

Geologic Storage of CO₂

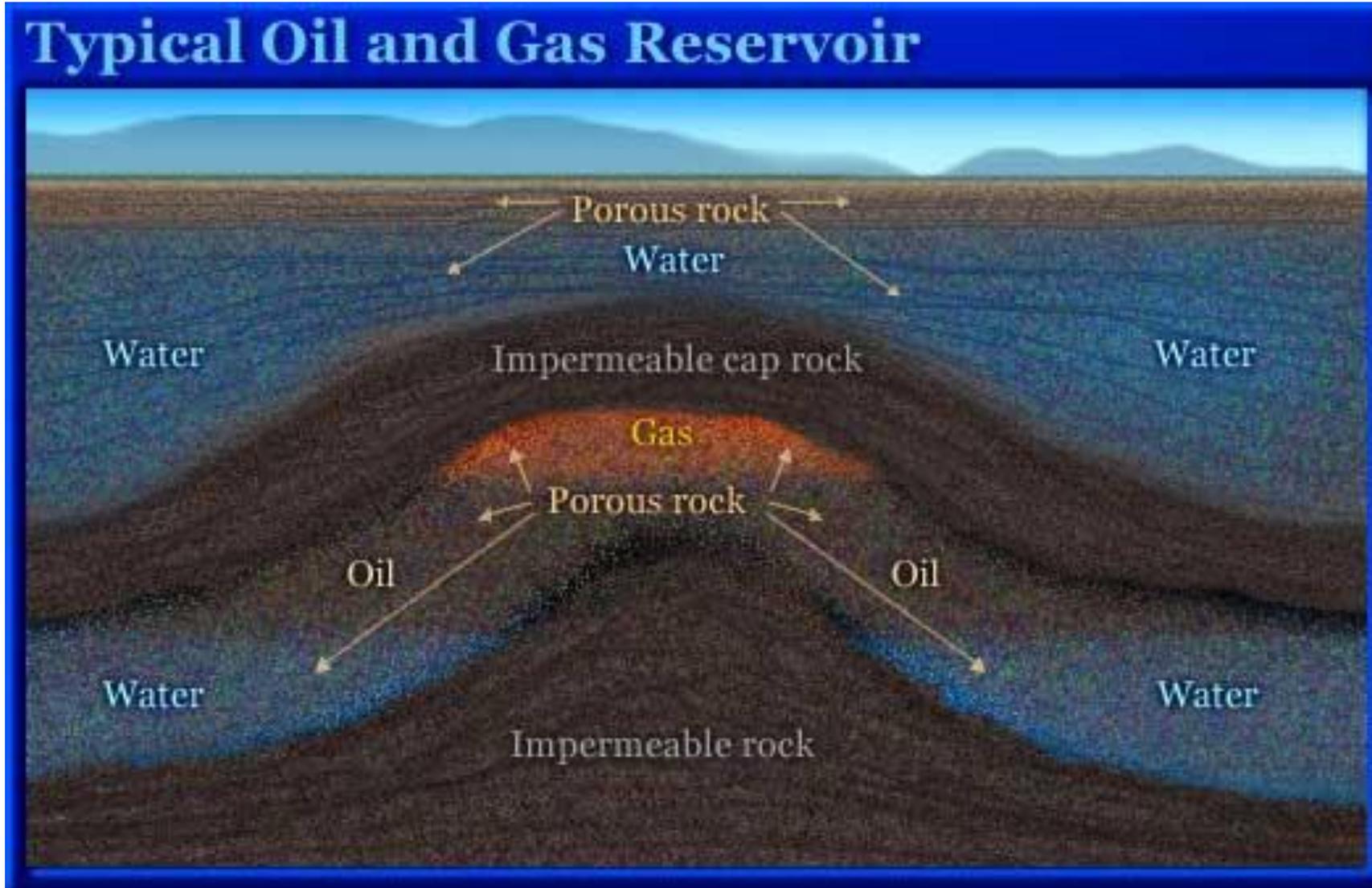
Manika Prasad, Colorado School of Mines



Outline

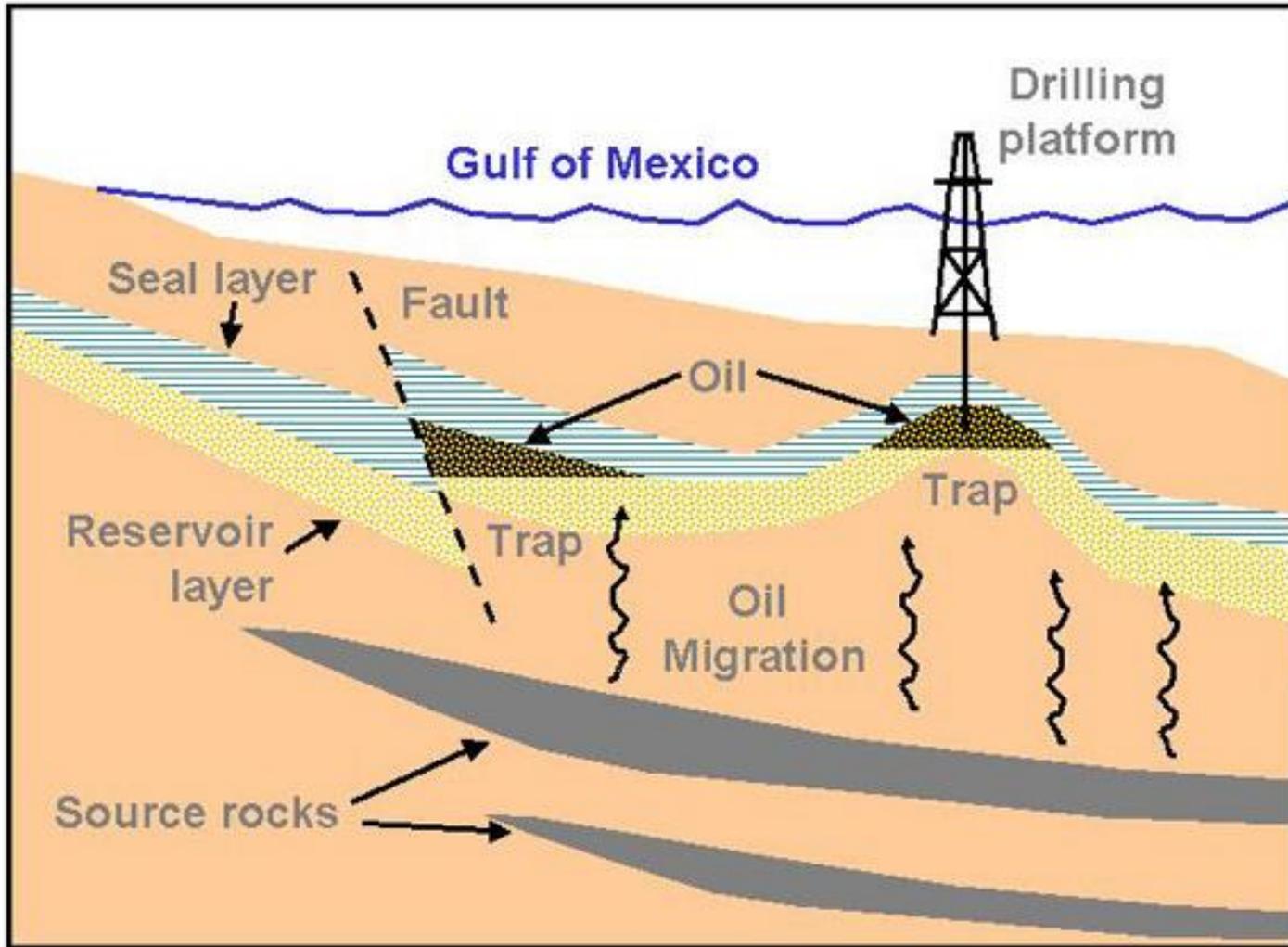
- Petroleum Storage Systems
- Water, Oil, and Gas in the Subsurface
- CO₂ Storage Systems
- *Storage Capacity*
- *Storage Compliance and Monitoring*
(In next talk)

