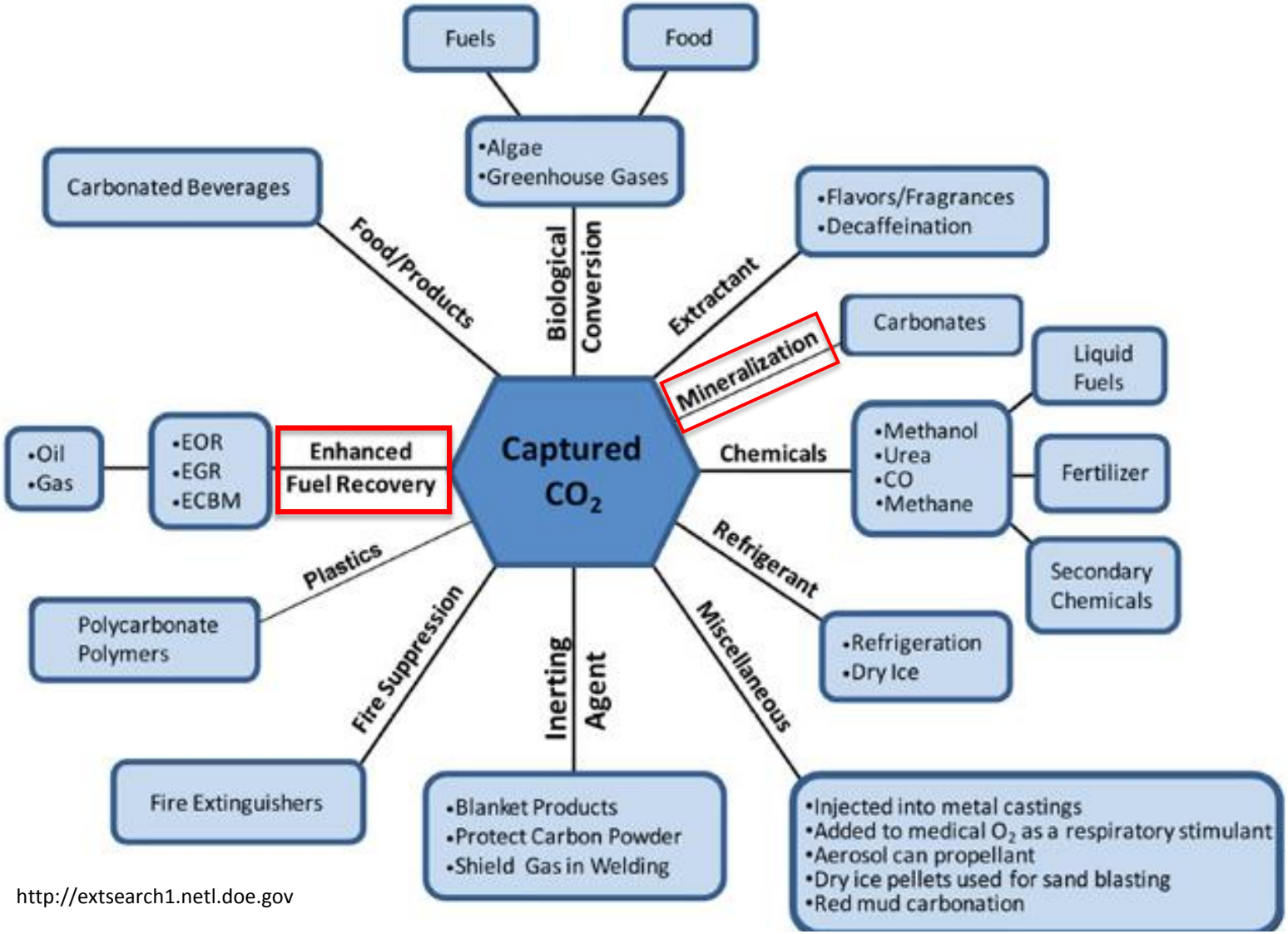
The current state of CO_2 utilization

- Overview
- EOR with CO2
- Building materials
- Outlook

How does CCU factor into emissions mitigation strategies?

