Pre- and post-combustion capture of CO_2

Presented by Dr Gustavo Fimbres Weihs
Research Associate
The University of New South Wales (UNSW)
CO2CRC Economics Team
Sydney, Australia

China Australia Geological Storage of CO_2

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Supporting Partners: The Global CCS Institute, The University of Queensland, Process Group

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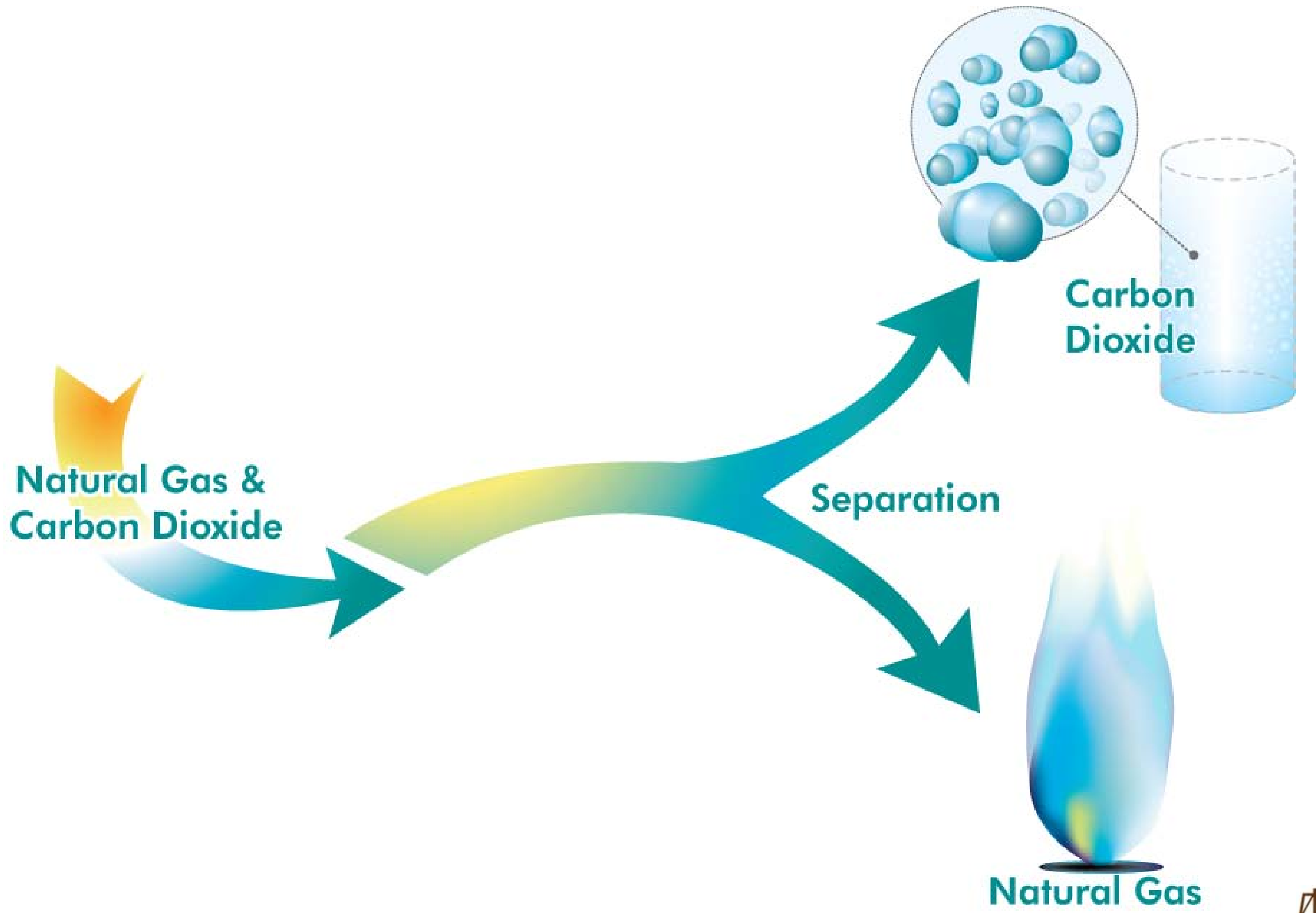
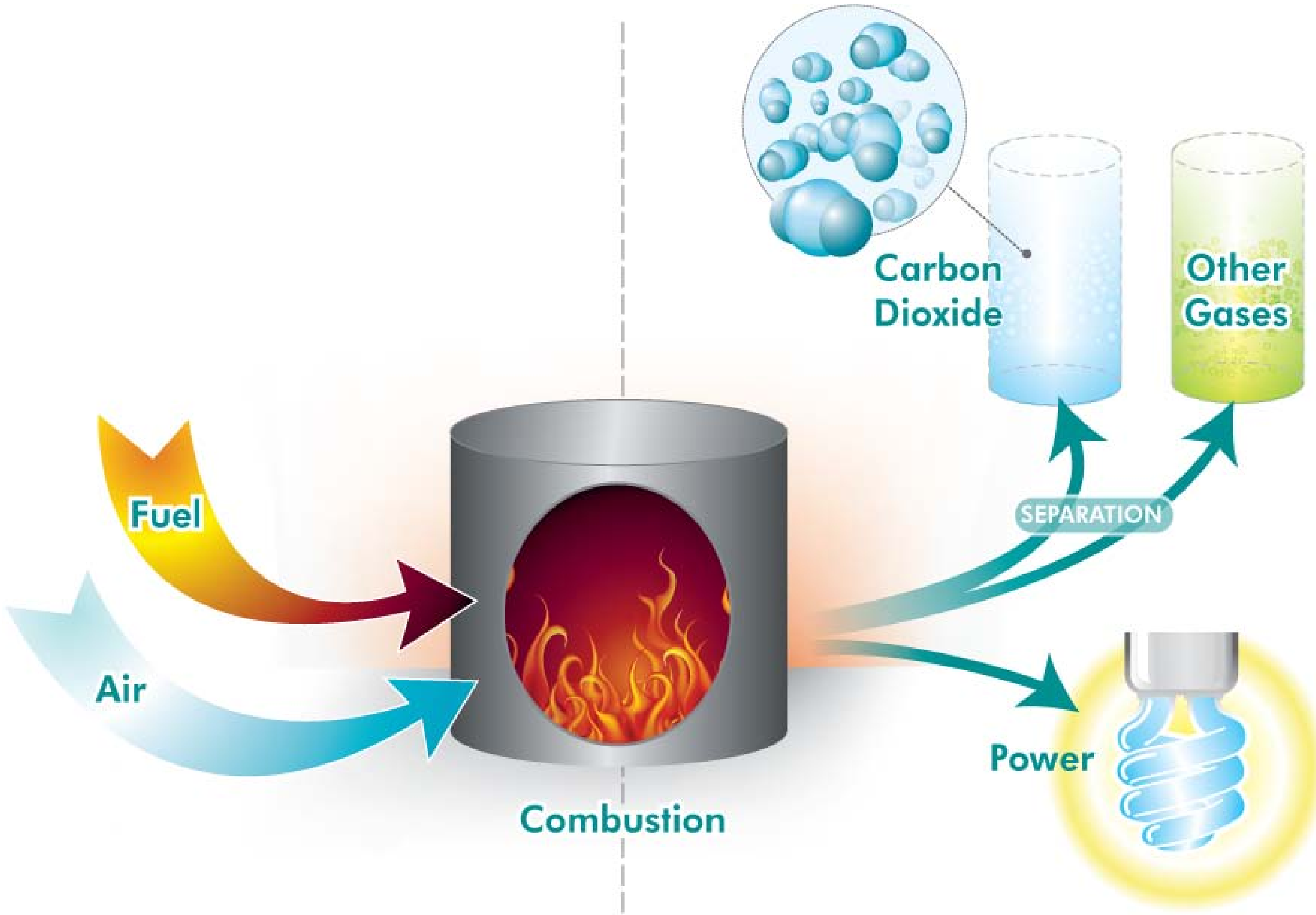
Outline

