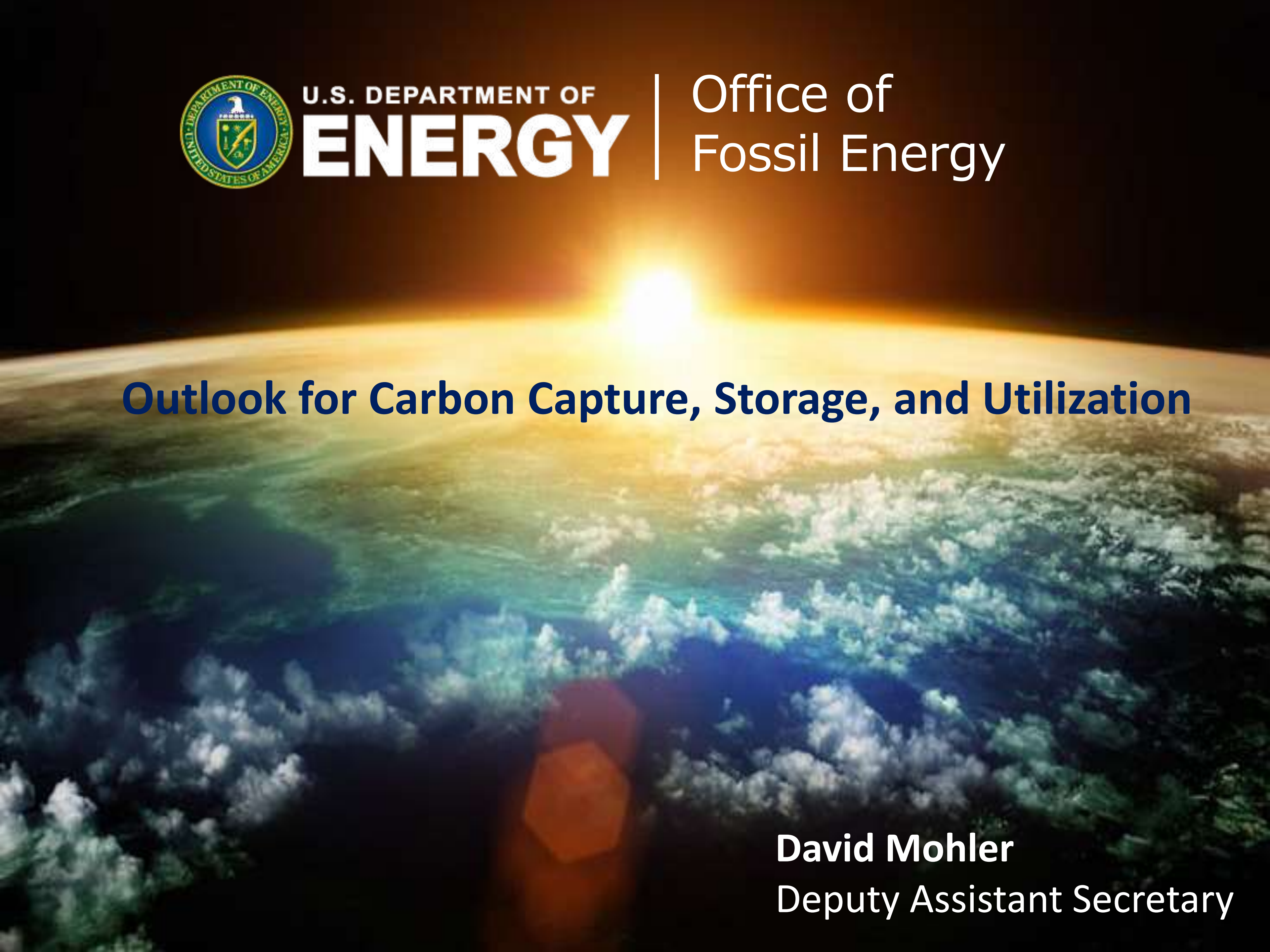
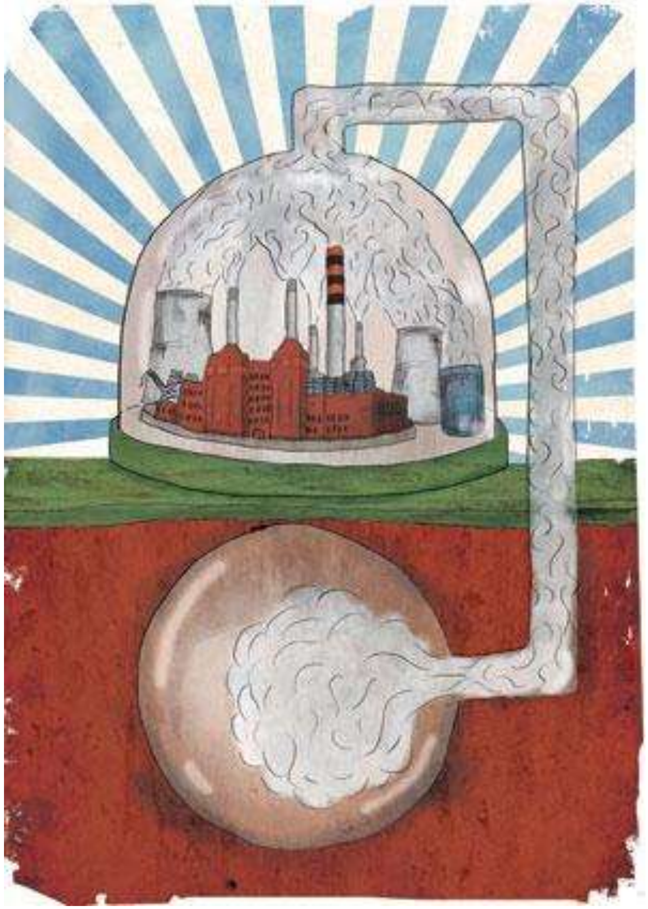


