Carbon Dioxide Capture at High Temperatures

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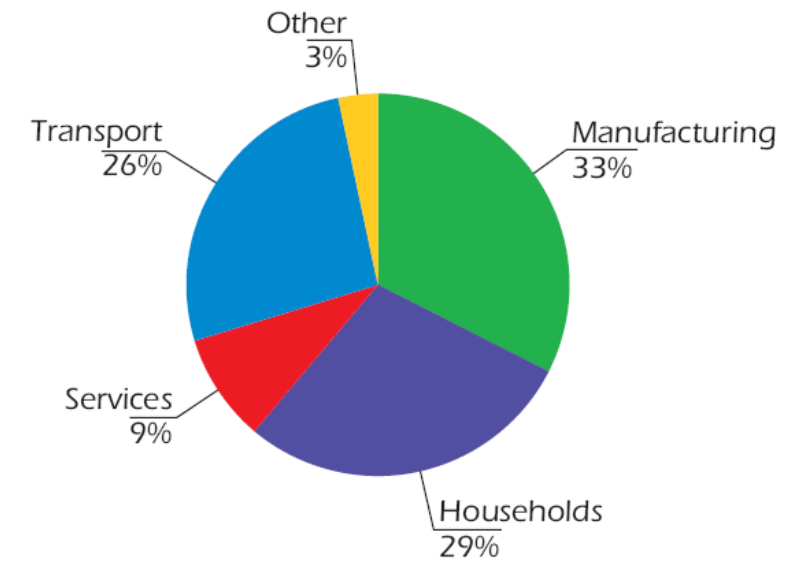
World Energy Consumption

- Total annual energy consumption (2005):
  ~ 500 EJ (=5×10^{20} J ~ 1.4×10^{14} kWh)

- World population: 6 billion (6×10^{9})
- Per capita energy consumption: ~ 65 kWh/day

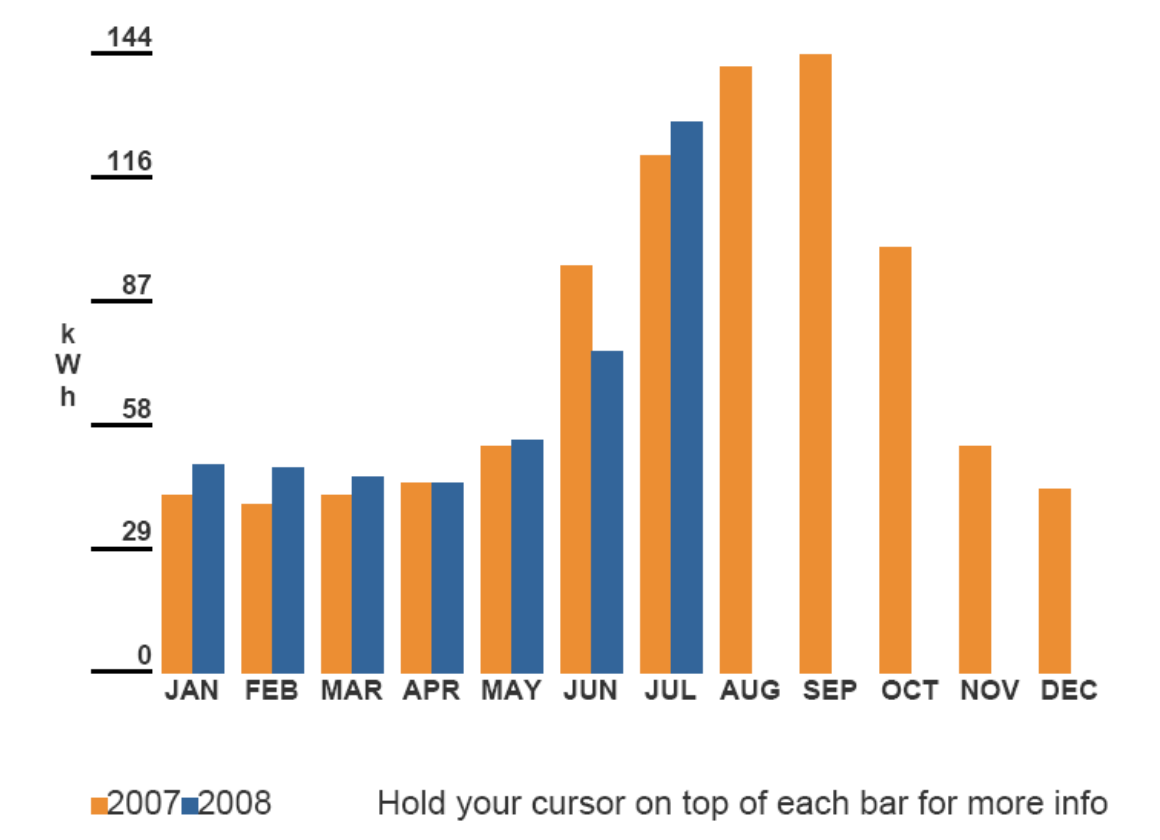


Data from IEA (2008)

Separation processes consume ~15% energy:

2.5×10^{13} kWh/year

Typical US 4 Person House-hold Electricity Bill



Electricity:

