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Status and Challenges in CO_2 Geological Storage

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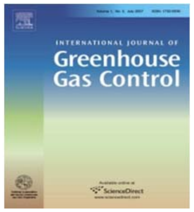
Associate Editor (Storage)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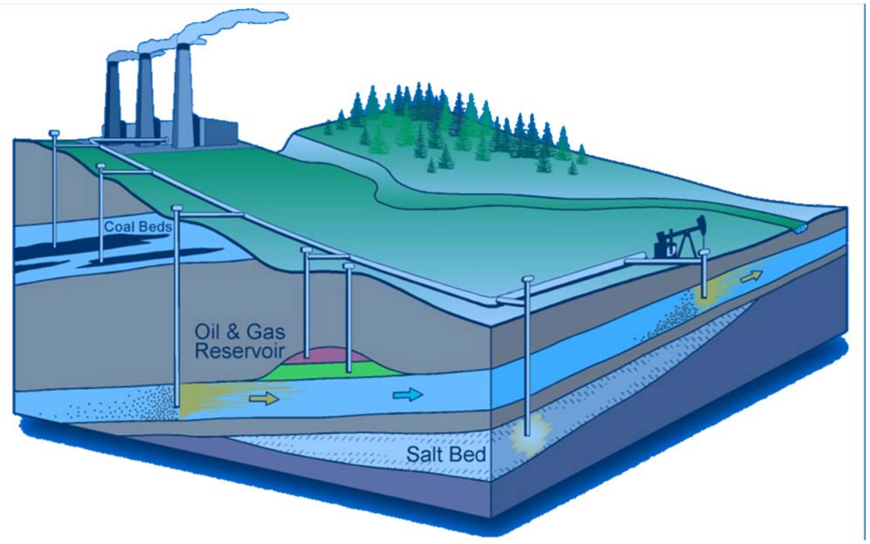
Outline

- The Case for CO_2 Capture and Storage
- Geological Storage of CO_2
- Storage Challenges to CCS Deployment
  - Scientific and Technical Issues
  - Legal and Regulatory Issues
- The Special Case of CO_2-EOR
- Closing Remarks

The Case for
CO_2 Capture and Storage



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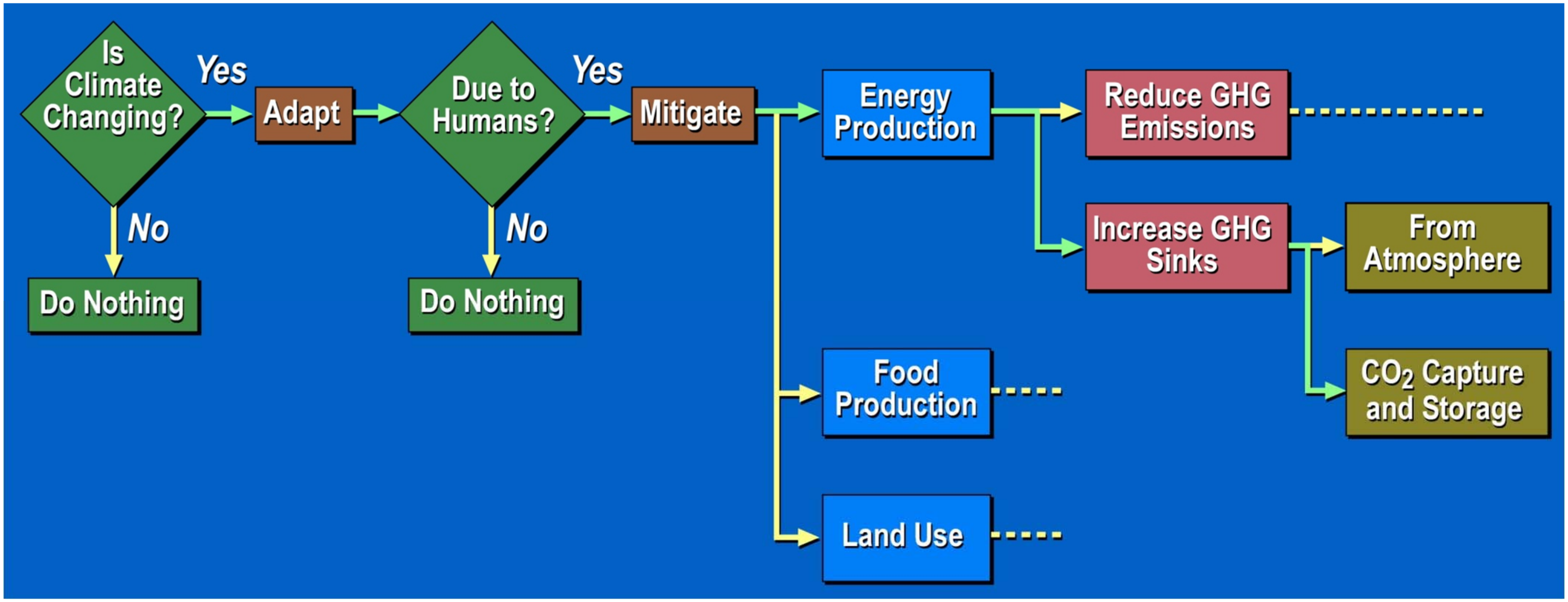
The Pathway
to CO_2 Capture and Storage


Is Climate Changing?
Yes
No
Do Nothing
Adapt
Due to Humans?
Yes
No
Do Nothing
Mitigate
Energy Production
Reduce GHG Emissions
Increase GHG Sinks
From Atmosphere
CO_2 Capture and Storage
Food Production
Land Use

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Anthropogenic Carbon Balance

$$C_{emmitted} = C_{produced}$$

Can be expressed by Kaya Identity (1995) as

$$C_{emmitted} = P \times (\frac{GDP}{P}) \times (\frac{E}{GDP}) \times (\frac{C}{E})$$

P - population; GDP/P – standard of living; E/GDP: Energy intensity of the economy
C/E: carbon intensity of the energy system

Historically $P \times (\frac{GDP}{P}) > (\frac{E}{GDP}) \times (\frac{C}{E})$

Modified Kaya Identity

$$C_{emmitted} = P \times (\frac{GDP}{P}) \times (\frac{E}{GDP}) \times (\frac{C}{E}) - C_{stored}$$

Source-Oriented Mitigation Measures

Addressing $\left(\frac{E}{GDP}\right)$ *and* $\left(\frac{C}{E}\right)$

- o Lowering E/GDP:
  - Energy conservation
  - Improving energy efficiency in production, transmission and use
- o Lowering C/E
  - Fossil fuel switching from coal to gas;
  - Use of nuclear energy ?? See Japan and Germany after Fukushima
  - Use of renewable energy ?? Insufficient, intermittent, can't be stored

- Use of coal as a primary energy source is declining only in North America as a result of the shale-gas revolution, but it is increasing in other parts of the world, particularly in China and India, South Africa, and also in some European countries
- Use of natural gas without CCS is only a bridging technology (IPCC AR5, 2014)

Sink-Oriented Mitigation Measures

Addressing C_{stored}

- By natural capture of CO_2 by forests and soils after emission and dispersal into the atmosphere (seems to be almost neutral and hard to control due to forest clear-cutting in tropical regions)

- By capture at large sources and:
  - Utilization (which is negligible, in the food and other industries)
  - **Storage in geological media** (ocean storage is unacceptable)

Energy Resources this Century

- **Fossil Fuels**
  - Have highest energy storage capacity, plentiful and most economic
  - Have geopolitical implications (see Middle East, Russia, North America)
  - Their use leads to CO_2 emissions
  - Will dominate energy production this century until other forms of energy are developed economically and corresponding infrastructure is put in place

- **Nuclear** – Mature base-load technology, with many associated risks
  - Very lengthy process and very costly to build new plants
  - Public opposition in some countries, particularly after Fukushima
  - Limited uranium reserves
  - Enrichment poses issues of nuclear arms proliferation

- **Solar** (Photovoltaic and thermal)
  - The most costly of all form of energy production, still needs direct/indirect support
  - Requires large surface areas for PV
  - Intermittent; storage of solar energy (like for wind energy) is still a challenge

- Other renewables are insufficient (e.g., hydro, wind, biomass), some are uneconomic and/or unreliable (e.g., wind, sometimes hydro), grid integration is a challenge, need financial support

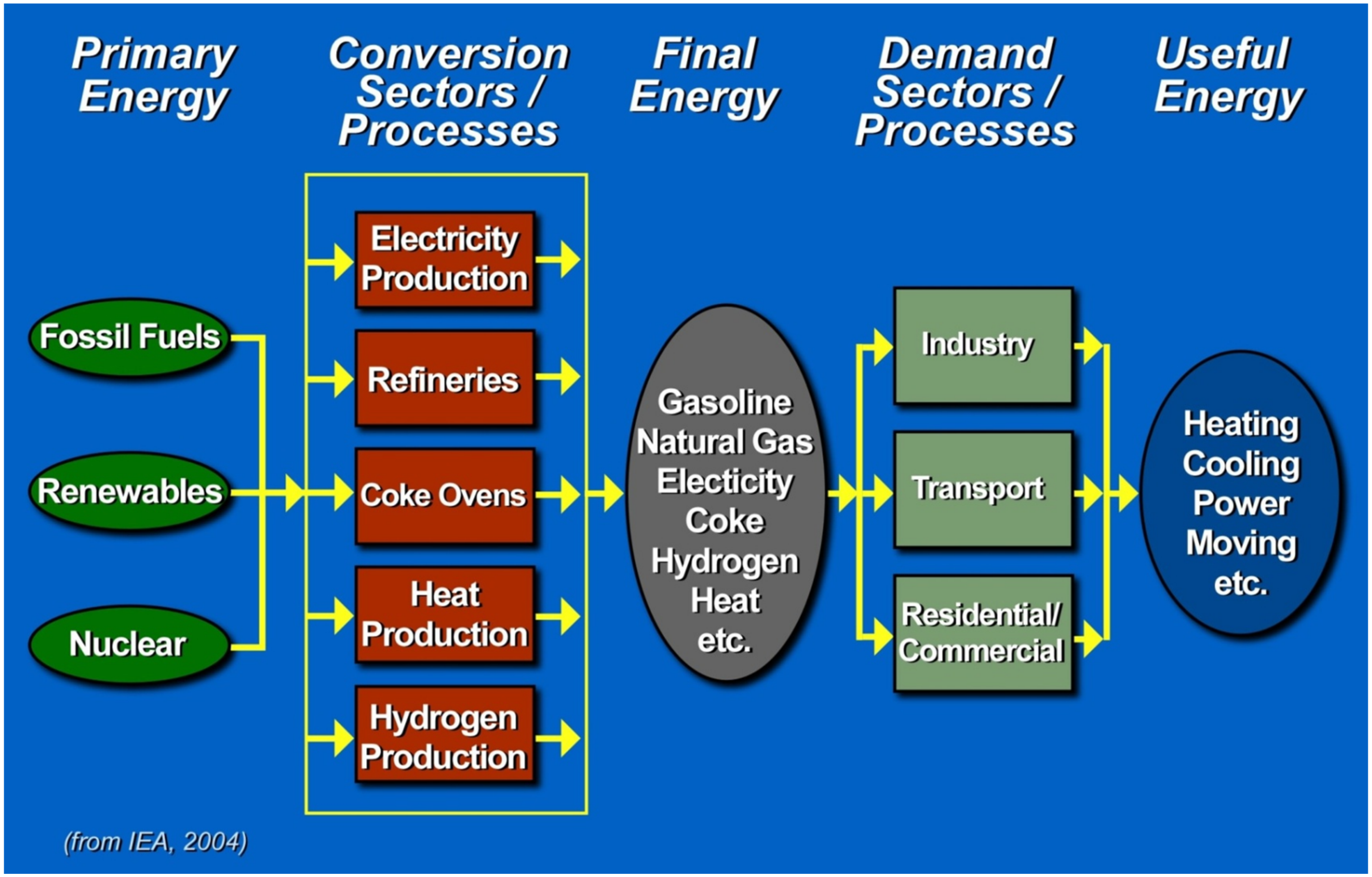
Energy Demand to 2035

Energy Source			Current Policies		New Policies
	2000	2011	2020	2035	2035
Coal	2,357	3,773	4,483	5,435	4,428
Oil	3,664	4,108	4,546	5,094	4,661
Gas	2,073	2,787	3,335	4,369	4,119
Nuclear	676	674	866	1,020	1,119
Hydro	225	300	379	471	501
Biomass	1,016	1,300	1,472	1,729	1,847
Other renewables	60	127	278	528	711
Total (Mtoe)	10,071	13,070	15,359	18,646	17,387
Fossil Fuel Share (%)	80	82	80	80	76
CO_2 Emissions (Gt)	**23.7**	**31.2**	**36.1**	**43.1**	**37.2**

Mtoe: Million tonnes oil equivalent

IEA World Energy Outlook 2013

Model Reference Energy System



(from IEA, 2004)

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Management of Anthropogenic CO_2

- Major technological breakthroughs are needed in:
  - Improving the efficiency of energy systems
  - Improving the efficiency of oil- and electricity-based transportation systems
  - Production (capture) of solar energy
  - Storage of solar and wind energy

- Move towards a hydrogen, electricity and oil-based economy by decarbonizing fossil fuels, with water and CO_2 as byproducts

- Increase of CO_2 sinks on a large scale through CO_2 capture and storage

Current Global Status of CCS

GCCSI carried out a global inventory of fully integrated CCS projects (February 2014)