U.S. DEPARTMENT OF ENERGY | Office of Fossil Energy

Outlook for Carbon Capture, Storage, and Utilization

David Mohler
Deputy Assistant Secretary

The Punchline, Upfront

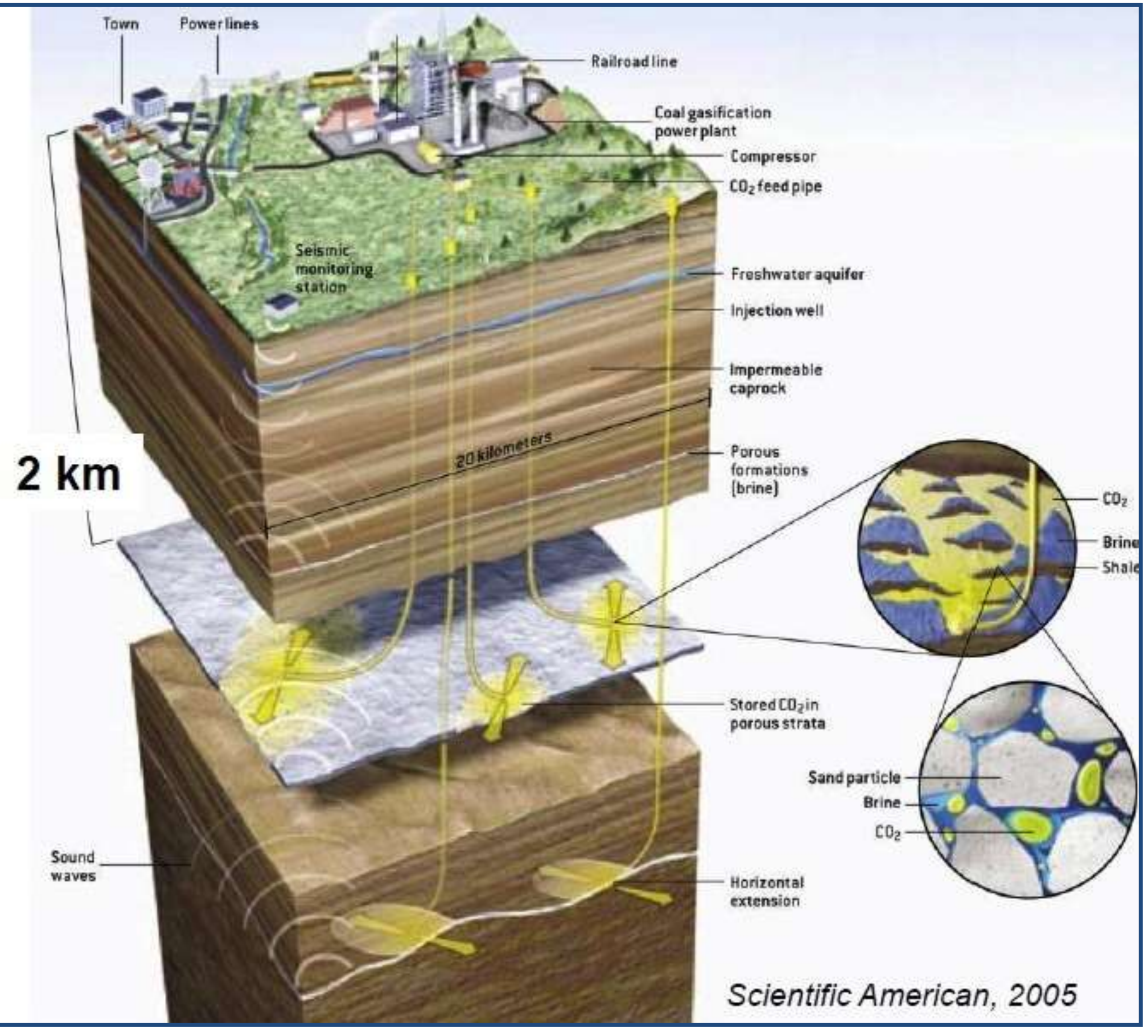


Typical CO2 injection depth 2-8km

Source: Schiermeier *et al*. 2008, Illustrator Jay Taylor, *Nature*

1. Carbon capture is a domestic and global necessity
2. CCUS will play a critical role in cutting emissions needed to limit global warming to 2°C
   - Limiting warming to less than a 2°C may not be possible without CCUS
3. CCUS is demonstrated and possible today, with <u>today's</u> technologies
4. Transformational technologies in the pipeline will enable reducing the cost of capture
5. CCUS deployment will require a combination of policy support and technological innovation
   - DOE analysis found that Federal RDD&D combined with tax credits could drive significant CCUS deployment

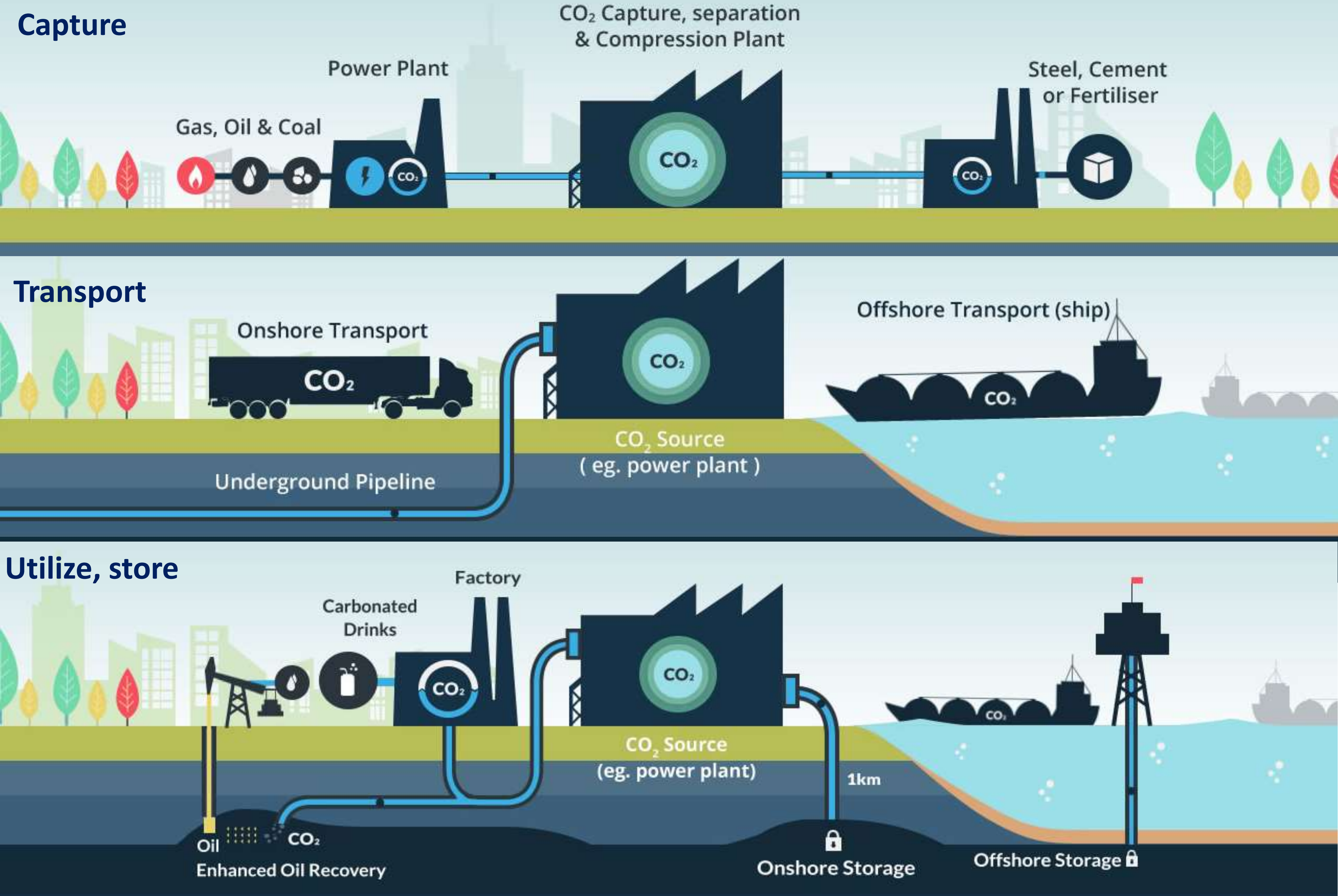
CO2 Storage (CCS—How Does It Work?



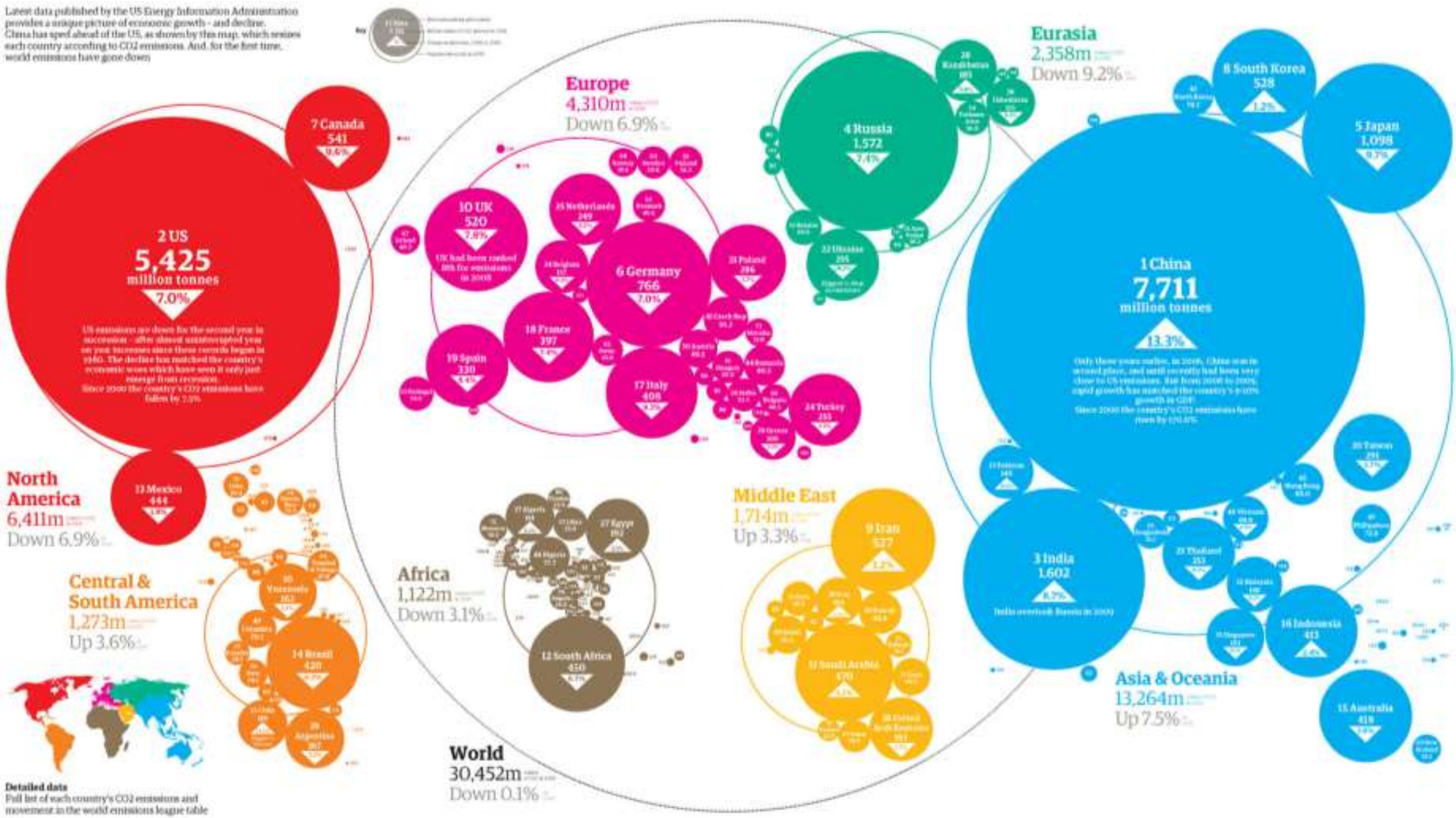
Geologic Storage of Captured CO_2:

