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Solid **F**uels and **T**echnology **A**pplication
(CERTH/ ISFTA)

INSTITUTE for SOLID FUELS TECHNOLOGY and APPLICATIONS

Perspectives and economic assessment of CO_2 transport and geological storage in Greece

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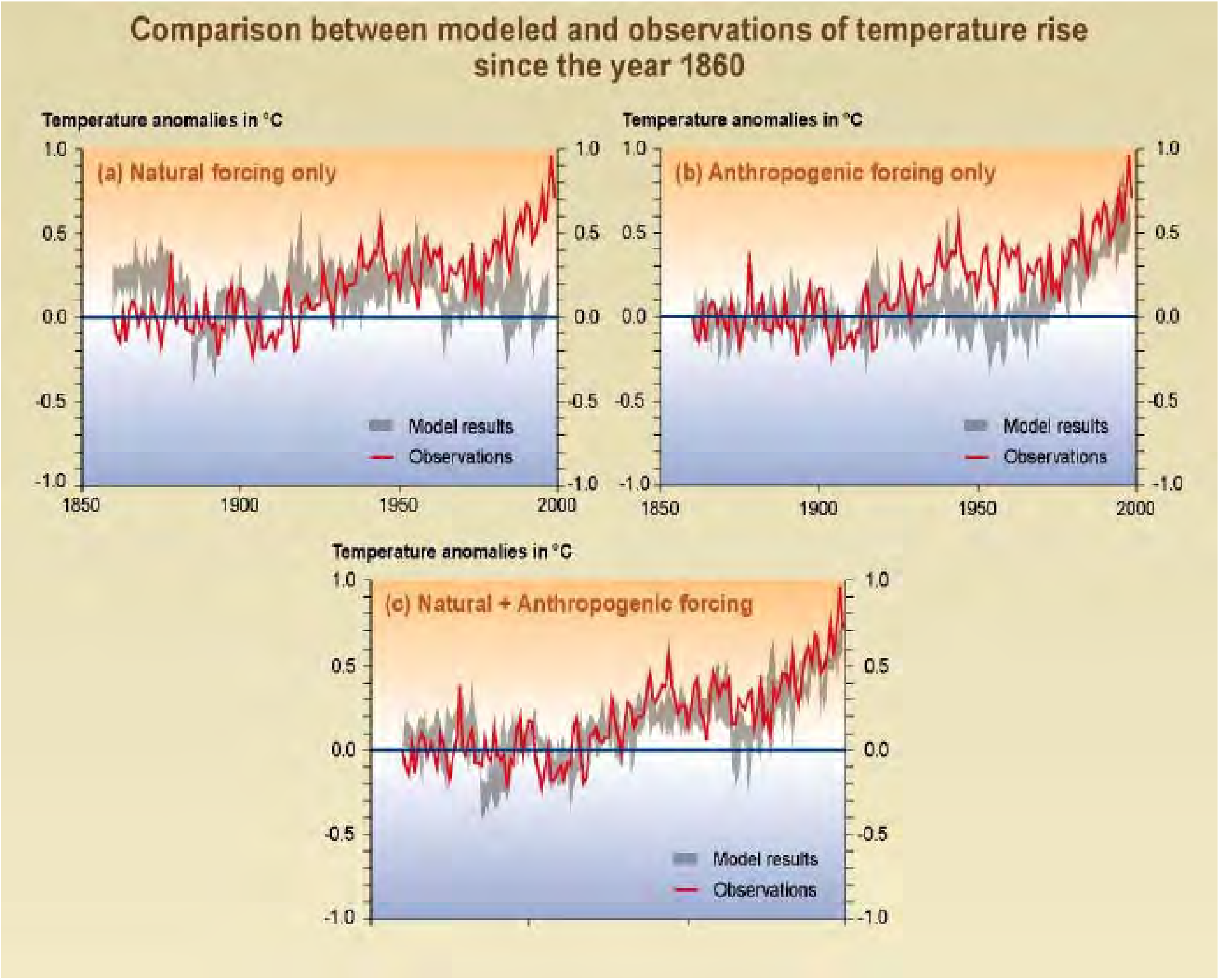
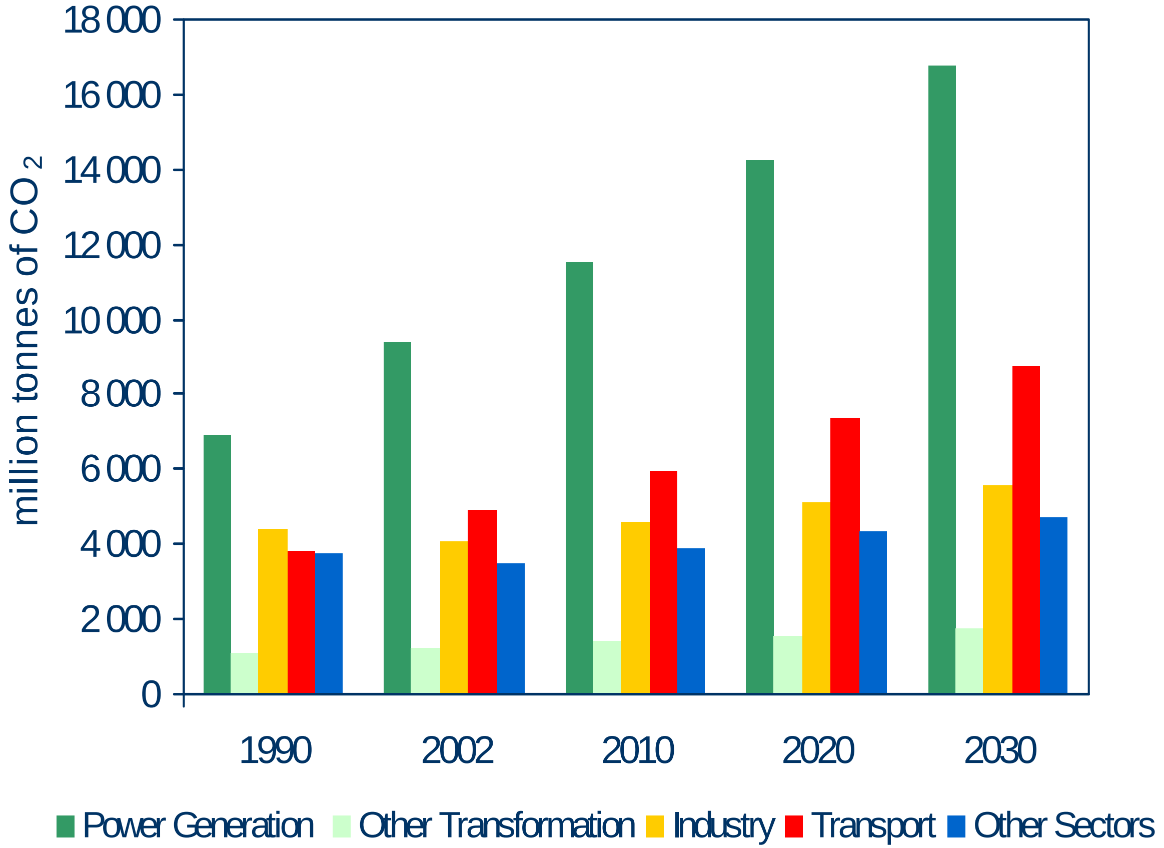


The increase of atmosphere's natural warming capacity - **Global warming -** is caused due to the increase of human-induced GHG's.

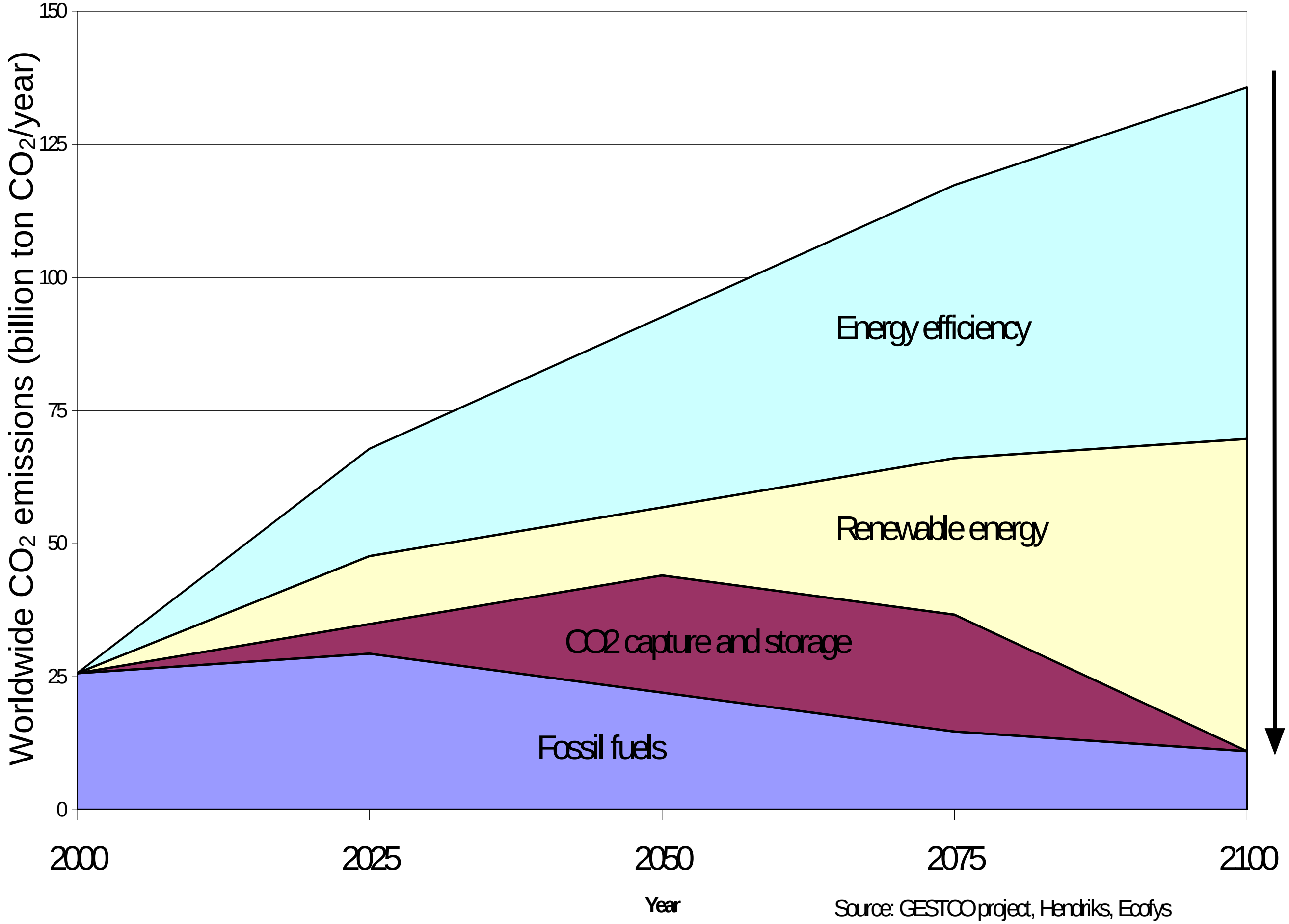
The greatest increase of CO_2 emissions originates from power generation and transport



