Sustainable Energy Conversion of Solid Wastes with Integrated In-Situ Carbon Sequestration

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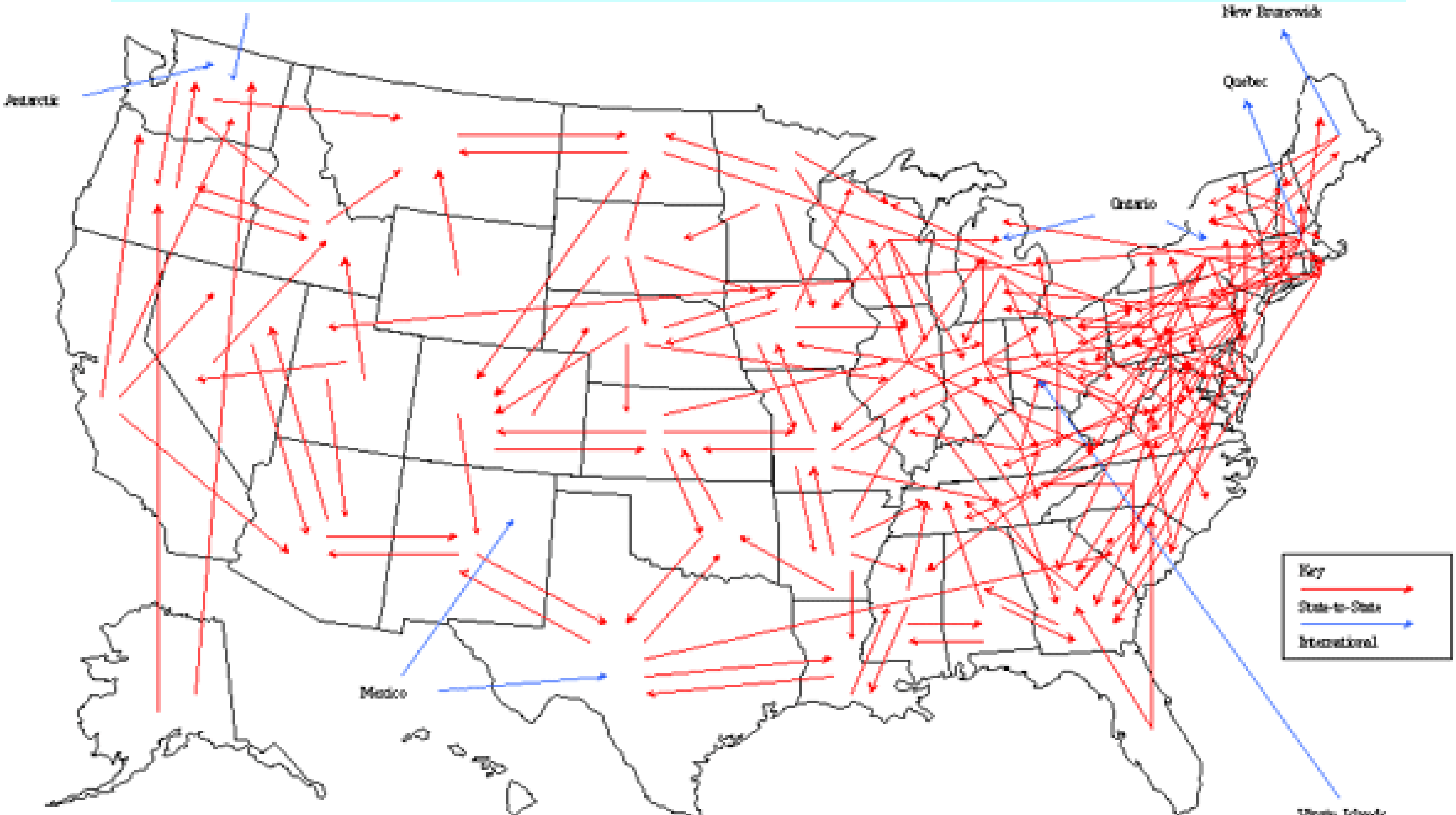
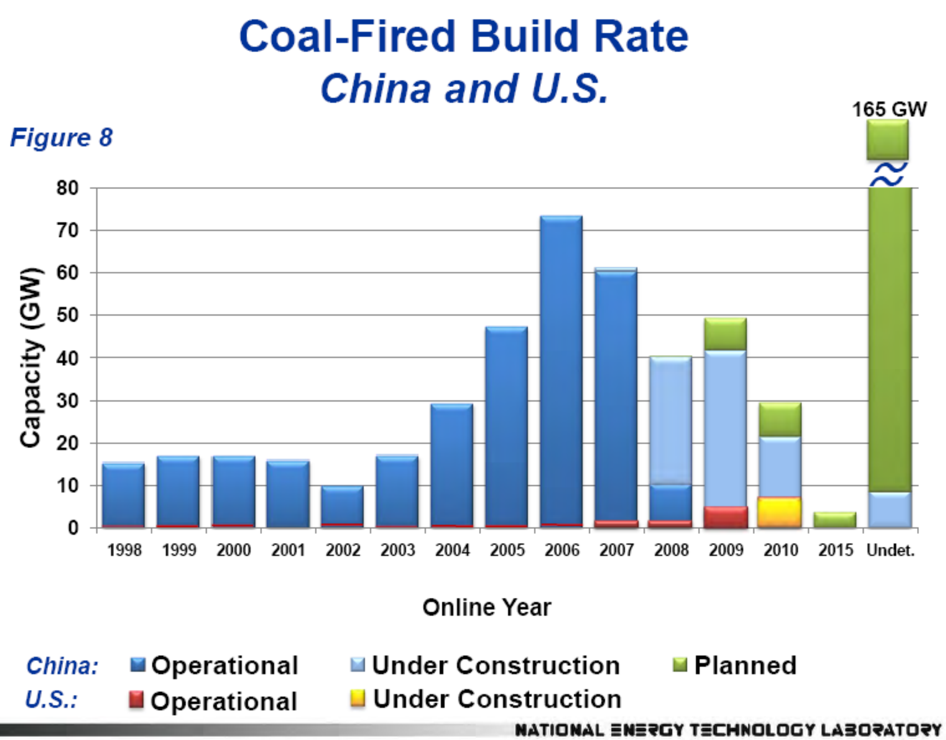
Interstate Transport of Municipal Solid Wastes (Congressional Research Service)

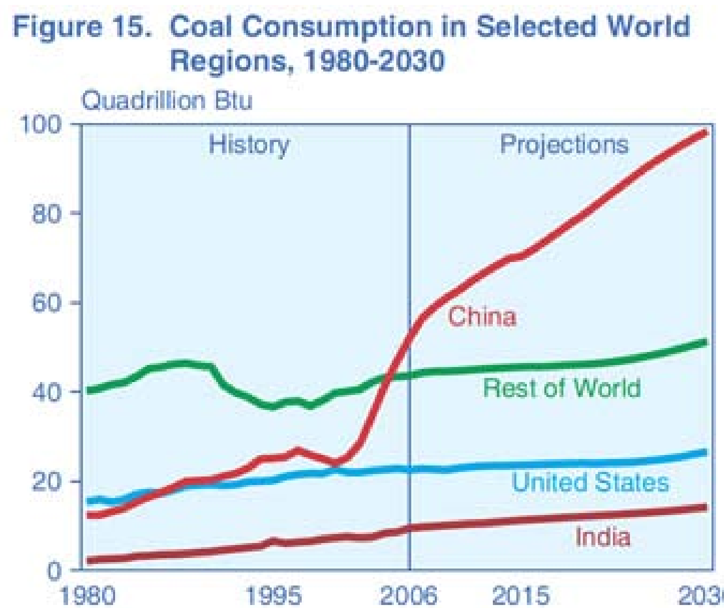


Interstate Shipment of Municipal Solid Waste in 2002 (CRS, 2002)
Note: Map does not include transactions with the District of Columbia.

Coal-fired Power Plants



Source: Platts - UDI Database - December 2008
Ventyx - Velocity Suite 1/8/2010



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2006* (June-December 2008), web site www.eia.doe.gov/iea. **Projections:** EIA, World Energy Projections Plus (2009).

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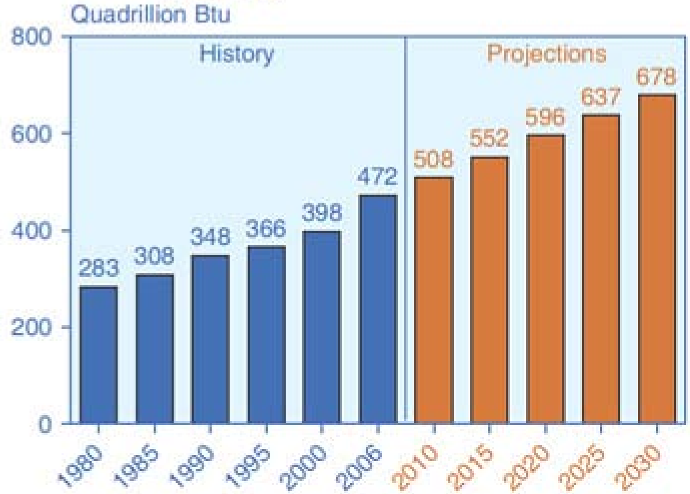
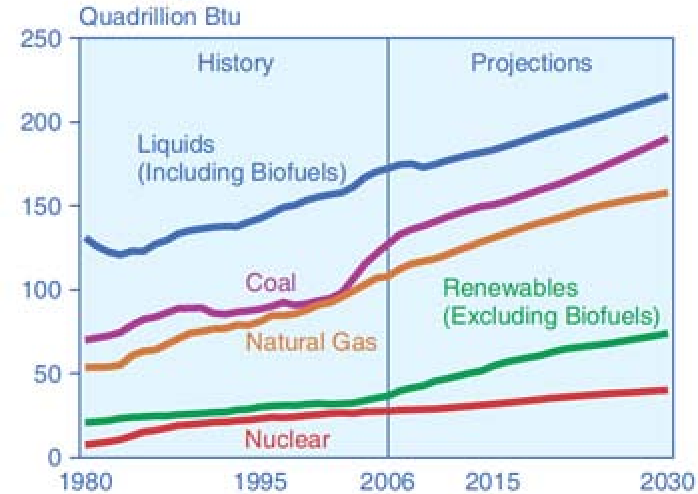
Projected Global Energy Demand & Supply

Figure 10. World Marketed Energy Consumption, 1980-2030



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2006* (June-December 2008), web site www.eia.doe.gov/iea. **Projections:** EIA, World Energy Projections Plus (2009).