Components of a Reservoir



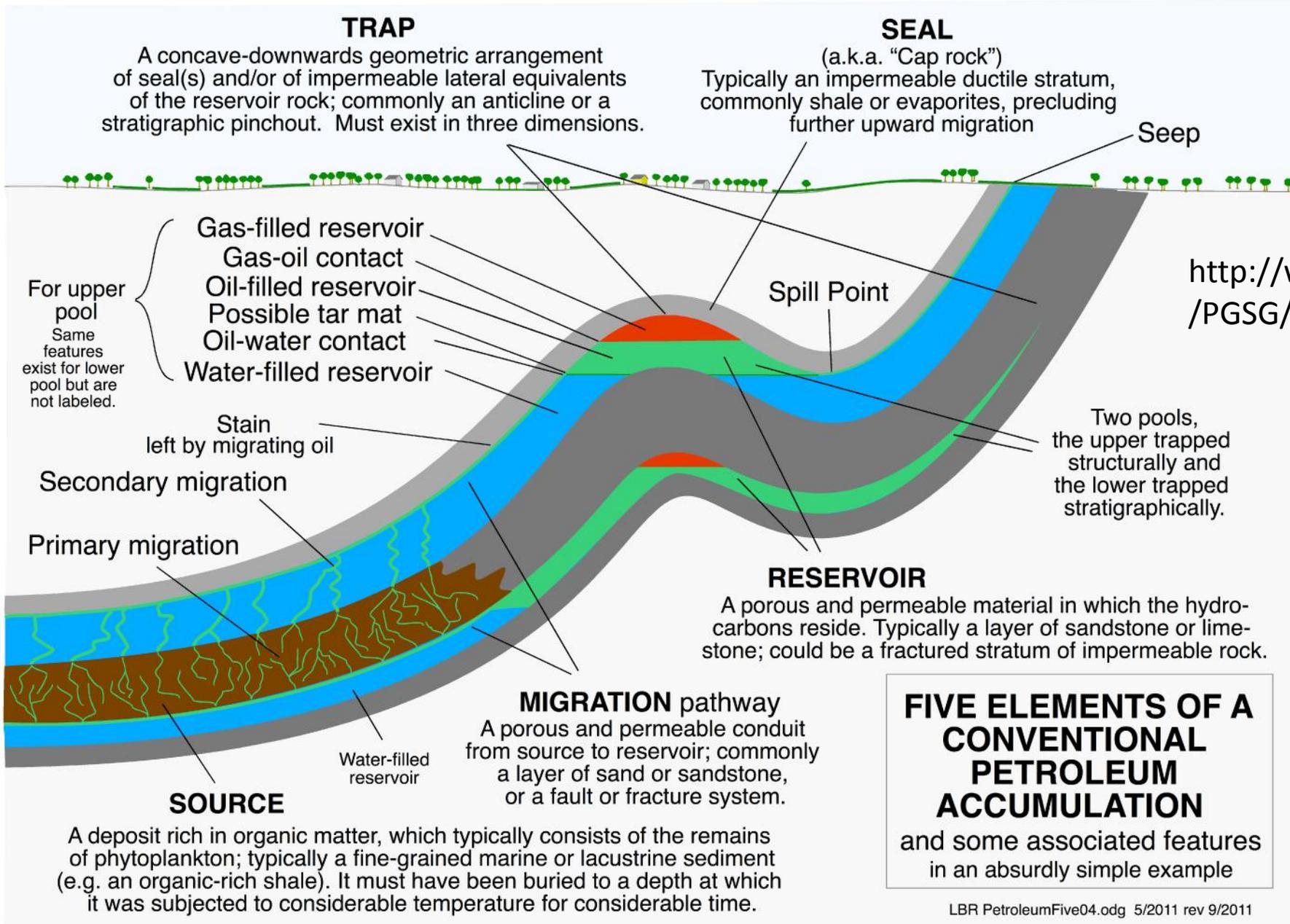
<http://petroleum101.com/what-is-a-petroleum-reservoir/>

Elements of a Petroleum Reservoir

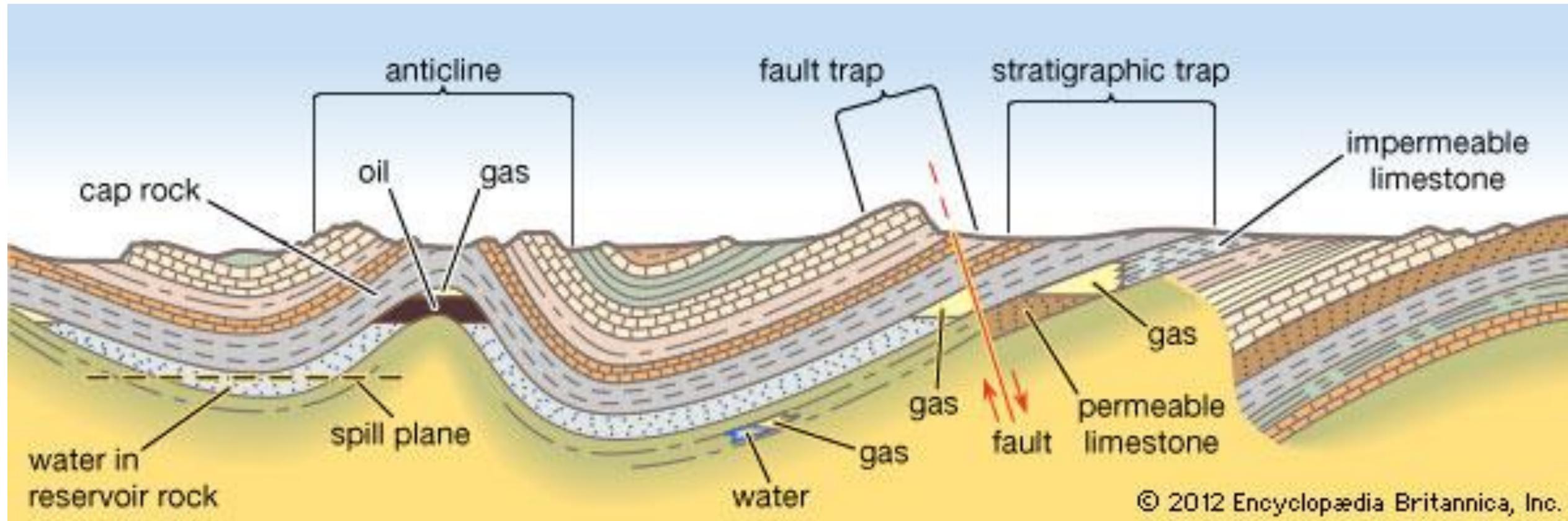


- Source Rocks “cook” with high pressure and temperature = **Mature (Generation)**
 - Source rocks are rocks rich with organic matter
 - Pressure and temperature increase with depth
- The produced oil and gas moves “up” = **migrates** to lower pressure zones (**Migration**)
- It finds a “good” host = **accumulates** in a **reservoir formation (Storage)**
- A good host also requires a seal to keep the oil and gas in place = **trap** in a **reservoir formation (Trap)**