- Capturing CO_2 from fossil fuels
- CO_2 Capture Technologies
  - Absorption (吸收)
  - Adsorption (吸附)
  - Membrane Separation
  - Other Technologies

Natural gas separation

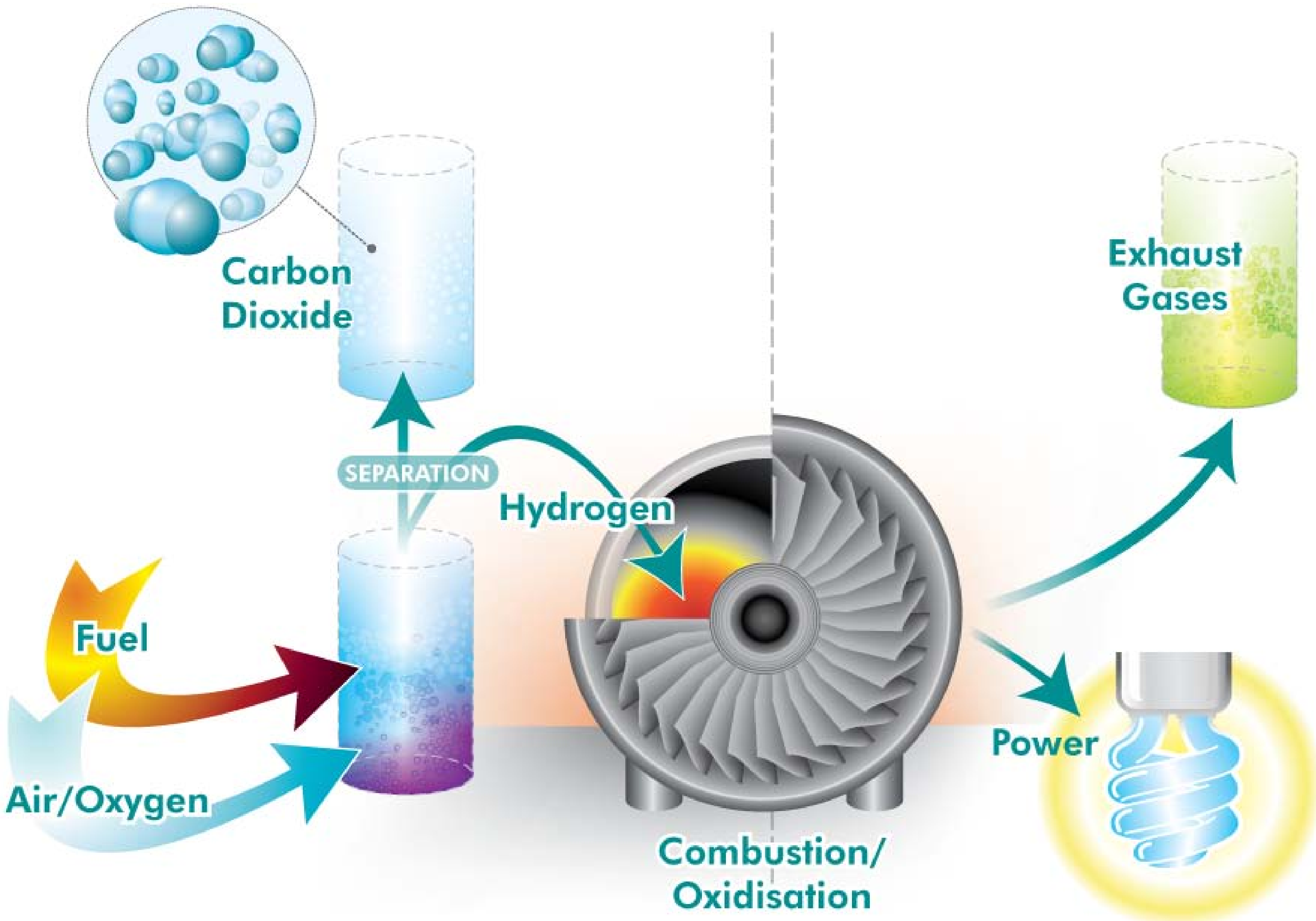


Post combustion capture



Oxyfiring for capture

Gasification – pre-combustion capture



Pre-combustion capture with IGCC

- Syngas is reacted with water convert the CO into CO_2
- $CO + H_2O \leftrightarrow CO_2 + H_2$
- Leaves CO_2 which is captured for storage, and H_2 which can be used in a gas turbine
- Other uses for hydrogen: fuel cells and ammonia production

CO_2 capture technologies – Absorption (吸收)