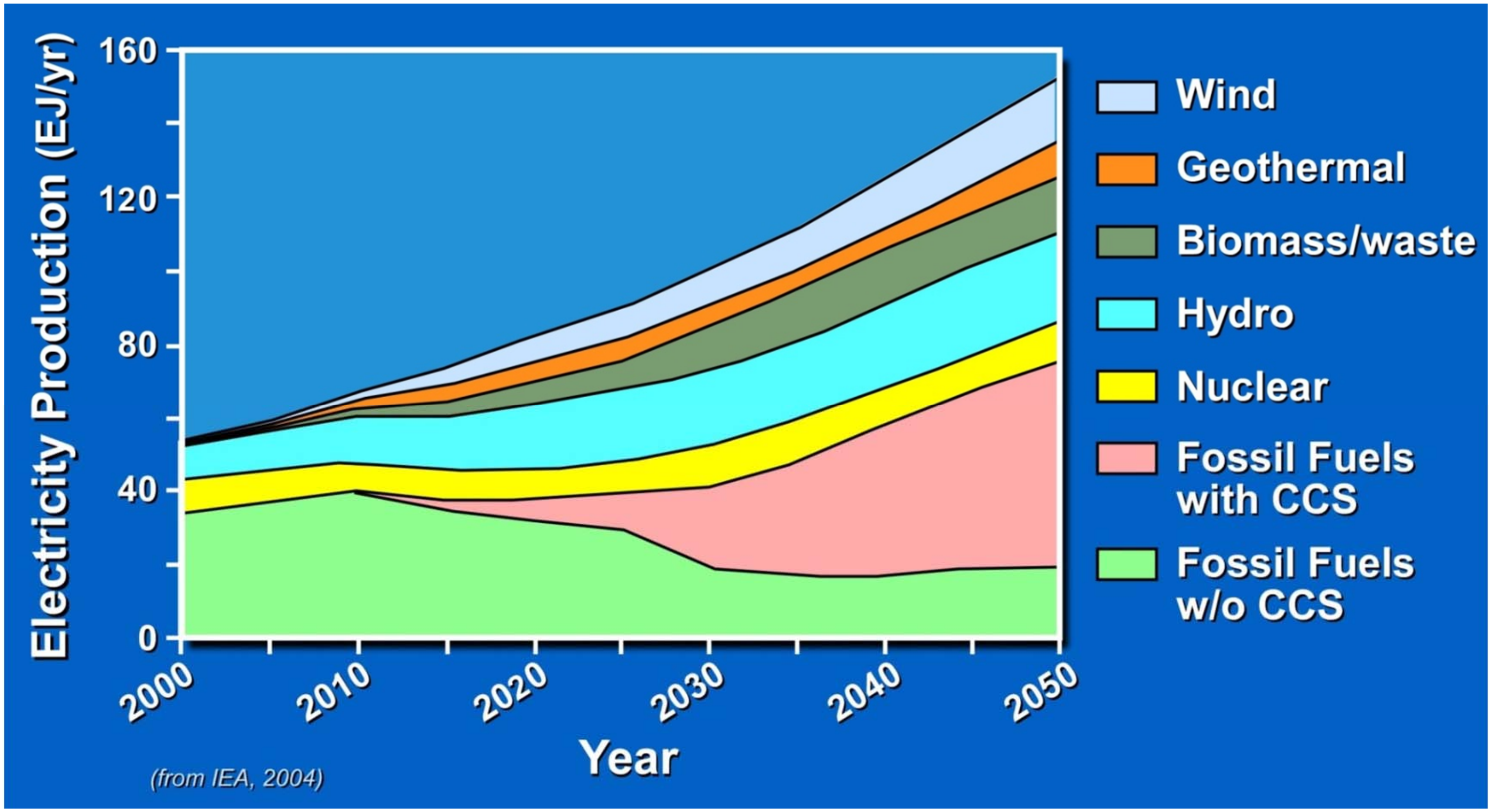
- **60** projects are of sufficient size to meet demonstration criteria, with a cumulative capacity of **40** Mt CO_2
  - **12** are currently operational, all in the oil & gas sector
  - **9** projects are in the execution stage, including **2** in the power sector in Canada and U.S., and **1** in the industrial sector (iron & steel) in the Middle East
- Lately many previously-announced projects were scaled down, discontinued or canceled, mostly in Europe and Australia (14 projects since 2011)
- In North America:
  - U.S. is conducting a vigorous R&D program led by US DOE, including mapping of CO_2 storage potential, risk assessment, pilot- and commercial-scale demonstrations (e.g., the Decatur project in Illinois with CO_2 sourced from an ADM plant)
  - Several commercial-scale projects are being implemented in US and Canada with government support (e.g., Shell's Quest project)
- China is pursuing several projects related to CO_2-EOR and Coal-to-Liquids

International Energy Agency Roadmap (Outdated)

- CCS is an integral part of the portfolio of measures needed to stabilize CO_2 emissions by 2050
- by 2050 CCS will provide ~1/5th of global CO_2 emissions reduction:
  - 10% in the power generation sector
  - 9% in the energy production and industrial sectors

  Revised now down to 17% because of delays in deployment!
- CCS is as much about the future of coal as an energy source as about other processes, such as oil and gas, cement and steel production (where there is no substitute for coal), and gas flaring
- To achieve CO_2-emission reduction targets, there is need for 20 demonstration projects to be launched by 2010 (not achieved), 100 commercial-scale projects to be implemented by 2020 (will not be achieved), and 3,400 CCS projects on line by 2050 (will it be achieved?)
- CCS will start in OECD countries, but by 2030 will be surpassed in developing countries (???)

Predicted
Worldwide Electricity-Production Mix

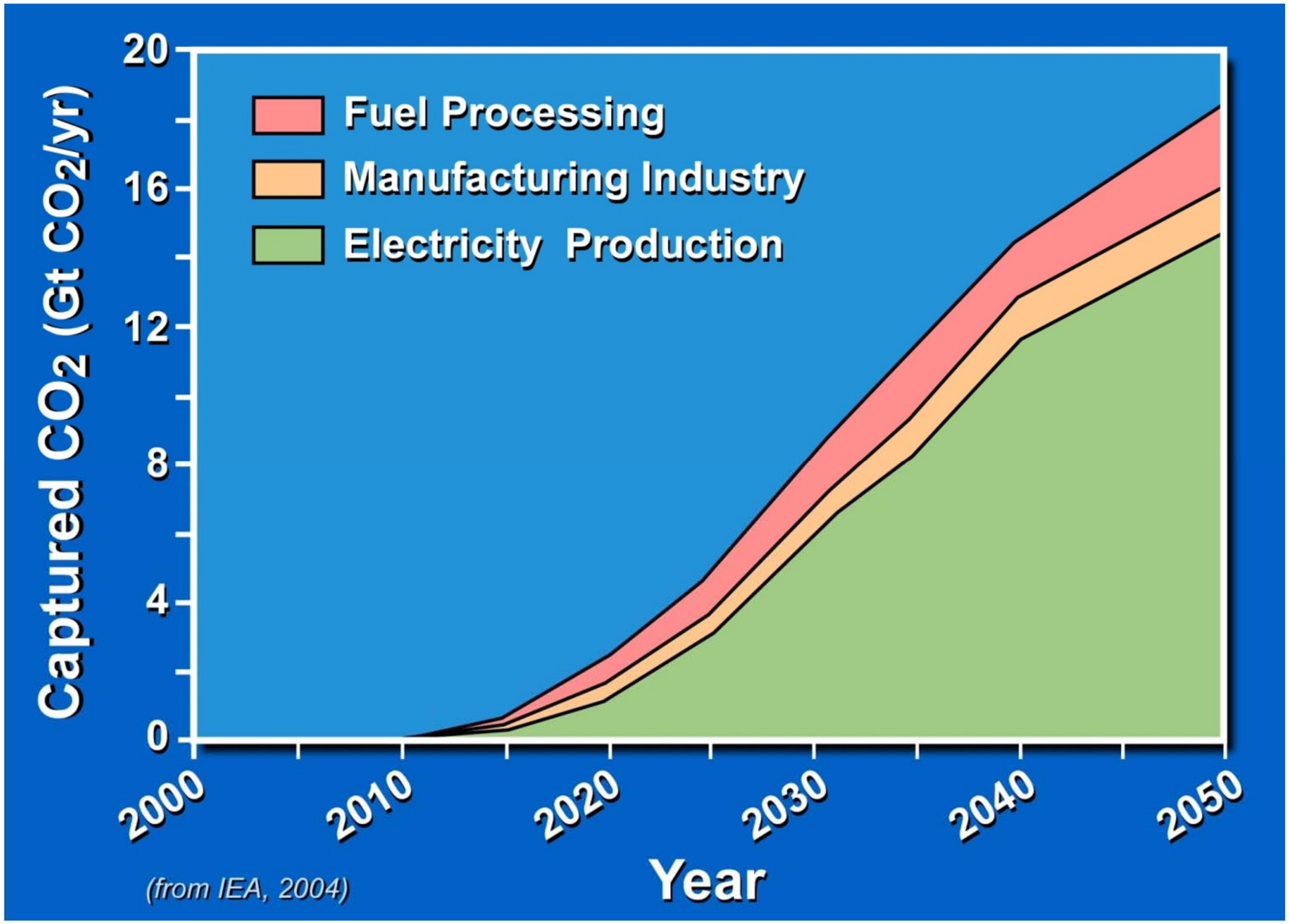


(from IEA, 2004)

The share of low-carbon electricity supply (including CCS) will increase to 80% by 2050

IPCC AR5, 2014

Predicted Global CO_2 Capture by Process



(from IEA, 2004)

Decarbonization will be more rapid in the power-generation sector than in the industrial, buildings and transportation sectors, and fossil-fuel power generation without CCS will be phased out by 2100
(IPCC AR5, 2014)

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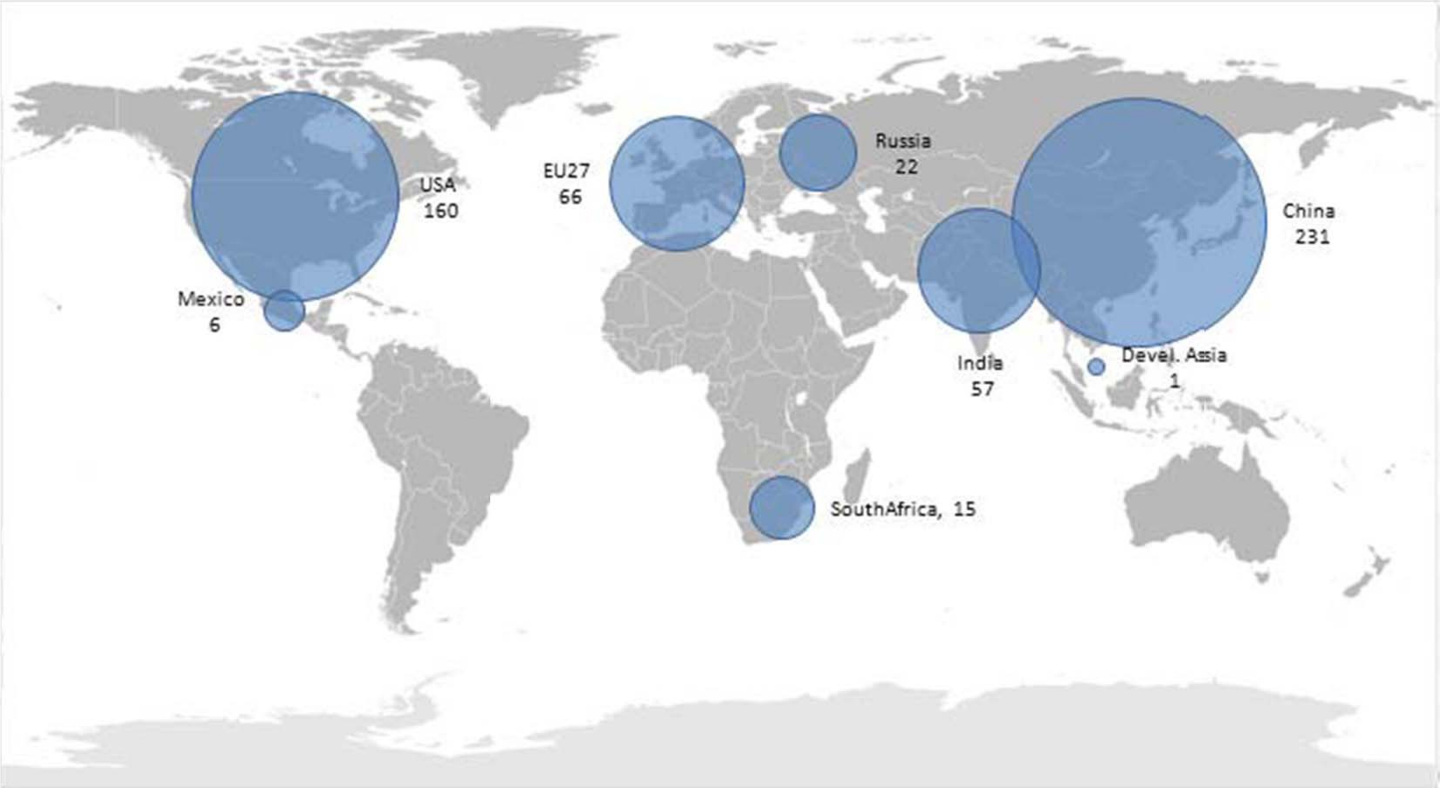
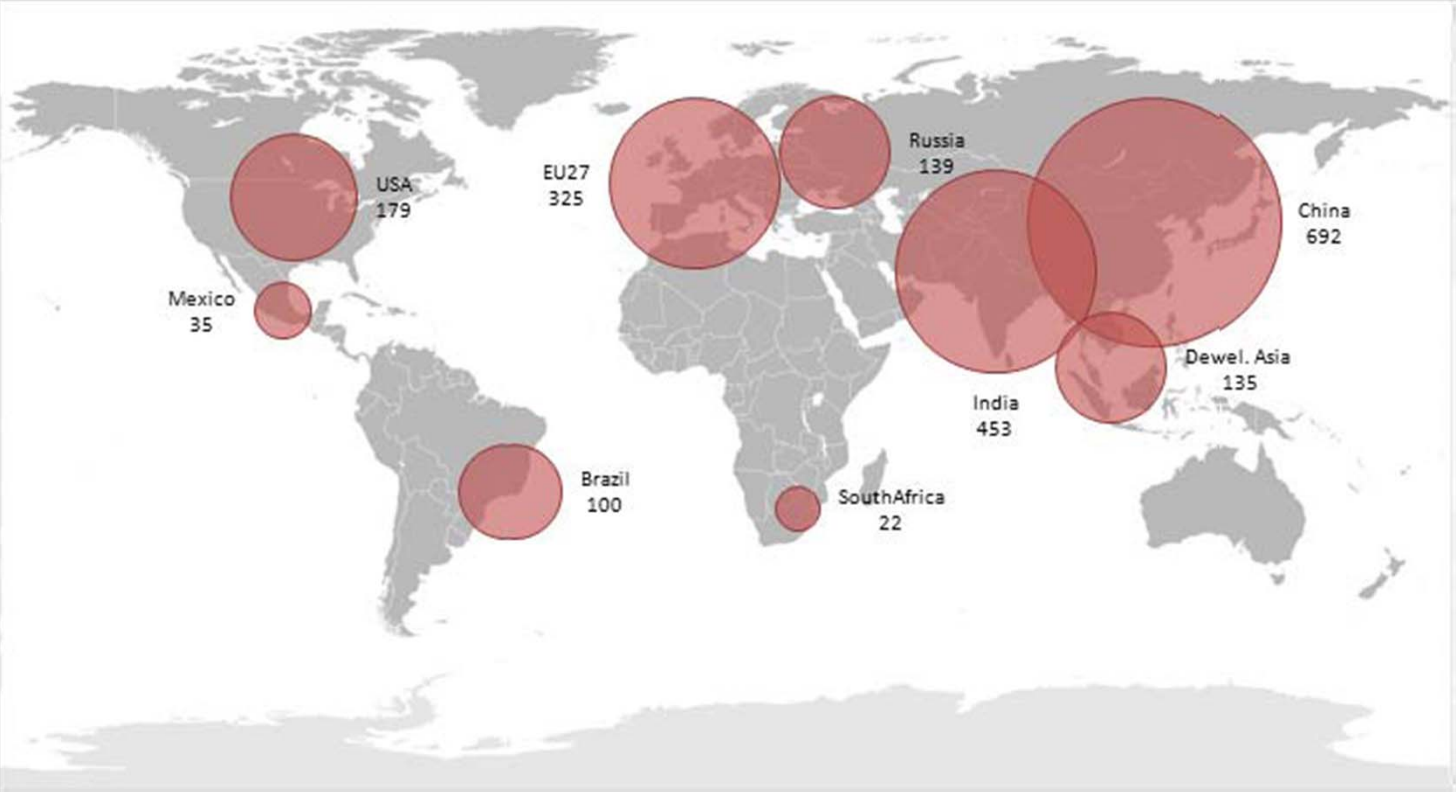
International Energy Agency Scenario for 2050: CO_2 Capture in Power Generation