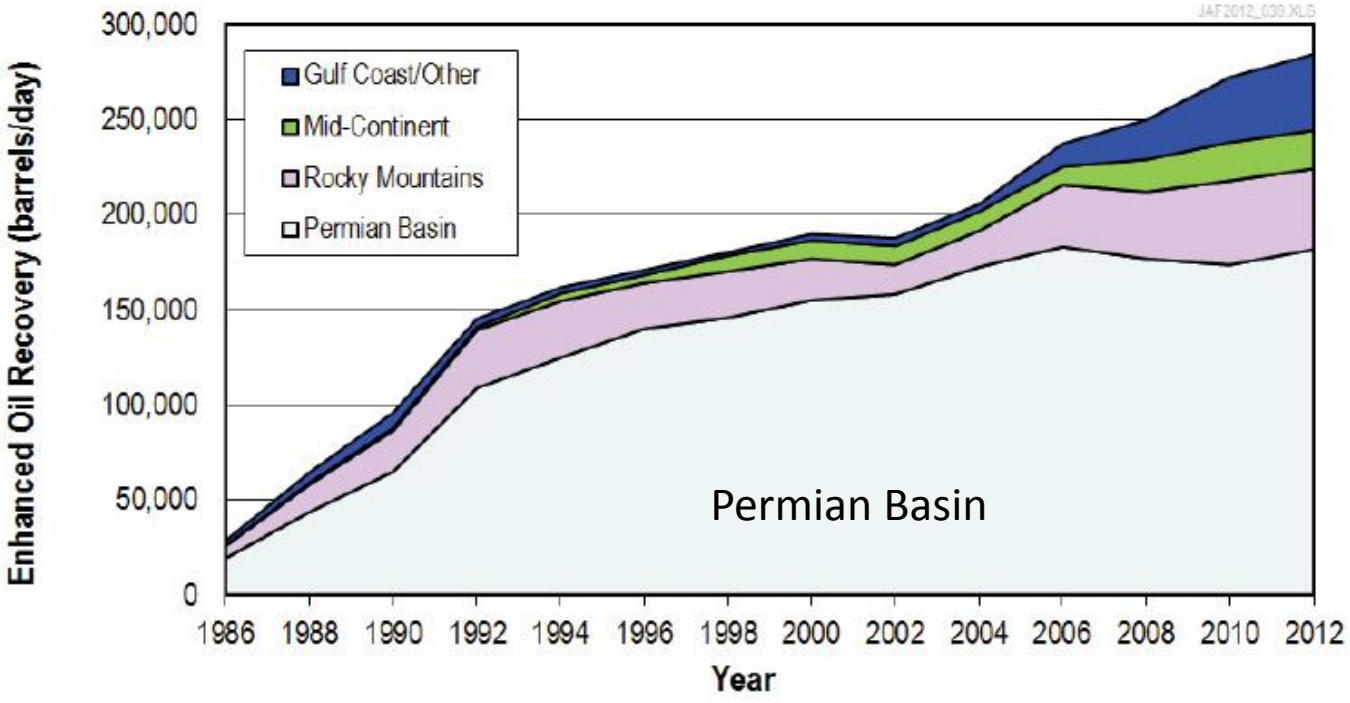


http://extsearch1.netl.doe.gov

Pros: Revenue for captured CO2, market entry & demonstration

Barriers: Unproven technologies, uncertain energy balances, CO2 scarcity

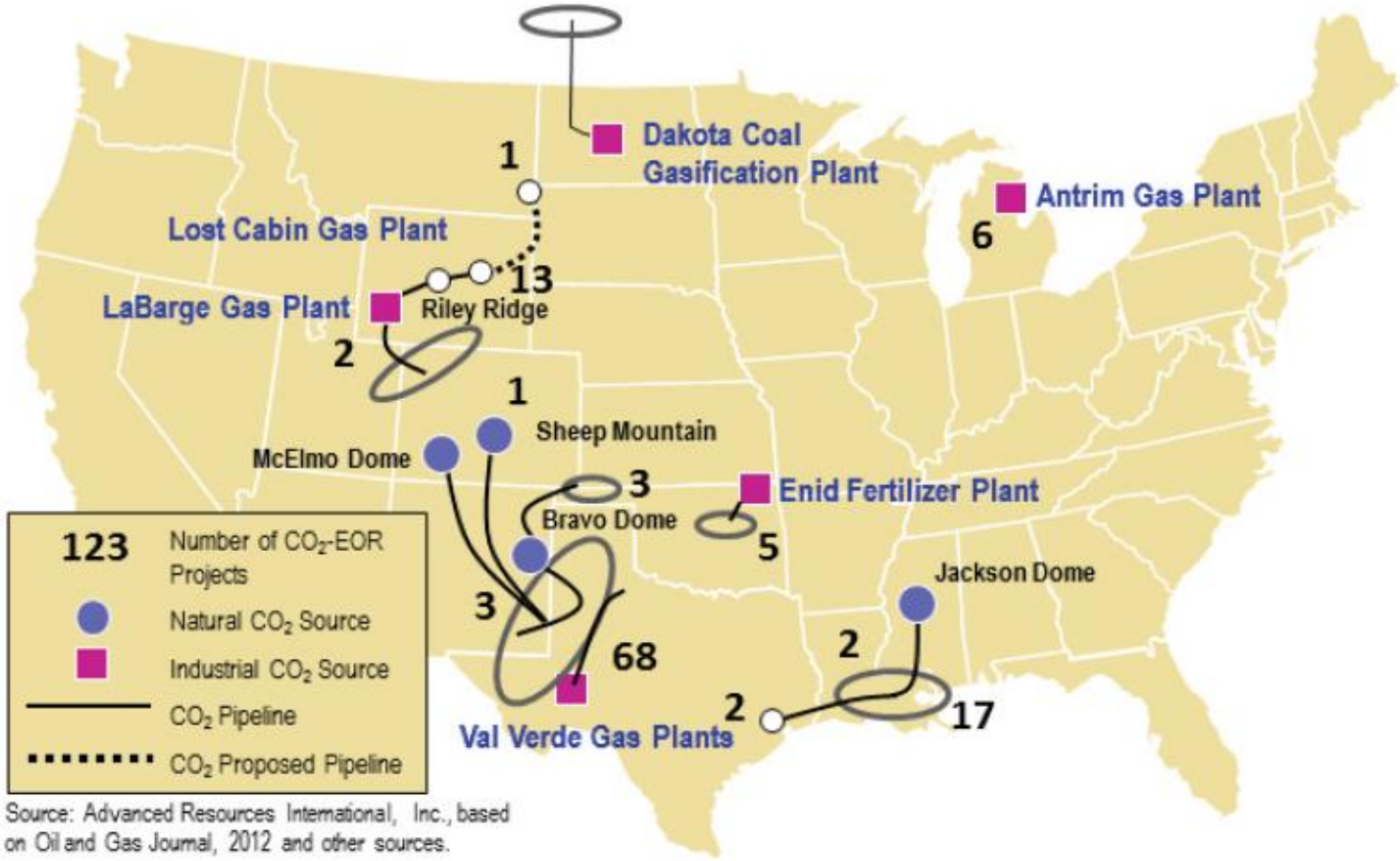
EOR with CO2 represented 6% of US crude oil production in 2012



- 130 CO2-EOR projects operating in US as of 2012
- 64 Mt CO2 used in EOR in 2010
- Carbon neutral oil: assuming closed loop operation where 1 metric ton of captured CO2 injected and stored for every 2.5 barrels of oil recovered

Kuurskaa et al. Energy Procedia 37 (2013) 6854 – 6866

Natural CO2 sources provided 80% (49 Mt) of CO2-EOR in 2010



- How much industrial CO2 is being vented?
  - Limited CO2 transport infrastructure, Cost competitive natural source
- DOE portfolio of CCUS projected to add 14 Mt CO2 new sources by 2020