- Large capacity to store CO_2
- Formations are isolated from the surface with impermeable layers of cap rock
- Two main types of formations:
  - Saline formations, with 2,200 Gigatons of storage capacity in North America alone
  - Enhanced oil recovery (EOR)
- Mineralization (e.g. converting CO_2 into solid form)

CCUS is a Critical Decarbonization Technology



Global atlas of CO_2 emissions



Source: US Energy Information Administration

U.S. and global need to accelerate development of reliable low-cost, low-carbon energy sources and products

COP-21 outcome pursues aspirational goal of limiting warming to +1.5^{o}C

- Unachievable without CCUS on **<u>all sources</u>**, and eventually **<u>negative emissions</u>**
- Requires **<u>Advanced Energy System</u>** technologies to increase efficiency, reduce costs
- Future fossil-based systems must be **<u>designed and built for grid and market of future</u>**
- Need to **<u>optimize value</u>** from feedstocks, products, and CO_2

Global collaboration to address a global issue

Country	CSLF Member	CCS in INDCs[1]	Large Scale CCS Projects (Source: Global CCS Institute)
Australia	✔		3 Large Scale Projects
Brazil	✔		1 Large Scale Project
Canada	✔	✔	6 Large Scale Projects
Chile			
China	✔	✔	9 Large Scale Projects
Denmark	Former Member		Pilot Scale Project
France	✔		Pilot Scale Projects
Germany	✔		Pilot Scale Projects
India	✔		Pilot Scale Project
Indonesia	Potential Member		Planned Pilot Scale Project
Italy	✔		Pilot Scale Projects
Japan	✔		Pilot Scale Projects
Mexico	✔		Planned Pilot Scale Project
Norway	✔	✔	2 Large Scale Projects
Republic of Korea	✔		2 Large Scale Projects
Saudi Arabia	✔	✔	1 Large Scale Project
Sweden			Pilot Scale Projects
United Arab Emirates	✔	✔	1 Large Scale Project
United Kingdom	✔		4 Large Scale Projects
United States[2]	✔		13 Large Scale Projects

[1] In addition to the countries listed in the chart above, Bahrain, Egypt, Iran, Malawi, and South Africa also included CCS within their INDCs.

[2] Although it did not list CCS specifically in its INDC, the U.S. is pursuing an all-of-the-above energy strategy to meet is climate targets that includes CCS.

Role of CCUS in Global Climate Mitigation

CCUS provides 13% of emissions reductions by mid-century in the International Energy Agency's scenario to limit global temperature increase to 2ºC (bigger role to limit warming to 1.5ºC)

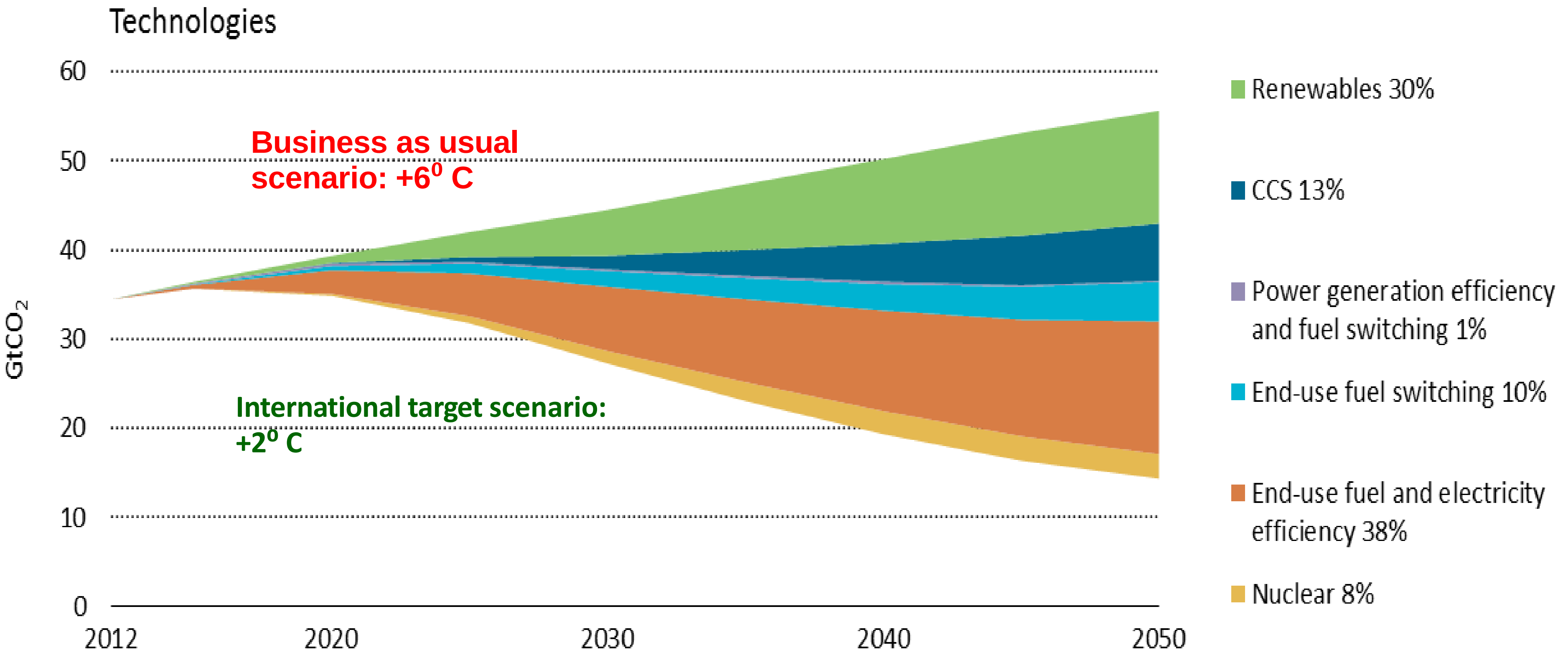
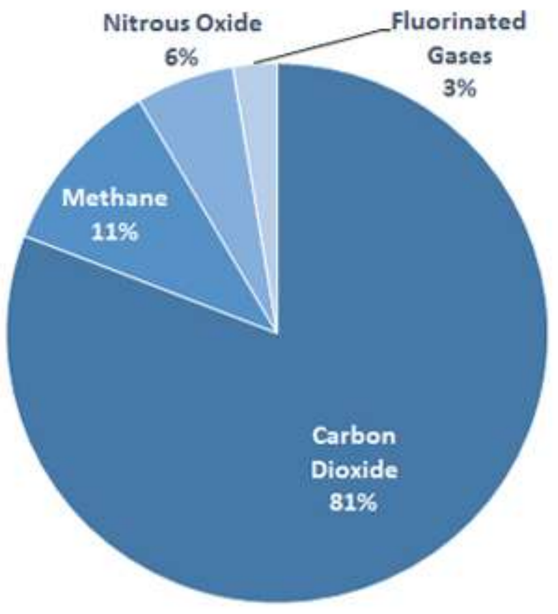