Figure 14. World Marketed Energy Use by Fuel Type, 1980-2030



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2006* (June-December 2008), web site www.eia.doe.gov/iea. **Projections:** EIA, World Energy Projections Plus (2009).

The world energy demand is projected to increase by over 40% in the next two decades

Fossil Fuels will remain the dominant source

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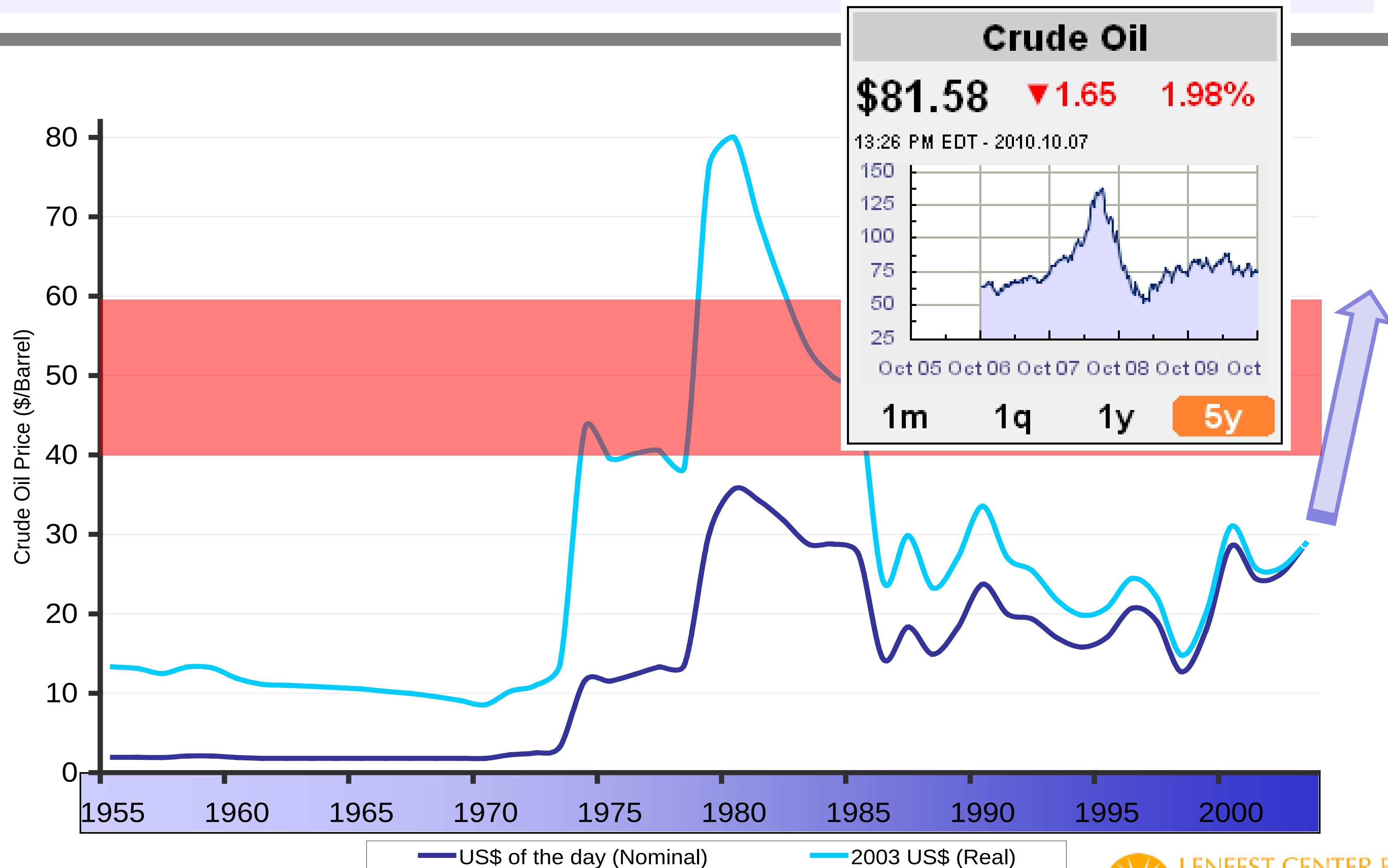
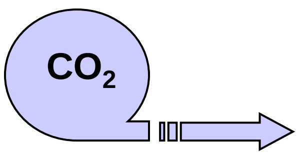
Petroleum-based vs. Synthetic Liquid Fuels



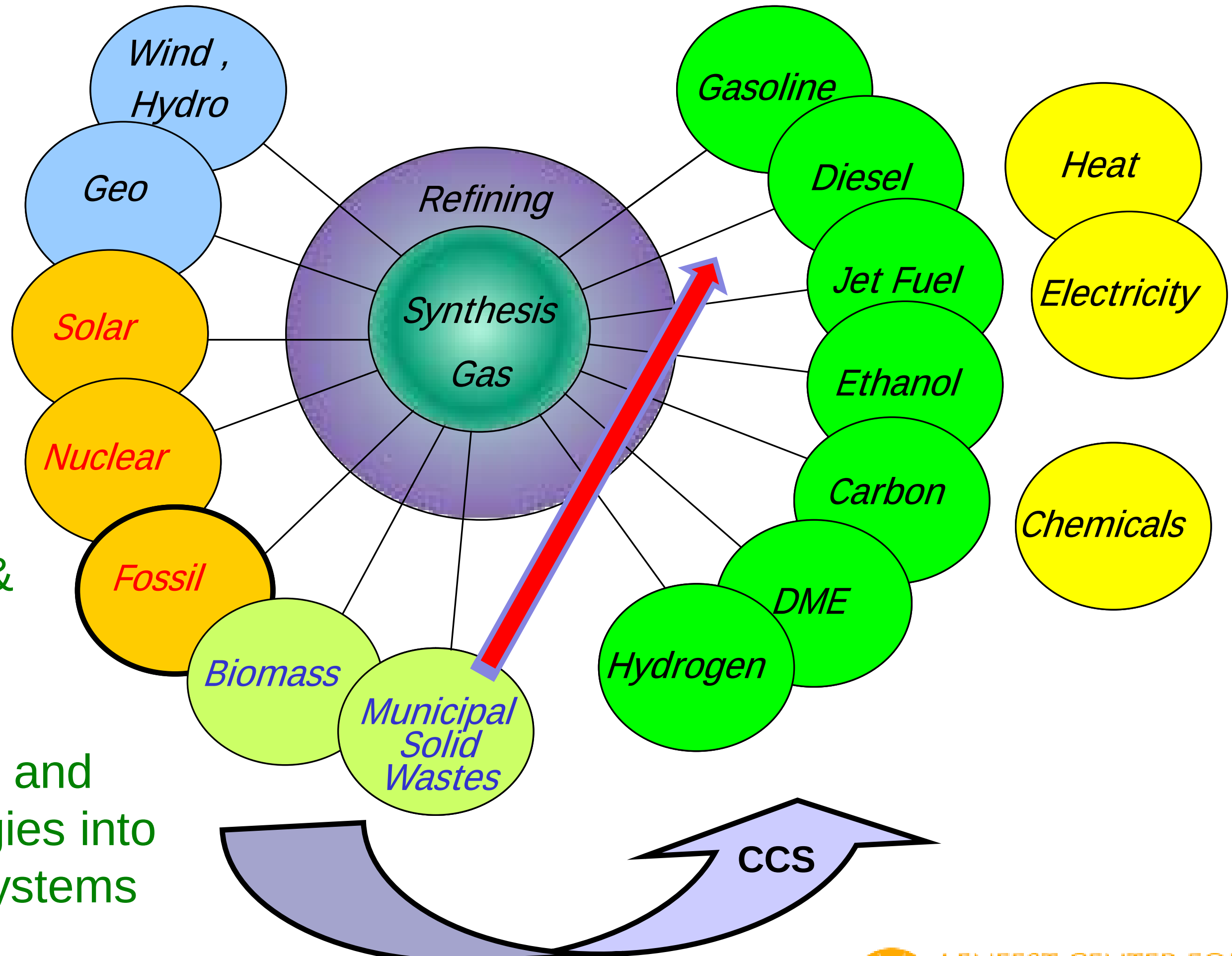
Steynberg, (2006)

Our Research Goals

Use domestic energy sources to achieve energy independence with environmental sustainability



Use carbon neutral energy sources such as biomass & MSW



Integrate carbon capture and storage (CCS) technologies into the energy conversion systems

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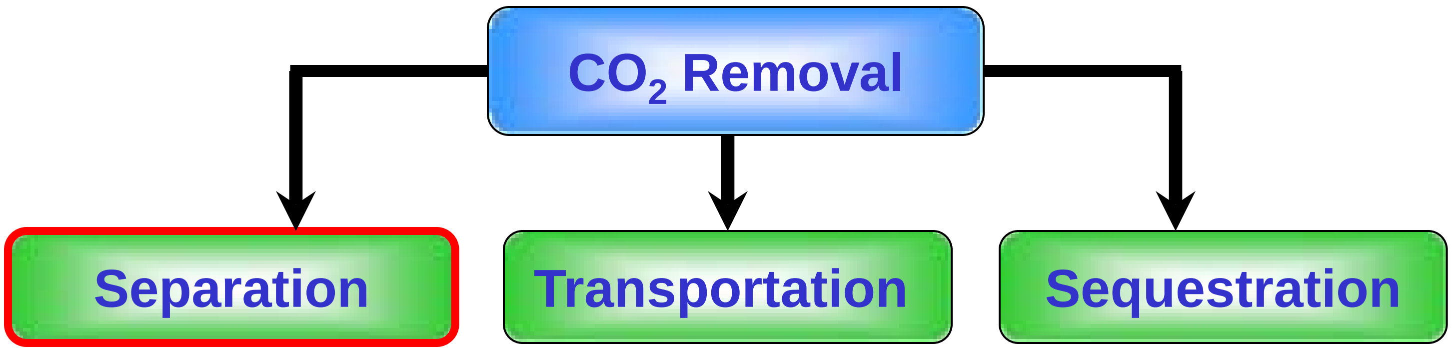
Carbon Dioxide Sequestration Options

