Captage et stockage du dioxyde de carbone: Quel chemin entre les installations pilotes et les installations industrielles?

LSGC

Eric FAVRE

Nancy-Université INPL

Laboratoire des Sciences du Génie Chimique

ENSIC Nancy Université FRANCE

Plan

i) Introduction: contexte

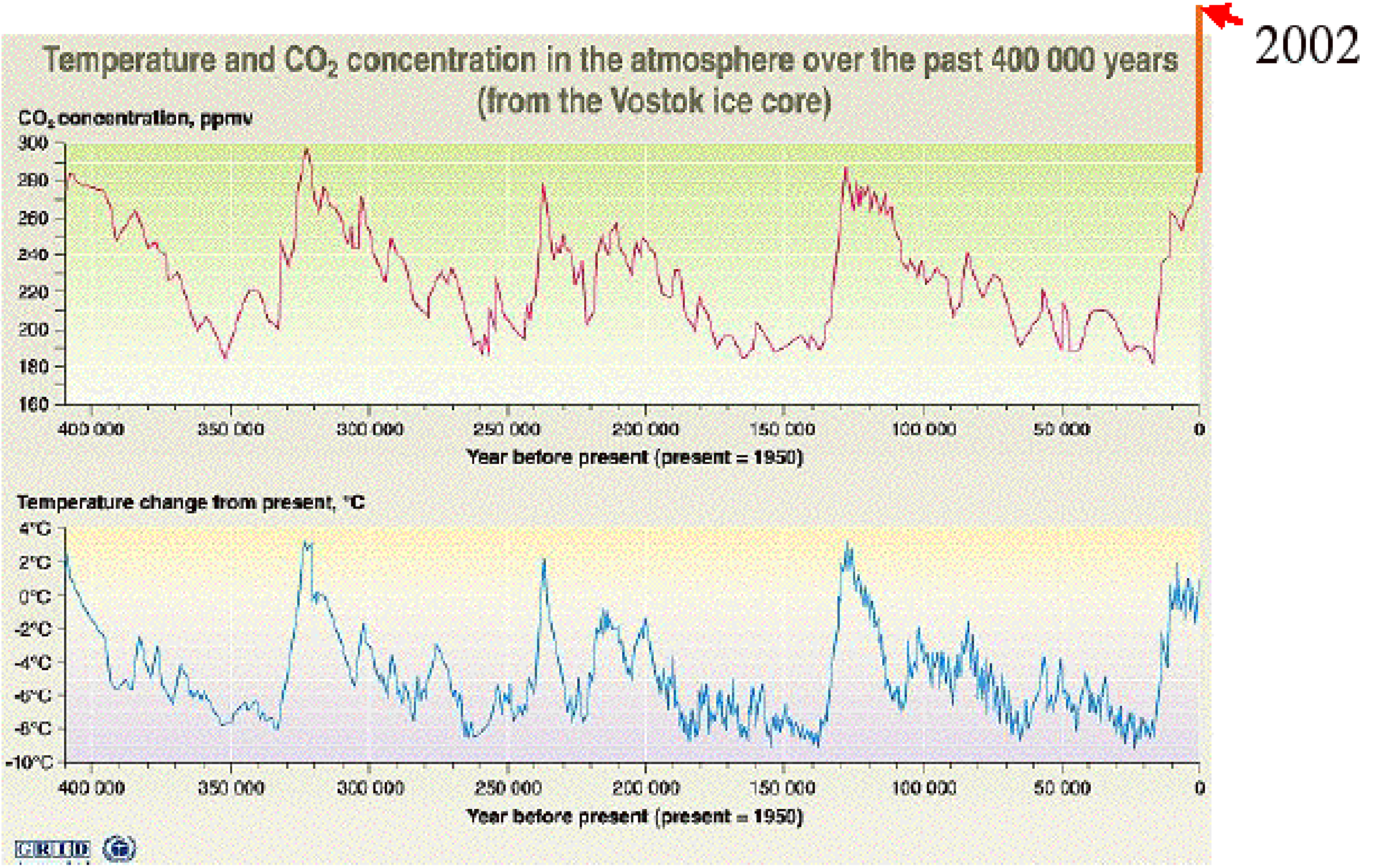
ii) CCS: Sources, captage, transport

iii) CCS: Stockage

iv) Conclusion & enjeux

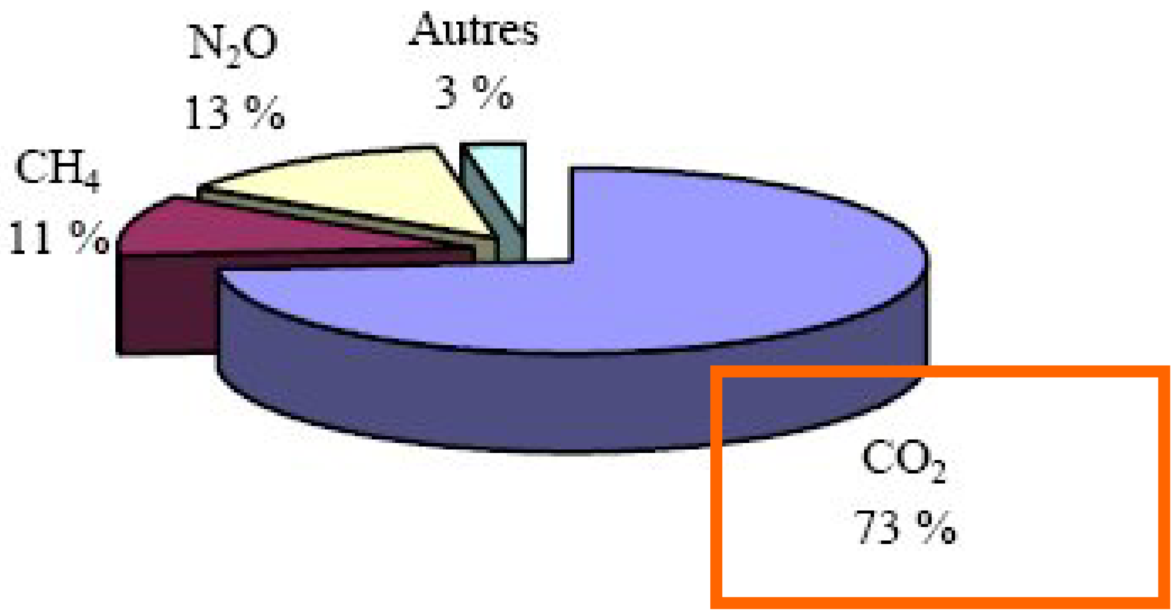
INTRODUCTION

Réchauffement climatique



Contribution des différents GES aux émissions de 2005 pour la France

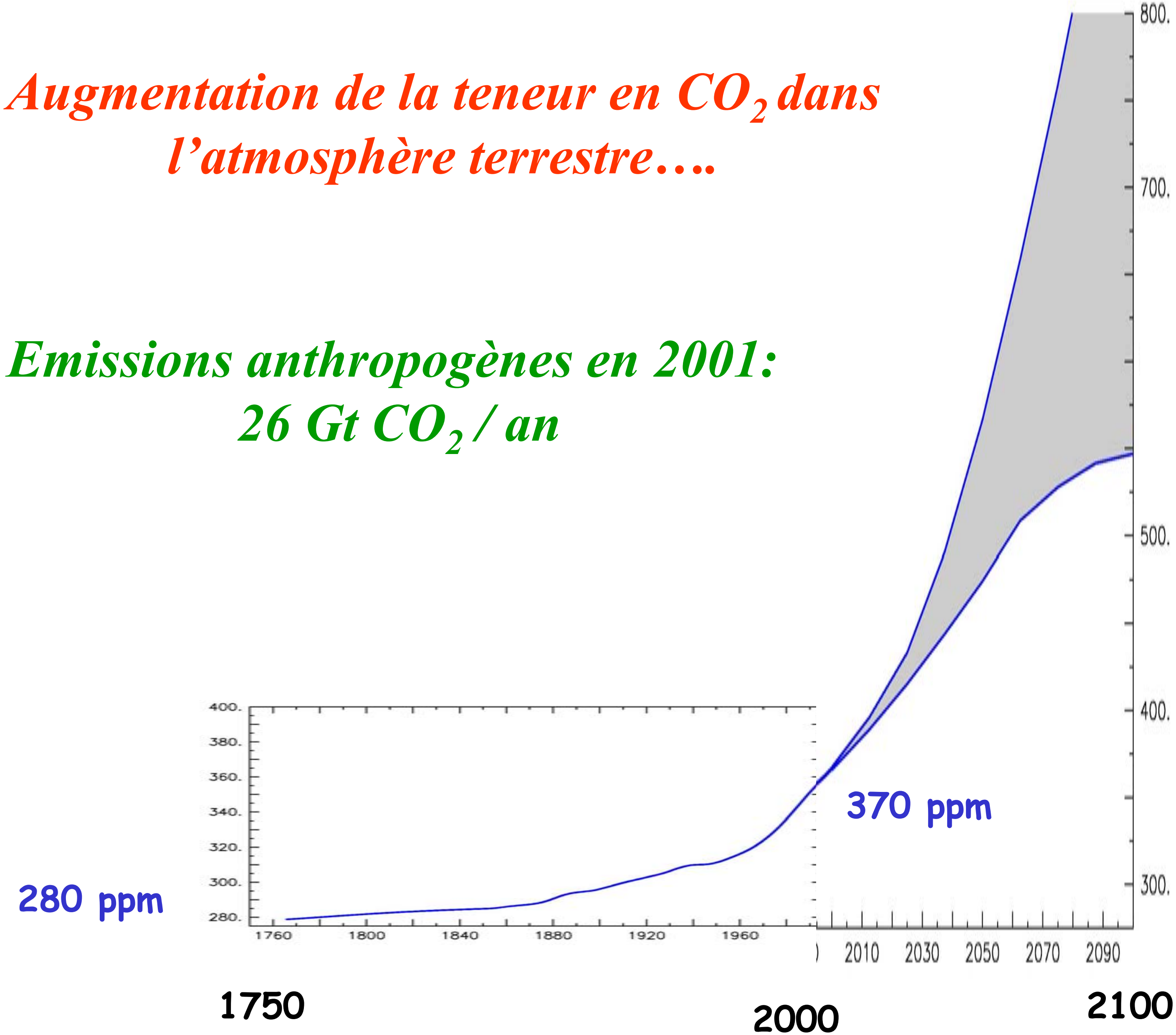
(hors puits)



Source : CITEPA

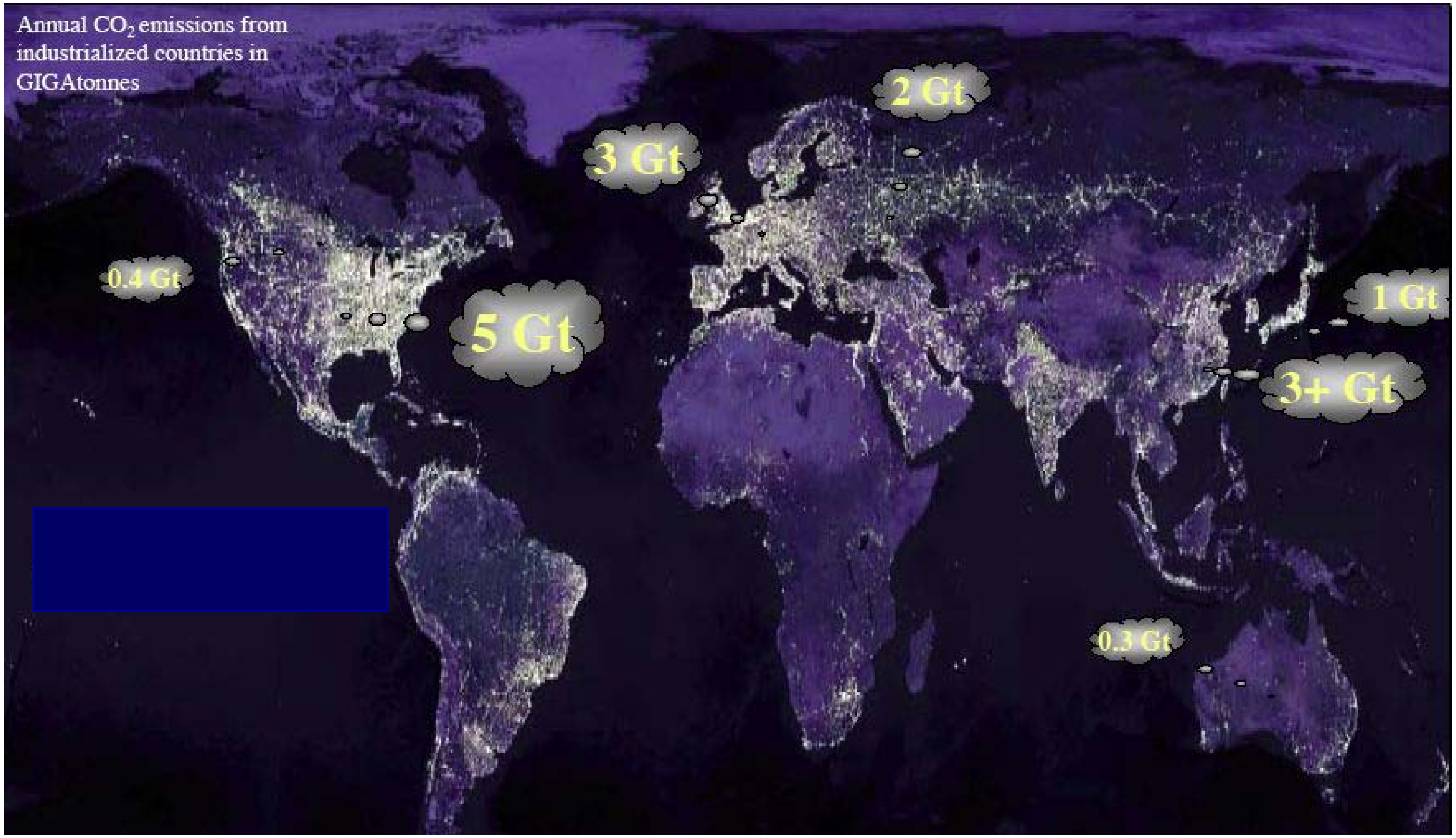
Augmentation de la teneur en CO_2 dans l'atmosphère terrestre….

Emissions anthropogènes en 2001: 26 Gt CO_2 / an



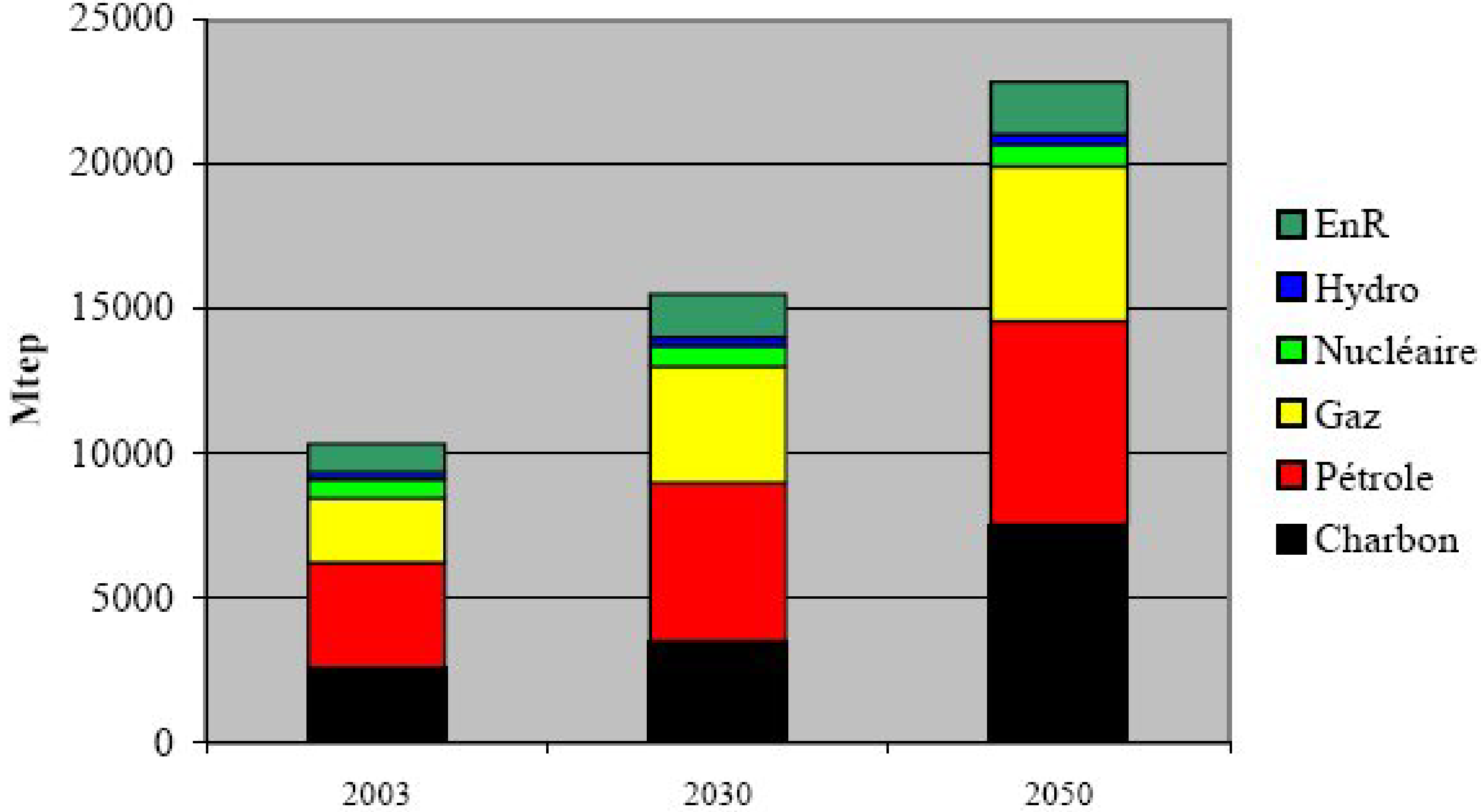
CO2 atmosphérique (ppm)

Emissions mondiales de CO_2

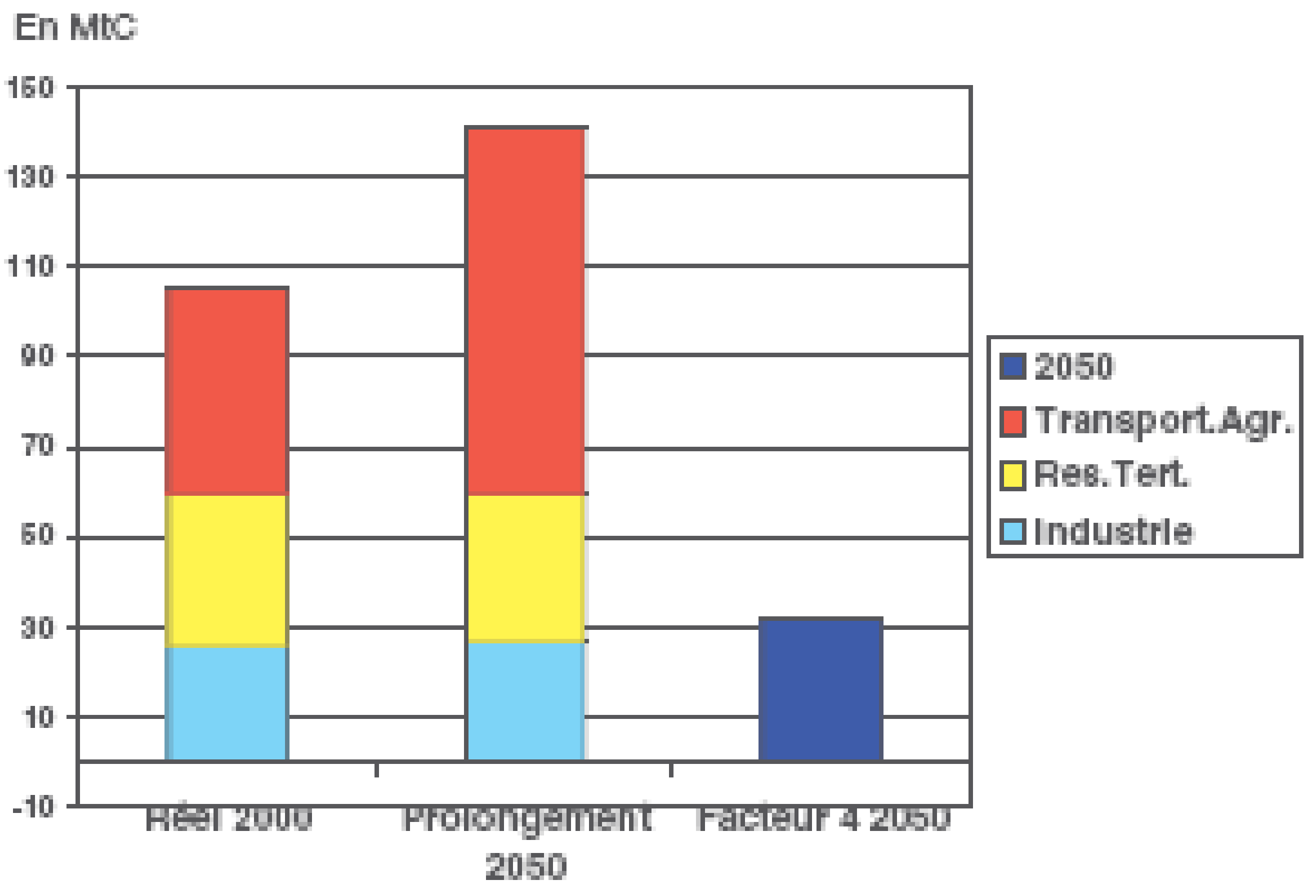


26 Gt = 26 milliards de tonnes

Dans le scénario tendanciel de l'AIE, la consommation mondiale d'énergie primaire double entre 2003 et 2050, tandis que la consommation de charbon est multipliée par trois...

