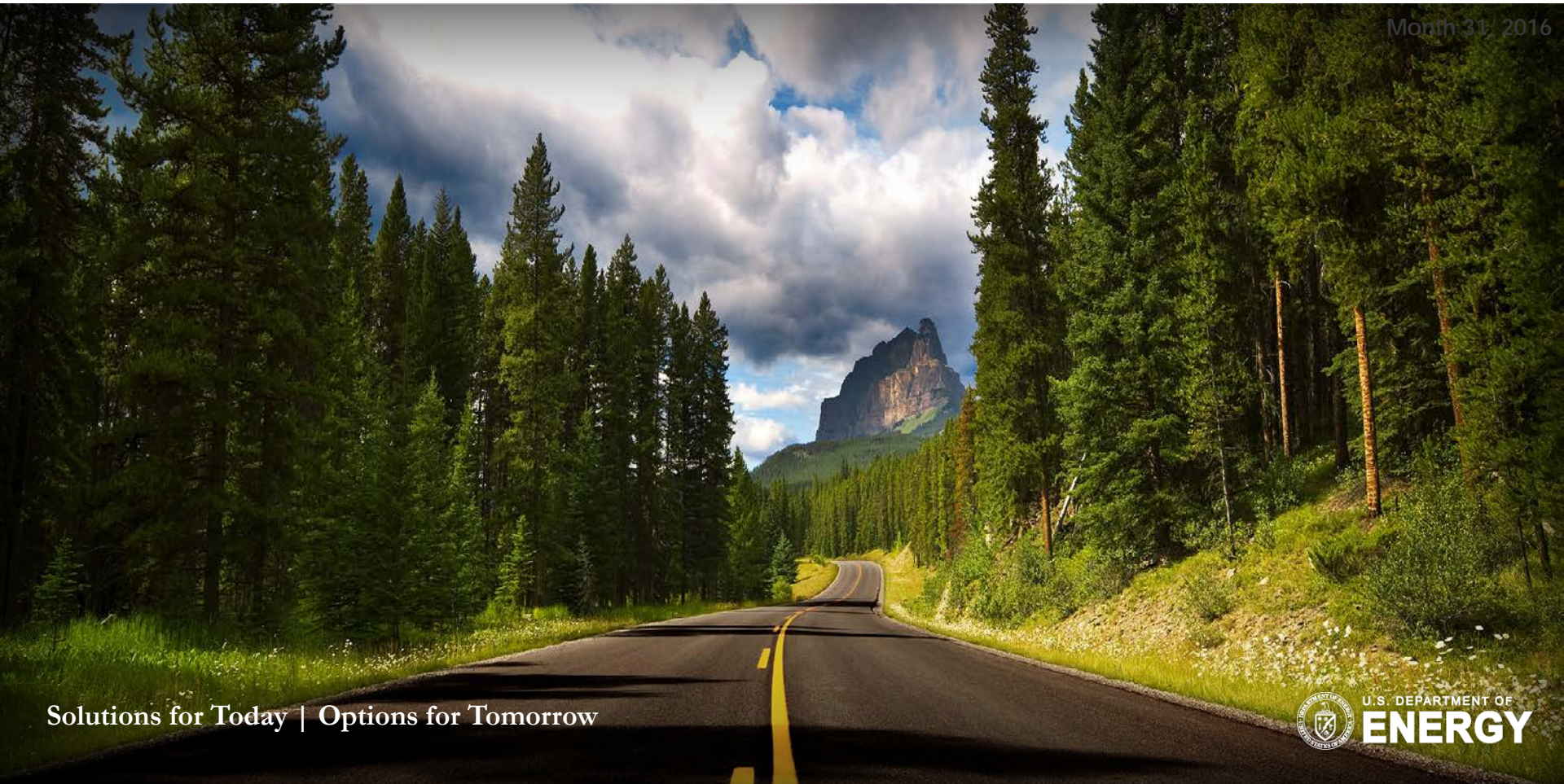




Removal of Carbon Dioxide from High-Pressure Gas Streams

Month 31, 2016

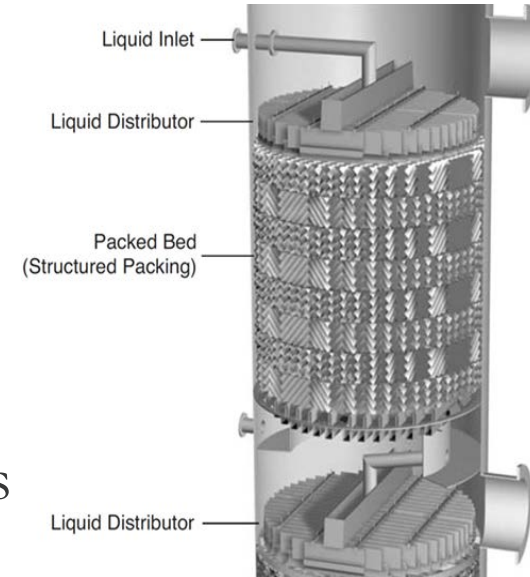


Market and Economic Assessment

Commercial Applications

Tailored markets

- Pre-combustion CO₂ Capture at IGCC-CCS
- Generation of H₂ from Reformed Natural Gas
- Generation of H₂ at Petroleum Refineries
- Adjust CO/H₂ ratio for Coal & Biomass to Liquids
- Remove CO₂ from syngas for Ammonia/Fertilizer



PRE-COMBUSTION SOLVENTS FOR CARBON CAPTURE



Problem:

Commercially available physical solvents for CO₂ /H₂ separation operate at below room temperature. Hence, they incur a significant electrical cost to chill and can't be regenerated using waste heat.

These solvents are hydrophilic and have high vapor pressure.

Selexol® operates at 10°C
Rectisol® operates at -10°C

