The SPE RD&D Advisory Committee and Carbon Dioxide Capture, Utilization and Storage (CCUS) Technical Section presents:

The Grand Challenge of Carbon Capture and Sequestration

March 2, 2017

Dr. Neeraj Gupta
Senior Research Leader/
Battelle Fellow,
Energy Business Line, Battelle

George Koperna
Vice-President,
Advanced Resources Int'l Inc.

Owain Tucker
Global Deployment Lead for CCS
Shell Global Solutions

Poll Question

Who is your employer?

Poll Question

How many years of experience do you have?

Poll Question

What geographic region are you from?

Poll Question

I am most interested in:

Poll Question

If you have you worked on a CCUS project, what stage was it at?

This webinar is a presentation of the article appearing on SPE.org at:

http://www.spe.org/industry/carbon-capture-sequestration-2016.php

Society of Petroleum Engineers Grand Challenge: Carbon Capture and Sequestration

George J. Koperna, Jr.[1], Neeraj Gupta[2], Michael Godec[1], Owain Tucker[3], David Riestenberg [1], Lydia Cumming[2]

SPE Grand Challenges

Carbon Capture and Sequestration is one of the SPE's Technical Directors Grand Challenges.

Read about the Grand Challenges at:
http://www.spe.org/industry/globalchallenges.php

Grand Challenges Facing the E&P Industry

The E&P industry faces numerous challenges as it addresses growing energy demand, the need for sustainable operations, declining production from older reservoirs, and new resources in harder to reach and harsher environments. The SPE Research & Development Committee (now Research Development Technical Section) identified five grand challenges for the industry and is developing white papers for each one that describe the challenge, the current state of R&D, and areas for further research.

Carbon Capture and Sequestration

Briefly stated, carbon capture and sequestration (CCS) will help us to sustain many of the benefits of using hydrocarbons to generate energy as we move into a carbon-constrained world.

The condensed version is featured in SPE's JPT magazine

Read it TODAY!

JPT
JOURNAL OF PETROLEUM TECHNOLOGY

January 2017 | Volume 69, Number 1

08 DECEMBER 2016

The Grand Challenge of Carbon Capture and Sequestration

This article is a summary of the 2016 follow-up paper on carbon capture and sequestration, one of the five grand challenges to the industry identified by the SPE R&D Committee in 2011.

10

Not a member of the CCUS Technical Section?

Join now at: http://connect.spe.org/ccusts/home

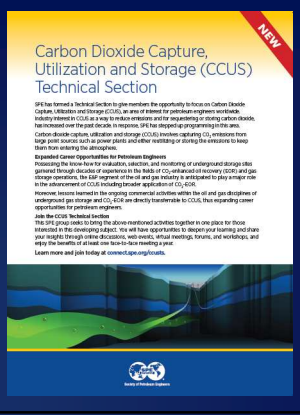
Carbon Dioxide Capture, Utilization and Storage Technical Section

Carbon Dioxide Capture, Utilization and Storage Technical Section

Carbon capture and storage (CCUS) is a method of reducing emissions of CO_2 from burning fossil fuels by capturing it from large point sources and storing it so that it doesn't enter the atmosphere. Depleted oil and gas reservoirs are promising sequestration sites, and the oil industry has 30 years of experience in injecting CO_2 to enhance oil recovery. The E&P industry will play a major role in any advancement of CCUS because it has the knowledge and skills required for the evaluation, selection, and monitoring of underground storage sites.

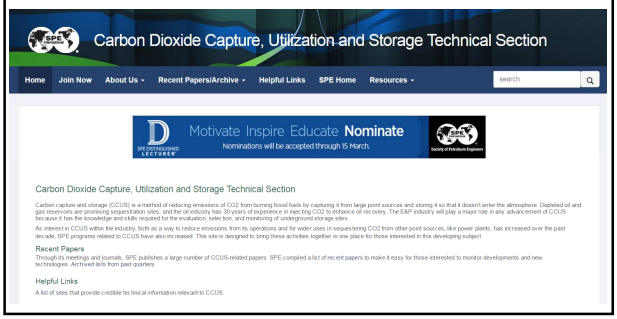
As interest in CCUS within the industry, both as a way to reduce emissions from its operations and for wider uses in sequestering CO_2 from other point sources, like power plants, has increased over the past decade, SPE programs related to CCUS have also increased. This site is designed to bring these activities together in one place for those interested in this developing subject.