GW of power generation equipped with CO_2 capture

International Energy Agency Scenario for 2050: CO_2 Capture in the Industrial Sector



CO_2 captured (Mt/yr)
In the industrial
sector

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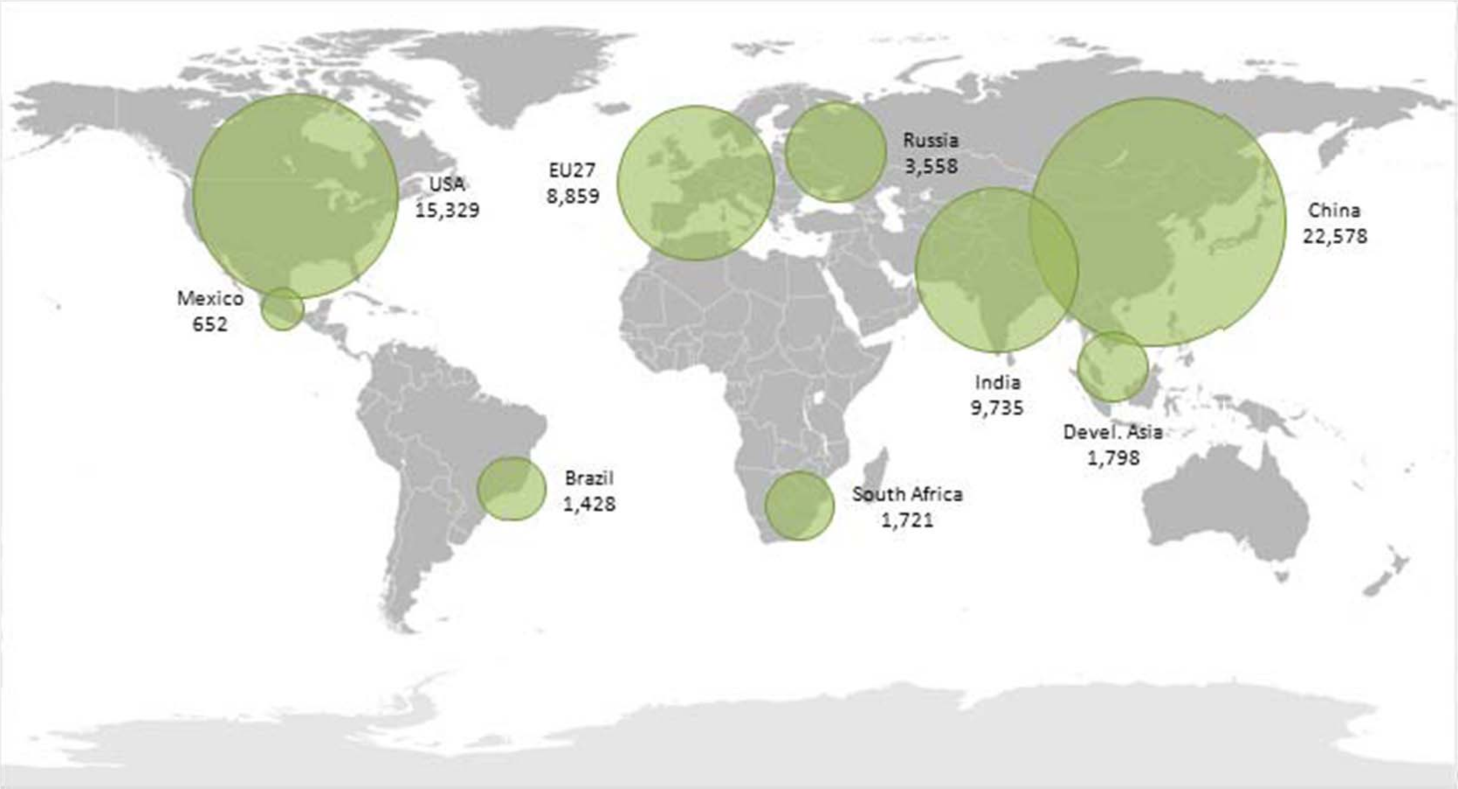
International Energy Agency Scenario for 2050: Predicted CO_2 Stored 2015-2050



Gt CO_2/year

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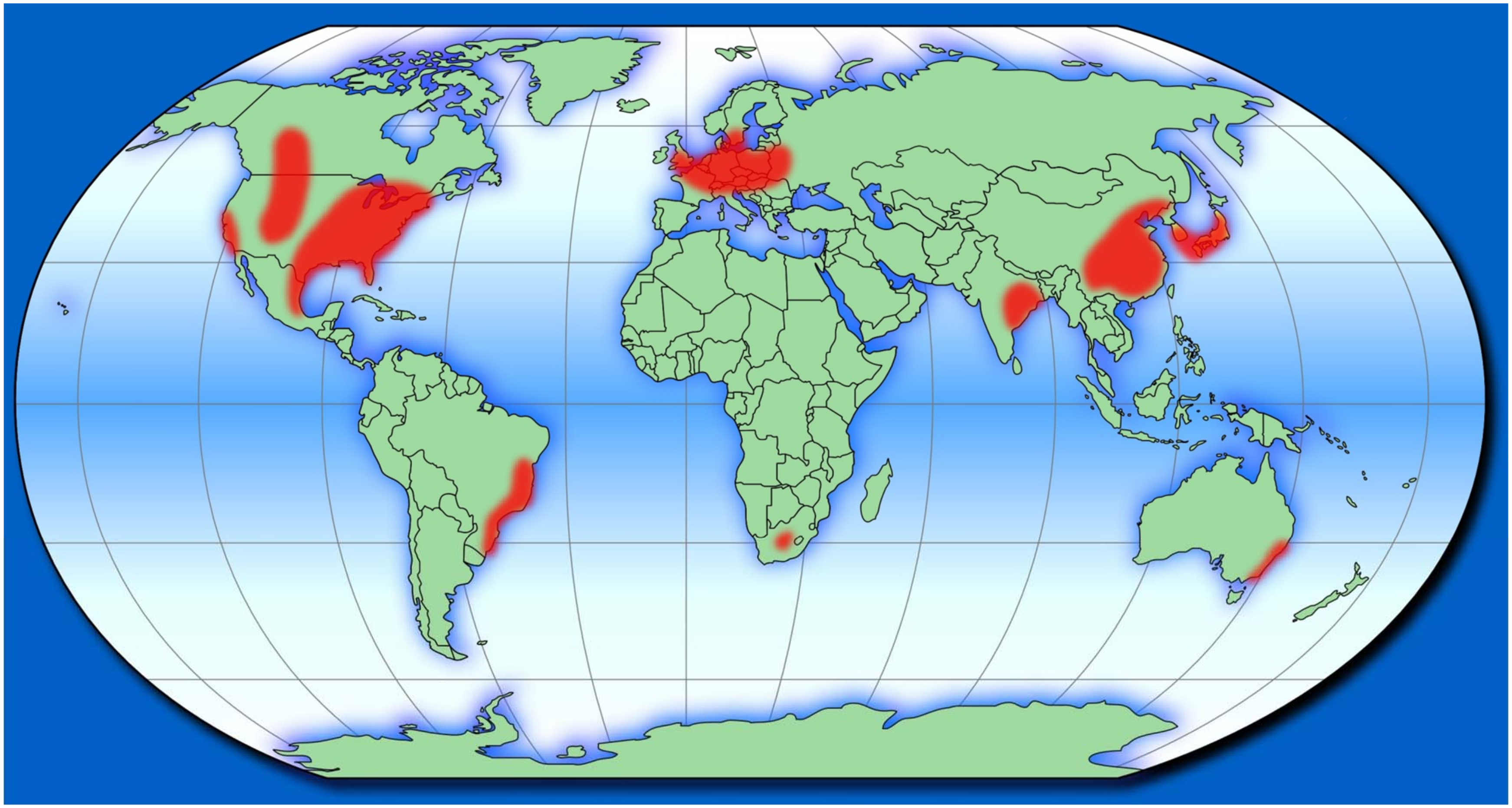
CO_2 Geological Storage is a Worldwide Opportunity and Challenge



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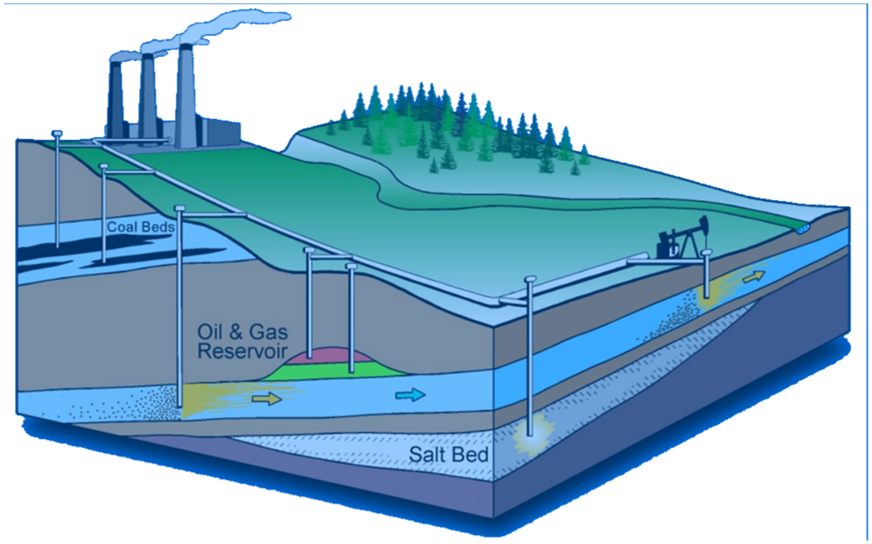
Geological Storage of CO_2



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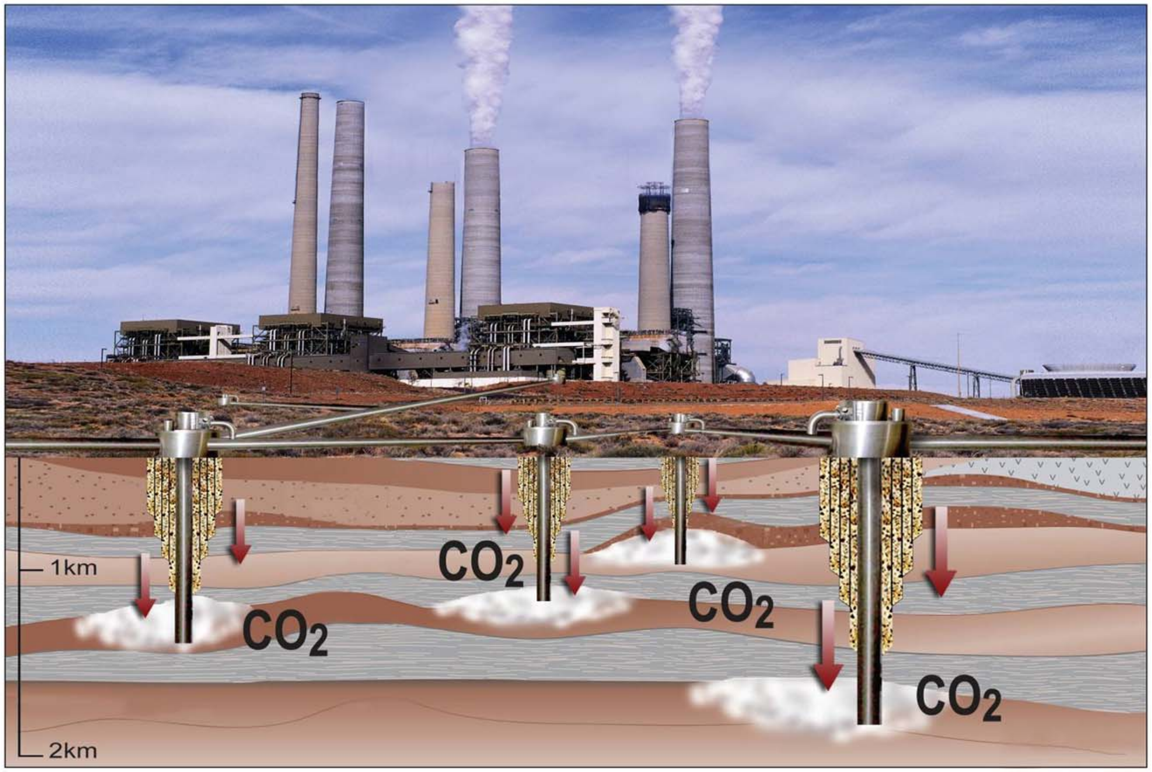
CO_2 Capture and Storage Chain

