen purification technology based on membrane systems, with the following aims and objectives –

Aims and objectives:

i. Stand alone (or hybrid) and small scale (suitable for 1-5 kW Fuel Cell applications for small residential heating)
ii. Demonstrated / Validated for operation under simulated environments – up to TRL 5 (Technology Readiness Levels)
iii. Projected Cost effectiveness to be superior to conventional Pressure Swing Adsorption

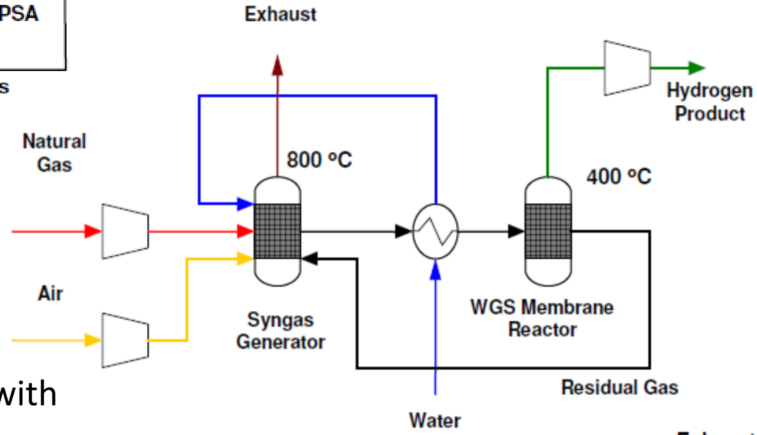


(Ref: "Technology Readiness Assessment (TRA) Guidance"; United States Department of Defense. April 2011.)

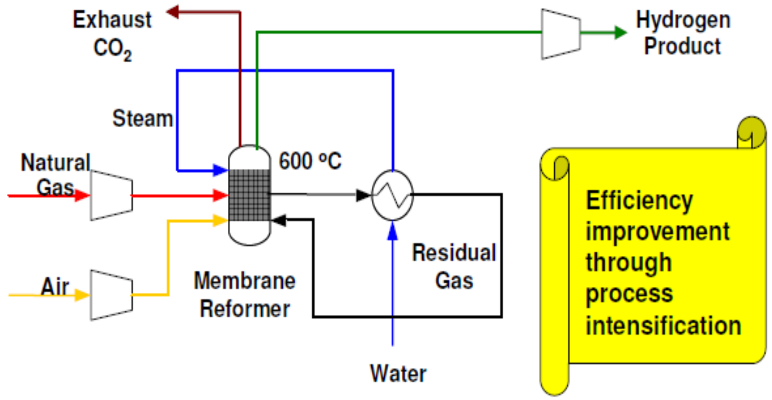


For Example:

Incorporating the use of Membrane reactor/ separator technology (source: Pall Corporation) to produce pure Hydrogen from a conventional Natural Gas Reformation setup

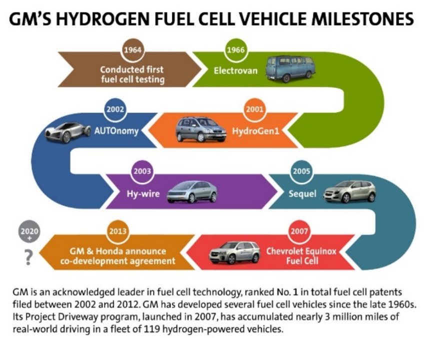


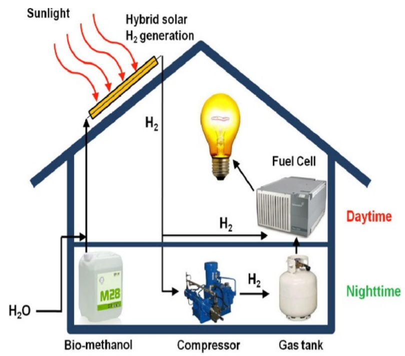
Replacing the Water gas Shift reactor with a WGS membrane reactor to combine reaction and separation/ purification of hydrogen in one module itself – one stage of process intensification



Incorporation of Membrane reactor at the reforming stage itself to induce more WGS during the reformation itself, and yield pure H_2 – ultimate process intensification