In Europe the Energy sector is responsible for:

- ≥ 80% of the EU-greenhouse gas (GHG) emissions
- ≥ 93% of the EU-CO2 emission

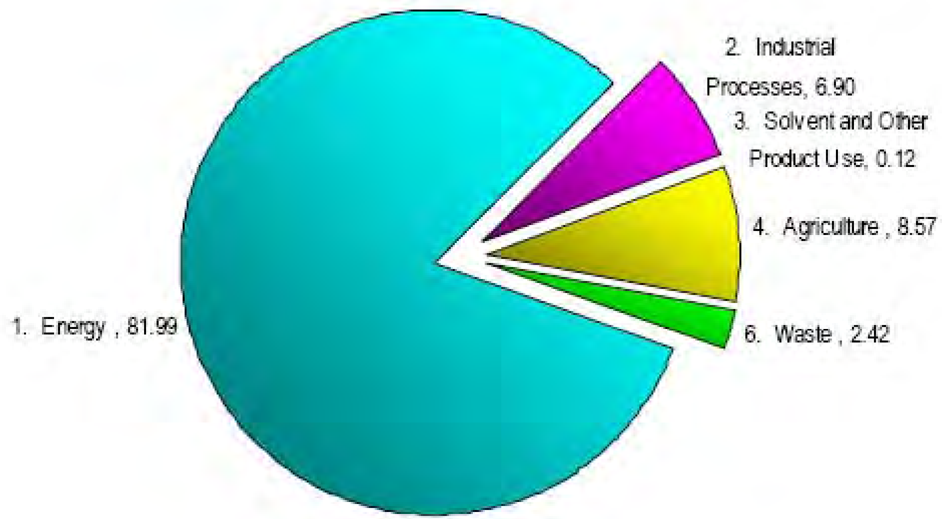
"CCS will play a significant role in GHG mitigation"



In the context of the long term objective of 60% reduction by 2050 CCS is a medium term (2020-2030) technology

Energy sector and CO_2 emissions in Greece

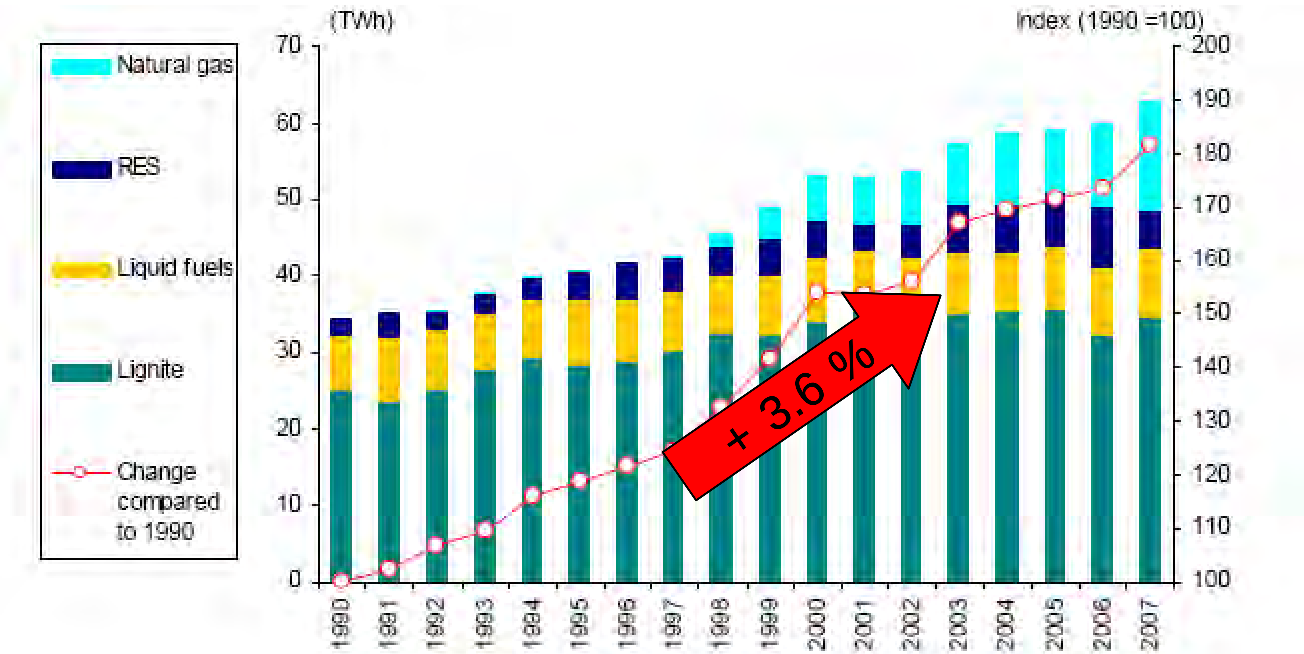
Relative contribution of activity sectors to total GHG emissions (without LULUCF) in Greece (2007)



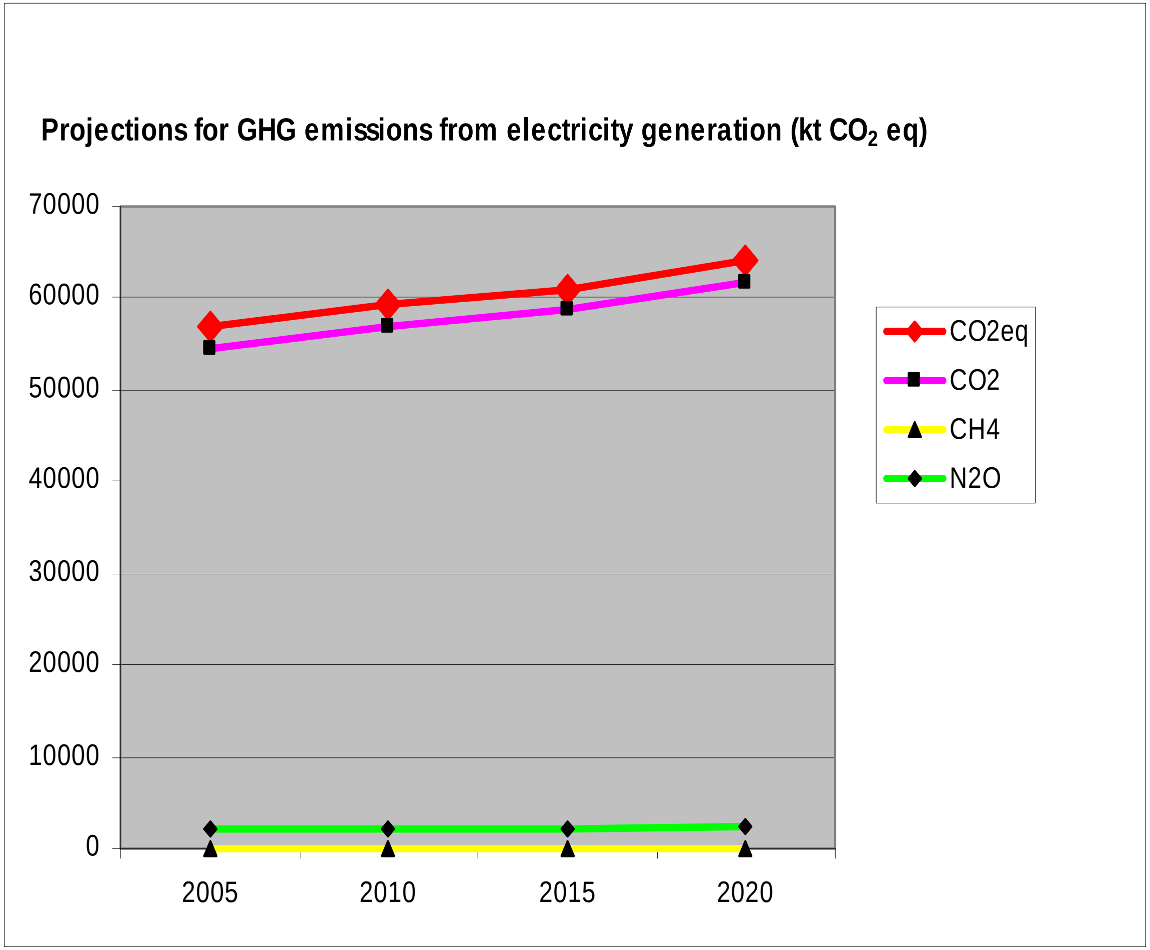
- Emissions from Energy in 2007 increased by approximately 37.91% compared to 1990 levels

