Research Coordination Network
Carbon Capture, Utilization, and Storage
NSF Science, Engineering, and Education for Sustainability

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

Lenfest Center for Sustainable Energy
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Towards Sustainable Energy : Carbon Capture, Utilization and Storage

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Columbia University

NSF RCN-CCUS Annual Meeting
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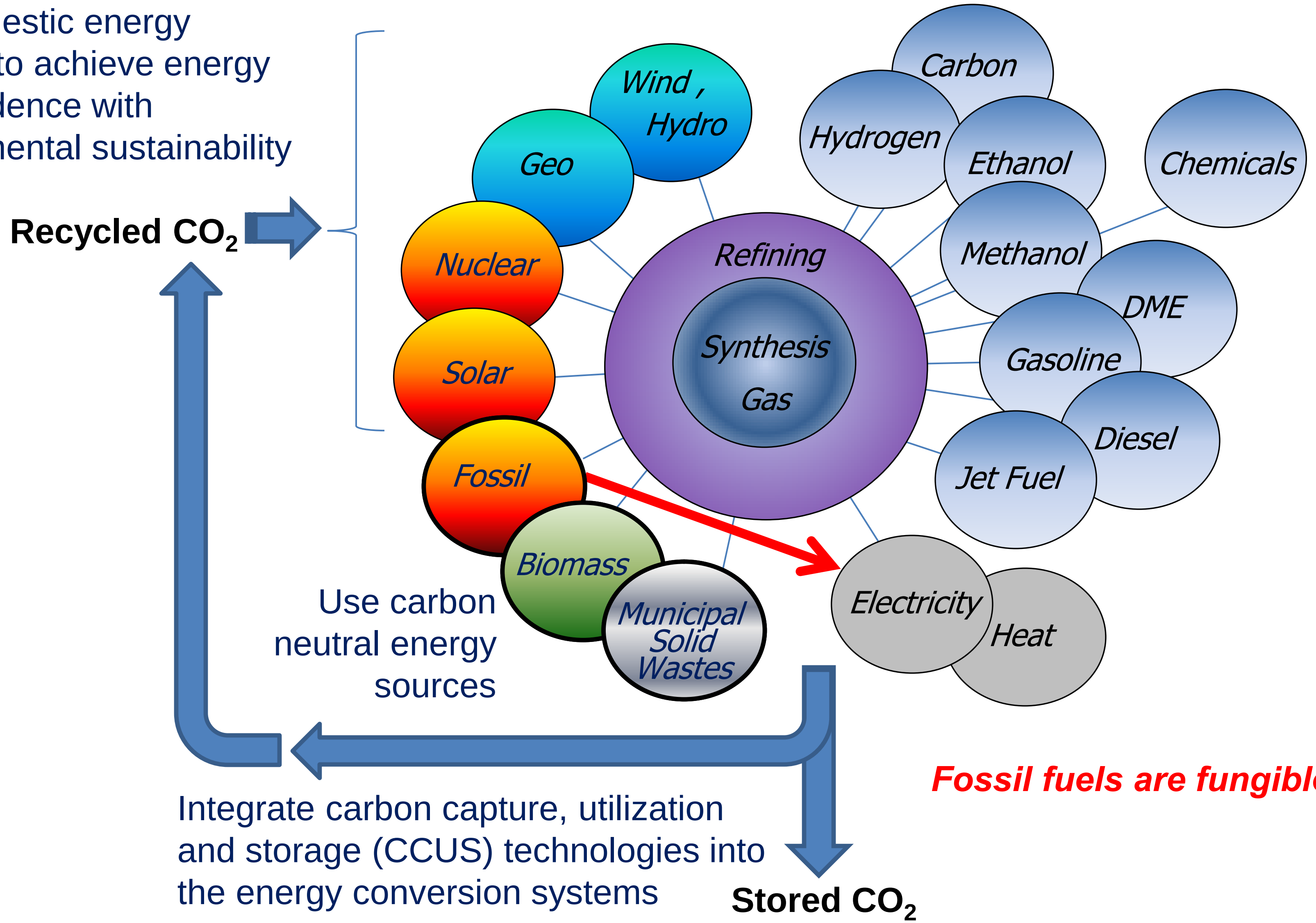
Towards Sustainable Energy and Environment

Use domestic energy sources to achieve energy independence with environmental sustainability



Use carbon neutral energy sources

Integrate carbon capture, utilization and storage (CCUS) technologies into the energy conversion systems

Fossil fuels are fungible…

Carbon Capture

- **From diffuse sources**
- **From concentrated sources**
  - Physical and chemical absorption and adsorption, Cryogenic separation, membrane separation, reaction-based sorbent injection
  - Oxyfuel combustion
  - **Integrated Carbon Capture Technologies**: ZECA, HyPr-Ring process, ALSTOM process, GE fuel-flexible process, Calcium looping process, Coal-direct chemical looping reforming process and Syngas redox process, Membrane process, etc

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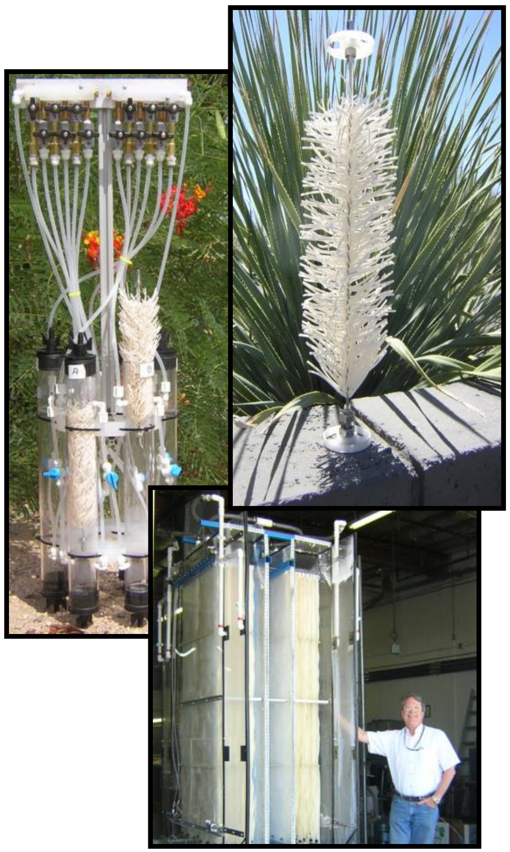
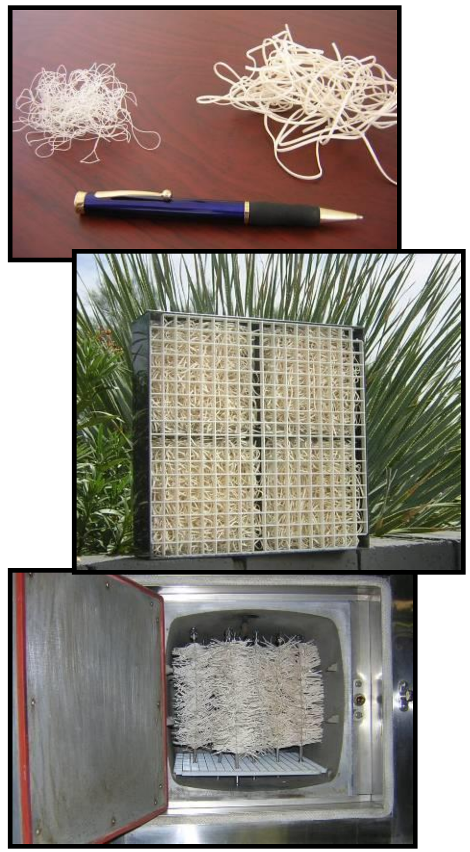
Collecting CO_2 with Synthetic Trees