<http://petroleum101.com/>



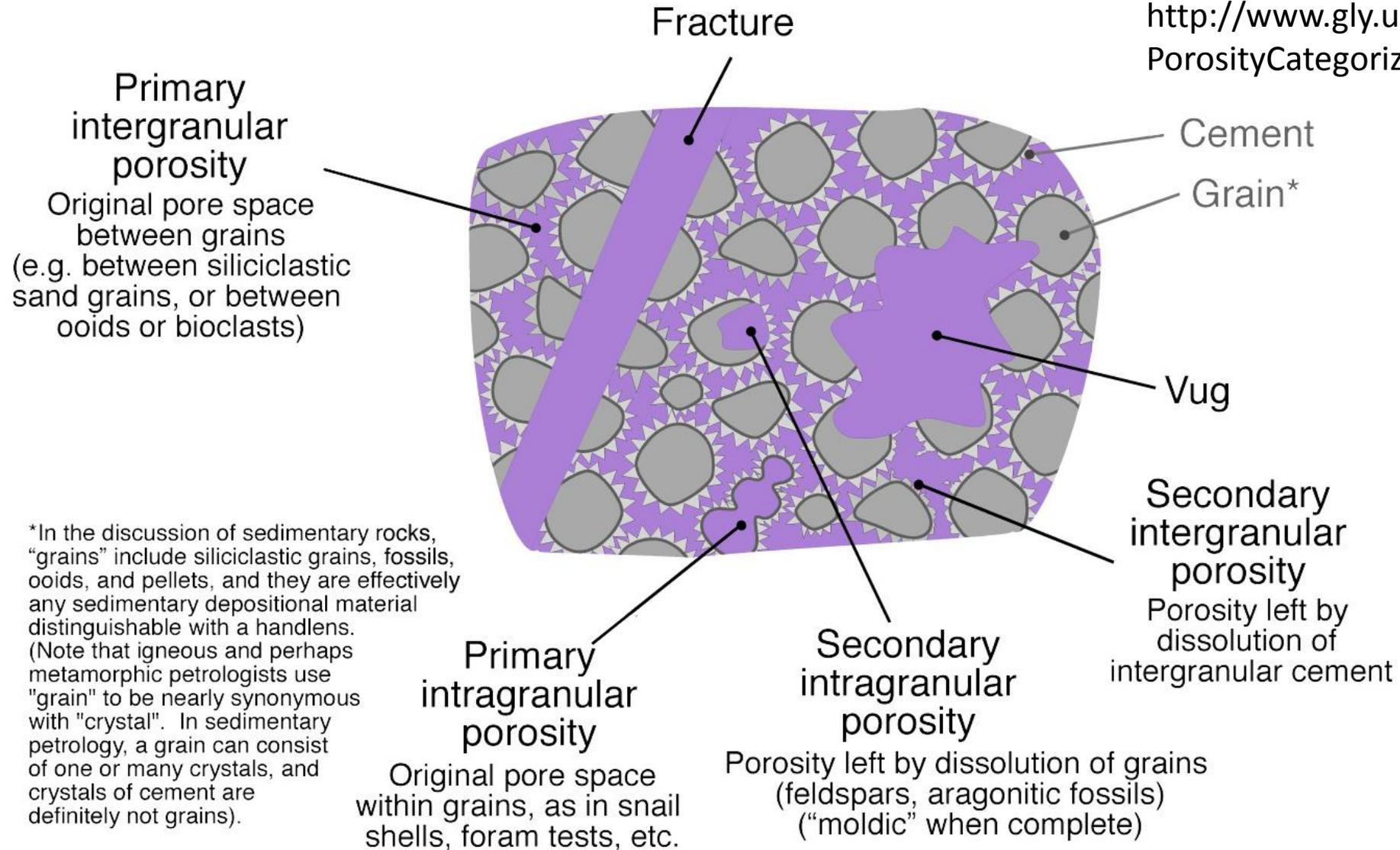
Petroleum Traps



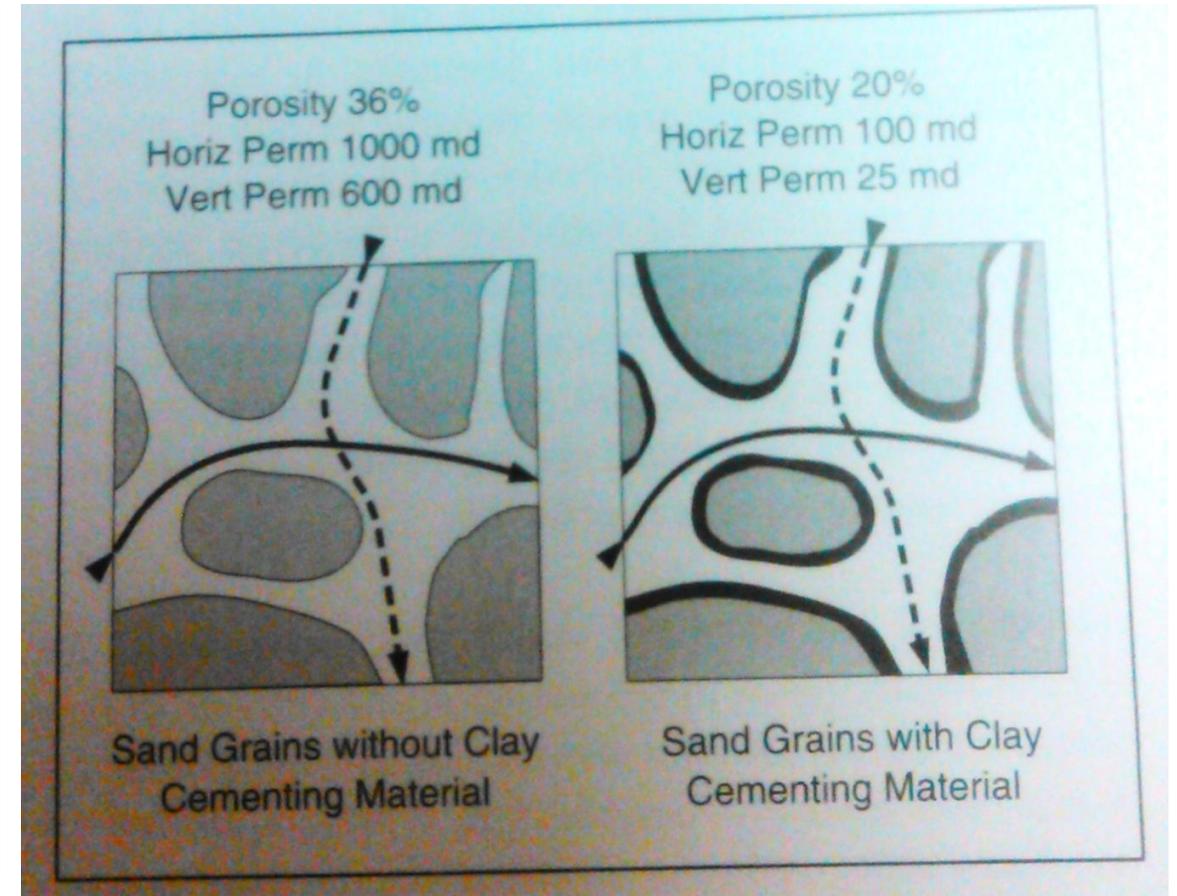
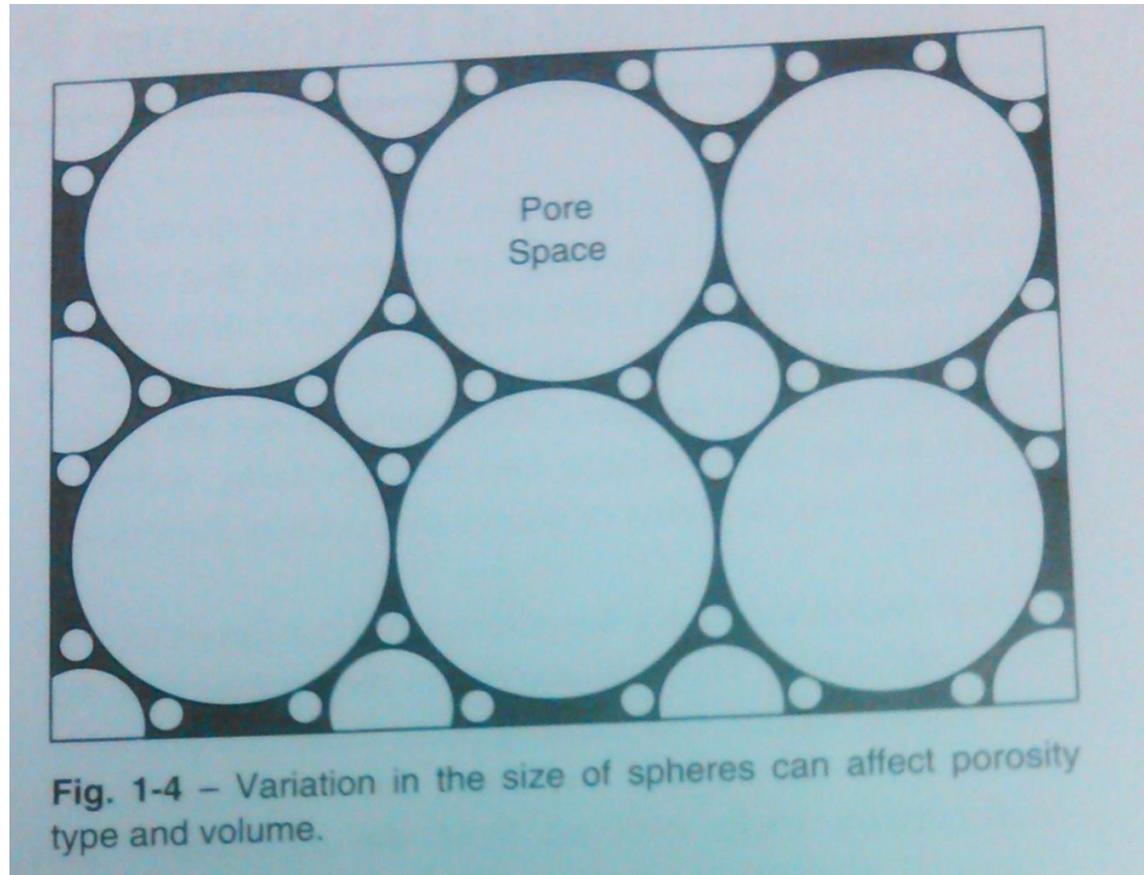
<https://www.britannica.com/science/petroleum/Accumulation-in-reservoir-beds#ref502612>