Capture is the most expensive, 60-80% of CCS cost for a power plant



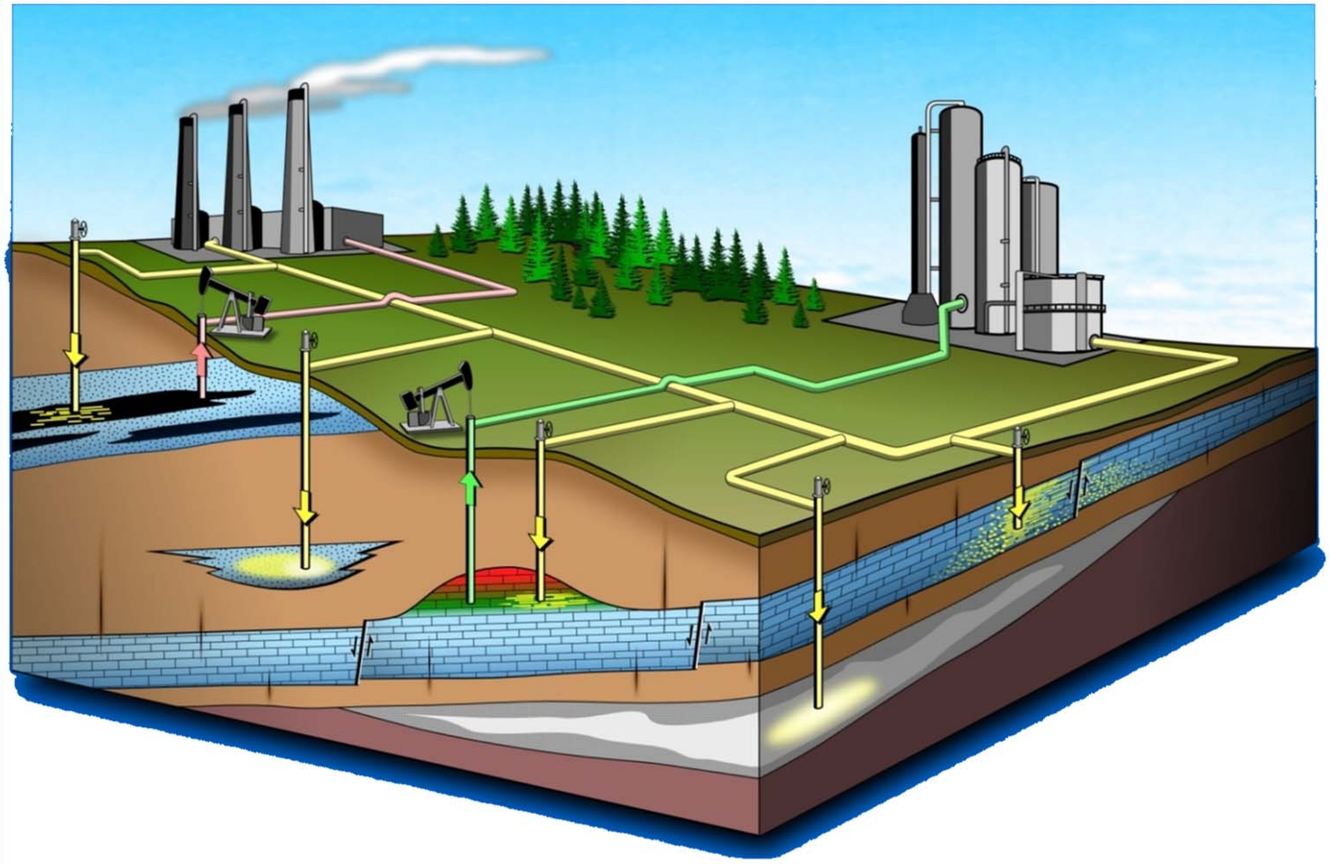
Getting to actual injection takes the longest: 7-10 years

Capture → **Compression** → **Pipeline or Ship Transport** → **Underground Injection & Storage**

CO_2 Trapping Mechanisms in Geological Media

- **Physical Trapping** (in free phase)
  - In Static Systems (no flow)
    - In large man-made cavities
    - In the pore space in stratigraphic and structural traps
      - Mobile (continuous phase able to flow)
      - At irreducible saturation (immobile residual gas)
  - In Dynamic Systems (flow in long-range regional-scale systems
- **Chemical Trapping**
  - Adsorbed onto organic material in coals and shales
  - Dissolved in formation fluids (oil or water)
  - Precipitated as a carbonate mineral (irreversible process)

Accepted Geological Media for CO_2 Storage



Oil and gas reservoirs, deep saline aquifers, unminable coal beds?, salt caverns?

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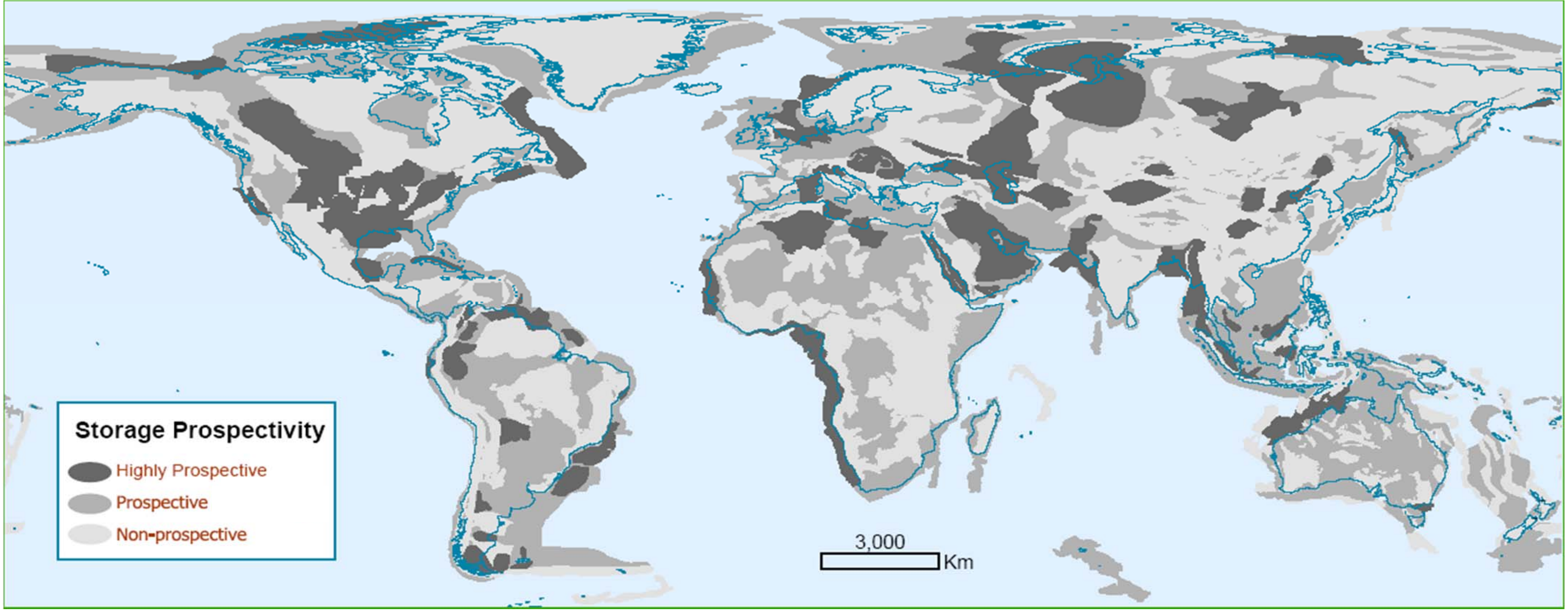
Prospectivity of Sedimentary Basins for CO_2 Storage



Three primary conditions

- Sedimentary rocks with storage media and seals
- Pressure and temperature greater than critical values (31^oC, 78.3 bars)
- Avoid contamination of other resources and groundwater

Many countries do not posses adequate storage potential

Trends Regarding Storage Media

Nine years after the IPCC Special Report on CCS:

- Ocean storage is “dead”
- Challenges in geological media for CO_2 storage:
  - Storage in salt caverns is neglected (minor potential, only as a buffer in delivery systems)
  - Storage in coal beds (ECBM) is still largely unproven and many challenges still need to be overcome, particularly loss of permeability (injectivity) as a result of coal swelling in the presence of CO_2 (is this option slowly “dying?”)
  - Storage in organic-rich shales is in the research stage, presents the same challenges as storage in coal beds, and as shale gas production advances (fracturing to increase permeability) it may destroy the integrity of the storage unit
  - Storage in basalts has yet to be demonstrated, it is based on the concept of rapid geochemical reactions, otherwise basalts are poor containers
  - Storage in shallow seabed sediments is researched because of special conditions of high pressure and low temperature, conducive to CO_2 hydrate formation

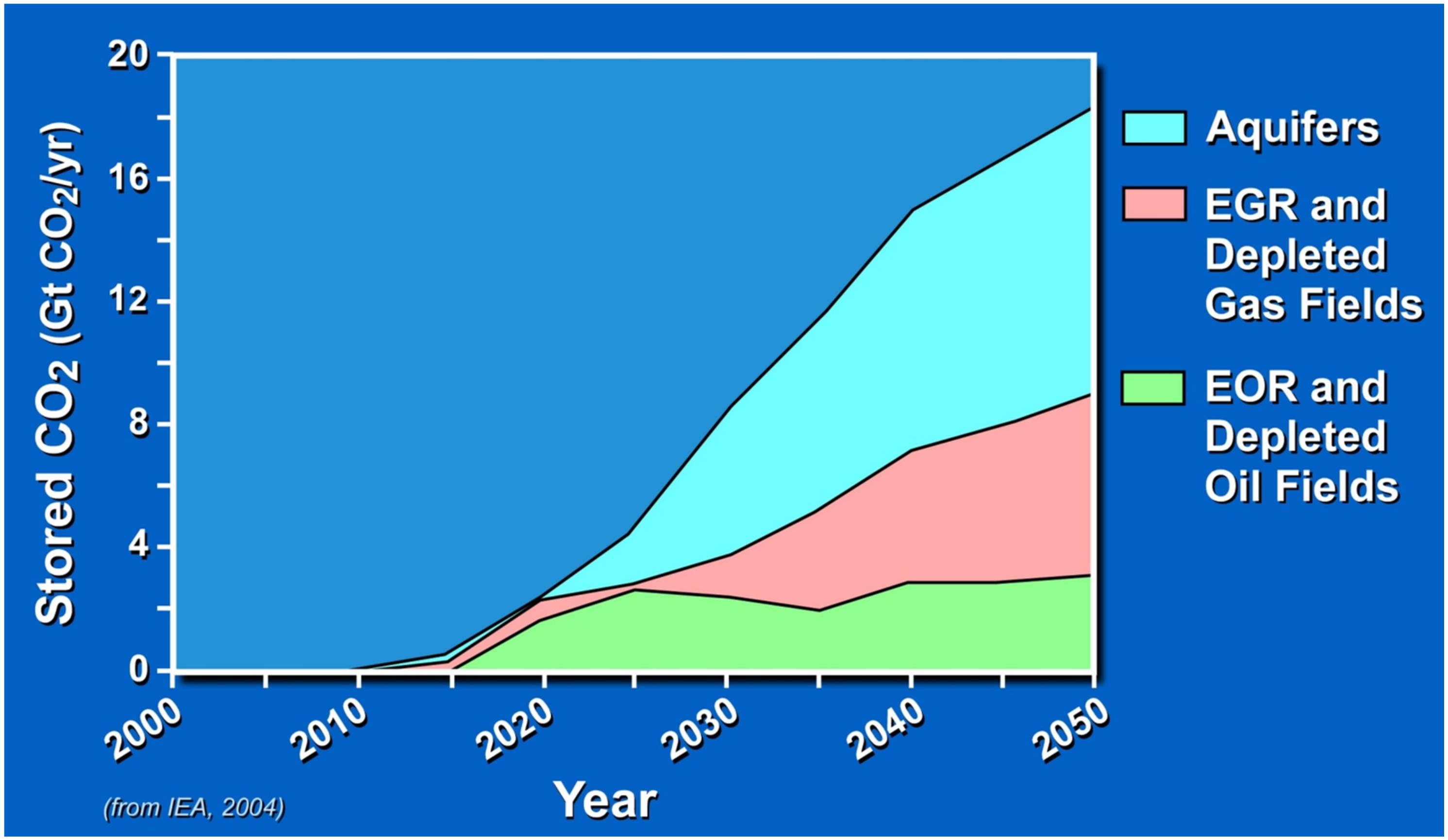
Media “Winners” in Geological Storage

- The focus is on demonstrating CO_2 storage in deep saline aquifers which are widespread and have the largest storage capacity!

