International Scientific and Practical Symposium - Roundtable
“Regional Roadmap for Implementation of Technologies to Carbon dioxide Capture and Storage in the East of Ukraine”, October 23, 2012 in Donetsk

CO2 geological storage technologies - the integrated approach

Prof.Saulius SLIAUPA
Institute of Geology and Geography Lithuania
of Nature Research Centre

How to achieve CO_2 emission reduction?

Portofolio

(1) improved energy efficiency

(2) improved energy demand management

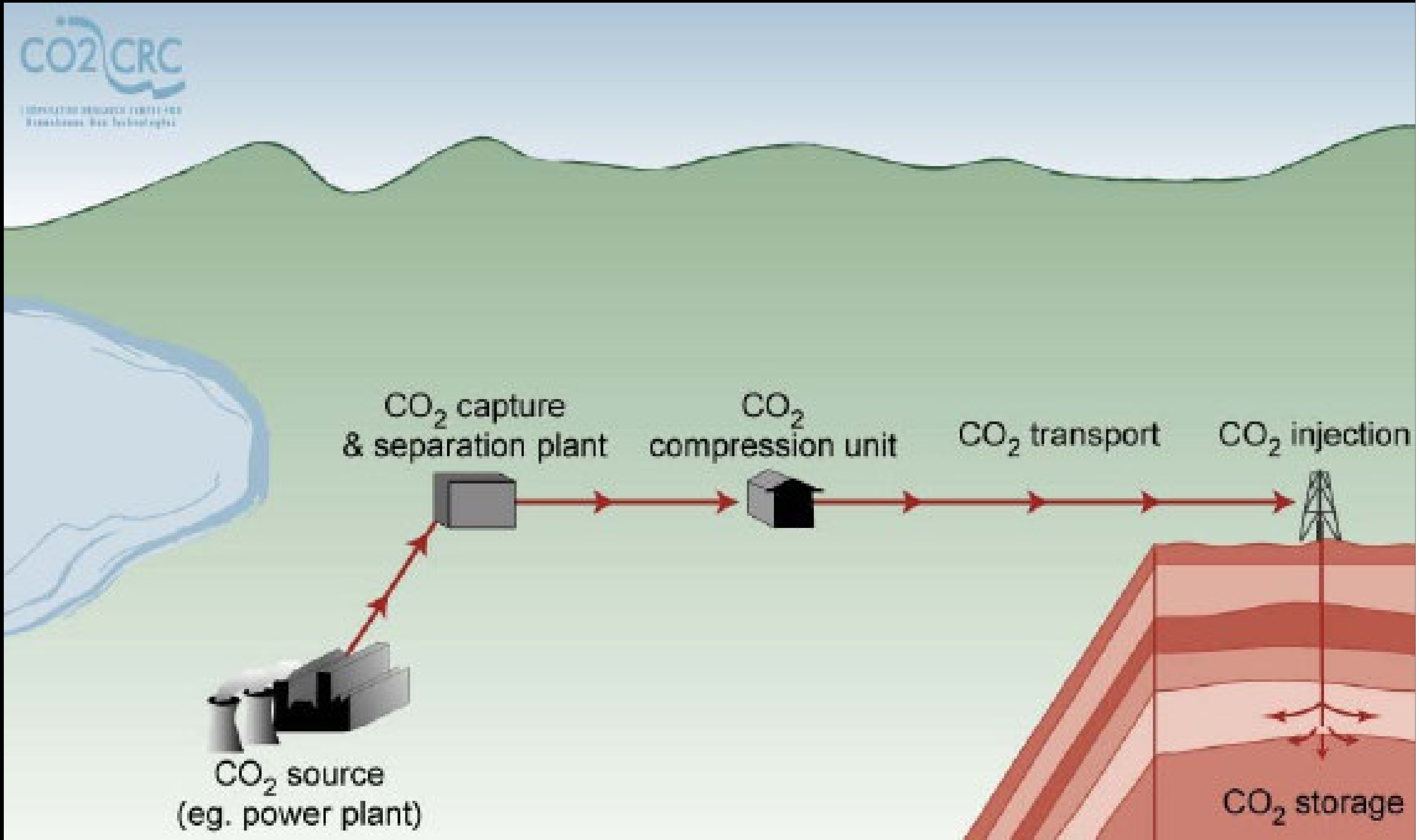
(3) renewable energy

(4) energy sources with lower CO_2 emissions

(5) Enhancement of natural sinks (e.g.biosequestration)

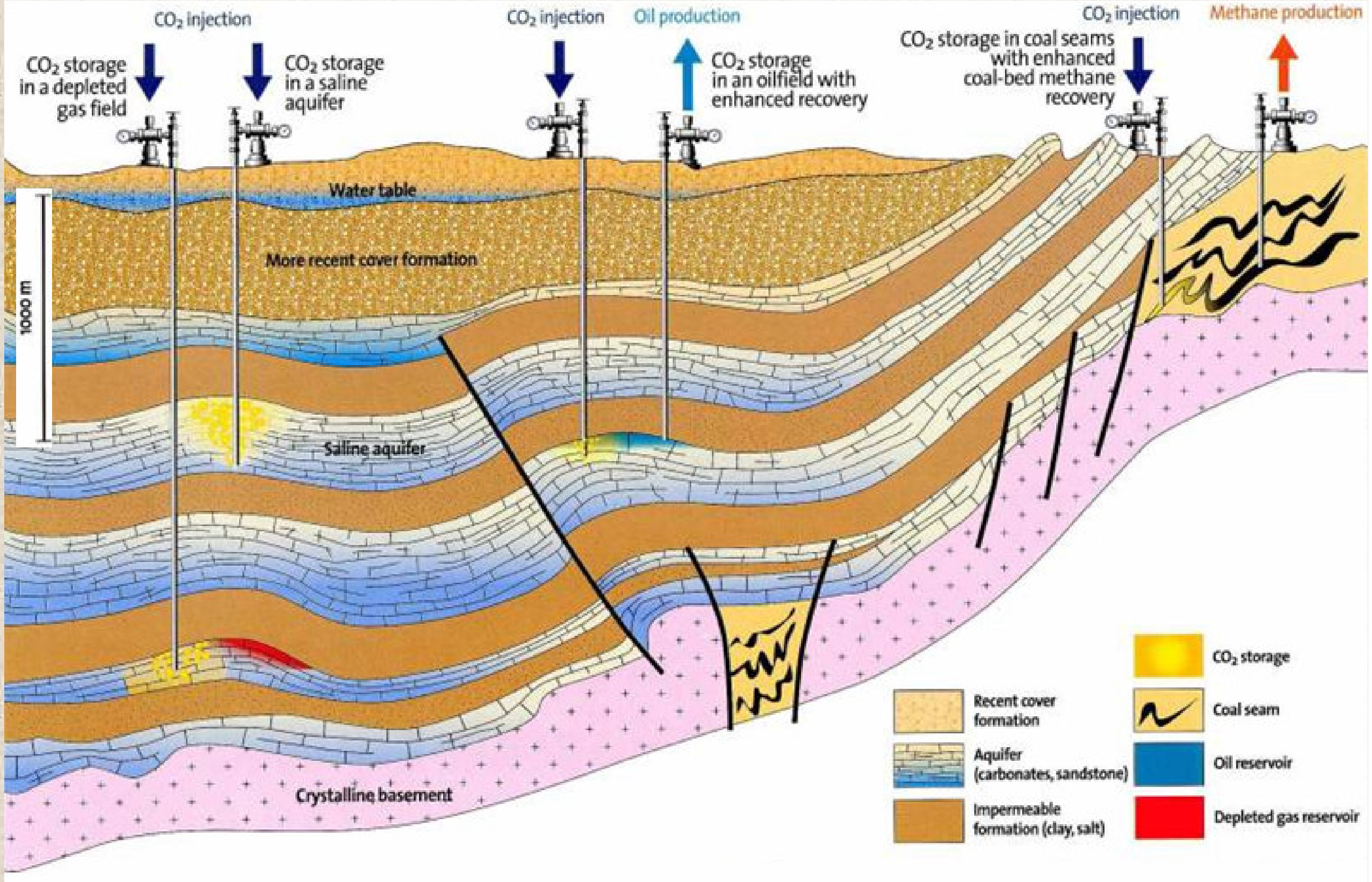
(6) CO_2 geological storage

Carbon Dioxide Capture & Storage Project Life Cycle



The rationale for carbon capture and storage is to enable the use of fossil fuels while reducing the emissions of CO2 into the atmosphere (*fossil fuels supply over 85 percent of all primary energy*)

Geological storage



<u>Technical global storage capacity comprises:</u>

saline aquifers

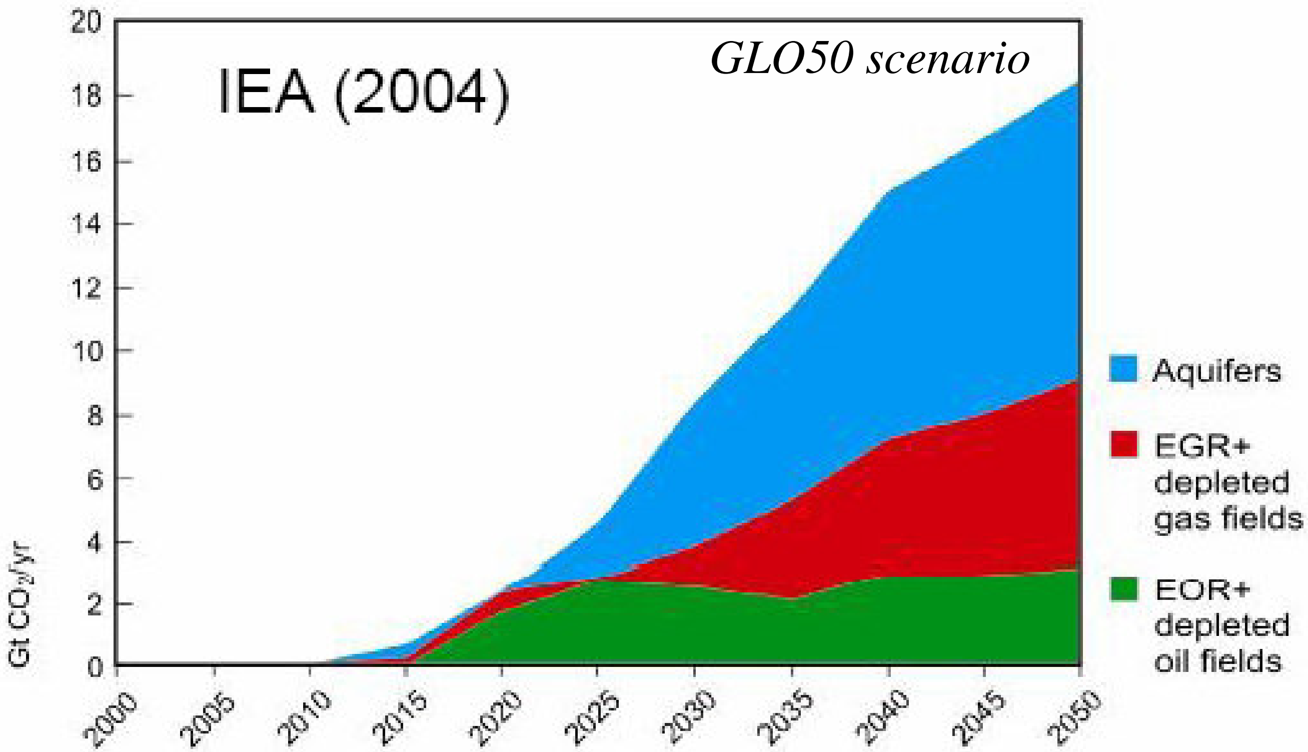
depleted HC fields, EOR, and EGR

unmineable coal seams (enhanced coal bed methane)

Technical geological storage capacity

Storage options	Capacity (Gt CO_2)
Deep saline aquifers	1 000 ... 10 000
Depleted oil and gas fields	675 ... 900* (+25%)
Coal beds	3-15 ... 200
Global CO_2 emissions	**25 Gt/yr**

IPPC



CO2 storage technologies

Being practiced
EOR

Short-term option
Physical trapping in deep saline aquifers

Mid-term options
Coal seems
EGR
CO2 geothermal

Long-term option
Mineral trapping

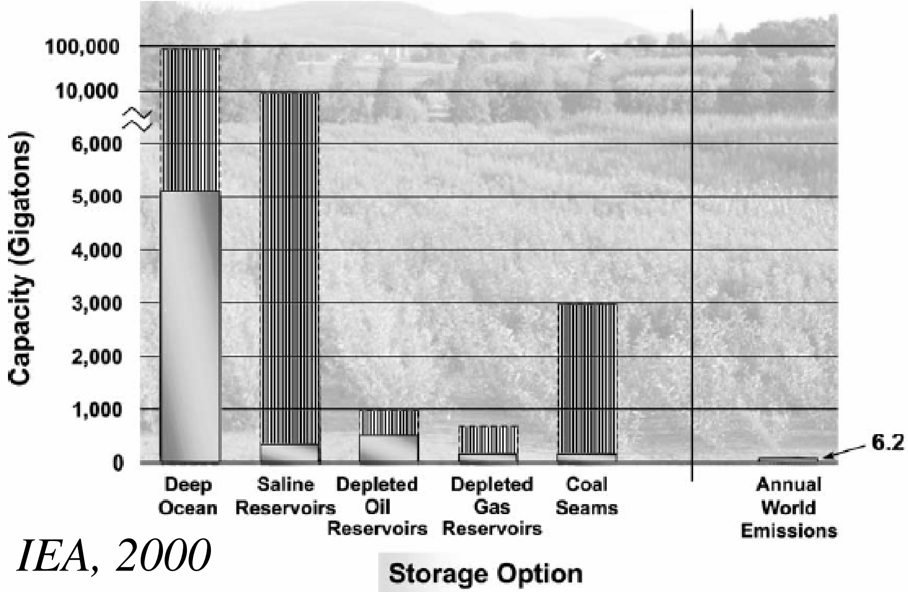
Storage capacity

Depleted oil and gas reservoirs
675–900 GtCO2.