From Technology Validation to Market-Flexible Products to Scalable Global Solutions

GRT Pre-Prototype Air Capture Modules - 2007



Current GRT Development

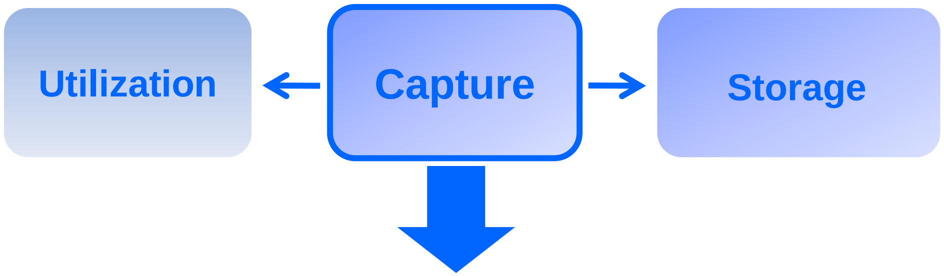


Mass-Manufactured Air Capture Units

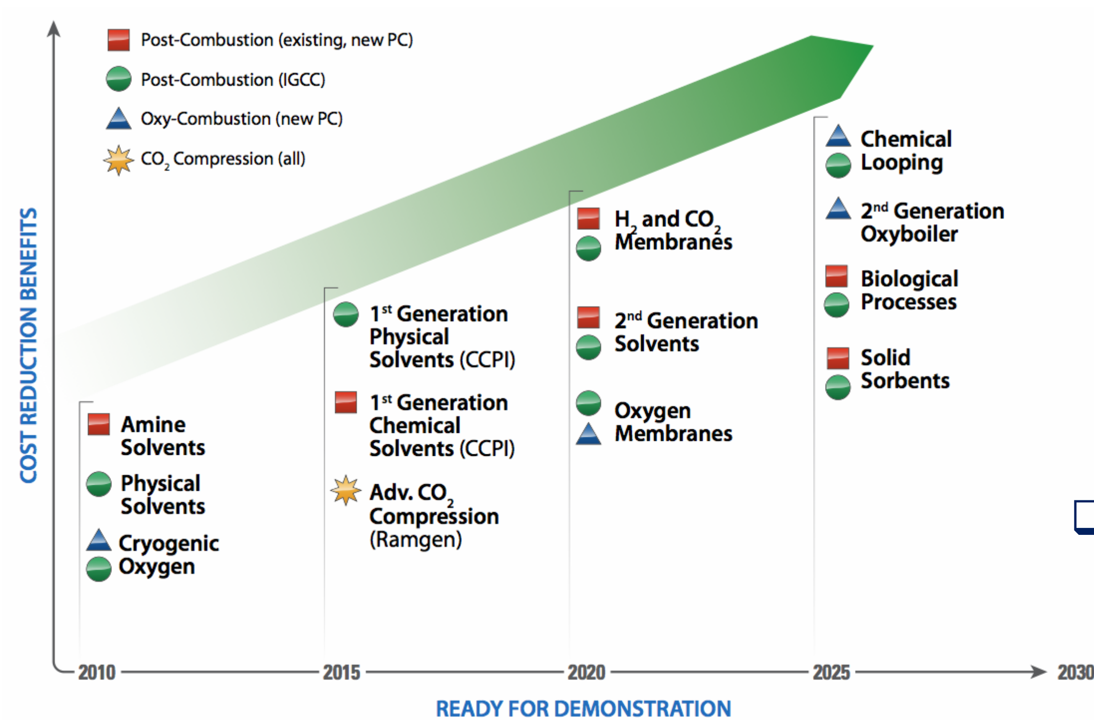
Courtesy GRT*

*K. S. Lackner is a member of GRT

Carbon Capture, Utilization and Storage Technologies (CCUS)



Carbon Capture Technologies



(NETL, 2010)

- Required characteristics for CCS
  - Capacity and economic feasibility
  - Environmental benign fate
  - Long term stability

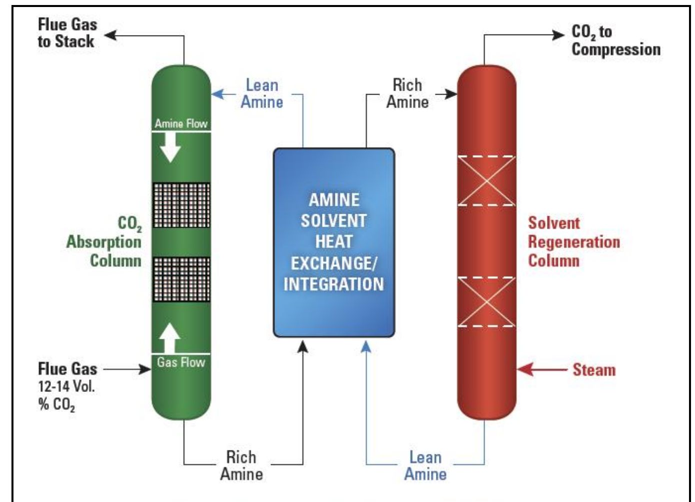
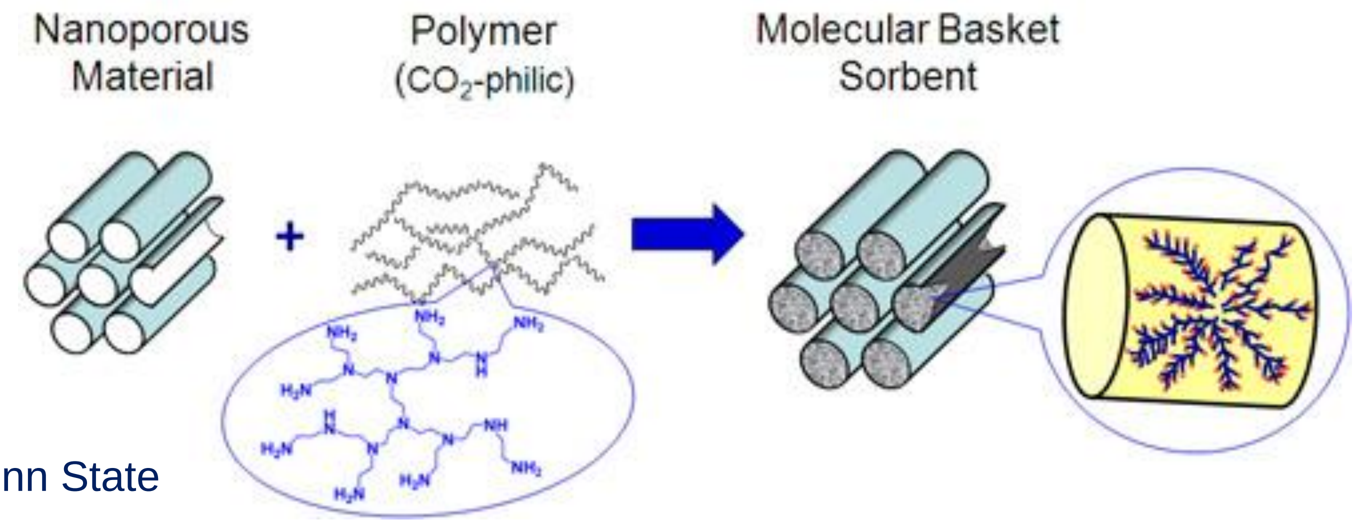