Figure source: International Energy Agency, Energy Technology Perspectives, 2015

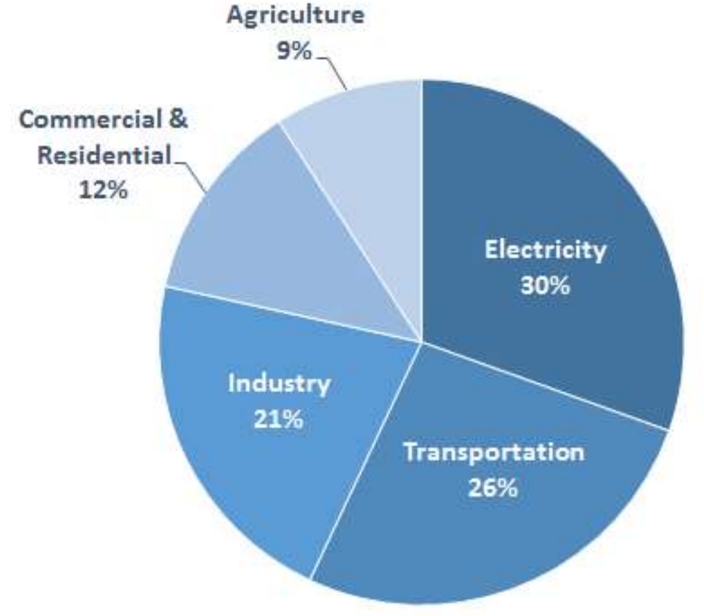
U.S. Greenhouse Gas Emissions in 2014

U.S. Greenhouse Gas (GHG) Emissions



Total: 6,870 Million Metric Tons (MMT) CO_2-e

U.S. GHG Emissions by Sector



Electricity: 2,081 MMT CO_2-e
Industry: 1,462 MMT CO_2-e

CCUS is applicable to > 50% of U.S. CO_2 emissions

CCUS is a key option to deeply decarbonize industry

(e.g. process emissions from cement, iron and steel, refining, some chemicals)

CCUS enables negative emission technologies (Biomass Energy CCS and direct air capture)

Source: United States Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014

CCUS is Possible and Demonstrated Today

Operational:

Air Products, Port Arthur TX – Since 2014, approaching 3 million tons CO_2 stored with EOR

Boundary Dam, Saskpower, Saskatchewan – Since October 2014, capturing 1.1 million tonnes CO_2 / Year for EOR and geologic storage

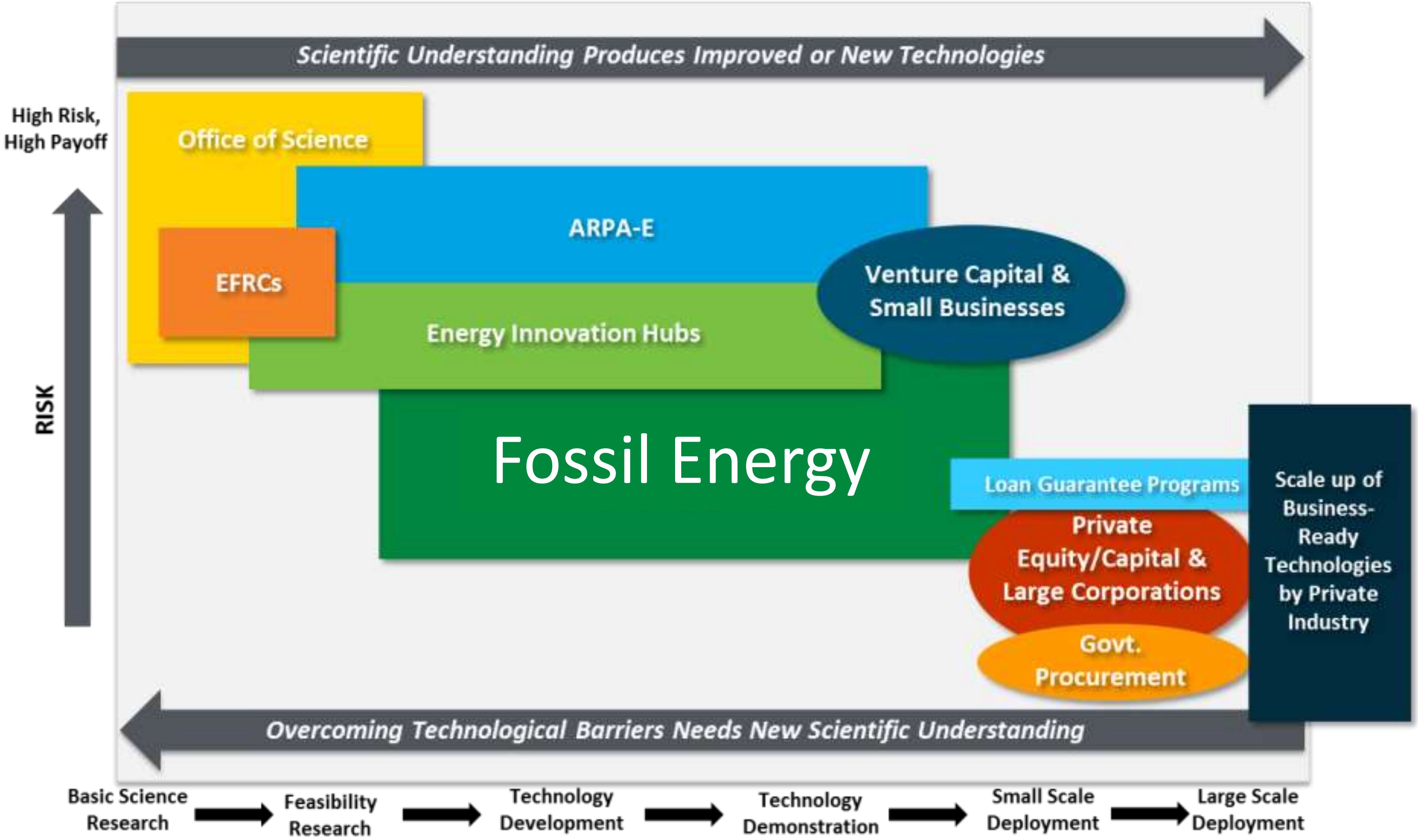
Soon to be Operational:

Southern Company Kemper Project, Operational fall of 2016, will capture 3 million tonnes CO_2 / Year for EOR and potentially geologic storage

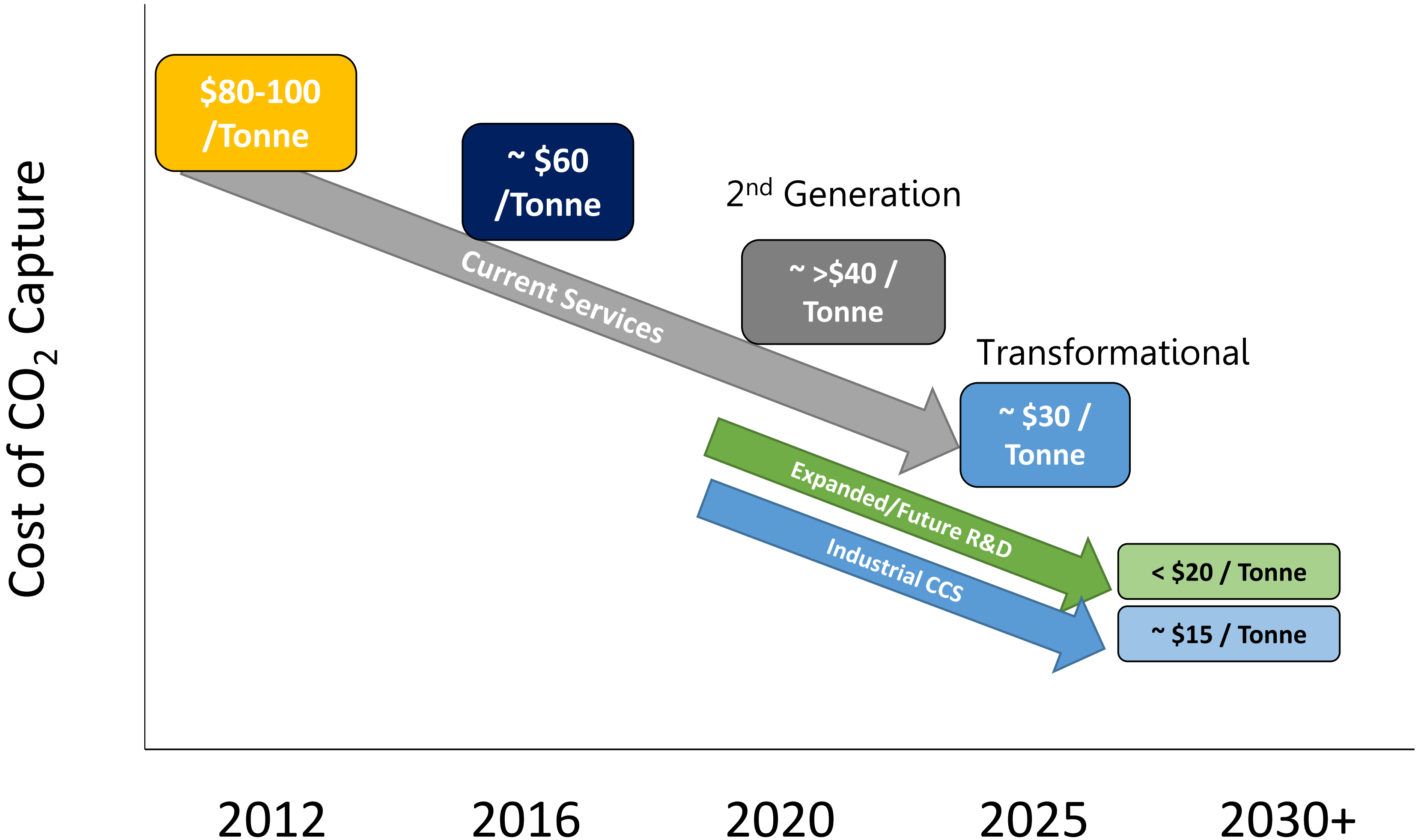
Petra Nova, Thompsons, TX – Full capacity operation January 2017, will capture ~1.6 million tonnes CO_2 / Year post combustion for EOR storage