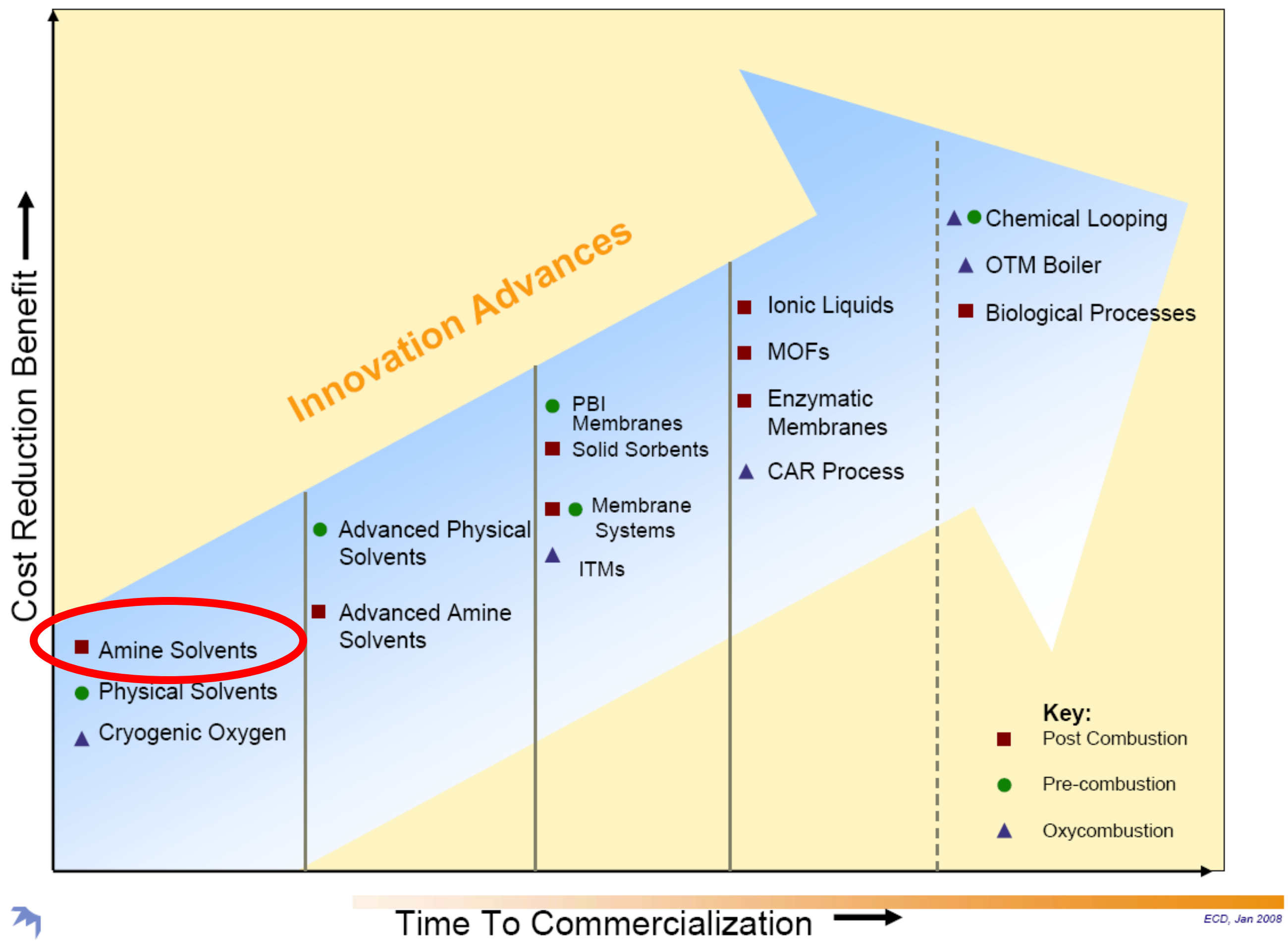


- Necessary Characteristics
  - Capacity and price
  - Environmentally benign fate
  - Stability

Carbon Capture

- **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
- **From diffuse sources**

Carbon Capture Schemes



Source: NETL, 2008

- From concentrated sources vs. diffuse sources
- Integrated Carbon Capture Technologies

Carbon Capture

- Most widely employed CO_2 capture method is using

  amine-based absorption

  (Amine Scrubbing)

Typical Amine Scrubbing Process

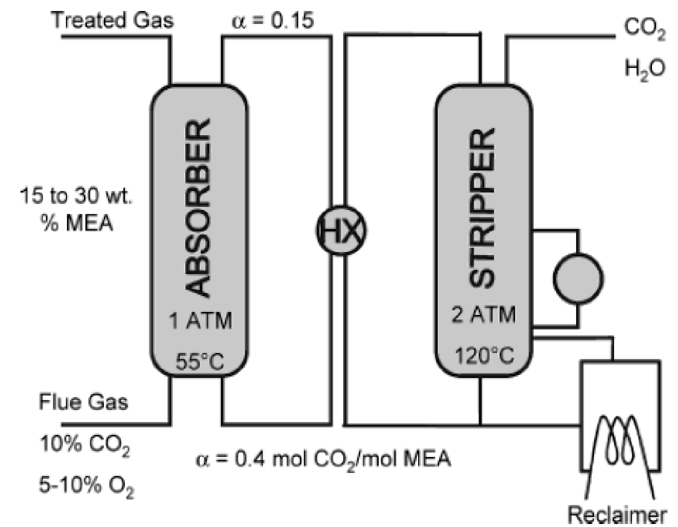
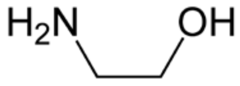


Figure 1. Process flow diagram for a typical MEA CO_2 capture process.

(Goff et al., *Ind. Eng. Chem. Res.* 2004)



- **Concerns with Amine Scrubbing Technology**

  1.High parasitic energy penalty

  2.High cost - capital and operating

  3.Corrosion & degradation (due to SO_2, O_2, particulate, etc)

  4.High vapor pressure leads to fugitive emissions

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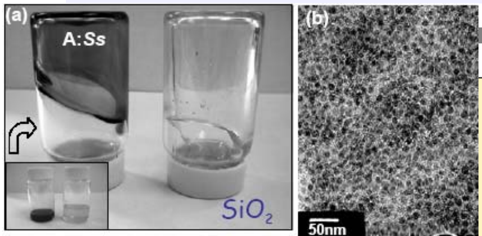
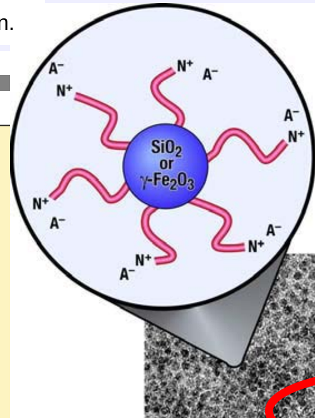
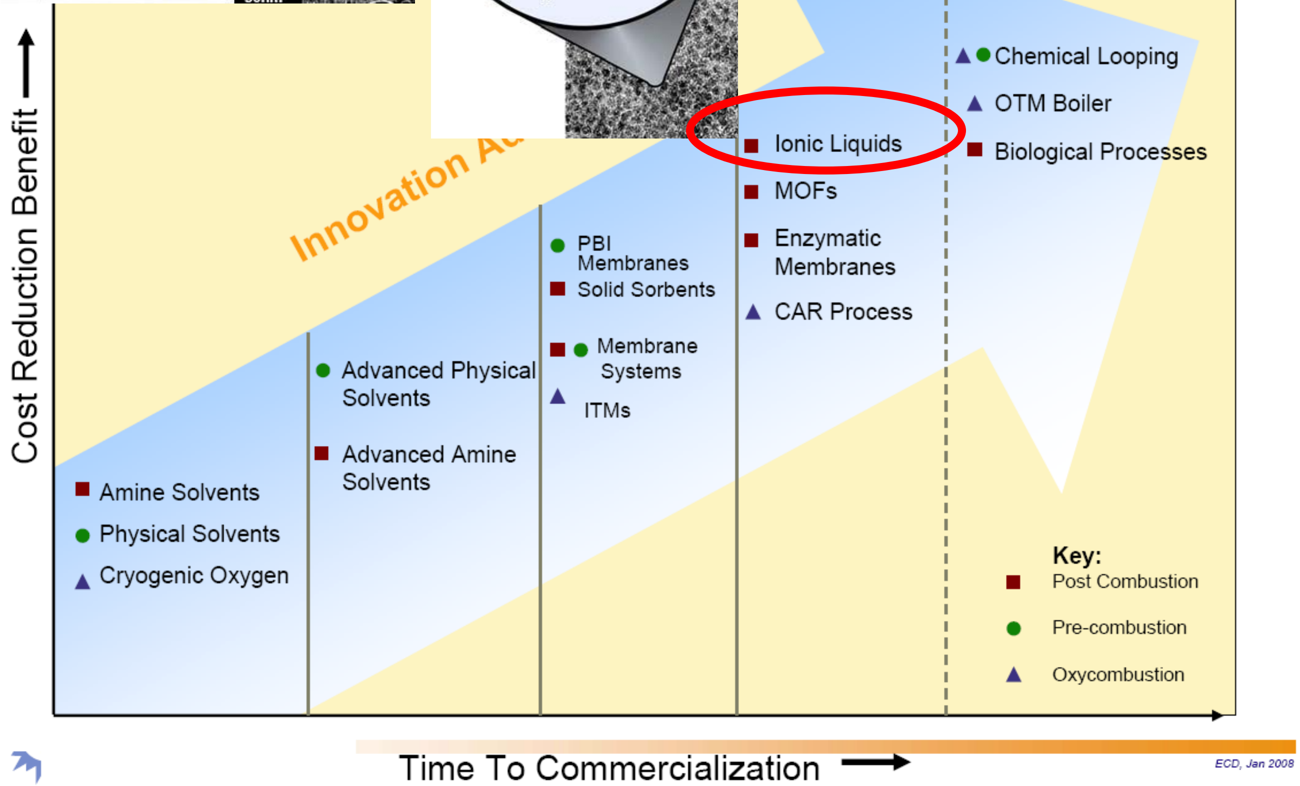
Liquid NIMS comprised of 14 nm SiO2 particle core, a tertiary amine, (CH3O)3Si(CH2)3N+(CH3)(C10H21)2, corona and an organic sulfonate (C13H27(OCH2CH2)7O(CH2)3SO3-) [Ss] counterion.