- Total CO_2 emissions increase of 36.57% from 1990 to 2007 (without LULUCF) - mainly attributed to the increased electricity production as well as to the increased energy consumption in the residential and transport sectors

- Electricity generation relies mostly on the use of fossil fuels (~ 92% of electricity production in 2007)
- 63% of electricity is produced by solid fuels while the share of liquid fuels and natural gas is 14% and 22% respectively
- CO_2 emissions in 2007 accounted for 99.64% of total emissions from public electricity and heat production, while emissions from solid fuels consumption accounted for 78% of total emissions in 2007.
- Due to the penetration of natural gas, total emissions per electricity produced by fossil fuels has a decreasing trend



Electricity production (in TWh) by energy type for the period 1990 – 2007



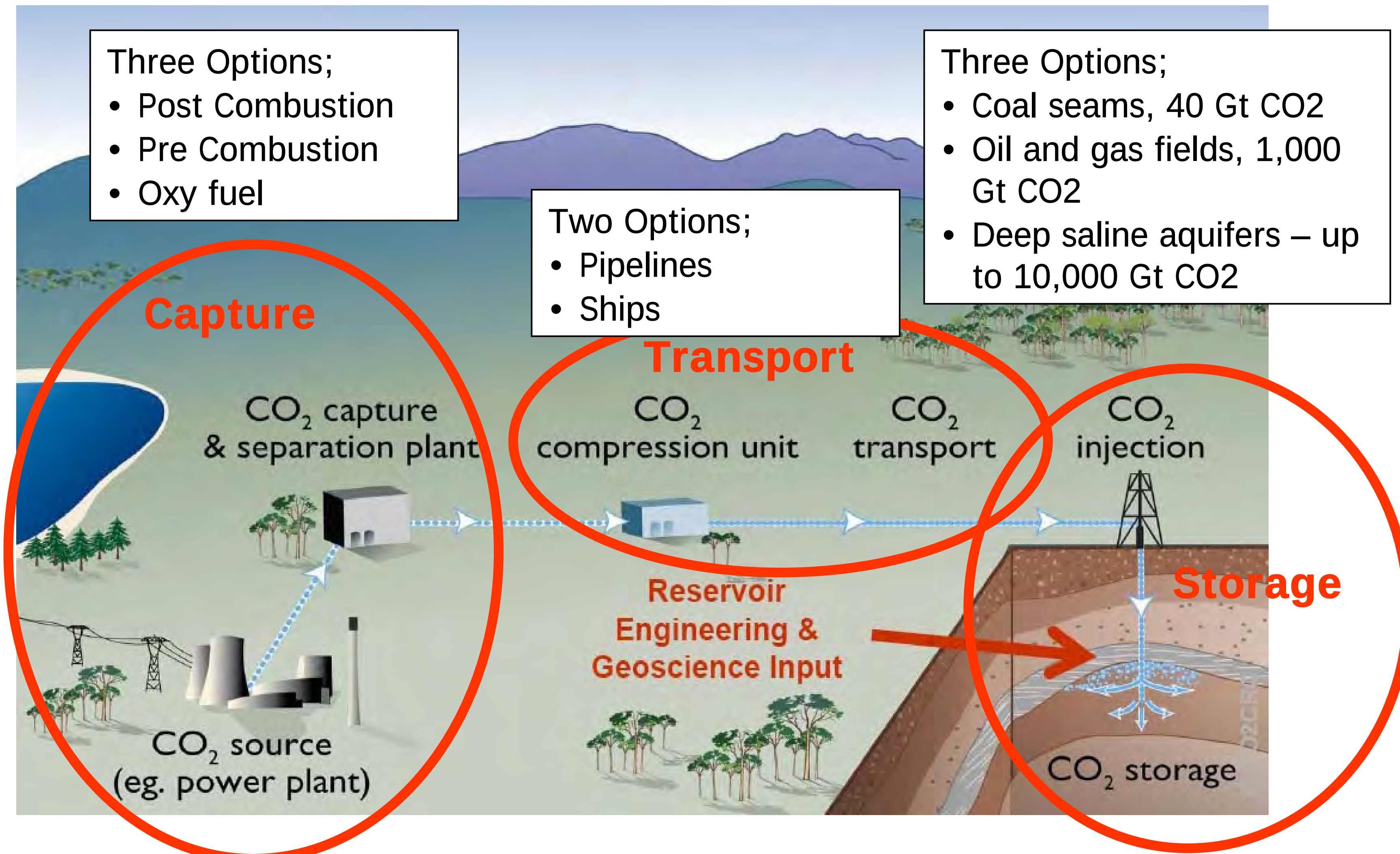
- The average annual increase rates of GHG emissions decreases to 1.0% up to 2010 and to 0.8% in the following period due to further penetration of natural gas., RES in the power sector and as a result of refurbishment of some old lignite-fired power units.

Overview of Carbon Capture and Storage technologies

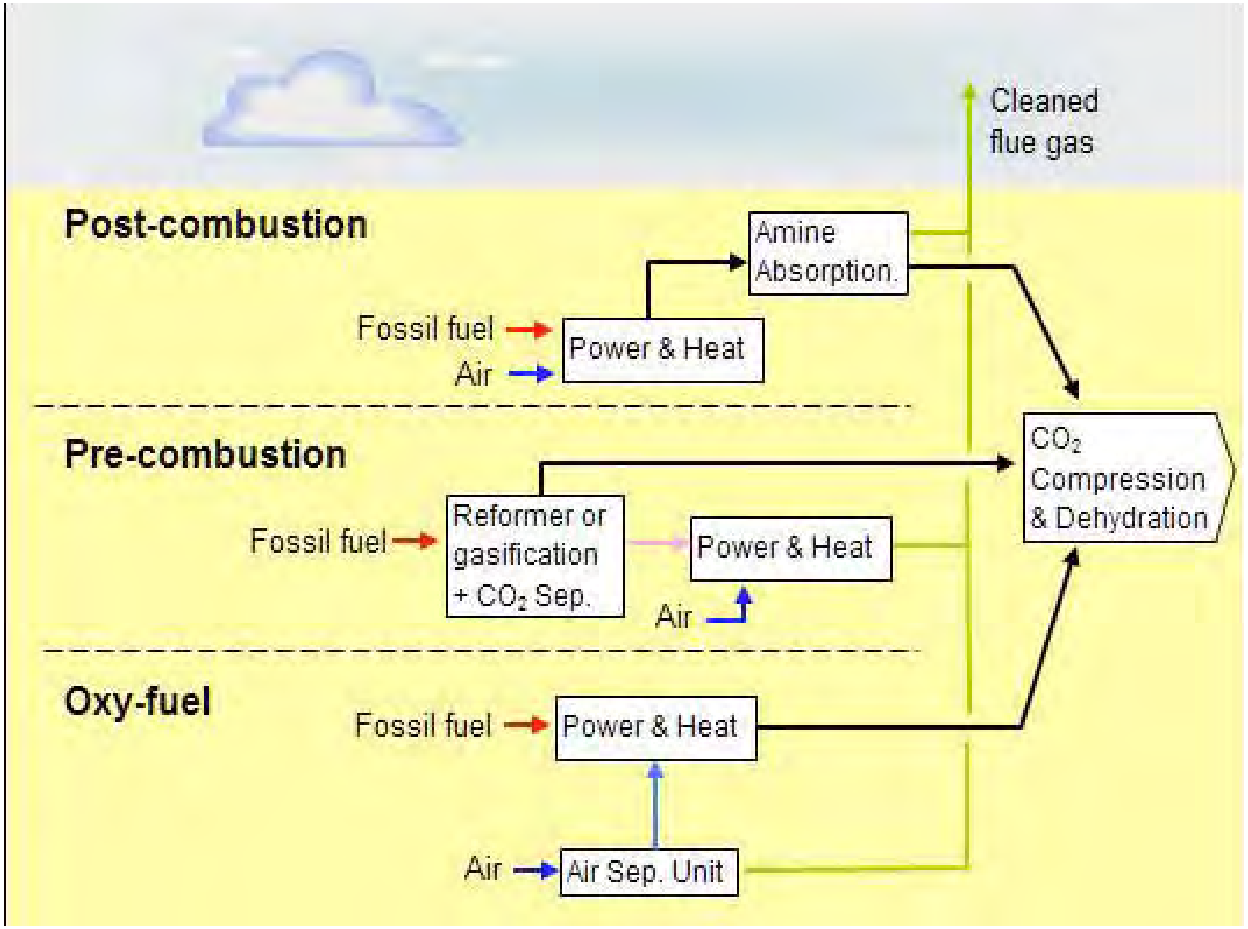
Three Options;
- Post Combustion
- Pre Combustion
- Oxy fuel

Two Options;
- Pipelines
- Ships

Three Options;
- Coal seams, 40 Gt CO2
- Oil and gas fields, 1,000 Gt CO2
- Deep saline aquifers – up to 10,000 Gt CO2