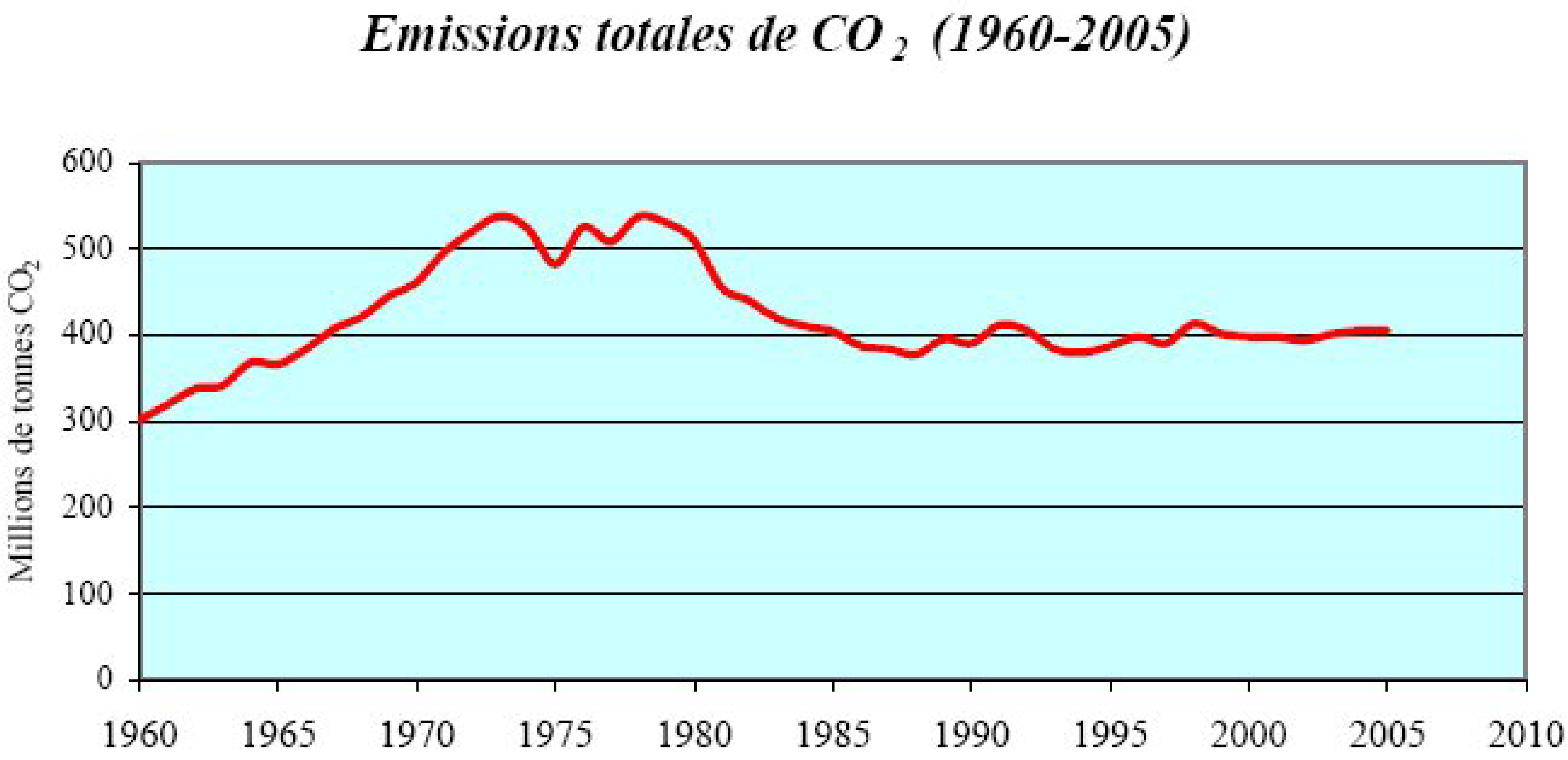


Rapport Chambolle (Juin 2004)



Objectif 2050: Diminution d'un facteur 4 des émissions de CO_2 sur le territoire national

Evolution des émissions en France



Source : CITEPA

Rapport Syrota

(Septembre 2007)

Du facteur 4 au facteur 2 ?


PREMIER MINISTRE

Centre d'analyse stratégique

25 septembre 2007

Perspectives énergétiques de la France à l'horizon 2020-2050

Rapport de synthèse

Jean Syrota, président de la Commission "Énergie"

Jean Bergougnoux, synthèse
Thierry Tuot, rapporteur général
Philippe Hirtzman, coordinateur

Rapports et documents

5.5. Un facteur un peu supérieur à 2 à l'horizon 2050 constitue un objectif déjà très ambitieux pour la France

5.4.2. Les résultats des scénarios volontaristes traduisent l'extrême difficulté pratique de dépasser le « facteur 2,1 à 2,4 », sans changements profonds des comportements et sans ruptures technologiques imprévues à ce jour

How can we achieve the factor 4 target?

1. **Decrease energy consumption**
2. **Improve energy efficiency**
3. **Promote renewable energy sources**
4. **Achieve Carbon Capture and Storage (CCS)**
5. **Use carbon dioxide**

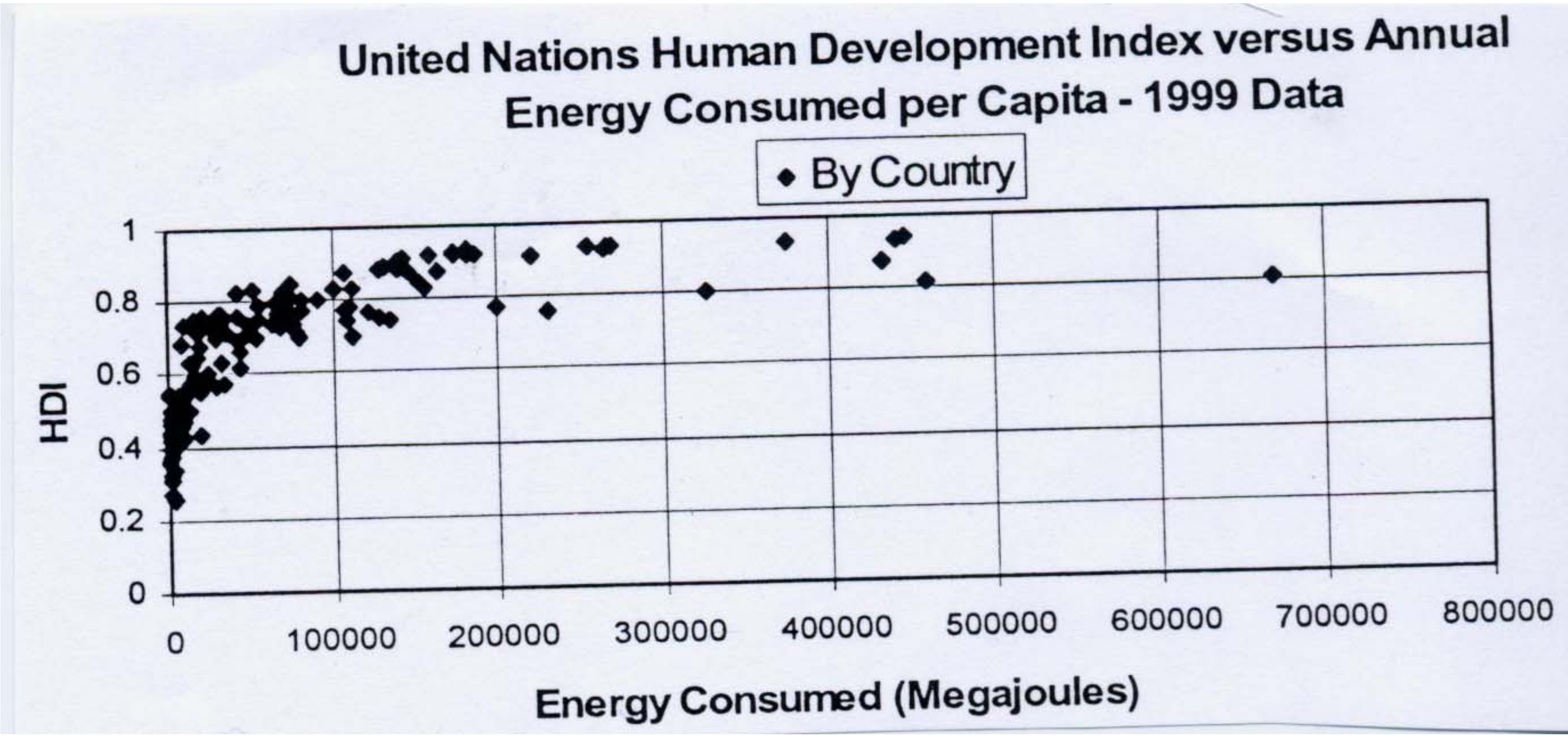
…..

Evolution de la consommation quotidienne d'énergie

		Alimentation	*Habitat & commerce*	*Agriculture & industrie*	*Transports*	*TOTAL (MJ)*
-1 000 000	Primitif	**8**				**8**
-100 000	Chasseur	**12**	**8**			**20**
-5000	Agriculture primitive	**16**	**16**	**16**		**48**
1400 (Renaissance)	Agriculture avancée	**24**	**50**	**30**	**5**	**109**
1875 (Révolution industrielle)	Industrielle	**30**	**140**	**100**	**60**	**330**
1970	Technologique	**45**	**270**	**380**	**260**	**955**

Adapté d'après Cook (1971) The flow of energy in an industrial society, Scientific american, 9, 135

Lien entre consommation d'énergie et indice de développement



HDI: Indicateur englobant
PNB/habitant + Espérance de vie + Education

NB: Notez le caractère non linéaire de la relation…

How can we achieve the factor 4 target?

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…..

2. Améliorer l’efficacité énergétique

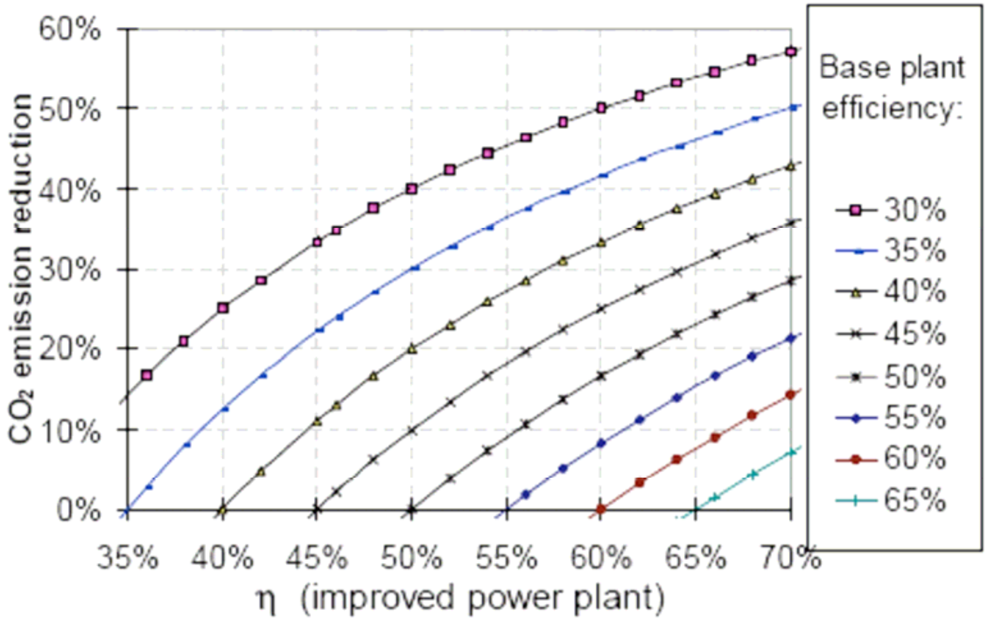

Figure 6.6: CO_2 emissions reduction by means of an improved power plant, as set against various benchmark power plants

How can we achieve the factor 4 target?

1. **Decrease energy consumption**
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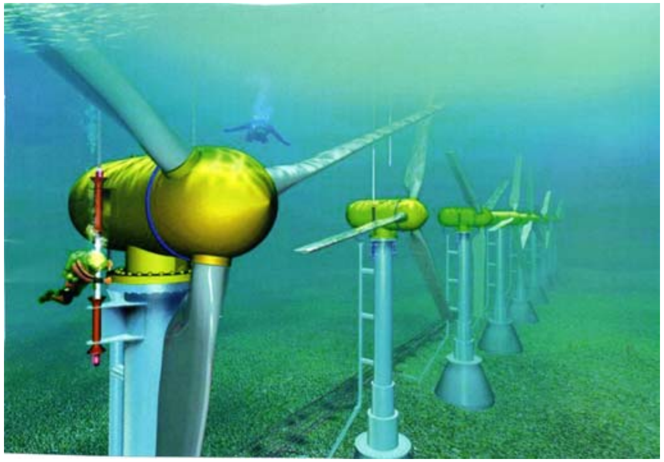
5. **Use carbon dioxide**

…..

3. Promouvoir les énergies renouvelables



How can we achieve the factor 4 target?

1. **Decrease energy consumption**

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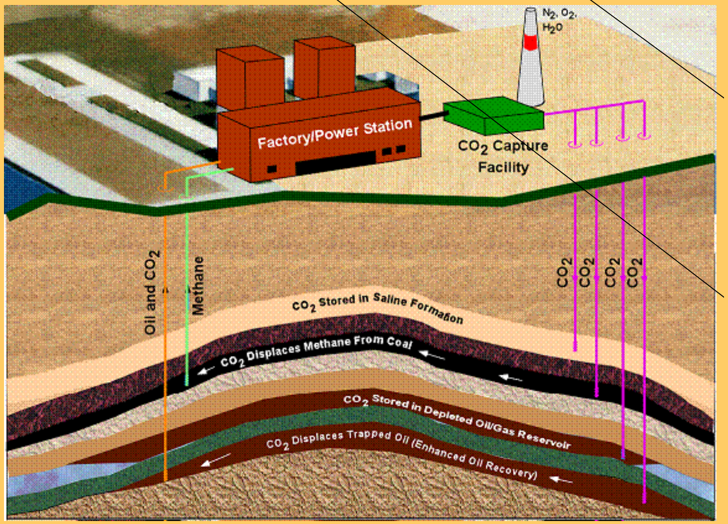
3. **Promote renewable energy sources**

4. **Achieve Carbon Capture and Storage (CCS)**

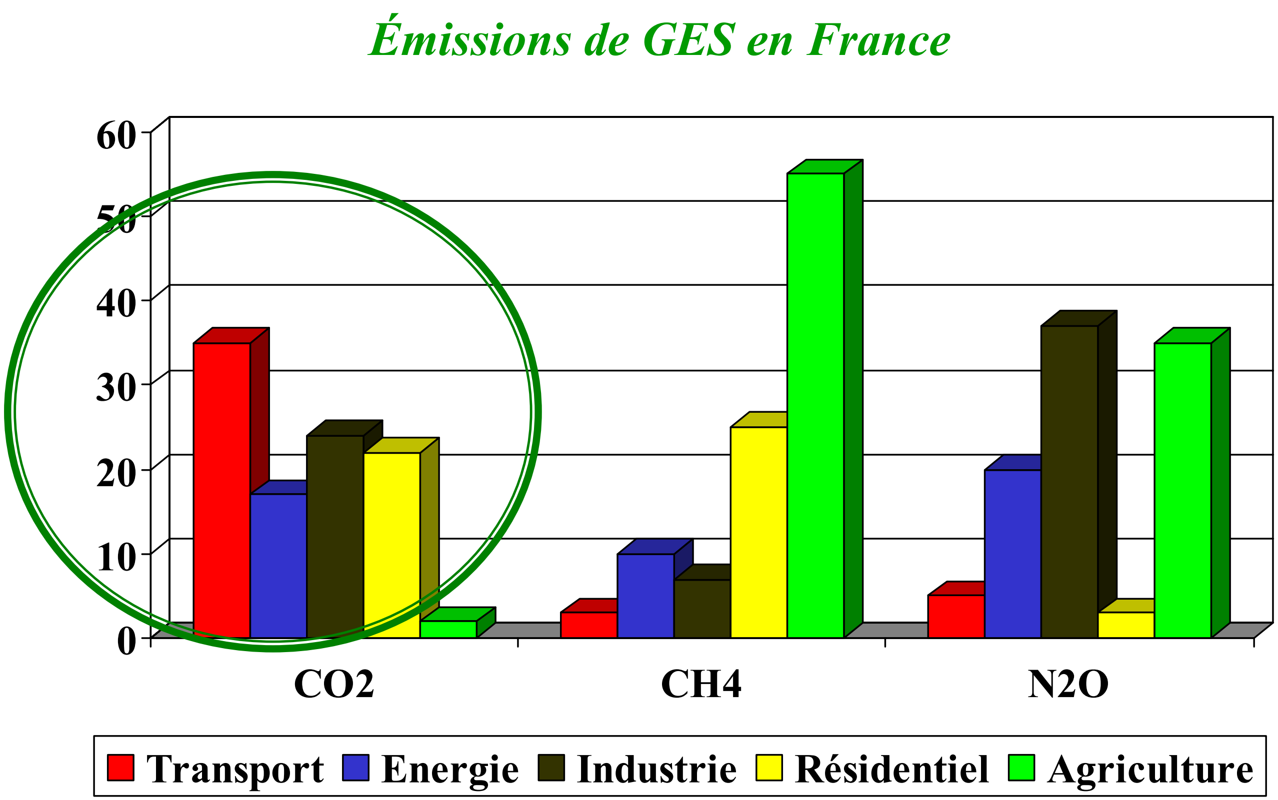
5. **Use carbon dioxide**

.....