Deep saline formations
> 1000s GtCO2

Unminable coal formations
3 GtCO2 up to 200 GtCO2

Saline aquifers
> 1000 GtCO2

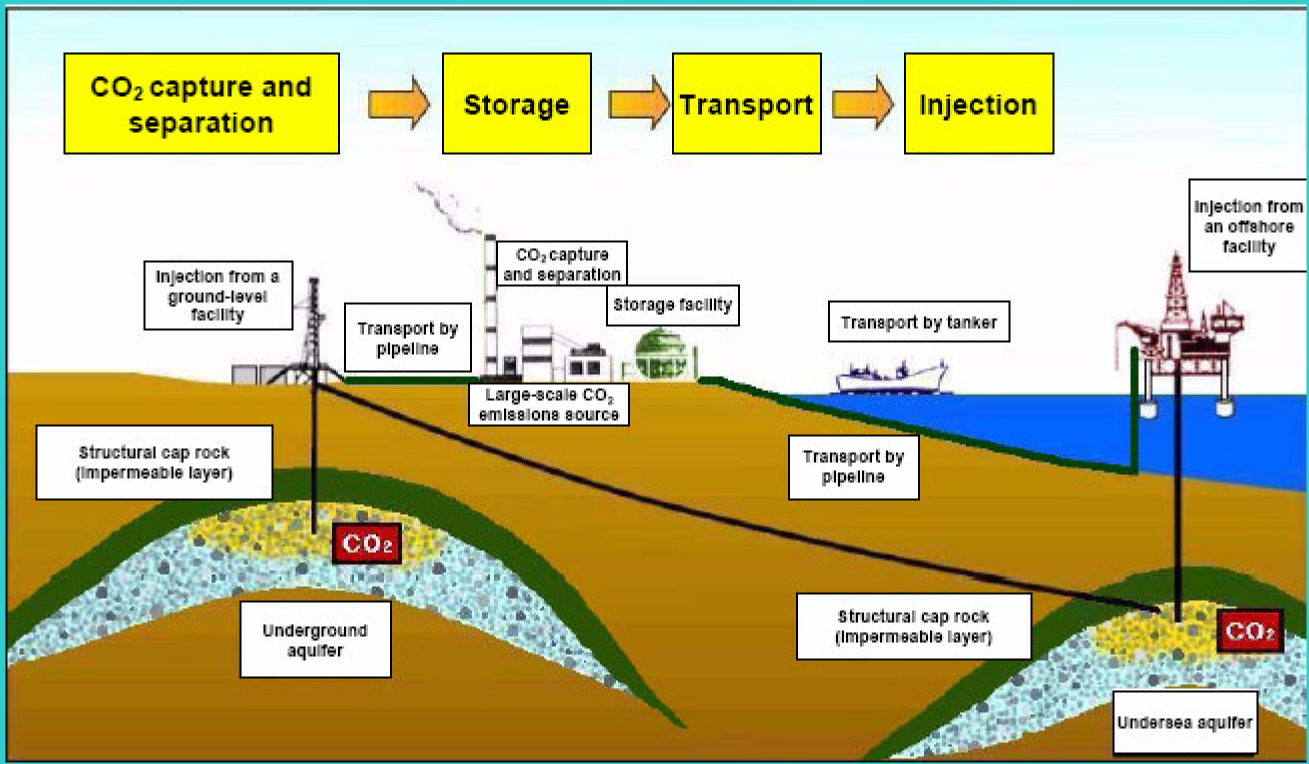


IEA, 2000

1. Geological storage in deep saline aquifers

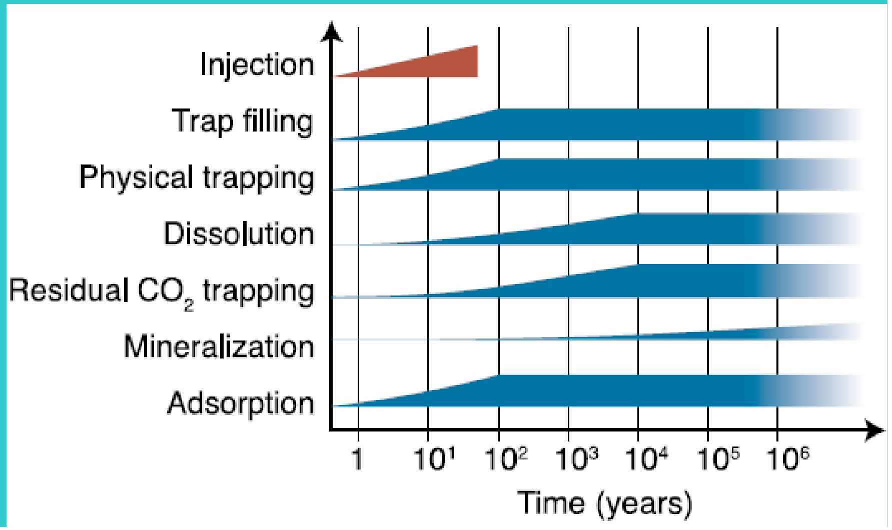
CO2 storage in deep saline aquifers

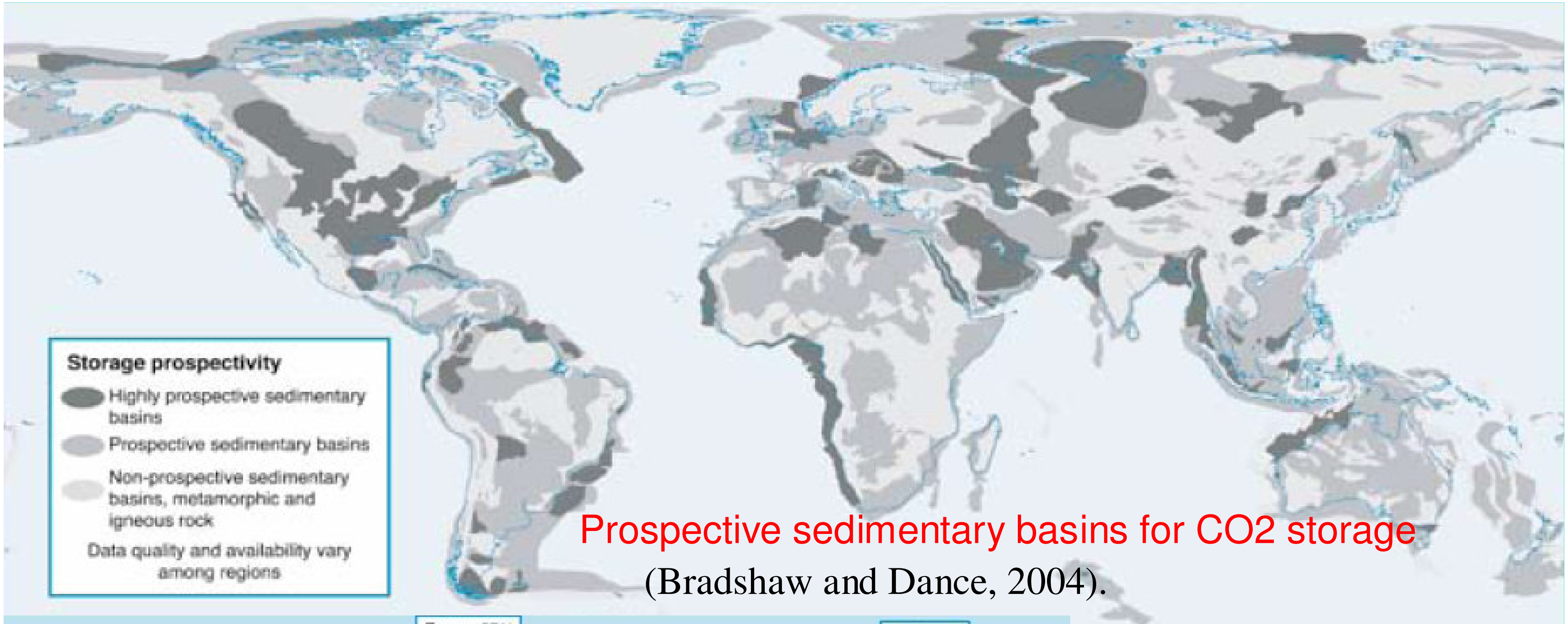
Major short-term option for CO2 storage



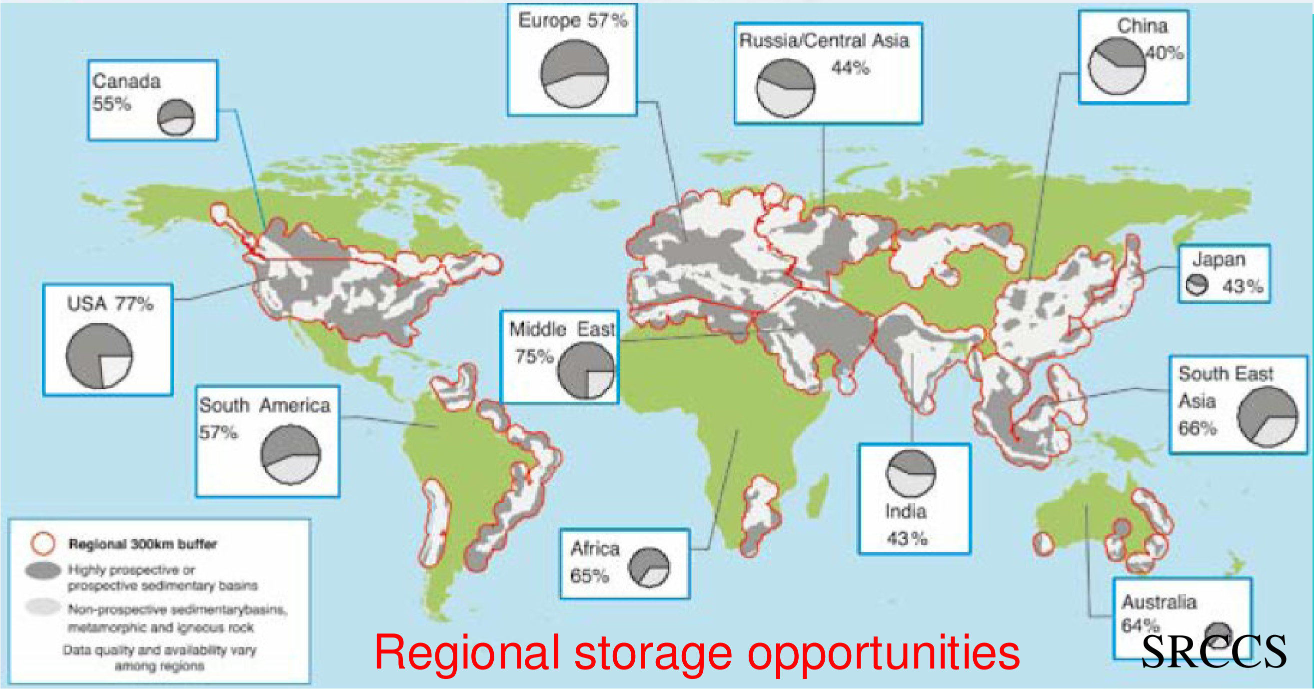
Multiple mechanisms for storage:

- physical trapping beneath seal
- residual CO2 trapping
- adsorbtion
- solubility trapping
- mineral trapping



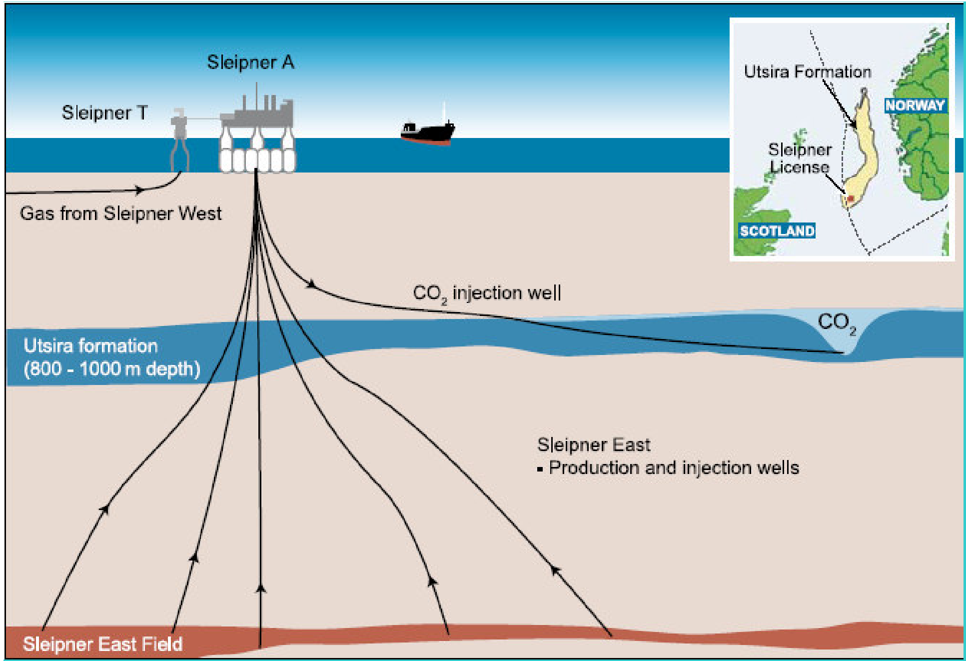


Prospective sedimentary basins for CO_2 storage
(Bradshaw and Dance, 2004).

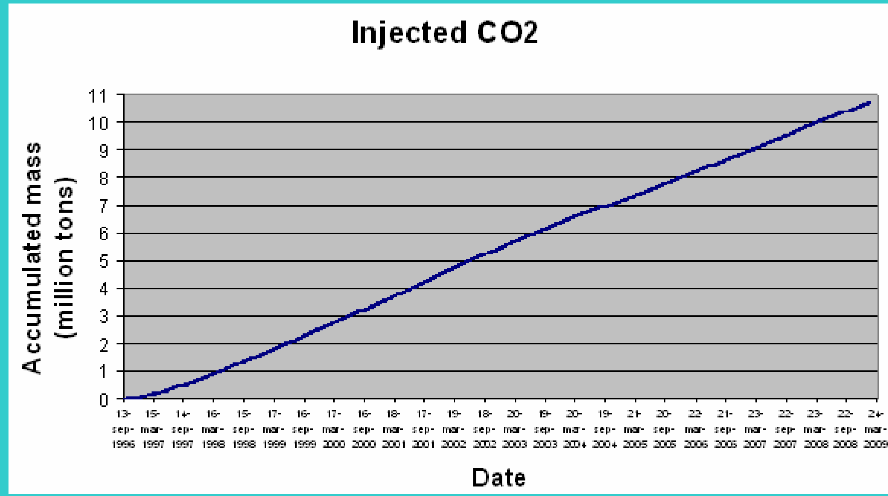


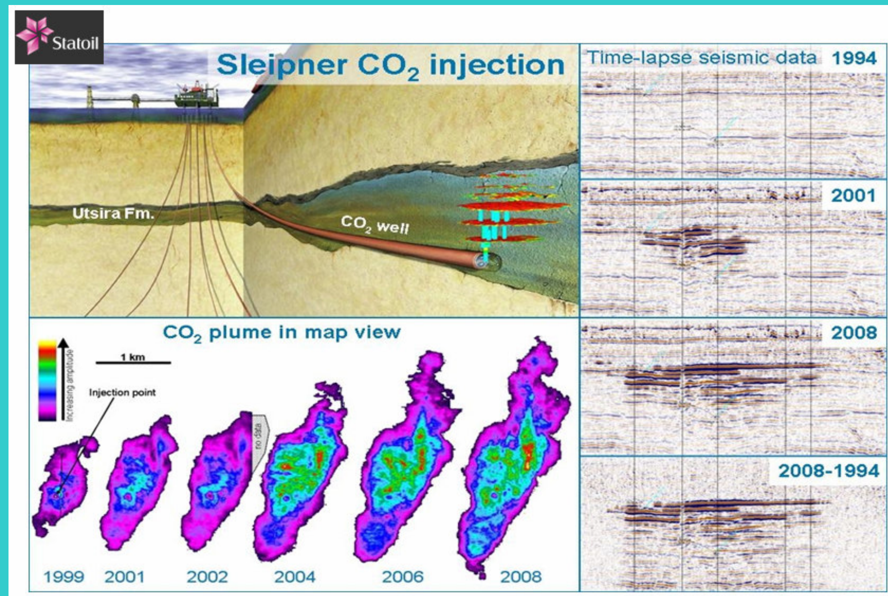
Regional storage opportunities

SRCCS



Sleipner industrial project



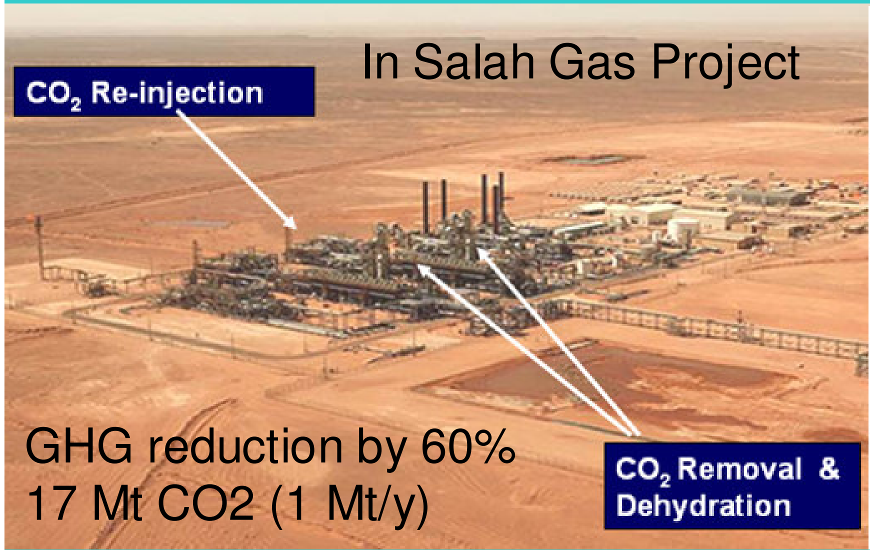


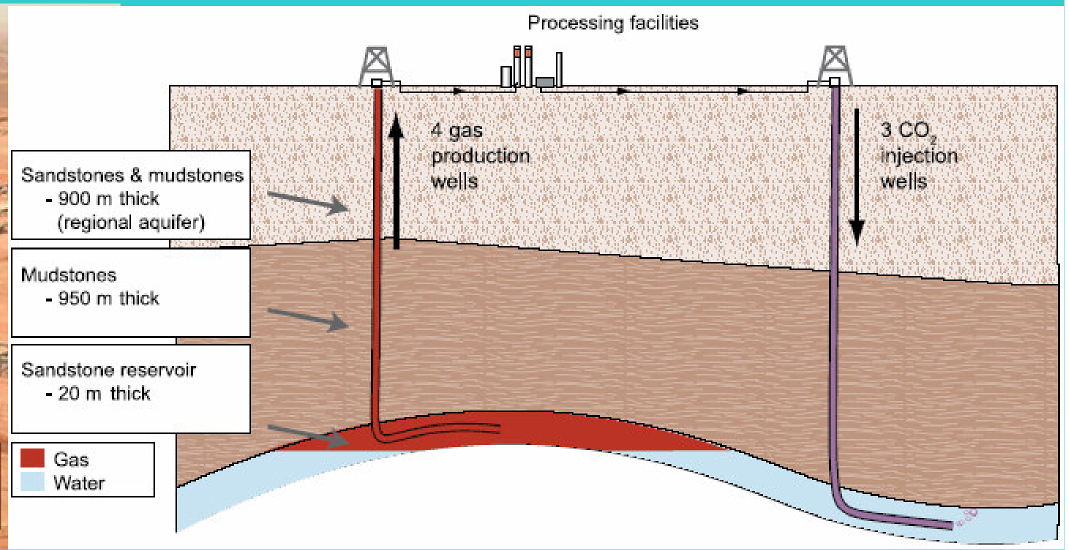
<u>Utsira Sand</u>

Operated by Statoil
Average daily injection rate 3000 t/d
Started in 1996
13 mill. tons injected until 2010

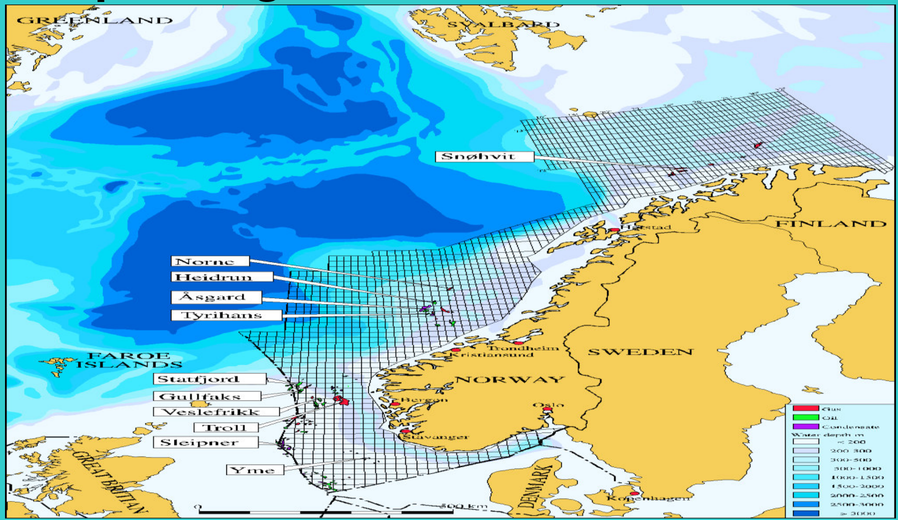
It demonstrates safe CO2 storage in the deep saline aquifer

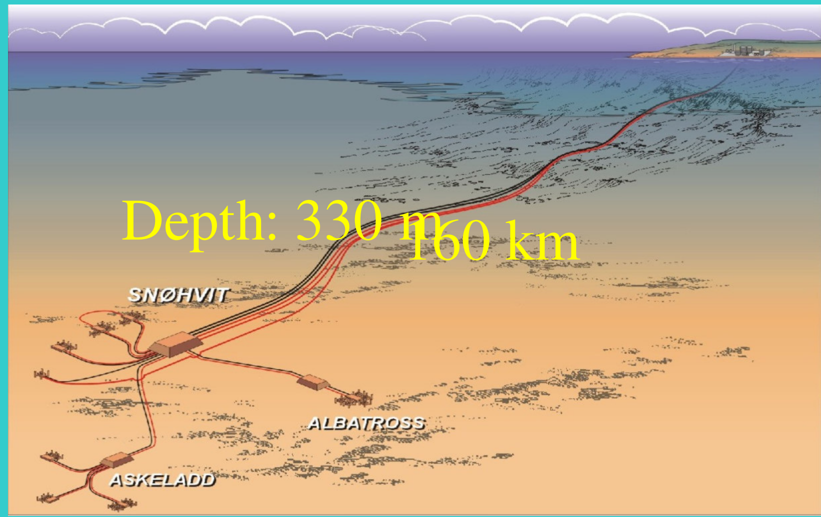
Injection of CO2 separated from gas of In Salah (onshore) field
Operting since 2004