arbon Capture Schemes



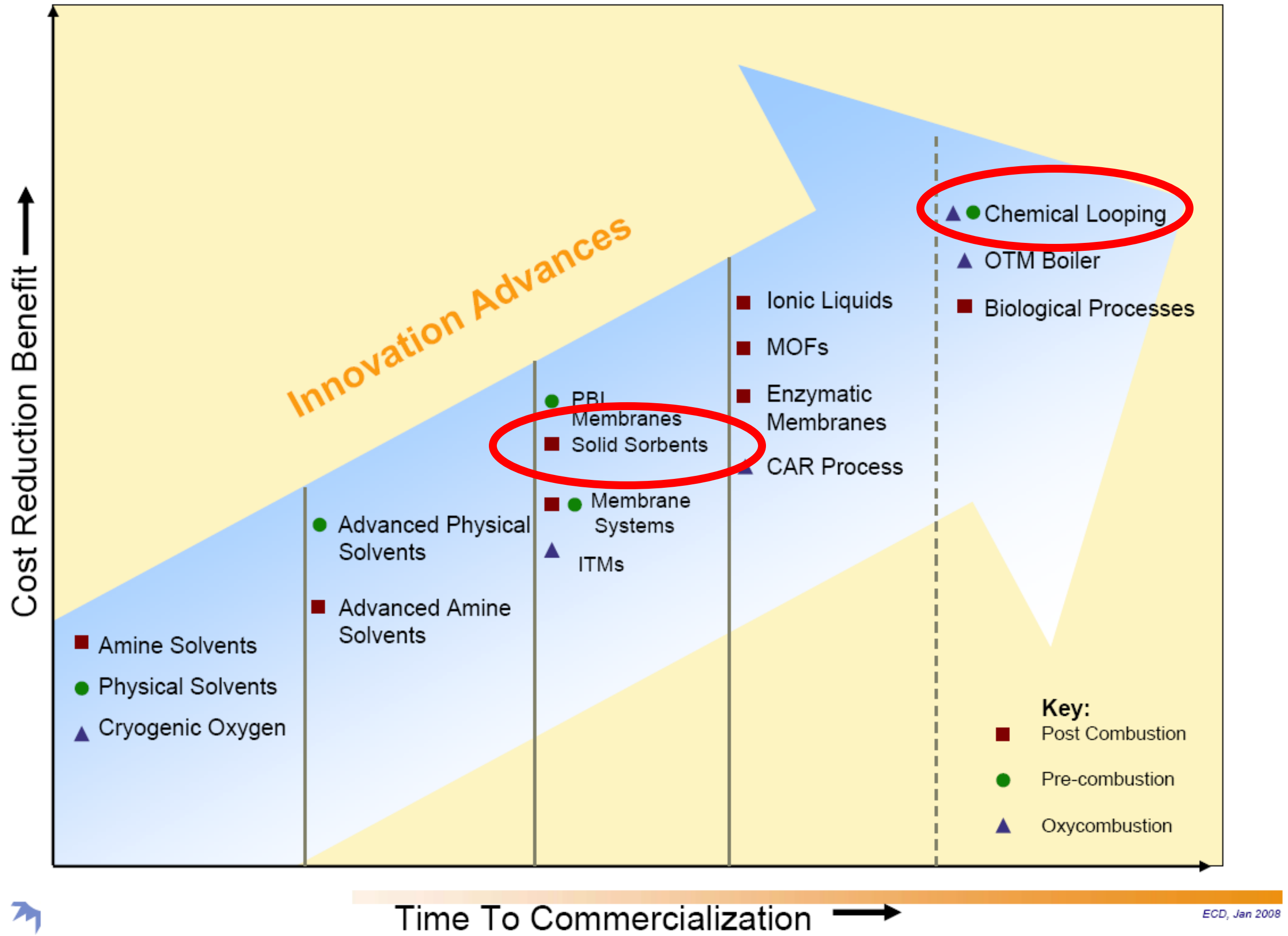




- **From concentrated sources vs. diffuse sources**
- **Integrated Carbon Capture Technologies**

Source: NETL, 2008

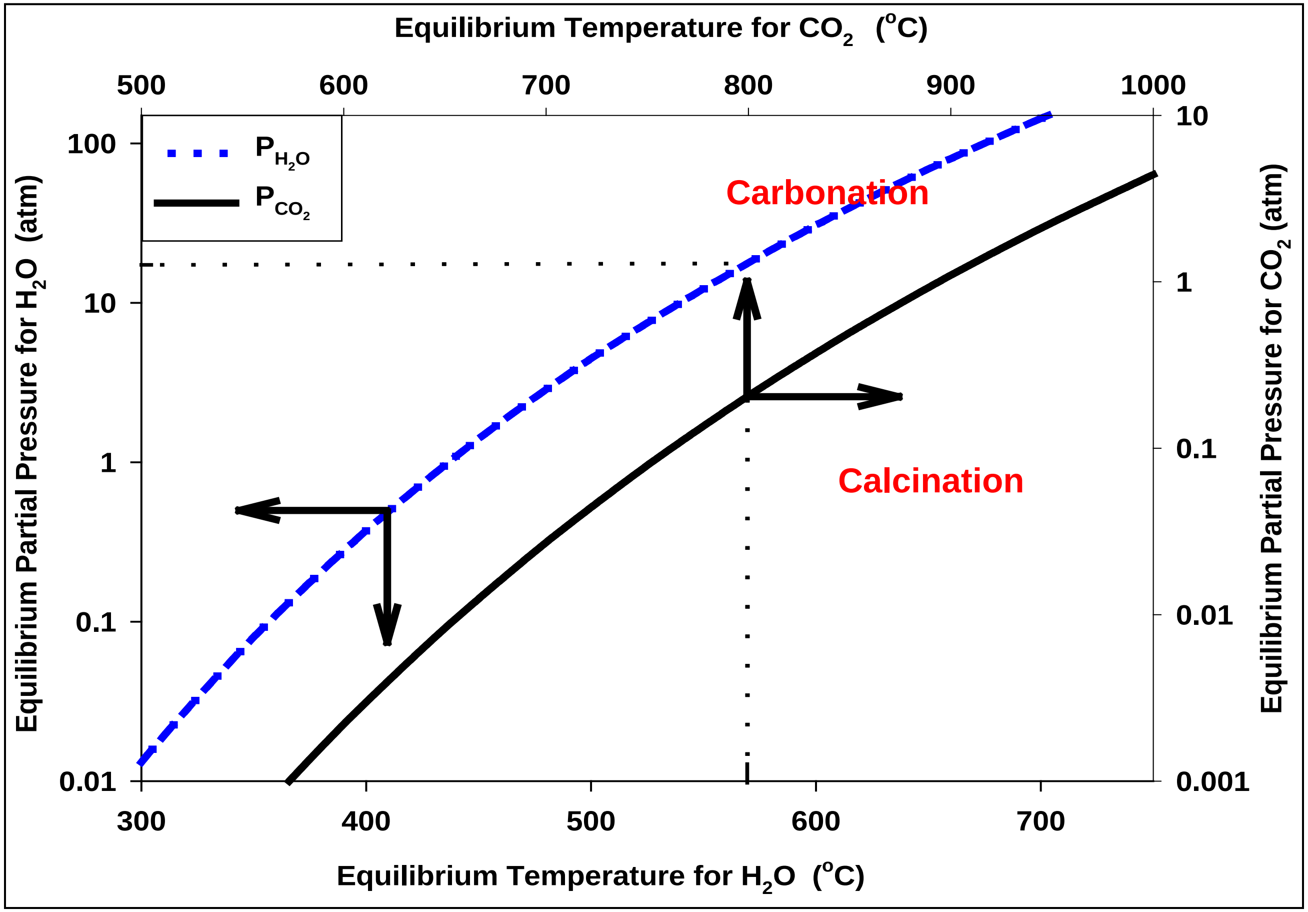
Carbon Capture Schemes



- From concentrated sources vs. diffuse sources
- Integrated Carbon Capture Technologies