Archer Daniels Midland Company, Decatur, IL – Full capacity operation first quarter 2017, 900,000 tonnes CO_2 / Year for saline storage

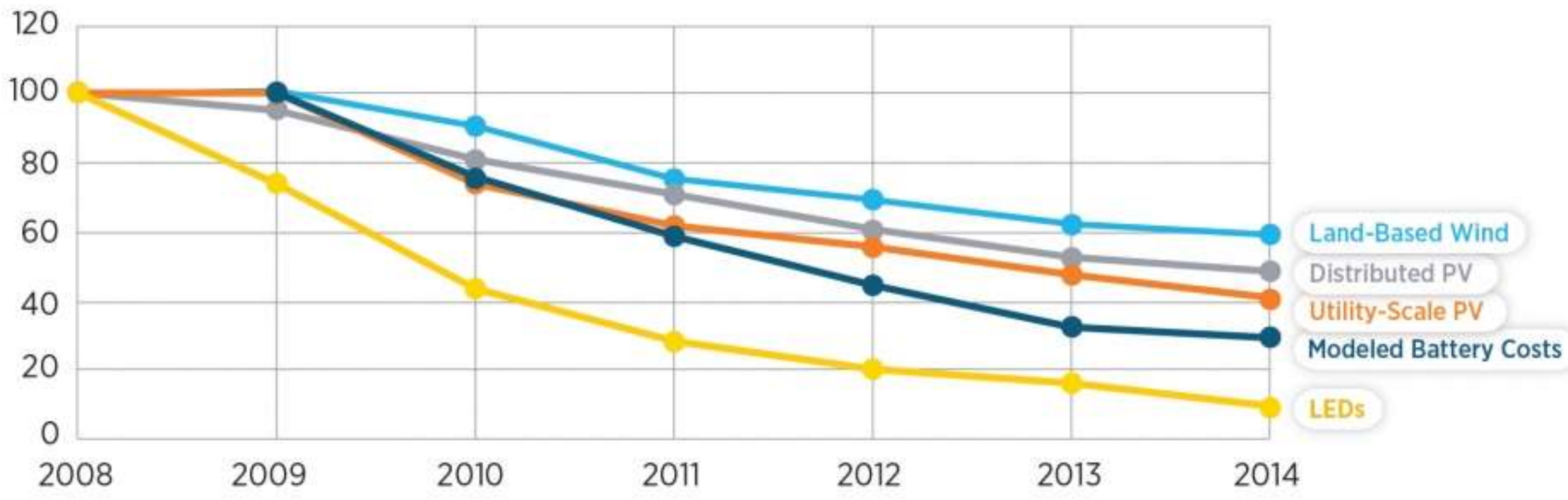
The Department of Energy R&D Landscape



DOE RDD&D: CCUS Program Goals



Falling Costs for Other Clean Energy Technologies



Each of these technologies has dropped 40-90% in cost since 2008
Indicates the opportunity pathway for CCUS

Indexed Cost reductions since 2008

R&D Budget: New Priorities and Repurposing of Lines

New Priorities

Carbon Capture

- Discovery of Carbon Capture Substances and Systems (DOCCSS)
- Industrial Carbon Capture

Carbon Storage

Transitioned higher priority activities over the past two years (e.g., large-scale site characterization (CarbonSAFE), BEST, offshore storage, SubTER).

- New activity on CO_2 Use and Reuse

Advanced Energy Systems

Program is refocusing R&D to be more responsive to the new challenges put in place with the Clean Power Plan. New priorities that will help us achieve the goal include:

- Oxy-Combustion with focus on Chemical Looping
- Modular Systems
- Advanced Turbomachinery (Hydrogen, HTGT, sCO_2)
- 1 MW pilot demo for Solid Oxide Fuel Cells
- STEP – Direct Fired Cycle Development