- As a result of the lack of incentives and regulatory requirements, lately storage in oil fields in conjunction with CO_2-EOR (CO_2 Utilization”) is receiving much attention ($$$$); however, they have comparatively small capacity and the cost of CO_2 from anthropogenic sources is prohibitive (cost of capture and transport infrastructure)

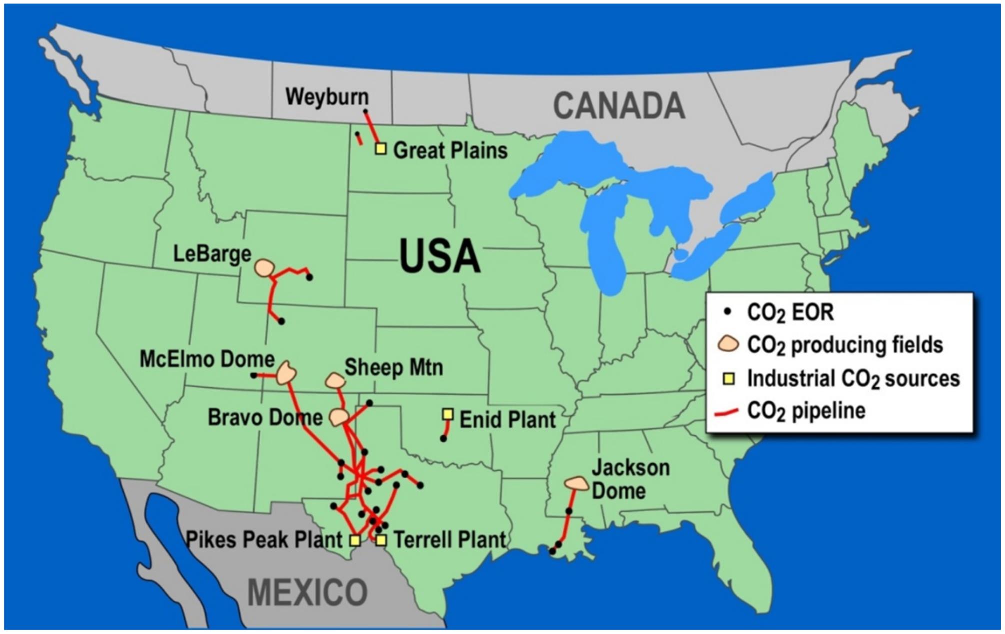
- Storage in depleted gas fields is an option rarely pursued, although capacity is significant (EGR is impractical, the gas price is low, infrastructure is lacking and the cost of CO_2 is high)

Predicted Global Use of Geological Media for CO_2 Storage



(from IEA, 2004)

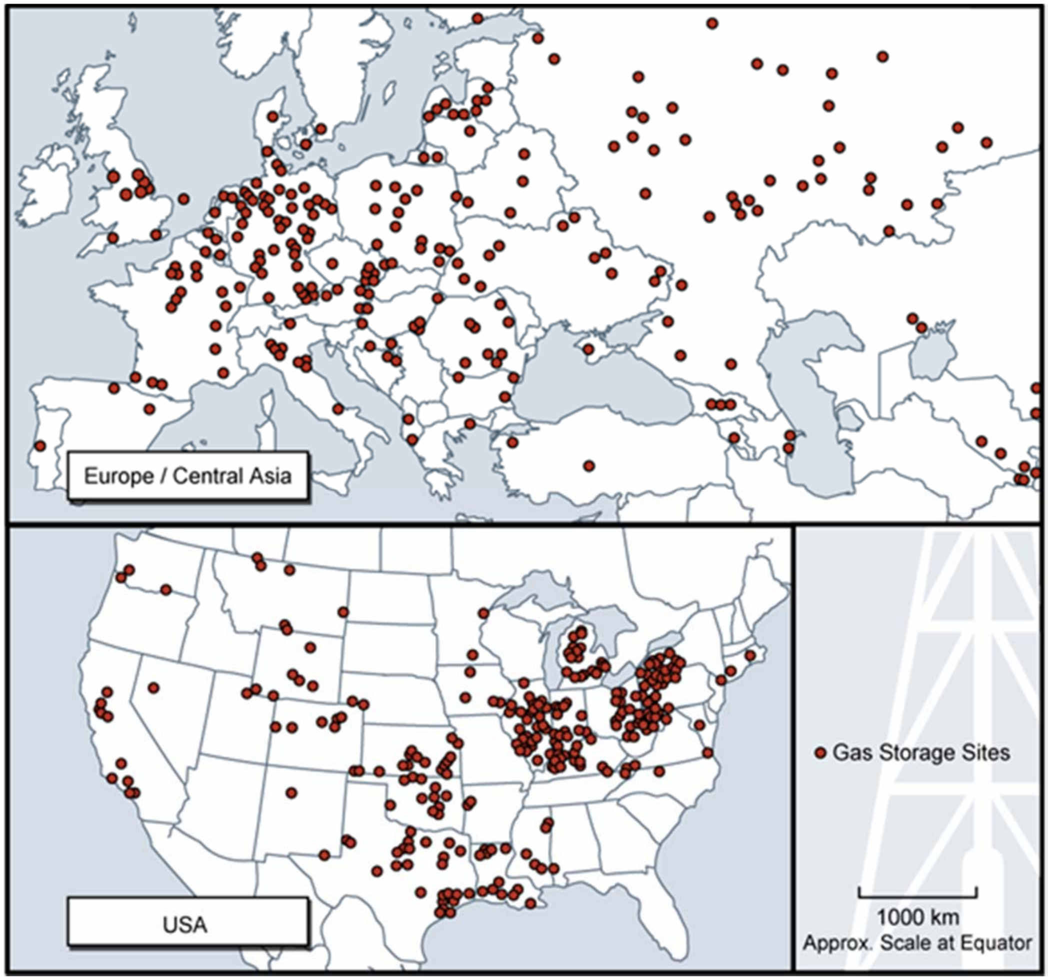
Technologically We Know How to Do It!



More than 3500 miles (5600 km) of CO_2 pipelines, annual transport ~50 Mt CO_2/year to > 120 CO_2-EOR operations

Acid gas (CO_2 & H_2S) disposal and CO_2-EOR in Canada

Natural Gas Storage in Europe and U.S.



- Seasonal storage to meet winter loads
- Storage formations
  - Depleted oil and gas reservoirs
  - Deep saline aquifers
  - Caverns

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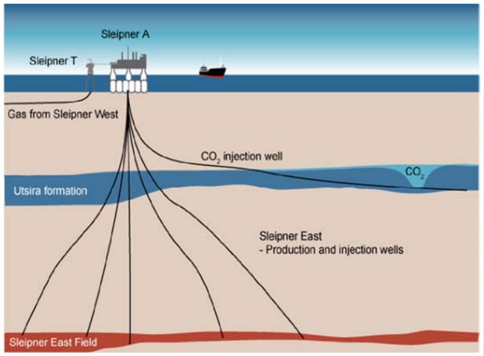
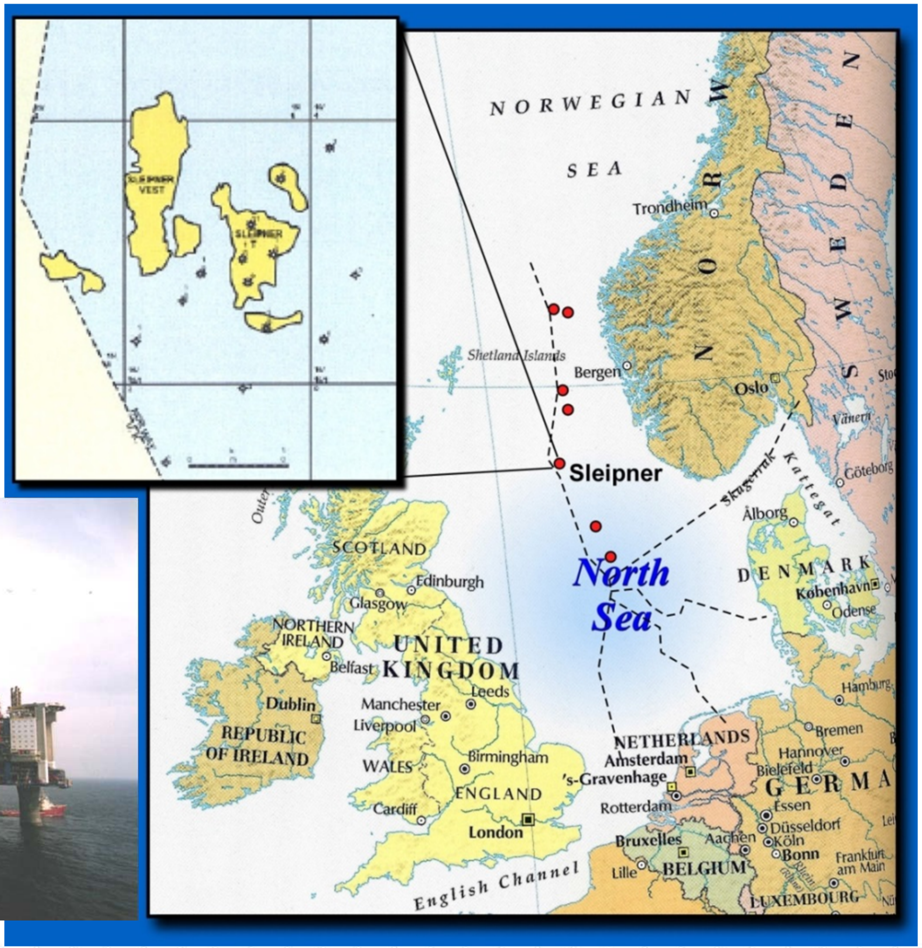
Offshore CO_2 Storage: The Sleipner Saline Aquifer CO_2 Storage

Injection of ~ 1 Mt CO_2/yr since 1996

- Capture using an amine based process
- Transportation by pipeline to Sleipner A platform
- CO_2 injection through a horizontal well
- Sweet gas pipelined to Europe





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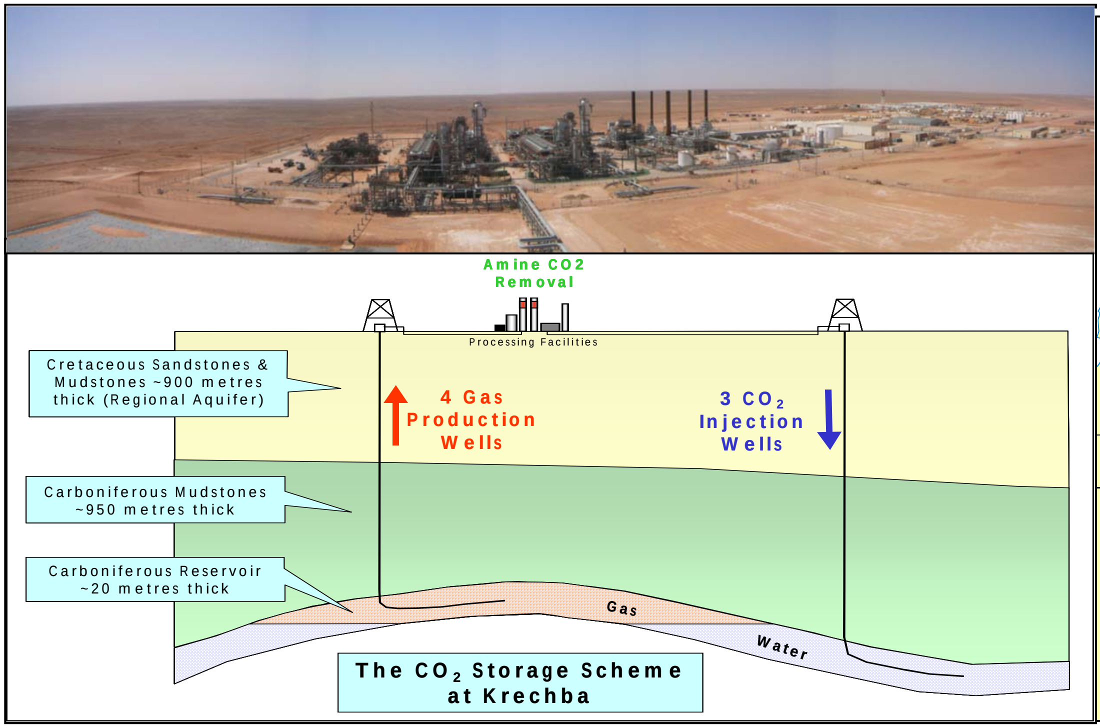
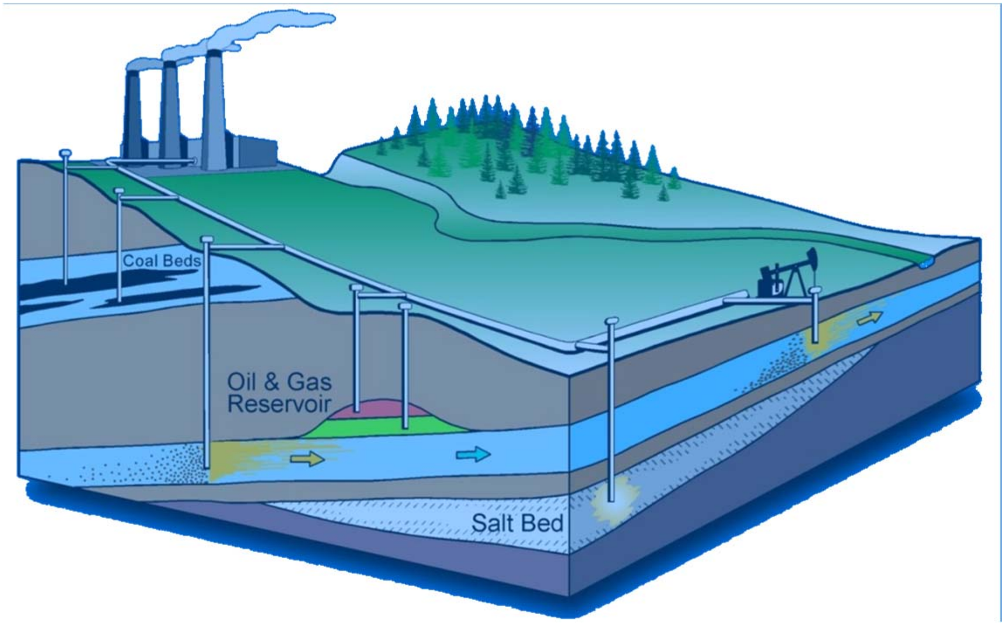
Onshore CO_2 Storage: In Salah Project in Algeria



