Point Source Capture vs. "Air Capture":

CO_2 Source Properties: Air/Flue

Property	Air	Flue
Amount of CO_2	**3 teratonnes**	20 gigatonnes/yr
Distribution	**400 ppm** - "infinite" mostly uniform source	**5-15%** point sources
Temperature	0-30 °C Low ΔT	45-65 °C High ΔT – heat integration!
Contaminants	**oxygen**	**SOx , NOx , oxygen**
Movement	**wind, fans**	**fans**

- Short term: CO_2 source for fuel or chemical synthesis
- Long term: CO_2 sequestration – climate change

Air Capture Approaches:

- Supported amine adsorbents (TSA/VSA)
- Humidity swing adsorbents
- Aqueous alkaline solutions (APS report)
- Aqueous amine solutions (submarines)
- Solid alkaline adsorbents (high temperature)
- Mineral sequestration

Needs for a Practical "Air Capture" Process:

1. Low Pressure Drop, High Surface Area Contactor:
   - must move 125-375 X more gas through process vs. flue gas

2. Adsorbent with strong binding energies with CO_2 (thermodynamics)
   - must adsorb a large amount of CO_2 at low P_{CO2}.

3. Adsorbent and process design that allows for rapid adsorption/desorption rates (kinetics)
   - need to remove massive amounts of CO_2.

4. Low cost source of energy for adsorbent regeneration by temperature-swing.
   - adsorption is exothermic, desorption is endothermic

5. Acceptable capital costs and ultra-long process/material lifetime
   - sorbent degradation and lifetime is a critical element.

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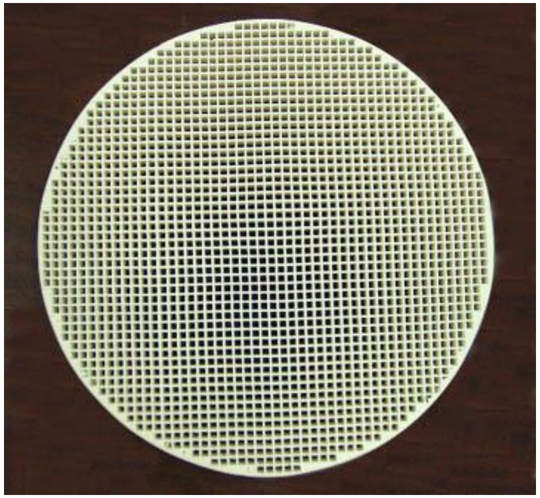

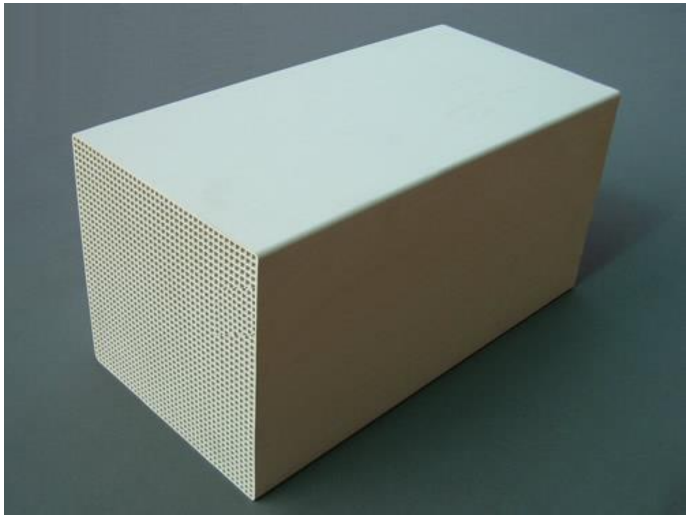

Oxide monoliths:
(i) commercially available (Corning)
(ii) low cost
(iii) low pressure drop [100-200 Pa or 0.015-0.03 psi]
(iv) easily coated with adsorbent materials
(v) high surface area