Main technology options for CO2 capture from power plants



Source: ZEP Technology Platform, Strategic Research Agenda

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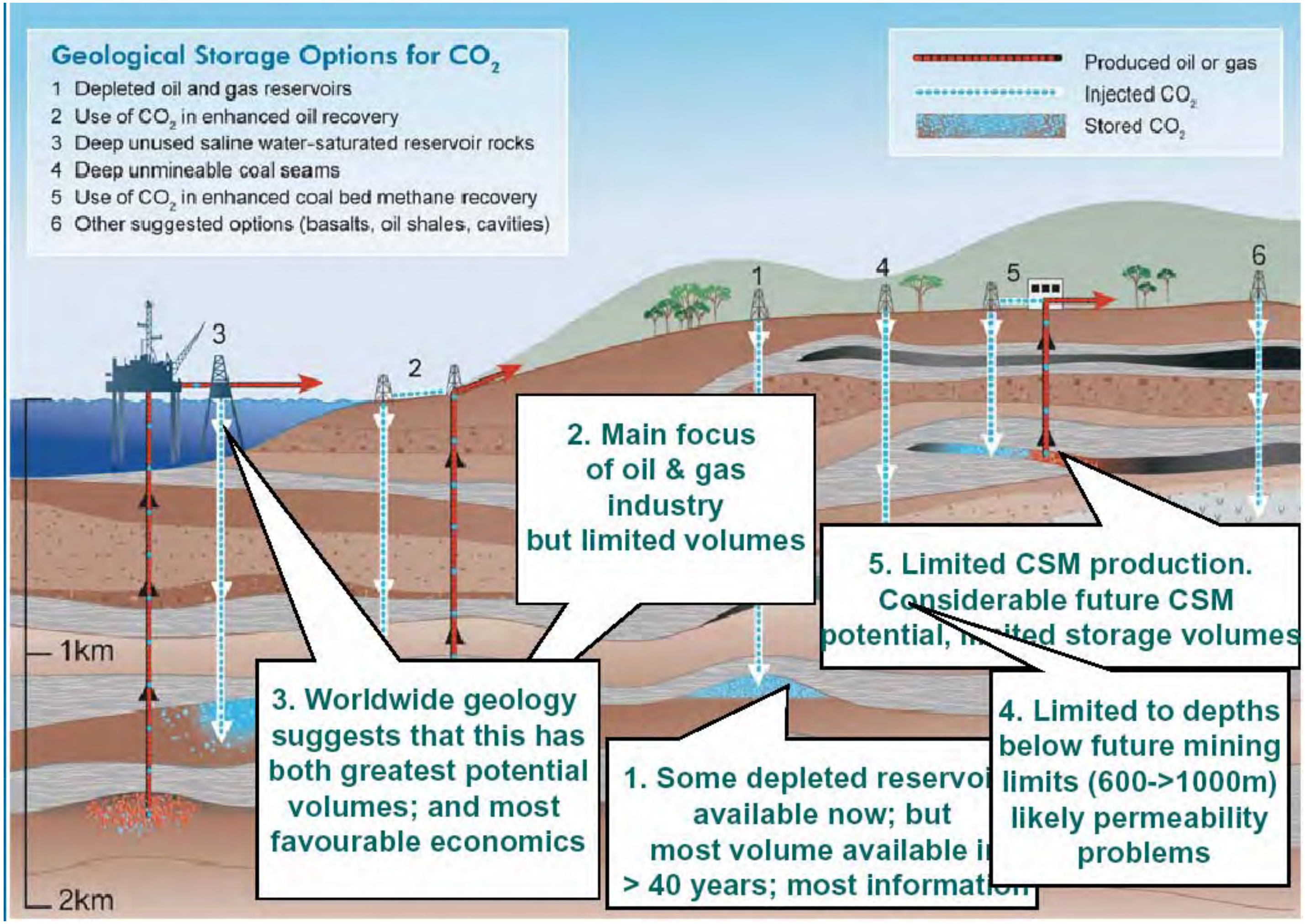
Geological Storage Options



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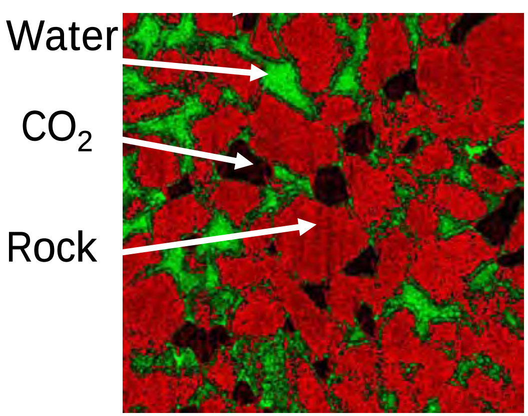
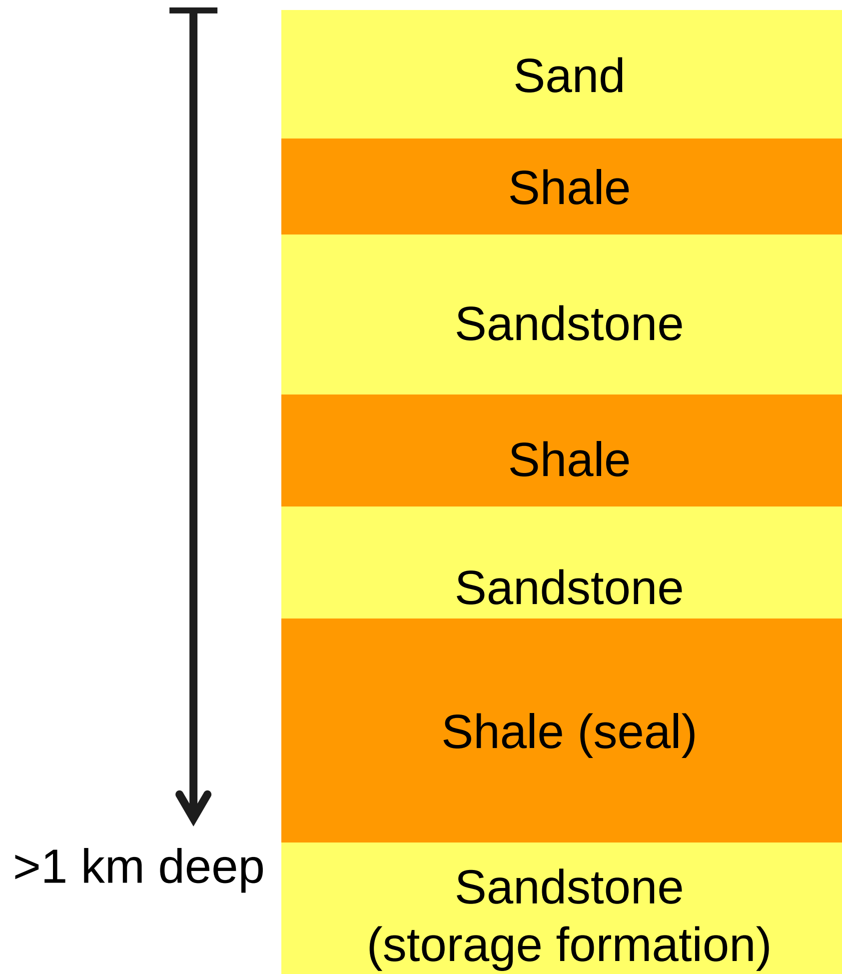
What Keeps the CO_2 Underground?

- Physically trapped beneath seals
- CO_2 dissolves in water

- CO_2 is trapped by capillary forces
- CO_2 converts to solid minerals

X-ray of CO_2 in sandstone





CO_2 Capture Facilities

Source: IEA CCC (2007)

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CO_2 Injection and Storage Activities

Source: IEA CCC (2007)

Proposed Integrated CCS Projects

Source: IEA CCC (2007)