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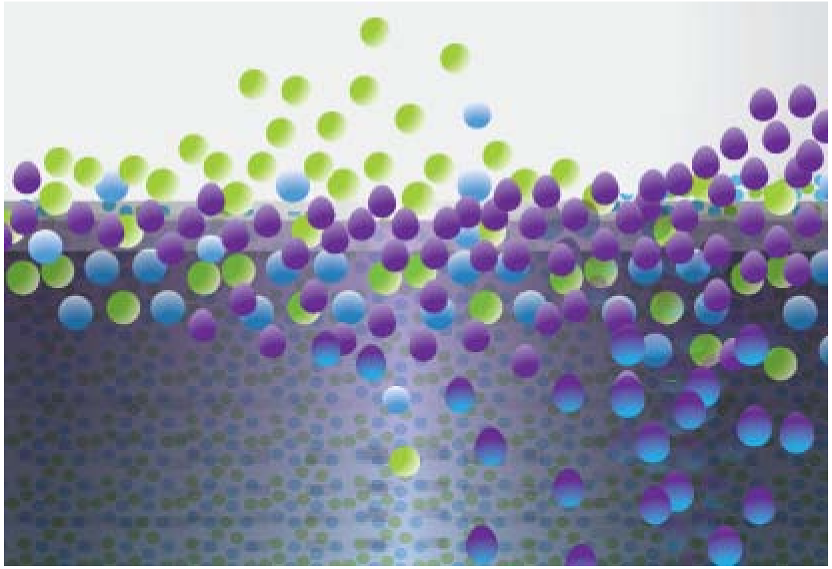
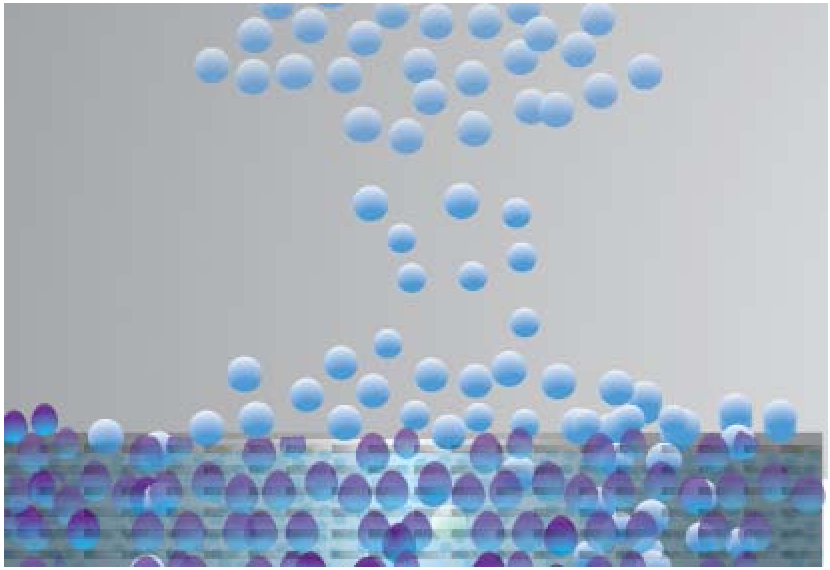
The absorption process





Absorption

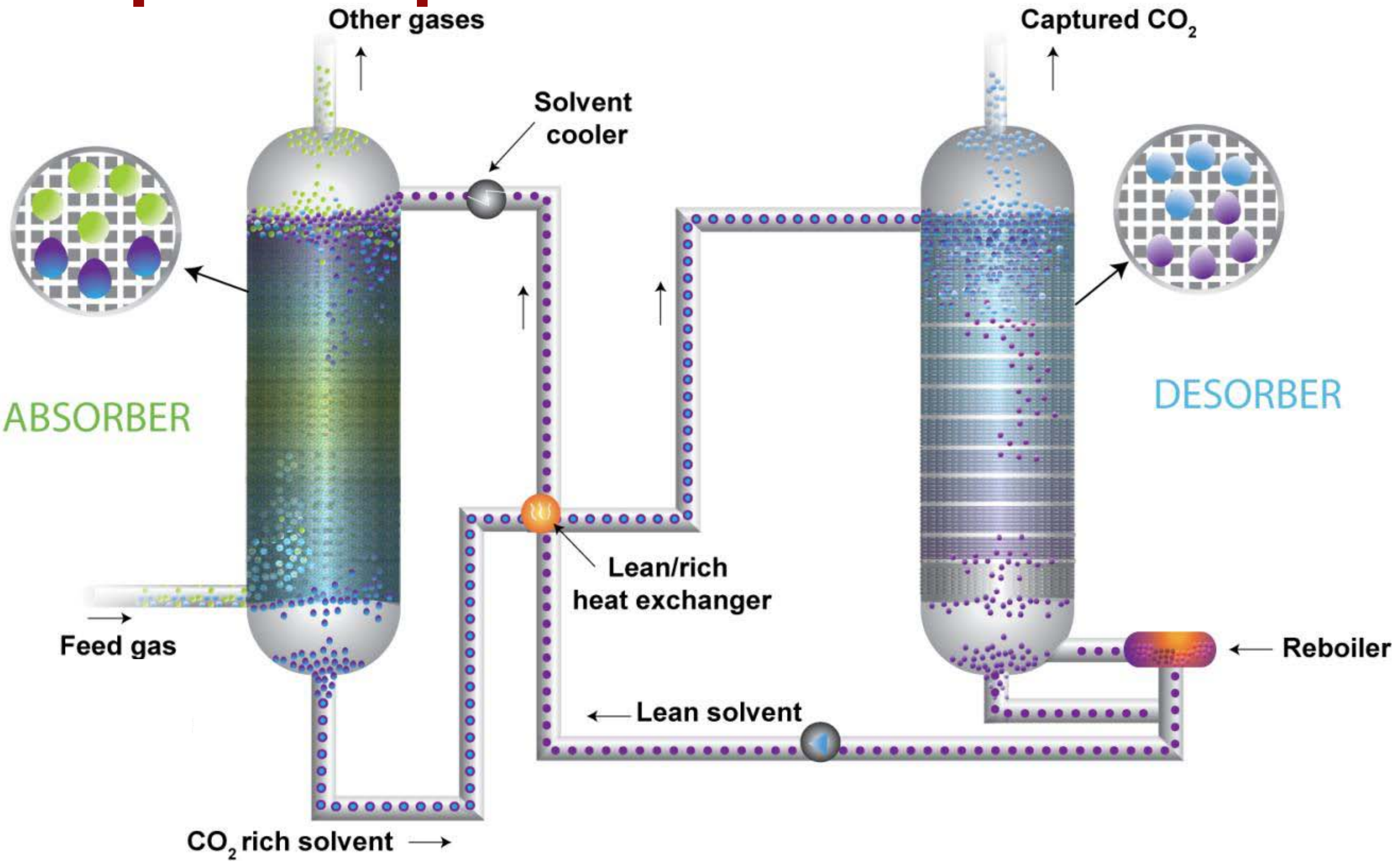
– Contact with liquid

Nitrogen green, solvent purple, carbon dioxide blue

Desorption

– Change T or P

Absorption equipment



>> *Animation of absorption and desorption cycle*

(http://www.co2crc.com.au/misc/Schematic_1_animation/absorption_n_desorption_animation.html

Solvent Absorption

- Countercurrent flow through a packed column is most common
- Plate towers are also used