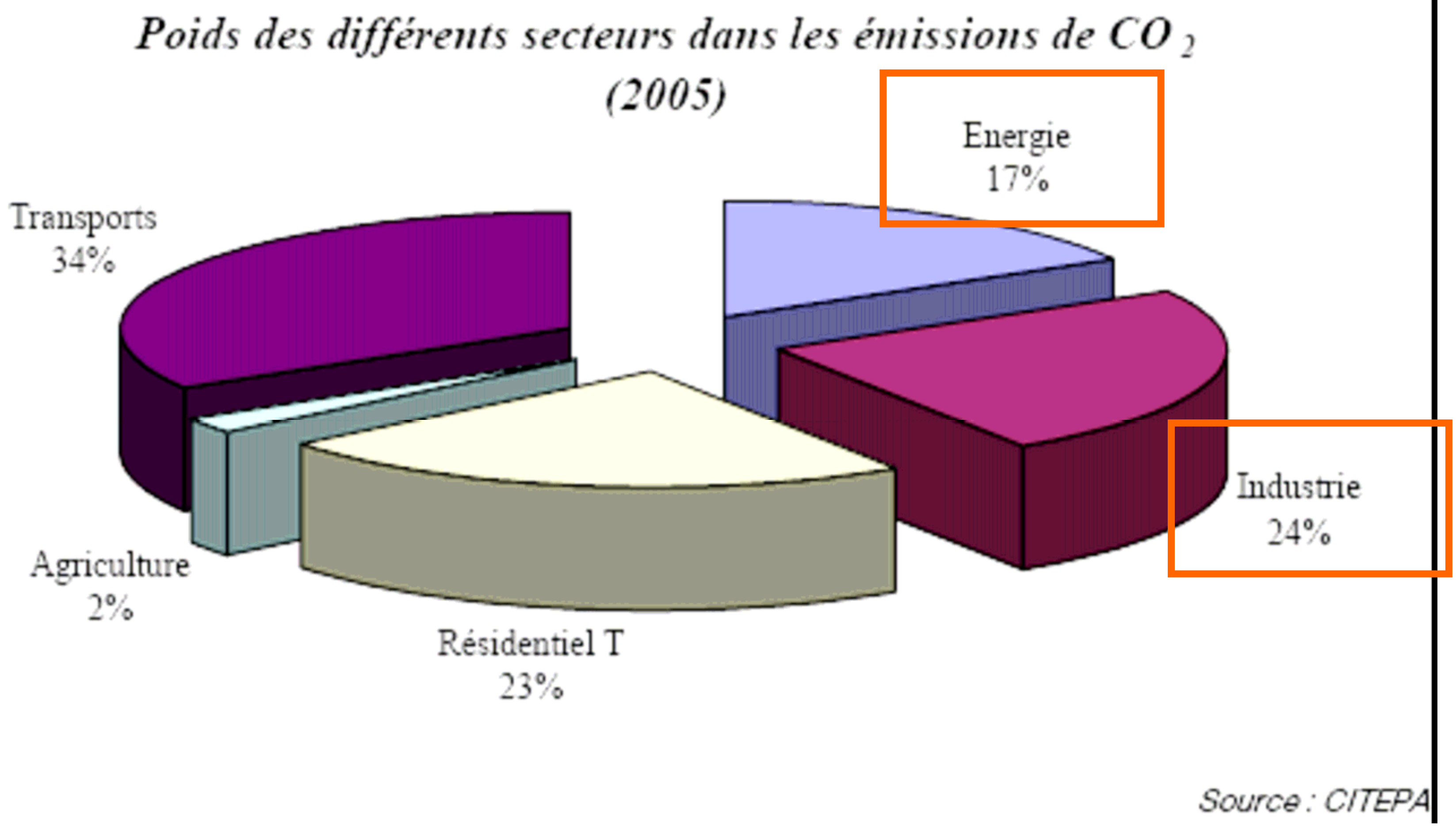
CCS: Sources, captage, transport



Sources d'émission



- **Grands procédés centralisés (centrales thermiques, industries)**
- **Grandes technologies décentralisées (véhicules)**
- **Petites sources décentralisées (habitat)**


Poids des différents secteurs dans les émissions de CO 2
(2005)
Energie
17%
Transports
34%
Industrie
24%
Agriculture
2%
Résidentiel T
23%
Source : CITEPA

CO_2 sources: World

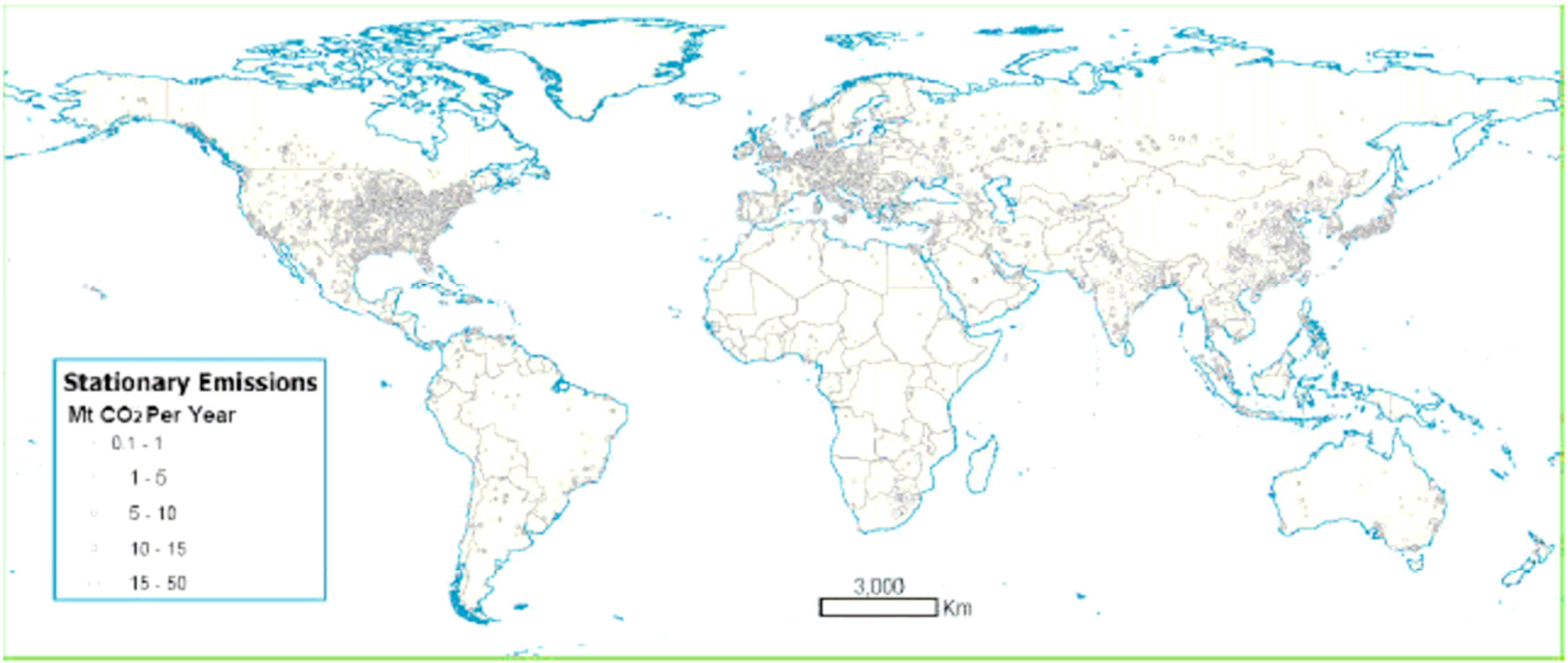


Figure 2.3. Global distribution of large stationary CO_2 sources (based on a compilation of publicly available information on global emission sources, IEA GHG 2002).

Large stationary sources inventory
(> 0.1 Mt CO_2 per year)

Table 1.1. Sources of CO_2 emissions from fossil fuel combustion in 2001

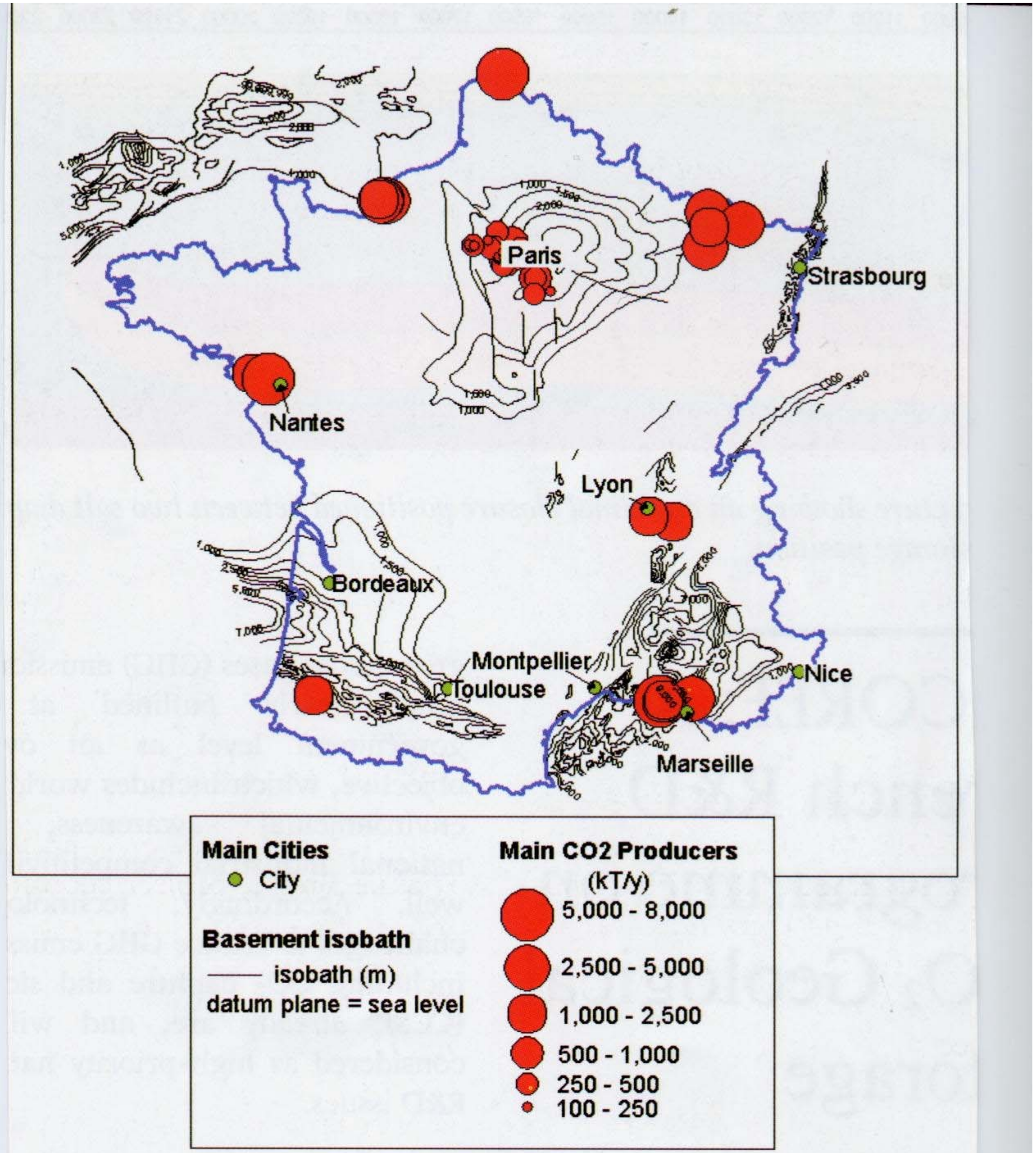
	Emissions	
	($MtCO_2\ yr^{-1}$)	($MtC\ yr^{-1}$)
Public Electricity and Heat Production	8,236	2,250
Autoproducers	963	263
Other Energy Industries	1,228	336
Manufacturing & Construction	4,294	1,173
Transport	5,656	1,545
of which: Road	4,208	1,150
Other Sectors	3,307	903
of which: Residential	1,902	520
TOTAL	23,684	6,470

Source: IEA, 2003.

Table TS.2. Profile by process or industrial activity of worldwide large stationary CO_2 sources with emissions of more than 0.1 $MtCO_2$ per year.

Process	Number of sources	Emissions ($MtCO_2$/yr)
Fossil Fuels		
Power (coal, gas, oil and others)	4,942	10,539
Cement production	1,175	932
Refineries	638	798
Iron and steel industry	269	646
Petrochemical industry	470	379
Oil and gas processing	N/A	50
Other sources	90	33
Biomass		
Bioethanol and bioenergy	303	91
Total	**7,887**	**13,466**

Source: IPCC SRCCS 2005

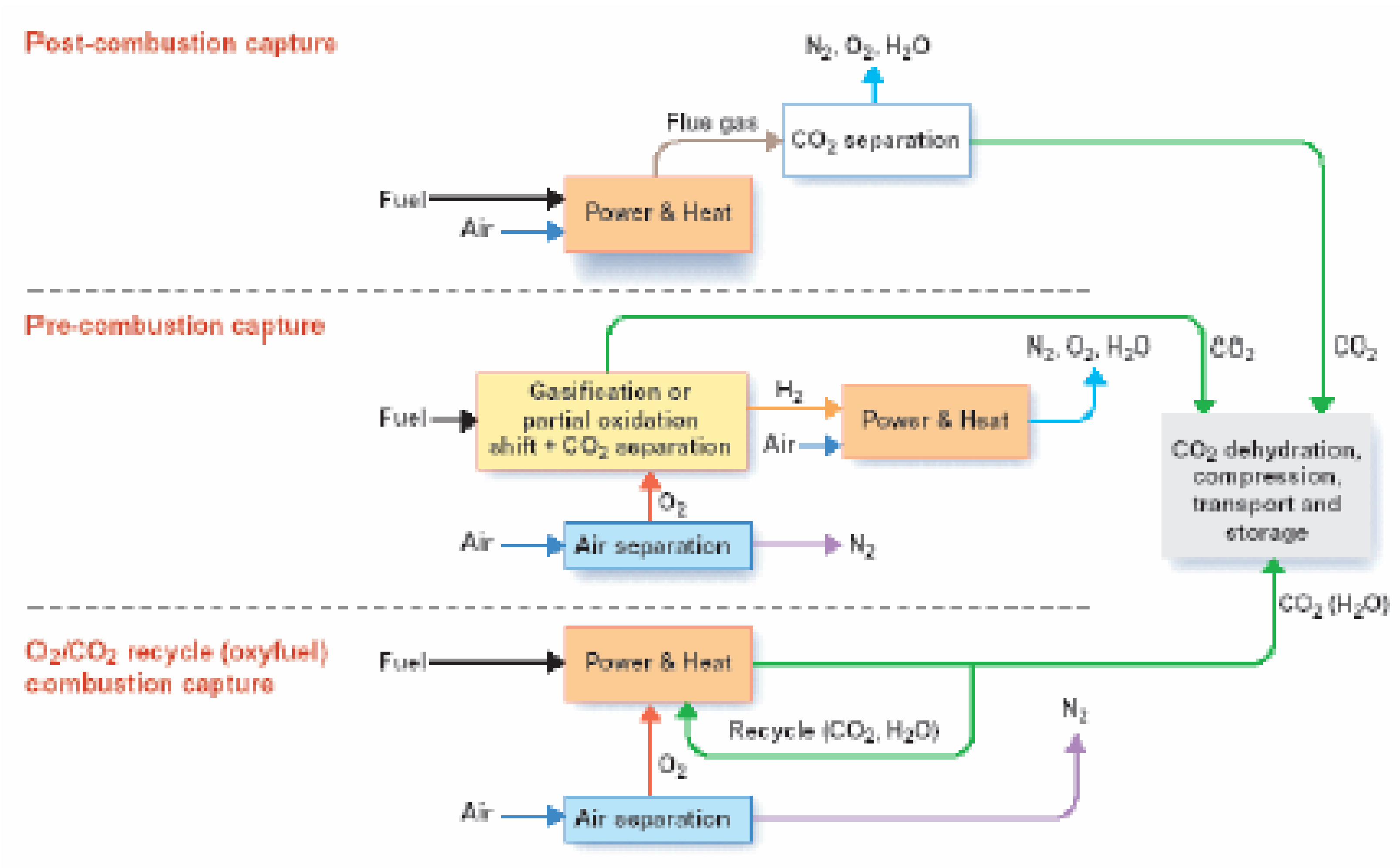

Paris
Strasbourg
Nantes
Lyon
Bordeaux
Montpellier
Toulouse
Nice
Marseille
Main Cities
City
Basement isobath
isobath (m)
datum plane = sea level
Main CO2 Producers
(kT/y)
5,000 - 8,000
2,500 - 5,000
1,000 - 2,500
500 - 1,000
250 - 500
100 - 250