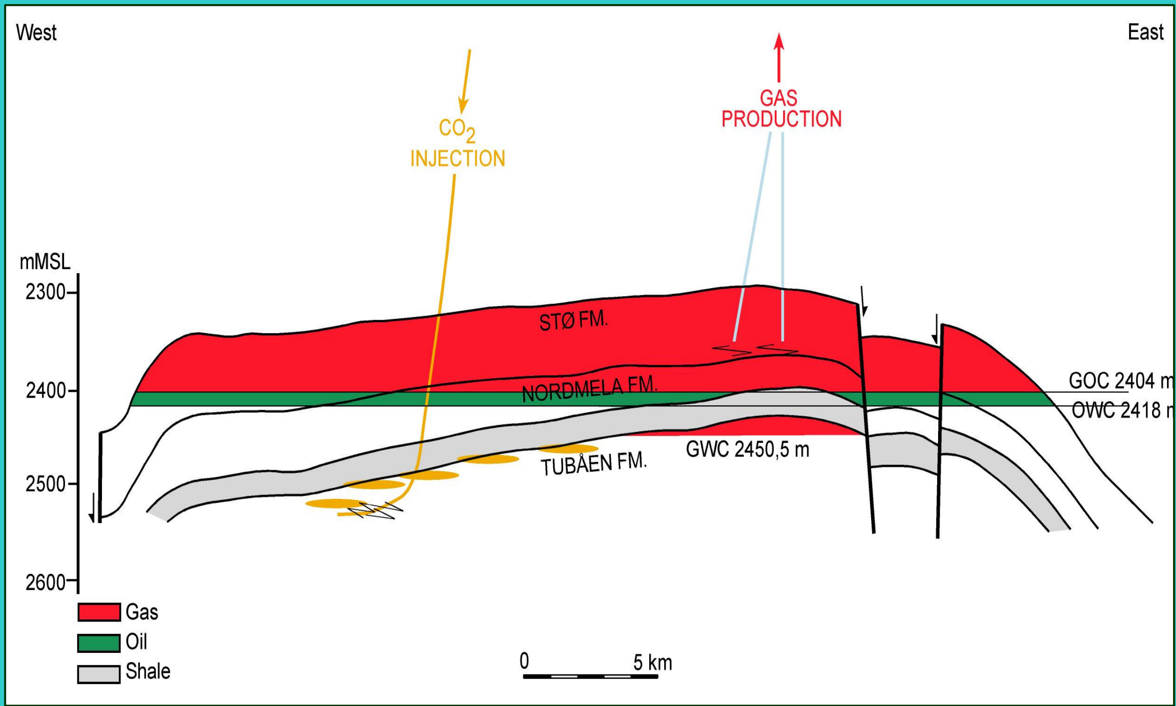




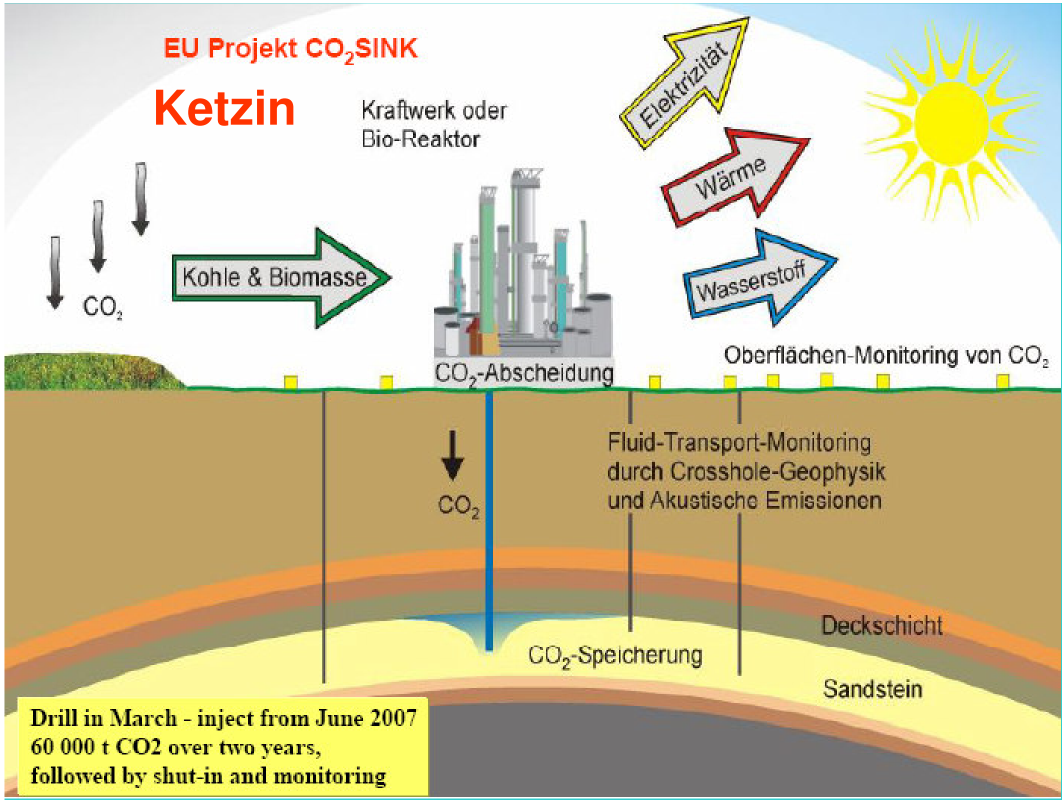
Snøhvit industrial project, implement CO_2 storage offshore in North Atlantic Operating since 2008

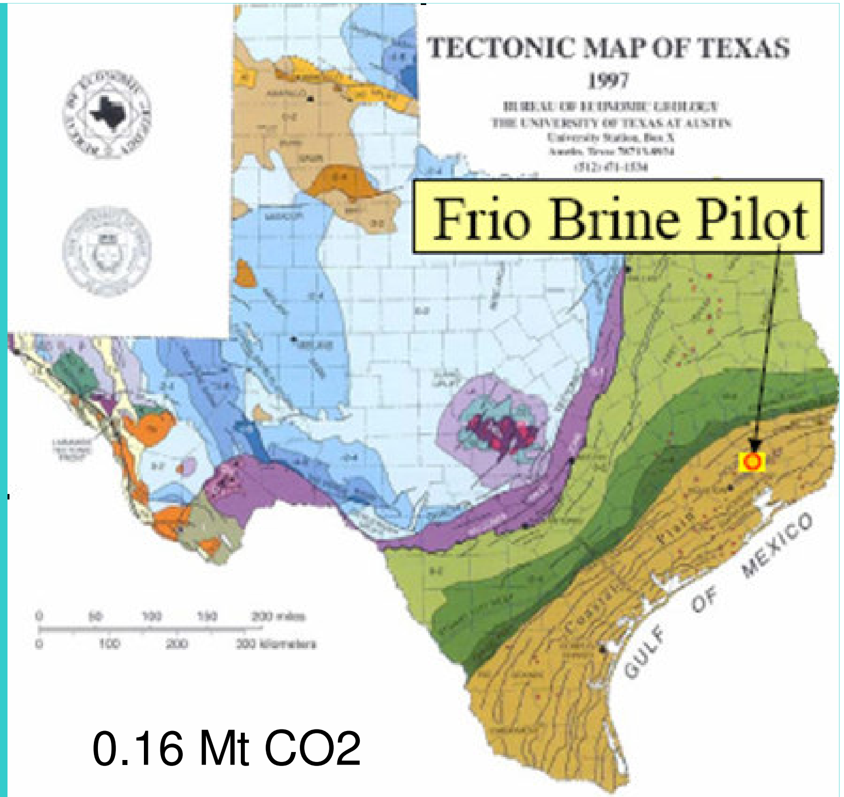






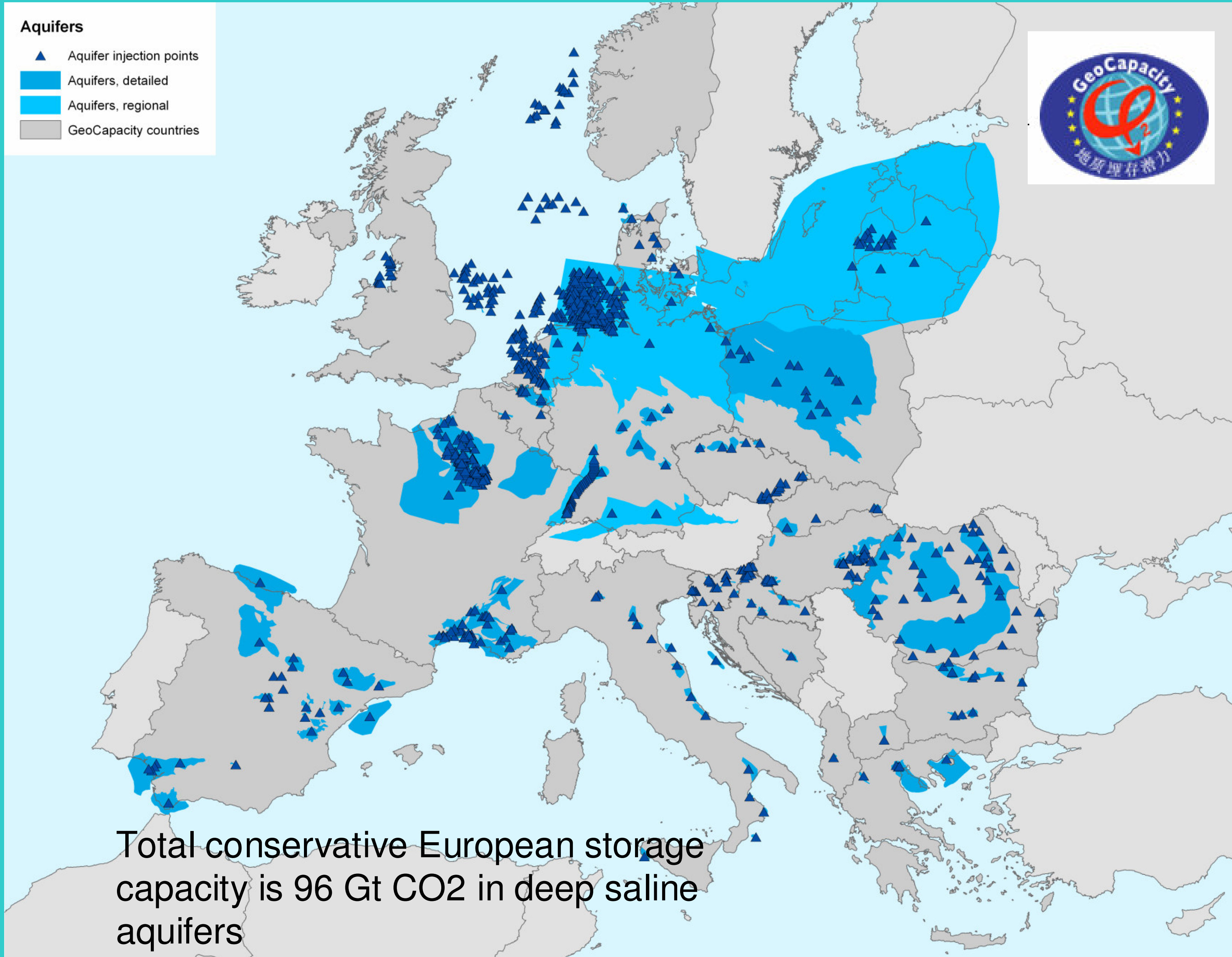
0.7 Mt CO_2/a injection rate
Maximum injection is planned for 31-40 Mt