Overview of commercial CCS projects

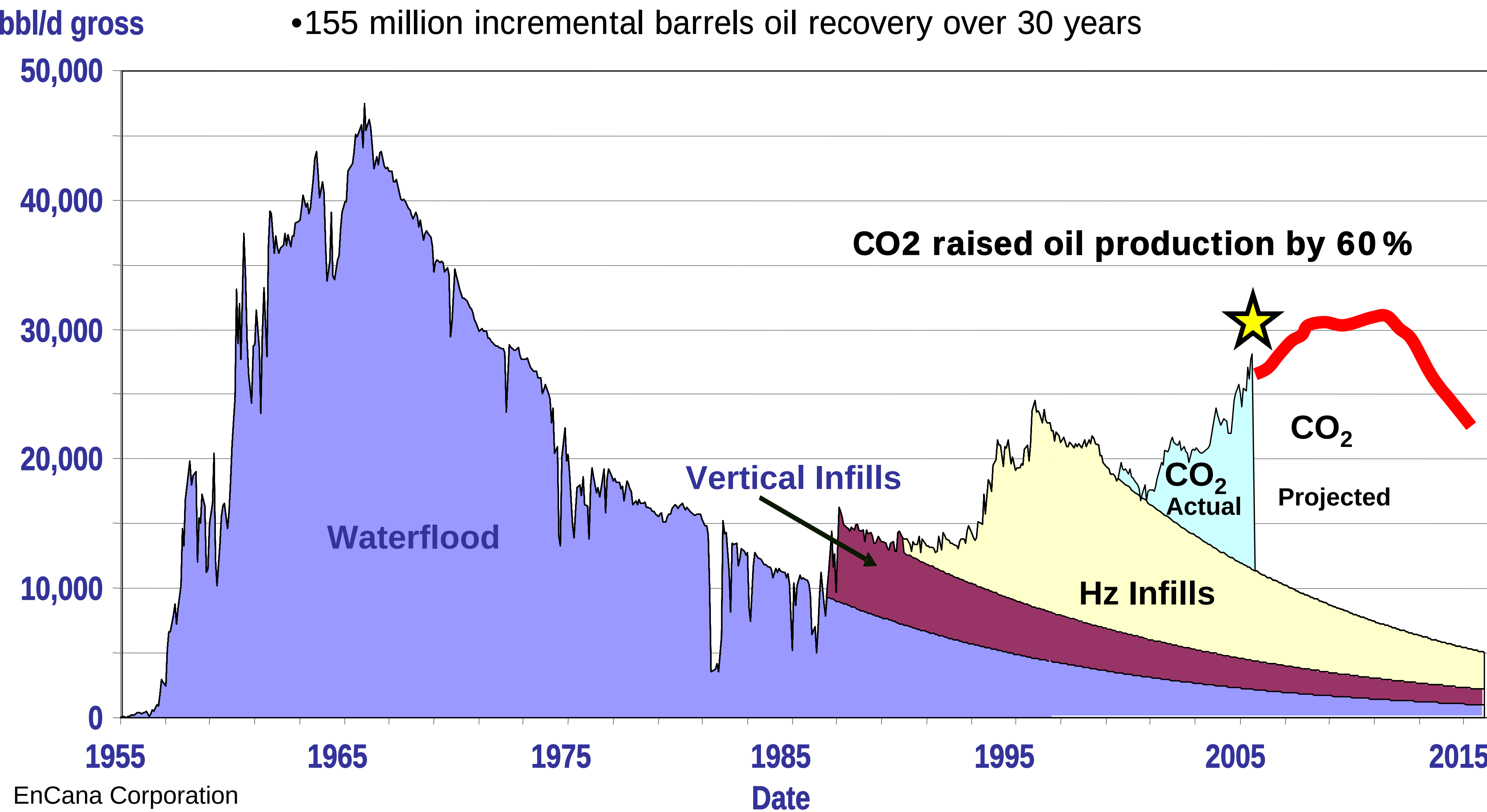
Weyburn-Midale CO_2 Project

- The Canadian Weyburn CO2 EOR project, injecting nearly 2Mt CO2/yr from fossil fuel-fired power plant since 2000
- The only commercial-scale large project directed to the co-optimisation of oil production and CO2 injection

•Cross border transfer of CO2 from the USA to Canada

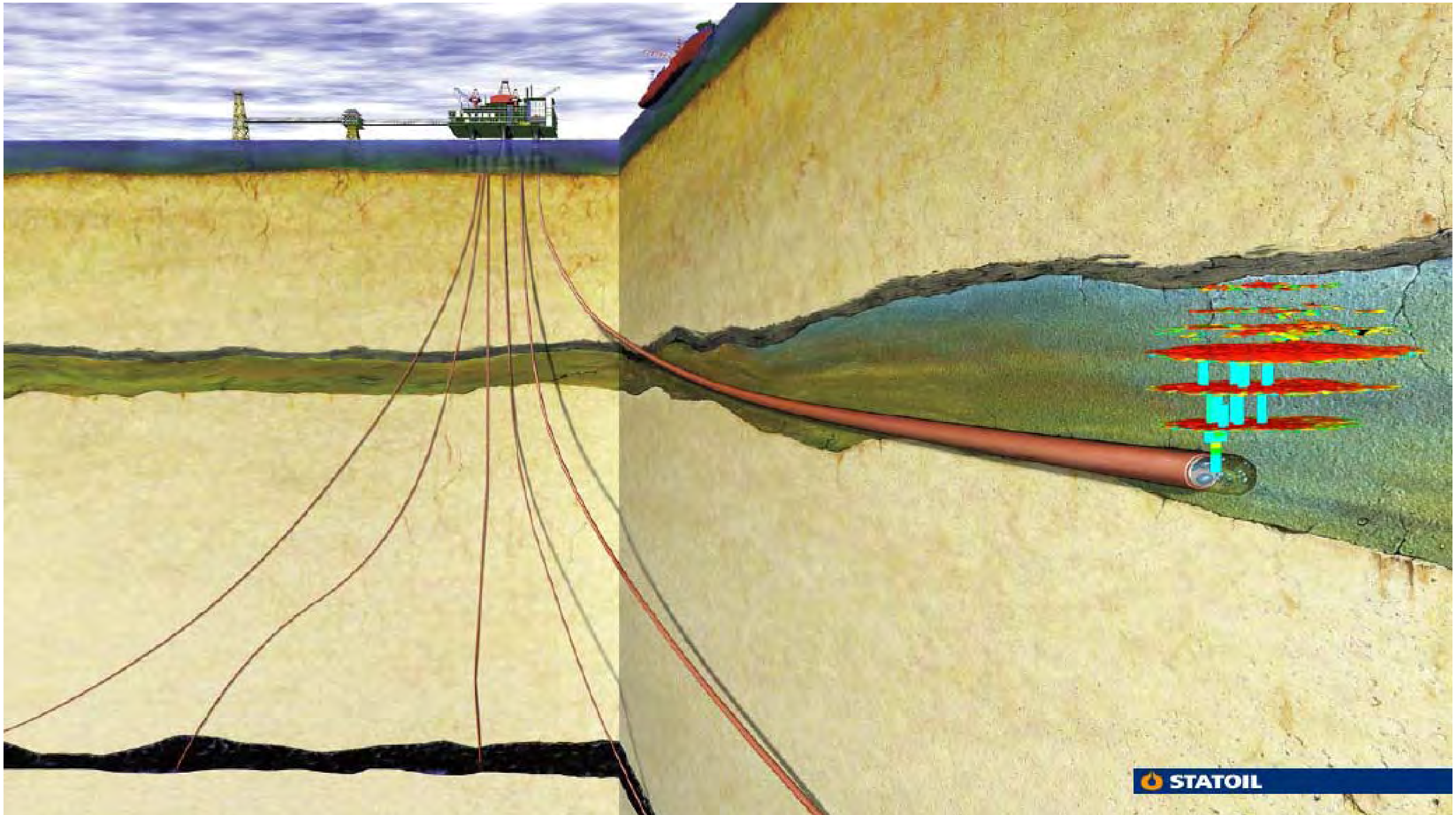
•The first international trading of ‘physical’ CO2 for the purposes of emissions reduction

- 7 million tonnes (net) of CO_2 injected by end of 2005
- 26+ million tonnes (net) will be geologically stored by 2035
- 155 million incremental barrels oil recovery over 30 years



EnCana Corporation

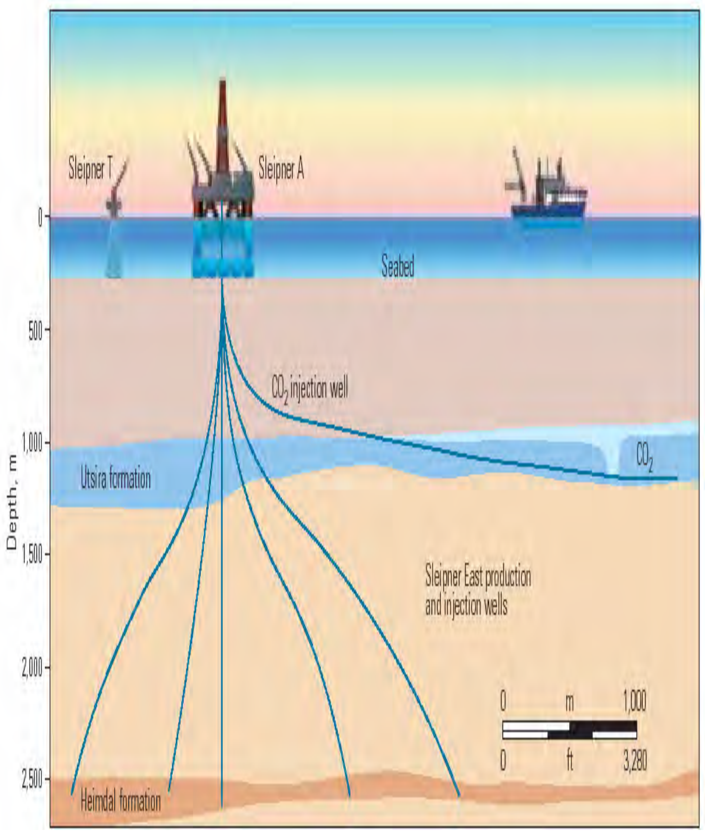
The Sleipner Project



- CO_2 Injection started in 1996 at a depth of 1000 m below sea level

- Operated by Statoil, located in the North Sea about 250 km off the coast of Norway

- Approximately 1 $MtCO_2$ is removed from the produced natural gas and injected underground annually at Sleipner corresponding to about 3% of Norway's total annual CO_2 emissions