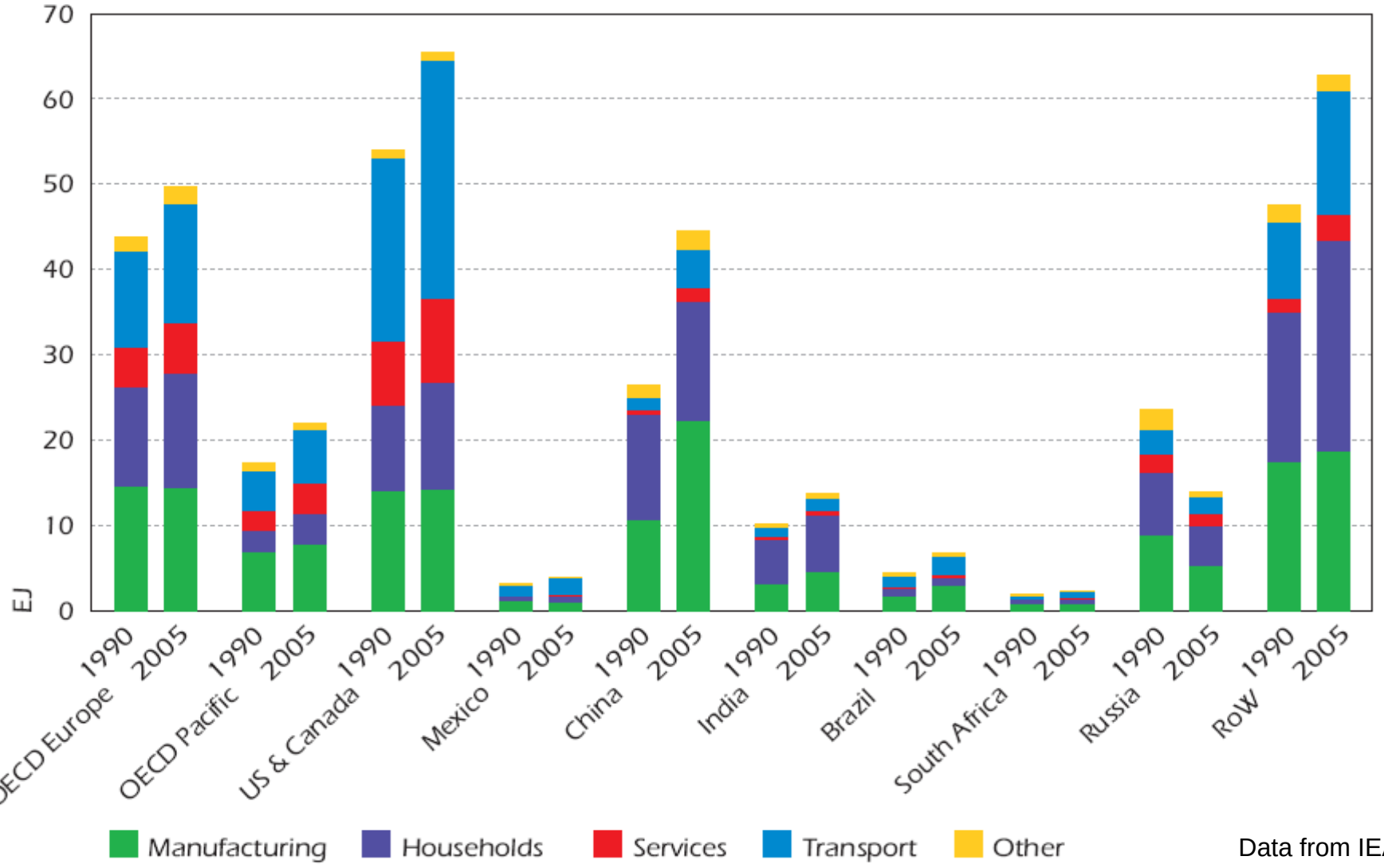
10 kWh/day/pers

↓ 20% eff.

Energy:

50 kWh/day/pers

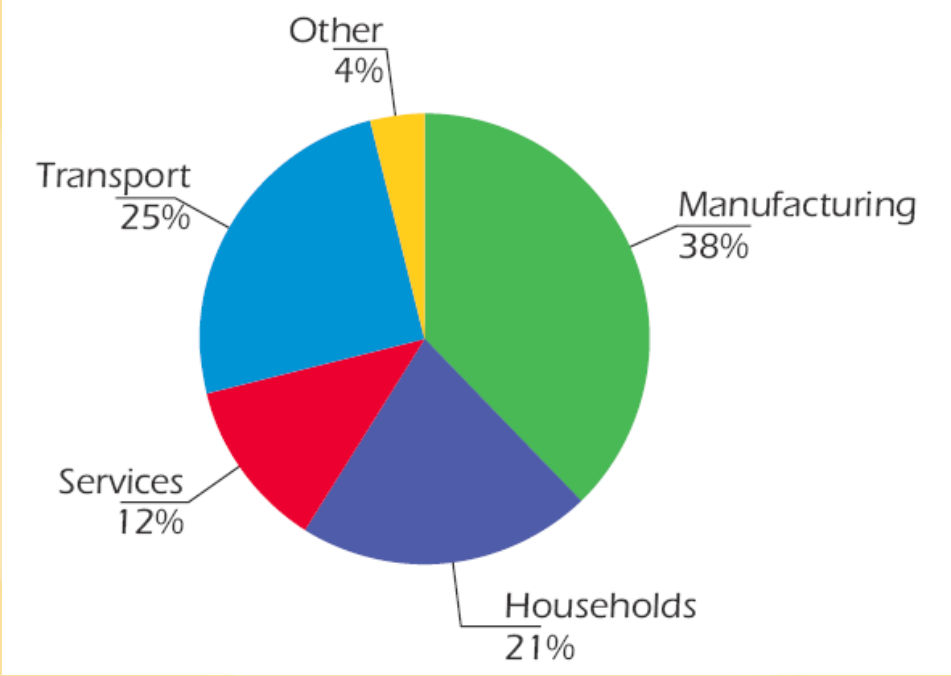
Annual Energy Uses by Countries or Regions (2006)