CO2 storage in brine-bearing sandstones – a number of pilot projects

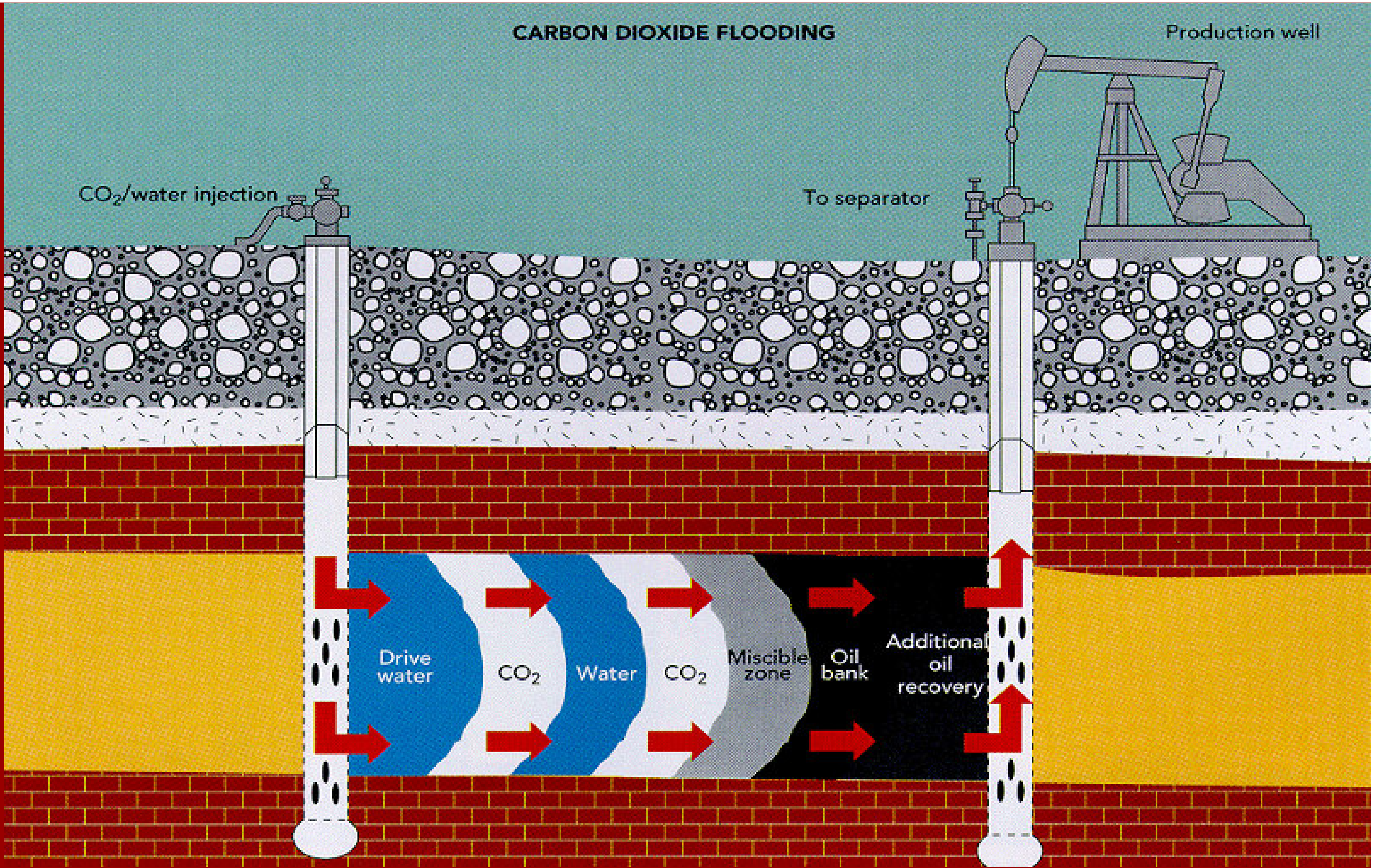
Aquifers



Total conservative European storage capacity is 96 Gt CO2 in deep saline aquifers

2. ENHANCED OIL RECOVERY
CO_2-EOR

EOR

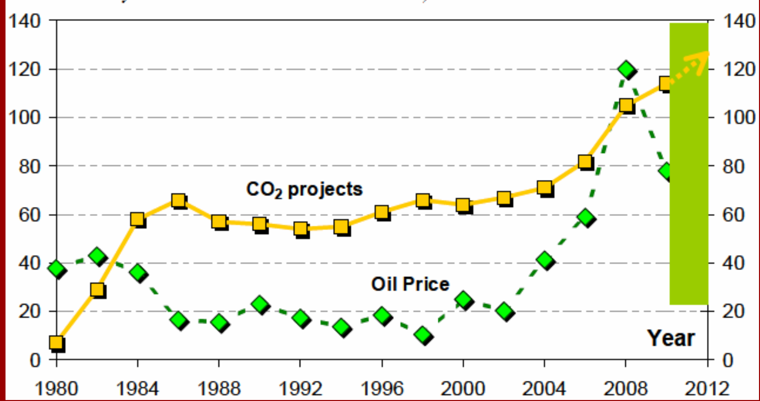


In general, using CO_2 for tertiary EOR may add an additional 5-18% of OOIP to the anticipated total production

The volumes of CO_2 injected solely for oil recovery are minimized due to the purchase cost of CO_2

90 CO2 EOR projects
(USA, 40 Mt/y of CO2)

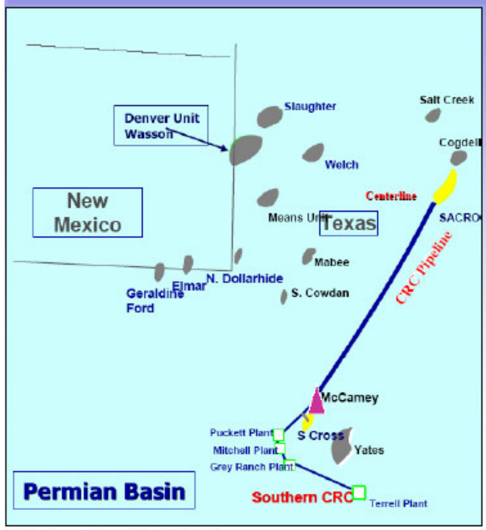
Evolution of CO_2 projects and oil prices in the U.S. (From Oil & Gas Journal EOR Surveys 1980–2010 and U.S. EIA 2010)



Country	Project Type	No of projects	Production Rate (b/d)
USA	Miscible	70	205 775
	Immiscible	1	102
Canada	Miscible	2	7 200
Turkey	Immiscible	1	6 000
Trinidad	Immiscible	5	313

EOR is currently performed in geologically favorable areas. Fiscal modifications are necessary to stimulate and create a 'CO2 category' of production in other regions

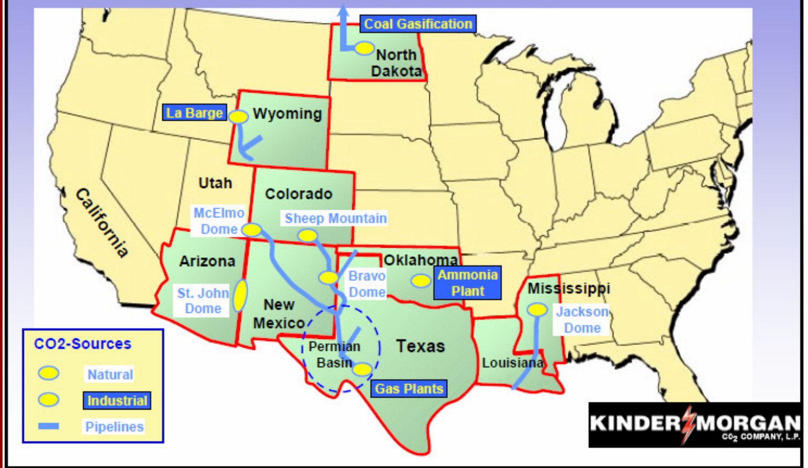
Permian Basin 1970 - 1973

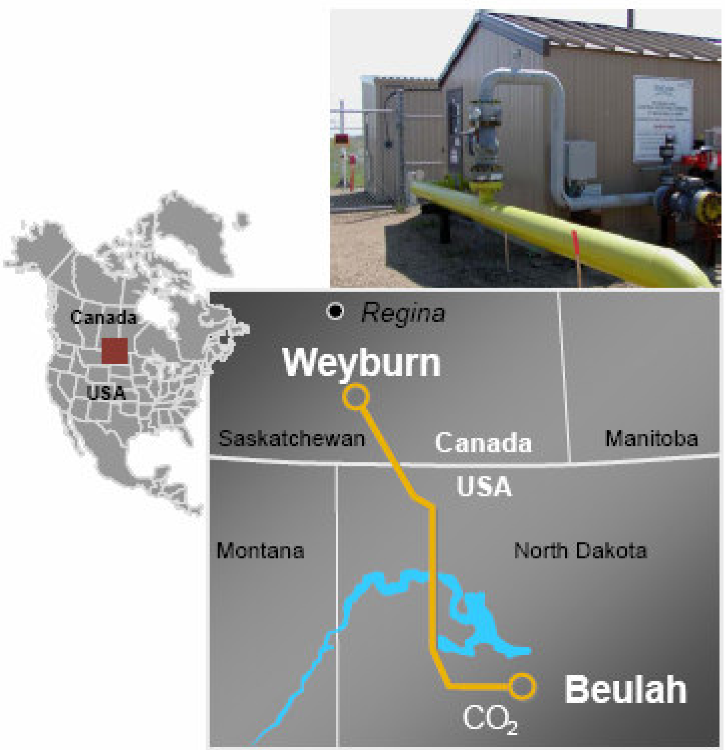


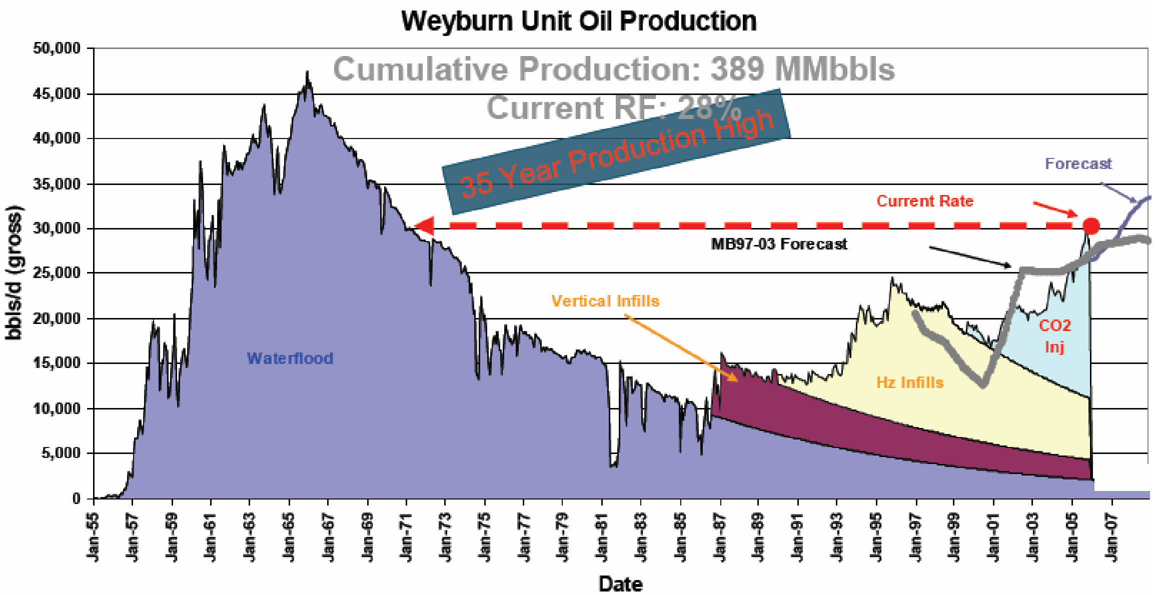
Map by courtesy of David L. Coleman

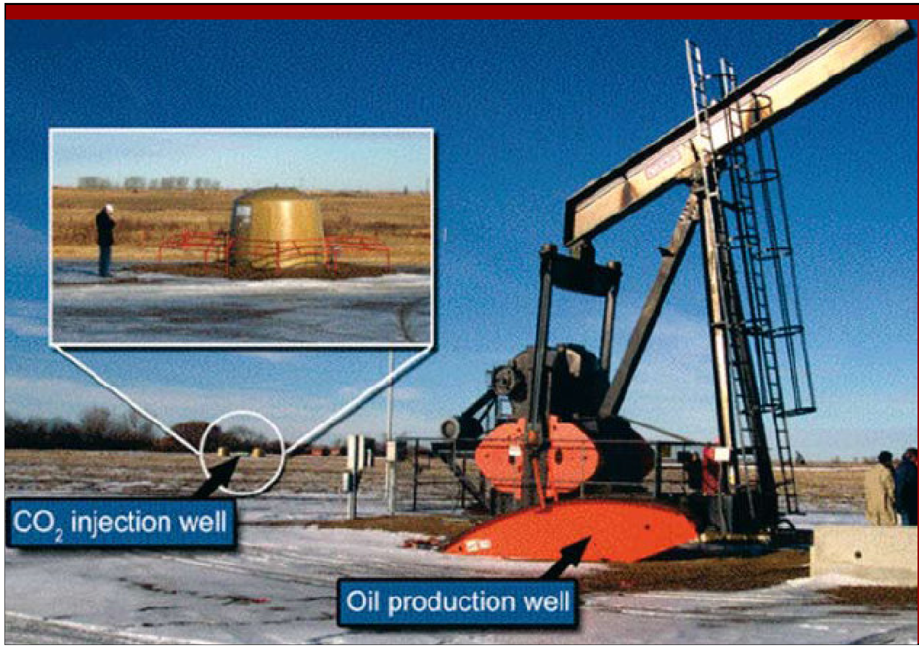
- Oil Production caps removed for Enhanced Oil Recovery (EOR) projects.
- Chevron / Shell collaborated and used Anthropogenic CO2 for EOR Projects.
- Chevron built 275 km CRC pipeline to SACROC.
- SACROC is first large CO2-EOR flood.
- Production dramatically increased.