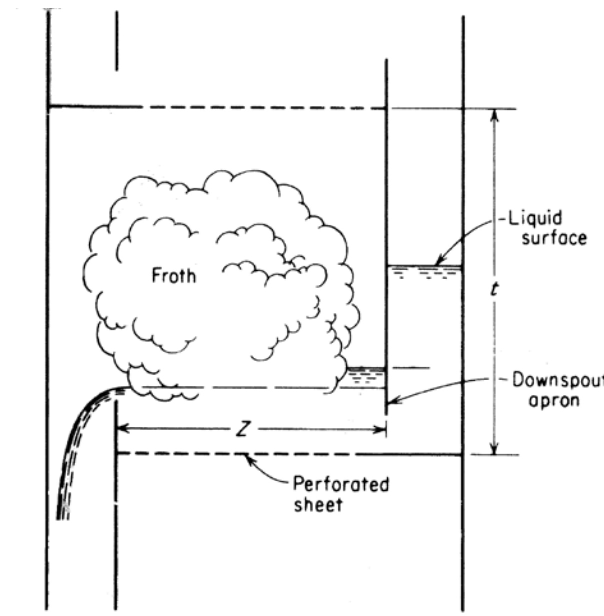


Image source: Mass Transfer Operations, R.E. Treybal, (1980) McGraw-Hill

Solvents

- Physical Solvents – Selexol
- Chemical Solvents –
  - Primary and secondary amines – MEA, DEA, ammonia
  - Tertiary and hindered amines – MDEA, KS1
  - Amino acid salts – BASF Puratreat, Siemens/TNO
  - Potassium Carbonate

Solvent Degradation

- Environmental impact
  - Waste disposal
  - Possible releases
- Economic losses
  - Purification/Replacement
  - Equipment corrosion
  - Waste disposal
- Performance losses
  - Reduced capacity for CO_2
  - Increased heat duty for reclaimer

Comparison of Solvent Properties

	Cost (US$/lb)	Volatility (atm x 10^3 at 40C)	Degradation	Corrosion	Stripper Steam Requirement (MJ/kg CO_2)
MEA	40	0.1	High 1.5 kg/t CO_2	High	4.2
MDEA	300	0.003	Moderate	Moderate	3.3
Chilled Ammonia	5	200	None	High	2.2
Potassium Carbonate	40	0	None	High	3.5

Source: Rochelle, 2007

Solvent absorption demonstration plants CO2CRC

Pre-Combustion
HRL, Mulgrave

Post-Combustion
International Power, Hazelwood

HRL

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An Amine-Based CO_2 Capture System Used to Purify Natural Gas at BP's In Salah Plant in Algeria

Source: Photo courtesy of IEA Greenhouse Gas Programme.

CO_2 capture technologies – Adsorption (吸附)

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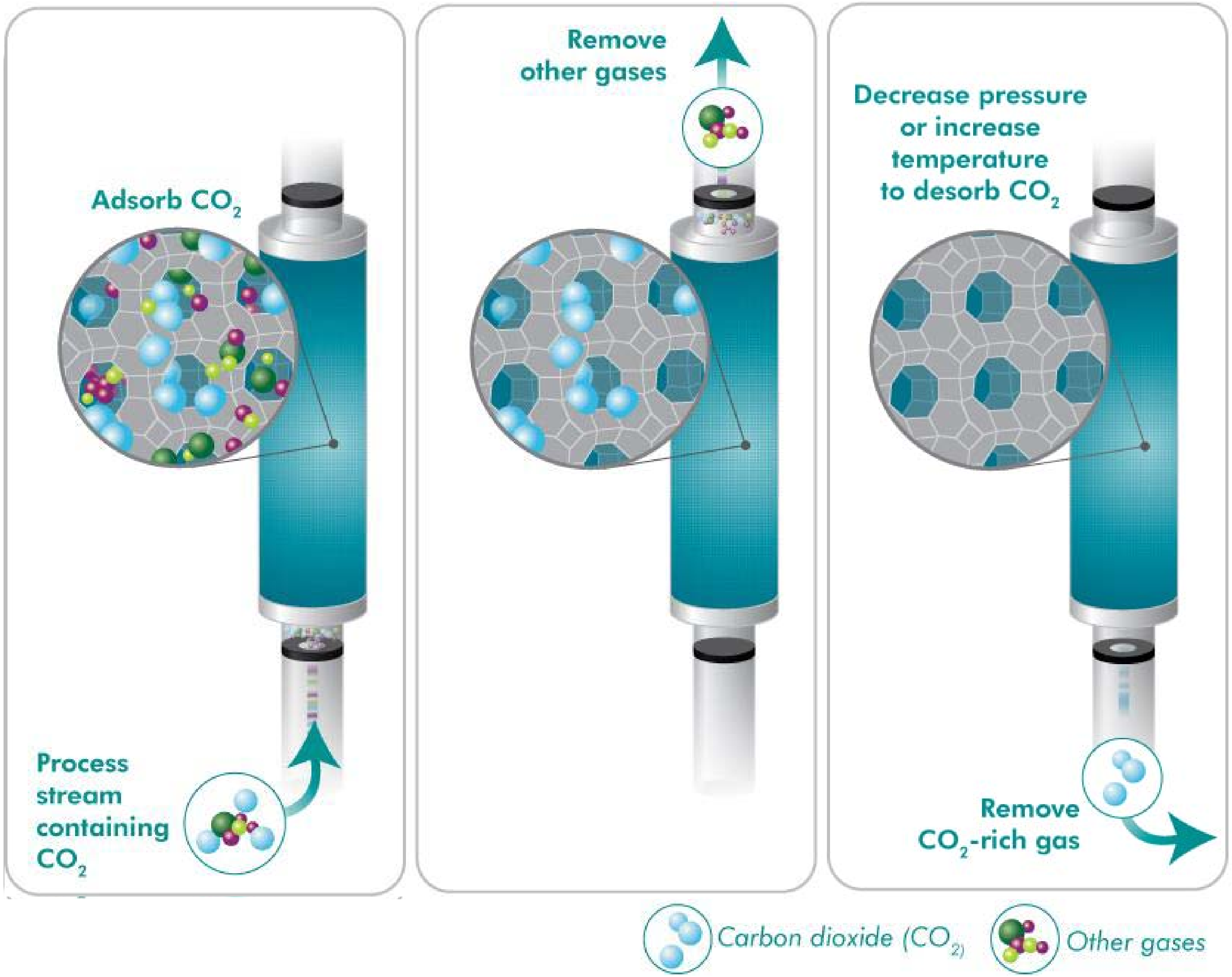
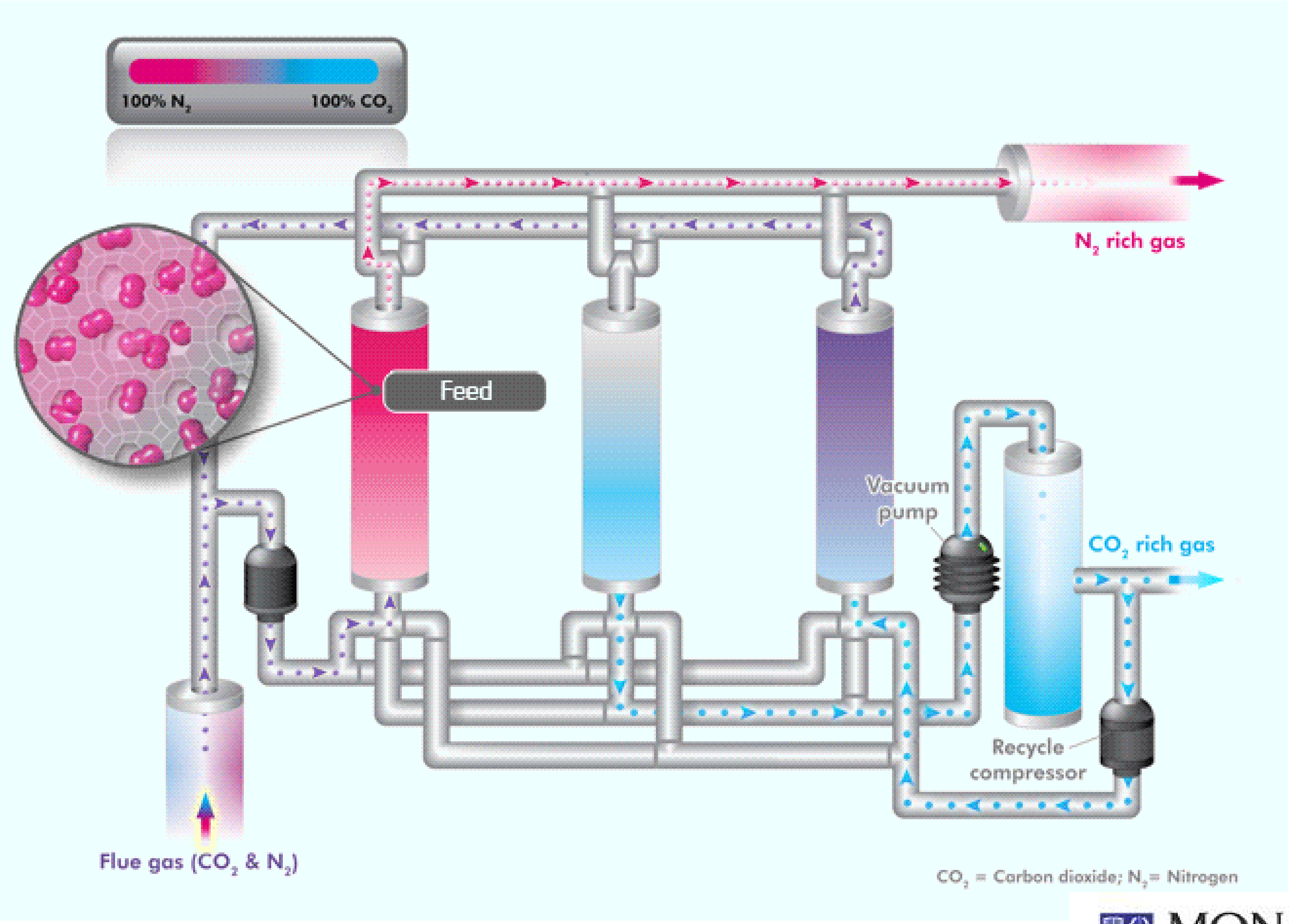
Principle of Adsorption Capture