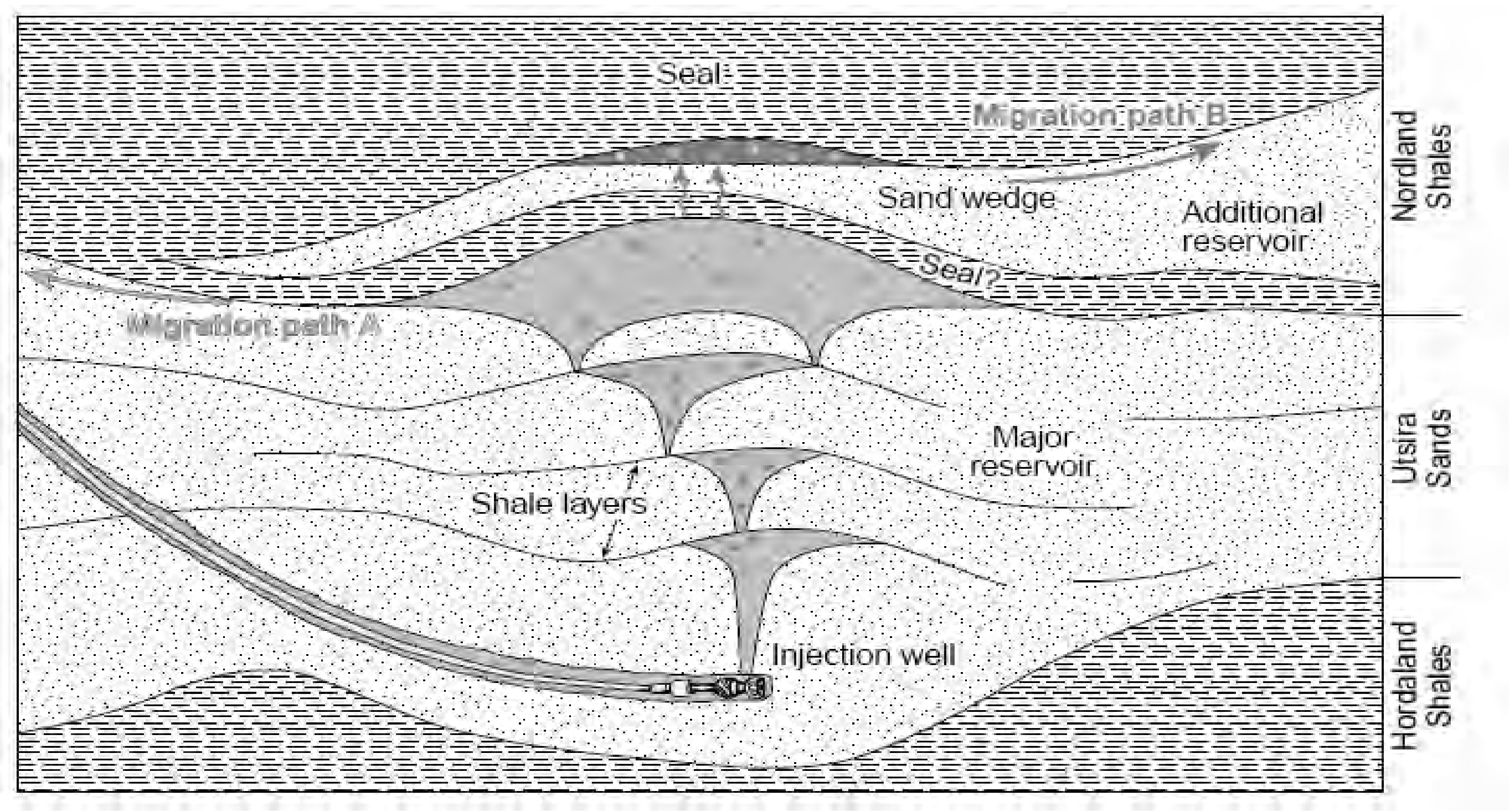


- The first, and to date only, commercial-scale project dedicated to geologic CO_2 storage in saline formation at the Sleipner West gas field

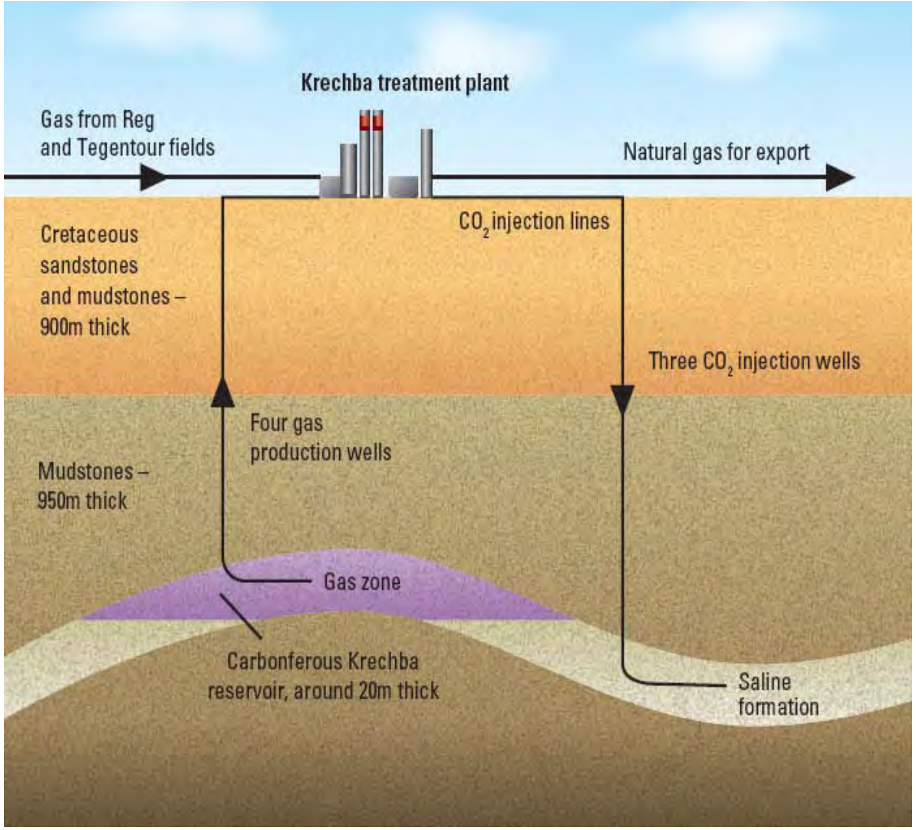
- By early 2005, more than 7 $MtCO_2$ had been injected at a daily rate of approximately 2700t

- Over the lifetime of the project (20 years) around 20 $MtCO_2$ is expected to be stored

Storage Formation:
the Mio-Pliocene Utsira Formation aquifer



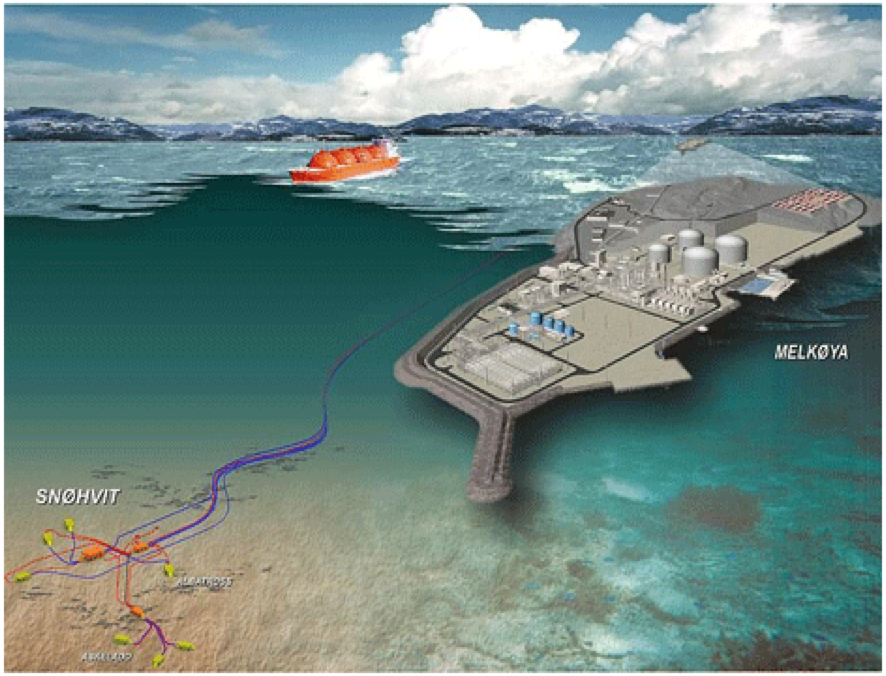
The In Salah Project



- Around 1 million tonnes of CO2/yr are injected into the producing gas field since 2004. The CO2 enters the same geological formation which holds the natural gas, but further north, into a deep saline aquifer 2,000 metres below the surface.

- It is estimated the project will eventually store 17 million tonnes of CO2 – an emission reduction equivalent to removing four million cars from the road.

The Snøhvit Project



- Statoil is operator for the development and operation of Snøhvit. Gas production started in October 2007 and the first CO2 was injected into the reservoir in April 2008

- CO2 is stored in a suitable geological layer of porous sandstone called the Tubåen formation at 2,500 metres beneath the seabed and under the layers in Snøhvit containing gas

- At full production around 700,000 tonnes CO2 will be captured and stored every year from this natural gas field

CO_2 stationary sources and geological storage capacity at national level

Results from the techno-economic assessment of CCS technologies implementation in Greece