Programme National d'Allocations des Quotas

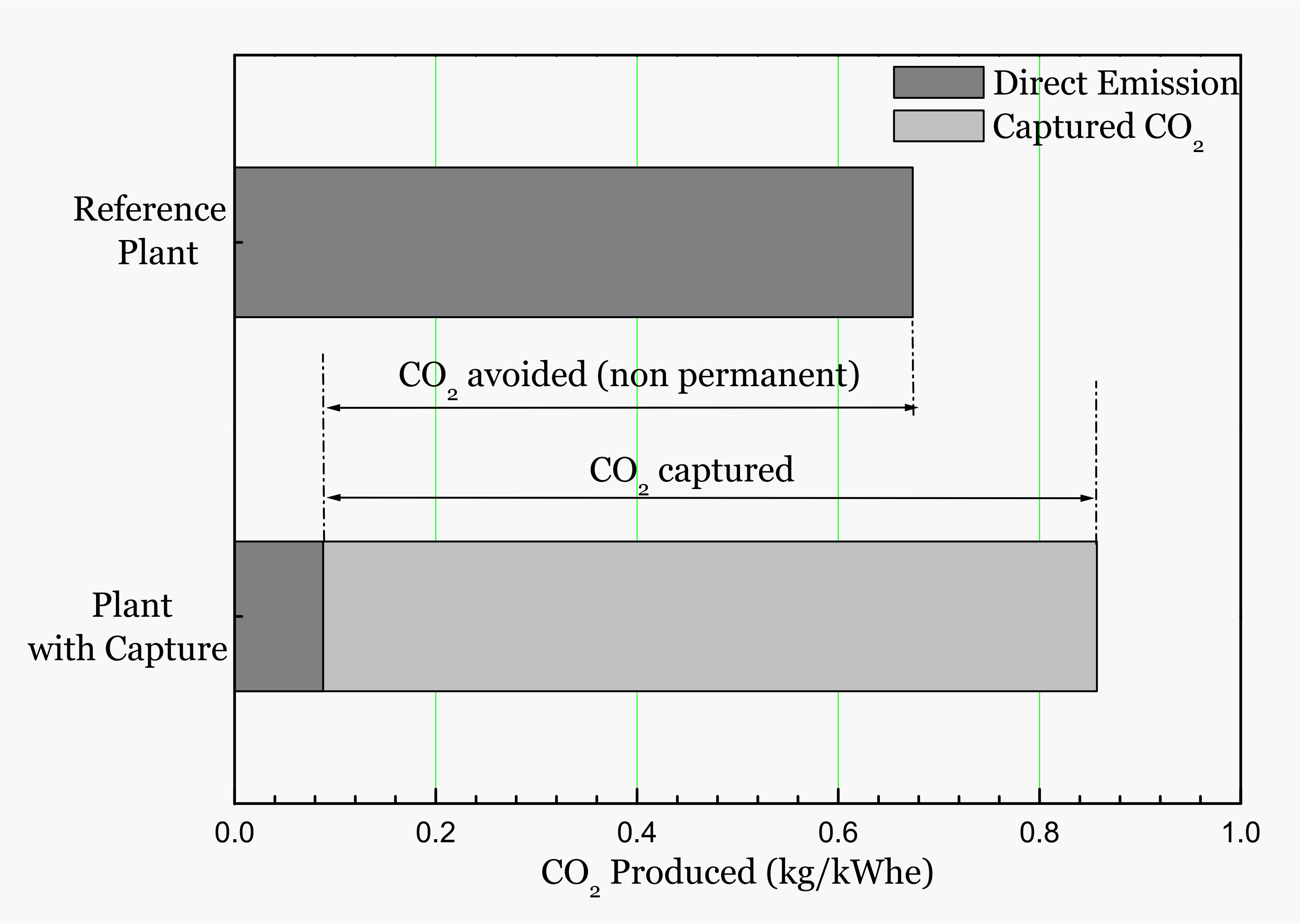
Secteur industriel	*Emissions (Mt CO_2 / an)*
Sidérurgie	28.3
Tuiles	1.3
Chaux ciment	13.3
Chauffage urbain	6.0
Electricité	30.6
Papier	4.2
Raffinage	18.2
Verre	4.1

Source: Ministère de l'industrie (2005)

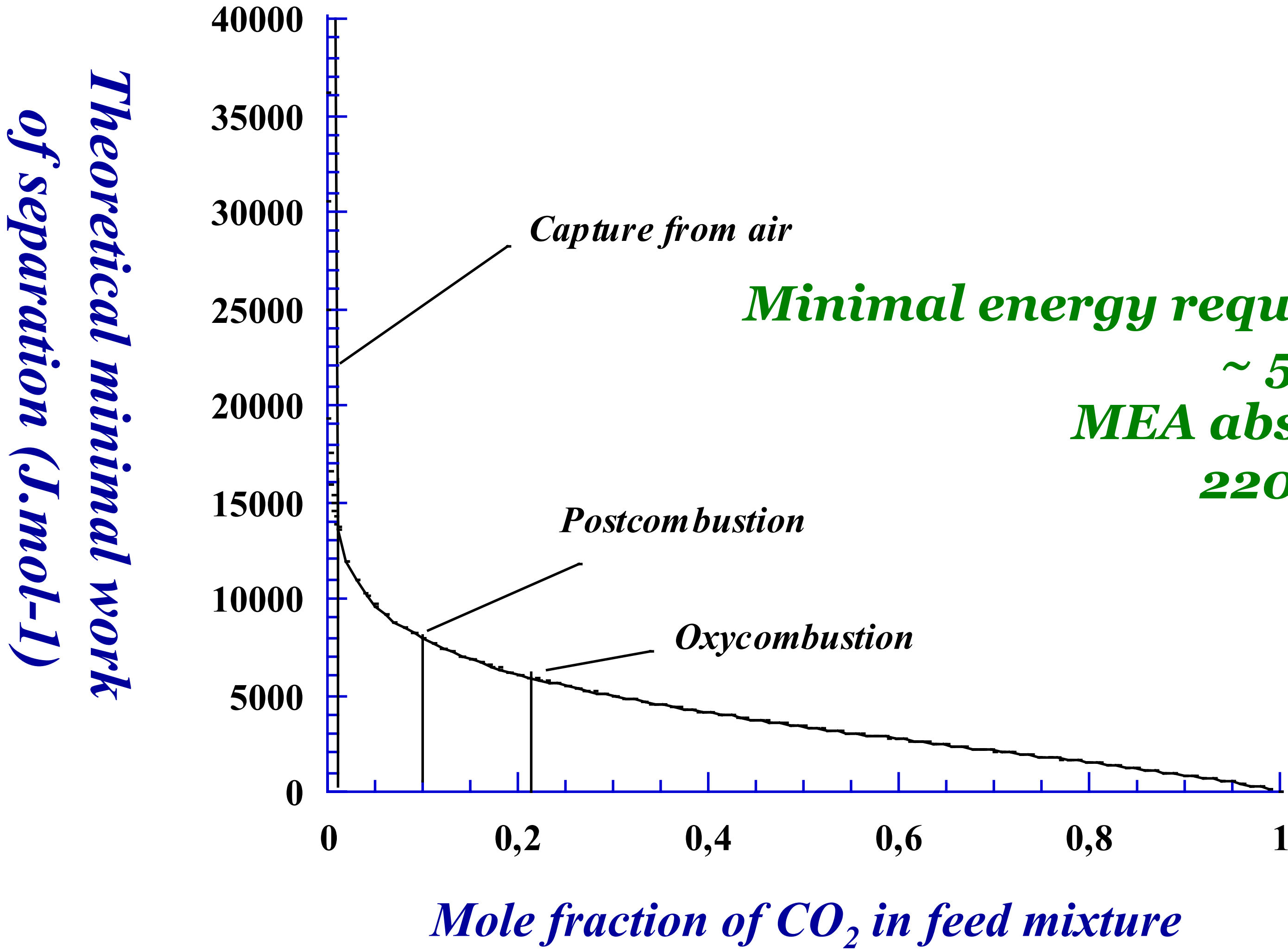
Schémas d'implantation: synoptique



Notion de CO_2 évité



The key issue of CCS: Minimize work of separation….



Minimal energy requirement:
~ 5 kJ.mol^{-1}
MEA absorption:
220 kJ.mol^{-1}

Post combustion capture at a glance…

Key issues:

Achieve CO_2 concentration (> 90%) and recovery (> 80%) under minimal cost

Key variables:

CO_2 content in fume (4-30 % vol)
Pressure (P atm)
Temperature (100 – 250 C)

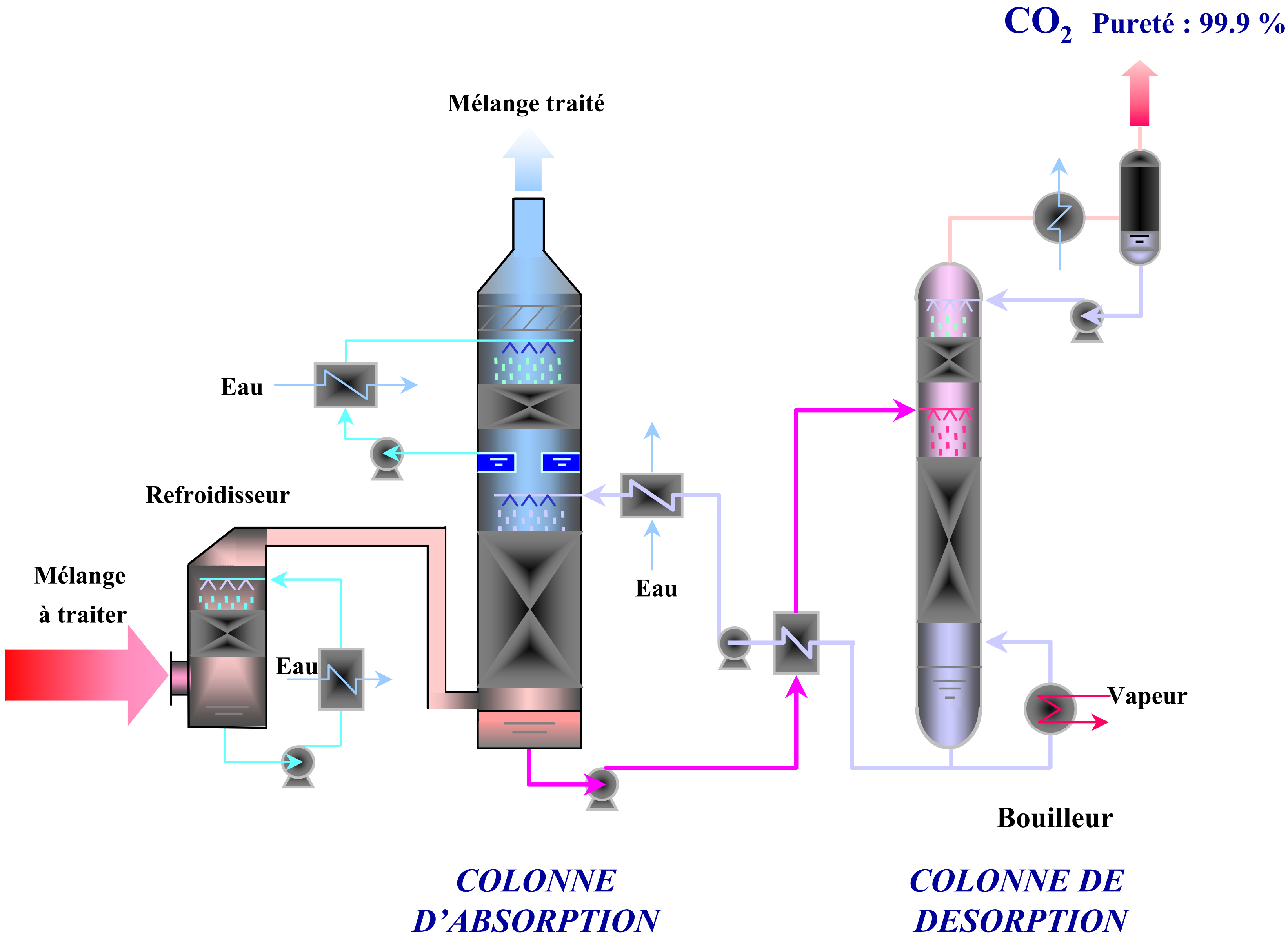
Best available technology:

Chemical gas liquid absorption

Current challenges:

Minimize energy requirement (< 2 GJ / ton CO_2: solvent formulation)
Minimize equipment size (intensification)
Overall cost (UE target: 20 € per ton)

Absorption gaz liquide conventionnelle: Principe



Exemple d'unité industrielle de capture pour synthèse

160 T/D CO_2 Capture Plant

Client : Petronas Fertilizer (Keda) Sdn. Bhd.

•Location : Kedah Darul Aman, Malaysia

•Feed Gas : Steam Reformer Flue Gas

•Capacity : Flue Gas 47,000 Nm3/H
(Max. Capacity = 210 T/D)

•Use of CO_2 : Urea Production

•Start Up : October 1999

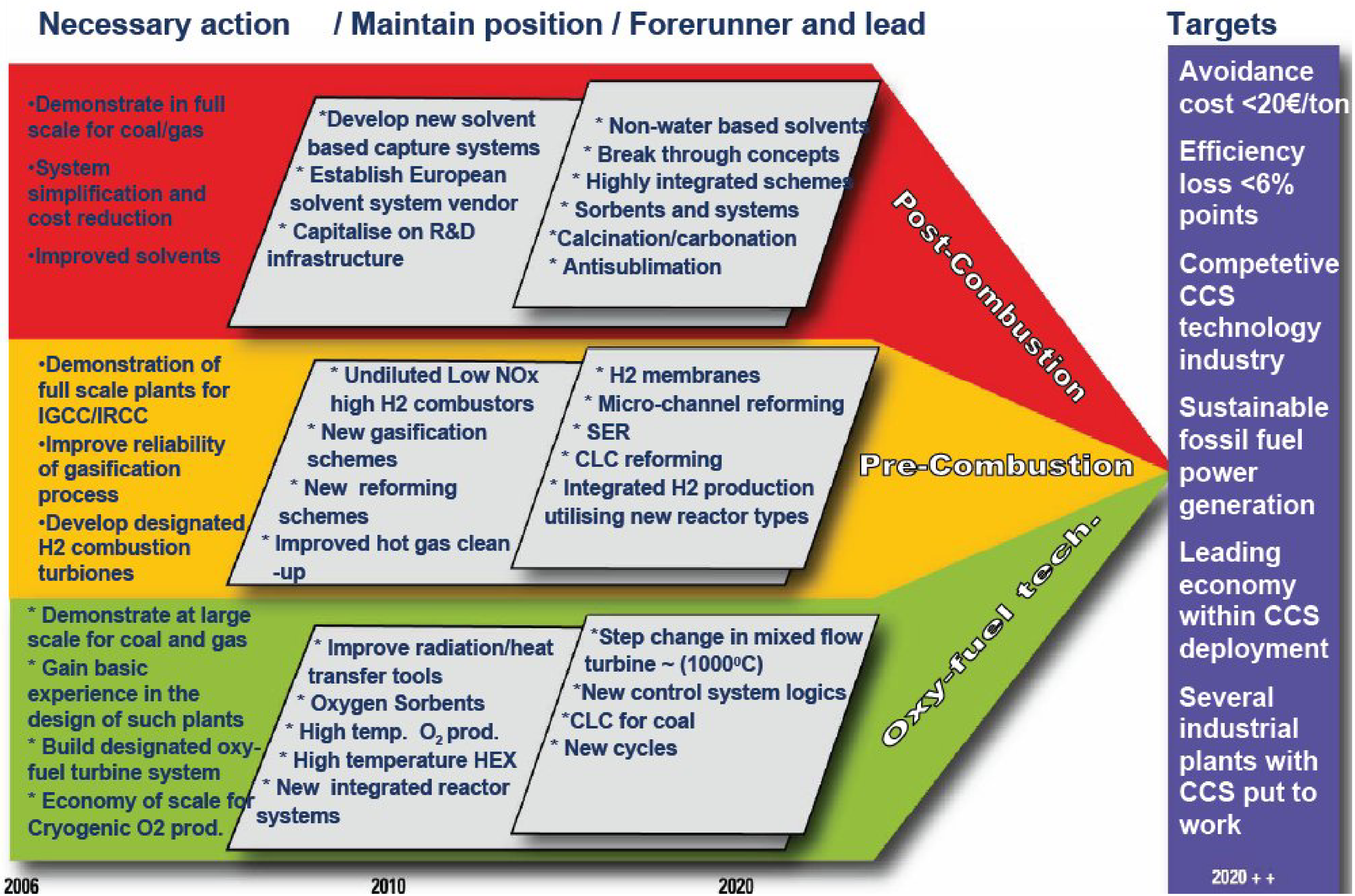
Elsam Esbjerg Power unit

CCS: Cost analysis

	CCS system components	Cost range
Capture	Capture from a coal- or gas-fired power plant	15–75 US$/t$CO_2$ net captured
	Capture from hydrogen and ammonia production or gas processing	5–55 US$/t$CO_2$ net captured
	Capture from other industrial sources	25–115 US$/t$CO_2$ net captured
Transport	Transport	1–8 US$/t$CO_2$ transported
Storage	Geological storage[a]	0.5–8 US$/t$CO_2$ net injected
	Geological storage: monitoring and verification	0.1–0.3 US$/t$CO_2$ injected
	Ocean storage	5–30 US$/t$CO_2$ net injected
	Mineral carbonation	50–100 US$/t$CO_2$ net mineralized

Source: IPCC SRCCS 2005

- *Broad range of cost estimates (7-220 €/t)!*
- *Capture step accounts for 60 to 80%*


Necessary action / Maintain position / Forerunner and lead
Targets
•Demonstrate in full scale for coal/gas
•System simplification and cost reduction
•Improved solvents
*Develop new solvent based capture systems
* Establish European solvent system vendor
* Capitalise on R&D infrastructure
* Non-water based solvents
* Break through concepts
* Highly integrated schemes
* Sorbents and systems
*Calcination/carbonation
* Antisublimation
Post-Combustion
•Demonstration of full scale plants for IGCC/IRCC
•Improve reliability of gasification process
•Develop designated H2 combustion turbiones
* Undiluted Low NOx high H2 combustors
* New gasification schemes
* New reforming schemes
* Improved hot gas clean -up
* H2 membranes
* Micro-channel reforming
* SER
* CLC reforming
* Integrated H2 production utilising new reactor types
Pre-Combustion
* Demonstrate at large scale for coal and gas
* Gain basic experience in the design of such plants
* Build designated oxy-fuel turbine system
* Economy of scale for Cryogenic O2 prod.
* Improve radiation/heat transfer tools
* Oxygen Sorbents
* High temp. O_2 prod.
* High temperature HEX
* New integrated reactor systems
*Step change in mixed flow turbine ~ (1000°C)
*New control system logics
*CLC for coal
* New cycles
Oxy-fuel tech.
2006
2010
2020
Avoidance cost <20€/ton
Efficiency loss <6% points
Competetive CCS technology industry
Sustainable fossil fuel power generation
Leading economy within CCS deployment
Several industrial plants with CCS put to work
2020 + +