Data from IEA

Greenhouse Gas

- 1 ton of coal => 3.6 ton CO_2
- Coal combustion heat: 15-21x10^9 J/ton
- Total world CO_2 emission: 21-26x10^9 ton/yr
- In the past 100 years CO_2 conc. in air increases from 250 to 380 ppm – causing global warming
- CO_2 needs to be sequestered



Data from IEA (2008)

Carbon Dioxide Sequestration

Oceanic

Terrestrial

Calcium Carbonate

Abandoned Oil Mines

Carbon Dioxide Capture and Separation

- CO_2 capture and separation: Key step in sequestration (~90% of total sequestration cost)

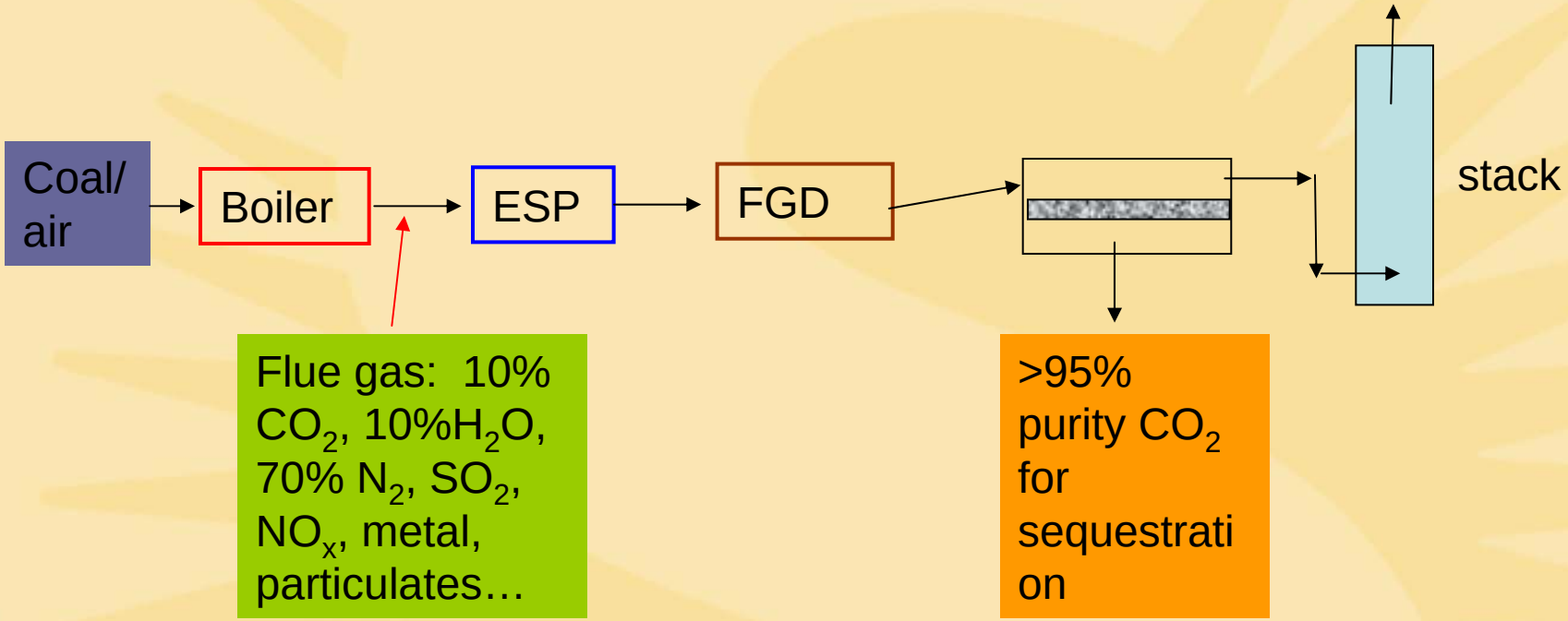
- CO_2 Capture/Separation Methods
  - **Post-combustion removal**
  - **Oxyfuel combustion**
  - **Precombustion removal**

- Difficult to Separate CO_2 from N_2

CO_2: 0.33 nm

N_2: 0.36 nm

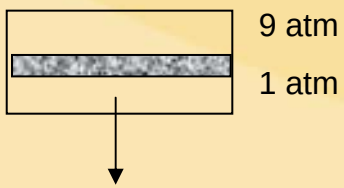
Membrane Use for Post-Combustion CO_2 Removal



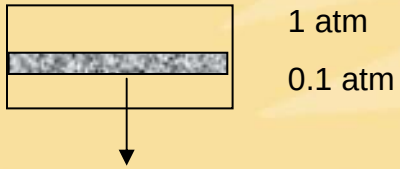
For 800 MW coal based power plant: ~460 ton CO_2/h to be removed

Membrane for CO_2 Removal from Flue Gas

- MTR Polaris Membranes for 800 MW power plant
- CO_2 permeance: 4×10^{-7} mol/m^2.s.Pa
- CO_2/N_2 selectivity: 50
- Processes and energy consumption (12-20% of the total)



104 MW



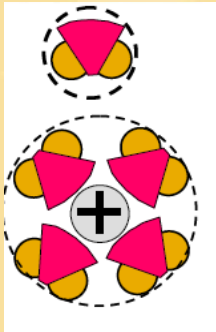
69 MW

- Membrane area: 500,000-1,000,000 m^2
- Operation cost: \$20-35/ton of CO_2
  (amine absorption process cost: \$40-60/ton of CO_2)
- Capital costs: \$250/m^2 of membranes (including module)
  (membrane cost: \$10/m^2)