Overview of Established CO2-EOR Pipeline Infrastructure in the US







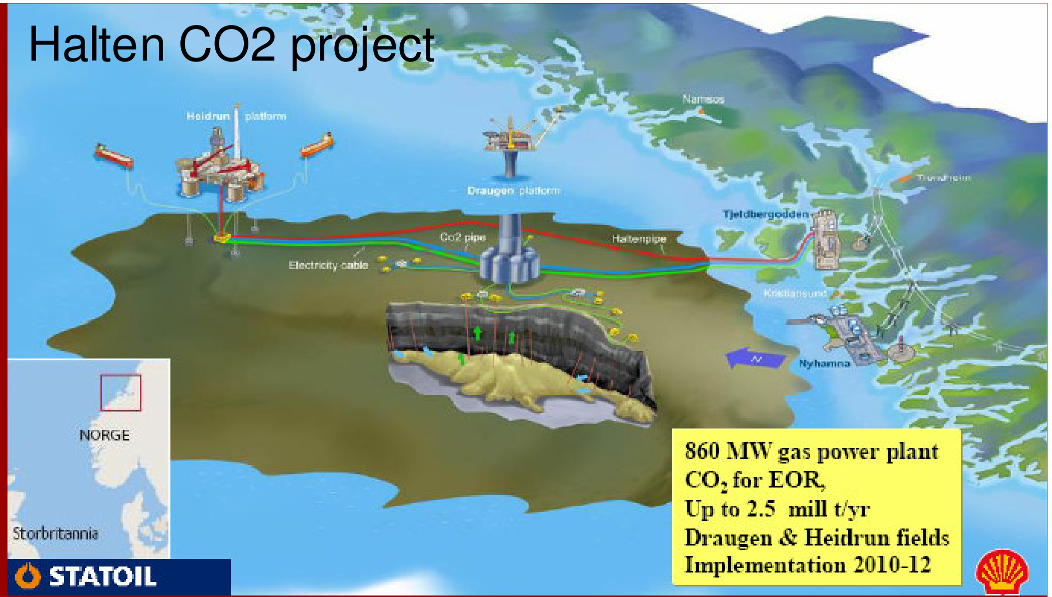


Started in 2000
4000 t/d CO2 (capacity 20 Mt CO2)

Goals

Verify long-term storage capacity of an oil reservoir, refine CO2 movement prediction and verification practices, understand migration and leakage risks, improve CO2 storage capacity and narrow down the economics of storage.

EOR European projects

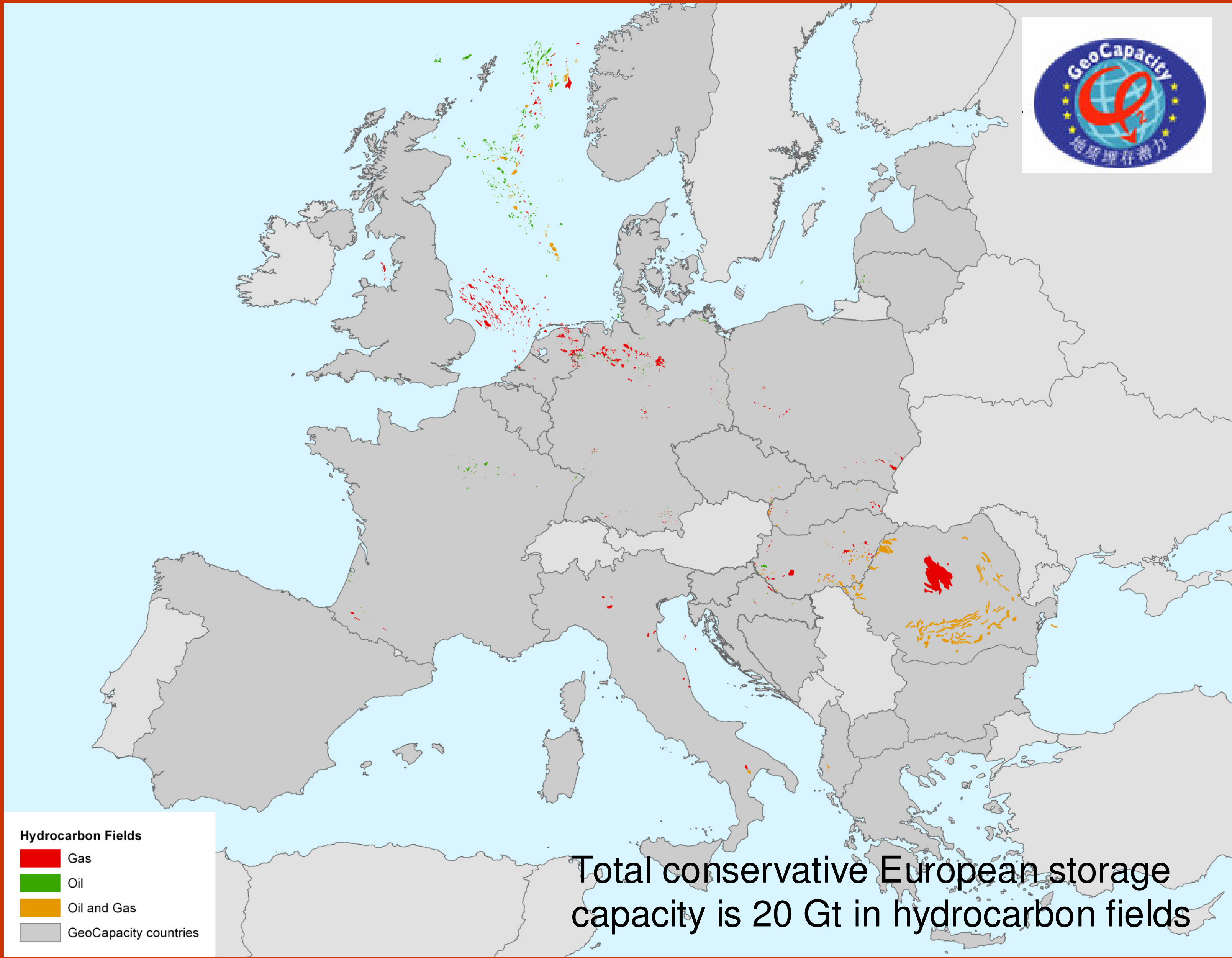


Many reservoirs of the North Sea are reaching end of conventional production life

In the North Sea CO2 storage capacity within oil and gas reservoirs is estimated to be about 16 GtCO2 (3 billion potential barrels of incremental oil)

EOR started in Hungary in 1960's. However, in most of countries CO2 for EOR is not currently economically viable in Europe. There are no natural sources of CO2 in the northern Europe that are large enough to enable EOR to take place on a commercial scale offshore. The price on carbon emissions dictated by the EU ETS scheme is too low at the present time

Hydrocarbon fields



Barriers for European CO_2-EOR

Offshore location of most of the oil fields (new technological challenges)

Reservoir modelling indicates somewhat lower oil recovery than that in USA

Effectiveness of the competing EOR methods

Benefit restricted mainly to a limiting number of countries (around the North Sea)

The lack of low cost CO_2 supply

Public acceptance?

3. ENHANCED COAL BED METHANE RECOVERY
ECBM

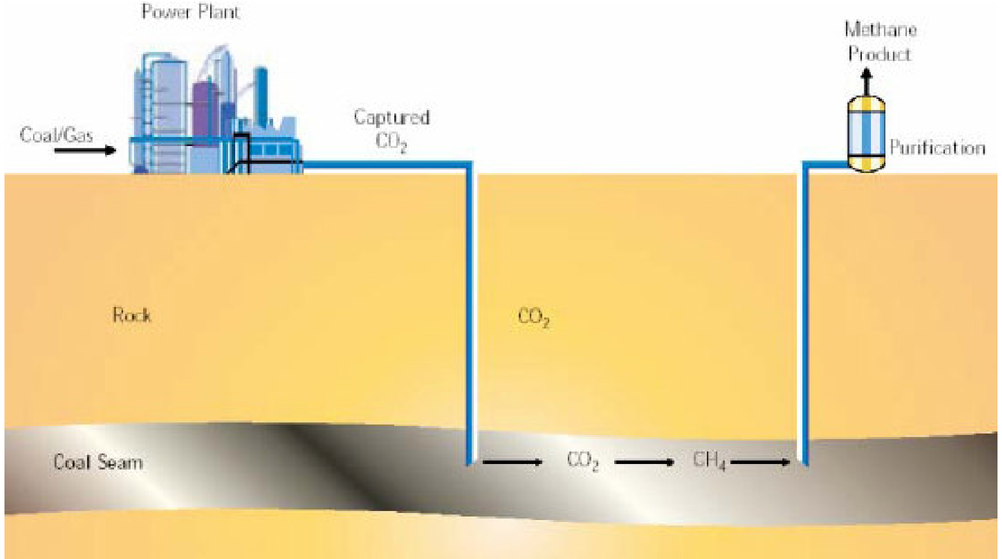
CO2 storage in coal seams

Methane extraction from coal seams has now reached an industrial scale (more than 8 % of the natural gas produced in the US derives from CBM).
A higher efficiency (> 50 %) can be achieved with CO2-ECBM.
It is near to commercial scale application in the USA and Canada.

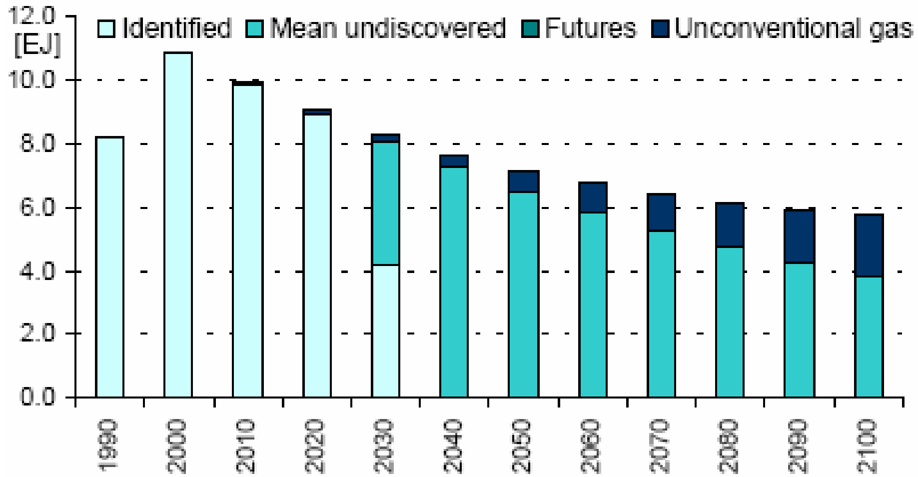
World potential 3-15 Gt to 200 Gt of CO2