Figure 6-1: Schematic Diagram of the Post-Combustion MEA CO_2 Capture Process

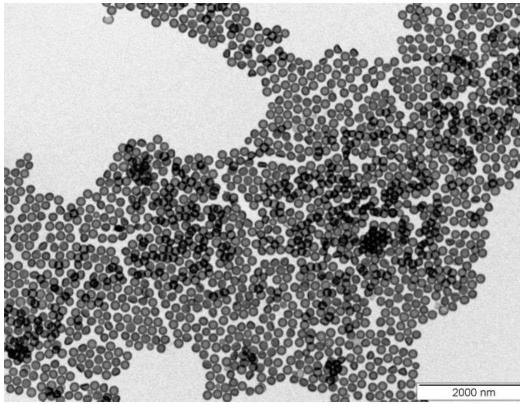
(NETL, 2011)

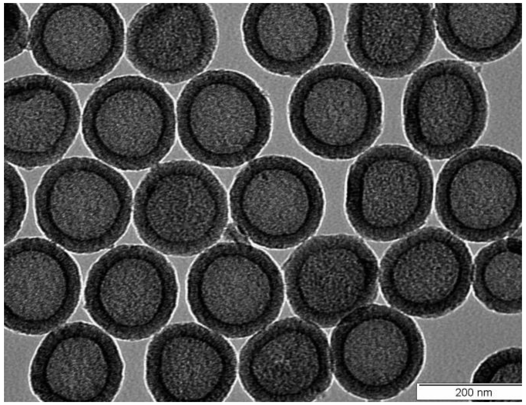
- MEA Challenges
  - Corrosion and solvent degradation
  - High capital and operating costs
  - High parasitic energy penalty

Novel CO_2 Capture Materials



Song at Penn State

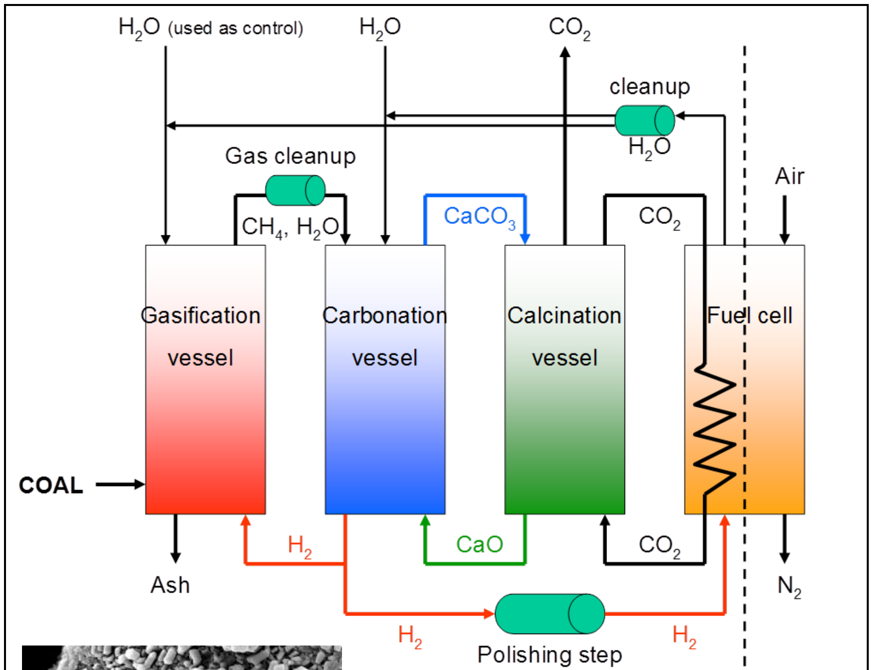




Giannelis at Cornell and Park at Columbia

Solid Sorbents & Chemical Looping Technologies

Carbonation / Calcination cycle



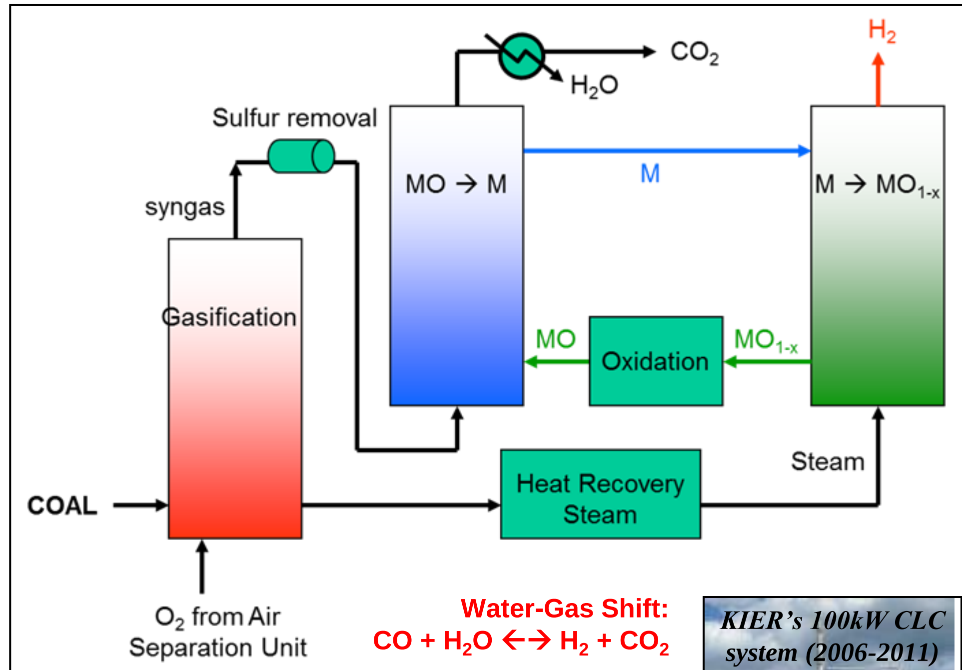
$$MO + CO_2 \rightarrow MCO_3$$

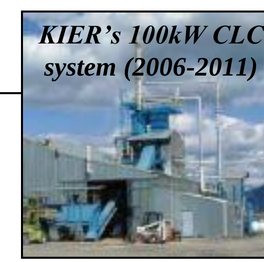
$$MCO_3 \rightarrow MO + CO_2$$

e.g., ZECA process

(Los Alamos National Lab)