Injection of 0.6 Mt CO_2 year since 2004, stopped in 2010

Storage Challenges to CCS Deployment



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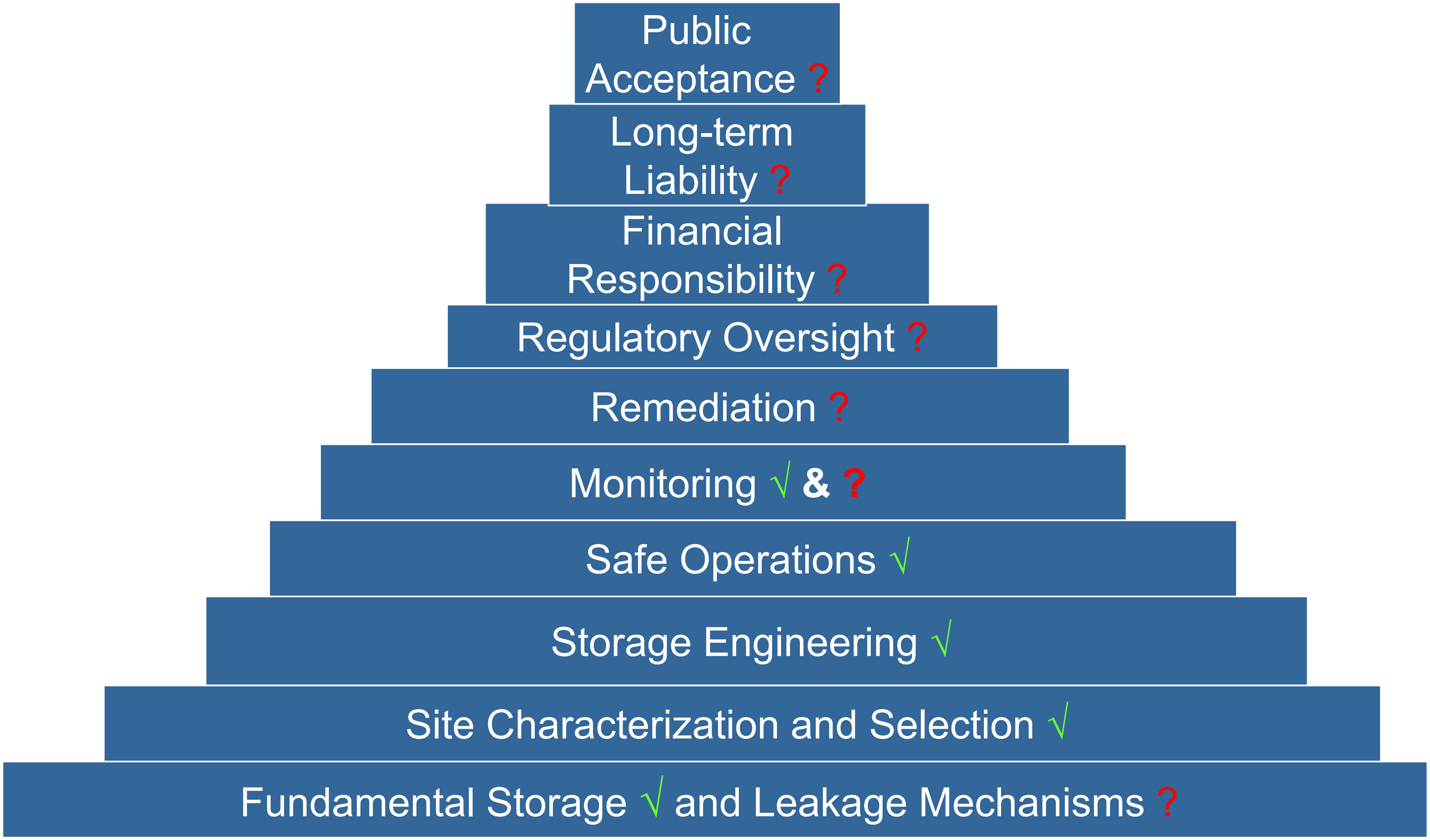
Where are the Issues in CO$_2$ Storage



Public Acceptance ?

Long-term Liability ?

Financial Responsibility ?

Regulatory Oversight ?

Remediation ?

Monitoring √ & ?

Safe Operations √

Storage Engineering √

Site Characterization and Selection √

Fundamental Storage √ and Leakage Mechanisms ?

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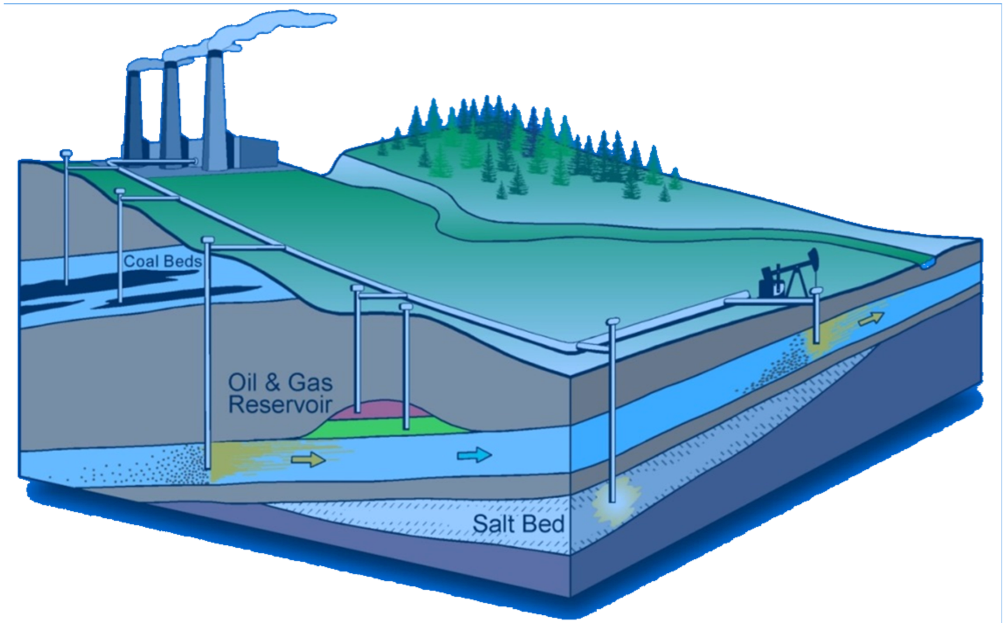
Scientific and Technical Issues



CO_2 Storage Capacity

- What media are suitable for CO_2 storage, meeting the conditions of capacity, injectivity and confinement (security)
  - Deep saline aquifers and hydrocarbon reservoirs √
  - Coal beds and shales **?**
  - Basalts**?**
- What is the global and regional size and distribution of the existing storage capacity (resource)
- What is the accessibility and economics of the existing storage capacity (reserve)
- Matching large CO_2 sources with appropriate CO_2 sinks

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CO_2 Storage in Oil and Gas Reservoirs

- Geomechanical effect of pressure decrease during production and build-up during storage on reservoir and caprock integrity
- Effect of water invasion in aquifer-supported reservoirs
- Multi-phase flow effects (oil, gas, CO_2, water)
- Storage efficiency
- Time of reservoir availability (time of depletion)
- Optimization of oil recovery and CO_2 storage

CO_2 Storage in Deep Saline Aquifers

- Real storage capacity and efficiency – knowledge still evolving
- Long term fate of the injected CO_2
- Are geochemical reactions and effects quick or slow, are they important?
  - If yes, how do they affect:
    - Flow (porosity and permeability)
    - Storage integrity and security (caprock integrity)
    - Storage capacity
  - If yes, how to get the data needed for assessment and modeling (e.g., mineral composition, contact area)
- Relative permeability for CO_2 trapping at irreducible saturation

Injection and Pressure Build-up Effects

- Induced micro-seismicity
- Size and spread of the pressure build-up beyond the CO_2 plume, possibly affecting other resources
- Surface effects due to ground heaving
- Fate of the displaced formation water (brine)

Modeling

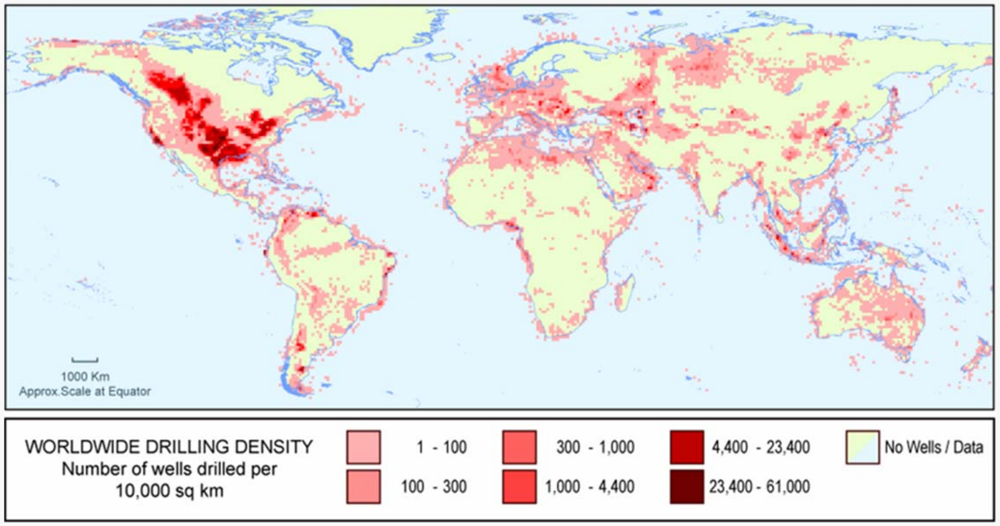
- HTMC Processes:
  - Hydraulic (pressure and fluid flow)
  - Thermal (difference in temperature between injected CO_2 and the fluids and rocks in the storage unit
  - (Geo) Mechanical as a result of pressure increase
  - (Geo) Chemical as a result of CO_2-water-rock interactions
- Models of coupled processes
  - Can we model them?
  - Do we have/can we get the data
- How to validate the results of modeling in the absence of real-field data?

Effects of Impurities in the Injected CO_2 Stream

- On storage capacity and injectivity
- On caprock and wells integrity
- On other resources, particularly groundwater, in case of leakage
- On life in case of leakage to the surface or seabed

Leakage through Wells

World Map of Active and Abandoned Wells



Potential Consequences

1. Worker safety
2. Groundwater quality degradation
3. Resource damage
4. Ecosystem degradation
5. Public safety
6. Release to atmosphere

Potential Release Pathways

- Well leakage (injection and abandoned wells)
- Poor site characterization (undetected faults)
- Excessive pressure buildup damages seal

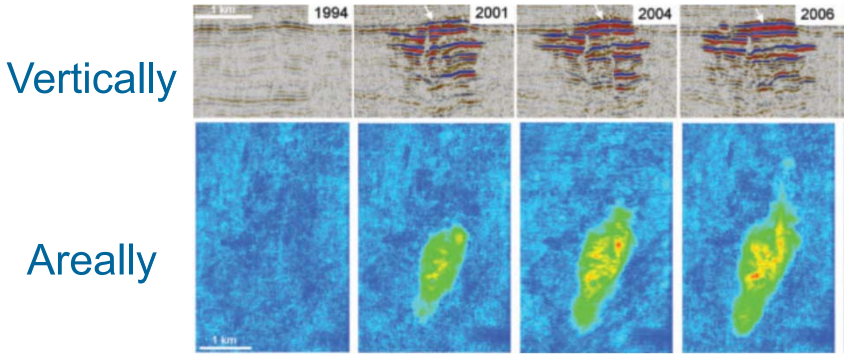
How serious is the abandoned well problem?
Are catastrophic releases possible?

Monitoring Techniques and Technologies

- Do they work always and everywhere?
- Monitoring at low levels of CO_2 saturation and/or concentration
- Monitoring beyond detection, towards quantification

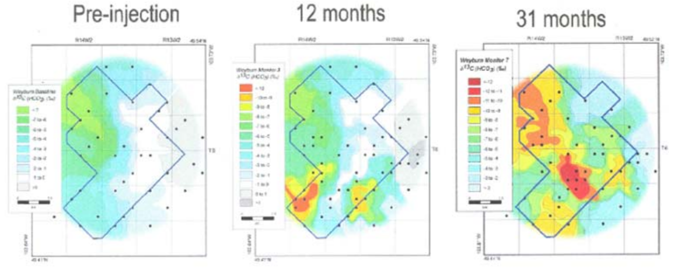
Monitoring Technologies for CO_2 Plume and Pressure Evolution

Geophysical Monitoring at Sleipner



Geochemical Monitoring at Weyburn

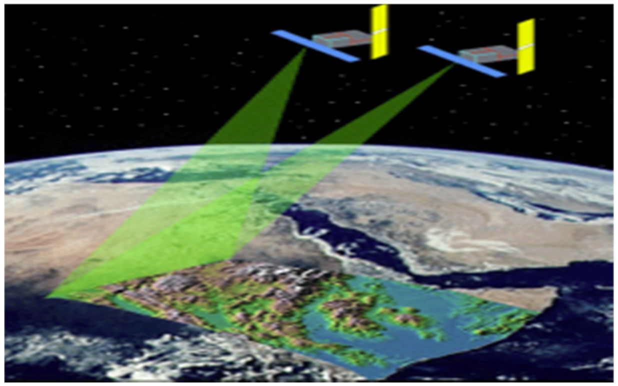
$\delta^{13}C_{HCO3}$ in produced fluids

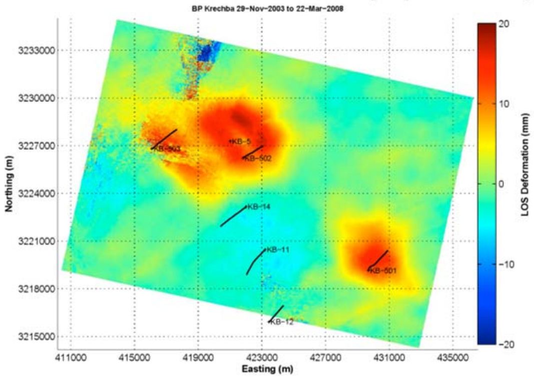


Injected CO_2 dissolution (decreasing $\delta^{13}C$ in produced fluid)

Injected CO_2: $\delta^{13}C$=-20‰

$CO_2 + H_2O \leftrightarrow H^+ + HCO_3^-$





Interferometric Synthetic Aperture Radar (inSAR) Monitoring at In-Salah

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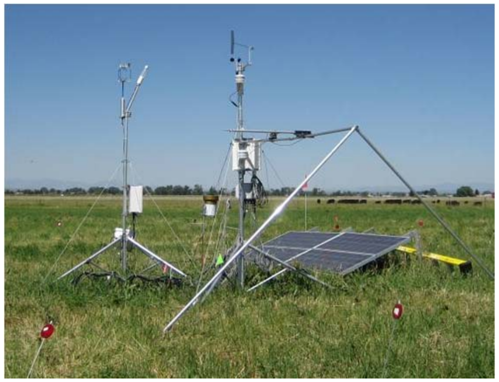
Surface Monitoring Technologies for CO_2 Leak Detection



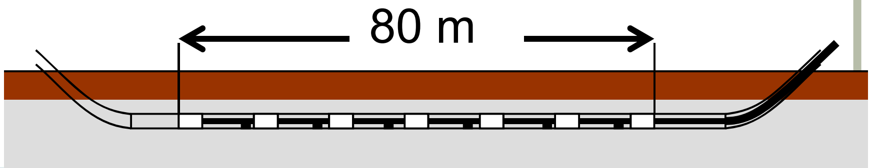
Flux Tower

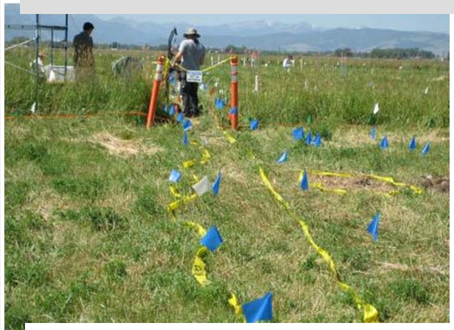
Hyperspectral imaging of vegetation

Soil Gas

Flux accumulation chamber

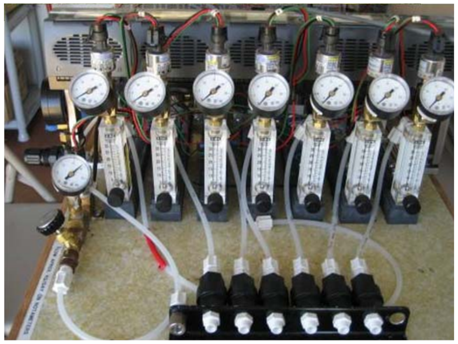
Detection Verification Facility (Montana State University)