Adsorption process cycle



>> [Animation](http://www.co2crc.com.au/misc/anim_adsorption_process.html) http://www.co2crc.com.au/misc/anim_adsorption_process.html

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Adsorption Technology

- Gas solid interaction
  - Physical bonding
  - Chemical bonding
- Simple, robust and energy efficient
- Regeneration methods
  - Pressure/vacuum swing (P/VSA)
  - Temperature swing (TSA)
  - Electrical swing adsorption (ESA)

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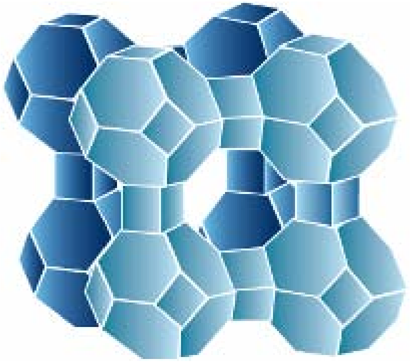
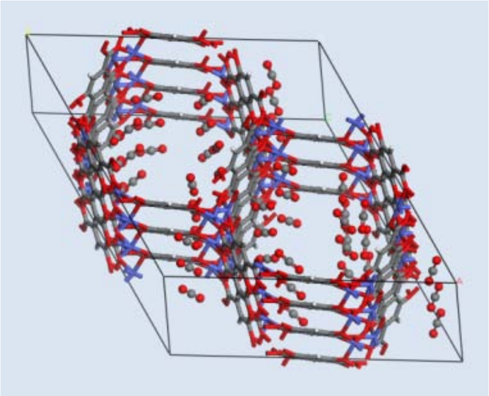
Adsorbent examples

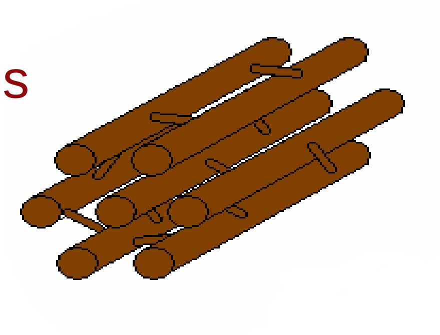
Zeolites



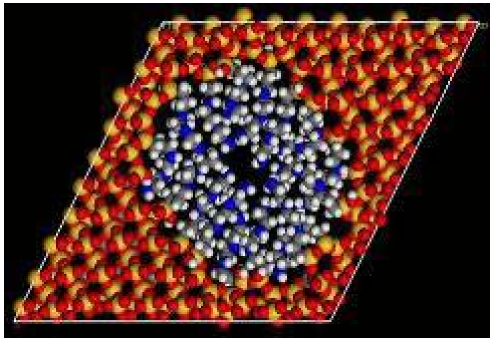
Metal Organic Frameworks (MOF)



Mesoporous Carbons



Inorganic-Organic Hybrids



Adsorption Technology

- Commercial process
  - Hydrogen PSA
  - Oxygen VSA
  - Landfill P/VSA
  - Air drying
  - Natural gas drying/purification
  - Syn-gas sweetening
  - Medical oxygen generator
  - VOC removal

Hydrogen PSA

Stocker and Whysall, UOP. 1998 30 years of PSA Technology for Hydrogen Purification

Oxygen VSA.

Image courtesy of Air Products and Chemicals, Inc .