CCUS Technical Section



Not a member of the CCUS Technical Section on SPEConnect?

http://connect.spe.org/ccusts/home



Carbon Dioxide Capture, Utilization and Storage Technical Section

Attending ATCE 2017?

Join CCUS members and professionals at ATCE and attend the

FIRST ANNUAL CCUS Annual Dinner at ATCE

Network with, listen to exceptional speakers and share discussions on topics of interest.

When: Monday 8 October
Where: ATCE 2017 – San Antonio, TX

Stay tuned for details

Outline

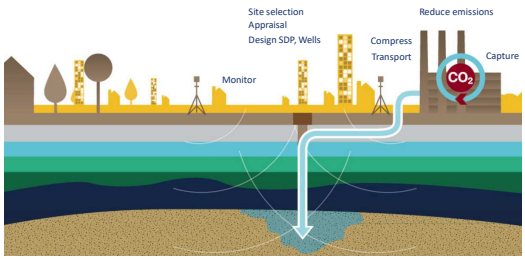
1. Introduction
2. Challenges of CCS
   a) Cost effective capture
   b) CO_2 storage in geologic formations
   c) Reusing old fields and infrastructure
   d) Demonstrating that storage is secure
   e) Dealing with the availability of much more CO_2
   f) Disseminating Best Practices
3. Summary

Owain Tucker, Shell (o.tucker@shell.com)

INTRODUCTION

What is CCS?

Permanent isolation of CO_2 from the atmosphere



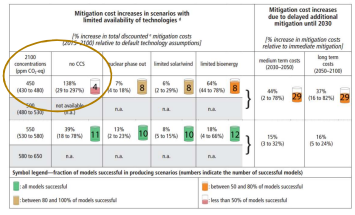
Storage or Sequestration: Depleted fields, CO_2 EOR storage, Saline formations

From: Zero Emissions Platform : http://www.zeroemissionsplatform.eu/carbon-capture-and-storage.html

Important part to deliver CO_2 reduction targets

- IPCC models show that CCS is almost always required
- Without CCS the cost of achieving 450ppm significantly higher
- Many models overshoot and require "net negative emissions" calling for bioenergy + CCS

Table SPM.2: IPCC, Climate Change 2014 Synthesis Report Summary for Policy Makers



2100 concentrations (ppm CO_2-eq)	Mitigation cost increases in scenarios with limited availability of technologies [3] (% increase in total discounted [1] mitigation costs (2015–2100) relative to default technology assumptions)					Mitigation cost increases due to delayed additional mitigation until 2030 (% increase in mitigation costs relative to immediate mitigation)	
	no CCS	nuclear phase out	limited solar/wind	limited bioenergy		medium term costs (2030–2050)	long term costs (2050–2100)
450 (430 to 480)	138% (29 to 297%)	4	7% (4 to 18%)	8	6% (2 to 29%)	8	64% (44 to 78%)	8	44% (2 to 78%)	29	37% (16 to 82%)	29
500 (480 to 530)	net zero/negative [2]		n.a.		n.a.		n.a.					
550 (530 to 580)	39% (18 to 78%)	11	13% (2 to 23%)	10	8% (5 to 15%)	10	18% (4 to 66%)	12	15% (3 to 32%)		16% (5 to 24%)	
580 to 650	n.a.		n.a.		n.a.		n.a.					

