US Potential for CCS and CCUS
Progress has been made

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Major Take-a-ways

• Status of geologic storage in porous media: mature, successfully underway and ready for large scale implementation

• Challenges: convincing key stakeholders this is true

• Capacity is large but unevenly distributed
Storage in Porous media

Capture > 800 m Land surface

Underground Injection Zone

Confining system limits CO₂ rise

Brine displaced

Pore-scale trapping

Storage in Porous media
Types of Geologic Storage

**Porous media**
- Stacked CO$_2$-EOR and Saline

**Geochemically-dominated storage**
- Rock-water-CO$_2$ reactivity
- Mafics and ultramafics
- Sorption-dominated
  - Coal, lignite, organic-rich shales
- Fractured rocks
Safe and Effective Injection > 50 years

Representative projects

- Water and gas injection for secondary recovery
- Well management, IWR, flood surveillance
- CO₂ capture from gas plants and injection for EOR
- CO₂ saline storage Sleipner
- Monitoring CO₂ EOR Weyburn
- Monitoring CO₂ Huff-n-puff West Pearl-Queen
- Monitoring CO₂ saline test Nagaoka
- Monitoring CO₂ saline test Frio I and II
- Monitoring Phase II EOR tests (Cranfield, Zama, SACROC)
- Injectivity + Monitoring Phase II saline tests
- Injection + monitoring InSalah
- Injection + monitoring Ketzin
- Injection + monitoring Mountaineer
- Injection + monitoring Laq
- Monitoring Phase III EOR + Saline Cranfield
- Monitoring Phase III Saline Decatur
- Monitoring Phase III Saline Citronelle
- Monitoring Phase III EOR Michigan
- NRG, QUEST, Gorgon, Air Products, Boundary Dam...
Examples of Integrated CCS Projects

Capture from

Storage type

For disposal

For EOR

Power production

Industry

Gas Separation

Storage type

For disposal

Boundary Dam, Saskatchewan

AEP Mountaineer, West Virginia

SECARB- Plant Berry Alabama

NRG/PetraNova-Houston TX

Offshore storage

Completed

Gas Separation

Sleipner – North Sea

Snøvit – Barents Sea

Otway Australia

Many fields in Permian Basin sourced from Val Verde Basin gas, TX

Bell Creek, Lost Cabin, WY

Multiple midcontinent US projects

Lula Field offshore Brazil

Uthmaniyah Saudi Arabia

ADM Ethanol, IL

Tomakomai-Hokkaido Japan

Shell QUEST, Alberta

Air Products- Port Arthur TX

Yanchang Ordos, China

Coffeeville and Enid OK

Extensive inventory

https://www.globalccsinstitute.com/projects/large-scale-ccs-projects
Questions Stakeholders are asking

• Leakage
  – Impact on humans, ecosystems, water

• Capacity
  – Is there really enough space to accept CO$_2$
    • In reasonable amounts
    • At reasonable rates 10GT/year

• Seismicity
  – Linked to injection rate via pressure limit
Leakage

• Based on analogs, per IPPC Special Report, a well selected and properly operated site should retain >99% per 1000 years.

• Based on experience, engineered features (wells) are most likely failure points.

Need more designed experiments to experience failures
Experiments: Long term plume stabilization
Wrong imbibition curve: plume migrates too far
Robustness of geologic systems

• Depth – storage below and isolated from fresh water, dense phase >1 km.
• Multi-layered system
  – Low permeability zones (shales and evaporites), high permeability zones.
• Residual trapping
First test: Post injection CO$_2$ Saturation Observed with Cross-well Seismic Tomography vs. Modeled
Measurement at a Well:
Saturation logging (RST) Observation well to measure changes in CO₂ saturation – match to model

Shinichi Sakurai, Jeff Kane, Christine Doughty

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Post injection

Shinichi Sakurai, Jeff Kane, Christine Doughty
Risk to Humans, Ecosystem, Water, Ocean from Storage Failure is Low

Available past practices = low rate of failure and low consequences

- 80MMT stored at SACROC field, Scurry County TX
  - No detection of CO\textsubscript{2} in groundwater
- 20 MMT stored at Sleipner field North Sea
  - No detection of loss by British Geologic survey
  - Well failure studies Kell 2011; Porse, Wade, Hovorka

Controlled release experiments

- What would happen if CO\textsubscript{2} leaked to air, water, soil, ocean
  - Small but detectible impacts. No massive damage.
Health and Safety

• Impact from failure of surface infrastructure and wells

Analog study: Aliso Canyon gas storage facility -- well failure

• Geologic failure – any flow will be retarded by tortuous flow paths – more relevant to long term benefit reduction than H&S

S. Conley et al. Science 2016;351:1317-1320
Protection of Underground Sources of Drinking Water

• Well-known Underground Injection Control (UIC) Risk
  – Brine, CO$_2$, or other impurities liberated during rock-water reaction

• No special risk from CO$_2$
Containment Failure Scenario

- A well fails to isolate the injection zone.
- Fluids, either under pressure or buoyancy, migrate out of intended zone and escape to the surface or into fresh water.

AZMI pressure monitoring
CO$_2$ Controlled Release Experiments

ZERT experiment:

Brackenridge and SECARB experiments
Changbing Yang -- BEG

Ginninderra
http://www.ieagghg.org/docs/General_Docs/1_Comb_Mon_EnvRes/3_GinnCRFSEC.pdf

http://www.pml.ac.uk/News/CCS_controlled_leak_results

http://www.stemm-ccs.eu/
Induced Seismicity

Microseismicity for tracking pressure elevation

Illinois Basin Decatur Project, Lee et al, 2014
Field Measurements of Seismicity

3 year seismic detection project by Makiko Takagish, RITE at Cranfield

- Injection of >5 MMT Co2 over 5 years.
- Pressure increase 1000 psi at times.
- No local microseismicity detection

Minimum detectable amplitudes at reservoir depth are .4 (horizontal) and 0.7 (vertical)
US Storage Resource

- Power Plants
- Pure CO₂ sources
  - Oil and Gas (USGS)
  - Coal (USGS)
  - Brine Aquifer > 1000m

<table>
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<th>Source</th>
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Compiled 2000 from USGS data

Uncertainty in methods Goodwin 2013 review
Gulf of Mexico Partnership - GoMCarb
Use of CO$_2$ for enhanced oil recovery (EOR) process

Residual oil will not move to production wells

At reservoir pressure, CO$_2$ is miscible with oil
- Viscosity decrease
- Volume increase

Oil-CO$_2$ phase can migrate to production wells

30% Remaining oil is residual, immobile

Note: Many other EOR techniques compete with CO$_2$
Overview of CO$_2$ Recycle

- CO$_2$ and oil come out of solution
- Miscible (dissolved) oil-CO$_2$ solution
- Brine
- Low pressure vessel
- High pressure vessel
- Brine
- Oil
- CO$_2$
Conclusions

• Status of geologic storage in porous media: mature, successfully underway and ready for large scale implementation

• Challenges: convincing key stakeholders this is true

• Capacity is large but unevenly distributed

• Methods for dealing with questions
  – Failure is rare: Need more experience via experiments
Where can storage occur:

Thickness of Sedimentary Cover

Prospect under study

Prospect

No prospect