Source: NETL, 2008

High Temperature Sorbent Injection Carbonation and Calcination Cycle



Regenerable PCC

$Ca(OH)_2 \rightarrow CaO + H_2O$

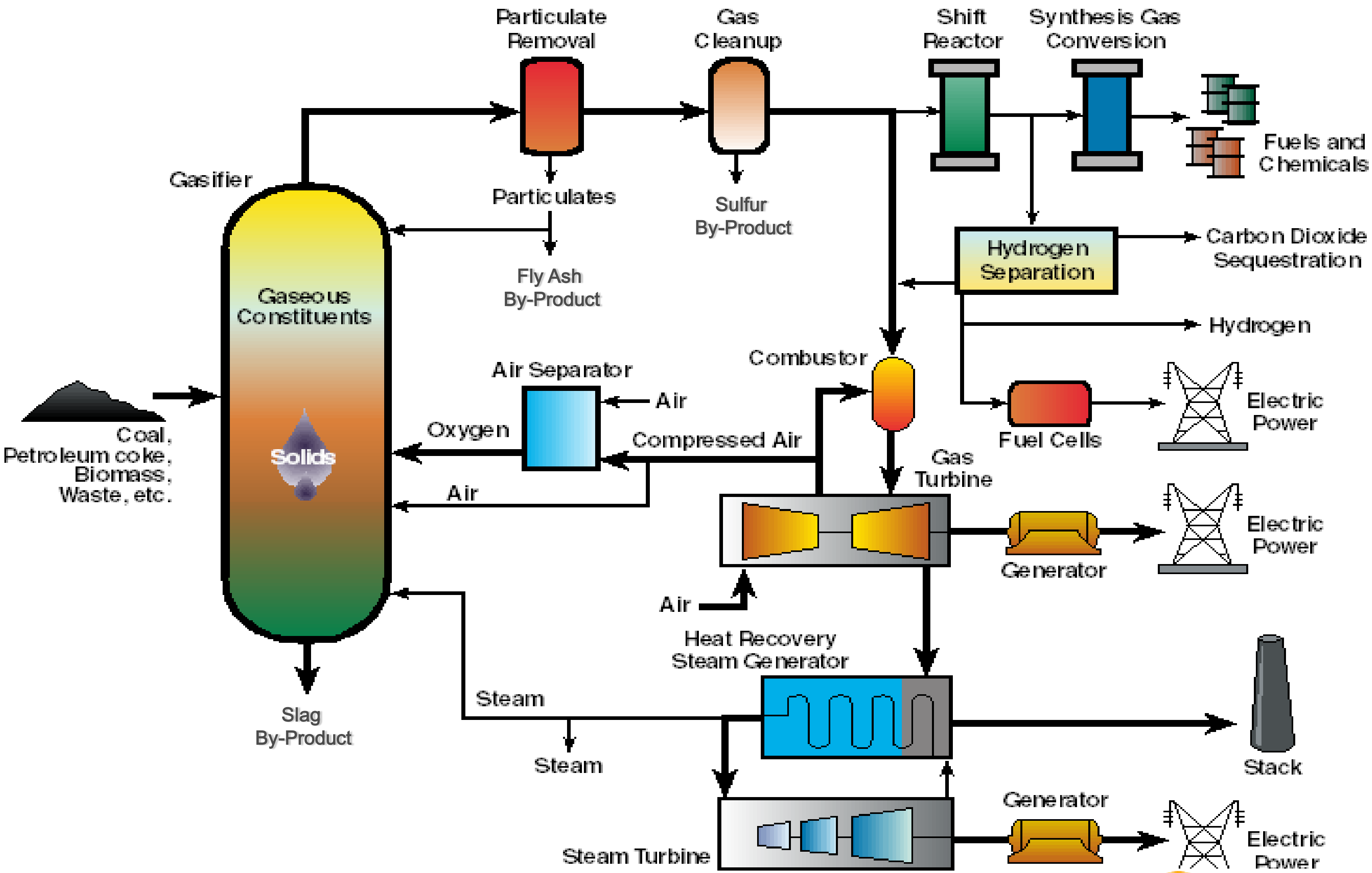
Carbonation

$CaO + CO_2 \rightarrow CaCO_3$

Calcination

$CaCO_3 \rightarrow CaO + CO_2$

Gasification-Based Energy Production System Concepts



Steigel and Ramezan, 2006

Alternative Energy Sources

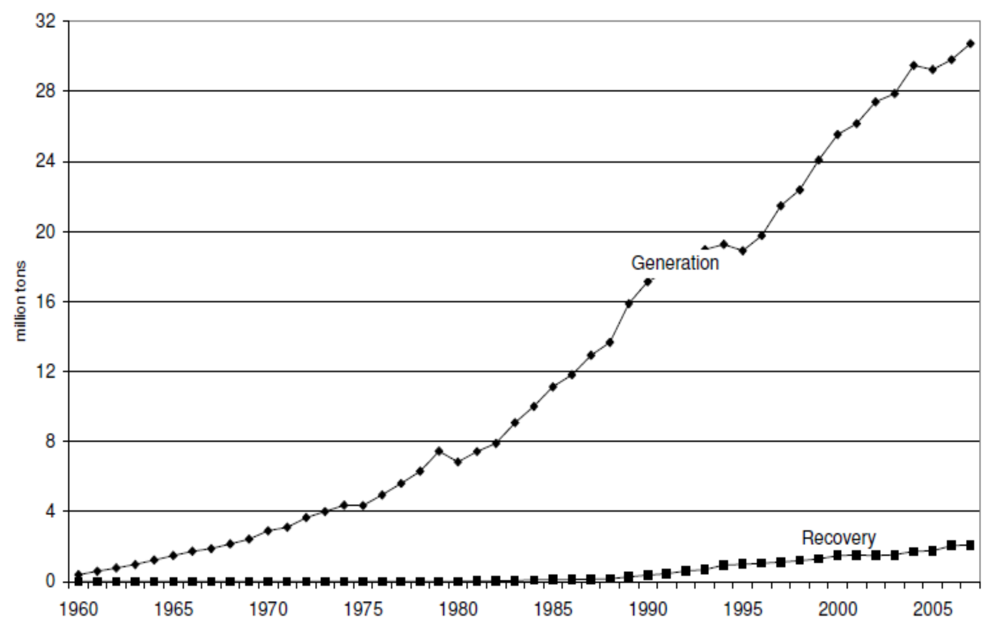
Synthetic Fuel Options

Fermentation of sugars/cellulose
→Ethanol
Esterification of oils/fats
→ Biodiesel
Gasification of any organic material
→ Hydrocarbon fuel

MSW Facts

Plastic Waste in the US
12% of landfilled waste
< 1% in1960
Recovery
6.8% overall recycled
36.6% PET
28% HDPE

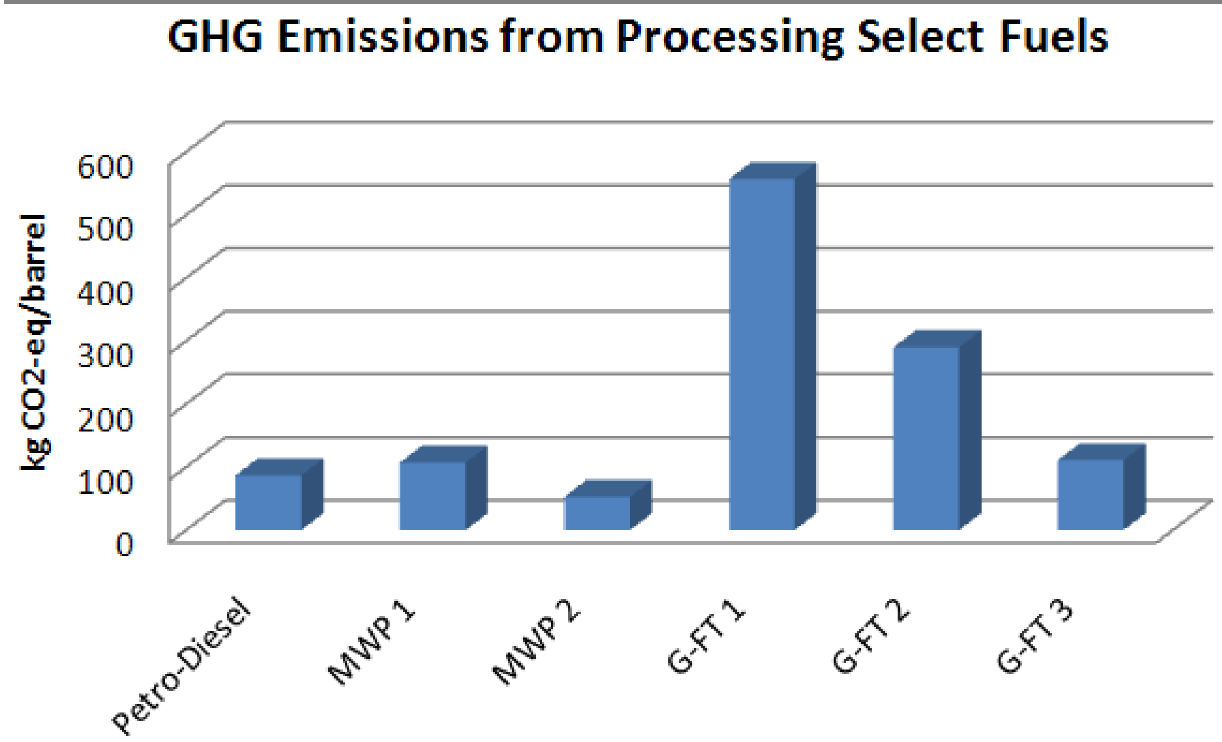
Plastics generation and recovery, 1960 to 2007



(EPA 2007)

- Need for liquid hydrocarbon fuels
- Embodied energy in waste
- Oil is a non-renewable resource
- Politically instability

GHG Emissions



GHG Emissions in thousand t CO2-eq/y

	Lower bound	Upper Bound
MWP 1	4.4	274
MWP 2	2.2	135
G-FT 1	5.6	350
G-FT 2	2.9	180
G-FT 3	1.1	69

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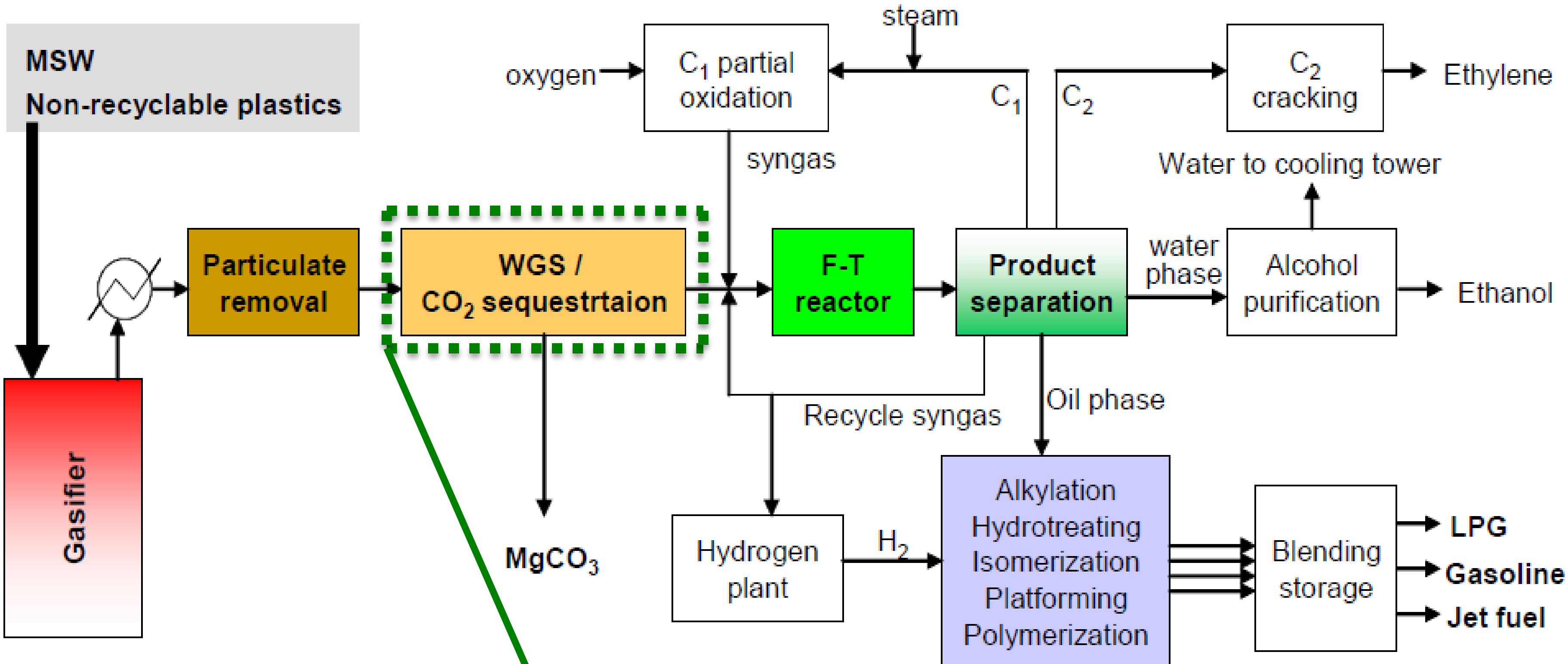
Big Picture