Symbol legend—fraction of models successful in producing scenarios (numbers indicate the number of successful models)

- all models successful
- between 80 and 100% of models successful
- between 50 and 80% of models successful
- less than 50% of models successful

Key to unlocking fossil energy

- Deployment of CCS allows fossil fuel to participate in the Net Zero emission future

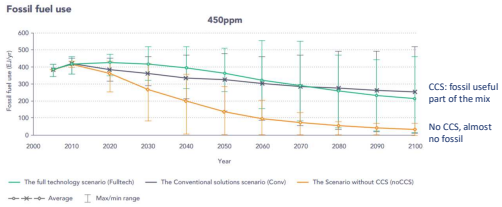
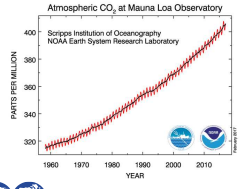


FIGURE ES1 Average consumption of fossil fuels across a range of integrated assessment model outputs: from Sustainable Gas Institute, Can Technology Unlock Unburnable Carbon

How have we been doing on CO_2 reduction without CCS?

- Petroleum engineers look at past performance as an indicator of future performance



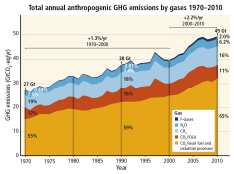
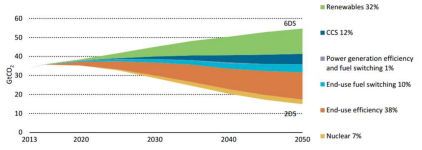


Figure SPM.2: IPCC, Climate Change 2014 Synthesis Report Summary for Policy Makers

CCS creates significant CO_2 engineering opportunities

- Injection of gasses & liquids ✓
- Well and facilities design, construction, operation ✓
- Subsurface forecasting, conformance and containment ✓
- 40 years of CO_2 EOR experience ✓
- Monitoring and information management ✓

Adding 150-300 Mt CO_2 storage capacity each year translates into an industry of scale comparable to natural gas



Source: IEA (2016b), *Energy Technology Perspectives 2016.*

Warning: CO_2 engineers at work

- Quest CCS in Alberta, Canada
- Started up 2015
- CO_2 from oil sands upgrader
- Deep saline injection
- Over 1.5 mln tonnes stored to date

Image courtesy of Shell, Marathon Oil, and Chevron

Neeraj Gupta, Battelle (gupta@battelle.org)

CHALLENGES OF CCS

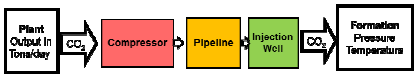
Cost effective capture of power and industrial CO_2 are needed to attain GHG reduction goals

- Fossil power plants emit ~2 gigatonnes CO_2/year in the USA
- Viable storage options justify the investment in capture technologies to lower costs
- Relatively high purity point sources of CO_2- gas processing, petrochemical, ethanol, cement, etc. - are attractive targets for CO_2 capture in the near term

Learning by doing: In 2014 Boundary Dam Power Station became the first power station to use CCS technology at full scale (source of photo: SaskPower)

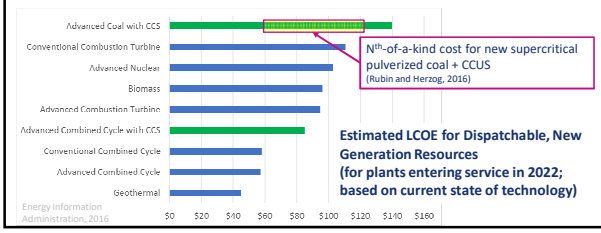
First-of-a-kind plants and early movers can provide important learning experiences

- Two post combustion capture plants operating
  - SaskPower Boundary Dam – Retrofit using proven technology, some difficulties but manageable
  - NRG's Petro Nova Facility – Retrofit using proven technology, on time and within budget.
- Kemper Counter Energy Facility is almost operational
  - New build using a first-of-a-kind gasification technology; experienced significant delays and cost increases
- Industrial sources of CO_2 that are easier to capture would still require significant investment in infrastructure to move CO_2
  - Could pave the way for infrastructure development for the larger point sources