Data from MTR presentation, ICIM2008

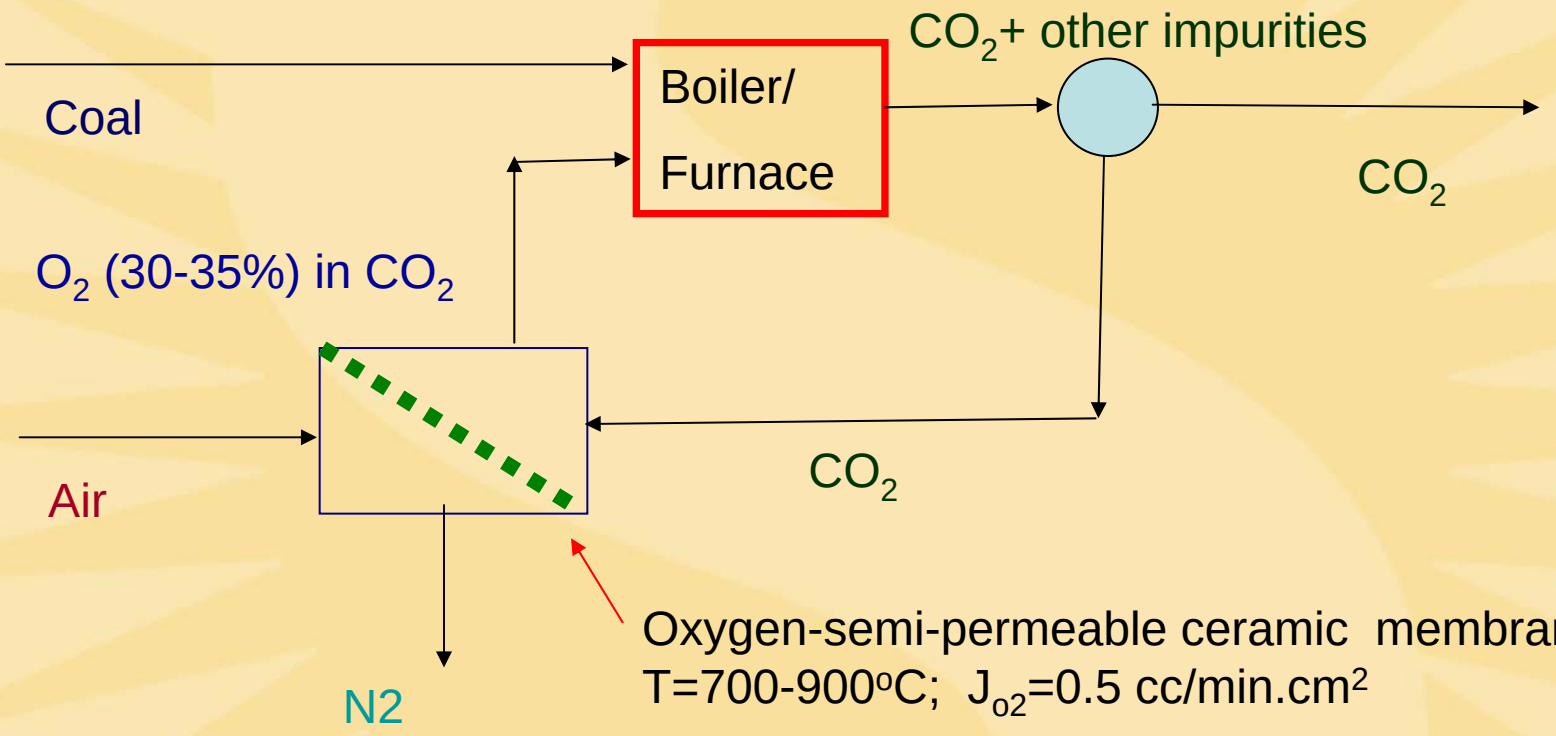
Large Membrane Area Not an Issue

- Removing salt from water by reversed osmosis (RO) is “easy” because kinetic size of water is about ½ of the hydrated salt ions



- The largest RO plant is being built by Hyflux Co.(Singapore):
  - Capacity: ~ 0.5 billion L/day water
  - Membrane area: 3,200,000 m^2