Categorization of pores in sedimentary rocks I

<http://www.gly.uga.edu/railsback/PGSG/PorosityCategorization04Part1.jpg>

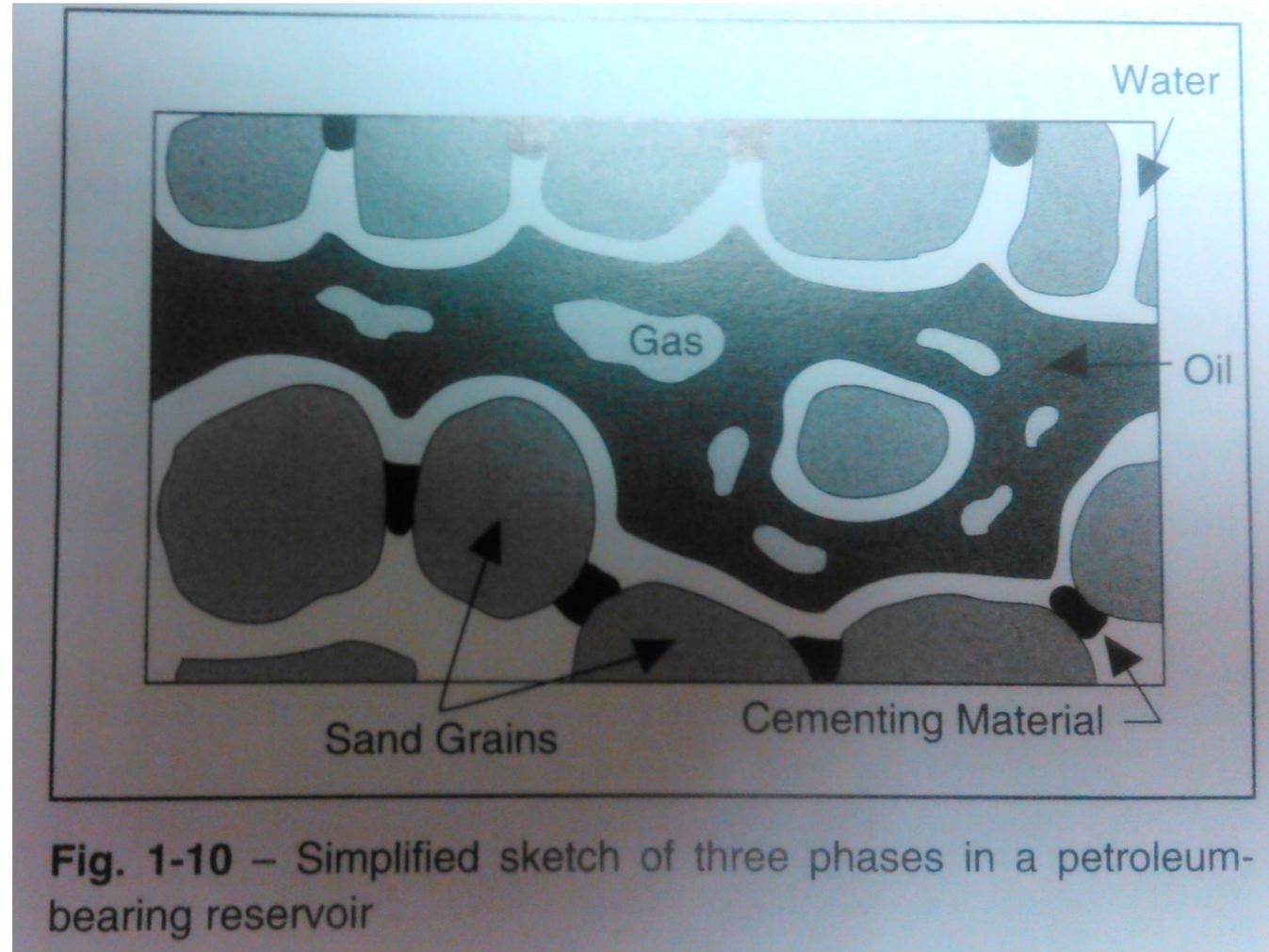


Where do oil and gas reside?



Baker-Atlas Handbook

Water, Oil, and Gas Co-exist in Pores



Baker-Atlas Handbook

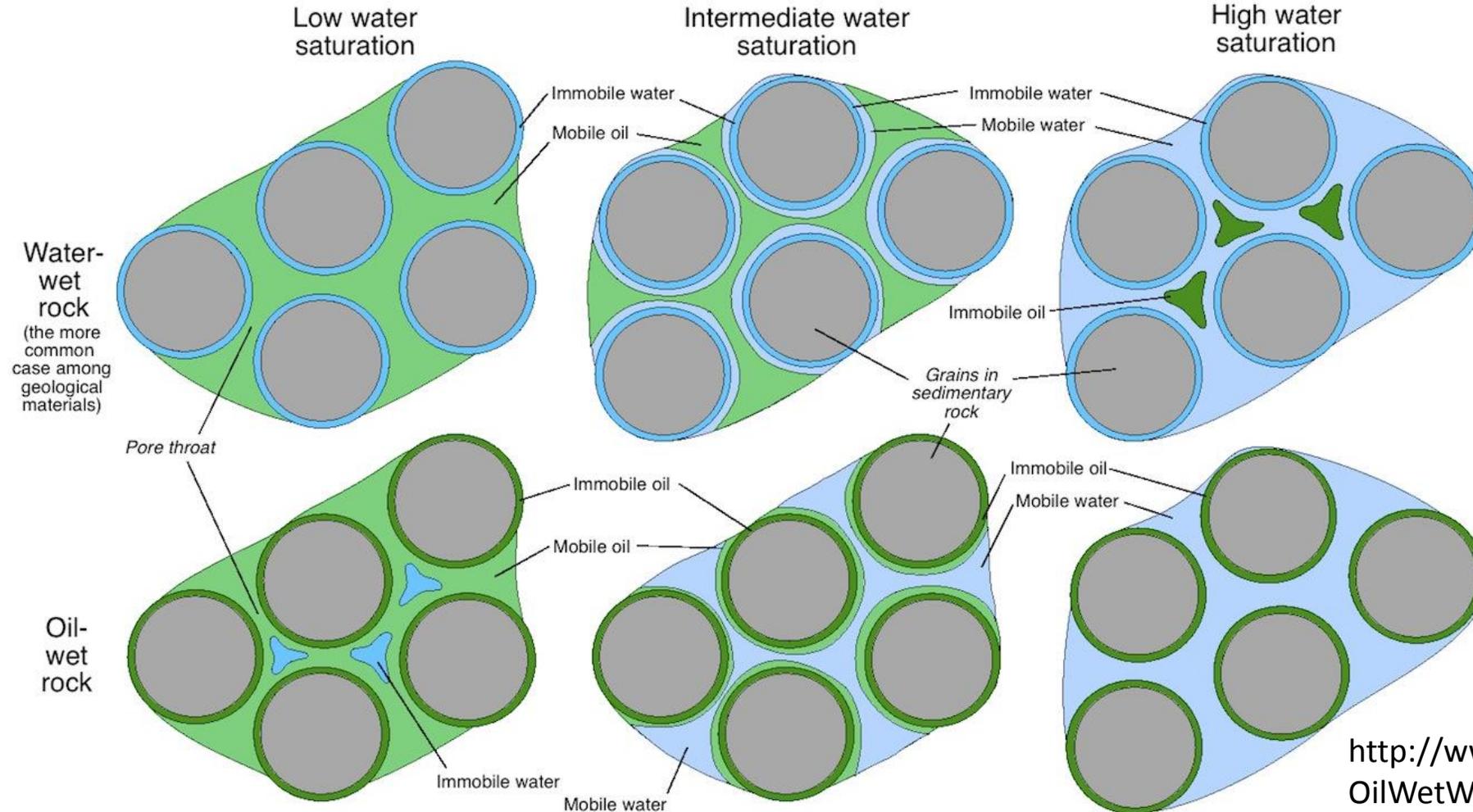
Prasad: CCUS course at CSM, Golden

Wetting surfaces and water saturation in petroleum reservoir rocks

Given a solid surface and two immiscible liquid phases, typically one of the two liquids will be present on the solid (will "wet" the solid). The other liquid phase will instead be present only away from the solid and thus in the centers of pores. In most situations in the Earth Sciences, one of the liquids is an aqueous solution ("water"), and the other is a non-aqueous-phase liquid