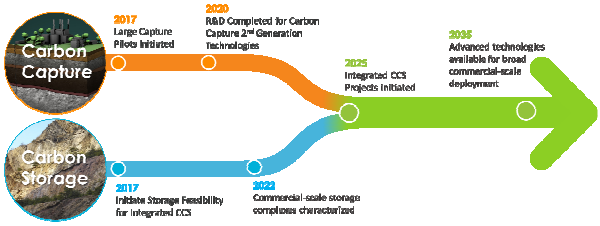


CO_2 capture at power plants is still a work in progress

- High auxiliary load decreases net electric generation
- Capture not economical without incentives/EOR
- Heavy investments in R&D of "game changers" but will take time
- More large-scale projects needed to bring down costs and only a small number are in the pipeline



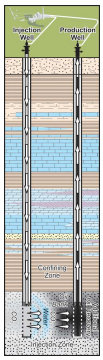
DOE is seeking to integrate carbon capture and carbon storage technologies



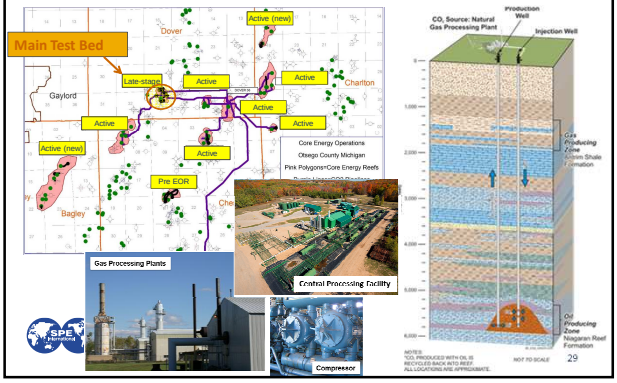
Source: Lynn Brickett, DOE-NETL, 2016

Many aspects of CCS mirror CO_2-EOR projects

- Land companies secure the acreage
- Geologists describe the reservoir and seal
- Engineers design the surface and subsurface equipment, plan to maximize value proposition
- Oversight agencies ensure compliance
- Operators generate cooperation with landowners through financial compensation, good project oversight

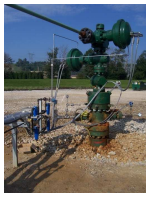


MRCSP Michigan Basin Project Example (www.mrcsp.org)



Preparing for a CO_2 Storage Industry requires oil & gas expertise and novel solutions

- Differs from CO_2 EOR mostly in scale and pore space access
  - CO_2 plumes could grow several kilometers in radius
  - Challenges in optimizing pore space usage and pressure management
  - Plume tracking includes plume modelling strategies coupled with advanced geophysical techniques
- Legislative enablers to develop a storage industry still elusive
  - Stronger political support is needed
  - No uniform framework to access to pore space rights or financially compensate landowners
  - Requires development of well conceived outreach strategy with mechanisms for local benefits and trustworthy stewardship

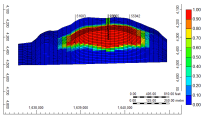


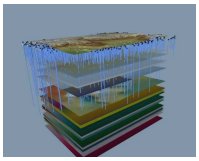
Appropriate regulatory regimes and international standards are evolving

- Builds on existing framework for regulating oil and gas activities
- Characteristics of desirable regulatory regime
  - Provides a mechanism for stakeholder engagement
  - Establishes a level playing field for project proponents
  - Provides sufficient transparency to support credits, etc.
  - Addresses ownership, property rights and liability considerations
- International Standards (ISO TC 265)
  - Standards for CO_2 capture, transportation and storage
  - Includes EOR

Depleted oil and gas fields offer several advantages and some challenges

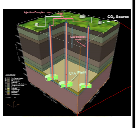
- Pros
  - Existing infrastructure and industry
  - Proven secure storage
  - Capacity is well understood
- Cons
  - Assessment, monitoring and repair of legacy wells can be costly
  - CO_2 has specific O&M challenges, for example
    - Management of fluid movement through phase changes
    - Cooling effect impacts design of downhole components
    - Formation of hydrates