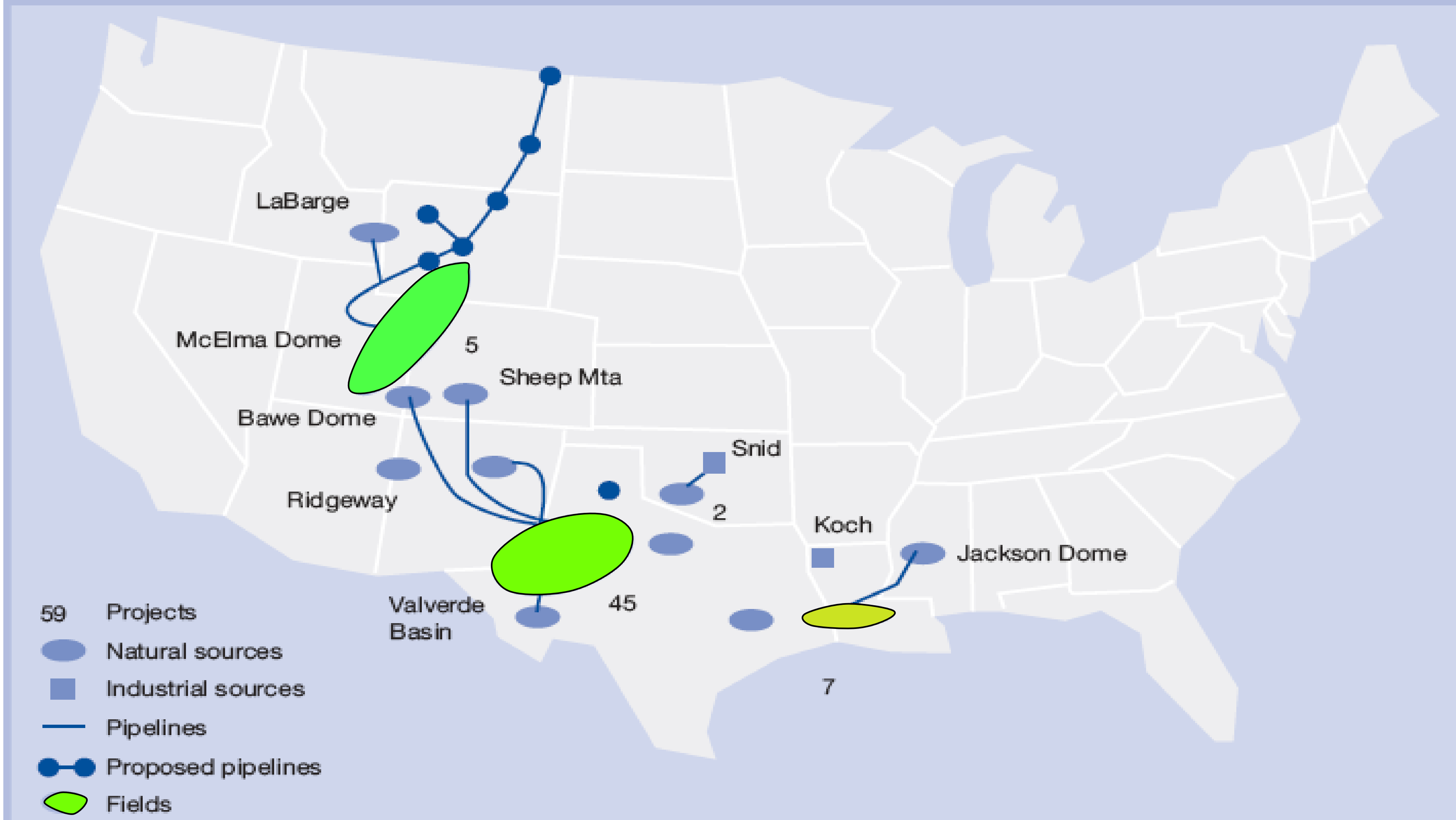
Transport: Bateau

Transport: Conduite (carboduc)

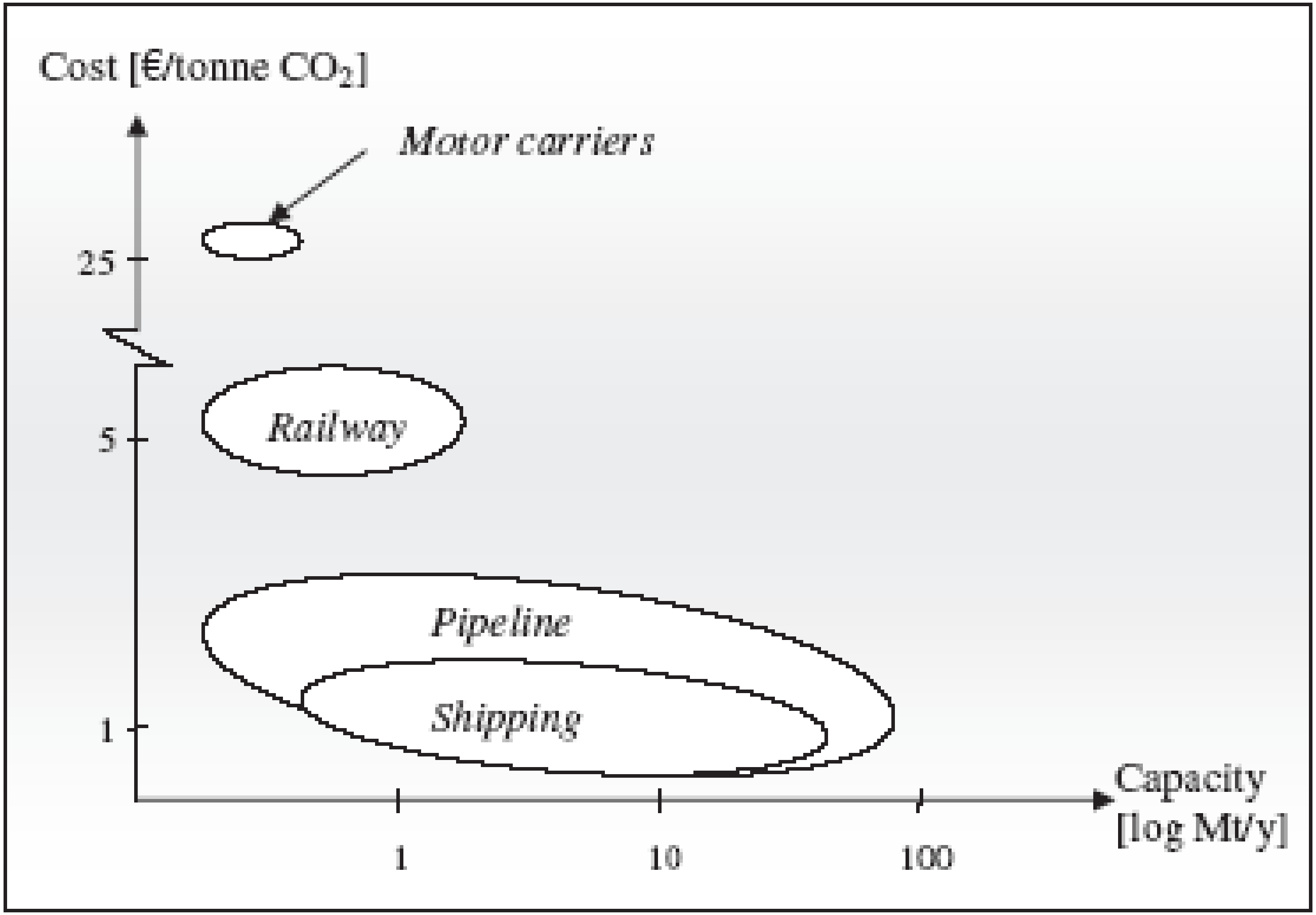
Contrainte de pureté pour acier au carbone: eau 150-500 ppm

Transport du dioxyde de carbone: carboducs

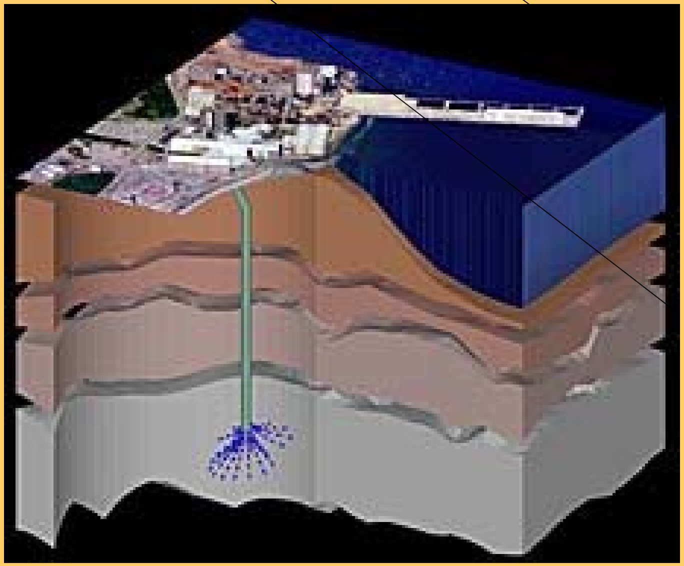
Le transport de CO_2 aux Etats-Unis (principalement de gisements naturels vers des champs de pétrole, pour des opérations de récupération assistée). *CO_2 transport in the USA (mainly from natural sources to oil fields, for enhanced oil recovery).*



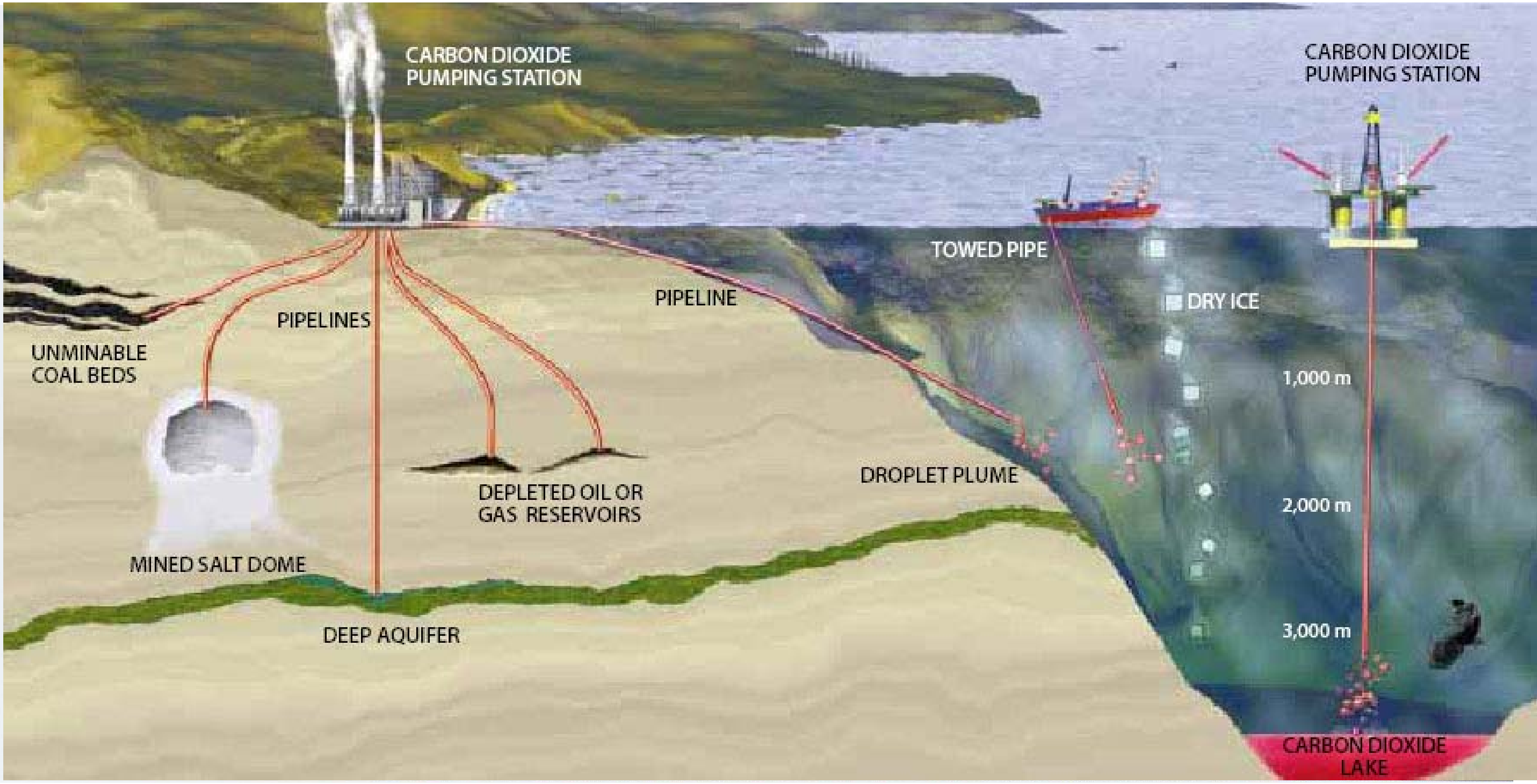
Transportation costs



Séquestration géologique: état de l'art & options



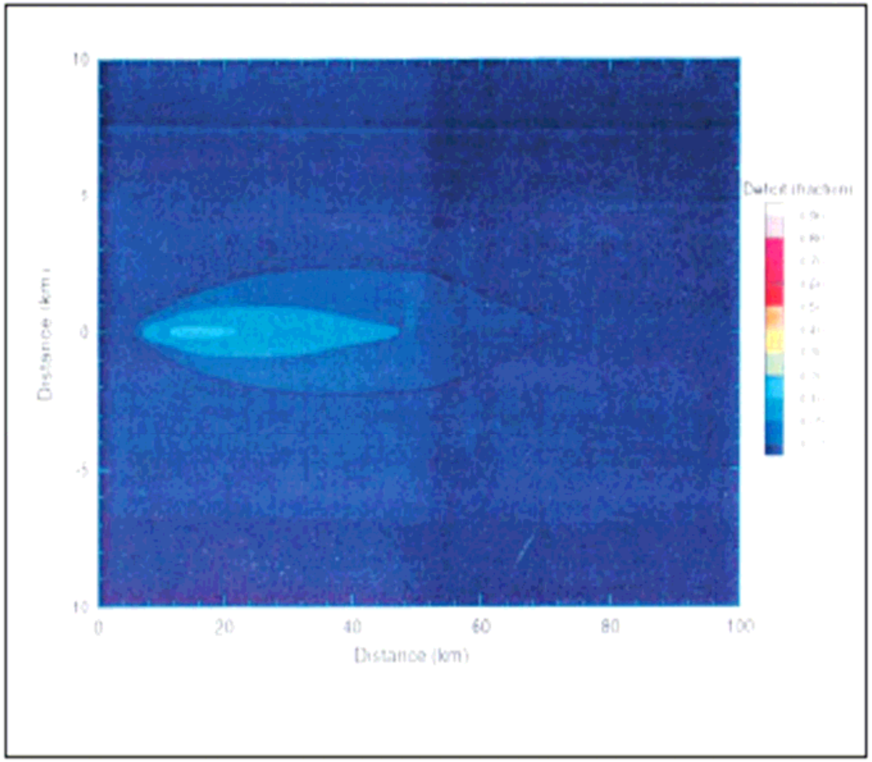
Capturer et séquestrer le CO_2



Stockage océanique profond

Fig 6
Reduction in pH resulting from a plume

(Calculation for a single power plant. Reprinted with permission from Adams and Herzog, in "Environmental Impacts of Ocean Disposal of CO_2, 1996)

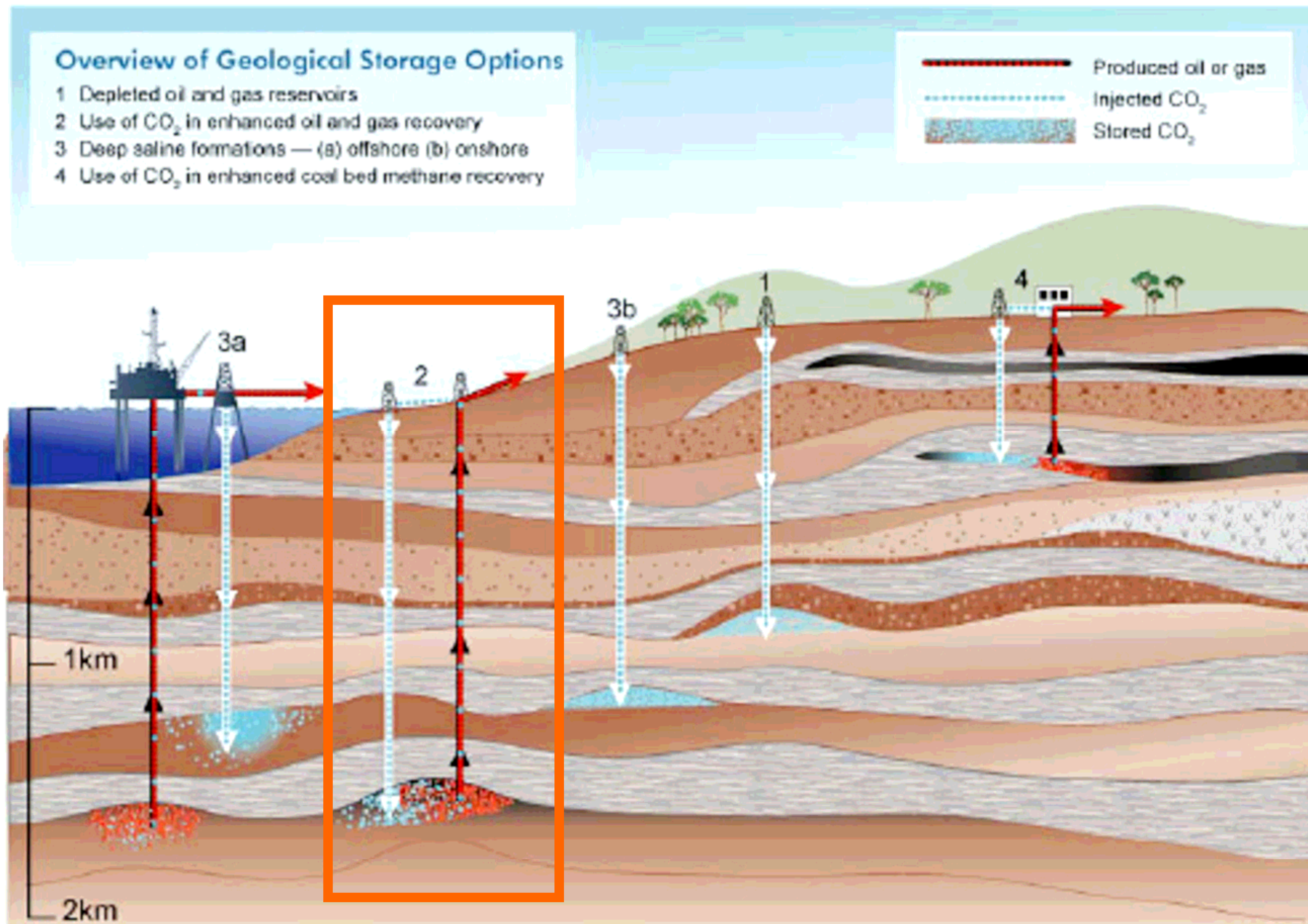


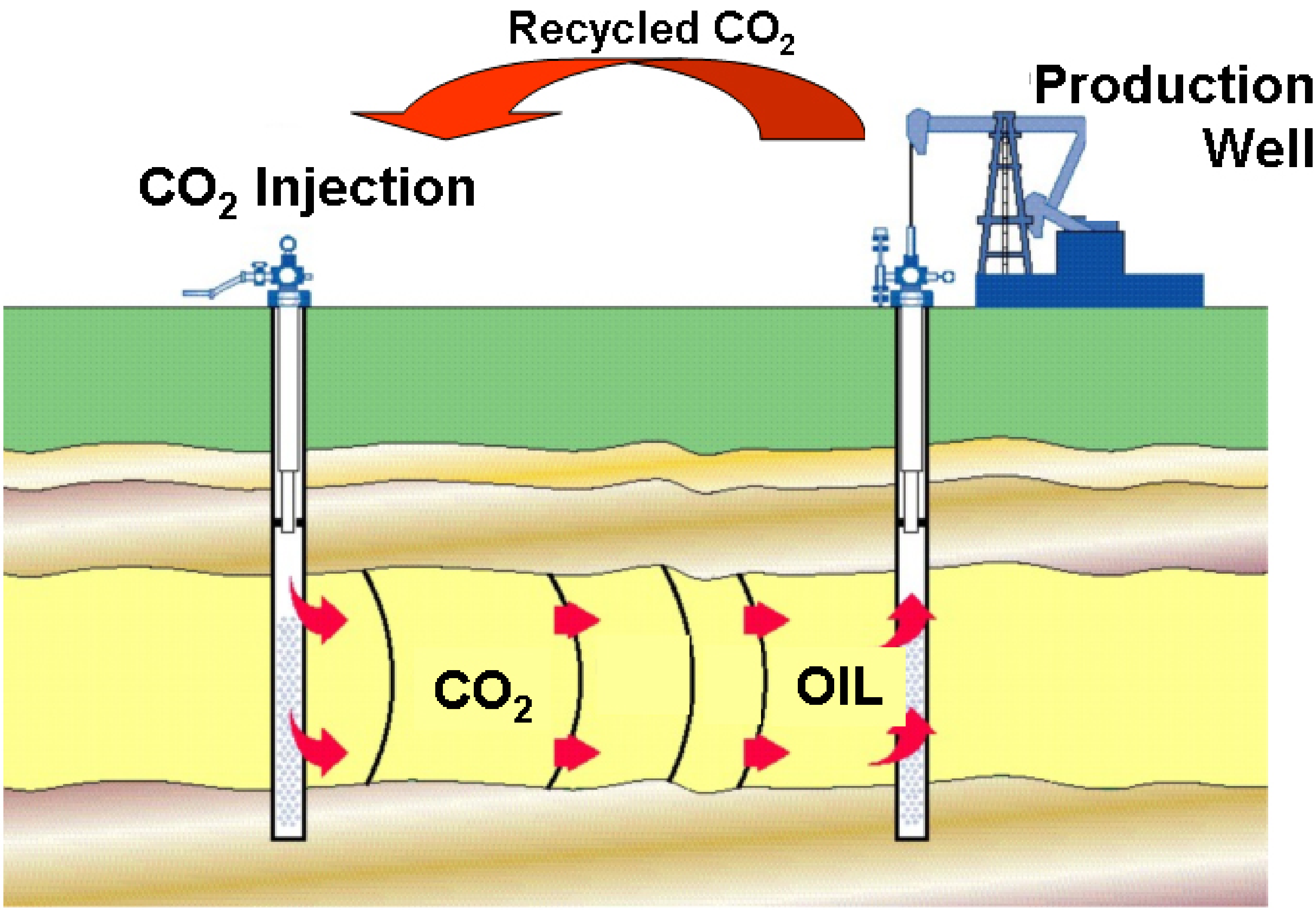
($Coryphaenoides$ $acrolepsis$) feeding close to CO_2 being released into a 20 inch diameter corral on the sea floor at 3600m depth; the fish is apparently unperturbed, however penetration of the thin boundary layer in direct contact with the CO_2 would result in a sharp avoidance reaction.