Three bed full cycle CO_2 capture VSA unit for wet flue gases in Monash Uni

95% purity,
80% recovery

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Adsorption demonstration plants

Pressure swing adsorption
Pre-Combustion

Vacuum swing adsorption
Post-combustion

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Advantages for adsorption in post-combustion CO_2 capture

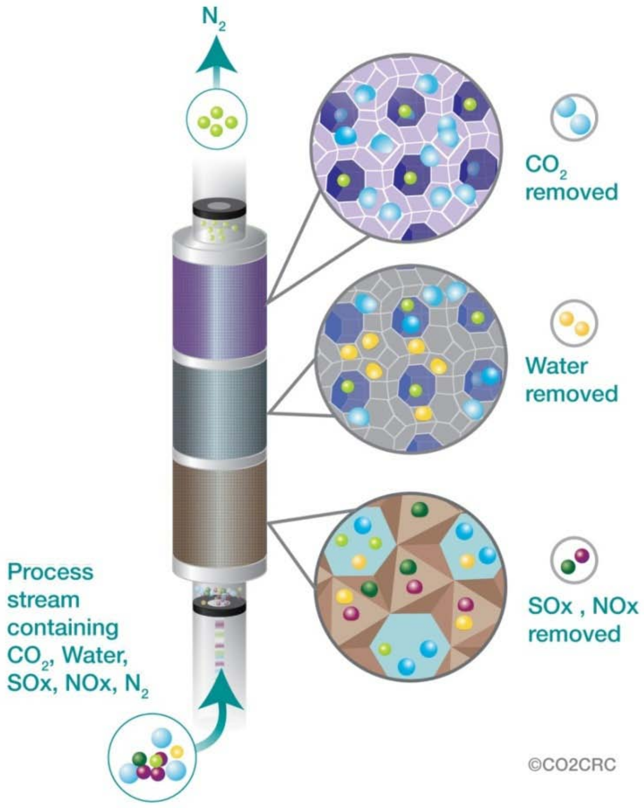
- Easy handling – using solid sorbents instead of liquid
- Low energy cost, ~1-2 MJ/kg CO_2
- Low cost adsorbent – Activated carbon, zeolites
- Simple process control logic
- Possibility of direct high temperature flue gas capture

Challenges for adsorption in post-combustion CO_2 capture

- Scale-up
  - Large throughput, million m^3 per hour
  - Large rotary equipment, blower, pumps etc.
- Impurity effects
  - Water vapor
  - SO_x/NO_x
- Pressure drop

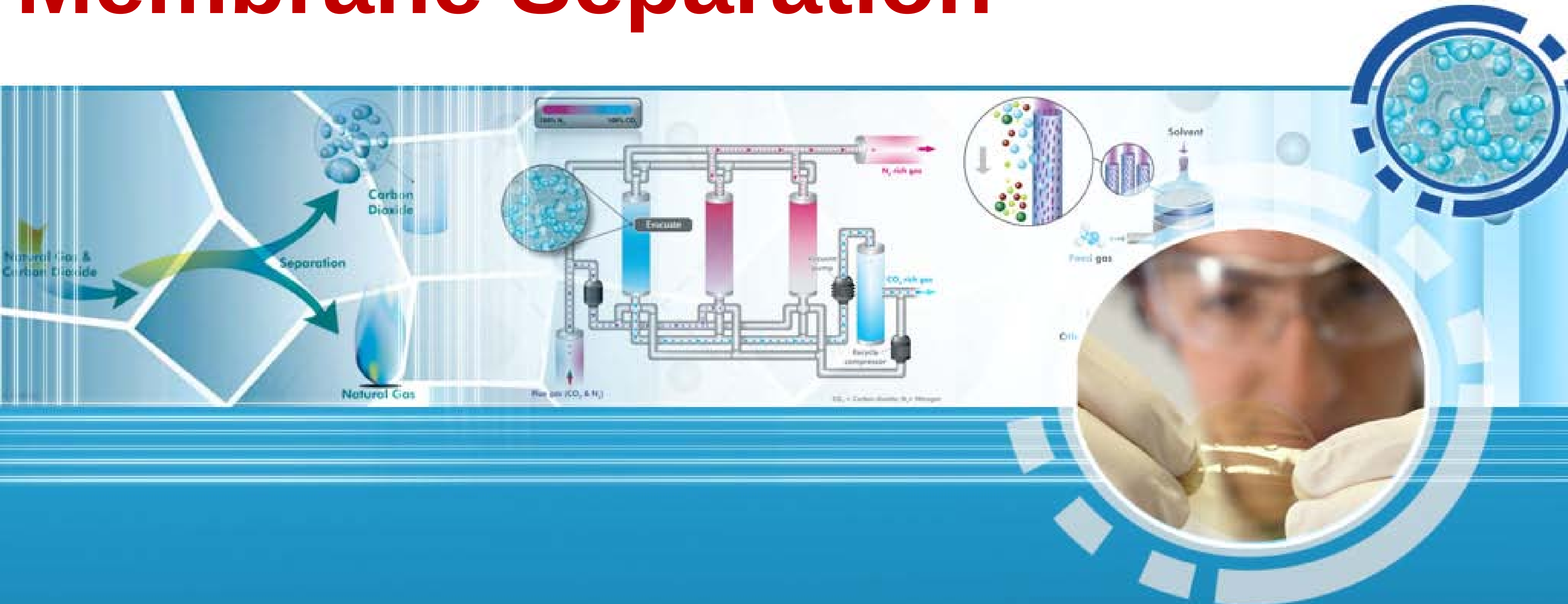
Advances in adsorption technologies

- **Process improvement**
  - New vacuum swing adsorption cycles
  - Temperature-assisted vacuum swing adsorption
  - Electrical swing adsorption
  - Heat integration
  - Multiple-layered column



Dong Xu, et al., *Adsorption*, in revision.