Oxidation / Reduction cycle





$$MO + CO \rightarrow M + CO_2$$

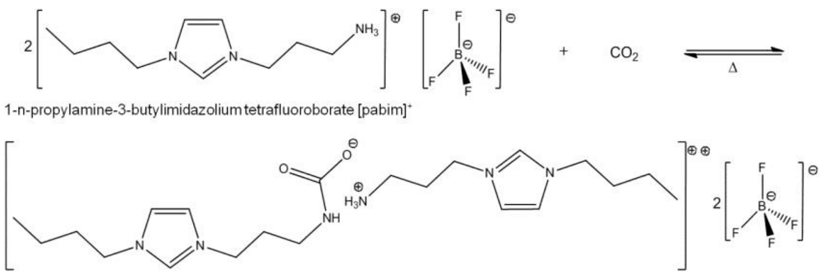
$$M + H_2O \rightarrow MO + H_2$$

e.g., Chemical Looping process for H_2 production

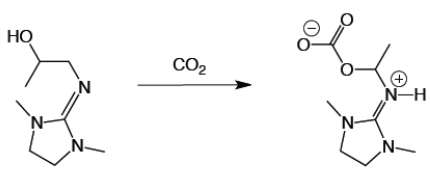
(Ohio State Univ.: U.S. Patent No. 11/010,648 (2004))

Novel CO_2 Capture Solvents *(NETL and ARPA-E funded projects)*

- ❑ Ionic liquids

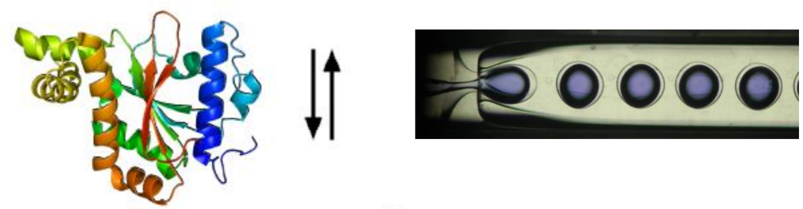


- ❑ CO_2BOLs



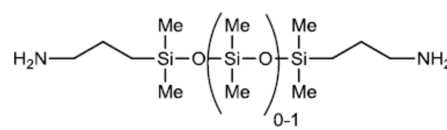
- ❑ Carbonic Anhydrase (Enzyme)

$CO_2 + H_2O$

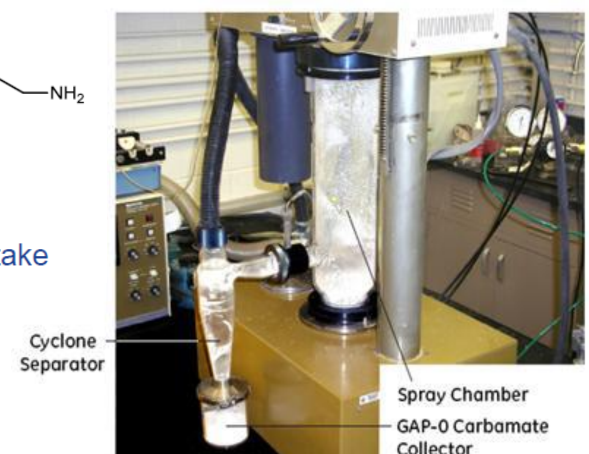


$HCO_3^- + H^+$

- ❑ Phase changing absorbents

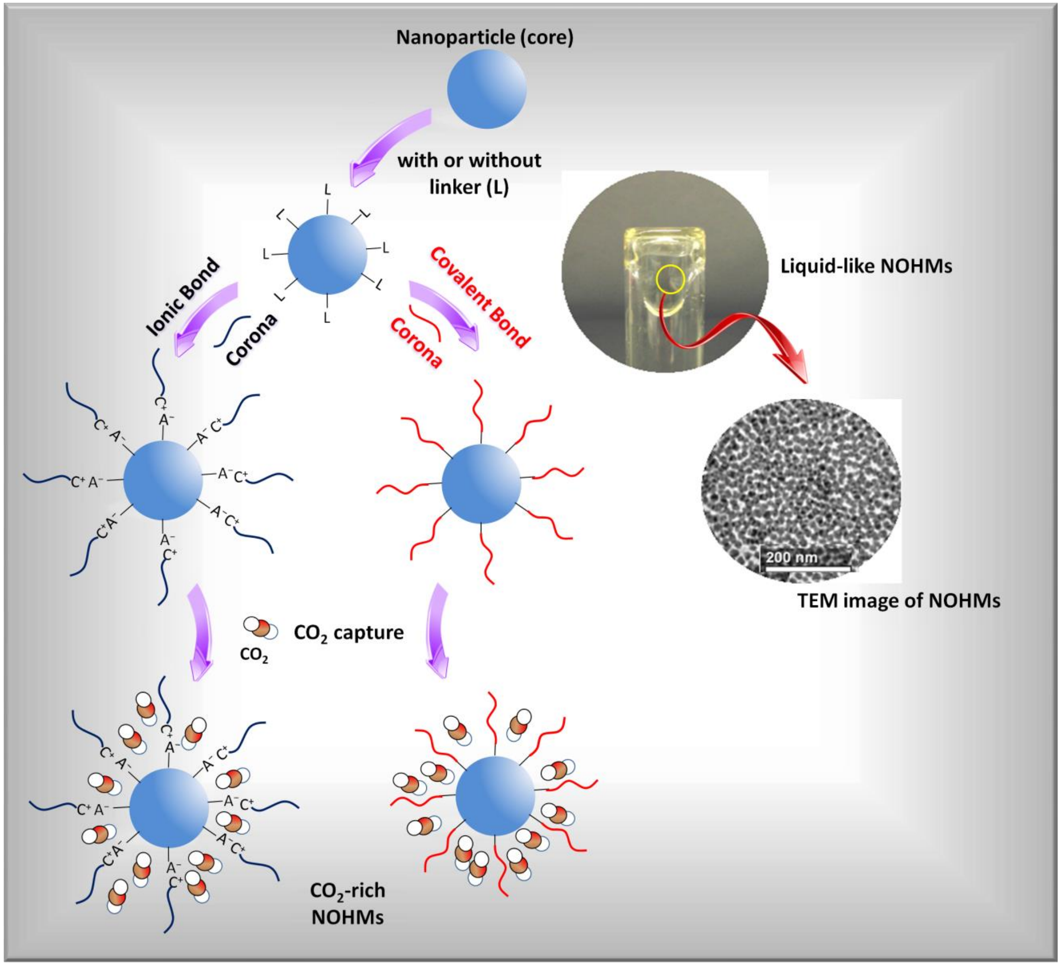


GAP-0/1
13.1 - 17.3% CO_2 uptake



- ❑ Liquid-like Nanoparticle Organic Hybrid Materials

Nanoparticle Organic Hybrid Materials (NOHMs)