Ionic Transport Membrane for Oxyfuel Combustion

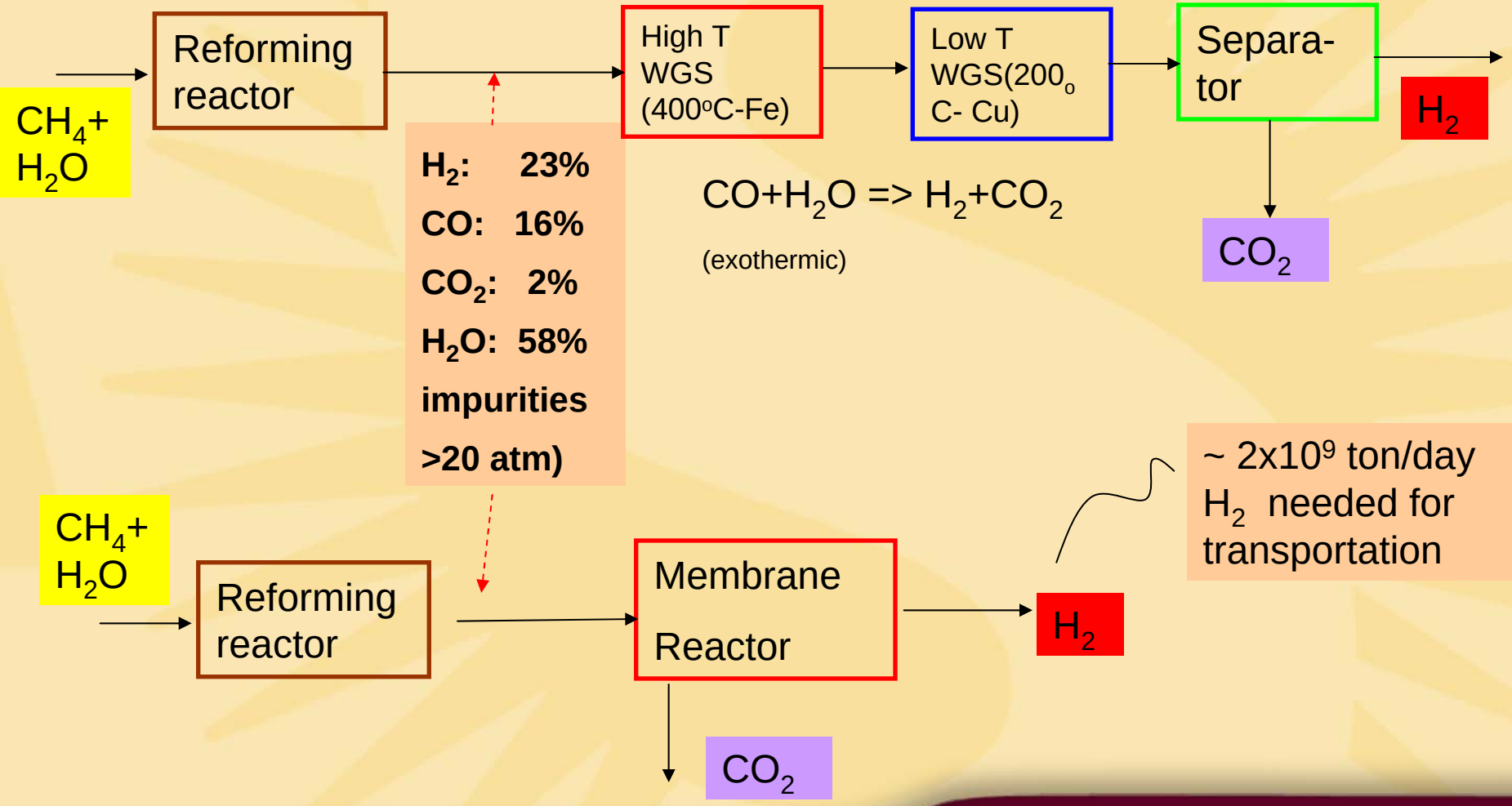


Oxygen-semi-permeable ceramic membranes;
T=700-900^oC; J_{o2}=0.5 cc/min.cm^2

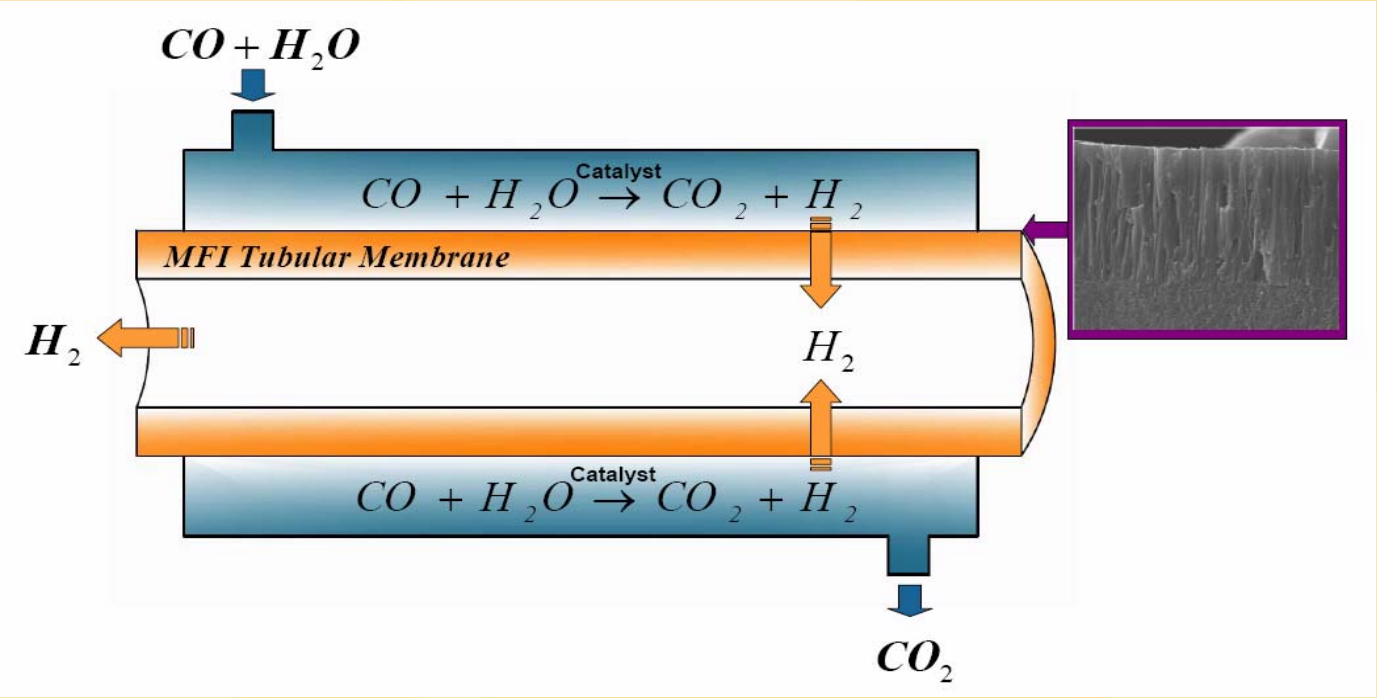
600 MW Plant=> ~ 5 ton coal/min:

Membrane area: ~20,000 m^2

Hydrogen Production with Membranes



Zeolite Membrane Reactor for Hydrogen Production

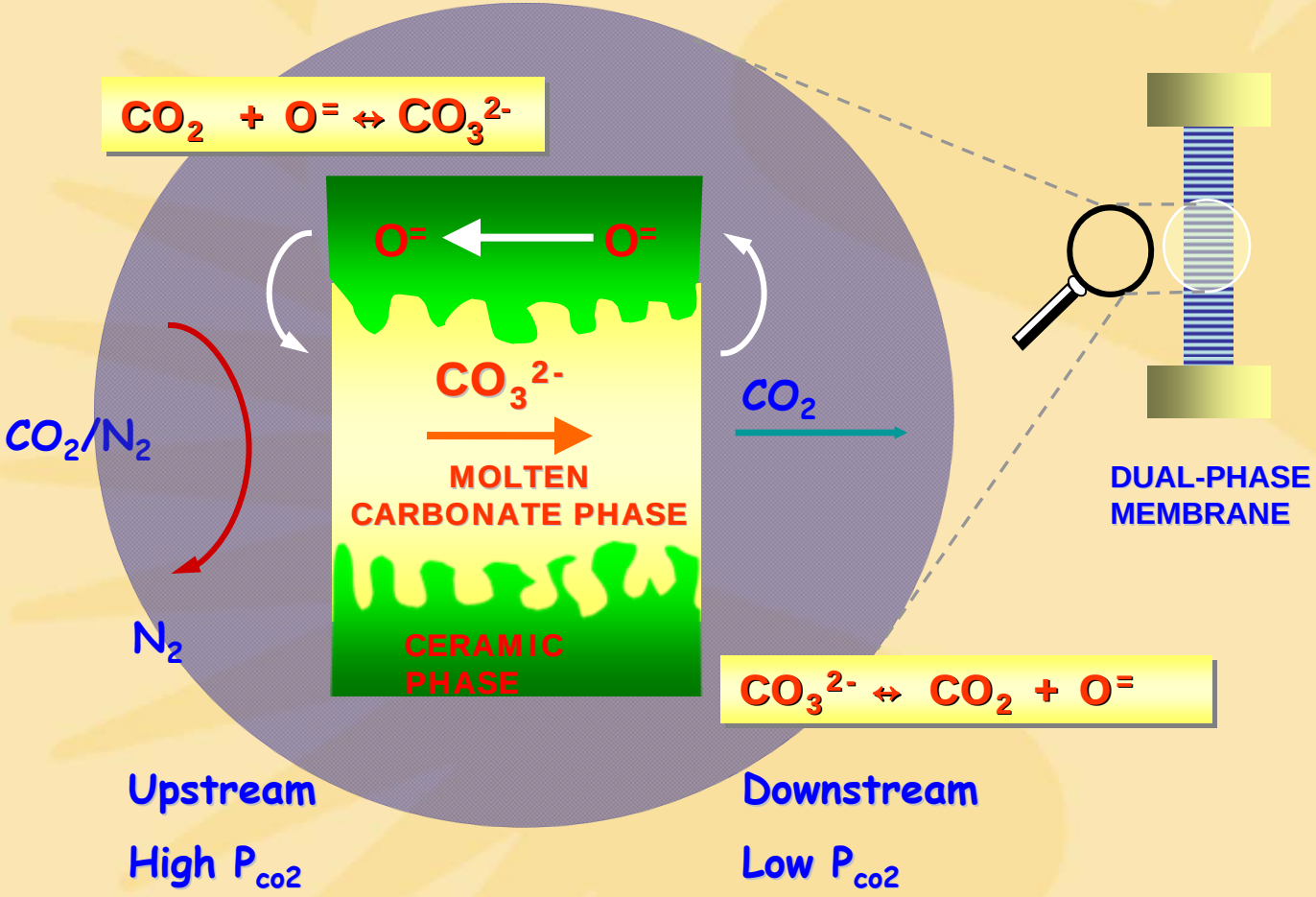


- Water-gas-shift reaction at one temperature (about 400°C)
- Two product streams: pure H_2 and pure CO_2