CO_2 capture technologies – Membrane Separation



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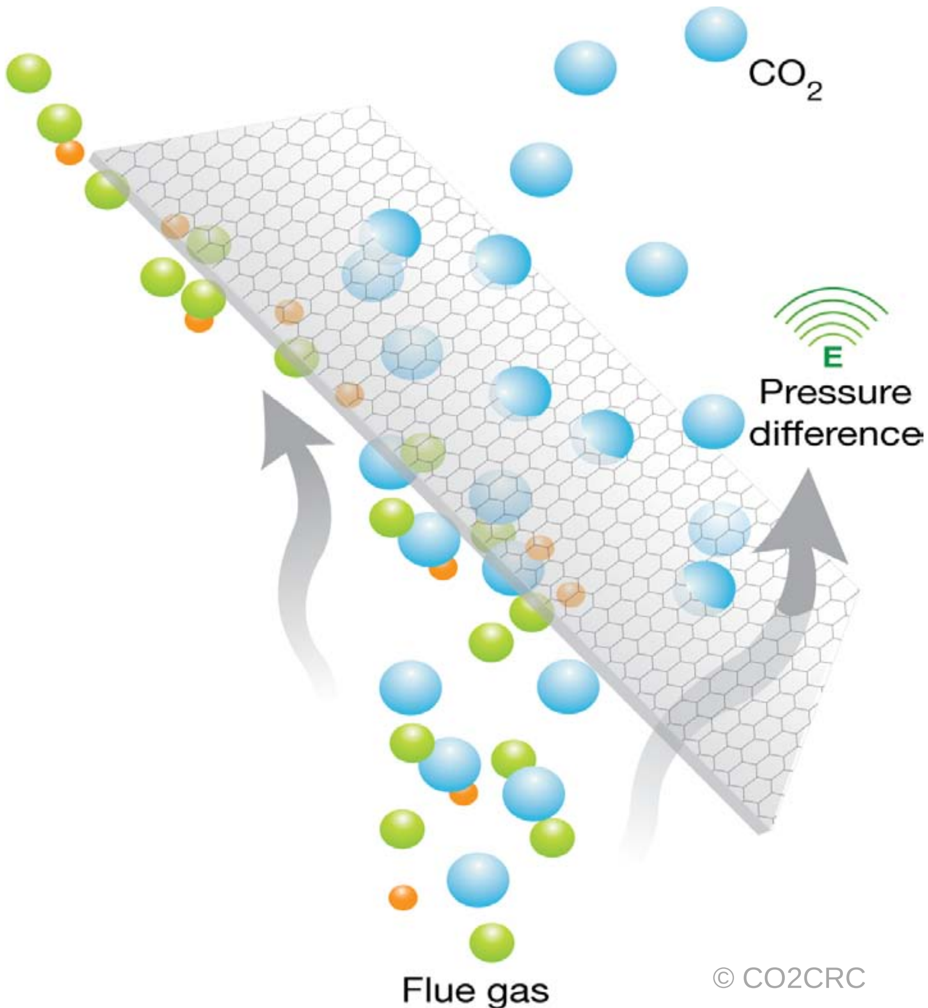
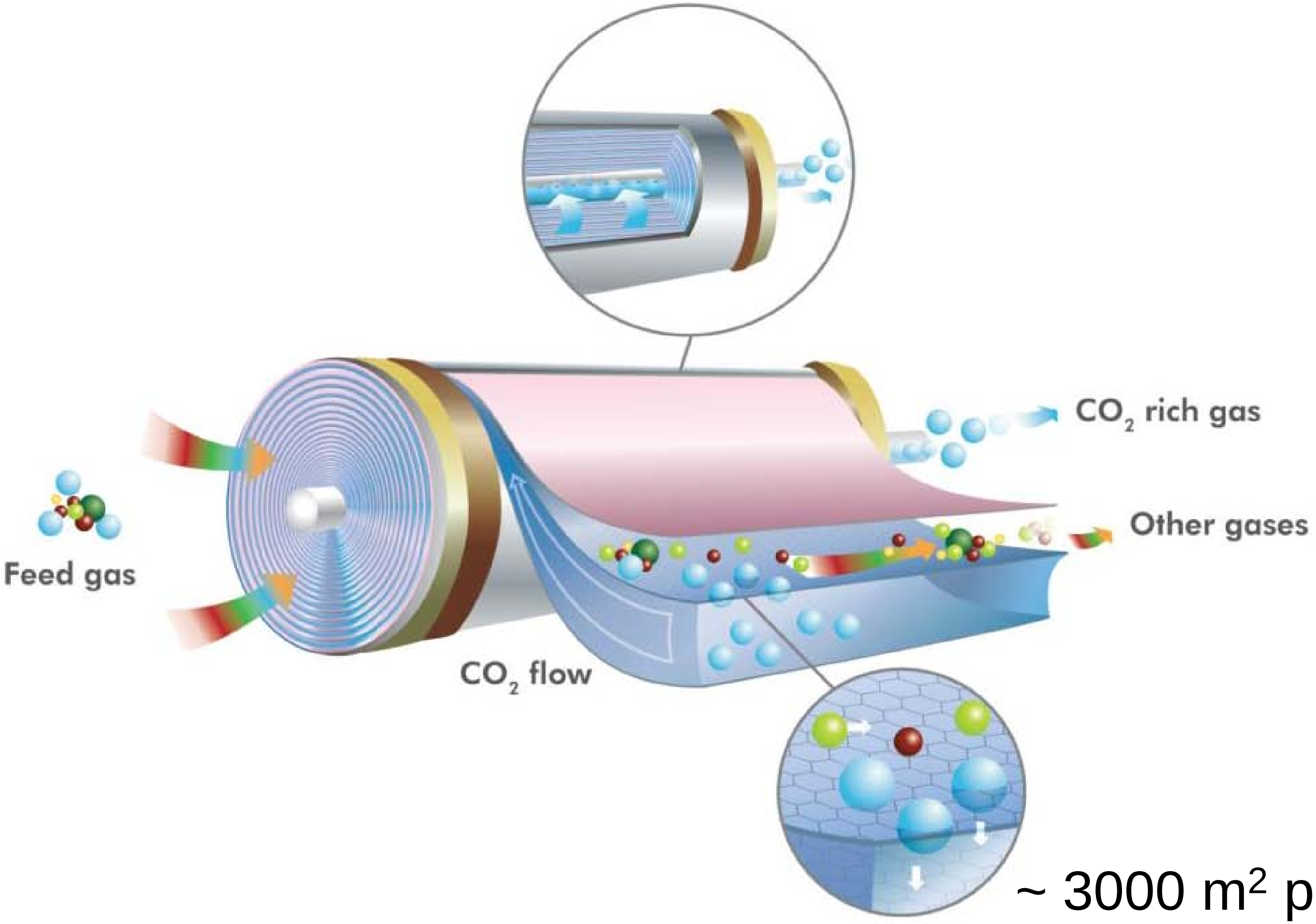
Membranes

CO_2 can selectively pass through gas separation membranes to be removed from the flue gas.