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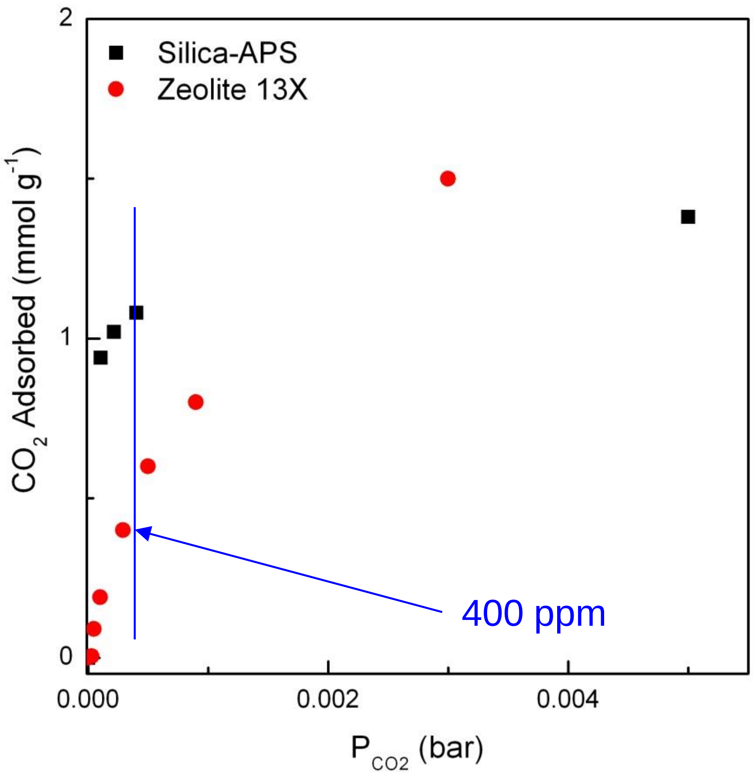
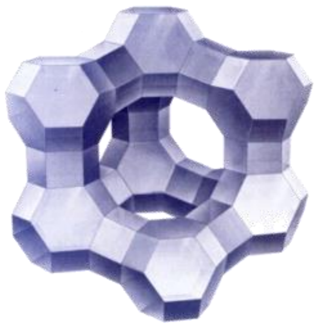
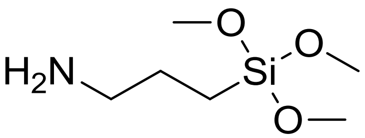




Zeolite 13X

-- physisorbant
(low ΔH_{ads} ca. 36 kJ/mol)

Silica-APS



-- chemisorbent (high ΔH_{ads} ca. 60-85 kJ/mol)

-- primary amines most effective

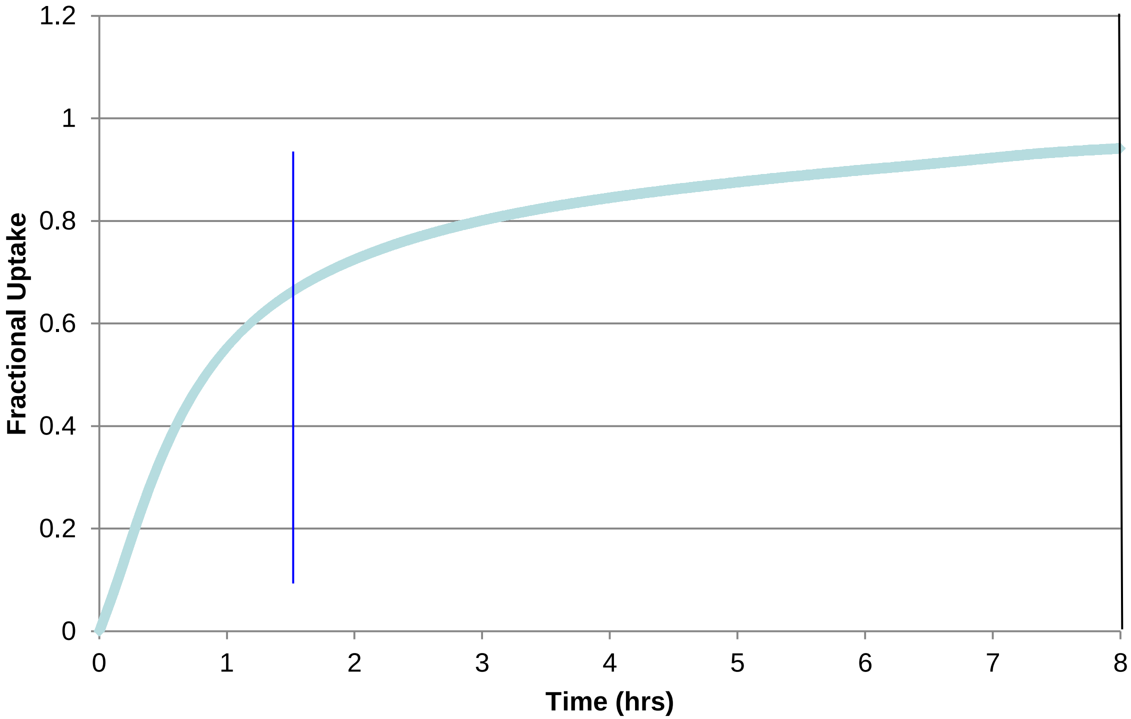
-- effective in all humidities

Choi et al. *ChemSusChem* **2011**, 4, 628.