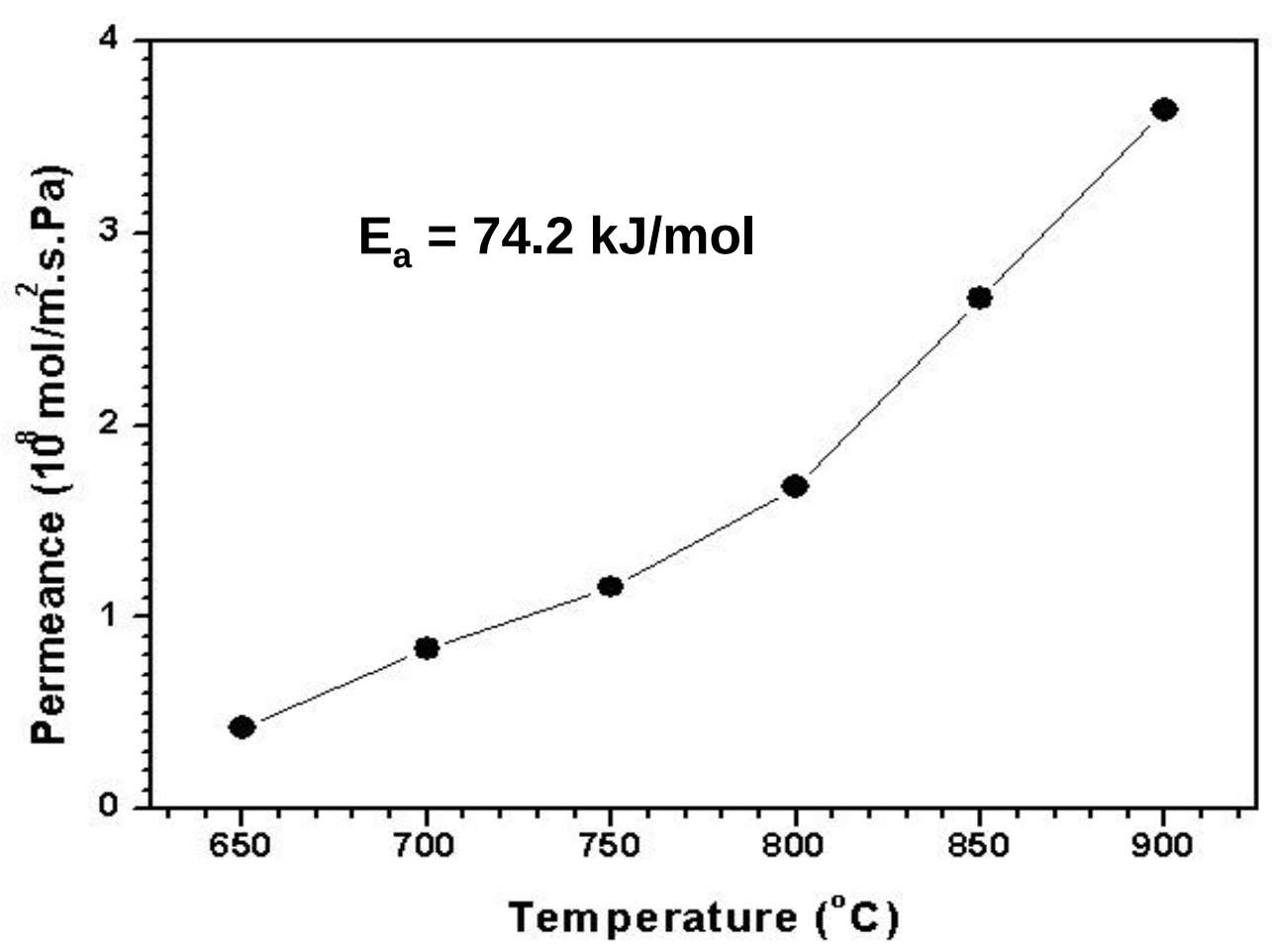
Zeolite Membrane Requirements:

- Operated in 350-550°C
- Chemically stable in H_2S, thermally stable at ~400°C
- Hydrogen permeance ~ 5×10^{-7} mol/m^2.s.Pa

Dual-Phase Ceramic Carbonate Membrane



Carbon Dioxide Permeation Results



High Temperature Sorbents for Carbon Dioxide Capture

Lithium Zirconate (Li_2ZrO_3)