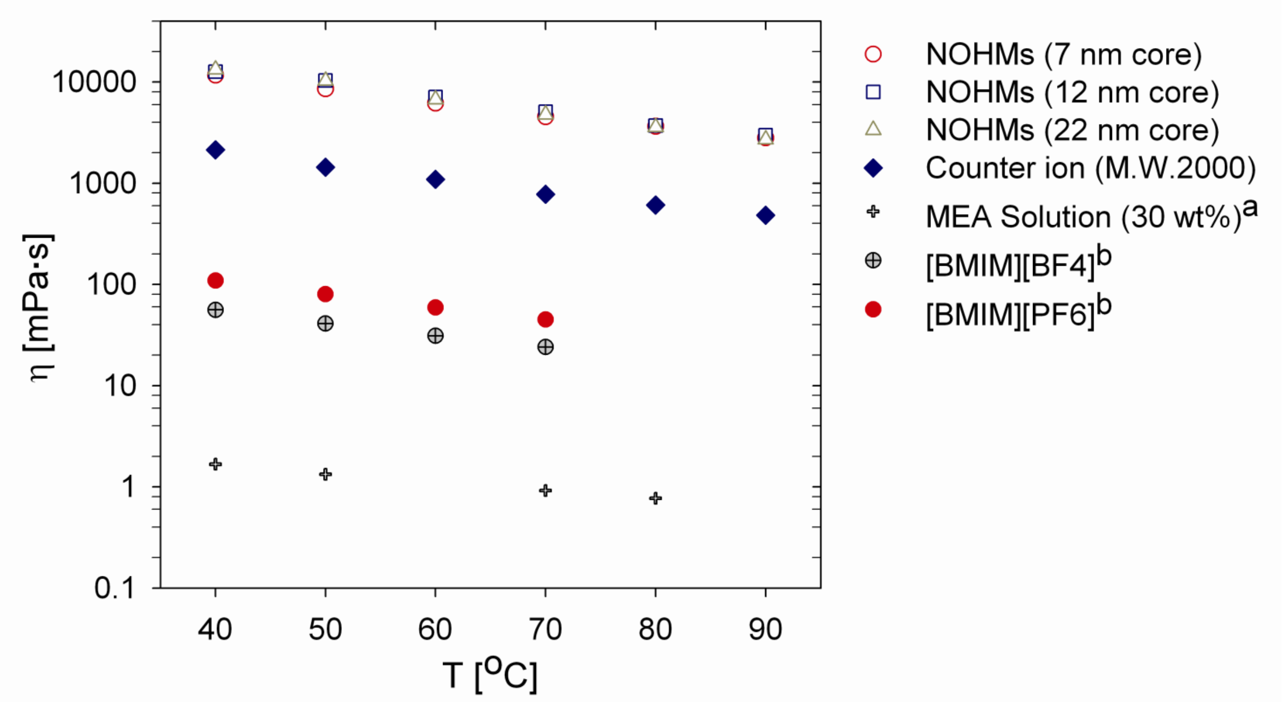


- Solvent-free liquid-like hybrid systems
  - Solvent tethered to nanoparticle cores
  - Zero-vapor pressure and improved thermal stability
- Tunable chemical and physical properties
  - Liquid, solid, gel
  - Solvation in NOHMs driven by both entropic and enthalpic interactions
- Straightforward synthesis
  - Easy to scale up