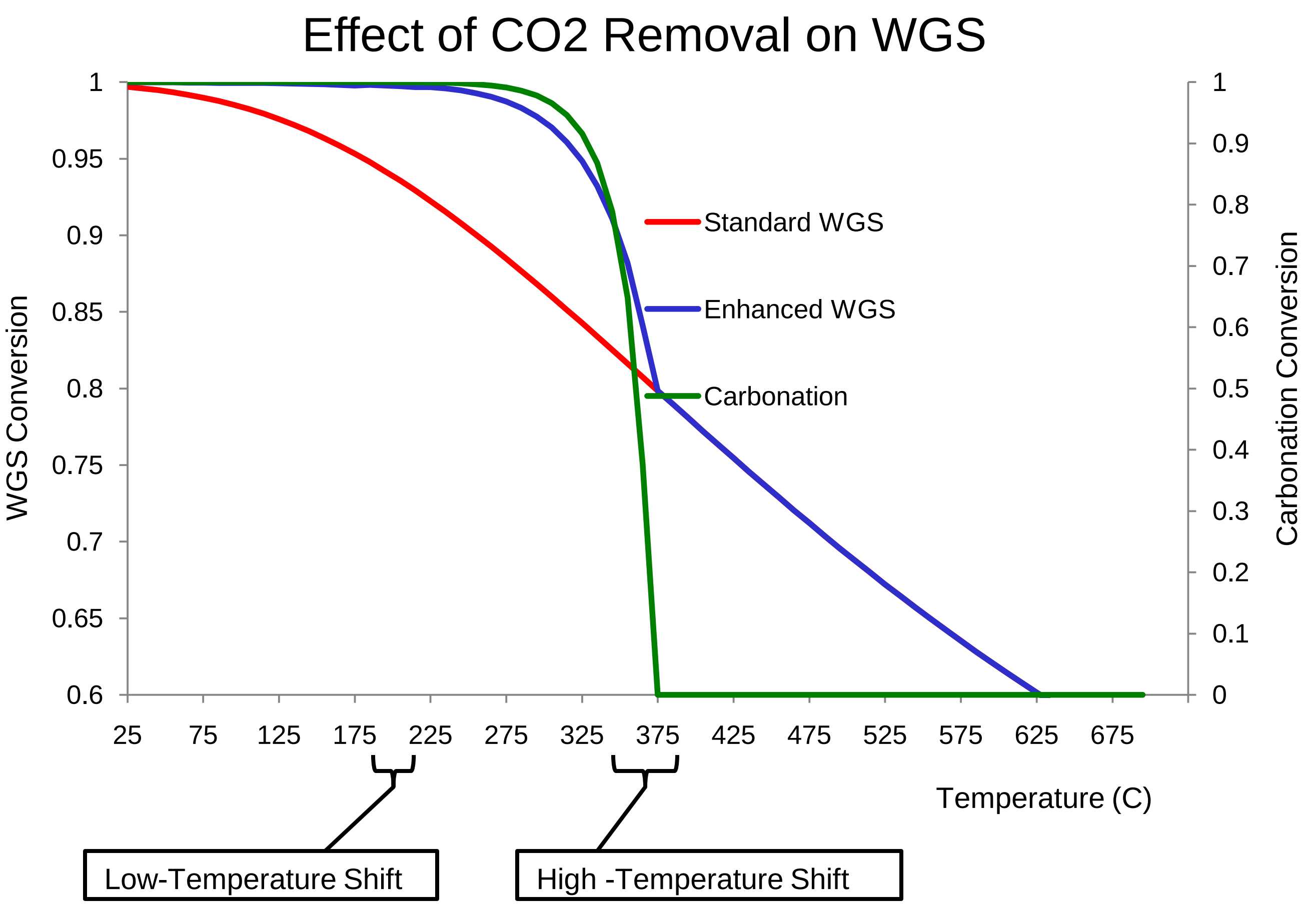


$$H_2O_{(g)} + CO_{(g)} \longleftrightarrow CO_{2(g)} + H_{2(g)}$$

$$M(OH)_{2(s)} \rightarrow MO_{(s)} + H_2O_{(g)}$$

$$MO_{(s)} + CO_{2(g)} \rightarrow MCO_{3(s)}$$

Process Integration



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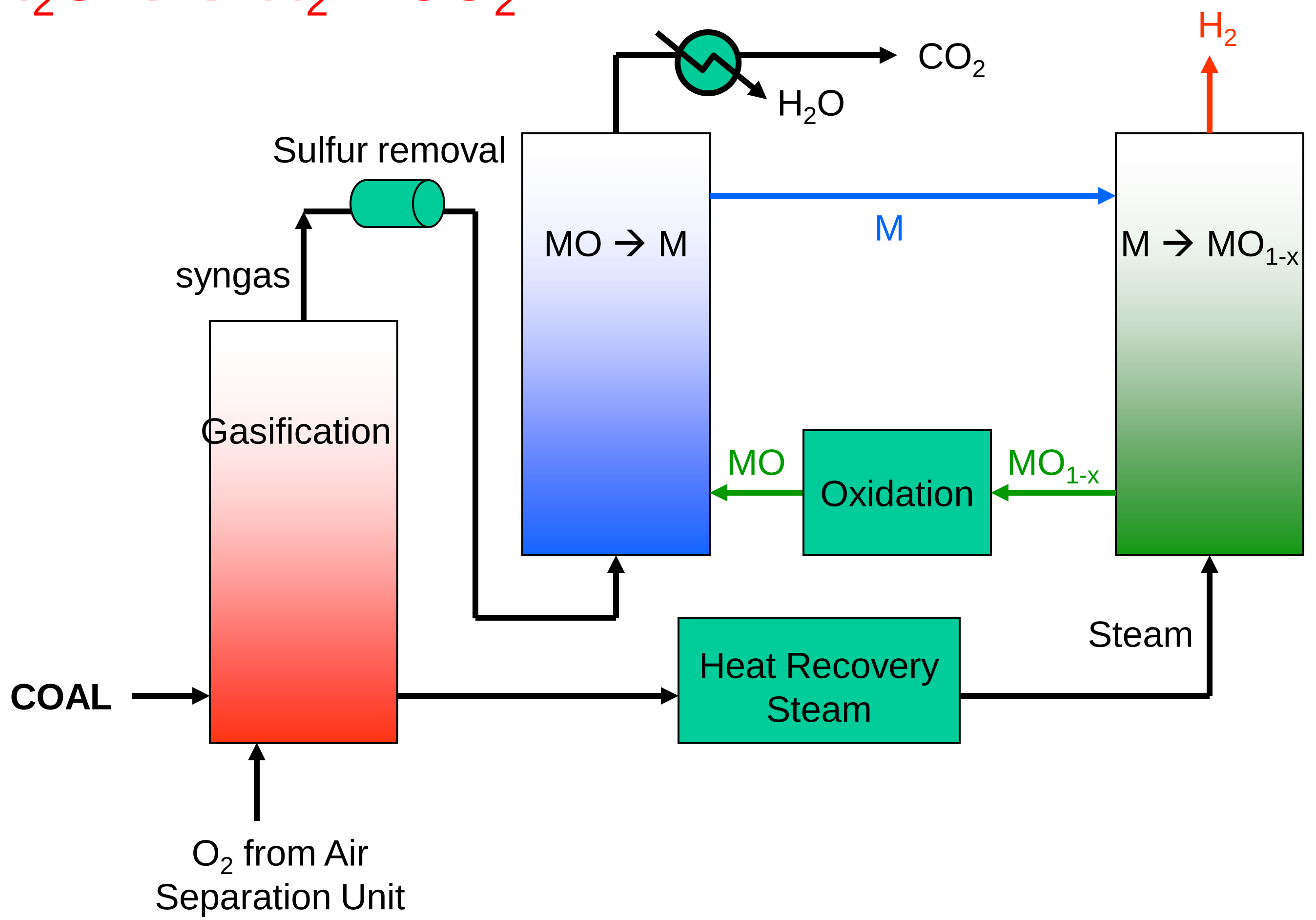
$CO + H_2O \leftrightarrow H_2 + CO_2$



Schematic of Chemical Looping process for hydrogen production: U.S. Provisional Patent Series No. 11/010,648 (2004) – (Fan's group at OSU)

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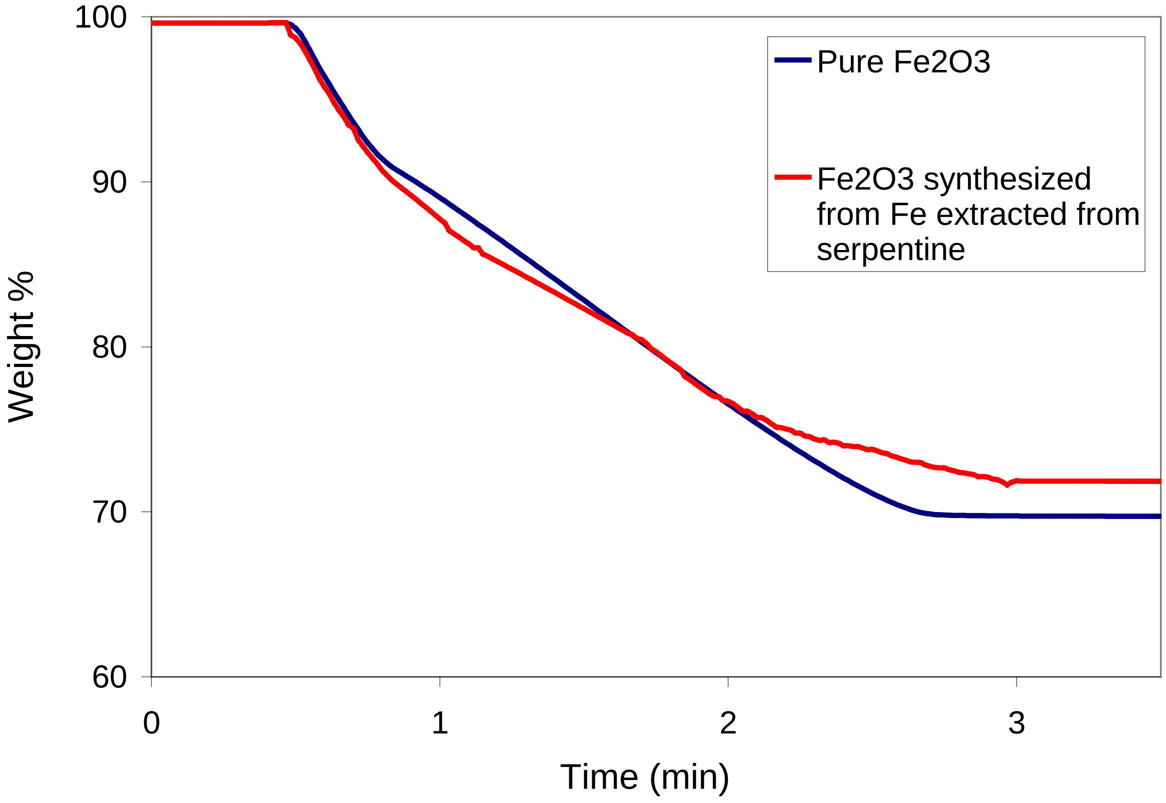
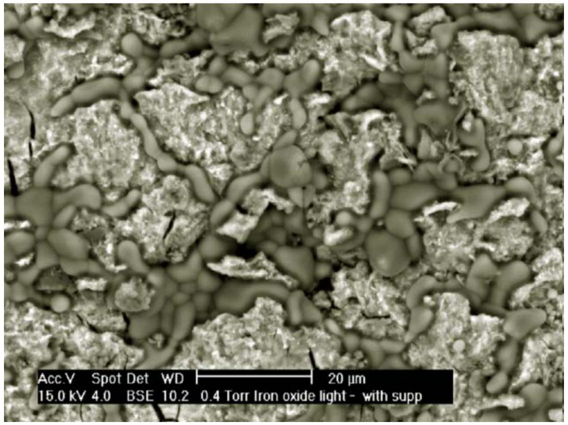
Reduction of Iron-based Sorbents
(under H_2 condition)