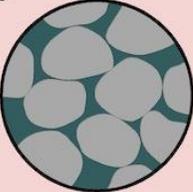
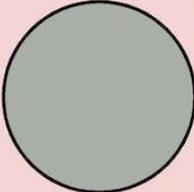
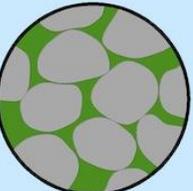
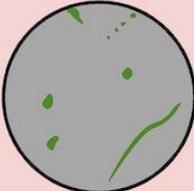
(a "NAPL", which is pronounced as "napple"). A NAPL may be denser than water (a DNAPL, or "dee-napple") or less dense ("lighter") than water (an LNAPL, or "ell-napple"). Natural petroleum ("oil") is a natural NAPL, typically an LNAPL, and various anthropogenic organic compounds or petroleum distillates are common non-natural NAPLs.

The sketches below explore the geometric relationships of wetting and non-wetting fluids, largely thinking of oil (petroleum) as the NAPL in the context of petroleum geology and engineering. In that context, water saturation (the proportion of pore space filled by water) is critical, because at greater water saturation the NAPL/petroleum is immobile and thus not exploitable.



<http://www.gly.uga.edu/railsback/PGSG/OilWetWaterWetWaterSatn4Some4.jpg>

Conventional and Unconventional Hydrocarbons and Reservoirs

<p>Unconventional</p> <p><i>Hydrocarbons</i></p>	<p>Tar sands (a.k.a. heavy oil, bitumen, and oil sands) (e.g., Orinoco and Athabasca tar sands)</p> 	<p>Methane hydrates (e.g., continental slopes; polar regions)</p> <p>Coal gasification/ liquifaction</p>  <p>Oil shale (e.g., Piceance Basin)</p>
	<p>Conventional oil and natural gas (mobile/flowing hydrocarbons) (e.g., Middle East, North Sea, US Gulf Coast; Gulf of Mexico)</p> 	<p>Tight oil (e.g., Bakken; Eagle Ford)</p> <p>Tight gas (e.g., Austin and Niobrara chalks)</p> <p>Shale gas (e.g., Marcellus and Barnett shales)</p> <p>Coalbed methane (e.g., Powder River Basin)</p> 

Conventional
(porous and permeable
sedimentary rocks)

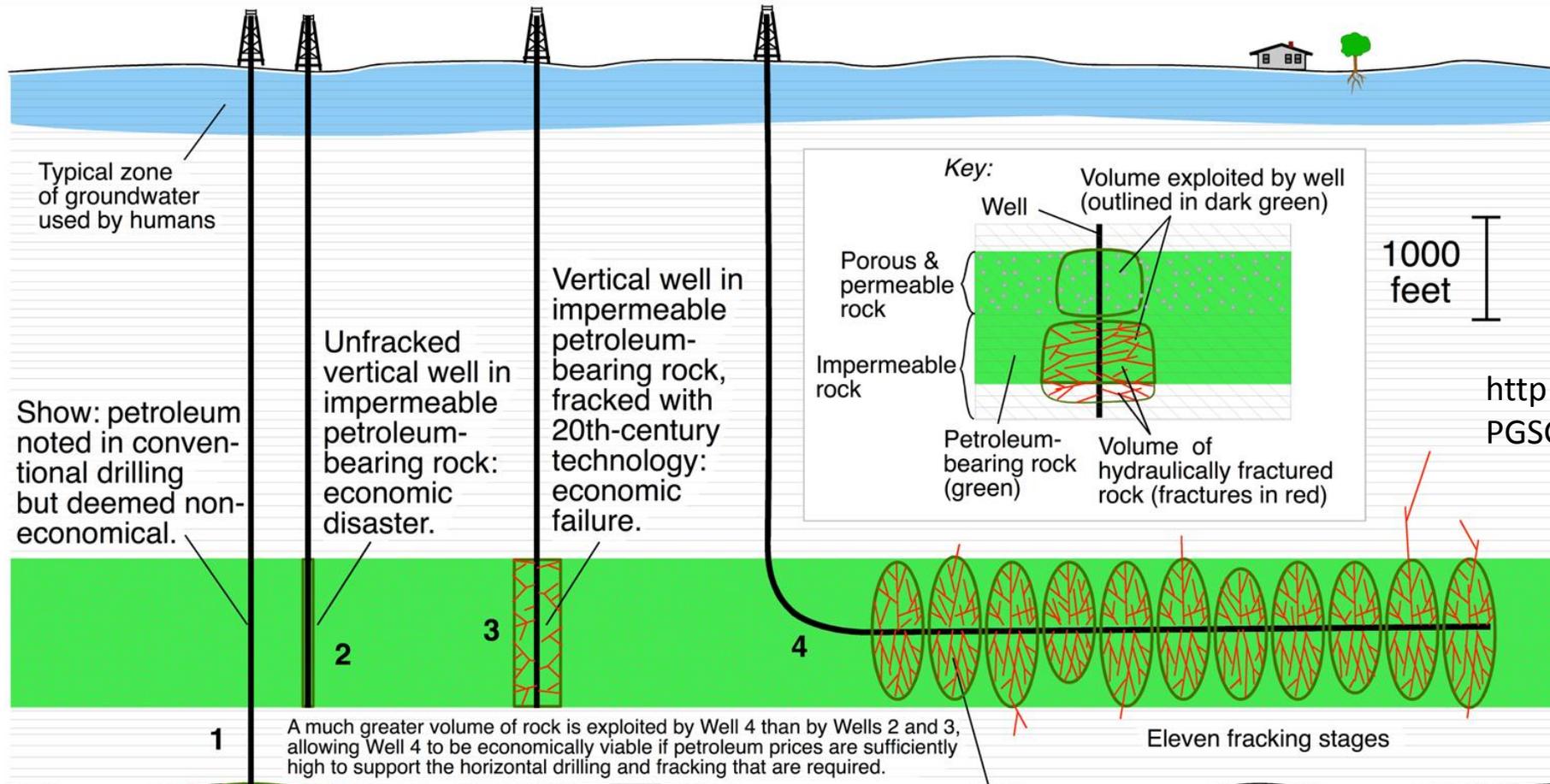
Unconventional
(mostly impermeable
sedimentary rocks)