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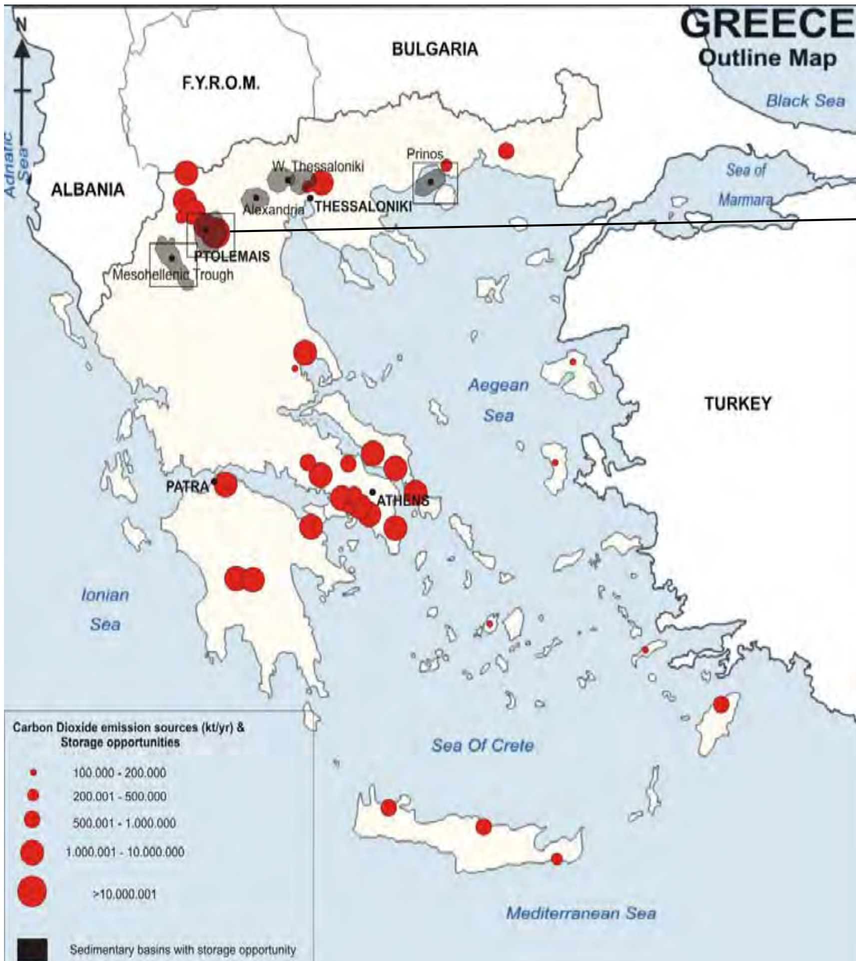
Stationary CO_2 emissions in relation to potential storage basins in Greece.



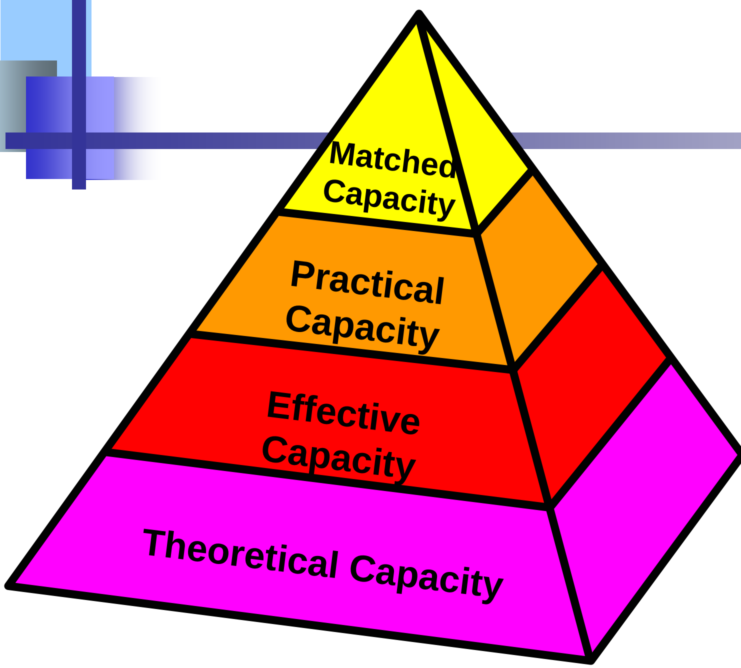
Power plant	Installed capacity	Emissions (t CO_2/year)
PPC S.A., TPS Ag. Dimitriou	1595 MW	13,629,229
PPC S.A., TPS Kardias	1250 MW	9,815,429
PPC S.A., TPS Ptolemaidas	620 MW	3,487,897
PPC S.A., TPS Amyndaiou	600 MW	5,124,545
PPC S.A., TPS Florinas	330 MW	1,955,721
PPC S.A., TPS Liptol	43 MW	358,515
Total		34,371,336

- Representing 70% of the country's total power and heat production
- 50% of stationary CO_2 emissions in Greece derive from this region

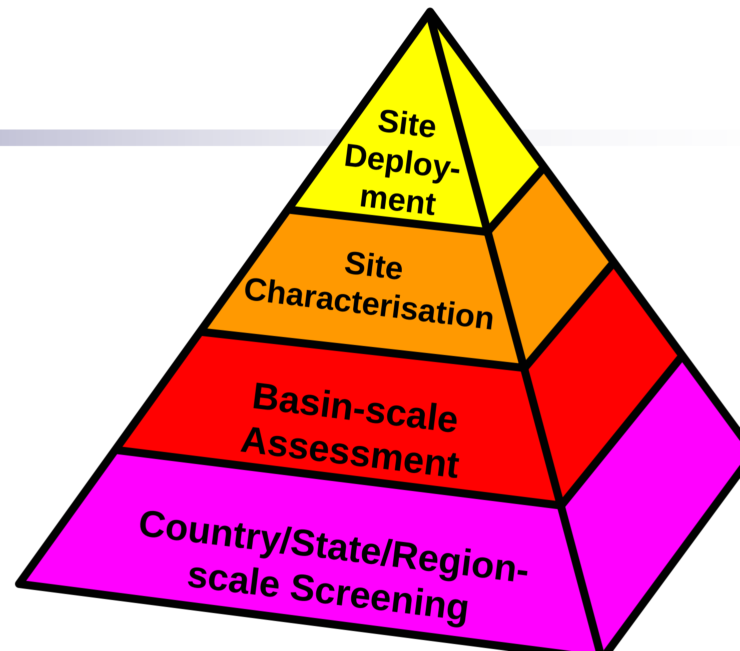
(Koukouzas et al., 2009 – Int. J. of GHG)

Storage Capacity & Site Selection

Techno-Economic Resource-Reserve Pyramid for CO_2 Storage Capacity



Assessment Scale & Resolution Pyramid for CO_2 Storage Site Selection

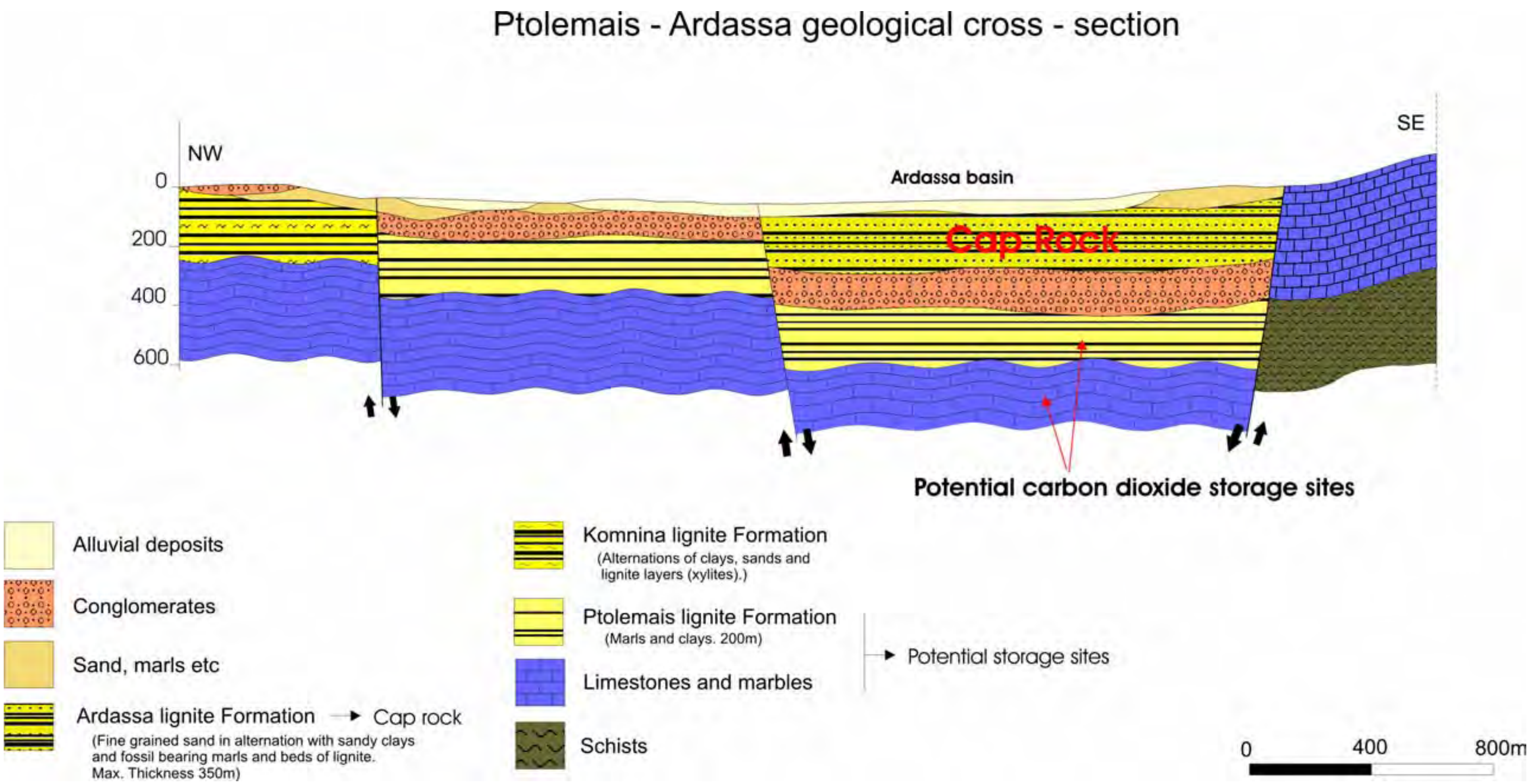


Bachu & Shaw, 2005;
CSLF, 2005

Evaluation of prospective sedimentary basins for CO_2 geological storage in Greece.