Making and using Hydrogen is happening





Making and using Hydrogen is happening

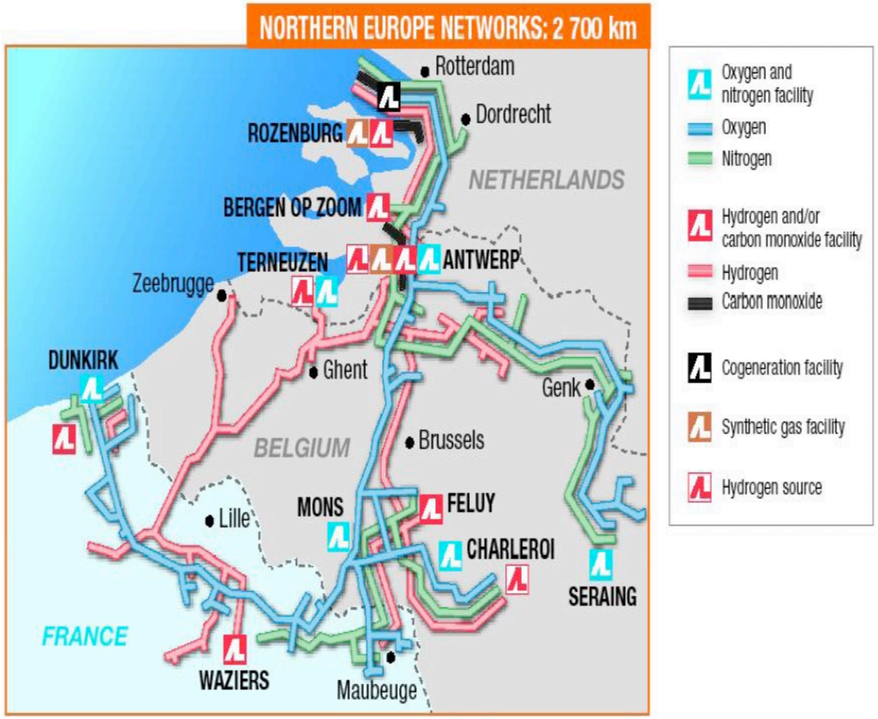
- BOC Linde in partnership with Daimler to build 13 new hydrogen fuelling stations in Germany by the end of 2015, to be supplied with sustainably sourced hydrogen.

- Head of Clean Energy & Innovation Management at Linde. “We are making a valuable contribution to the successful commercialisation of fuel-cell vehicles while supporting initiatives like the Clean Energy Partnership (CEP) and ‘H2 Mobility’.”

  “There is no question that fuel-cell technology is reaching maturity. From 2017, we are planning to bring competitively priced fuel-cell vehicles to market. So now is the time to build a nationwide fuelling infrastructure. The aim is to enable motorists to reach any destination in Germany in their hydrogen fuelled vehicles. This initiative is a huge step forward on the journey to a truly nationwide H2 network,” states Professor Herbert Kohler, Vice President Group Research & Sustainability and Chief Environmental Officer at Daimler AG.

Making and using Hydrogen is happening

Blending hydrogen into natural gas pipeline networks has also been proposed as a means of delivering pure hydrogen to markets, using separation and purification technologies downstream to extract hydrogen from the natural gas blend close to the point of end use. As a hydrogen delivery method, blending can defray the cost of building dedicated hydrogen pipelines or other costly delivery infrastructure during the early market development phase.