Reservoirs

LBR UnConventionalReservoirs&HCs21.odg 11/2012 rev 3/2014

<http://www.gly.uga.edu/railsback/PGSG/UnConventionalReservoirs&HCs02.jpg>

Unconventional petroleum exploitation I: historical and spatial context



<http://www.gly.uga.edu/railsback/PGSG/PGSGFrackingI02.jpg>

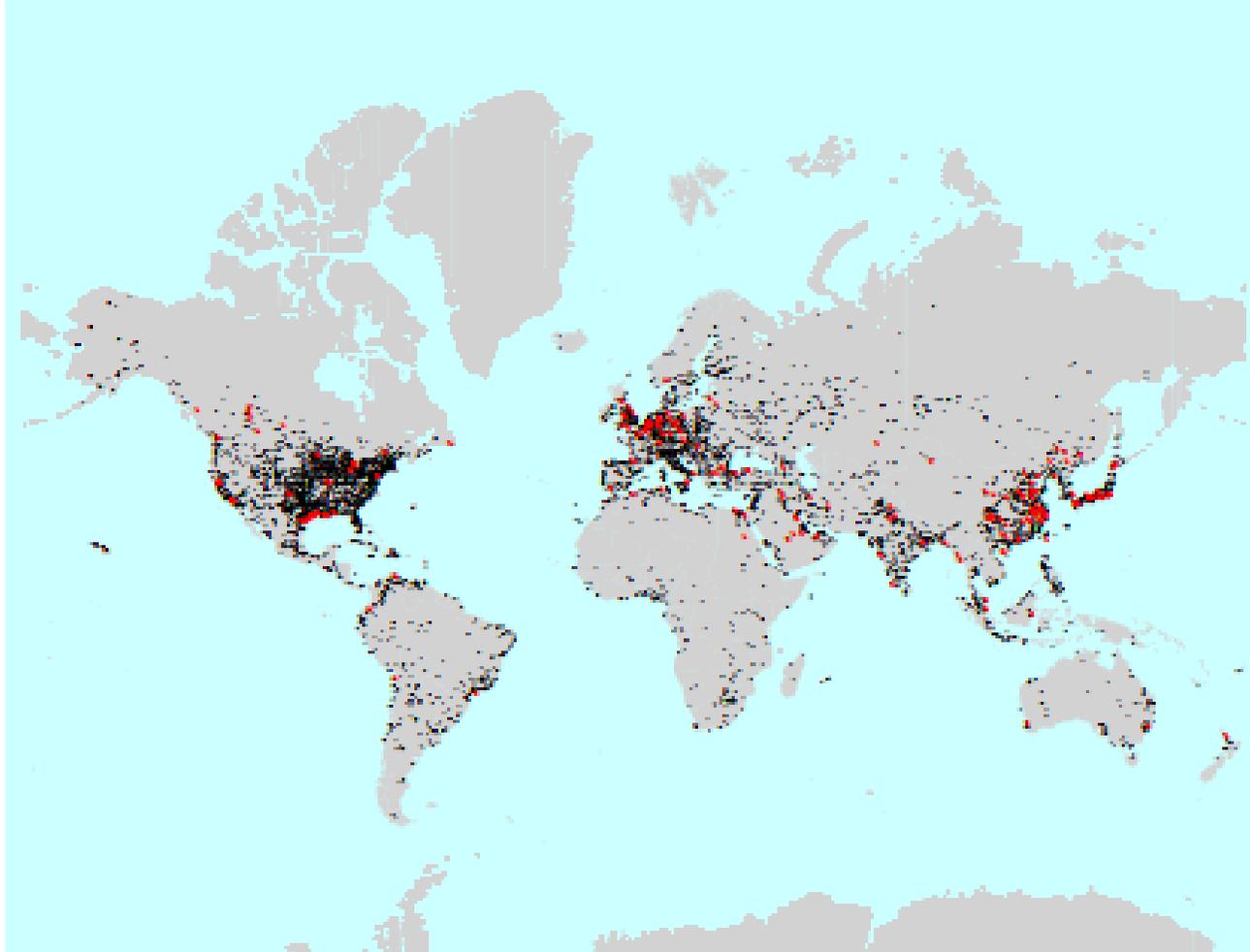
Conventional exploitation: vertical well in porous and permeable rock, where buoyancy has induced natural localization of petroleum, which flows to well: the economic bonanza that fueled the 20th-century economy.

Unconventional exploitation: horizontal well in hydraulically fractured impermeable rock, where technologically challenging horizontal drilling and hydraulic fracturing tap enough rock volume to yield expensive petroleum for the 21st-century economy.

CARBON CYCLE

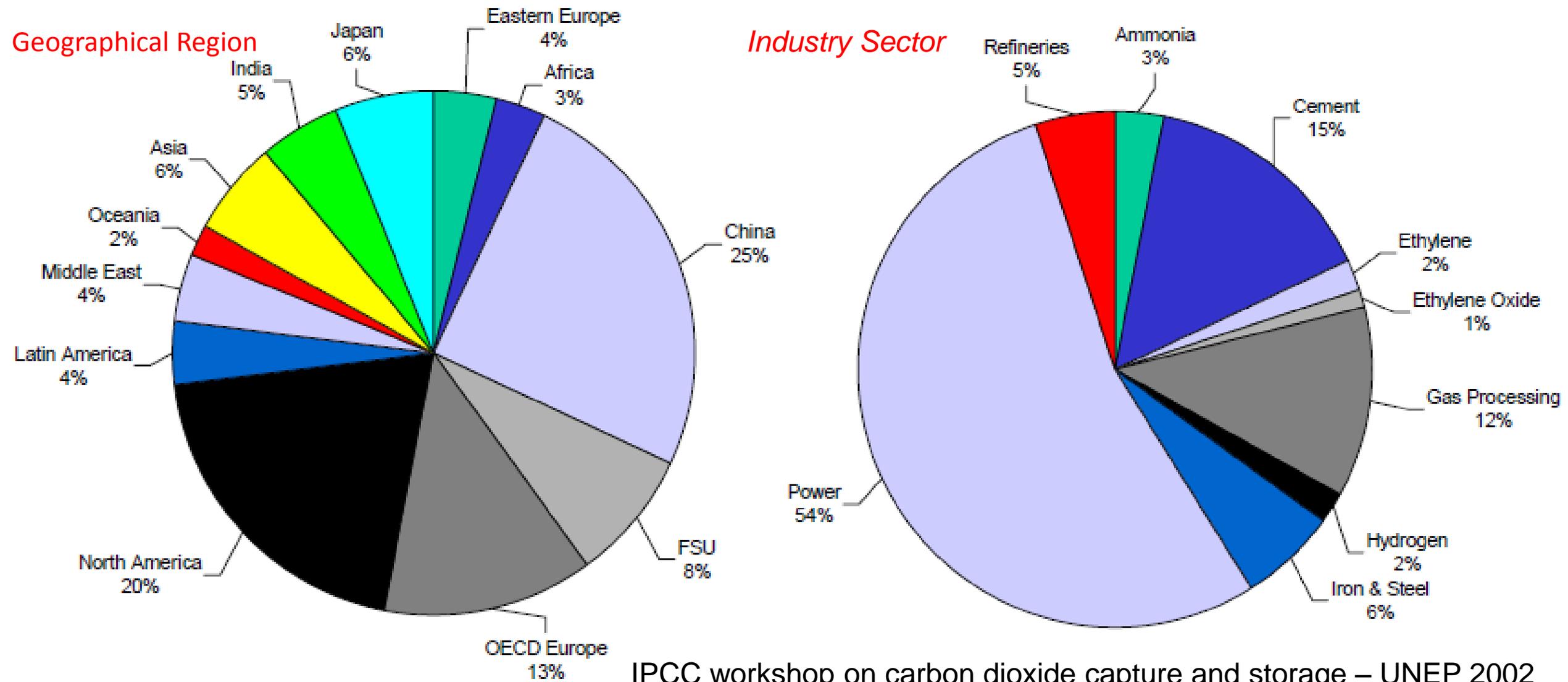
HOW MUCH CO₂ CAPACITY DO WE HAVE?

DISTRIBUTIONS OF CO2 EMISSION SOURCES



IPCC workshop on carbon dioxide capture and storage – UNEP 2002

CO₂ EMISSION SOURCES



IPCC workshop on carbon dioxide capture and storage – UNEP 2002

COMPOSITION OF AIR

Gas	Quantity (%) or ppm
N ₂	~ 78 %
O ₂	~ 21 %
H ₂ O	0.2 to 4 %
Ozone	
CO ₂	0.04 % or 400 ppm
Methane (CH ₄)	1.8 ppm
N ₂ O	0.3 ppm
Halocarbons	

Dressler, 2016

Red indicates “absorbs photons”

CARBON CYCLE

Stage	Capacity [Gt C]
Atmosphere	850
Land Biosphere	2,500
Ocean (mixed layer)	900
Ocean (deep ocean)	40,000
Rocks	Millions