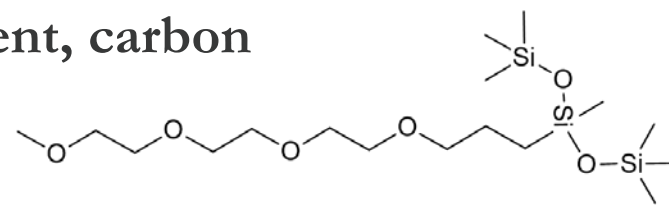
Selexol® (Union Carbide, Houston, Texas, United States) &
Rectisol® (Lurgi AG, Frankfurt am Main, Germany)

Solution:

- NETL has patented a number of solvents that absorb selectively at temperatures between 25°C and 100°C
- NETL has also patented a process for direct removal of CO₂

Patent#1: “High performance hydrophobic solvent, carbon dioxide capture”

[Patent 9,643,123 \(issued May 9, 2017\)](#)

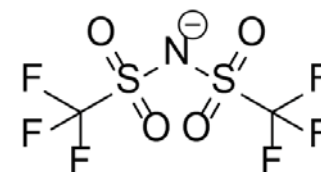
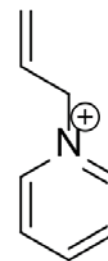


- Inventors and affiliations: David Luebke (DOE), Hunaid Nulwala (CMU)
- Above room temperature operation (25°C - 60°C)

Patent#2: “Sulfur tolerant hydrophobic ionic liquid solvent for pre-combustion carbon capture”

[Non-provisional patent application 15/045,201 \(filed 2/16/16\)](#)