Photo © 2001 MBARI

- *Convention de Londres*
- *OSPAR*

Séquestration: Les différentes options





Recycled CO2
Production
Well
CO2 Injection
CO2
OIL

CO_2 Infrastructure Studies
Natural CO_2 fields in southwest U.S.

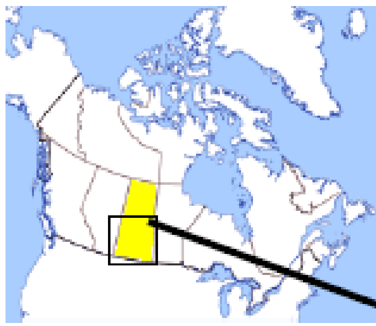
- ***McElmo Dome:***

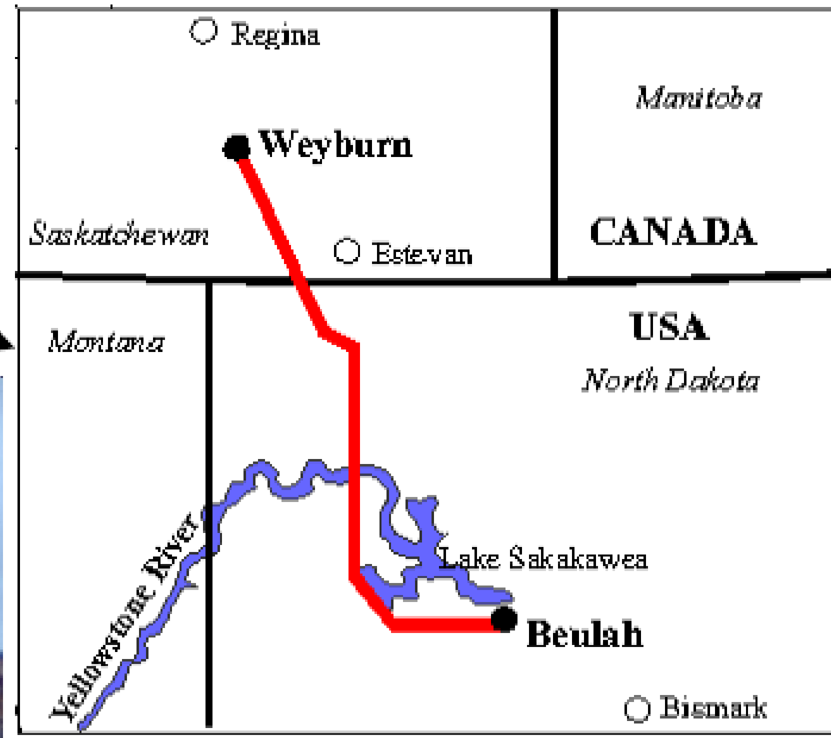
0.4Gt(C) in place

- ***Pipeline from McElmo to Permian Basin: 800 km***

IEA Weyburn CO_2 Monitoring and Storage Project

Stockage de CO_2 dans le champ pétrolier de Weyburn, combiné à la récupération assistée de pétrole





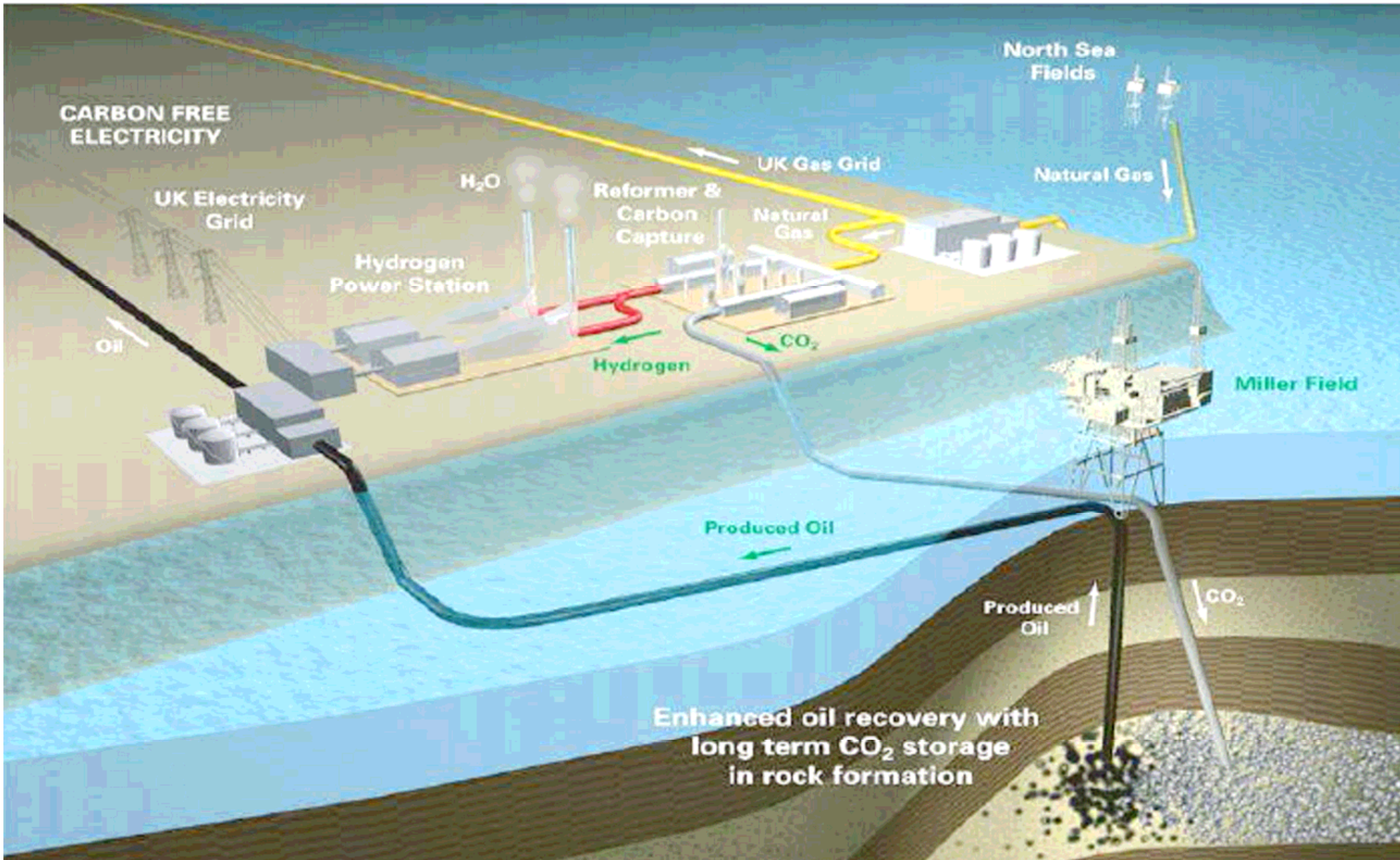
1,8 Mt/an depuis sept. 2000

Pipeline 330 km

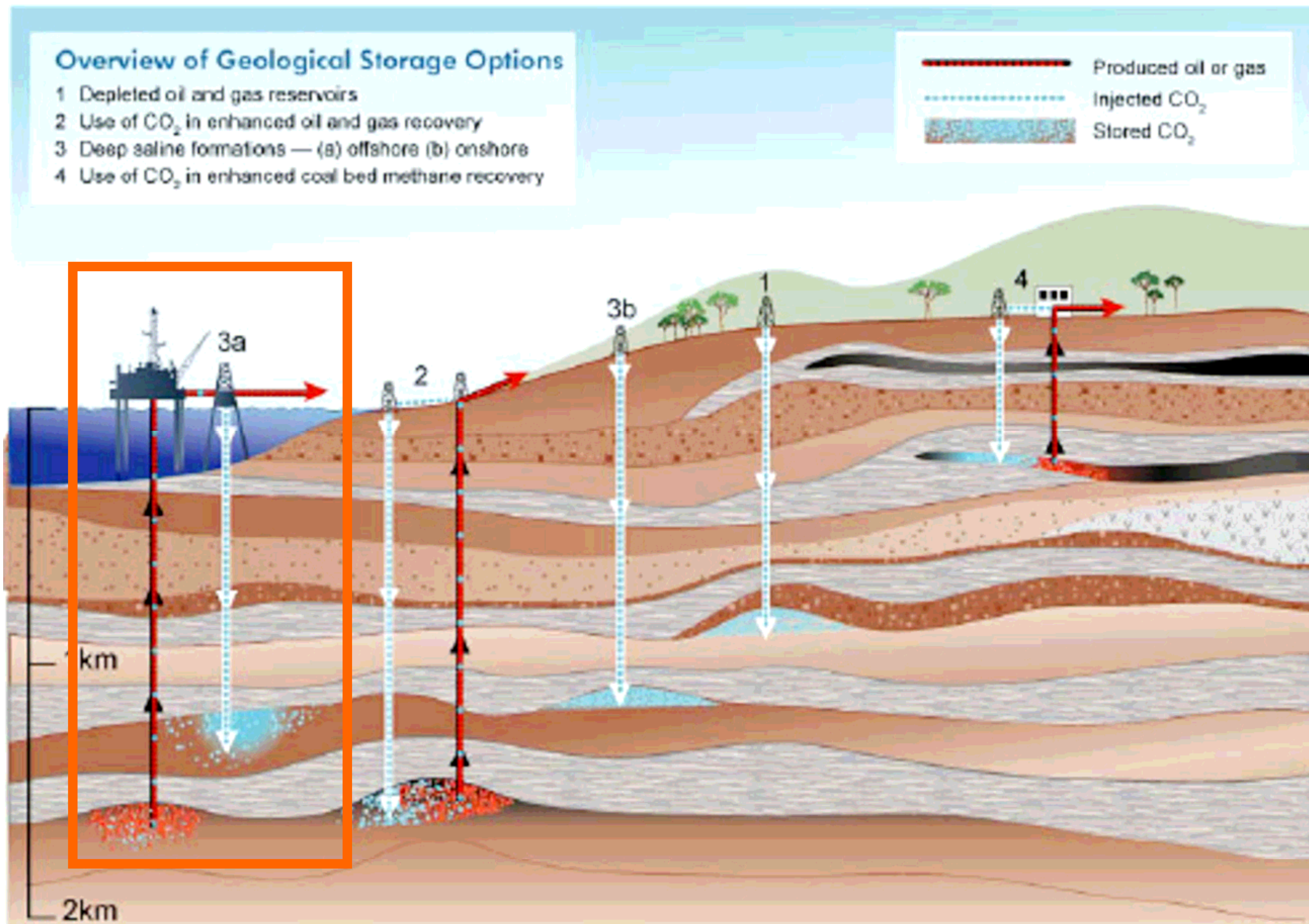
5000 t CO_2 / jour

brgm

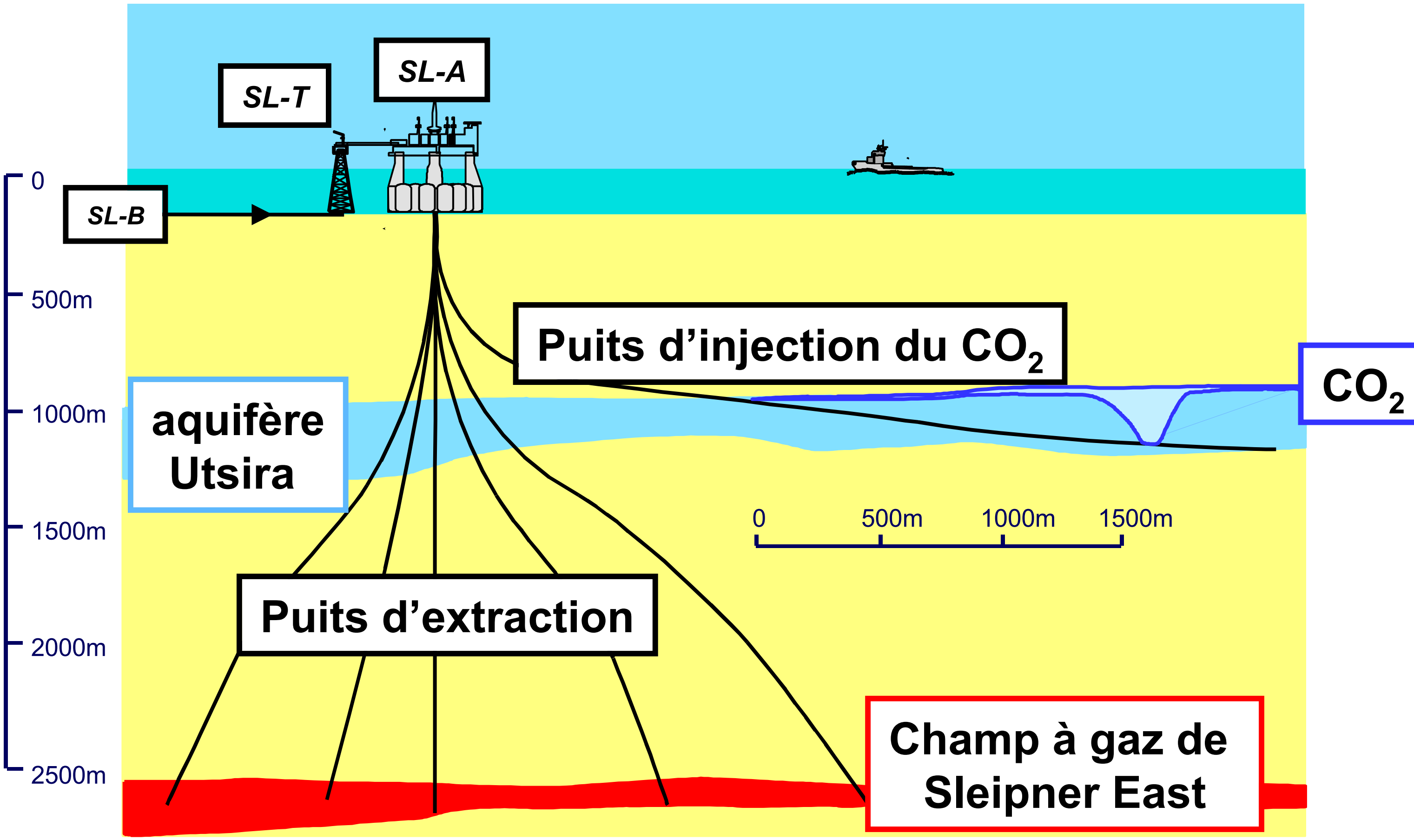
The DF-1 (Decarbonised Fossil Fuels) Project



Séquestration: Les différentes options




Sleipner



- Puits injecteur horizontal, à 3 km des autres puits
- Injection sous une structure
- Aquifère peu profond

S. Thibeau, TOTAL, Fête Science 2005

Séquestration: Sleipner

STATOIL

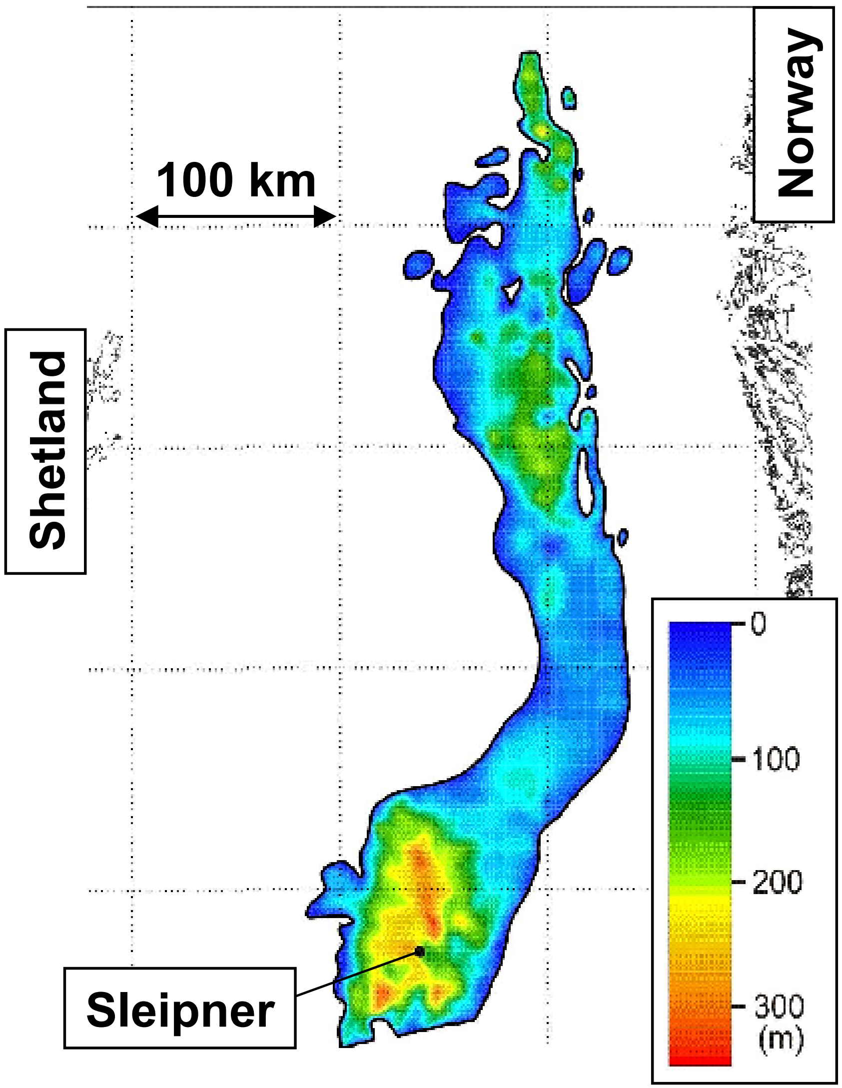
CAPTURE AND REINJECTION OF CO_2
IN A SALINE AQUIFER AT SLEIPNER

Paramètres de l'aquifère

- extension : 400 km x 50 km
- profondeur : 500-1000 m
- épaisseur : 100 à 300 m
- porosité : 35 à 40%