Field Site

Horizontal Injection Well



Flow Controllers

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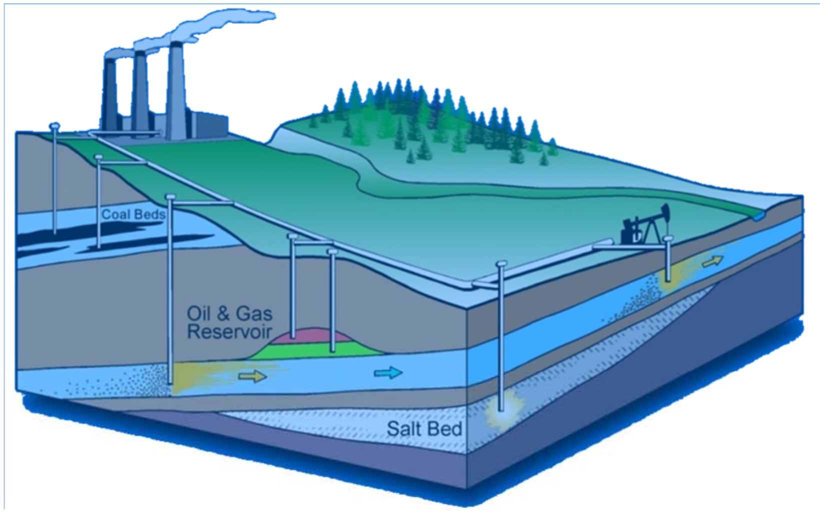
Trends Regarding the Science

Nine years after the IPCC Special Report on CCS there is a general sense that, after significant growth in the late 1990's and early 2000's, the science of CCS has reached a plateau (most of what could be done in the laboratory or with simulations has been done) and that the next significant advances will come only with the deployment of large-scale CCS demonstration projects

Legal and Regulatory Issues



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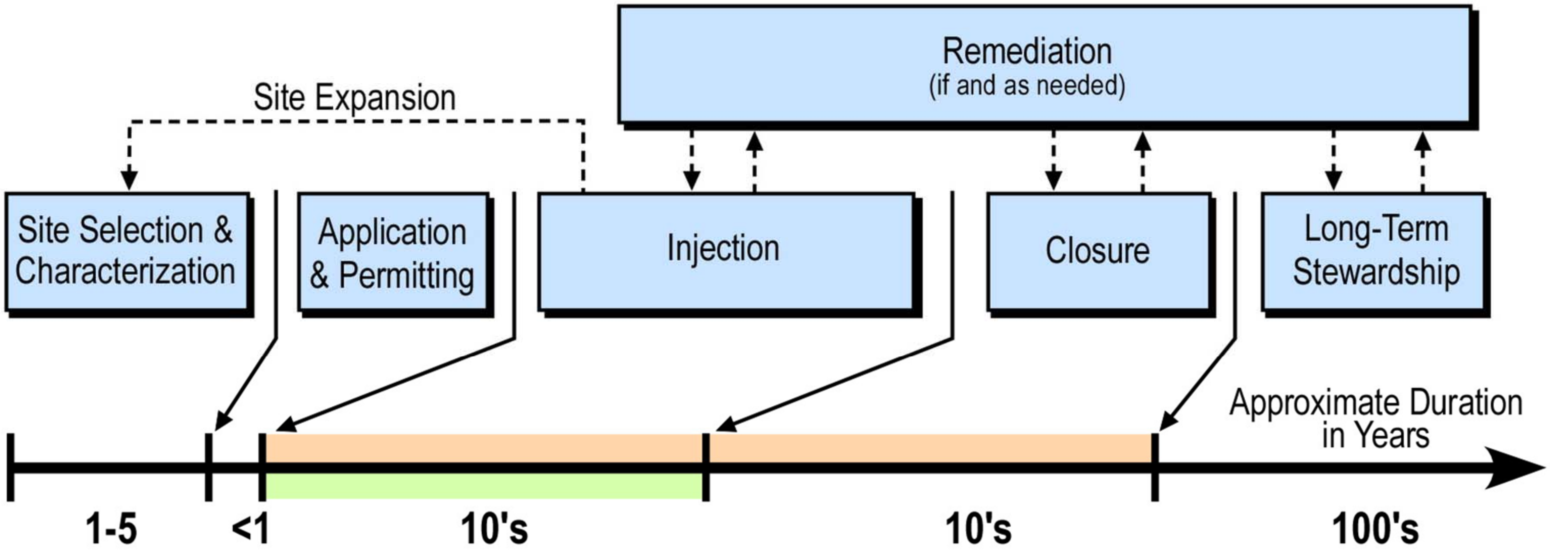
Stages of CO_2 Storage Operations and Liability



🟩 Injecting firm pays fee on injected CO_2 to cover costs associated with long-term stewardship

🟧 Injecting firm carries insurance to cover liabilities

←--- Conditional paths

modified after Rubin et al., 2007

Beware: capture and infrastructure are the costliest, storage permitting is the lengthiest!

The Components of CCS in a Legal and Regulatory Framework

1. Capture: Handled by existing legislation and regulations regarding industrial facilities for permitting, operation and liability: the owner/operator is responsible and liable

2. Transport: Similarly handled by existing legislation and regulations regarding pipelines and shipping of LNG regarding permitting, operation and liability: the owner/operator is responsible and liable

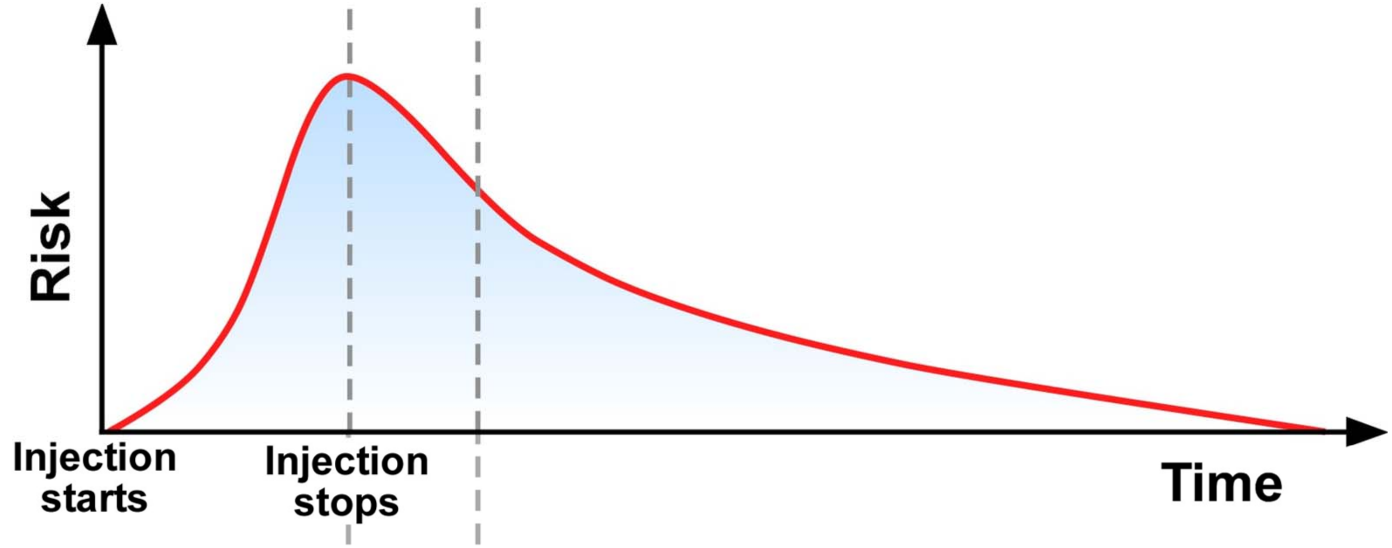
3. Storage: No complete legal and regulatory framework in place anywhere in the world
    - ❖ In Australia, the amendment to the Offshore Marine Petroleum Act establishes legislation for tenure and primacy of hydrocarbon production over CO_2 storage
    - ❖ In North America, some states and EPA in the US, and provinces in Canada variously established legislation regarding tenure, permitting and liability
    - ❖ In Europe EU Directive establishes requirements for permitting
    - ❖ During the active, injection phase, the operator is responsible and liable, but who is responsible and liable after cessation of CO_2 injection?

General Risks as a Result of CO_2 Leakage

- Assessing the risks of CO_2 storage in the case of leakage:
  - To equity (other underground resources)
  - To potable groundwater
  - To soil and vegetation
  - To life
  - To property
  - Financial
  - Economic

- Developing appropriate risk models, including both processes and financial

Relation between Risk and Liability During CO_2 Storage Operations



Operational Period	Active	Closure	Post-Closure	
Monitoring Frequency & Resolution	High	Targeted	Decreasing	Low
Liability	Operator and/or Emitter		State Agency	

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The Three Legs of a Legal & Regulatory Framework for CO_2 Storage

1. Legal (Property): The right to engage in a particular lawful activity on your property – PNG and mineral tenure/rights are handled by Resource Departments – Generally there is no legislation regarding the pore space!

2. Regulatory (Permitting): Permission to engage in that particular activity if certain conditions are being met – Handled by Environment Departments (groundwater) and Oil and Gas Regulatory Agencies – Need for new Regulatory Framework to cover CO_2 Storage

3. Liability: Who assumes the risks and who is responsible in case of failure – No liability framework for closure and post-closure of CCS operations
   - ❖ in North America, operator's liability ends at abandonment, except for wells, for which the operator is liable in perpetuity; if the operator "disappears", then fixing orphan wells is in the care of the "Orphan Well Fund" into which companies pay
   - ❖ In Europe (e.g., France) the state assumes liability of abandoned wells after certain conditions are being met

Legal and Regulatory Issues in CO_2 Storage

- Ownership of the pore space
- Access rights
- Ownership of the stored CO_2 and third party transfer
- Relationship between ownership of the pore space and other property rights
- Permitting for CO_2 storage
- Trans-boundary CO_2 storage and/or migration
- Post-operational long term liability (after cessation of injection)
- Conditions for liability transfer to State Agency

Consequences of the Lack of Legal and Regulatory Framework

- The engineering risks posed by CO_2 storage are manageable
- The current uncertainty about the legal and regulatory framework that will apply to CCS projects means that industry is unlikely to invest in the technology and financial institutions won’t assume lending risks

Public Acceptance

- The public is not necessarily convinced about climate change, and about the need for CO_2 capture and storage as part of the solution

- The public is not convinced that CO_2 storage is safe, hence "Not in my backyard" (NIMBY) syndrome
    - Concerns about transportation risks (CO_2 pipelines, terminals, ships)
    - Concerns about long-term integrity of CO_2 storage, leakage and groundwater contamination
    - Concerns about health and safety risks in case of CO_2 leakage

- Many ENGOs see CCS as a means to extend the life of fossil fuels and, as such, oppose it

- The public is misinformed about CCS and asked the wrong questions in opinion polls

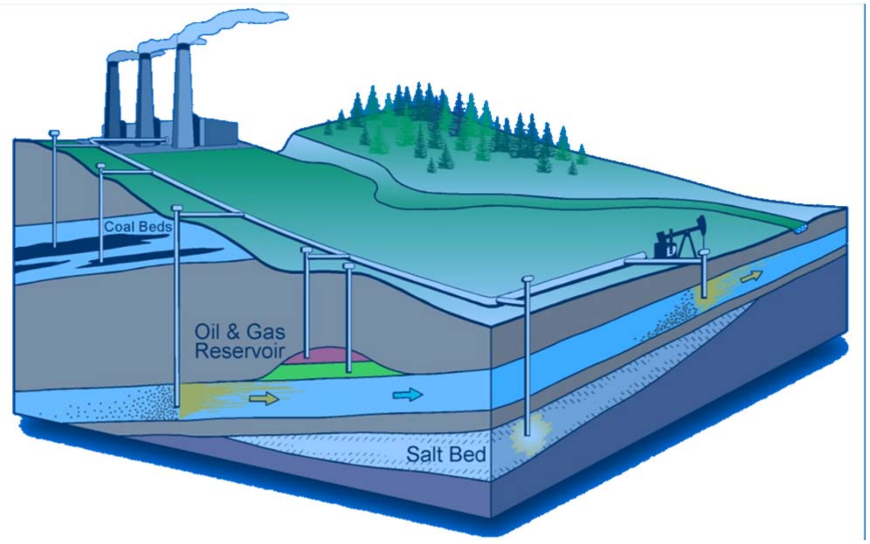
Human Capacity

CO_2 capture and storage needs engineers for capture, transportation and storage, geologists and hydrogeologists for site selection and characterization, economists, ………………. i.e., a skilled work force that does not exist today and is not available, and that has to be trained formally and in the field

Summary of Barriers to Deployment

- High cost of capture, including high energy penalty
- Lack of knowledge regarding storage capacity and safe storage sites
- Lack of Infrastructure
- Lack of certainty regarding government policies regarding GHGs
- Lack of economic incentives ☺ or regulatory requirements ☹
- Lack of financing
- Risk identification and mitigation to increase investor and public confidence
- Lack of public awareness and acceptance
- Absence of legislative and regulatory framework regarding CO_2 storage
- Lack of human capacity (skilled work force) in executing CCS projects