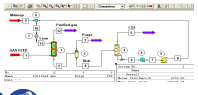


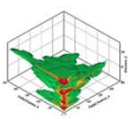


Demonstrating long-term security will be key

- Degree of risk aversion to "novel" technology
  - Fluid injection brings out public concern (e.g., leakage, seismicity)
- Requires integrated subsurface resource planning where activities like gas storage, brine disposal, occur
- Application of risk management tools is critical





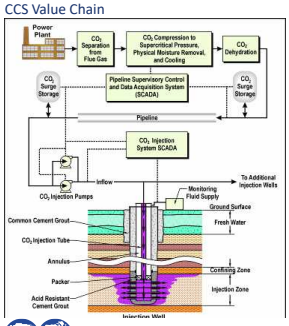


Petroleum engineers will need to make the bridge between O&G and CO_2 storage

- Possible to combine CO_2-EOR with storage; Saline reservoirs offers largest resources
- Requires CCS specific monitoring, permitting and long term care processes
  - Storage operations will be decades long and very large in magnitude
  - Presents unique data archiving and technology evolution/obsolescence challenges

Organizations like SPE to can contribute to the development of best practices

CCS Value Chain



Enterprise Strategic Planning
- Carbon foot print analysis
- Source reduction analysis
- Asset opportunity screening

Capture
- Development of new capture concepts
- Applications screening
- Process optimization and integration

Surface Transport
- Analysis of CO_2 transport properties
- Process optimization and integration
- System design support
  - Compression and processing
  - Pipeline transport
- Monitoring (inspection, corrosion analysis etc.)

Subsurface and Injection
- Site characterization
- Permitting and NEPA
- Well field design and implementation
- Injection operations

Measurement Mitigation and Verification
- MMV design, implementation and operation
- Data analysis

George Koperna, Advanced Resources International, Inc.
(gkoperna@adv-res.com)

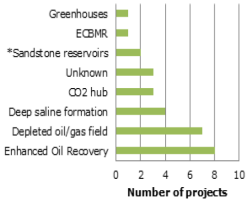
NEW FLOODING PARADIGMS

Dealing with the availability of much more CO_2

If R&D and technological development are successful in bringing down the cost of capture, there will be a ***flood*** of CO_2 into the market. Using the US as an example, this CO_2 volume is estimated at 2 gigatonnes per annum or ~100 Bscfd (US EPA, 2016).

Many researchers believe that EOR would provide the storage sink for a large number of early projects, as many projects look to monetize the CO_2 returns to offset operational costs.

Sinks for 29 Current Pipeline Projects



Source: Nothout, P., et al., "CO_2 Pipeline Infrastructure – lessons learnt," GHGT 12, 2012.

Dealing with the availability of much more CO_2

2 Gt per year is a lot of CO_2. If we are to think about it in terms of oil recovery, we can begin to understand how large scale CO_2 capture can impact oil extraction when CO_2-EOR is applied to amenable oilfields.

200 MMt/yr * 1bbl/0.4 t * 1 yr/365 days = 1.4 MMbbl/d

Where,

1 tonne CO_2 = 18.9 Mscf

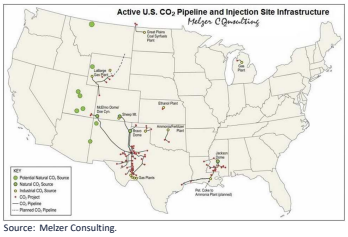
1bbl/0.4 t = ~8 Mcf/bbl

200 MMt/yr = ~10Bscf/d

Dealing with the availability of much more CO_2

Unfortunately, world-wide CO_2 infrastructure is scant. In the U.S., where it is most mature, there is only 4,500 miles of transportation line, capable of moving 3.5 Bscfd of CO_2 per day.

These pipelines are situated for natural CO_2 delivery to EOR projects and are not located to take advantage of the large coal-fired electric generating facilities.

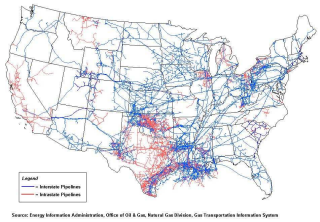


Source: Melzer Consulting.