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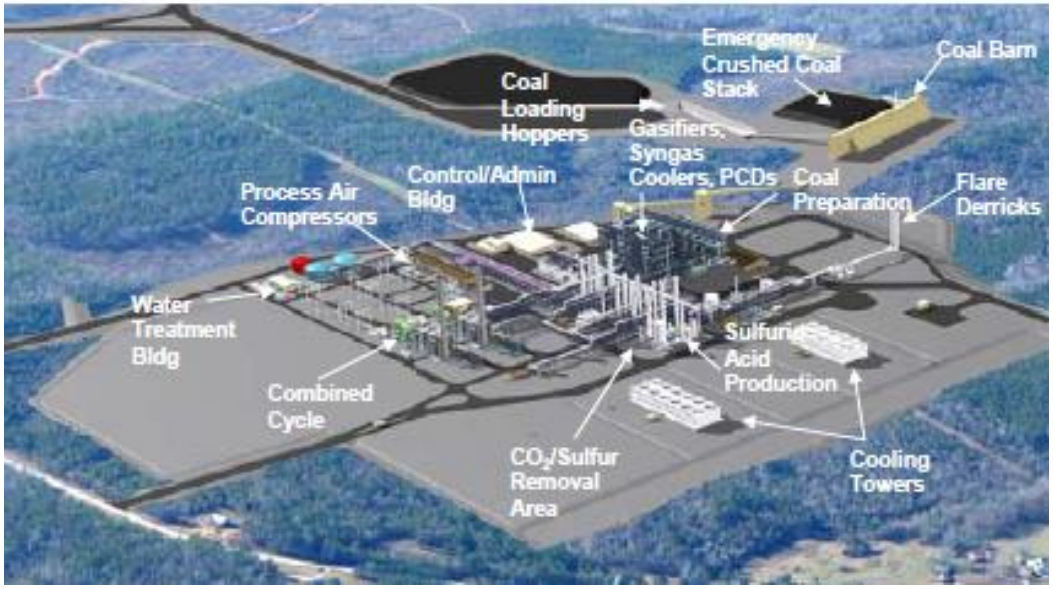
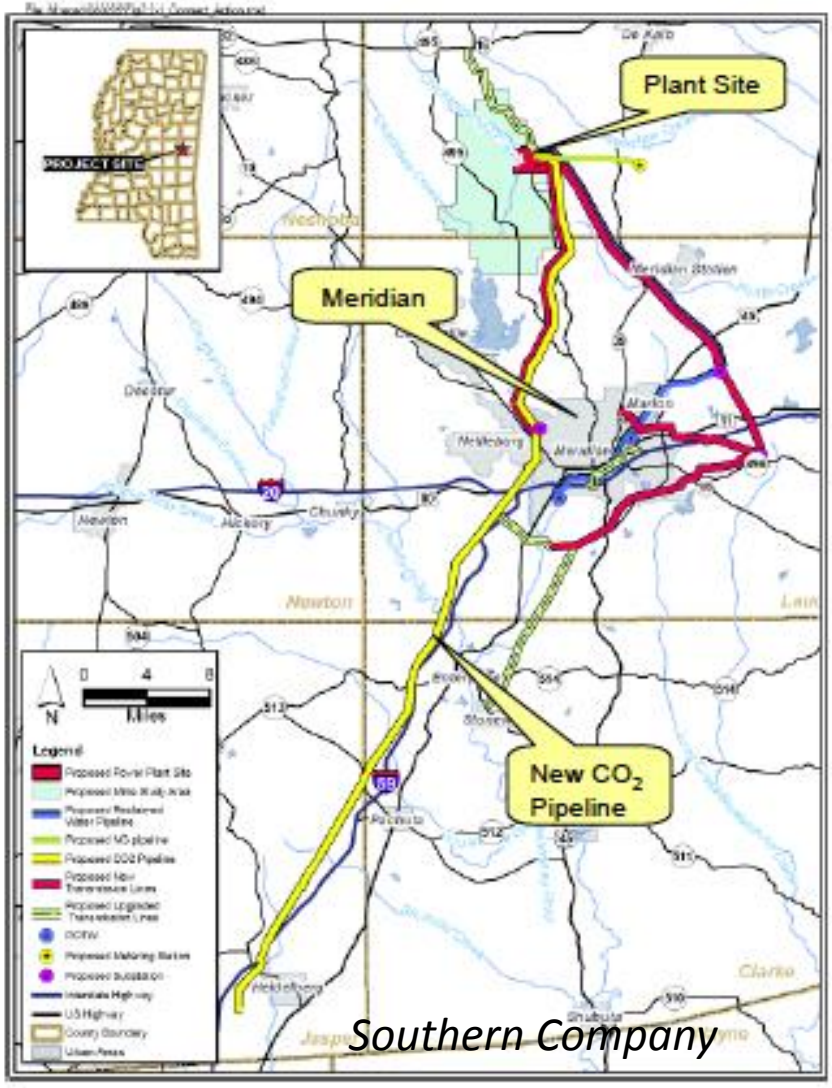
Kemper County IGCC with Precombustion CO2 Capture