ZERO VAPOR PRESSURE+ TUNABLE PROPERTIES

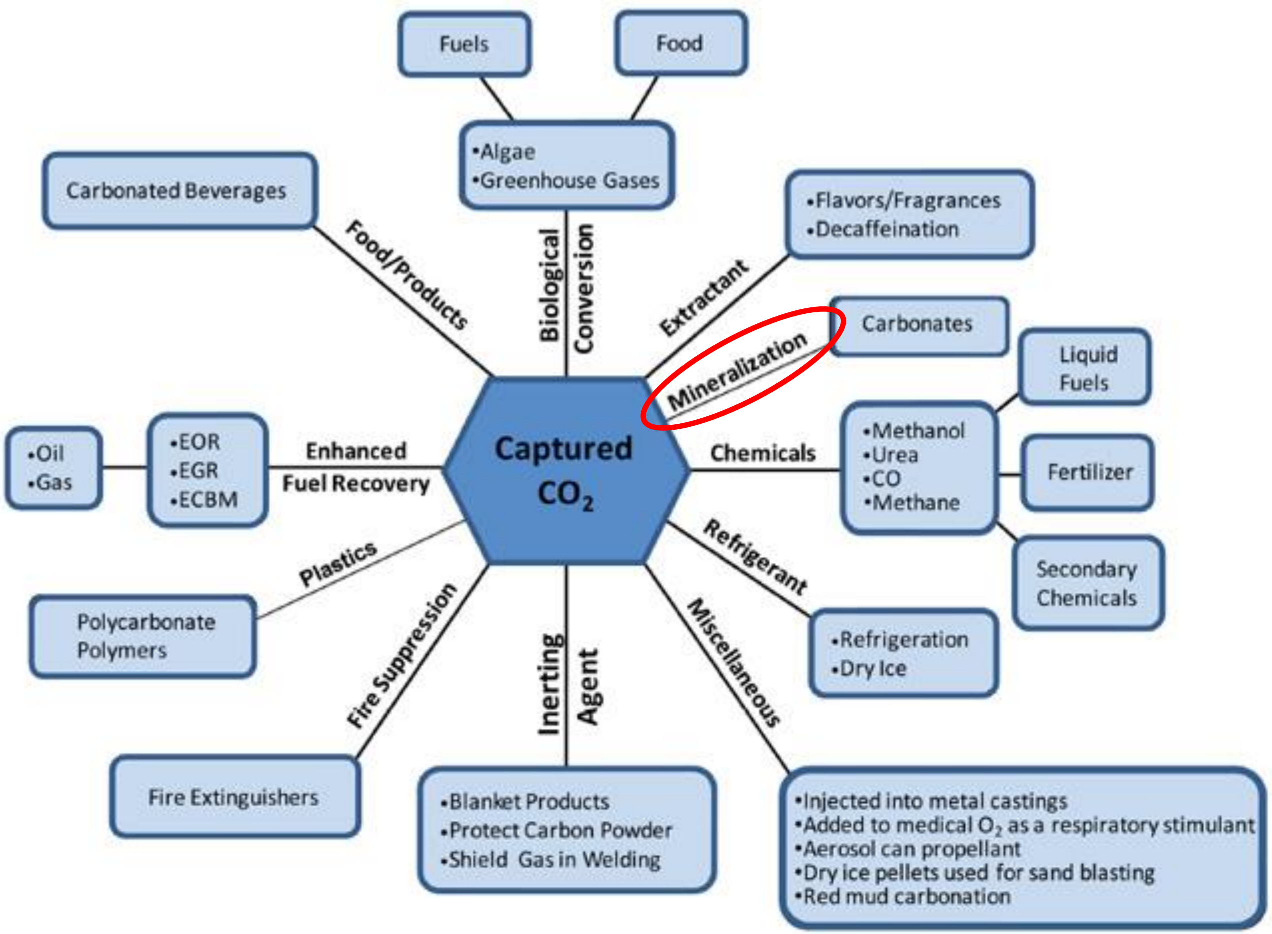
Viscosity

Effect of core size



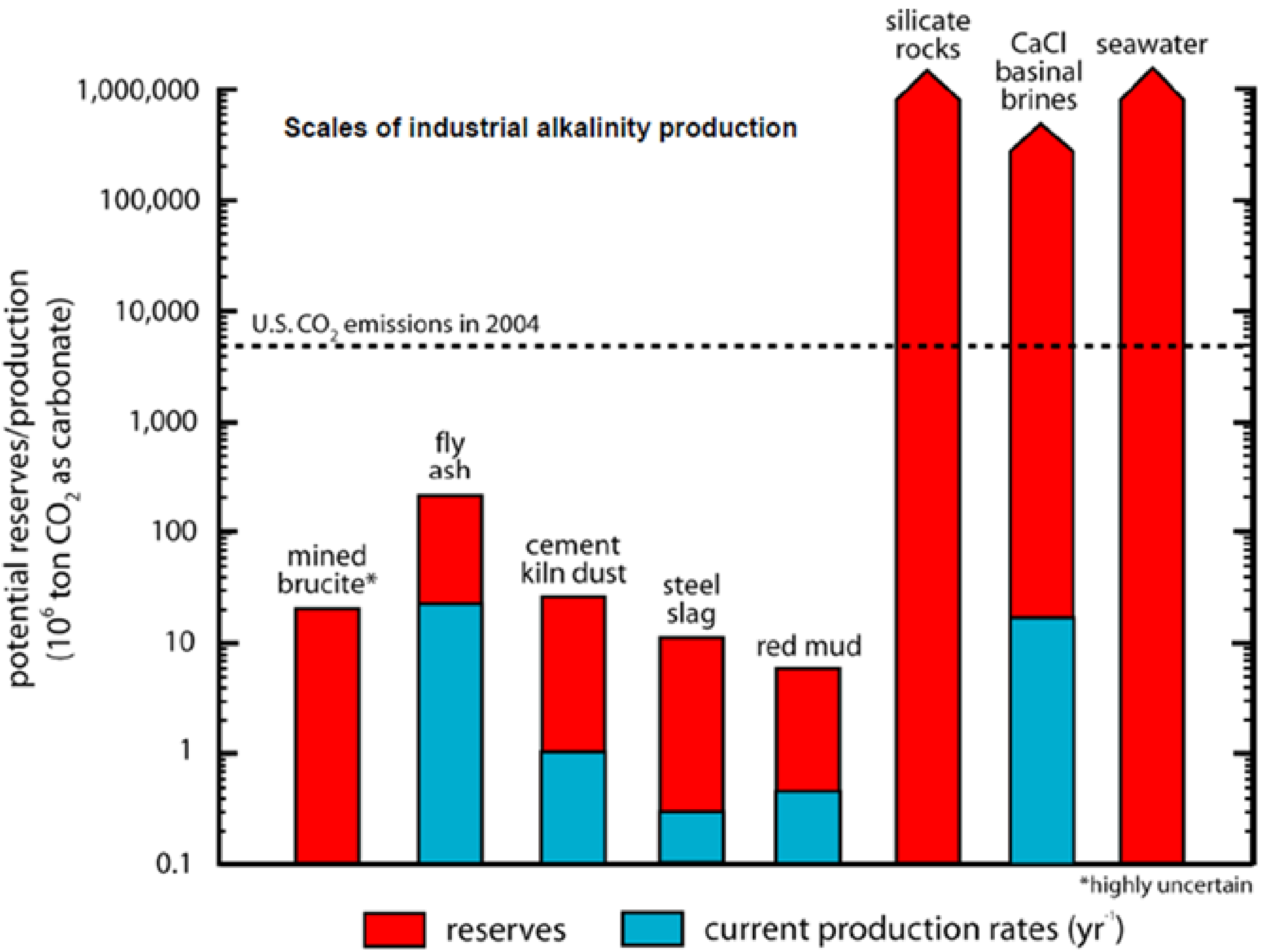
- Introduction of nanoparticles increases the viscosity of the system

CO_2 Utilization



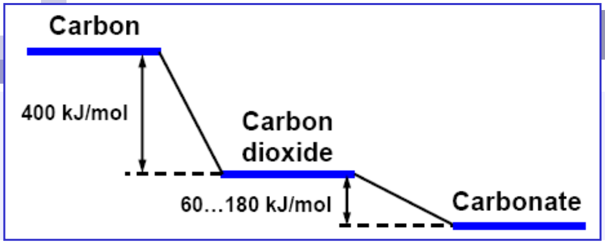
http://www.netl.doe.gov/research/coal/carbon-storage/research-and-development/co2-utilization

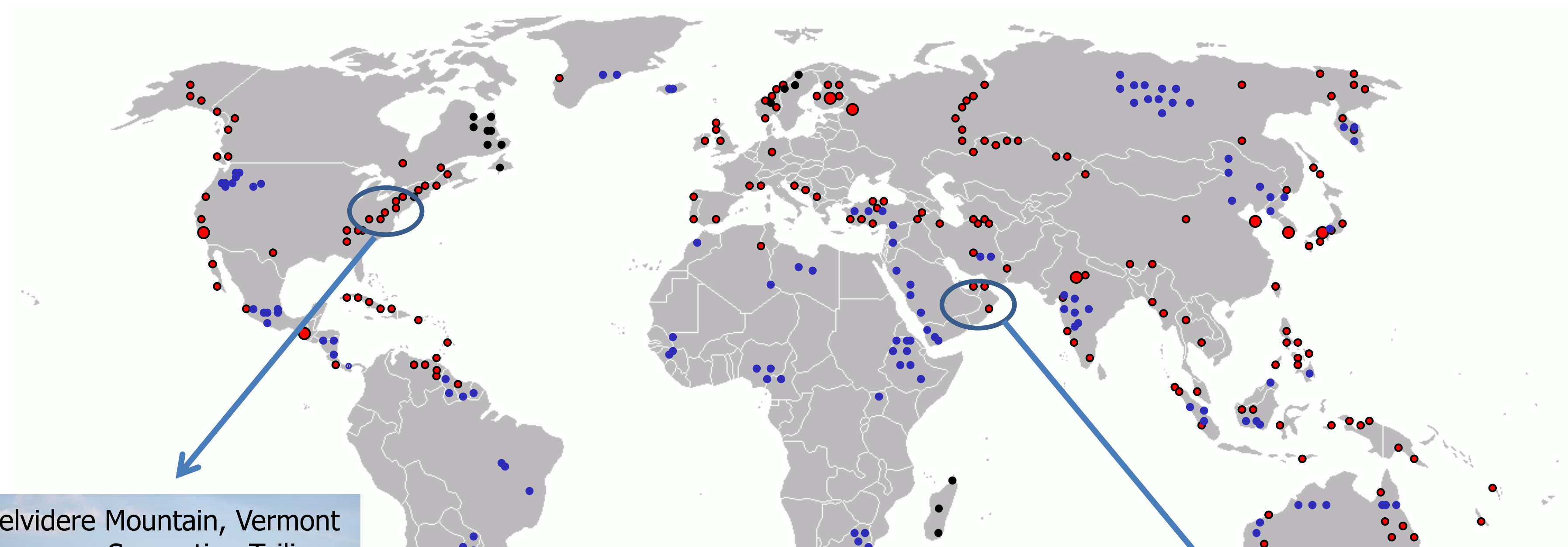
Carbonation of Industrial Wastes



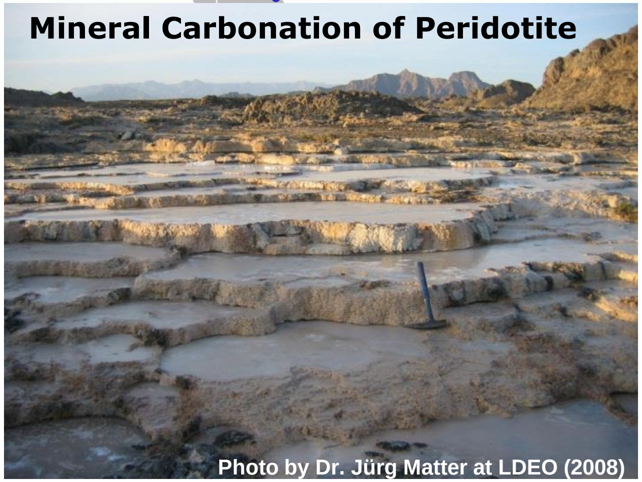
Columbia University
In the City of New York