Dealing with the availability of much more CO_2

As a comparison, the natural gas transportation system, in the U.S., totals more than 300,000 miles of intrastate and interstate pipelines, reflecting 70 times that of CO_2 pipelines.

Because of their existing infrastructure, depleted oil and gas fields may be the first targets for these potentially large volumes of CO_2. This would allow saline storage projects to develop.



Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System

Dealing with the availability of much more CO_2

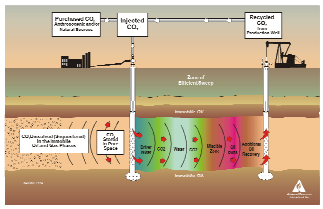
The infrastructure buildout would be tremendous.

- Existing oil and gas fields would require extensive workover to prepare the facilities and wells to safely and securely accept the CO_2
- Large diameter interstate CO_2 pipelines would require design, financing, and construction to move the CO_2 from large anthropogenic sources to the storage/EOR sites
  - This is a lot like Eisenhower's interstate highway buildout
- Once delivered, this CO_2 volume could, conceivably, be at a greatly reduced cost to the operator

Dealing with the availability of much more CO_2

Conventional CO_2-EOR floods use horizontal flooding technologies and water-alternating-gas strategies to conform the flood and optimize the amount of CO_2 used per barrel of oil.

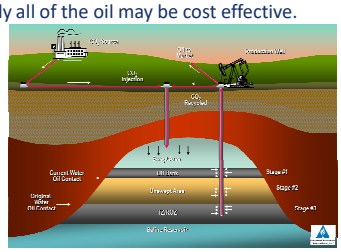
In some cases, the EOR flood does not employ a WAG. Rather the high perm, relatively thin pay zones are flooded with straight CO_2.



Dealing with the availability of much more CO_2

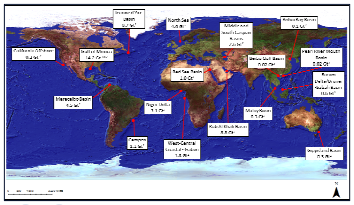
Where geology is cooperative, top-down or bottoms-up vertical flooding protocols that use significantly larger volumes of CO_2 and recover essentially all of the oil may be cost effective.

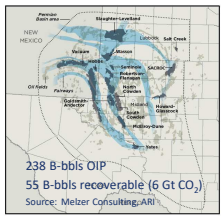
Source: Barnes, D., et al., "CO_2/EOR and Geological Carbon Storage Resource Potential in the Niagaran Pinnacle Reef Trend, Lower Michigan, USA," GHGT 11, 2010.



Dealing with the availability of much more CO_2

Conventional CO_2-EOR flooding protocols could be applied to giant storage/hydrocarbon recovery opportunities in the offshore or onshore in residual oil zones.





Disseminating Best Practices

Lessons learned from ongoing projects are key to the efficient development and deployment of CCUS.

1. Few large-scale storage projects exist
2. Most large-scale injection projects are CO_2-EOR projects
   i. It's an analogue
   ii. But…regulations, ownership issues, liability, outreach, plume and pressure management differ
3. Oil & Gas should work more closely with electricity cos
4. Support of professional societies is key

SUMMARY

Summary

To support global climate initiatives, CO_2 storage at such a large scale represents a Grand Challenge requiring:

a) Cost effective capture
   i. We are still very early on the learning curve
   ii. Large demonstrations of next generation capture technologies required
b) Safe, secure CO_2 storage on a large scale
   i. CO_2-EOR experience is a plus
   ii. Containment, regulations, pore ownership, public outreach, plume management are still salient issues
c) Access to pore space
   i. Plume growth could be significant
   ii. Continue R&D to develop reservoir, drilling, and completion practices
d) Infrastructure buildout
e) Technology Transfer

Let's Play our Role!

CO_2 storage at the scale necessary to support global climate change initiatives presents a Grand Challenge, albeit one SPE is well-positioned to help address, with openness from industry.

a) Dissemination of Best Practices
b) SPE Members are particularly skilled in CCUS operations, across the value chain
c) It's a new business opportunity