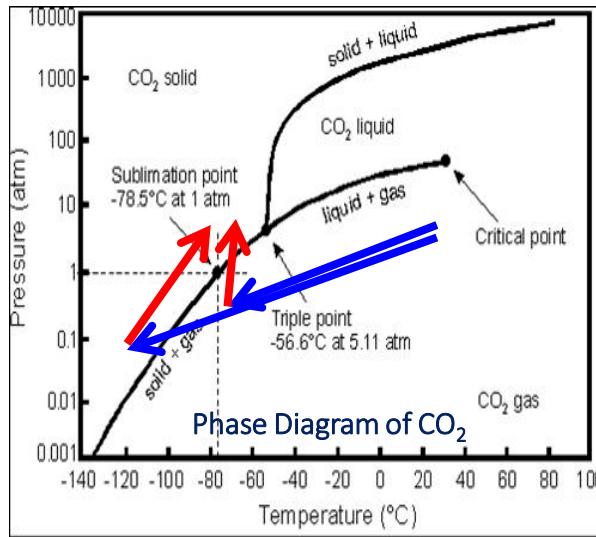
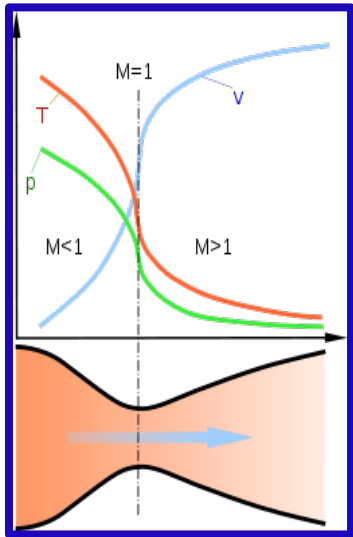
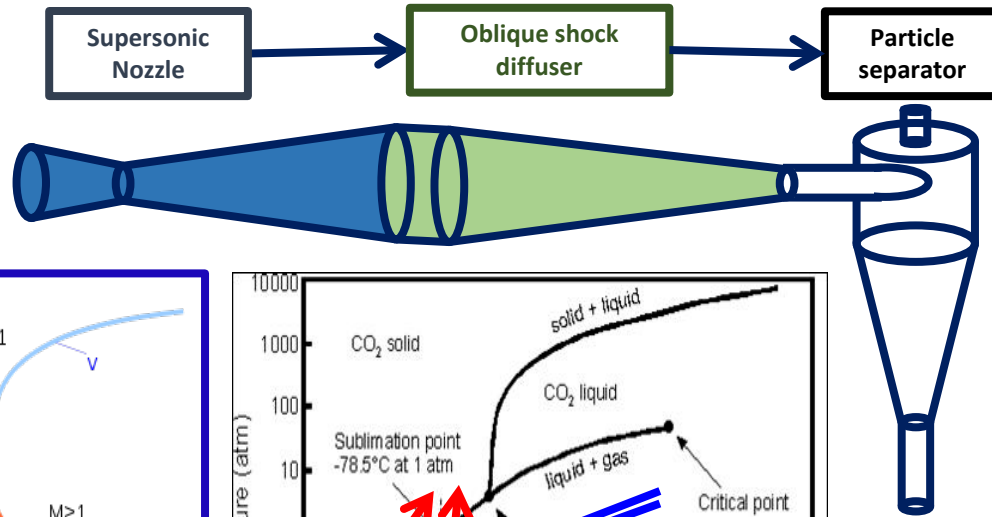
- Inventors and affiliations: David Luebke (DOE), Hunaid Nulwala (CMU), Brian Kail (AECOM), Fan Shi (AECOM), Robert Thompson (AECOM), and Nicholas Siefert (DOE)
- Operation at or well above room temperature (40°C - 100°C)



Patent#3: “Distributed PEG-Siloxane Solvents for Selective Gas Capture” [Provisional patent application](#) (25°C - 80°C)

CO₂ Separation Using Phase Change

Remove CO₂ from syngas streams using its physical property difference compared with H₂



Flow in all regions is:

- Supersonic
- Inviscid
- Irrotational

Similar technologies fail because the flow in boundary layers is:

- Very viscous
- Very rotational
- Extreme viscous heating

U.S. patent 8,771,401 titled "Apparatus and Process for the Separation of Gases Using Supersonic Expansion and Oblique Shock Wave Compression," was issued July 8, 2014 for the gas separation technology.