From 2002 – 2011: 90 GtC released to the atmosphere from burning hydrocarbons

Gt C = Gigatonne C

Dressler, 2016

CARBON CYCLE AND EXCHANGE

TOTAL ABOUT 46,000 GtC

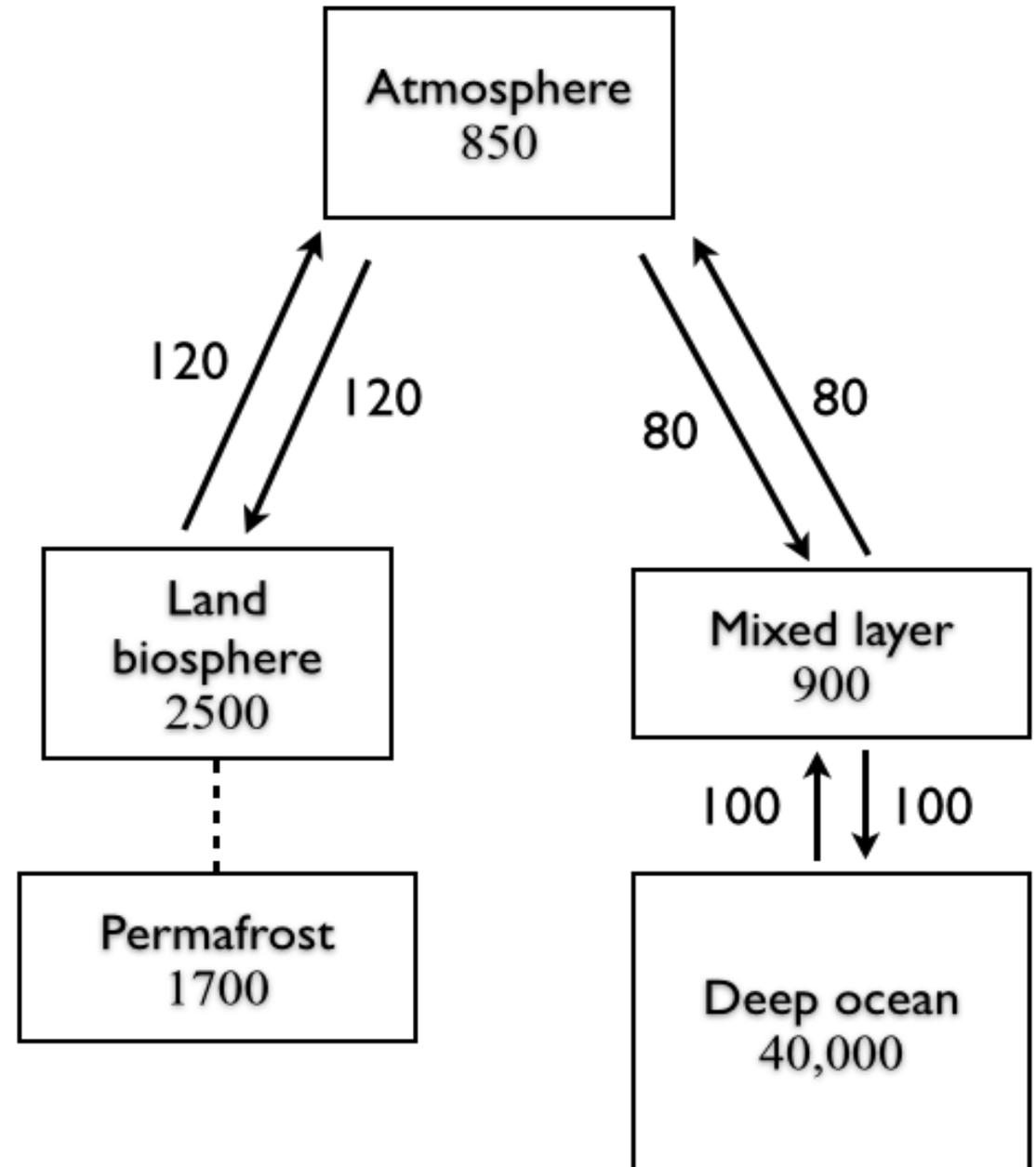
Reservoirs (Boxes) :