Needs for a Practical "Air Capture" Process:

3. Adsorbent and process design that allows for rapid adsorption/desorption rates (kinetics)
   - need to remove massive amounts of CO_2.

Air capture is an extraction,
not a purification:
capture what is economically feasible



-- rapid initial uptake
   to 70+% total capacity
   = "working capacity"

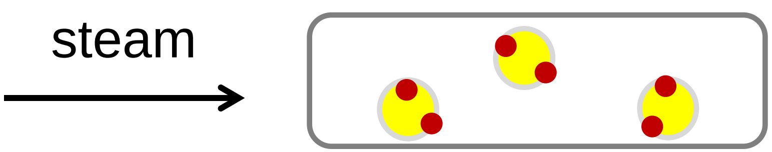
-- practical conditions,
   gas velocity 2-5 m/s
   working capacity, <0.5 h

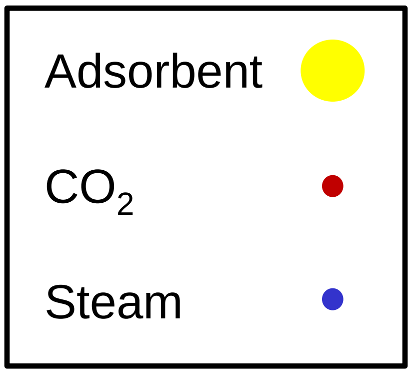
- Monolith contactor yields good kinetics

Needs for a Practical “Air Capture” Process:

4. Low cost source of energy for adsorbent regeneration by temperature-swing; Adsorption is exothermic, desorption is endothermic

- Amine adsorption occurs at ambient temperatures (0-35 ˚ C)
- Only low grade heat for regeneration (80-100 ˚ C) = waste heat.
- Steam-stripping gives pure CO_2 upon compression = highly efficient





- Low grade waste heat from:
  - (i) Manufacturing processes
  - (ii) Solar-thermal heating = minimal costs in short term

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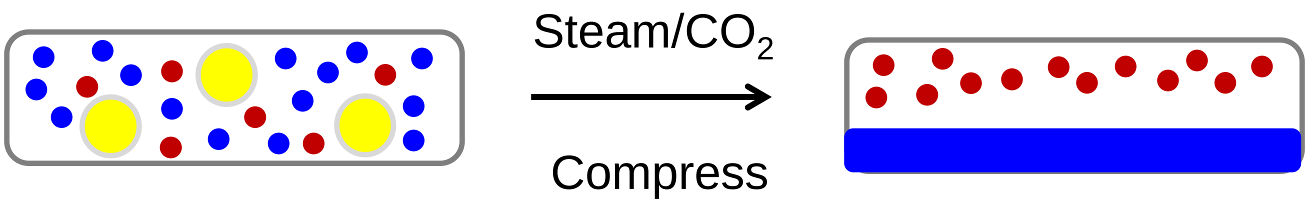

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Georgia Institute of Technology
School of Chemical & Biomolecular Engineering

Li et al. *ChemSusChem* **2011**, 3, 899.

Needs for a Practical “Air Capture” Process:

5. Acceptable capital costs and ultra-long process/material lifetime
   - sorbent degradation and lifetime is a critical element.

- Capital costs (as in PCC) significant, installations big (0.01 m^2 / tonne CO_2-yr)
- Capital costs for large scale equipment can be estimated.
- Largest cost unknown = lifetime of adsorption media.

Global Thermostat, LLC, is a technology start-up that is incorporating GT-designed sorbents into a pilot-scale air capture process, pilot testing at SRI in Menlo Park, CA.

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Conflict-of-Interest Statement: Georgia Tech receives research funding from Global Thermostat, LLC, and Jones has a financial interest in Global Thermostat Operations, LLC.

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Air Capture Summary:

- **Supported amine adsorbents** are promising materials for the extraction of CO_2 from ambient air.
- Supported amines offer the advantage of **high capacities** (1-2 mol CO_2/kg sorbent) and operation in all humidity levels.
- Reasonable adsorption kinetics achieved with **monolith contactors**.
- **Primary amines** are most effective air capture adsorbents, also most resistant to oxidation.
- **Optimizing** swing capacity and **sorbent lifetime** ongoing………