Integral Science and Technologies

- Computational modeling

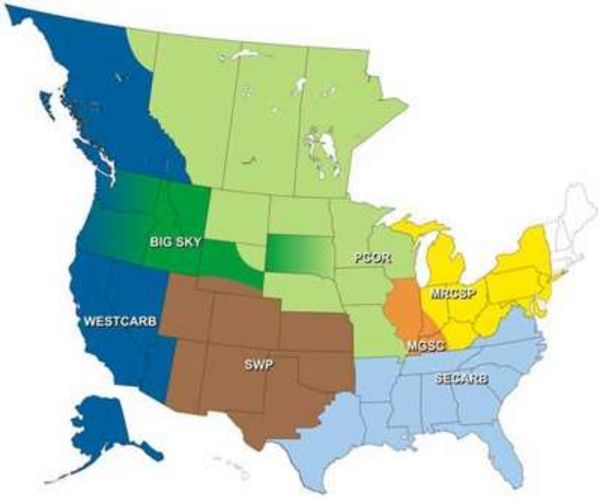
Sunsetting

Carbon Capture

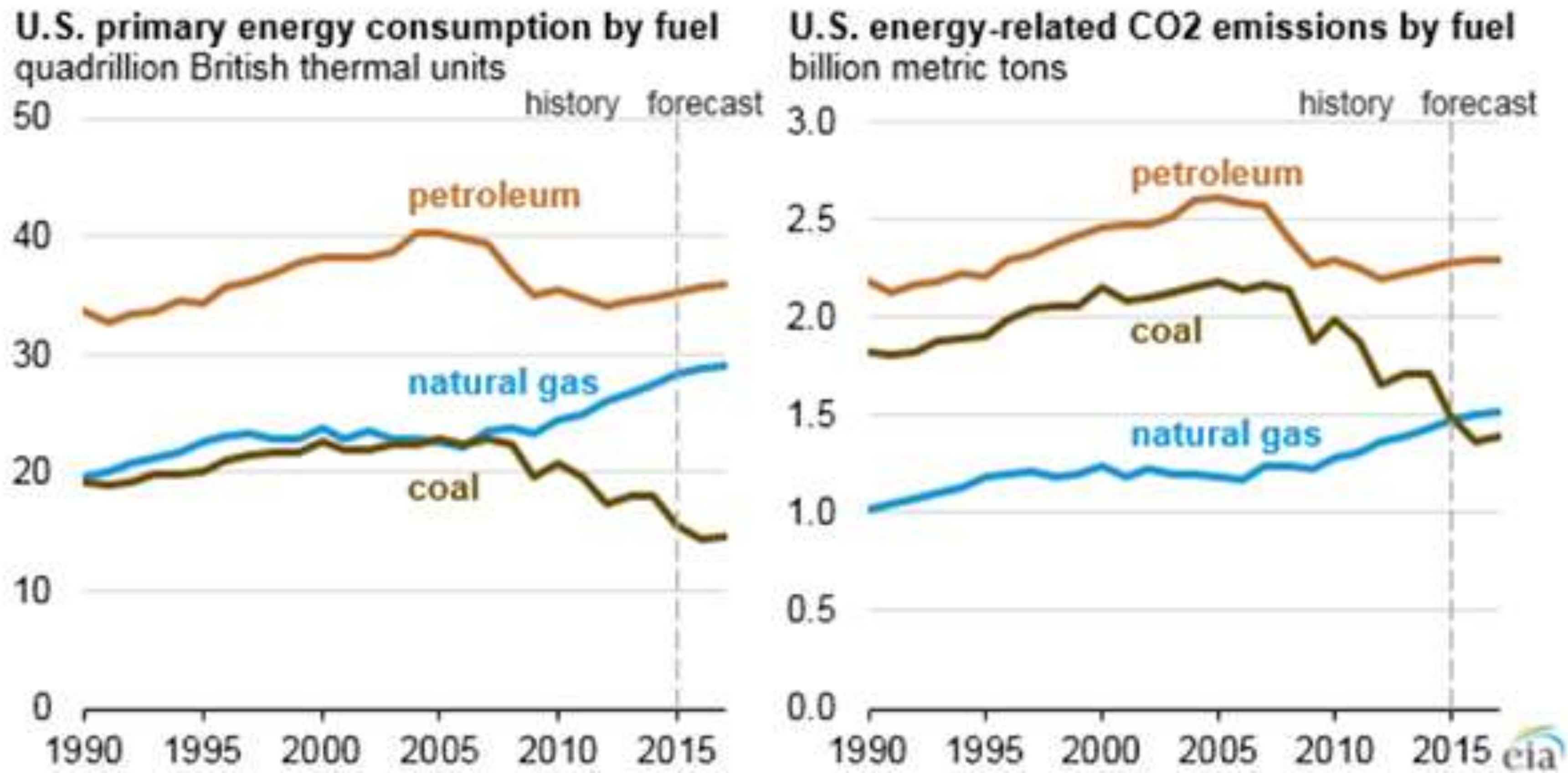
- Large demos

Carbon Storage

- Regional Carbon Sequestration Partnerships



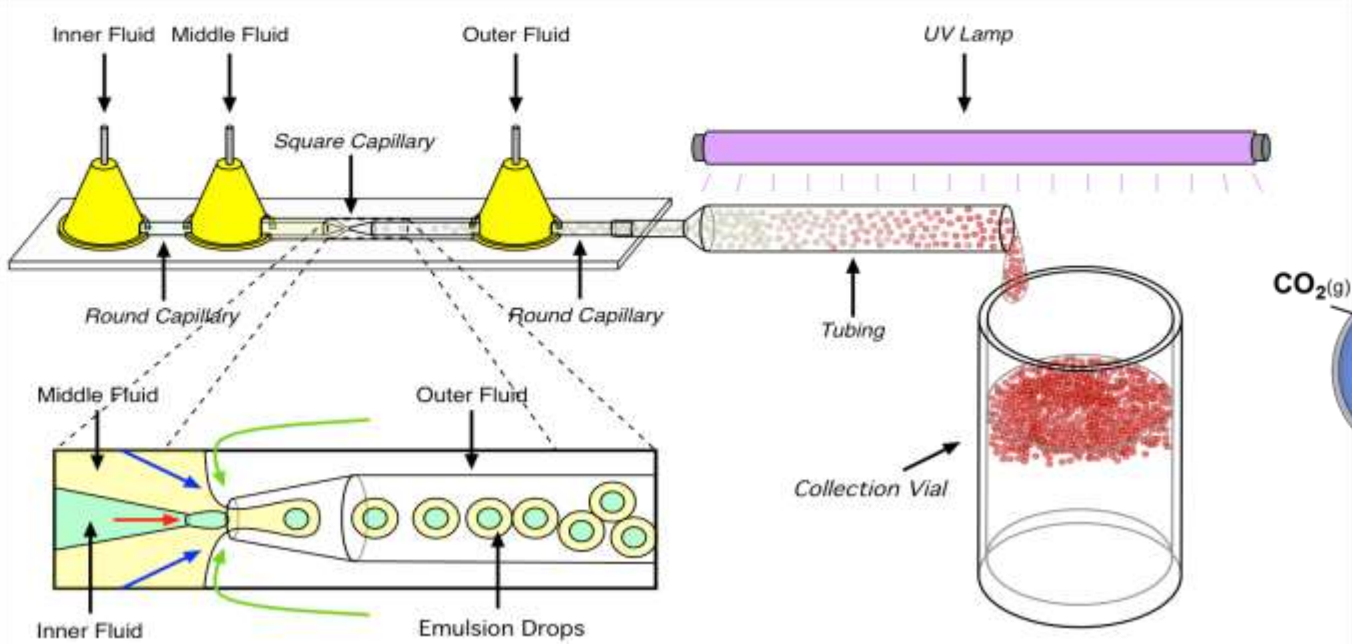
Low [CO_2] capture

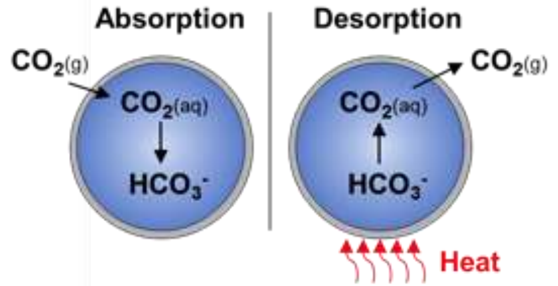


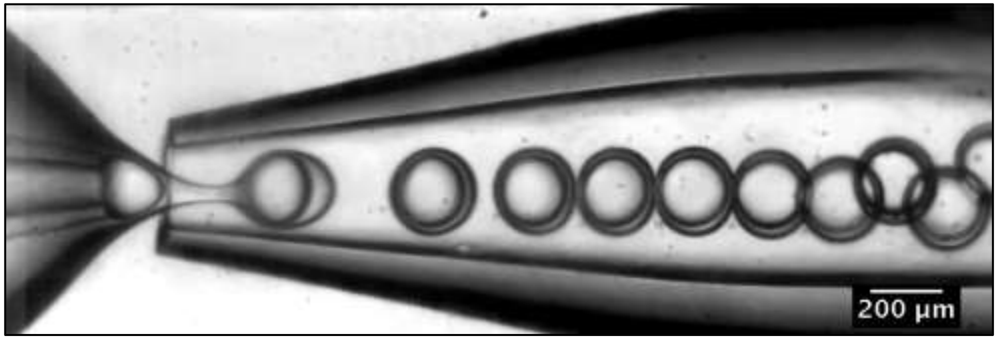
National Academies of Science study funded by DOE