GtC = 10^9 tonnes Carbon

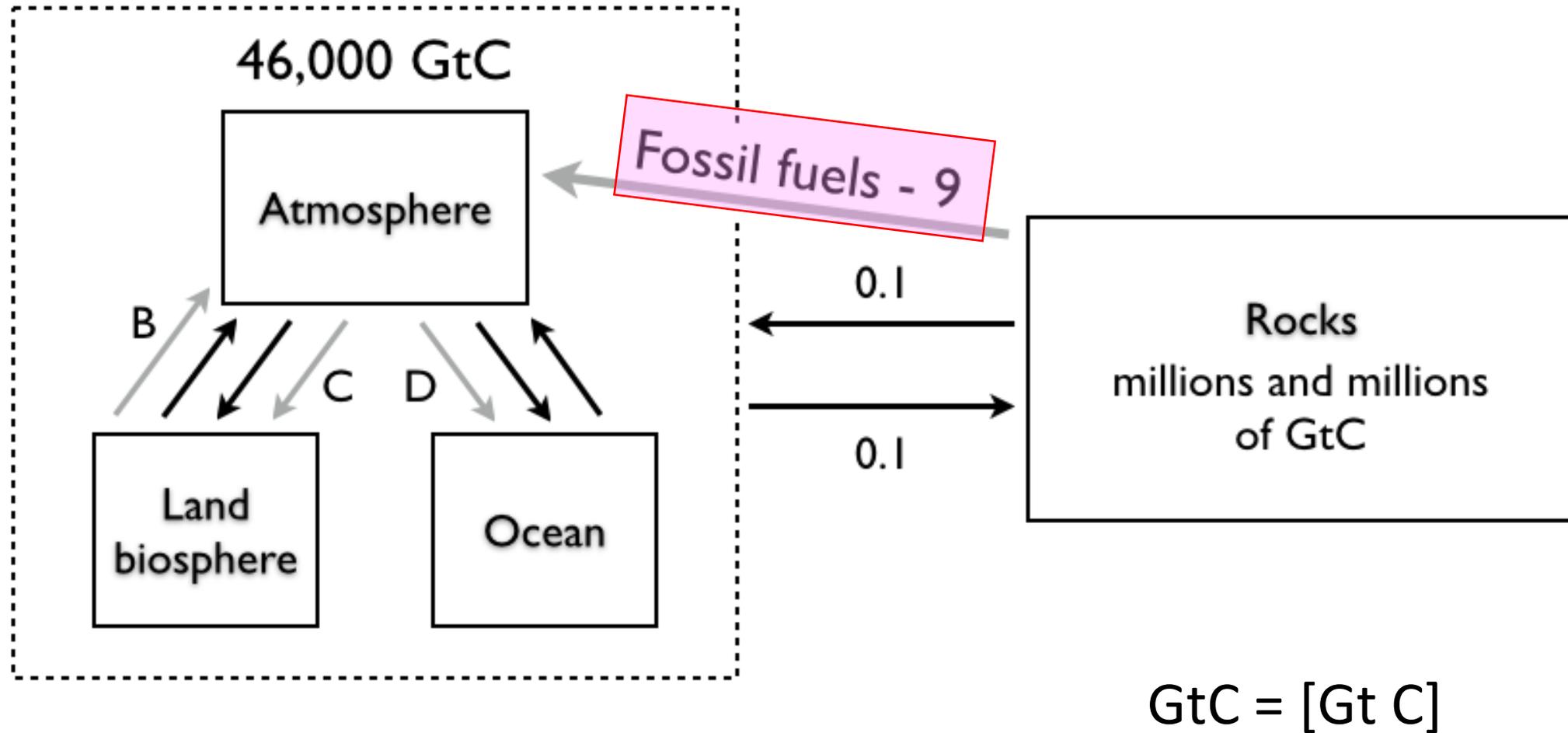
GtC = 10^{12} kg Carbon

Fluxes (arrows): GtC/year

Dressler, 2016



CARBON EXCHANGE AND EXCHANGE WITH GEOLOGIC AND ANTHROPOGENIC INPUT



Dressler, 2016

GEOLOGIC STORAGE AND MVA

ENSURING THAT CO₂ STAYS IN PLACE

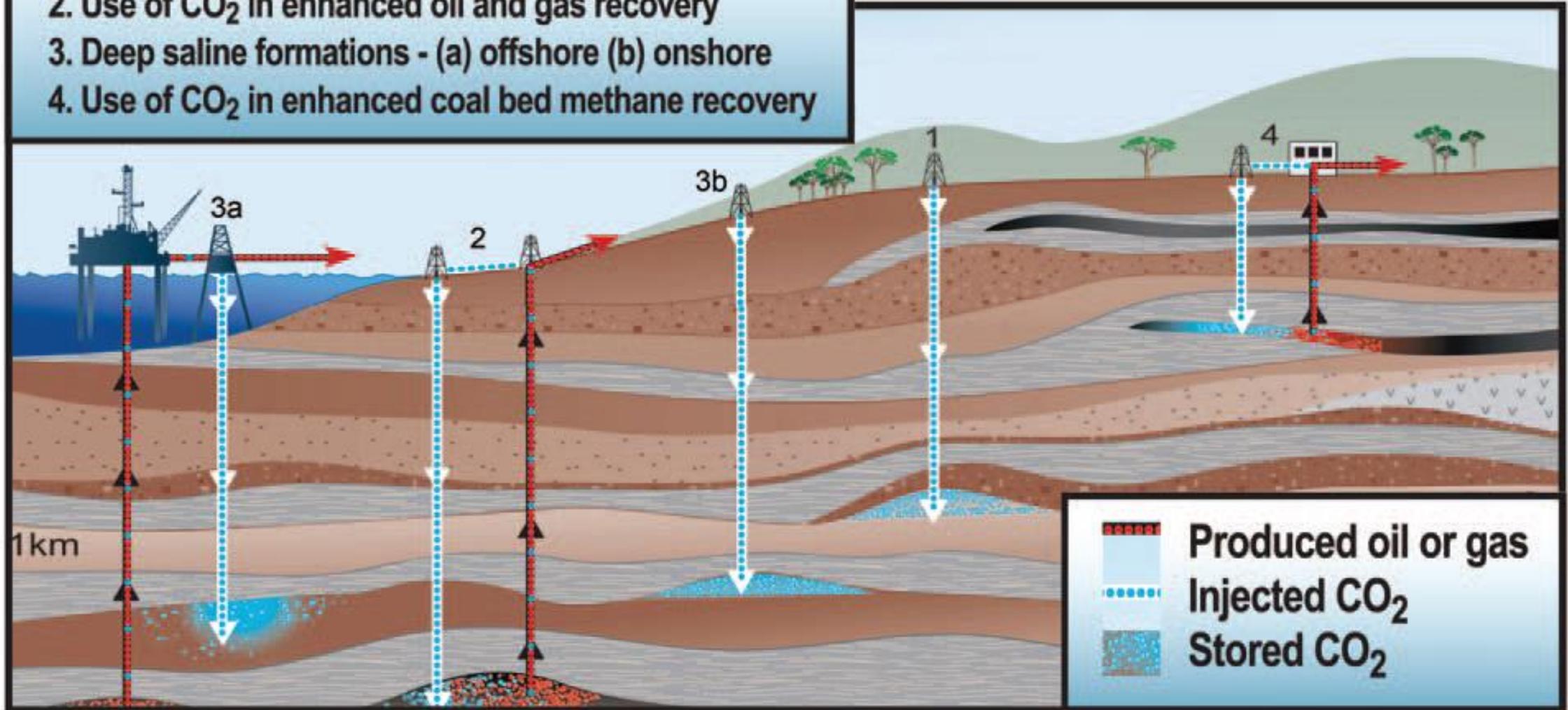
ESTIMATE OF STORAGE CAPACITIES FOR DIFFERENT GEOLOGICAL TRAP TYPES

Storage Option	Global Capacity	
	[Gt C]	[%] of total emissions to 2050
Depleted gas fields	690	34
Depleted oil fields/CO2 EOR	120	6
Deep saline aquifers	400 - 10 000	20 - 500
Un-mineable coal seams	40	2

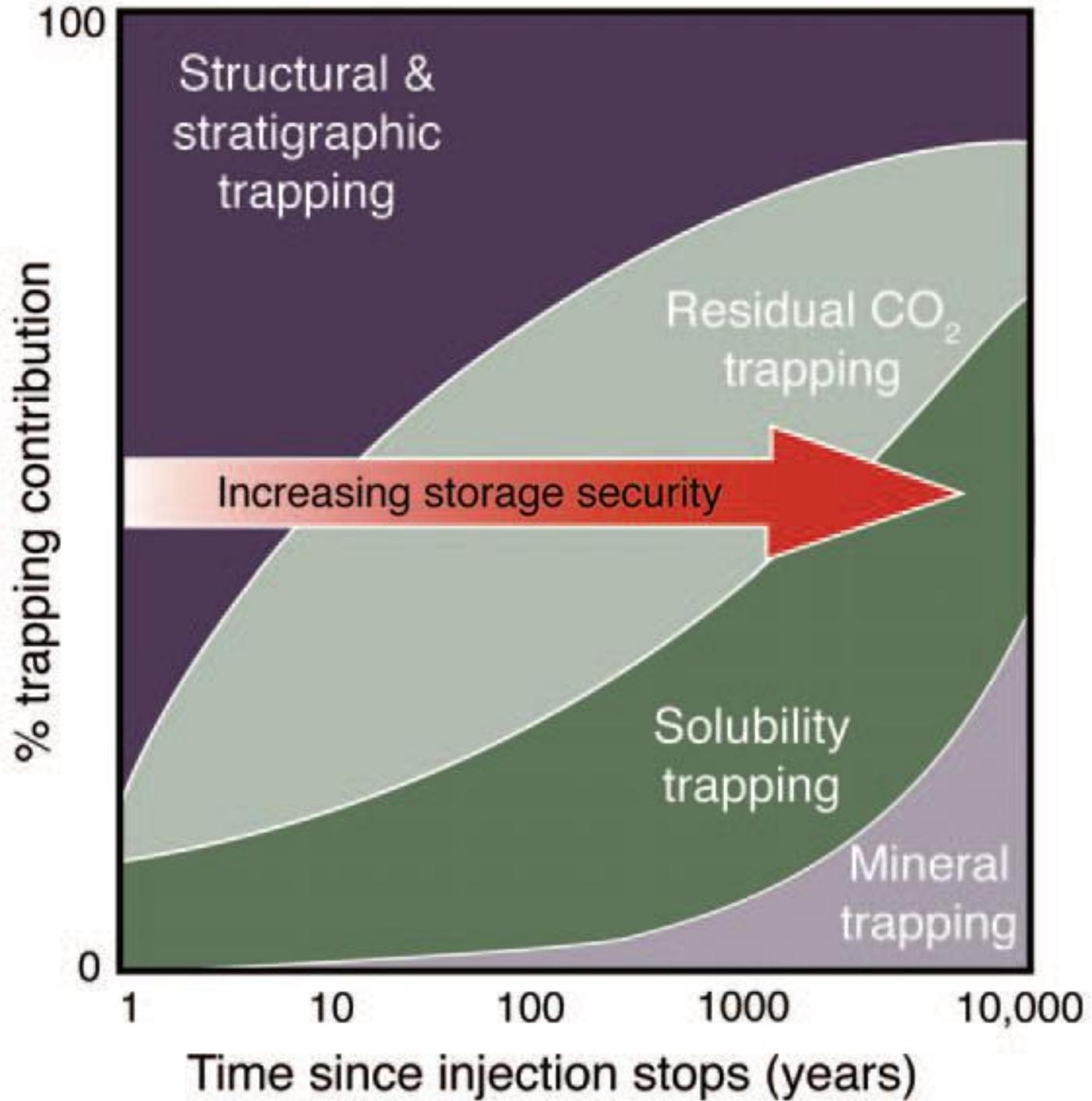
Dressler, 2016

Overview of Geological Storage Options

1. Depleted oil and gas reservoirs
2. Use of CO₂ in enhanced oil and gas recovery
3. Deep saline formations - (a) offshore (b) onshore
4. Use of CO₂ in enhanced coal bed methane recovery



Benson and Cole, 2005



Benson and Cole, 2005

Assuring project performance and guard against safety and environmental hazards

Basic monitoring program	Enhanced monitoring program
<i>Pre-operational monitoring</i>	<i>Pre-operational monitoring</i>
Well logs Wellhead pressure Formation pressure Injection- and production-rate testing Seismic survey Atmospheric-CO ₂ monitoring	Well logs Wellhead pressure Formation pressure Injection- and production-rate testing Seismic survey Gravity survey Electromagnetic survey Atmospheric-CO ₂ monitoring CO ₂ -flux monitoring Pressure and water quality above the storage formation
<i>Operational monitoring</i>	<i>Operational monitoring</i>
Wellhead pressure Injection and production rates Wellhead atmospheric-CO ₂ monitoring Microseismicity Seismic surveys	Well logs Wellhead pressure Injection and production rates Wellhead atmospheric-CO ₂ monitoring Microseismicity Seismic survey Gravity survey Electromagnetic survey Continuous CO ₂ -flux monitoring Pressure and water quality above the storage formation
<i>Closure monitoring</i>	<i>Closure monitoring</i>
Seismic survey	Seismic survey Gravity survey Electromagnetic survey CO ₂ -flux monitoring Pressure and water quality above the storage formation Wellhead pressure monitoring