Precipitated with the presence of support

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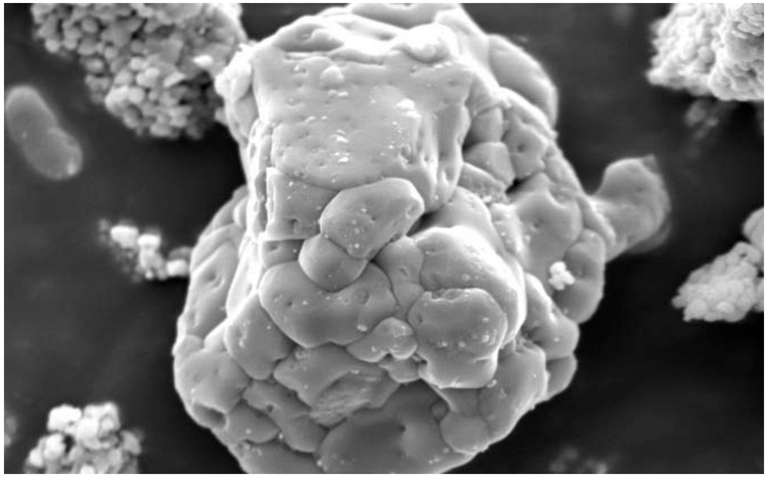
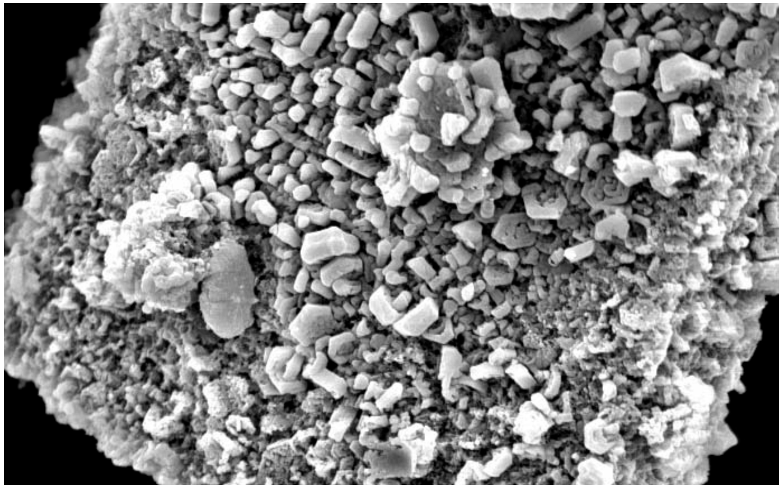
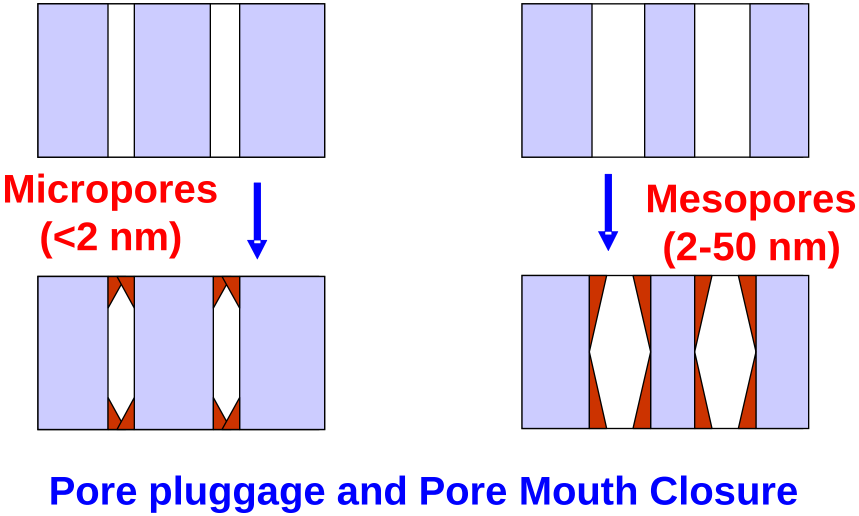
Engineered Particles







Precipiated calcium carbonate (PCC) – $CaCO_3$

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Effect of pH on PCC synthesis