Feedstock: Mississippi lignite coal
Size: 582 MW, 65% CO2 *capture goal*
3.5 Mt of CO2 captured annually for EOR





- $1 billion over budget, ratepayer burden looming
- $700 million in federal grant funds and tax credits averages to $10/ton captured CO2 over 20 years
- Revenue from selling CO2 for EOR is TBD

Lignite Energy Council

Cement manufacture makes up 5-8% of all CO_2 (3rd highest emitter) & Market to double by 2050

Annual embodied energy and CO2 emissions from common building products in US.

Material	Annual U.S. Energy Consumption (MMBTU)	Annual U.S. CO_2 Emissions (MT)
Brick / masonry	86,000,000	6,000,000
Concrete products	50,000,000	12,000,000
Gypsum Wallboard	150,000,000	10,000,000
Cement	500,000,000	100,000,000

Source: NIST BEES database. Image courtesy of CalStar Products, Inc.

Portland Cement Production

Clinker: $3CaO{\cdot}SiO_2$

CO_2 sources:

- **Chemistry ~ 55%**

  $CaCO_3 \rightarrow CaO + CO_2$

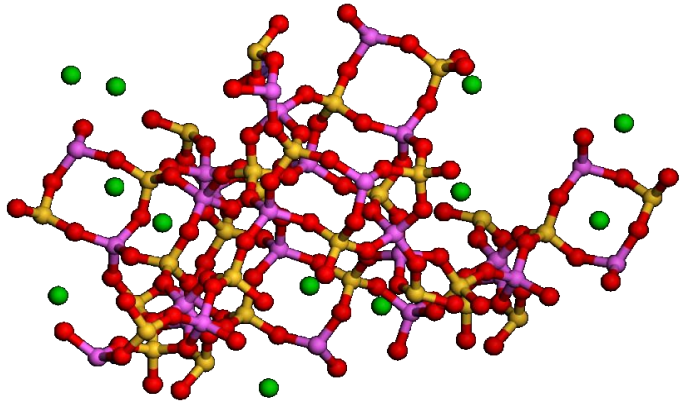
- **Fuel ~ 45%**

Total ~0.8 t / t clinker

- ~ 0.8-0.9 ton of CO_2 per 1 ton of cement

Alternatives to Ordinary Portland Cement

- Binding phase based on carbonation vs. Hydration
  - CCS Materials, Piscataway, NJ funded by DOE NETL
- Carbonates as Supplementary Cement Materials
- Geopolymer cement
  - Highly crosslinked gel structure (pseudo-zeolitic)
  - Waste products as precursors: Fly ash and slag
  - Growing academic research efforts
  - Commercial application: Zeobond (AUS)



C-S-H image from: I.G. Richardson, *Cement and Concrete Research*, **2004**, 34(9): 1733-1777.

Niche applications & formidable challenges to scaling

- Reduced mechanical strength with carbonate additives
- Durability of carbonation and geopolymer
  - Gel stability &
- Must meet ASTM standards (or modify prescriptive code)

Outlook

Opportunities to demonstrate ‘distributed’ direct air capture at CO2-EOR sites [and carbonated building material manufacture]

Robust MVA regulations required for CO2-EOR

Limited progress with scale-up of CCUS points to the need to pursue negative emissions mitigation strategies