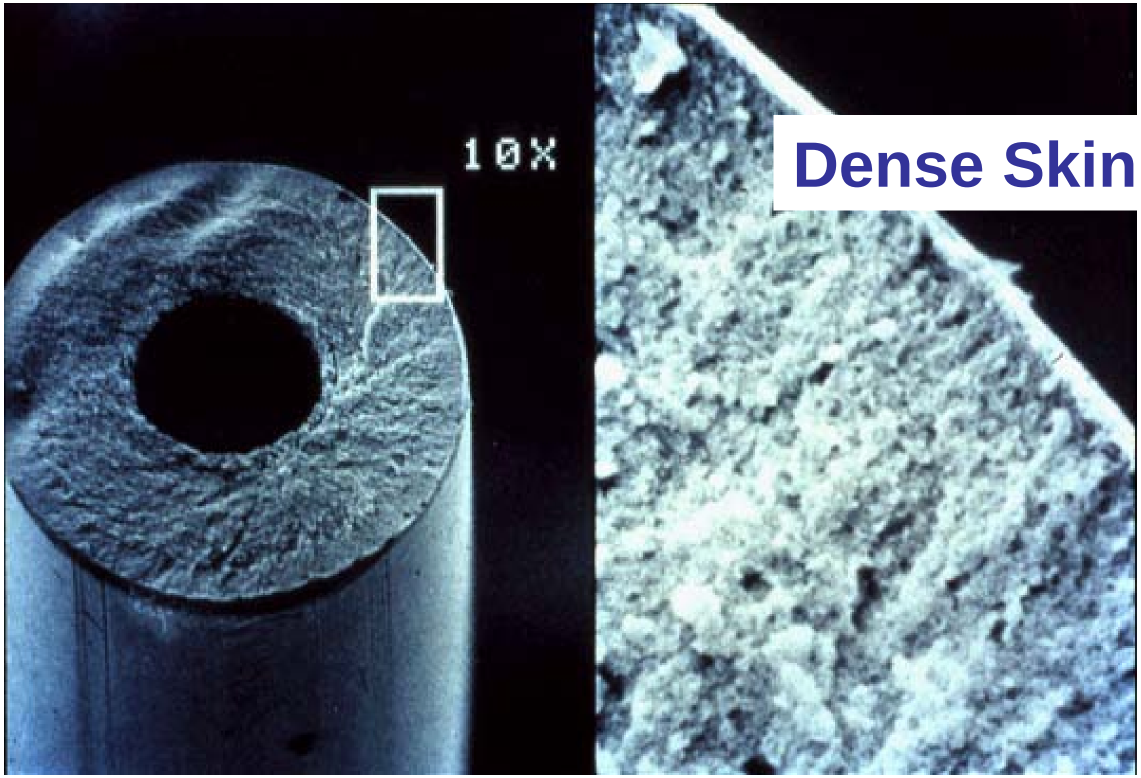
>> Animation

Spiral Wound Module



~ 3000 m^2 per m^3 volume

Hollow Fibre Membrane



Fibre diameter 0.1 to 0.5 mm diameter

Skin layer ~0.1 micron thick

Polymer Membranes for CO_2 removal

- First Generation:
  - Cellulose acetate (Cynara by Natco, Grace)
  - Polysulfone (Prism by Air Products)

  Generally spiral wound
- Second Generation:
  - Polyimides (MEDAL by Air Liquide)
  - Perfluoropolymers (Z-Top by MTR)
  - Poly ether ether ketone (PEEK by Porogen)

  More likely to be hollow fibre
- Third Generation??
  - Polaris by MTR

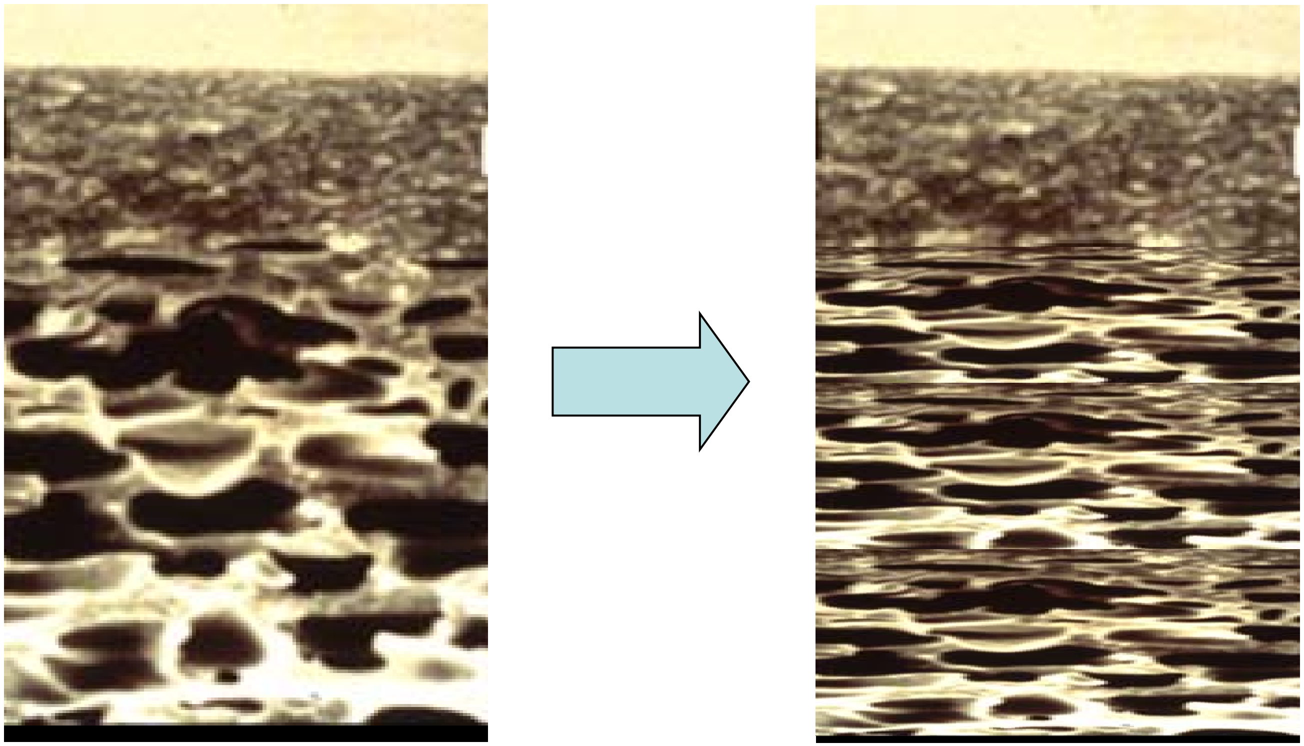
When are Membranes Competitive?

- When the feed contain moderate concentrations (10% to 85% vol) of the more permeable gas.
- When the feed is already at moderate to high pressure (15 to 150 bar gauge) and for polymeric membranes at moderate temperature (0° to 70° C)
- When the product gases are not required at very high purities or with 100% recovery.
- Polymeric membranes are proven in the capture of CO_2 from natural gas

Operational Performance Issues

Compaction

Collapse of the porous support layer adjacent to the selective layer.



- Mechanical compression due to high transmembrane pressure
- Evaporation of liquid contaminants causing capillary pressures

Plasticization

Polymer swelling due to sorption of condensable gases (water, aromatics, hydrocarbons)

- Plasticization causes:
  - Increases in permeability/losses in selectivity
  - Time dependent permeation behavior (hours to days)
  - Loss of mechanical strength
  - Increased rates of compaction

Physical Aging – diffusion of 'excess' free volume out of a glassy polymer over time (weeks to years)

Fouling – Liquid and solid contaminants can coat the membrane surface with a film that adds an additional mass transfer resistance e.g. compressor oil, fine particulates

Chemical Interactions – Some contaminants can chemically interact with the polymer e.g. HCl with cellulose acetate.

Membrane demonstration plants CO2CRC

Membrane separation Pre-combustion

Membrane separation Post-combustion

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CO_2 capture technologies – Other technologies

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Other Capture Technologies

- Membrane gas absorption
- Low temperature separation
  - Chilled water
  - Cryogenic distillation
- Oxy combustion
- Chemical looping
- Algae (bio-fuel)
- Enzymes

Acknowledgments

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