The Special case of CO_2-EOR



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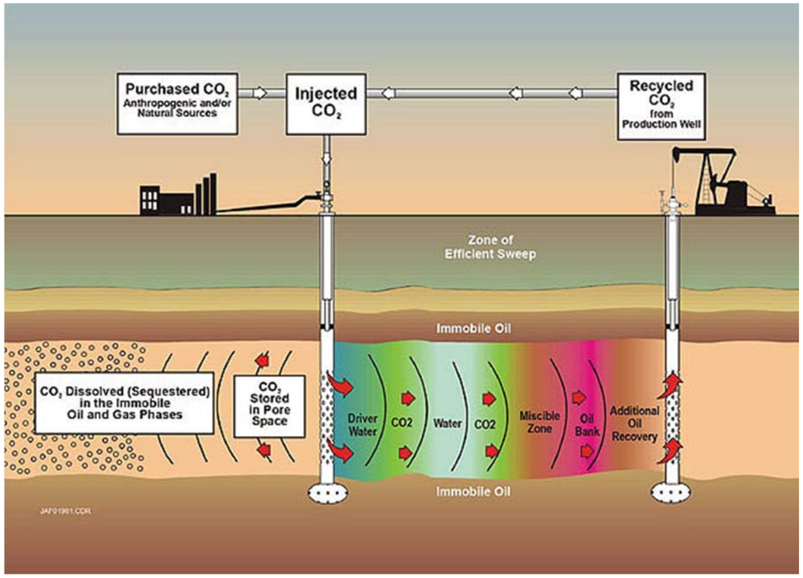
Phases of Oil Production

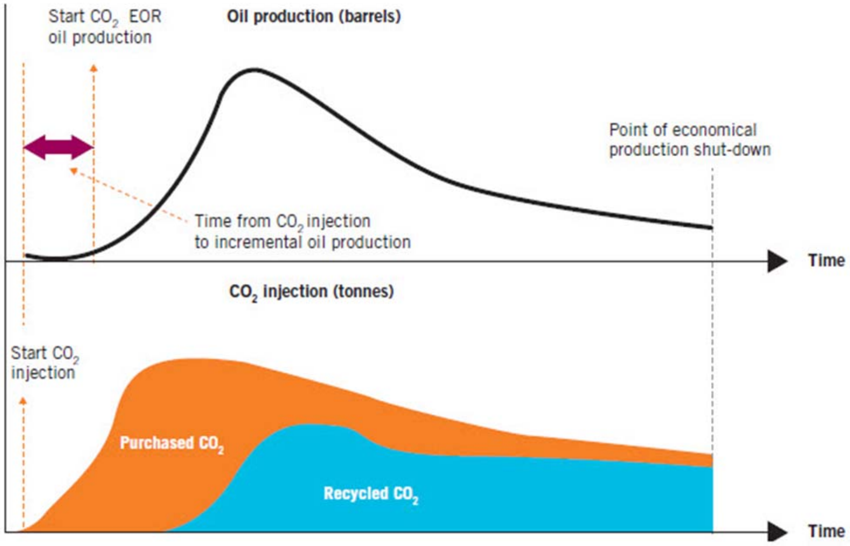
1. **Primary recovery**: oil is produced under reservoir pressure forces. As oil is produced, reservoir pressure declines to the point that production declines. Oil and reservoir water, and gas, if present, are produced at producing wells, separated and:
   a. Oil is sent to market
   b. Gas is vented, flared or captured and sent to market
   c. Reservoir water is disposed off

2. **Secondary recovery**: water is injected in the reservoir to increase pressure and also push oil towards producing wells. Same separation and handling processes apply.

3. **Tertiary recovery**: gas or solvent is injected in the reservoir to lower oil viscosity (e.g., CO_2, natural gas, foams, polymers, steam, etc.), increasing oil mobility and also pushing it to injection wells

Diagrammatic Representation of a CO_2-EOR Operation





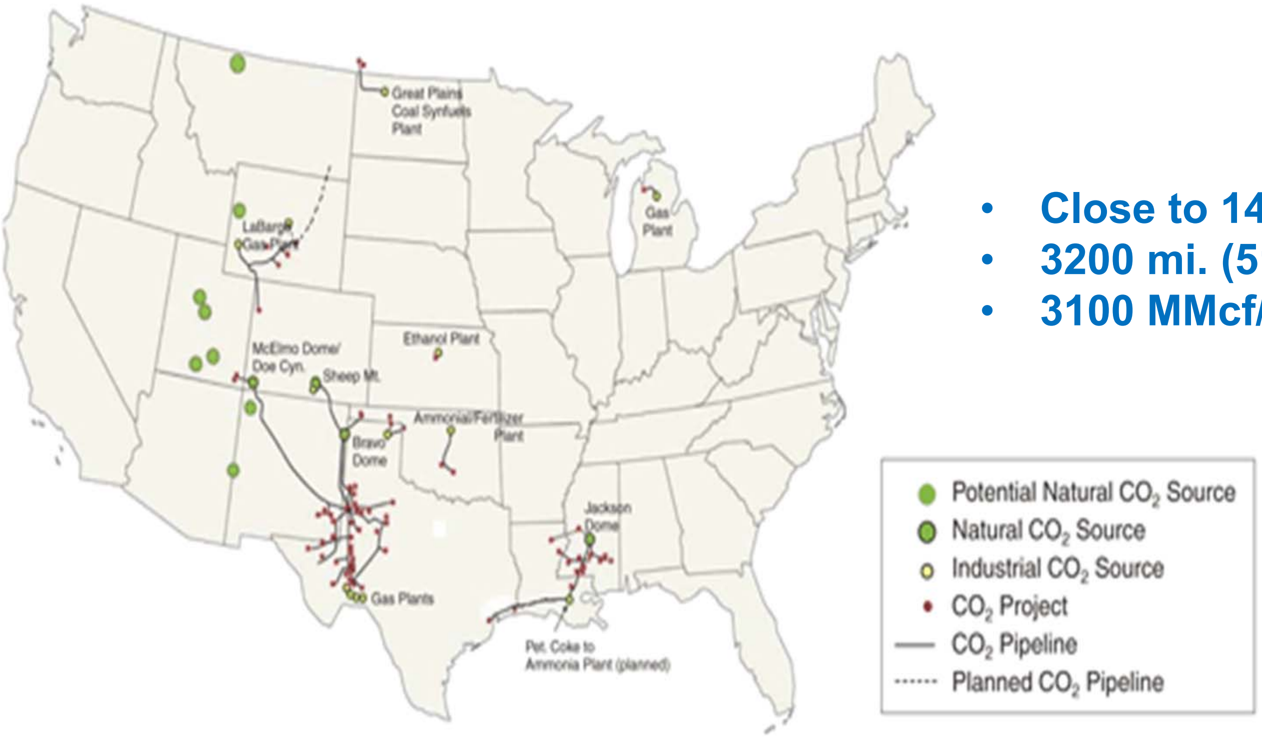
Incidental CO_2 Storage in CO_2-EOR Operations

From an oil-producer point of view, CO_2 losses include CO_2 lost in the reservoir, but from a storage point of view this CO_2 is still stored, as opposed to fugitive CO_2 losses

$$CO_2\,Injection\,Retention = \frac{CO_2\,Injected - CO_2\,Produced}{CO_2\,Injected} \approx 50\%\ on\ average$$

$$CO_2\,Storage\,Retention = \frac{CO_2\,Injected - CO_2\,Produced - CO_2 Losses}{CO_2\,Purchased} > 90\%$$

CO_2-EOR Operations in the U.S



- **Close to 140 CO_2-EOR operations**
- **3200 mi. (5150 km) pipeline**
- **3100 MMcf/d (65 Mt/yr) CO_2**

American Oil & Gas Reporter, May 2014

CSLF Task Force Findings

- There is sufficient operational and regulatory experience for this technology to be considered as being mature, with an associated CO_2 storage rate of the purchased CO_2 greater than 90%

- There are no specific technological barriers or challenges *per se* in transitioning and converting a pure CO_2-EOR operation into a CO_2 storage operation.

- The main reason CO_2-EOR is not applied on a large scale is the unavailability of high-purity CO_2 in the amounts and at the cost needed for this technology to be deployed on a large scale

- The absence of infrastructure to both capture the CO_2 and transport it from CO_2 sources to oil fields suitable for CO_2-EOR is also a key reason for the lack of large scale deployment of CO_2-EOR

Basic Differences between CO_2-EOR and CO_2 Storage

CO_2-EOR	CO_2 Storage in Deep Saline Formations
Commercial O&G Model!	**Waste Disposal Model!**
1. Driven by profit and market forces	1. Driven by regulations
2. CO_2 is a valuable commodity	2. CO_2 is "waste" to be disposed of
3. Objective: maximize oil production while minimizing CO_2 purchase	3. Objective: maximize CO_2 storage
4. Reservoir pressure remains below initial pressure, low risk operation to groundwater and other resources	4. Reservoir pressure increases above the initial pressure and is limited by regulatory agencies: higher risk!

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Main Legal and Regulatory Differences between CO_2-EOR and CO_2 Storage

- Acquisition and transportation of CO_2 are governed in both cases by basic commercial law, and by federal and/or state/provincial regulations regarding pipeline right of access, construction, operation and safety

- Injection of CO_2 is governed by different laws and regulations regarding
  - Acquisition of PNG or Mineral rights versus rights to the pore space,
  - Well construction,
  - Monitoring, and
  - Liability

Jurisdictional Differences between CO_2-EOR and CO_2 Storage

CO_2-EOR	CO_2 Storage in Deep Saline Formations
1. Governments interested in royalties	1. Main concerns: safety and permanence of storage
2. Under jurisdiction of economic/energy departments	2. Under jurisdiction of environment departments (EPA)
3. Tenure and permitting under Oil and Gas (PNG) or Mineral legislation	3. Patchwork tenure and permitting
4. Regulated and monitored by State and Provincial Oil and Gas regulatory agencies	4. Regulated by federal EPA under the Underground Safe Drinking Water Act

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Well Construction Differences between CO_2-EOR and CO_2 Storage

CO_2-EOR	**CO_2 Storage in Deep Saline Formations**
Class II wells	New Class VI wells

Common law for damage from injection, financial security (bonds) required for wells

The transition of wells from Class II to Class VI imposes a huge cost to CO_2-EOR operators, particularly considering the large number of CO_2 injection wells in CO_2-EOR operations, which practically precludes the transition from CO_2-EOR to CO_2 storage

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Liability Differences between CO_2-EOR and CO_2 Storage

CO_2-EOR

1. Operator liable during operations
2. Operator liable only for wells after abandonment
3. “Orphan Wells” funds established, into which industry contributes, to take care of wells with no owner
4. No liability for the CO_2 left in the reservoir
5. CO_2 can be withdrawn for reuse

CO_2 Storage in Deep Saline Formations

1. Operator liable during operations
2. Where legislation or regulations have been introduced, the operator is liable for wells and the CO_2 in the ground for the duration of the “Closure Period”
3. In some jurisdictions the government agreed to take over long-term liability, in others did not, or no decision was made

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Monitoring and Reporting Differences between CO_2-EOR and CO_2 Storage

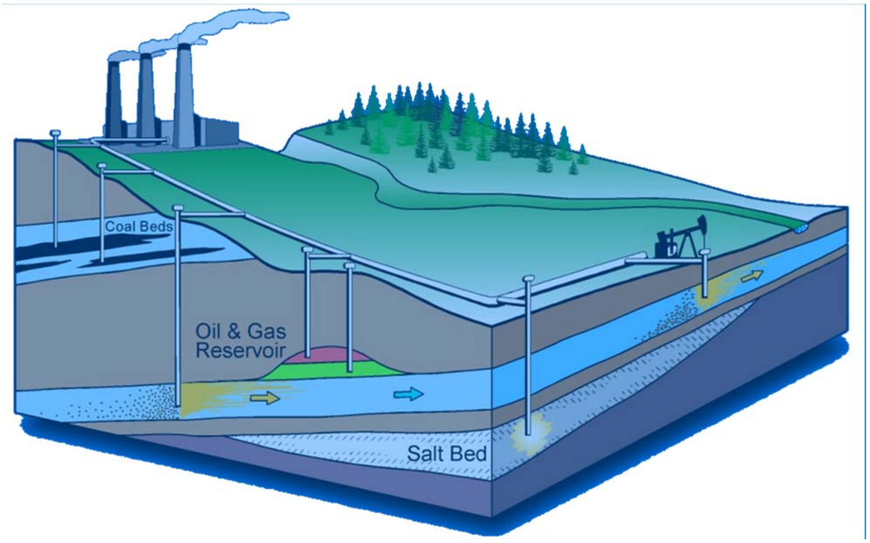
CO_2-EOR

The operator has to monitor and report to the state oil and gas regulatory agency wellhead injection rate, pressure, temperature and composition of the injected CO_2 stream, and the fluids produced at producing wells (oil, water, CO_2, methane) – **Black box material balance**

CO_2 Storage in Deep Saline Formations

Much more stringent monitoring and reporting requirements to EPA, including subsurface parameters - **Greenhouse gas accounting**

Closing Remarks



Current Challenges

- Moving ahead in the absence of incentives or requirements
- Lowering the cost of CCS
- Identifying secure storage sites of sufficient capacity
- Demonstration of fully integrated (“cradle to grave”) systems
- Proving CCS in the power and industrial sectors
- Gaining public acceptance and support

The Past

In the early 2000's great hopes and efforts were put into CCS, in advance of, and during the Kyoto Protocol period (2008-2012), in the belief that a post-Kyoto agreement will be reached in time and countries will get serious about reducing their CO_2 emissions

The Kyoto Protocol was flawed in that top large CO_2 emitters, such as China (currently #1 with 25% of world emissions and growing), India, Brazil and South Africa were not part of it

After the Great Recession in 2008, when governments priorities changed, and the collapse of COP negotiations in 2011 regarding a successor to the Kyoto Protocol that would include countries such as China, India and Brazil, CCS activities slowed down and many announced projects were delayed or cancelled

The Future

CCS will rebound in a few years because it has to be part of the portfolio of measures for reducing anthropogenic CO_2 emissions into the atmosphere; any other solution without CCS will be more costly, by ~70% according to IEA

Background intergovernmental negotiations are preparing the ground for hopefully reaching a GHG reduction agreement at the COP in Paris, 2015, to enter in force in 2020

Unless China and U.S. will sign and ratify, no substantial progress will be made in the near future

Considering the length of time (8-10 years) it takes to move a CCS project from the concept stage to the operational stage, we need to start today for any project scheduled after 2020

Concluding Remarks

- There is need to demonstrate the feasibility of fully-integrated CCS projects (“cradle-to-grave”)
- Significant scientific and technological advances will be made from large-scale demonstration projects (“learning by doing”)
- Public safety must be paramount in deploying CCS projects
- Proper legal, regulatory and economic frameworks must be put in place
- Economic and financial instruments are needed for support of the “early movers”