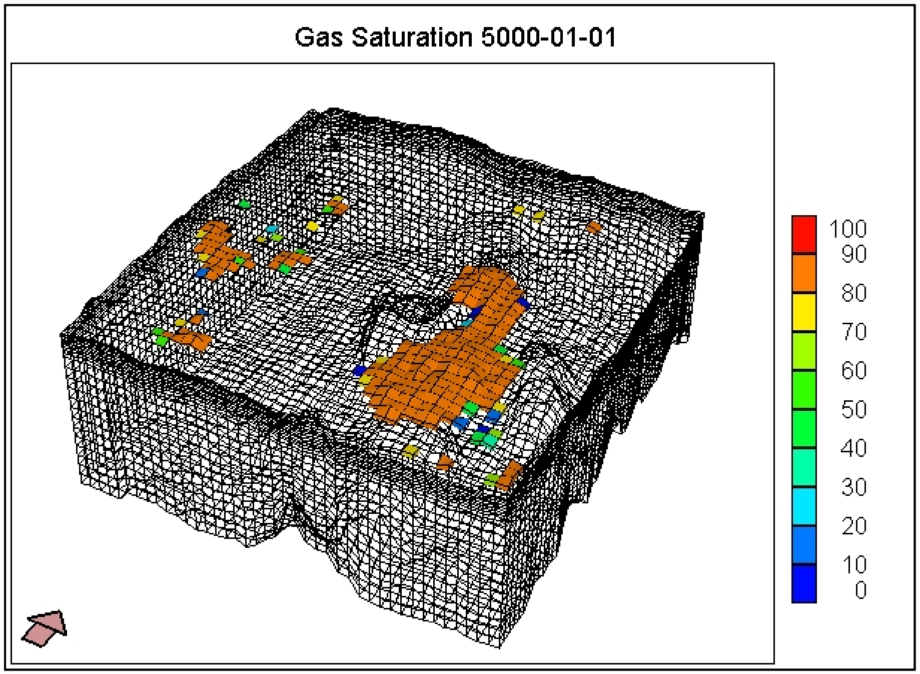
Volumes

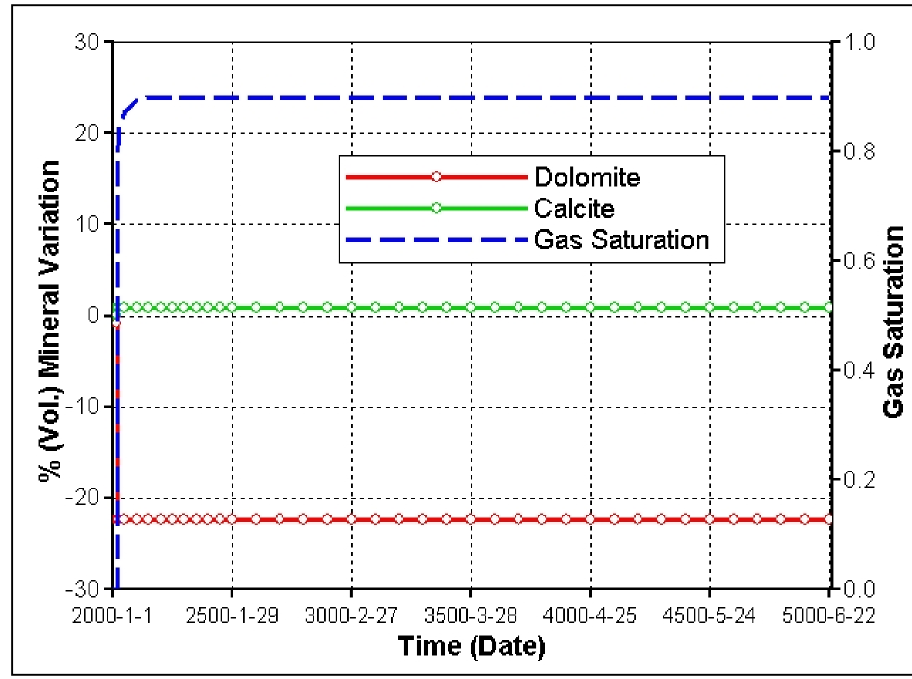
- poreux : ~ 600 Gm^3
- pièges : ~ 1,5 Gm^3
- capacité : > 500 Mt de CO_2
- (Sleipner : ~ 25 Mt de CO_2)



S. Thibeau, TOTAL, Fête Science 2005

Migration du CO_2 au toit de la structure

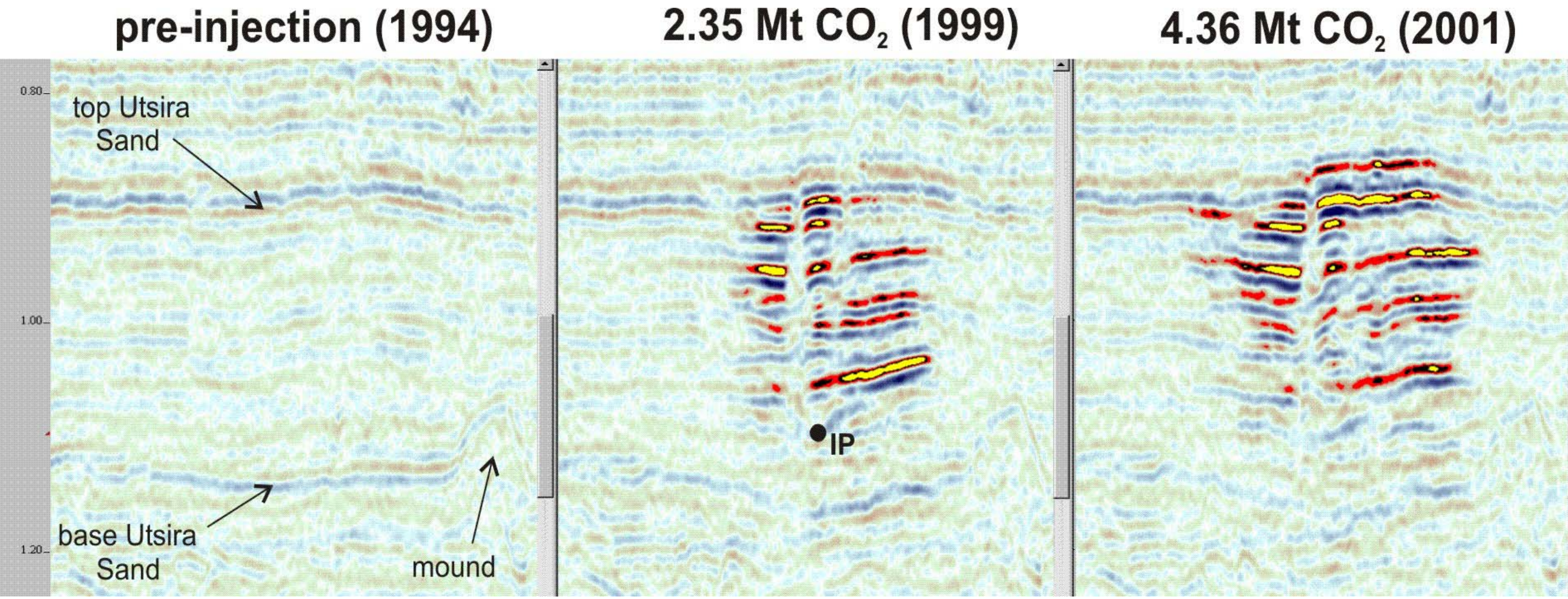




- Faible réactivité de la roche (carbonates, feldspaths, plagioclases)
- chute de pH, point froid, assèchement

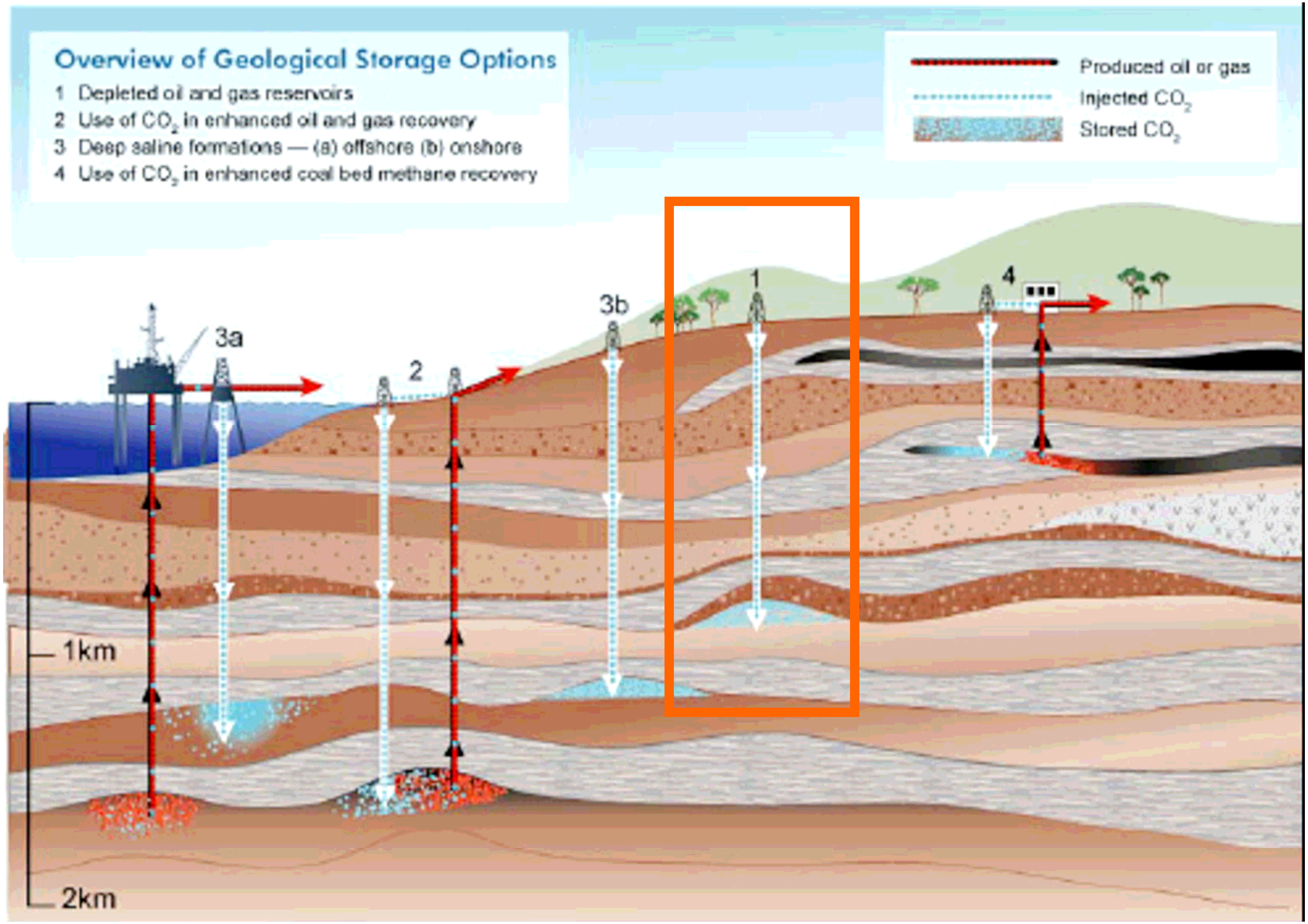
S. Thibeau, TOTAL, Fête Science 2005

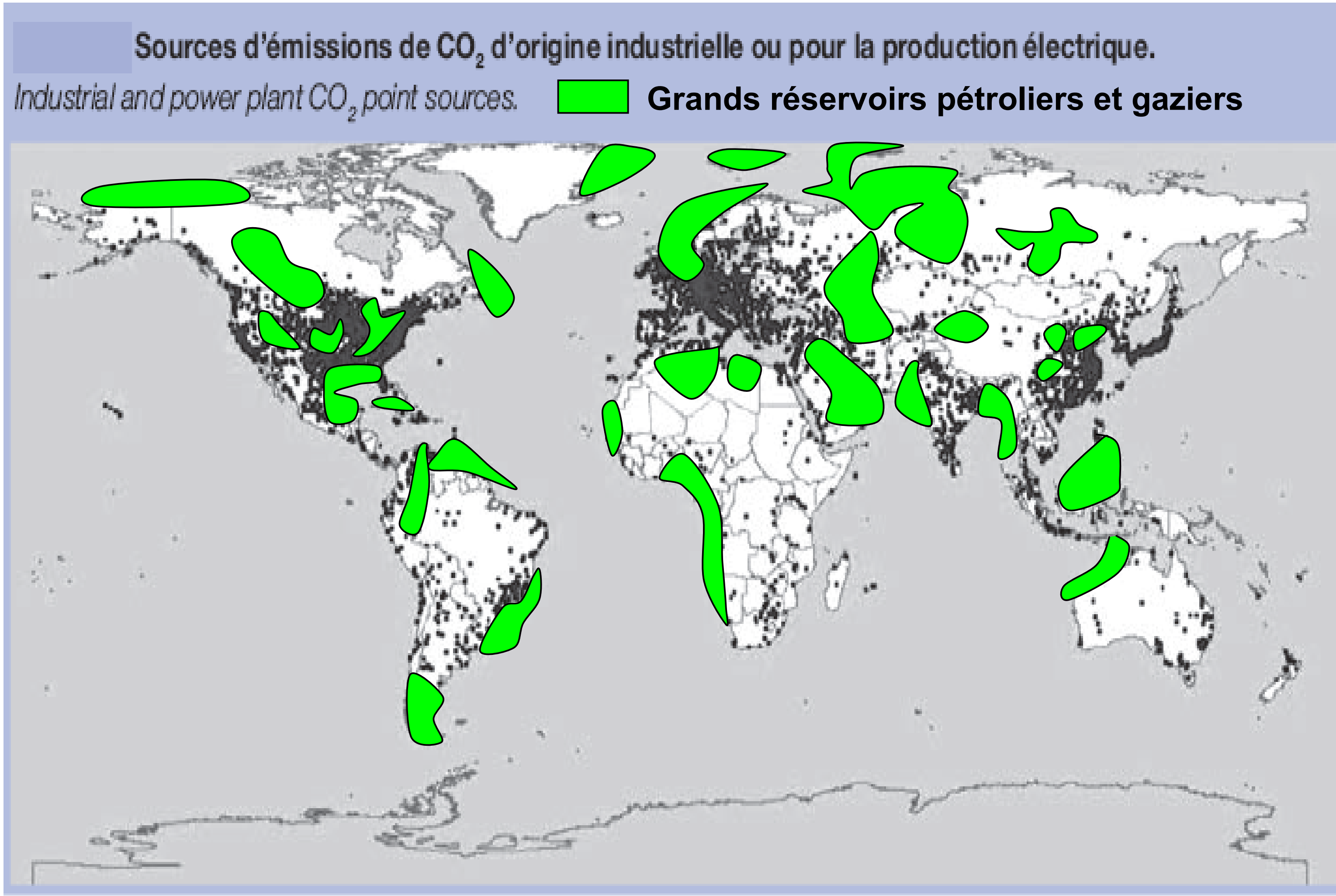
Monitoring sismique (Offshore-Sleipner)



- Démonstration faite de la possibilité de suivre la migration du CO_2 dans l'aquifère d'injection
- Absence de migration détectable vers la couverture
- Difficulté de quantifier la quantité de CO_2 injectée