Market and Economic Assessment

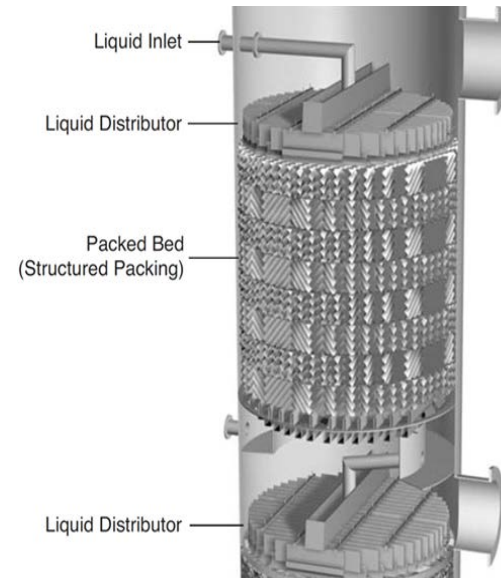
Commercial Applications

Tailored markets

- Pre-combustion CO₂ Capture at IGCC-CCS
 - 50 MW additional power at a 500 MW power plant
 - Equates with a savings of \$20M per year per plant
- Generation of H₂ from Reformed Natural Gas
- Generation of H₂ at Petroleum Refineries
- Adjust CO/H₂ ratio for Coal & Biomass to Liquids
- Remove CO₂ from syngas for Ammonia/Fertilizer

Potential markets

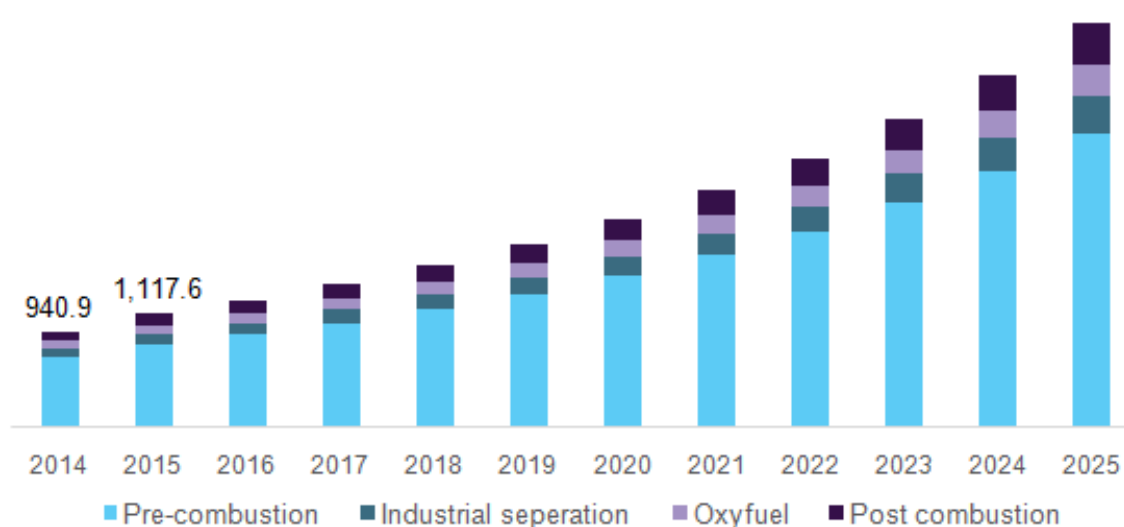
- Natural Gas Sweetening
- Ethane Cracking Plants
- Upgrading of Landfill Gas
- Upgrading of Biogas



Market Assessment is Promising

- Over 22 CCS projects were in operation globally in 2016 with another 14 planned projects expected to be functional in the next few years.

U.S. CCS market revenue by capture technology, 2014 - 2025 (USD Million)



- Pre-combustion capture technologies** for CO₂ constituted the largest share accounting for over 73% in 2015 and are anticipated to witness considerable growth over the forecast

Grand View Research 2016a. Carbon Capture And Storage (CCS) Market Analysis By Application (EOR, Industrial & Agriculture), By Capture Technology (Pre-Combustion, Industrial, Oxy-Firing & Post-Combustion), Competitive Strategies, And Segment Forecasts, 2014 – 2025. Published November 2016. <http://www.grandviewresearch.com/industry-analysis/carbon-capture-storage-ccs-market>