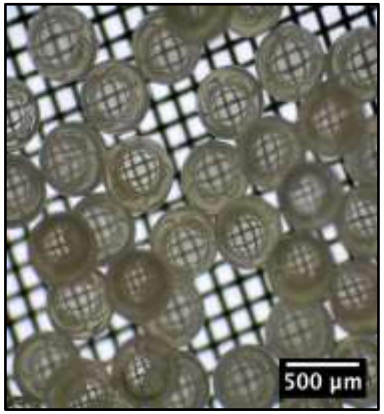
Transformational Carbon Capture R&D

Microencapsulation: an enabling technology for CO2 solvents

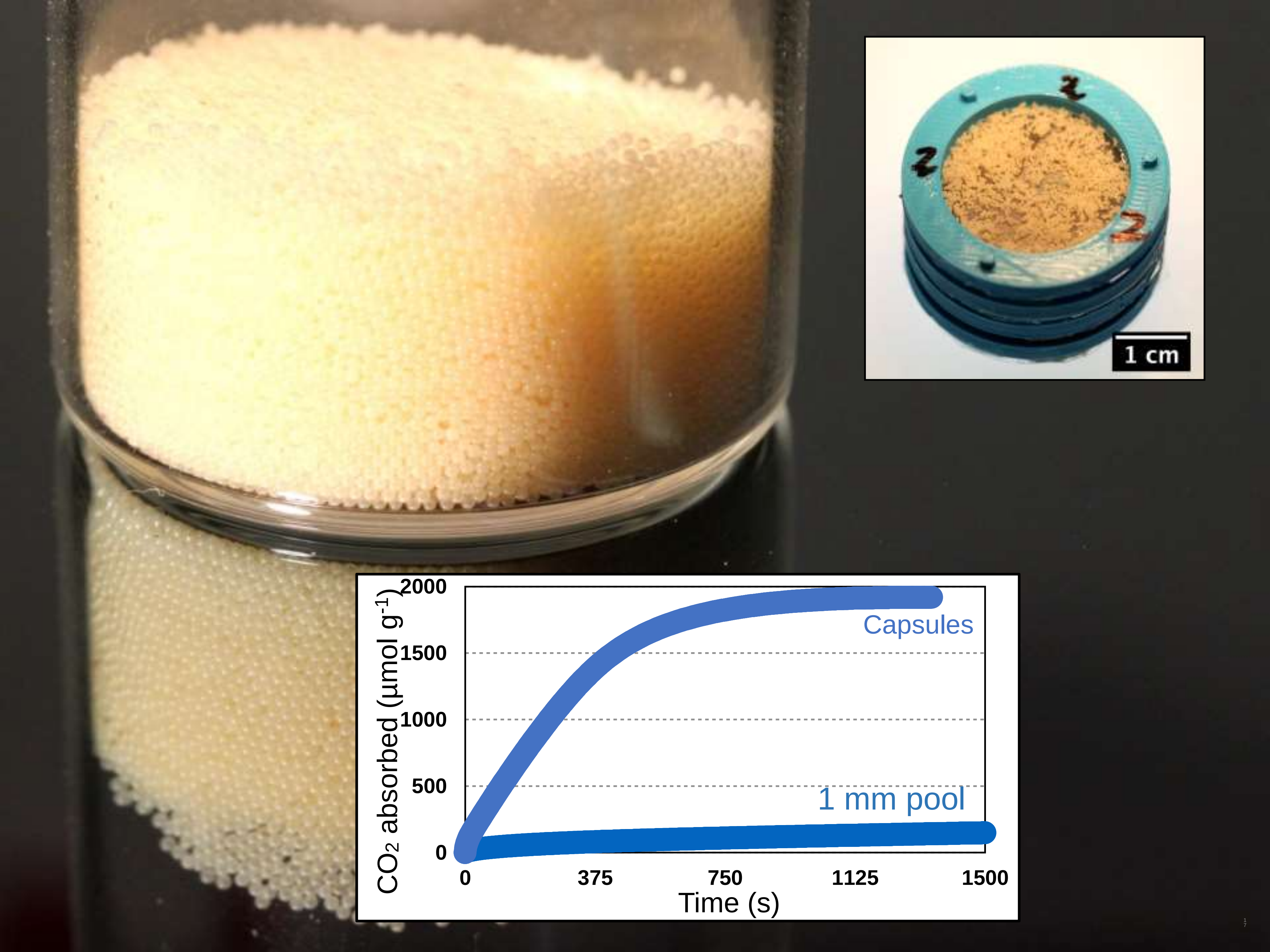






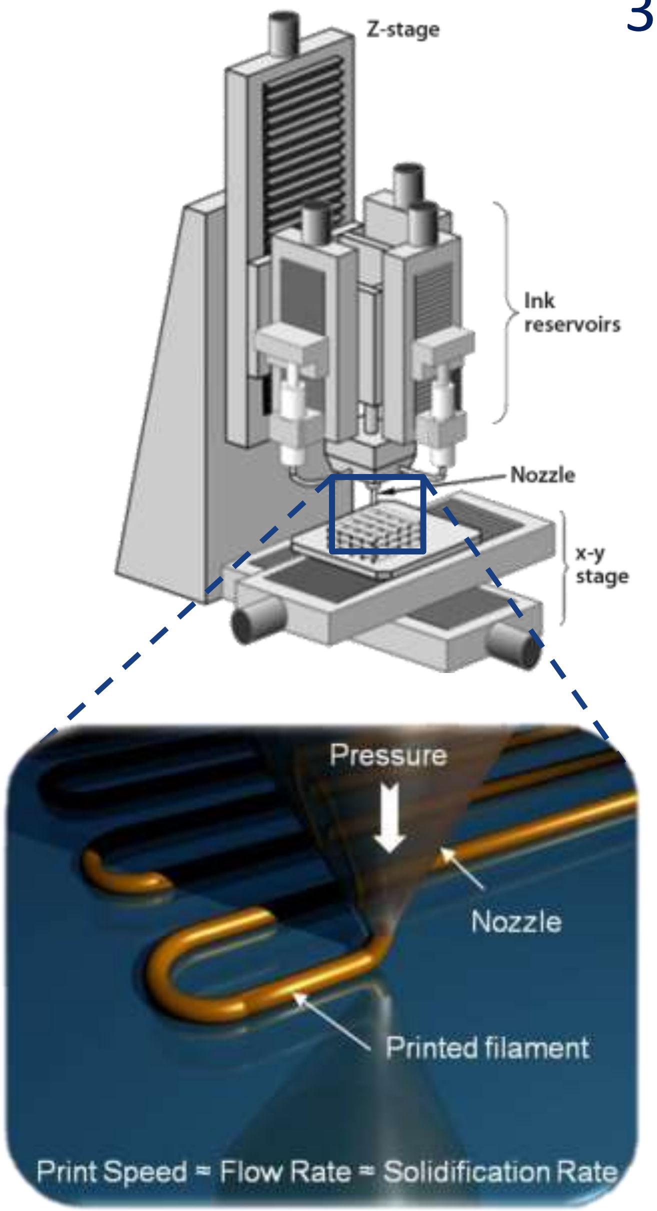


Source: Lawrence Livermore NL, Joshua Skolaroff

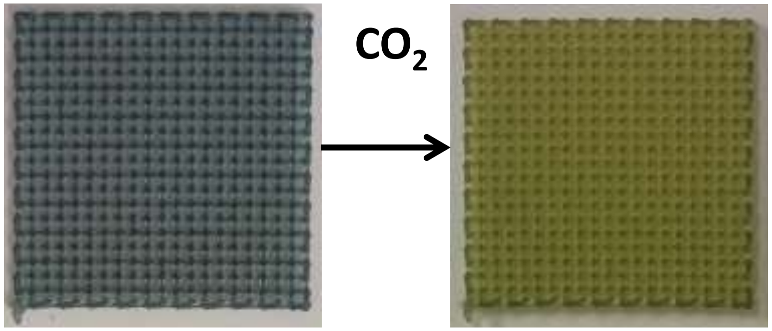

1 cm
CO_2 absorbed (µmol g^{-1})
2000
1500
1000
500
0
Capsules
1 mm pool
0
375
750
1125
1500
Time (s)

Transformational Carbon Capture R&D

3D Printed Composites



- Shear-thinning polymer allows for Direct Ink Write (DIW) of composites
- Can include color indicating dyes to identify CO_2 loading