Carbon Mineralization



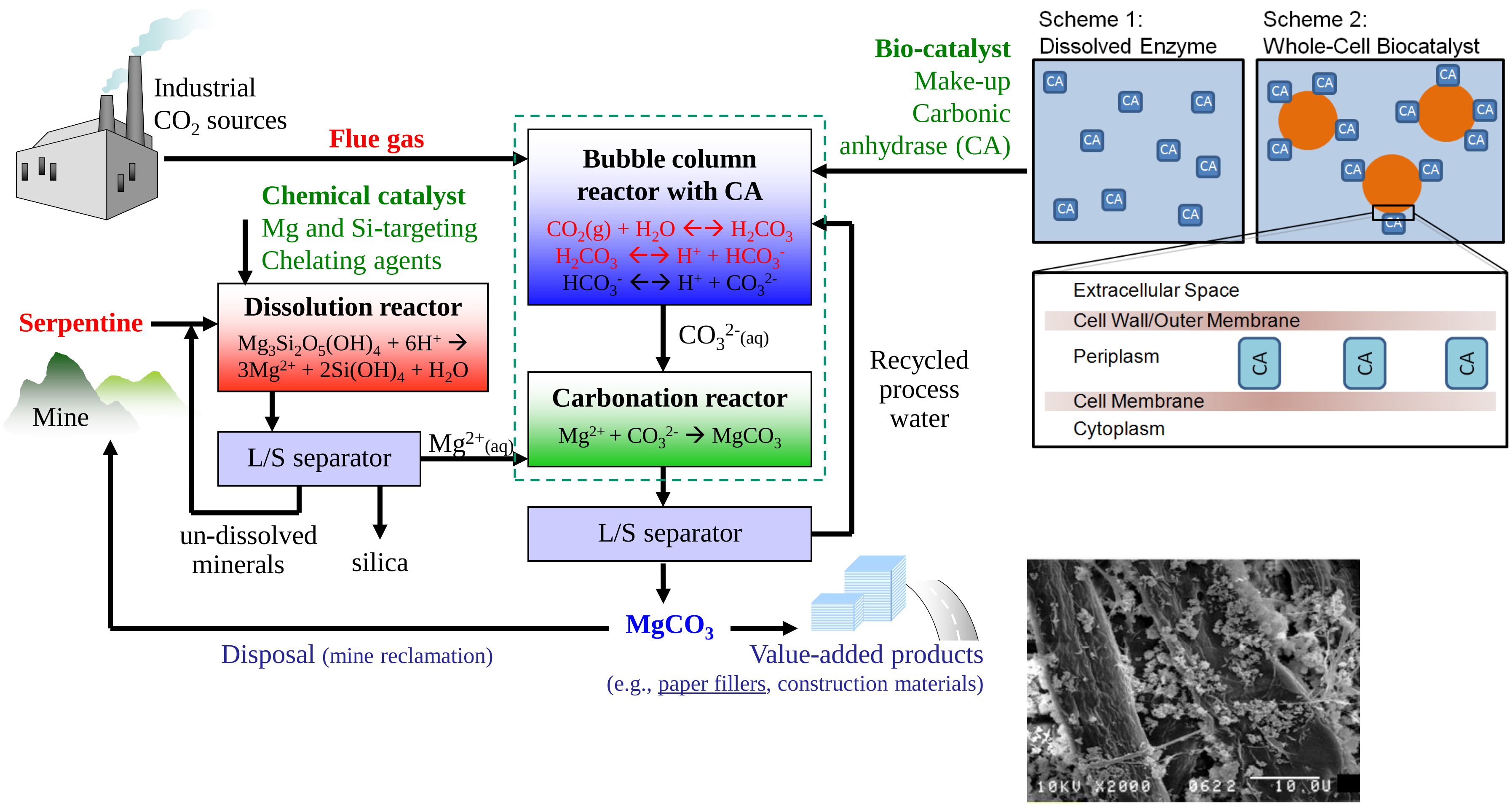



Belvidere Mountain, Vermont
Serpentine Tailings


Mineral Carbonation of Peridotite
Photo by Dr. Jürg Matter at LDEO (2008)

- Basalt
- Labradorite
- Magnesium-based Ultramafic Rocks (Serpentine, Olivine)

Chemical and Biological Catalytic Enhancement of Weathering of Silicate Minerals as Novel Carbon Capture and Storage Technology



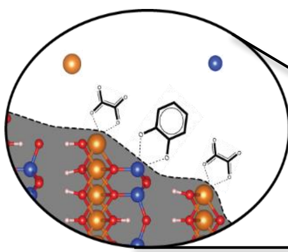
Chemical and Biological Catalytic Enhancement of Weathering of Silicate Minerals as Novel Carbon Capture and Storage Technology