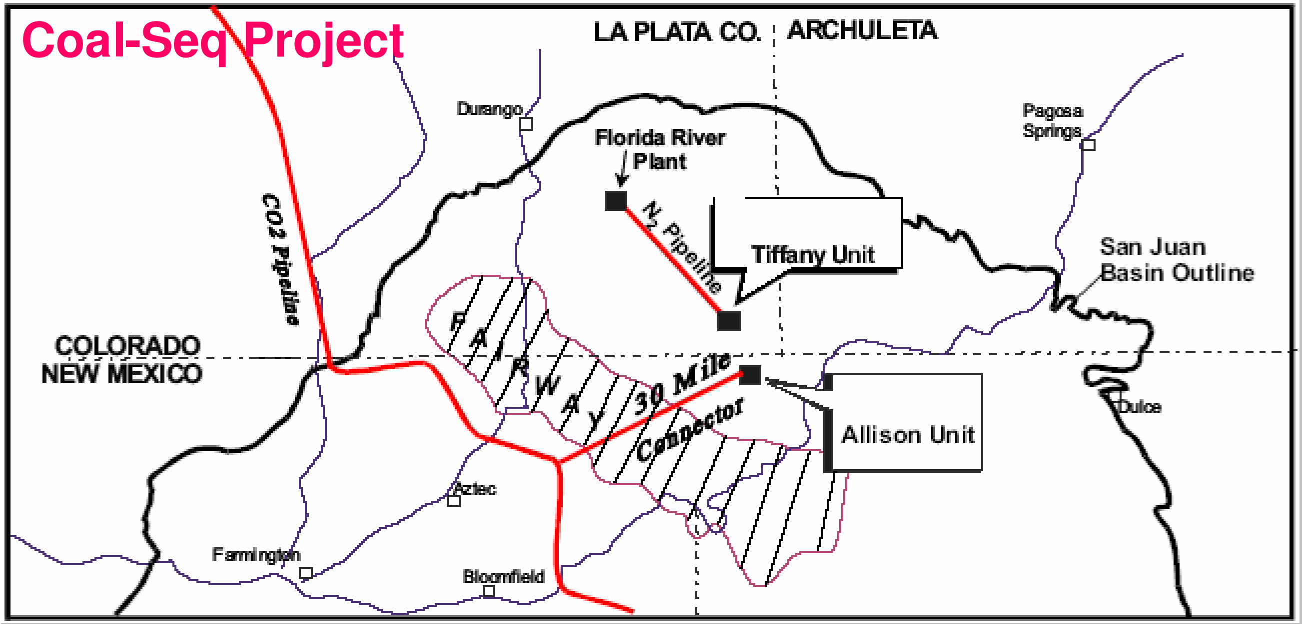
Two plants in the US, and demo units in Canada, China, Poland, Hungary

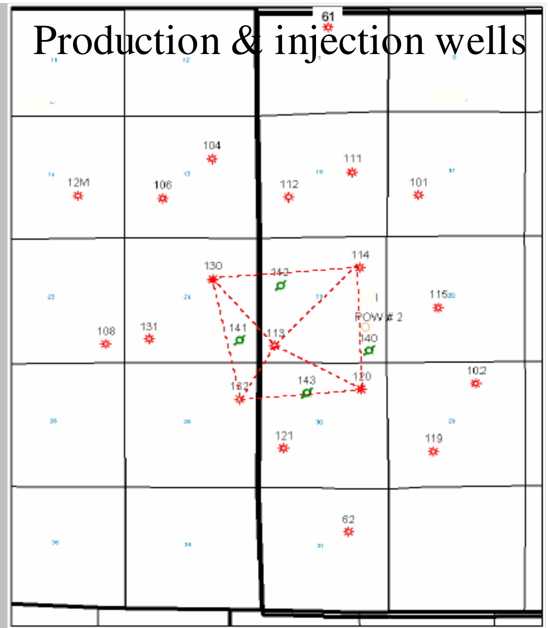
Application of ECBM is highly dependend on the geological specifics of the region (e.g. unfavorable in the Netherlands, favorable in US, India)



Gas production in Europe 1990-2100







Methane recovery of 17 - 18% of original-gas-in-place
CO_2/CH_4 ratio of about 3:1
CO_2-ECBM appears economically attractive (breakeven gas price ~ $2.60/Mcf)

Significant coal permeability reduction with CO_2 injection (important topic for future research)

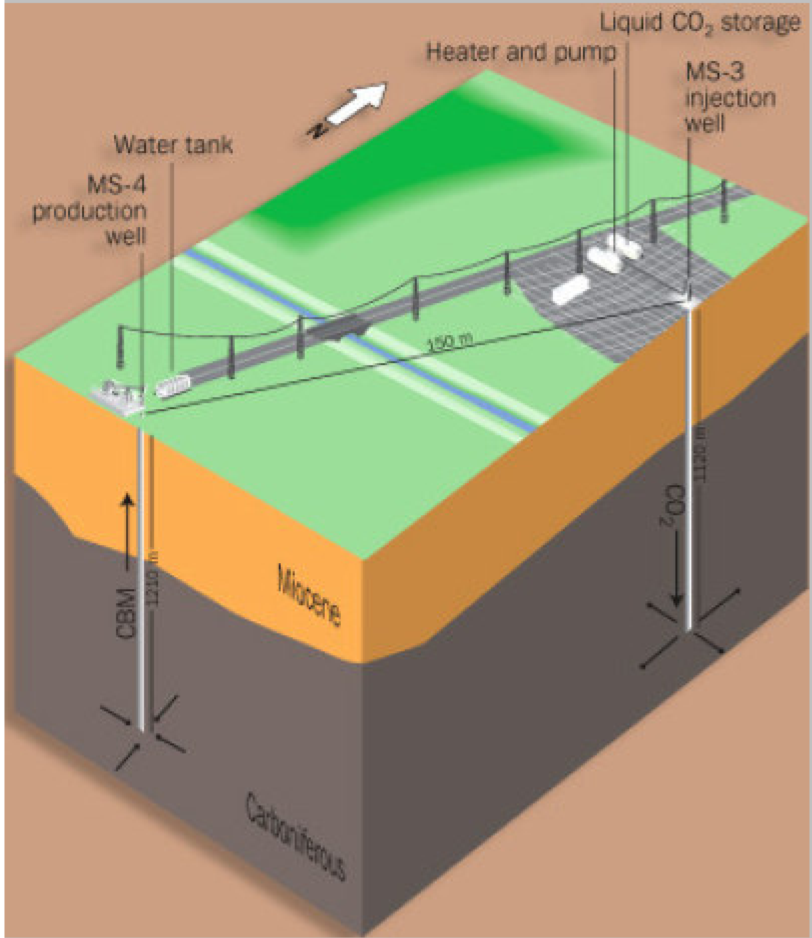
USA ECBM:

85 % - San Juan basin

10% - Black Warrior basin of Alabama

5% - from rapidly developing Rocky Mountain coal basins

EC RECOPOL project



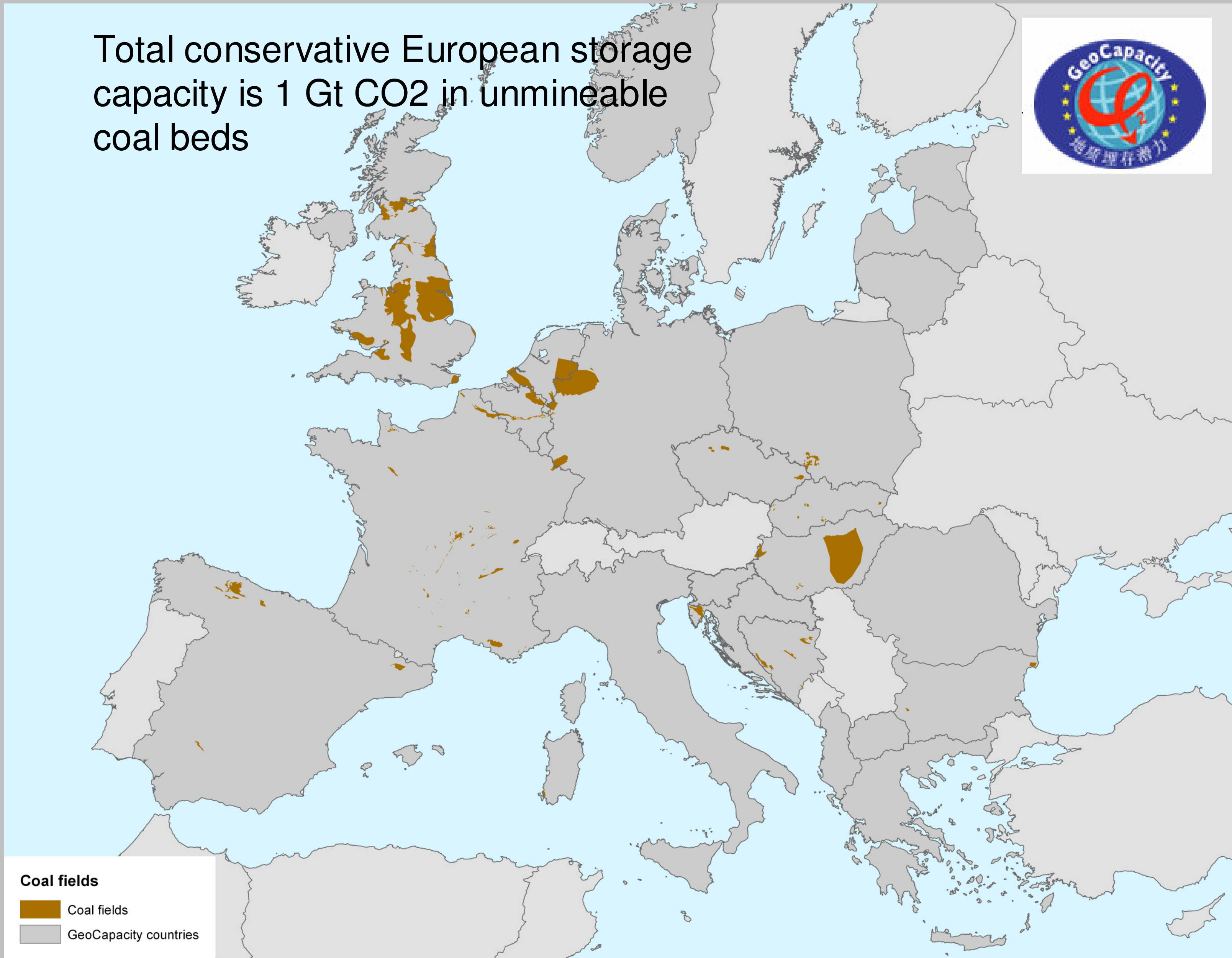
12-15 t CO2/ day (total 760 t)
55 – 70% of incremental methane

It is shown that ECBM CO2 storage can be developed in Europe

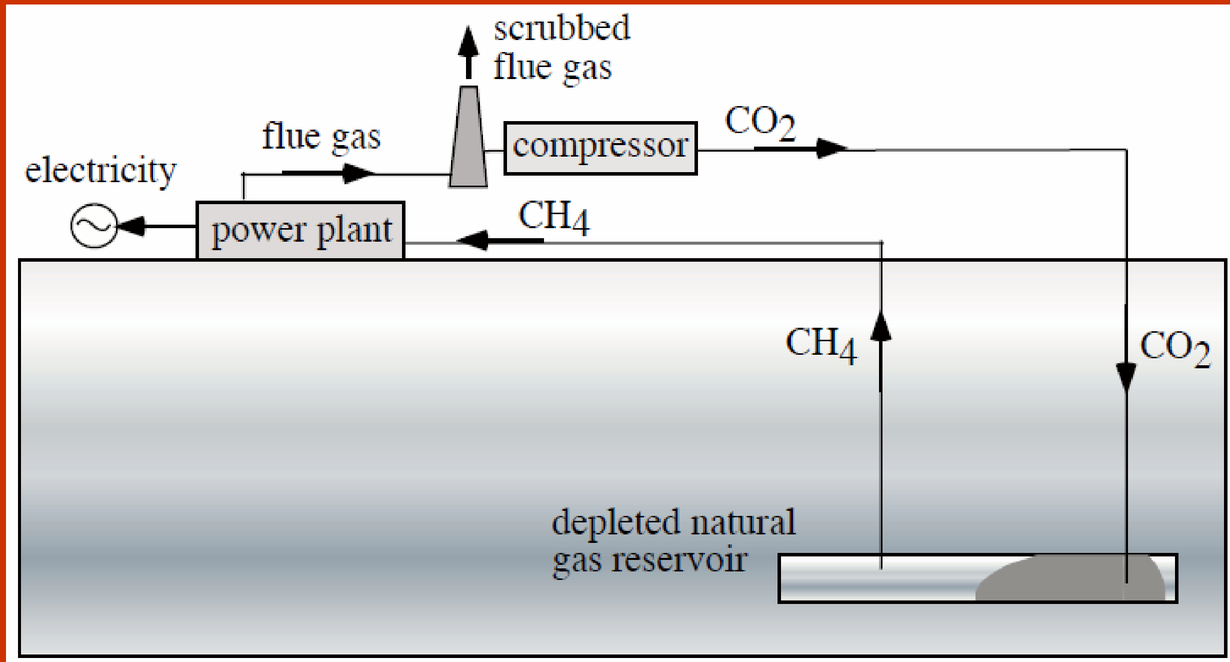
MOVECBM (2006-2008)

Monitoring and Verification of CO2 storage and ECBM

Coal fields

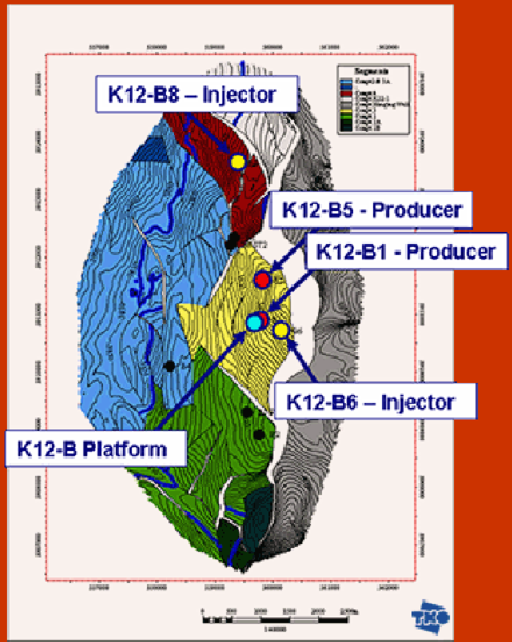

Total conservative European storage capacity is 1 Gt CO2 in unmineable coal beds
GeoCapacity
Coal fields
Coal fields
GeoCapacity countries

4. ENHANCED GAS RECOVERY
CO2-EGR



There already some experience in EGR: sour gas (natural gas with amounts of hydrogen sulphide, H2S) is used as treatment fluid in more than 50 projects in North America.