Source: Lawrence Livermore NL, Joshua Skolaroff

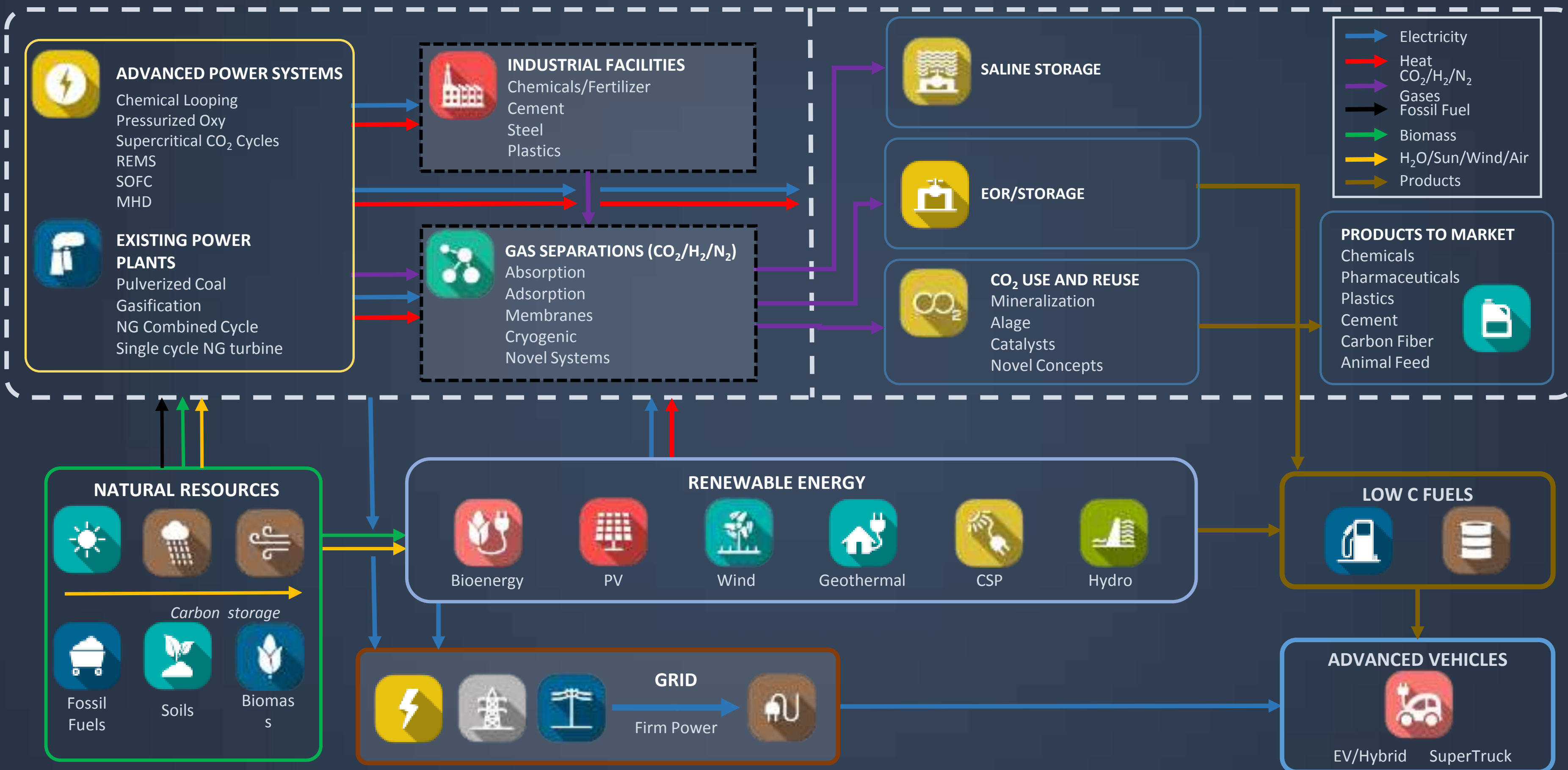
Transformational Carbon Capture R&D

Advanced Non-Aqueous Solvents

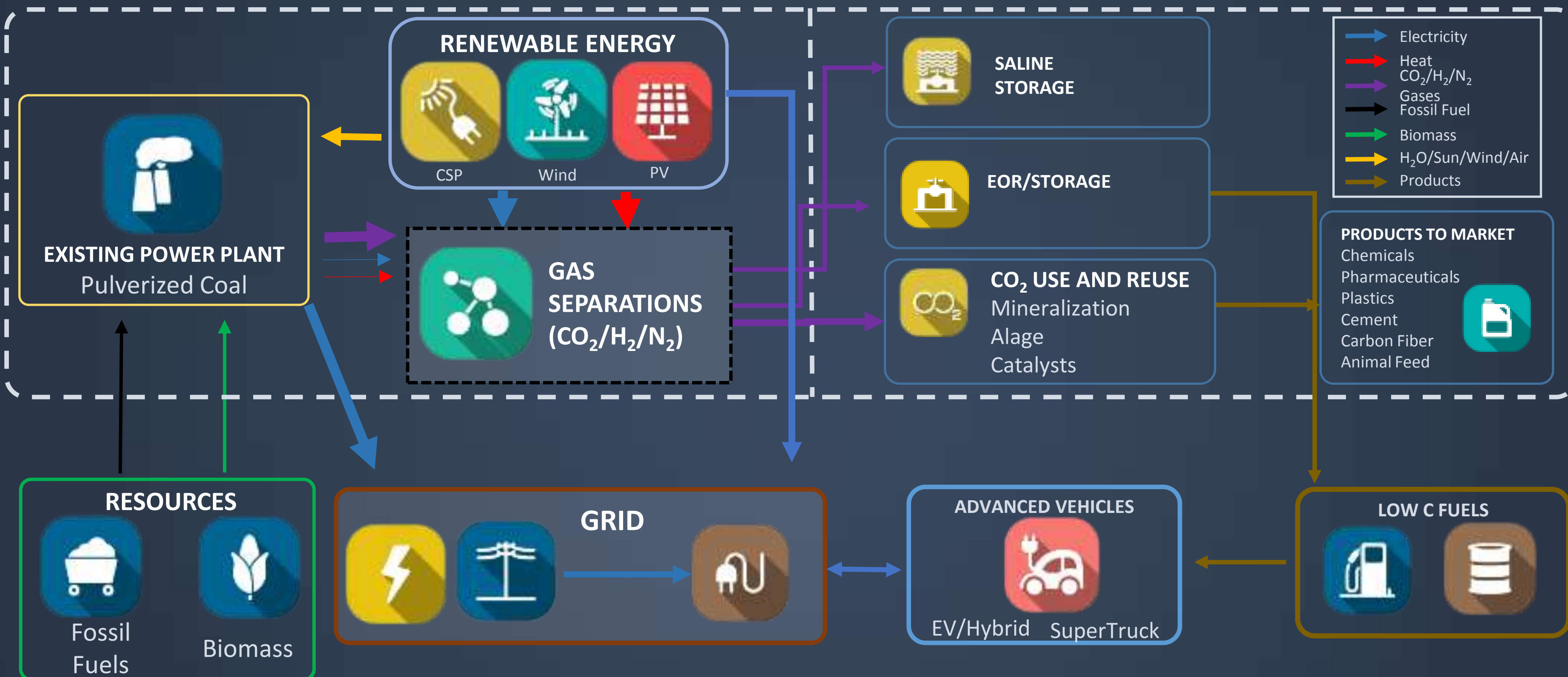
TECHNOLOGY
CENTRE
MONGSTAD

TCM, Monstad, Norway – testing non-aqueous solvent October 10th (collaboration among DOE, TCM, SINTEF, and Statoil to test a U.S. sponsored R&D project at the Norway facility)

Office of Fossil Energy: Integrated System Approach

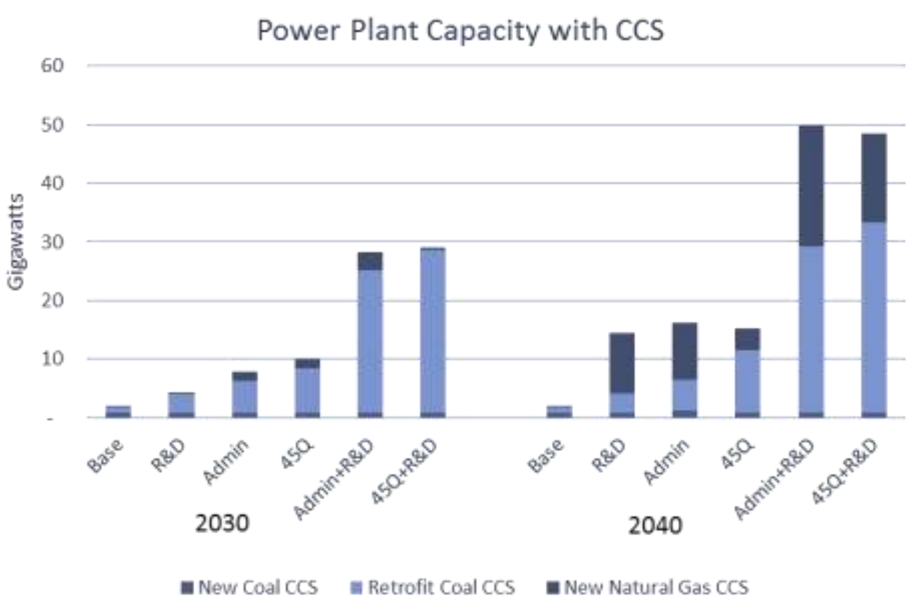


Configuration #1: Renewable resources provide electricity and heat for power plant and industrial processes and CO_2 separation, access electricity goes into the grid



Increasing CCUS Deployment

The combination R&D and tax credits significantly increase CCUS capacity, generation, and the associated CO_2 sequestered from power plants, in comparison to business as usual.



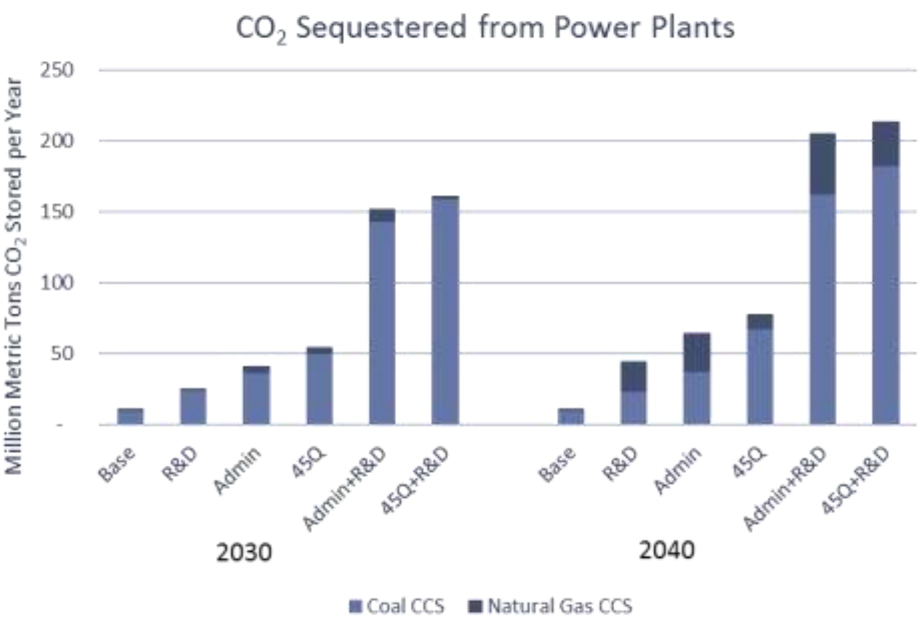


Figure source: DOE Issue Brief "Carbon Capture, Utilization, and Storage: Climate Change, Economic Competitiveness, and Energy Security", August 2016