9.95

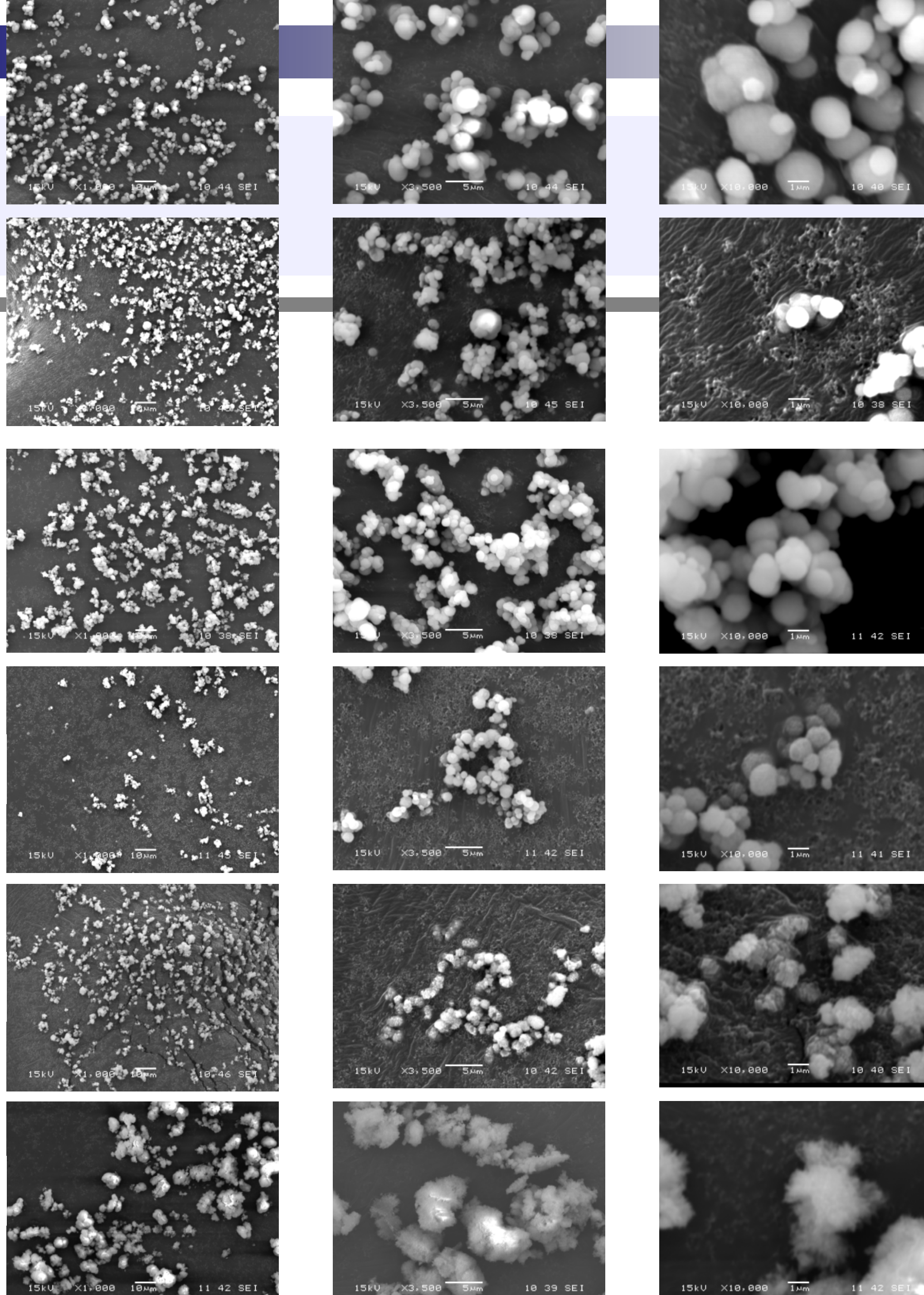
10.25

11.3

11.45

12.74

13.49



- Measured PSD did not change significantly but morphological structures changed

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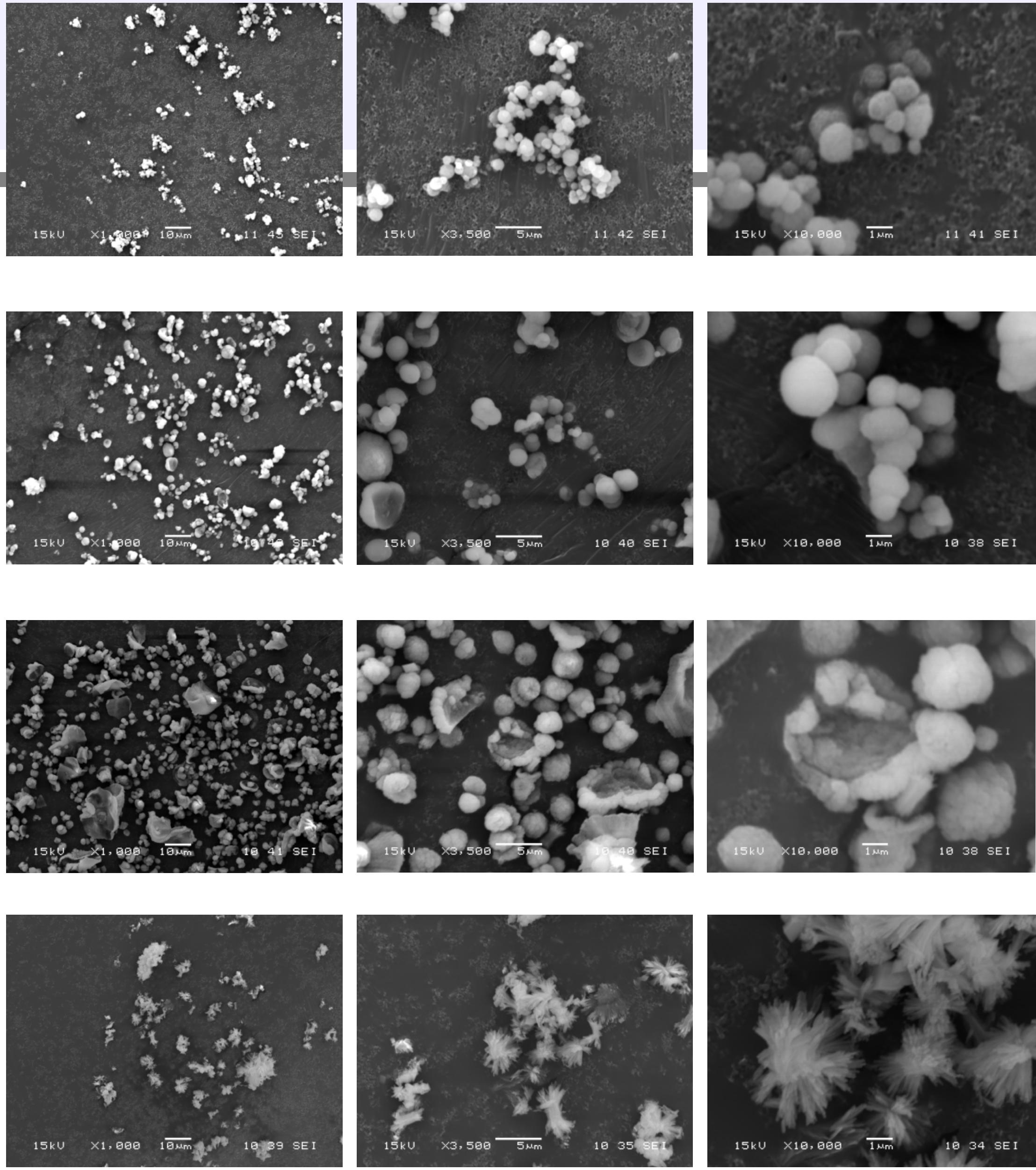
Effect of T on PCC synthesis

20°C

40°C

60°C

80°C



- Measured PSD did not change significantly but morphological structures changed

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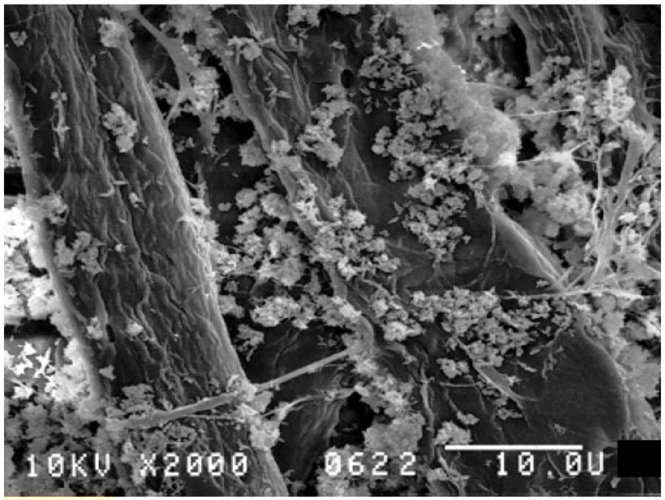
Controlled Precipitation of $MgCO_3$



Desired particle characteristics:

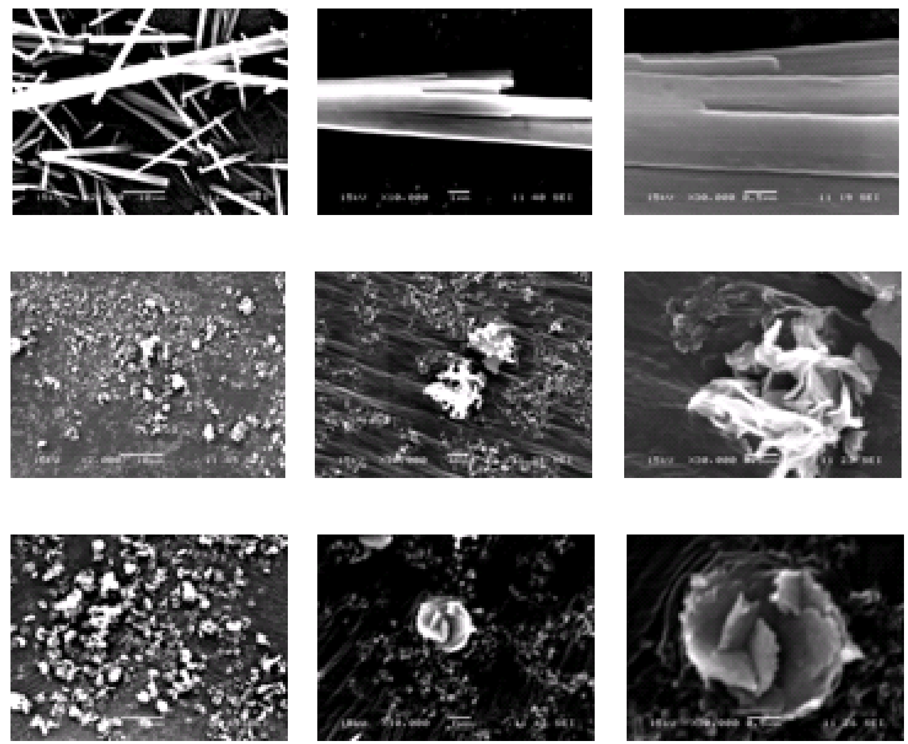
- ~2 µm, narrow PSD
- High Reflectivity
- Uniform Spherical/rosette shape

Effect of Temperature

42 °C

67 °C

92 °C



Future directions

- Development of Multifunctional smart particles (e.g. capture carbon and sulfur at the same time)
- Integrated systems (e.g. chemical looping technologies, ZECA, and enhanced WGS using mineral carbonation)
- Process intensification and flexibility (production of heat, electricity, chemicals and fuels (e.g. hydrogen and liquid fuels) in any combination
- Combined Technology of Carbon Capture and Storage

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Acknowledgement

National Science Foundation
WHERE DISCOVERIES BEGIN

KAUST

U.S. DEPARTMENT OF ENERGY

Department of Energy

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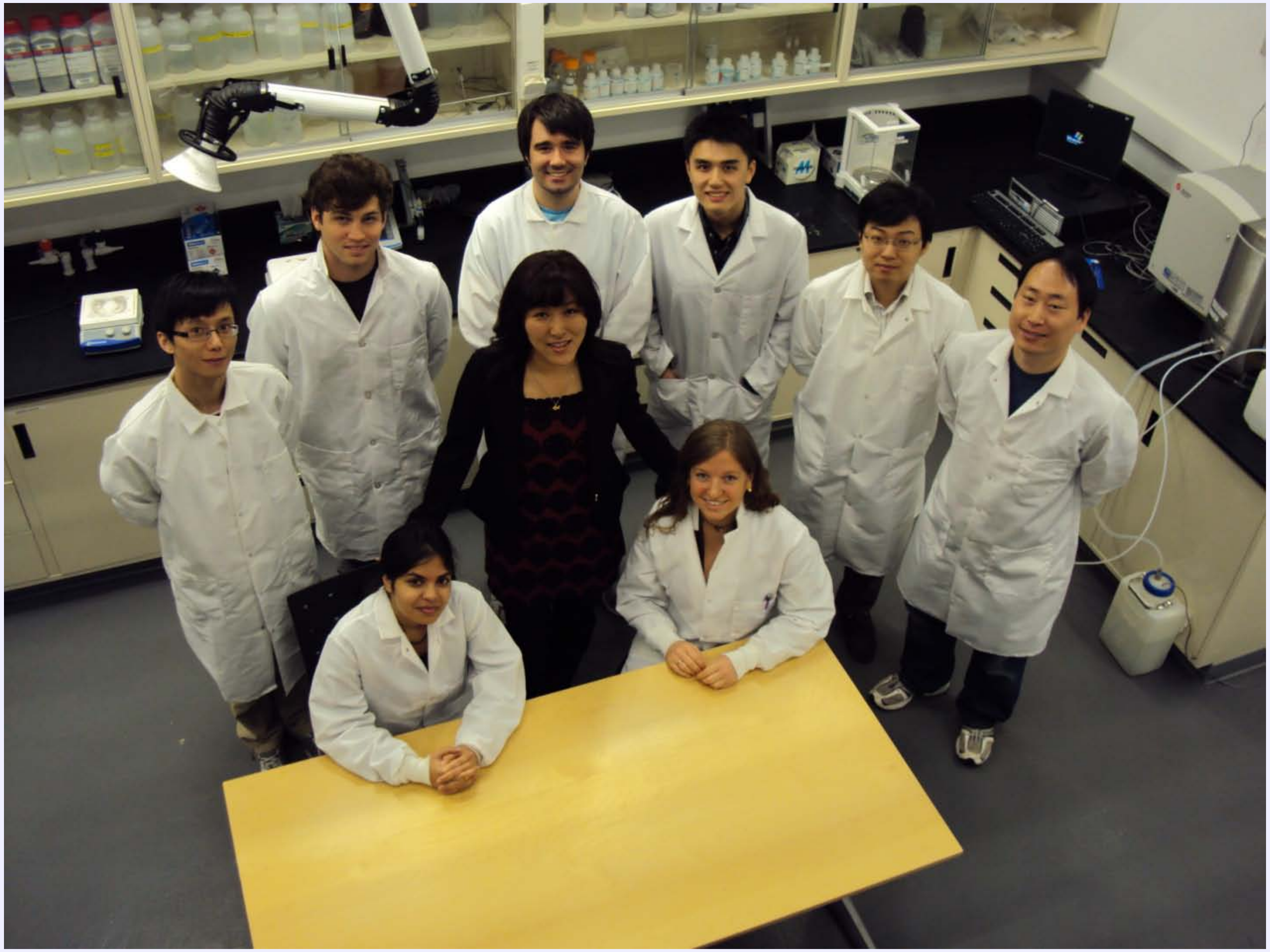
Thank you



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