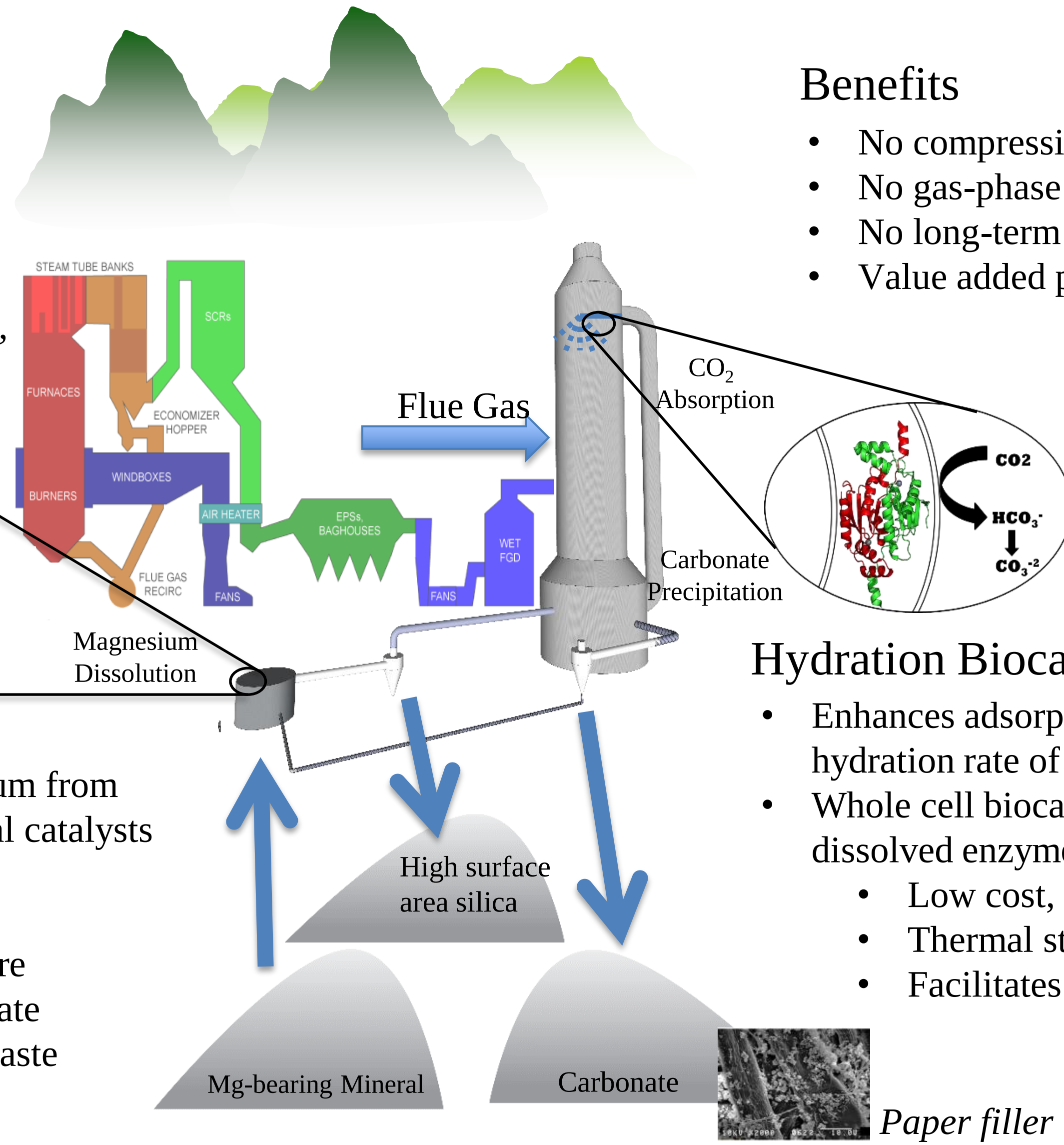
Why Combine Capture and Storage?

- Converts carbon into thermodynamically stable solid
- Onsite at fossil-fuel power plant
- Flexible feedstock (e.g. steel slag, fly ash, waste cement)

Benefits

- No compression
- No gas-phase storage
- No long-term monitoring
- Value added products possible





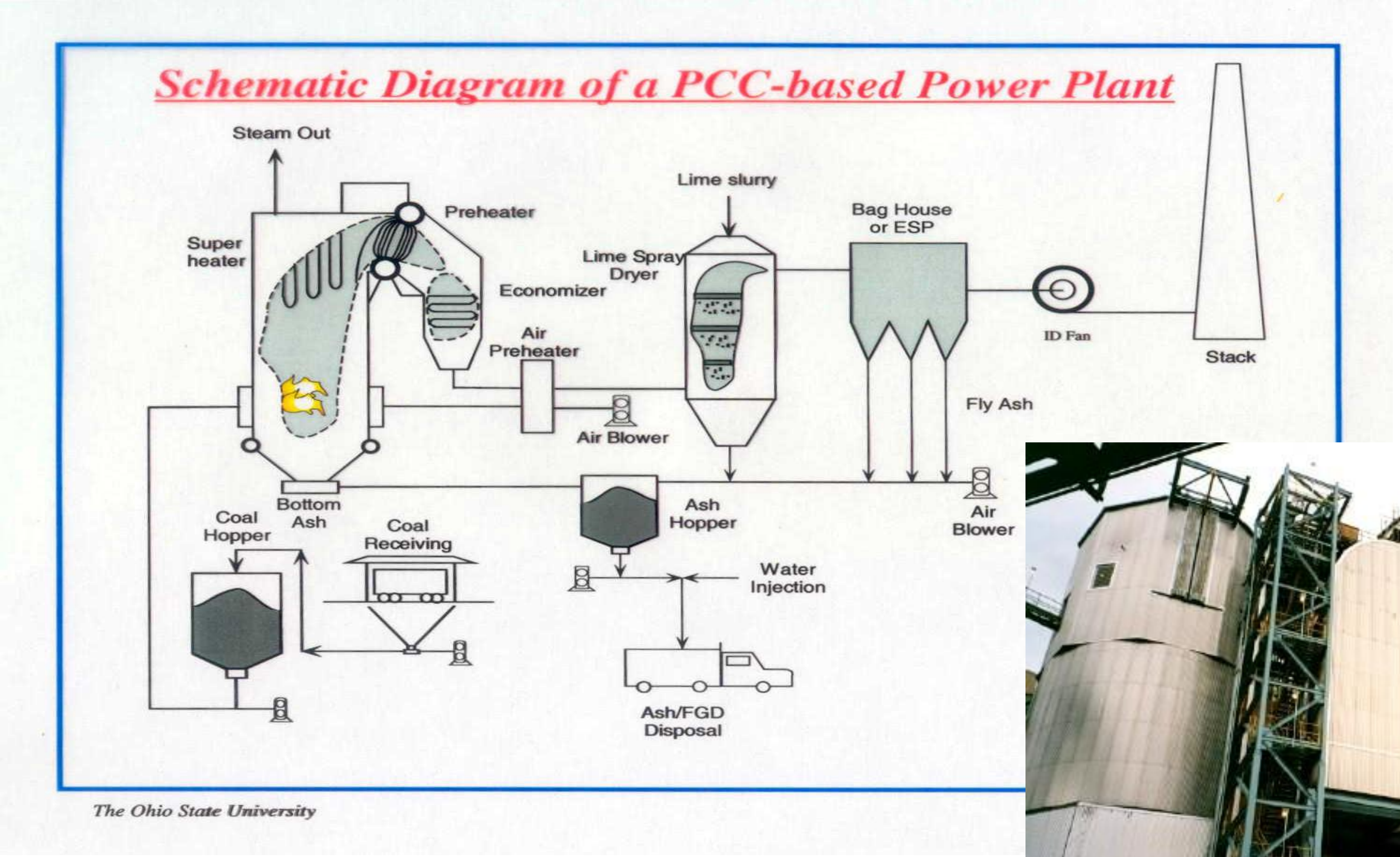
Hydration Biocatalyst

- Enhances adsorption and hydration rate of carbon dioxide
- Whole cell biocatalyst vs. dissolved enzyme
  - Low cost, no purification
  - Thermal stability
  - Facilitates separation

Mineral Dissolution

- Enhanced dissolution of magnesium from minerals and waste using chemical catalysts
- Enhanced conversion:
  - 85% in 30 minutes
  - Compared to 9% in literature
- Amendable to many alkaline silicate minerals and alkaline industrial waste

Scale of the Problem



http://www.xcelenergy.com

Combustion System – Lime Spray Dryer

Current Challenges? Opportunities?

- Lower parasitic energy consumption (heat integration)
- Reduce the compression cost
- Viscosity issues for anhydrous solvents
- Moisture effect
- Multi-pollutant control
- Water requirement?
- Combined CO_2 capture and conversion
- etc