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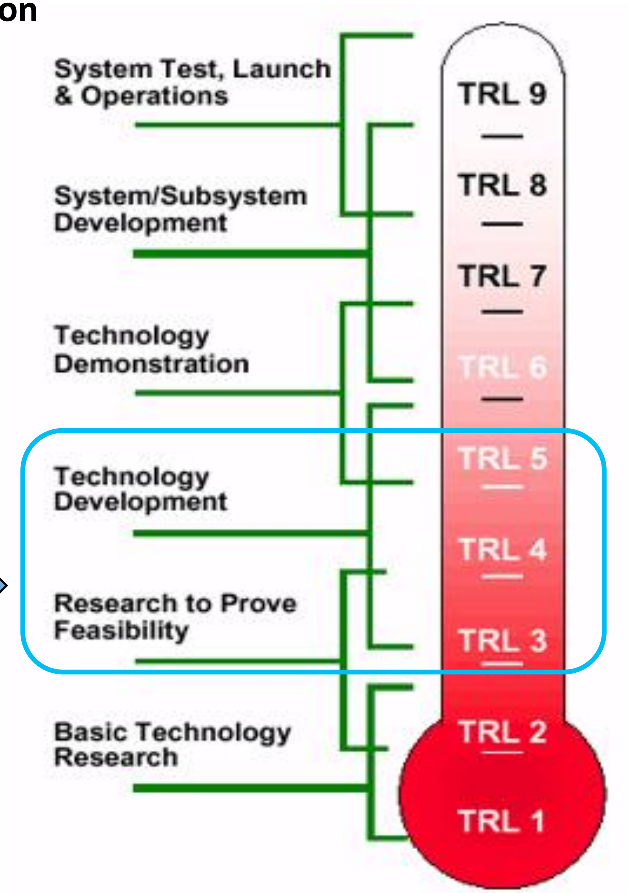

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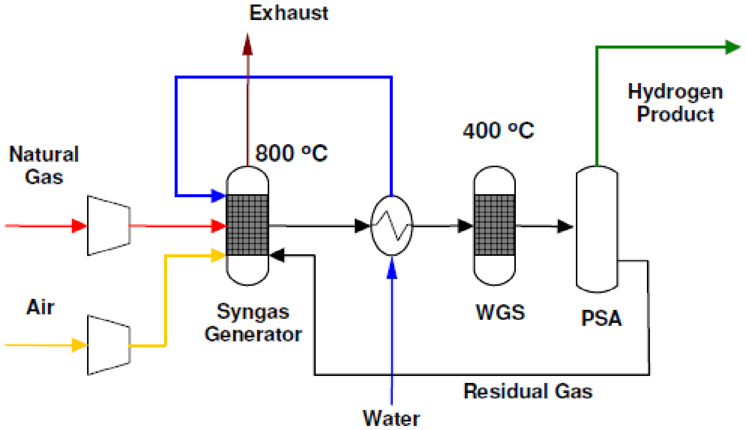

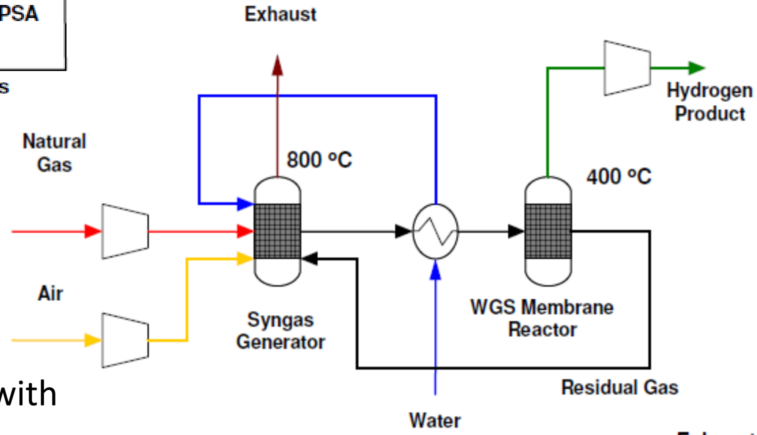

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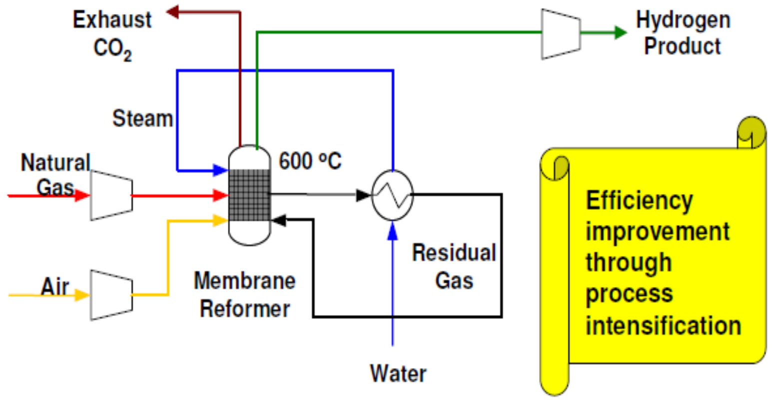