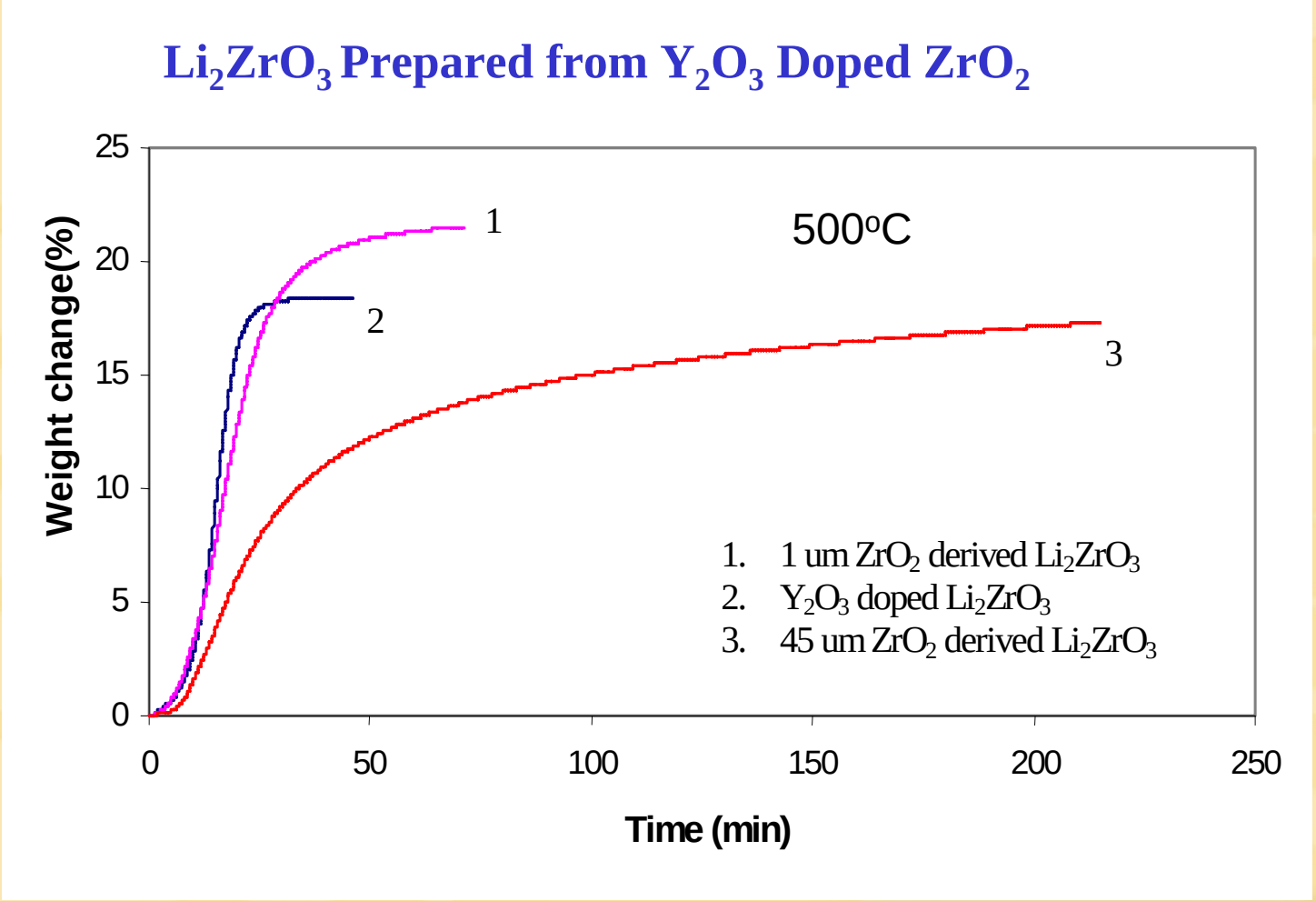
$$Li_2ZrO_3 + CO_2 = Li_2CO_3 + ZrO_2$$

(at 400°C – 550°C)

$$Li_2CO_3 + ZrO_2 = Li_2ZrO_3 + CO_2$$

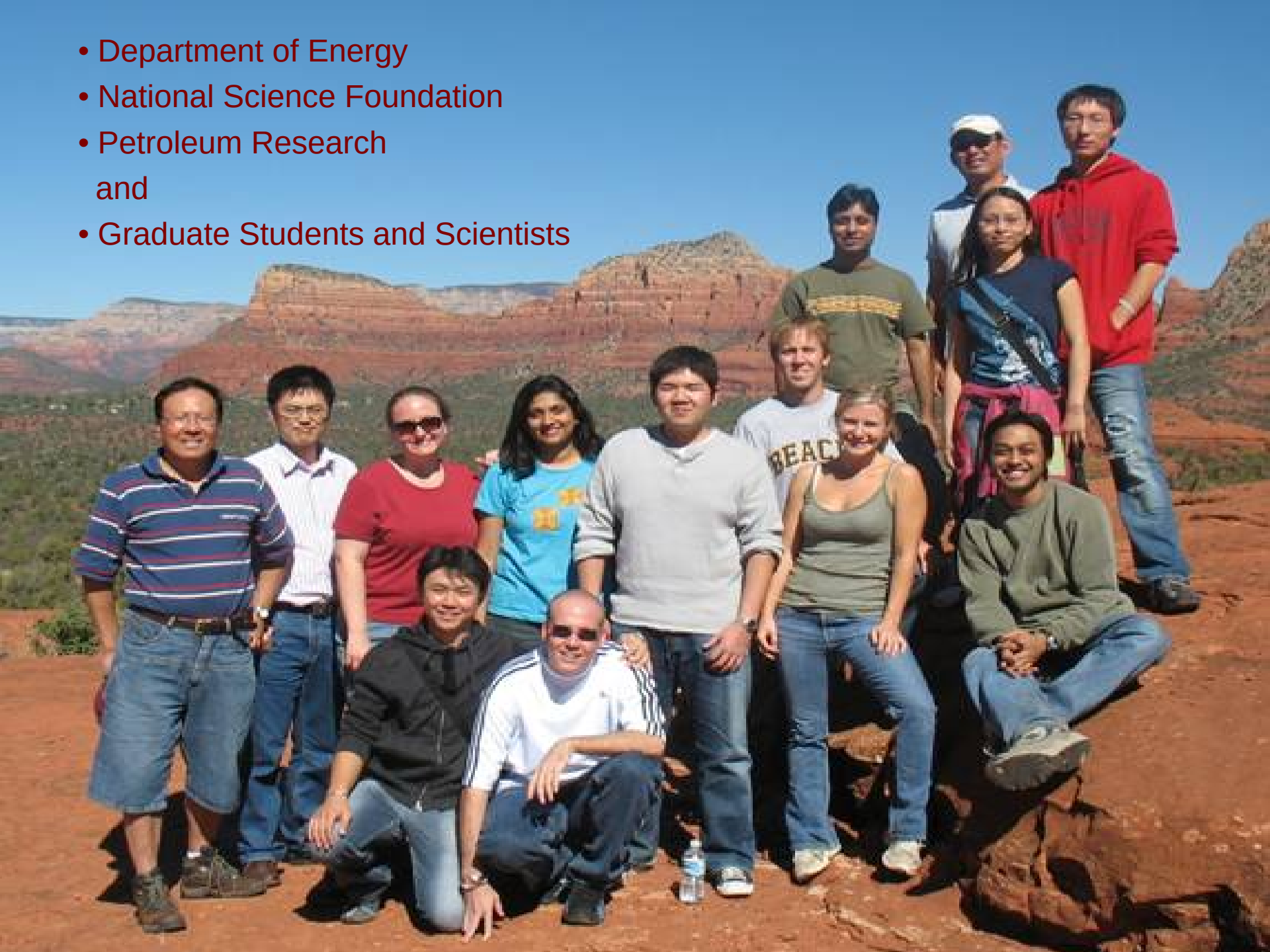
(over 600°C)

Improved Sorbents



Concluding Remarks

- Energy is one of the major grand challenges facing the mankind in coming 10-50 years
- Major energy and environment demands present several new, large scale separation processes challenging the chemical engineering community
- Membranes will play a key role in post-combustion, oxyfuel and pre-combustion processes for carbon dioxide capture.
- High temperature membrane or sorbent technologies are critical to pre-combustion carbon dioxide capture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and
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