	Prinos basin	Thessaloniki basin	Ptolemais basin	Messohellenic Trough
Tectonic stability	Stable	Stable	Stable	Intermediate
Size	Small (1000 km^2)	Medium (1000 – 5000 km^2)	?	Large (5000 – 25000 km^2)
Depth	Intermediate (1500 – 3500 m)	Shallow (,1500m) and intermediate (1500 – 3500m)	?	Intermediate (1500 – 3500m)
Reservoir – Seal Pairs	Excellent	Excellent	Intermediate	Intermediate
Faulting intensity	Limited	Limited	Moderate	Extensive
Geothermal	Warm basin (>40ºC/km)	Cold basin (<30ºC/km)	?	Moderate (30-40ºC/km)
Hydrocarbon potential	Large	Small		Small
Maturity	Matute	Unexplored	Mature	Unexplored
Coal			Very shallow (<300m)	
Coal rank			Lignite	
Onshore/ offshore	Offshore	Onshore	Onshore	Onshore
Accessibility	Easy	Acceptable to easy	Easy	Difficult
Infrastructure	Extensive	None	None	None
CO_2 sources	Few	Moderate	Major	Major within 100km

➢ Ptolemais – Kozani basin



(Koukouzas et al., 2009)

CO_2 theoretical storage capacity of the saline aquifers in Greece

Aquifer	Location	Storage capacity (Mt CO_2)
Prinos	Offshore	1343
W. Thessaloniki	Onshore	459
W. Thessaloniki (sandstones)	Onshore	145
Alexandreia	Onshore	34
Messohellenic Trough	Onshore	360
Total		2345

(GESTCO PROJECT)

•"Techno economic study of the potential to store underground the emissions from a new built capture-ready 650 MWe coal fired power plant using supercritical steam cycle, to be constructed in the Region of Western Macedonia"

•Carried out by CERTH/ISFTA under contract with PPC S.A. – December 2008

• The pipeline transport cost calculations are based on the methodology of the IEA Greenhouse Gas R&D Programme

	Messohellenic Trough – Pentalophos saline aquifer	**W. Thessaloniki saline aquifer**	**Prinos saline aquifer**
Distance (km)	120	150	190
Storage capacity (Mt CO_2)	216	605	1.350
Total pipeline investment costs (M€)	29,6	31,5	52,3
Annual transport cost (M€/y)	3,6	3,8	7,7
Specific transport cost (€/t CO2)	**1,00**	**1,06**	**2,15**

*Based on transport flow 126 kg/s CO2 captured at 90%

- Calculations of CO2 geological storage costs in saline aquifers of North Greece in the proximity of the 650 MWe coal fired power plant to be erected in Western Macedonia, based on the methodology of the IEA Greenhouse Gas R&D Programme

	Capital Investment costs CAPEX (M€)	**Operational costs– OPEX (M€/y)**	**Annual Storage costs (M€/y)***	**Cost of geological storage (€/t CO_2)**
Prinos saline aquifer	38,4	3	7,5	**2,1**
W. Thessaloniki saline aquifer	11,1	0,7	2	**0,6**
Messohellenic Trough – Pentalophos saline aquifer	11,5	0,8	2,1	**0,6**

* Assuming: lifetime of the storage facility 20 years and a discount factor of 10%.

DIRECTIVE 2009/31/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 23 April 2009

on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006

(Text with EEA relevance)

The Directive should apply to the geological storage of CO_2 (greater than 100 kilotonnes) and Enhanced Hydrocarbon Recovery combined with geological storage of CO_2, within the territory of the Member States, in their exclusive economic zones and on their continental shelves.

❖ CO_2 Capture

- ✓ Integrated Pollution Prevention and Control Directive (**IPPC**) - Directive 2008/1/EC for regulating the risks of CO_2 capture to the environment and human health and should be applied to the capture of CO_2 streams for the purposes of geological storage from installations covered by that Directive.
- ✓ **BAT** Reference Document for capture technologies

❖ CO_2 Transport

- ✓ Transport by pipeline: Regulation at Member State level **as for gas transport**
- ✓ Transport by ship: similar approach

The suitability of a geological formation for use as a storagesite shall be determined through a characterisation and assessment of the potential storage complex and surrounding area pursuant to the criteria specified (Annex I).

❖**Exploration of storage sites:** exploration permits should be granted for a limited volume area and for a limited time on a case by case basis) during which the holder of the permit should have the sole right to explore the potential CO2 storage complex (that to be converted into storage permit or relinquished)

❖**Characterisation and verification of storage sites:** Characterisation of the storage site and assessment of the expected security through different modelling exercises (Annex I); site should only be selected if assessment shows that there is no significant risk of leakage

❖**Criteria for CO_2 stream:** shall consist ”overwhelmingly” of CO_2

No CO2 stream purity. The permitted levels of impurities in the CO2 stream are based on their potential impacts on environmental integrity of transport and storage systems.

- **Review of draft permit:** MS submit draft permit to EC for review; EC will provide opinion within 4 months; competent authorities have to take EC opinion into account, but final decisions taken by MS

- **Monitoring and reporting obligations:** comparison between actual and modelled behaviour and detection of any leakage/migration/adverse effects for surrounding environment

- **Inspections:** routine once a year until three years after closure and every five years until transfer of responsibility to the competent authority has occurred and non-routine environmental inspections to check compliance with requirements of the Directive

- **Measures in case of leakage:** corrective measures to be taken by the operator (or by the government if operator fails or is unable)

- **Closure of storage sites and after-care:** implement closure plan

- **Transfer of responsibility to the state:** competent authority takes over responsibility including all legal obligations in post-closure phase if all available evidence suggests long-term security of the storage

- **Financial security:** operators should make financial securities regarding closure procedures, post-closure provisions and obligations arising from EU ETS

- **Access to transport and storage network:** should be non-discriminatory, access may be refused under certain conditions

- **Entry into force:** on the 20th day following its publication in the *Official Journal of the European Union*.

❖The Directive **does not make CCS mandatory** but provides

a **"capture ready"** provision, by way of amendments to the Large Combustion Plants Directive (Directive 2001/80/EC) to include an obligation on ***all new built combustion plants*** *with a rated electrical output of 300 MW or more to have* ***suitable space*** *on the installation site for the equipment necessary* ***to capture and compress CO2*** *and that the availability of suitable storage sites and the* ***technical feasibility of CCS retrofit*** *have been* ***assessed****" ("capture ready" definition).*

Project: “Scrutinizing the impact of CCS communication on the general and local public” – Results at national level

- The project:"**Scrutinizing the impact of CCS communication on the general and local public"** is funded under the FENCO-ERA 1st Joint Call

- Partners from six European countries: Germany, Greece, Netherlands, Norway, Romania and United Kingdom.

- Objective: to investigate how opinion quality (e.g. stability) will vary depending on the communication method through:

a) Survey of a representative sample of citizens to collect data on public awareness and knowledge of climate change, energy policy and CCS in general

b) Comparison of the effectiveness of two CCS communication methods: 1) oral presentation of information by experts to a small group of lay persons who will have the opportunity for extensive discussion on CCS (focus group), and 2) written presentation of the identical expert information to a number of individual lay persons (who cannot interact) by an instrument helping them to make use of the information provided to form opinions on CCS (Information-Choice Questionnaire, ICQ).

- The two technologies selected for Greece were:

a) “Cluster of four coal-fired power plants with CO_2 capture and storage” (Technology 1)

b) “One gas turbine power plant with CO_2 capture and storage” (Technology 2)

- Participants were not very enthusiastic about these technologies but without considering the technologies very problematic.
- The participants recognized that both technologies could lead to CO_2 emissions decrease in Greece.
- Participants considered that Greece would rely on local coal sources by implementing Technology 1
- Positive position of participants towards the construction of a gas turbine power plant in the country by implementing Technology 2 but also skepticism regarding a potential dependence of Greece on imported energy sources (natural gas).
- Main concerns: the high implementation cost of both technologies due to lack of infrastructure and know-how in Greece.

Conclusions (1)

- The Greek energy sector is characterized by a high degree of energy imports dependency due to limited primary energy sources- apart from lignite. Fossil fuels will continue to be an important part of the national energy mix during the following decades.
- CCS technology is seen as a high R&D priority in Greece's 2007–2013 Energy Programme in order to enable Greece to continue the use of domestic lignite reserves as a secure and competitive energy source.
- The application of CCS technologies increases considerably capital costs and reduces efficiency and, as a consequence, increases electricity generation costs. Nevertheless, taking into account the CO_2 price, they can remain competitive.
- The geological settings of the sedimentary basins in Greece appear to provide a promising option for CCS implementation as the identified potential reservoirs and overlying seal units occur within approximately 100 km of the significant stationary CO_2 emissions in NW Greece, which is favourable in terms of infrastructure costs.
- The CO_2 pipeline transport and geological storage cost for the planned coal-fired unit varies from **1.6 €/tCO2** for onshore saline formations to **4.2 €/t CO2** for the offshore Prinos saline aquifer

Conclusions (2)

- National research institutes, PPC S.A. are actively involved in European research projects related to clean coal technologies and CCS technologies.
- A range of research activities is required in order to assess the storage potential's availability with a higher degree of certainty in combination with each of the large point sources in Greece requiring a more detailed evaluation of geological, geochemical and reservoir engineering data.
- The Directive on the geological storage of CO_2 provides a regulatory framework for CO_2 storage activities, which should allow potential developers and investors to adequately assess and manage their risks and liabilities with respect to CO_2 geological storage and consequently facilitate the adoption and deployment of CCS.
- Public acceptance is widely considered as a major barrier to the commercial deployment of carbon capture and storage (CCS) technologies. Understanding of public concerns over global warming and knowledge on CCS technologies is crucial as basis for decision makers developing communication strategies with the public and deciding what information and policies would make CCS more acceptable.