Incorporation of Membrane reactor at the reforming stage itself to induce more WGS during the reformation itself, and yield pure H_2 – ultimate process intensification

Approach to the problem

- Using the concept of Process Intensification for production of Hydrogen, i.e., multi-functional reaction separation systems, to lower capital costs;

- Introduce complexity and multi-functionality in the reactor – it is much more effective to do so in smaller scale, and hence the applicability to smaller systems

- Integrated materials processing and characterization, reactor design and testing, module and process design

Impure Hydrogen or Hydrogen containing feedstock, obtained by using small scale processes

Note: By developing a process for generating high purity hydrogen from biomass, we are addressing a more complex system; all other purification modules can be subsets of the larger project

Process	Composition of feedstock	Options for Hydrogen purification by use of membranes
Anaerobic fermentation of Biomass	50-85 % Methane; 20-35% CO_2; H_2, O_2, N_2 and H_2S in varying amounts, up to a few percent	1. Sulphur removal (from H_2S) 2. Reformation of Methane to syngas 3. Water Gas Shift/ Hydrogen Separation-concentration
Hydrogen from pipelines, caverns	Over 99% Hydrogen, particles, dust, soils, S-odorant	Only Membrane assisted purification

Ref: Alberta Gas Ethylene Co. (AGEC) hydrogen pipeline (3.7 km in length) –
The line currently carries 4,825 kg-mole/hr of 99.99% pure hydrogen at a maximum operating pressure of 5,790 kPa (57 bar) from the AGEC hydrogen purification plant to the Cominco Fertilizers/Alberta Energy Co. Ltd. plant.

Work Breakdown Structure (Work packages)

1. Process Configuration, Process Design Calculations for component design

1.1 Identify a representative Biomass anaerobic digestion system as supplier for biogas, to ascertain expected compositions, and impurity concentrations; also identify other sources of Hydrogen locally, which require purification and are feedstocks for PEMFCs – TU, with other partners