K12-B CO2 Injection Project



K12-B is the first site in the world where CO2 is being injected into the same reservoir from which it was, together with methane, produced.

CO2 sequestratin started in 2004

The gas produced from the field has a 13% CO2 content

5. Mineral trapping

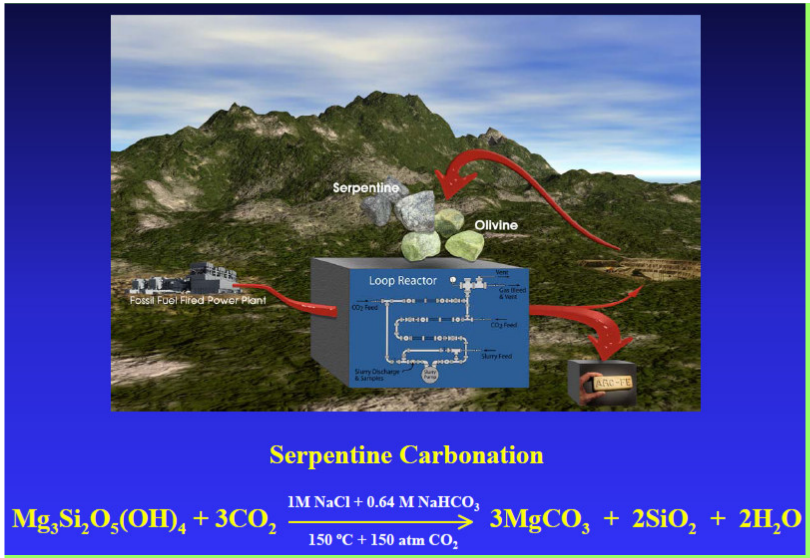
Carbonation of silicate minerals

$$(Mg,Ca)_x Si_y O_{x+2y+z} H_{2z}(s) + xCO_2(g) \rightarrow x(Mg,Ca)CO_3(s) + ySiO_2(s) + zH_2O$$

Calcium- and magnesium-based silicates react with CO_2 to form environmentally harmless carbonates.

- Analogies are known in natural weathering processes of Ca- and Mg-silicates.

- The major hold-up for this technology is the large amounts of material involved and the carbonation reaction kinetics.



Carbonatization of rocks

The serpentine group (e.g. chrysotile) reacts with CO_2 to produce magnesite during its carbonatization in atmosphere conditions.

A process of artificial carbonatization uses NaCl and $NaHCO_3$ to produce intermediate product of $MgCl_2$ + $Mg(OH)_2$ and consequently, the final carbonatization reactions are following :

$$\underset{\text{chrysotile}}{Mg_3Si_2O_5(OH)_4} + 3CO_2 \xrightarrow[150^{o}C + 150\ atm\ CO_2]{1M\ NaCl + 0.64M\ NaHCO_3} \underset{\text{magnesite}}{3MgCO_3} + SiO_2 + H_2O$$

$$\underset{\text{brucite}}{Mg(OH)_2} + CO_2 = \underset{\text{magnesite}}{MgCO_3}$$

After Radvanec et al., 2011

Results in reactions at 50 °C

(metaperidotite source) *50°C + 0.1MPa CO_2*

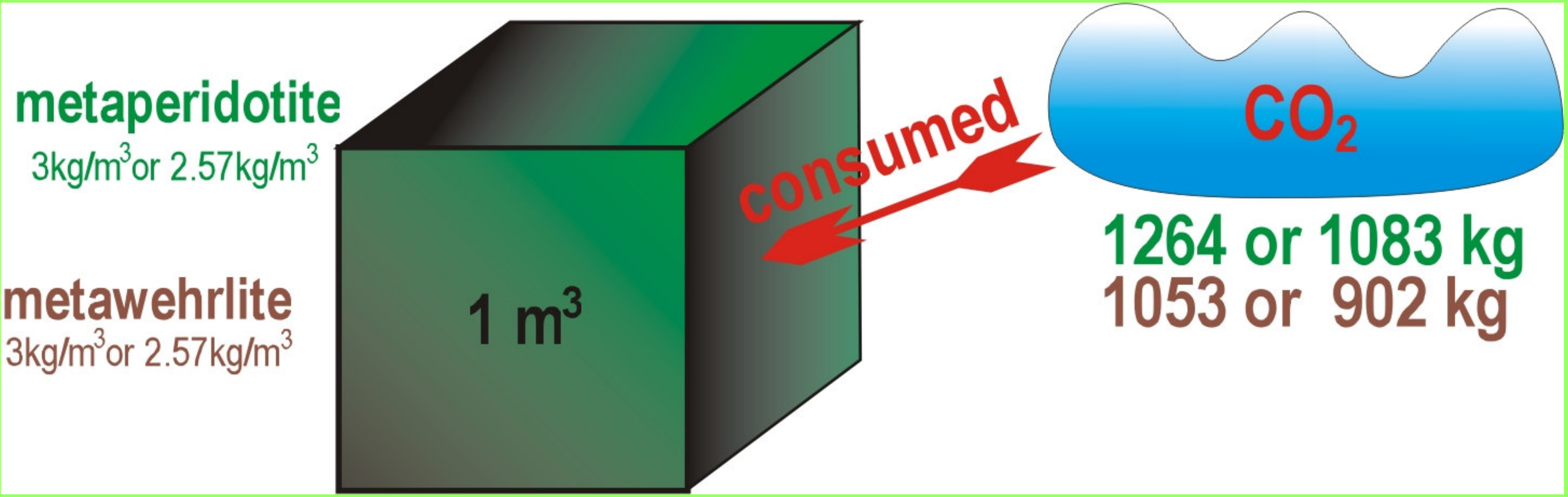
$Mg_3Si_2O_5(OH)_4 + 3CO_2 + 6H_2O \rightarrow 2MgCO_3.3H_2O + MgCO_3.2H_2O + SiO_2$

serpentine group → nesquehonite, barringtonite

(metawehrlite sourse) *50°C + 0.1MPa CO_2*

$2Mg_3Si_2O_5(OH)_4 + 5CO_2 + 4H_2O \rightarrow MgCO_3.3H_2O + Mg_5(CO_3)_4(OH)2.4H_2O + 2SiO_2$

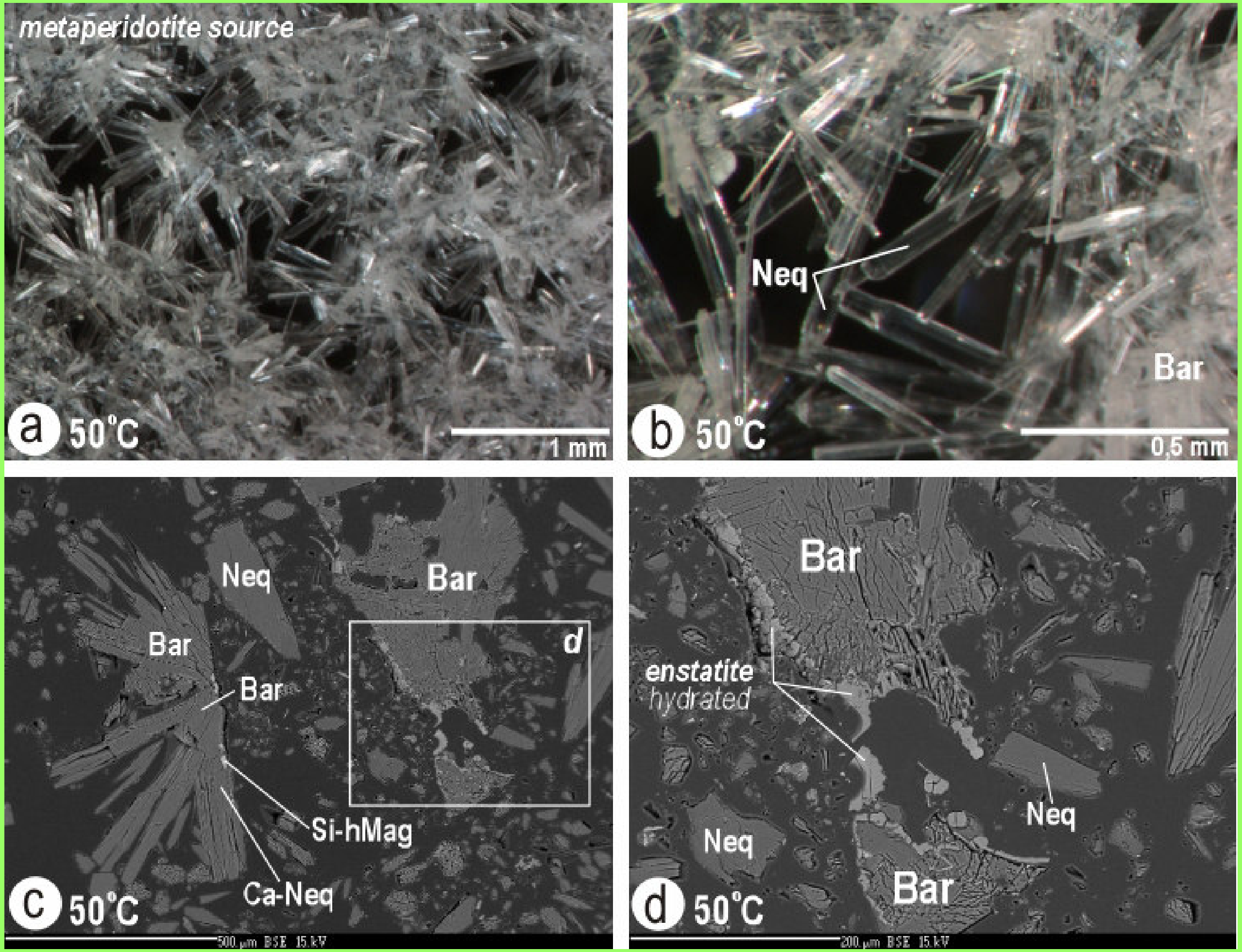
serpentine group → nesquehonite, hydromagnesite



After Radvanec et al., 2011

Minerals of artificial carbonatization formed at temperature 50 °C from metaperidotite source

a) nesquehonite (Neq) in binocular loupe
b) nesquehonite and barringtonite (Bar) in binocular loupe
c) nesquehonite, barringtonite, Ca – nesquehonite (Ca-Neq) and Si hydromagnesite (Si-hMag). Back-scattered electron image
d) detail-c relict hydrated enstatite and new barringtonite and nesquehonite. Back-scattered electron image



After Radvanec et al., 2011

6. CO_2 in Geothermal Systems

Future technological potential

Demo under construction

CO_2 in Geothermal Systems

In 2000, Los Alamos National Laboratory physicist Donald Brown proposed replacing water with supercritical carbon dioxide, a pressurized form that is part gas, part liquid. Supercritical CO_2 is less viscous than water and thus should flow more freely through rock.

GreenFire Energy (USA) began work to demonstrate a process that would use CO_2 to harness geothermal energy to make electricity in 2011. The technology has the potential to add carbon sequestration and reduction of water consumption to the benefits associated with geothermal power.

CONCLUSIONS

Different CO_2 geological storage technologies are developed and under development that may significantly contribute to reducing CO_2 emissions to the atmosphere

The application of a particular option primarily depends on the geological conditions. Therefore the integrated approach is required while evaluating CO_2 storage potential of a particular region.

Combination of CO_2 storage with other benefits (gas, oil, geothermal extraction) may accelerate implementation of CO_2 geological storage technologies

Thank you very much!