1.2 Process Design – PFD, Mass-Energy Balances, P&ID, and detailed design of reactors, and purification systems - TU

1.3 Fabrication of membrane-module assembly – Partners, Industry

2. Laboratory Scale development of 'selected' Membrane Systems

2.1 Membrane synthesis to generate optimal morphology – TU, Other Universities/ Labs (collaborative)

2.2 Basic characterization – XRD, Surface area, microstructure (TU, Other Universities/ Labs (collaborative)

2.2 Design of suitable 'module', and membrane-module integration (TU)

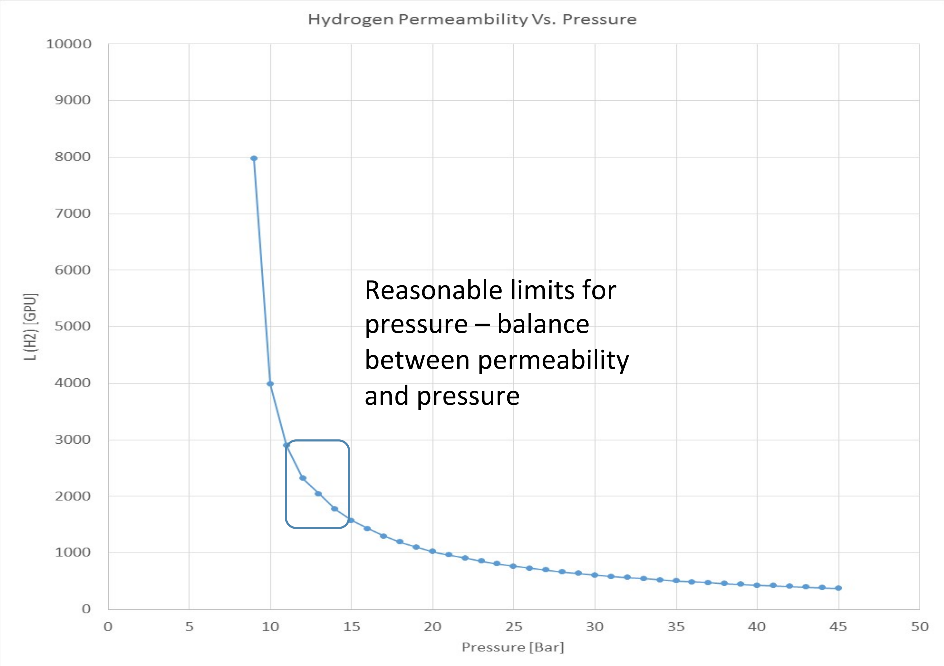
3. Measurement of Membrane Performance

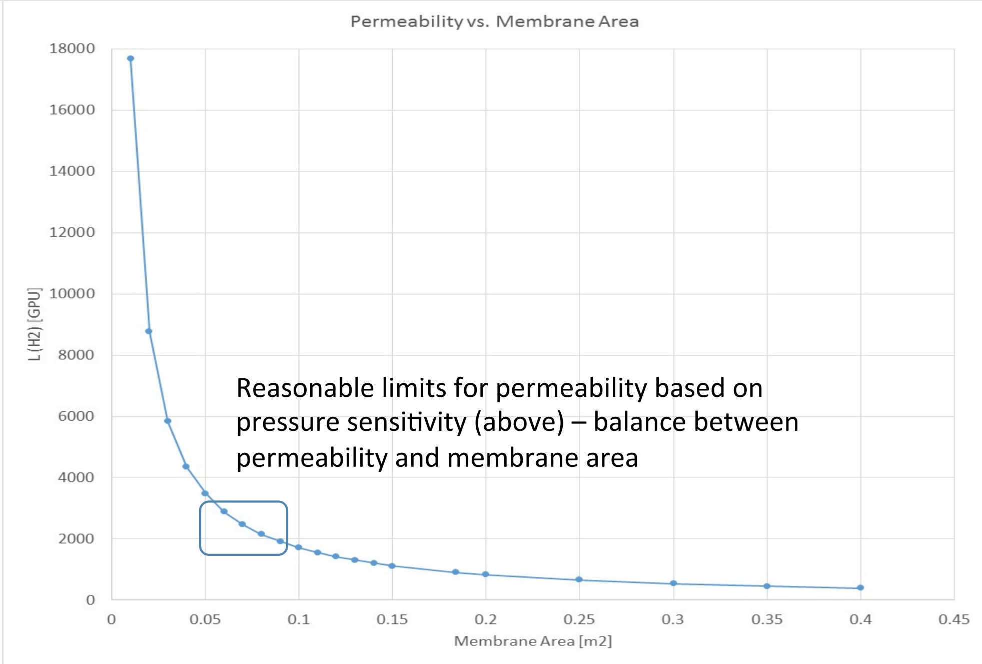
3.1 Permeability experiments on single membranes with focus on achieving selective exclusion/ adsorption of CO_2 and other impurities, in biogas with high throughput of H_2, close to 100% perm-selectivity (TU)

3.2. Membrane - Module Testing (TU and Partners)

3.3 Degradation studies, and mitigation of flaws and imperfections in the membrane, membrane-module assembly (TU and Partners)

Process Calculations for 50% Hydrogen feed, 5 kg/day – estimation of permeability, area, and pressure requirements





Performance Targets

- 99.99 % hydrogen purity
- 90% recovery of Hydrogen from feed
- Feed compositions to be > 50% Hydrogen

Membrane Module attributes, based upon calculations

Permeability – 1500 GPU

Pressure – 10-15 bar

Areas – 0.06 to 0.10 m^2

Based upon similar calculations, Membrane Module attributes can be projected, and such numbers can be achieved by materials and module design optimization

Research Areas for Partnership

- Purification of Hydrogen using membrane for fuel cell application (Clean energy)
- Purification of biogas as renewable energy source using hollow fibre membrane process
- Hybrid Membrane-Absorption process for CO2 Capture