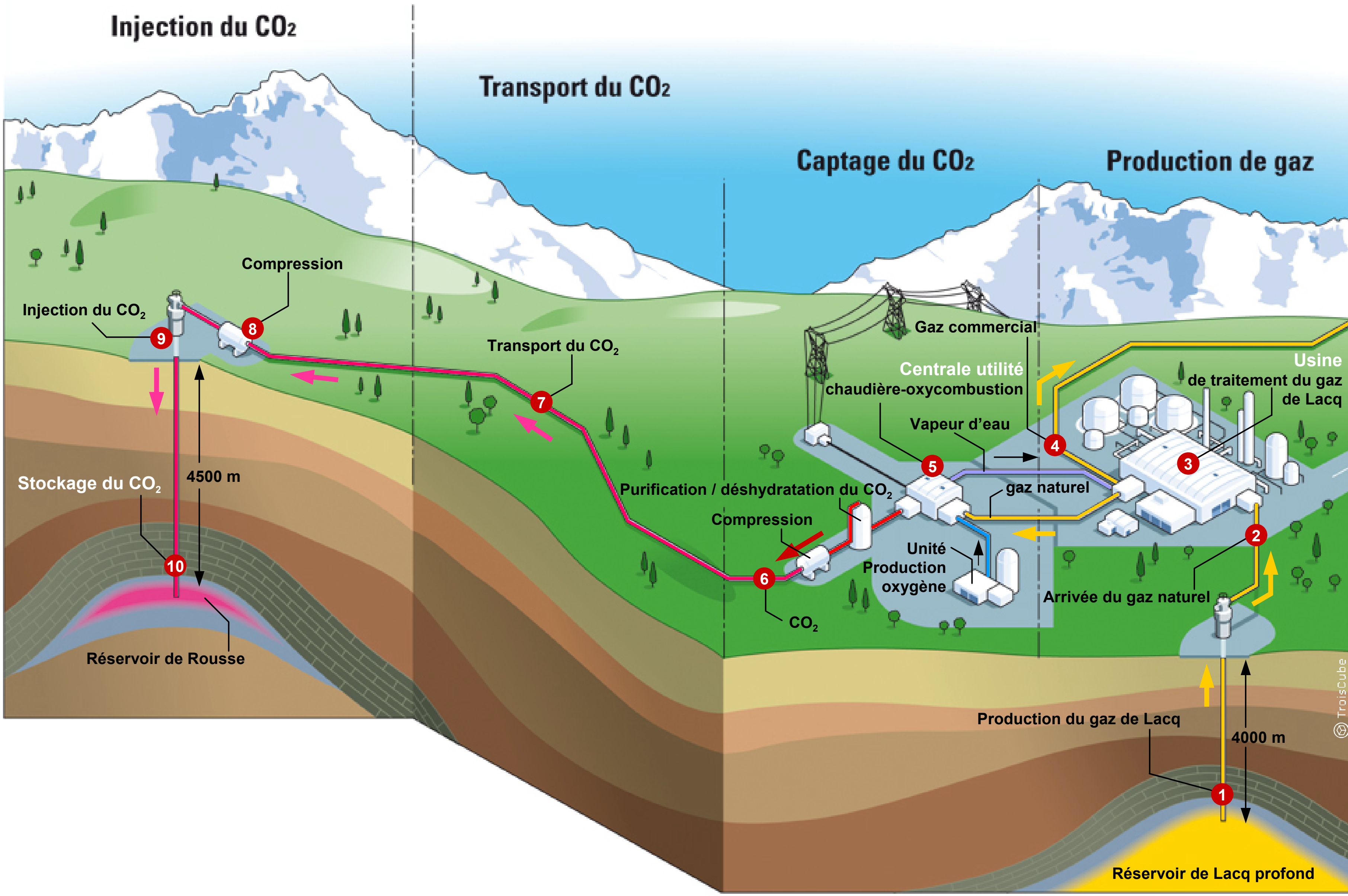
Séquestration: Les différentes options





IDDRI-2005 http://www.iddri.org

Pilote CO_2 dans le bassin de Lacq

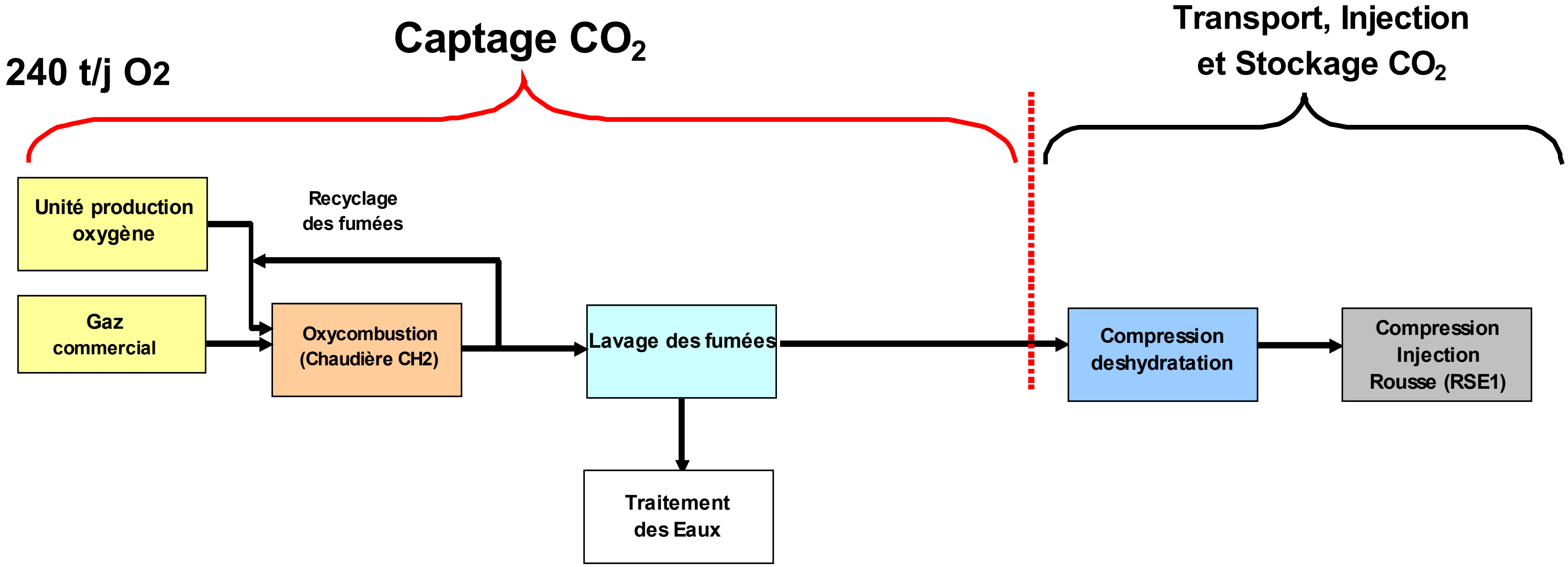


Projet CCS Lacq: Synoptique

Puissance chaudière CH2 convertie = 30 MW - 40t/h de vapeur

Débit de gaz injecté = 100 000 Sm3/j

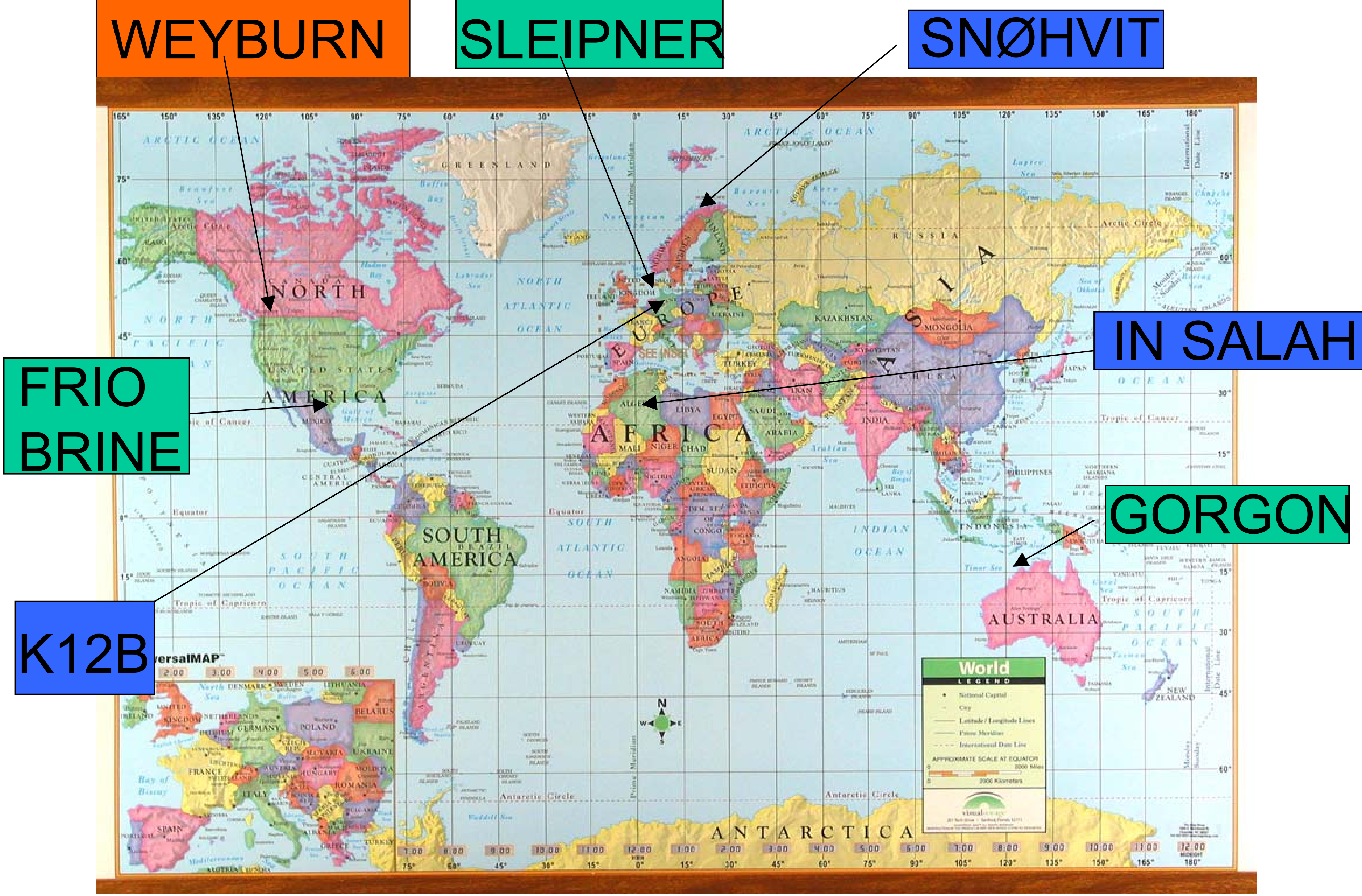
Total injecté sur 2 ans = 73 Mm3 (~150 kt CO_2)



Project name	Country	Injection start (year)	Approximate average daily injection rate (tCO_2/day)	Total (planned) storage (tCO_2)	Storage reservoir type
Weyburn	Canada	2000	3,000-5,000	20,000,000	EOR
In Salah	Algeria	2004	3,000-4,000	17,000,000	Gas field
Sleipner	Norway	1996	3,000	20,000,000	Saline formationn
K12B	Netherlands	2004	100 (1,000 planned for 2006+)	8,000,000	Enhanced Gas Recovery
Frio	U.S.A.	2004	177	1600	Saline formation
Fenn Big Valley	Canada	1998	50	200	ECBM
Qinshui Basin	China	2003	30	150	ECBM
Yubari	Japan	2004	10	200	ECBM
Recopol	Poland	2003	1	10	ECBM
Gorgon (Planned)	Australia	~2009	10,000	unknown	Saline formation
Snohvit (Planned)	Norway	2006	2,000	unknown	Saline formation

Reservoir type	Lower estimate of storage capacity ($GtCO_2$)	Upper estimate of storage capacity ($GtCO_2$)
Oil and gas fields	675[2]	900[2]
Unminable coal seams (ECBM)	3–15	200
Deep saline formations	1,000	Uncertain, but possibly 10^4

Source: IPCC SRCCS 2005

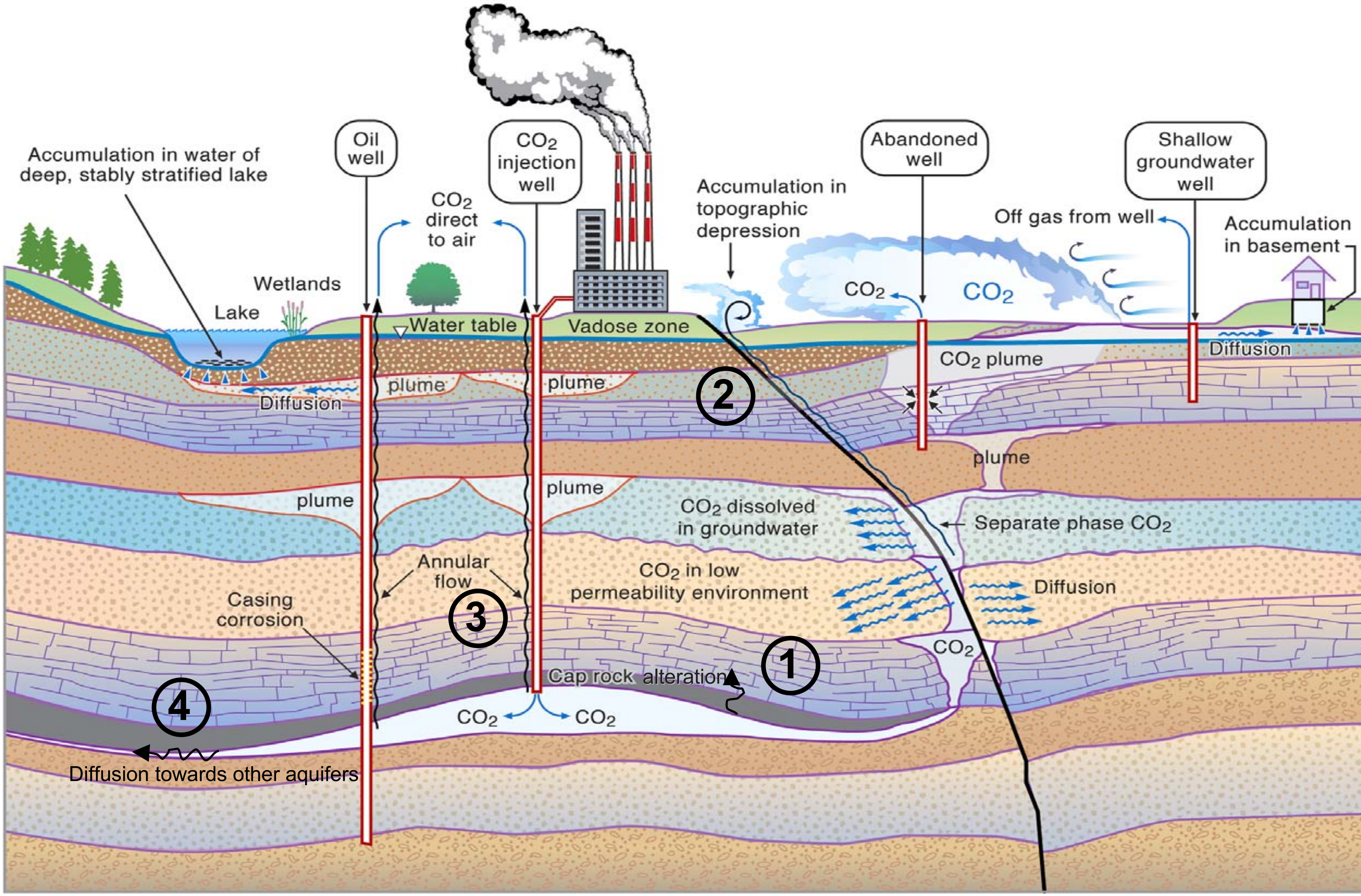


Saline aquifers

Gaz recovery

Oil recoverey (EOR)

Stockage profond: Inventaire et évaluation des risques



Réactivité des ciments de puits lors d'une injection de gaz acides (H_2S et CO_2) 200°C et 500 bar

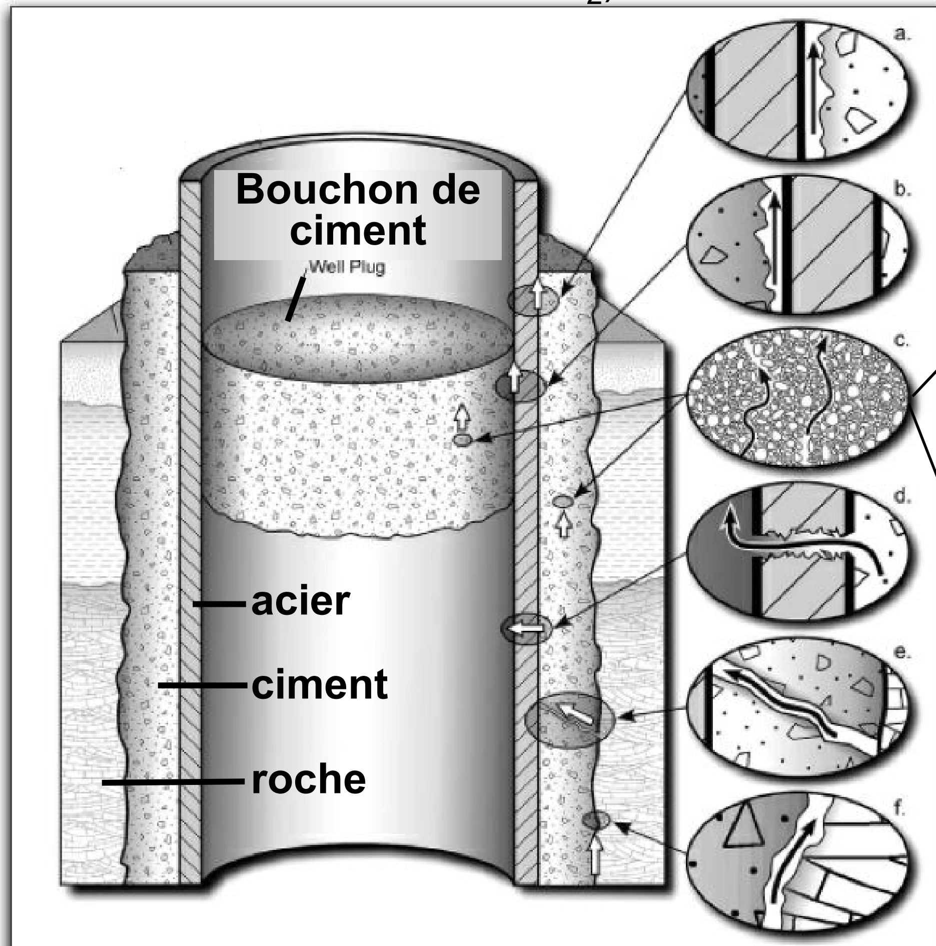
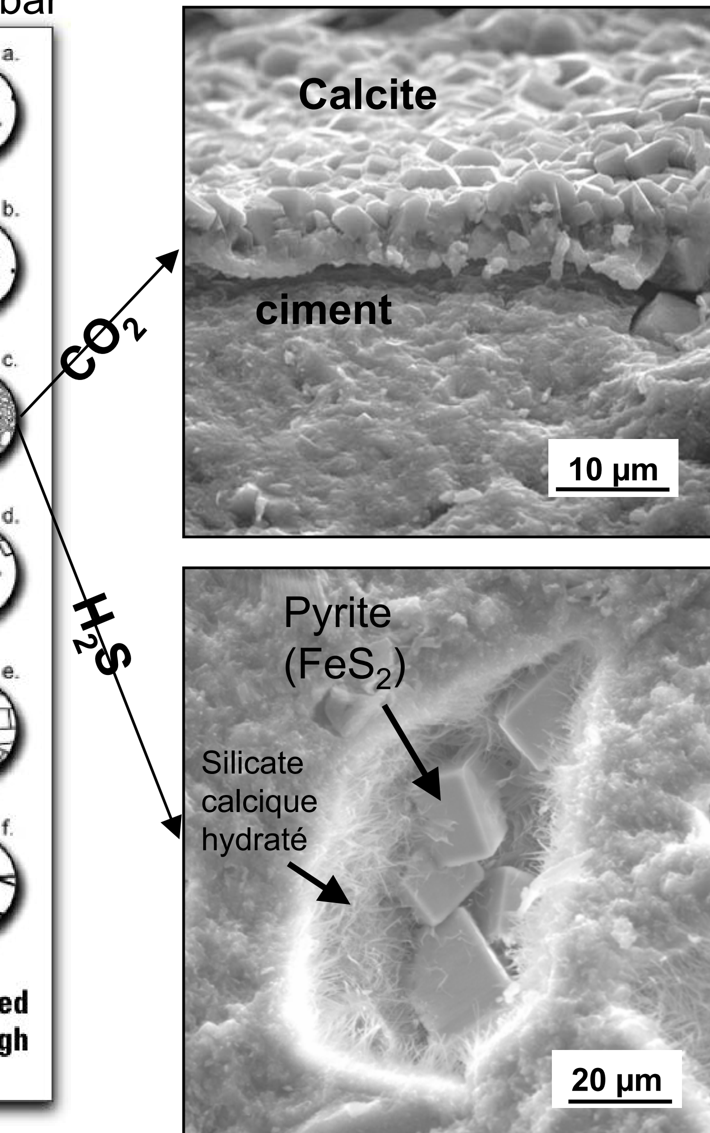


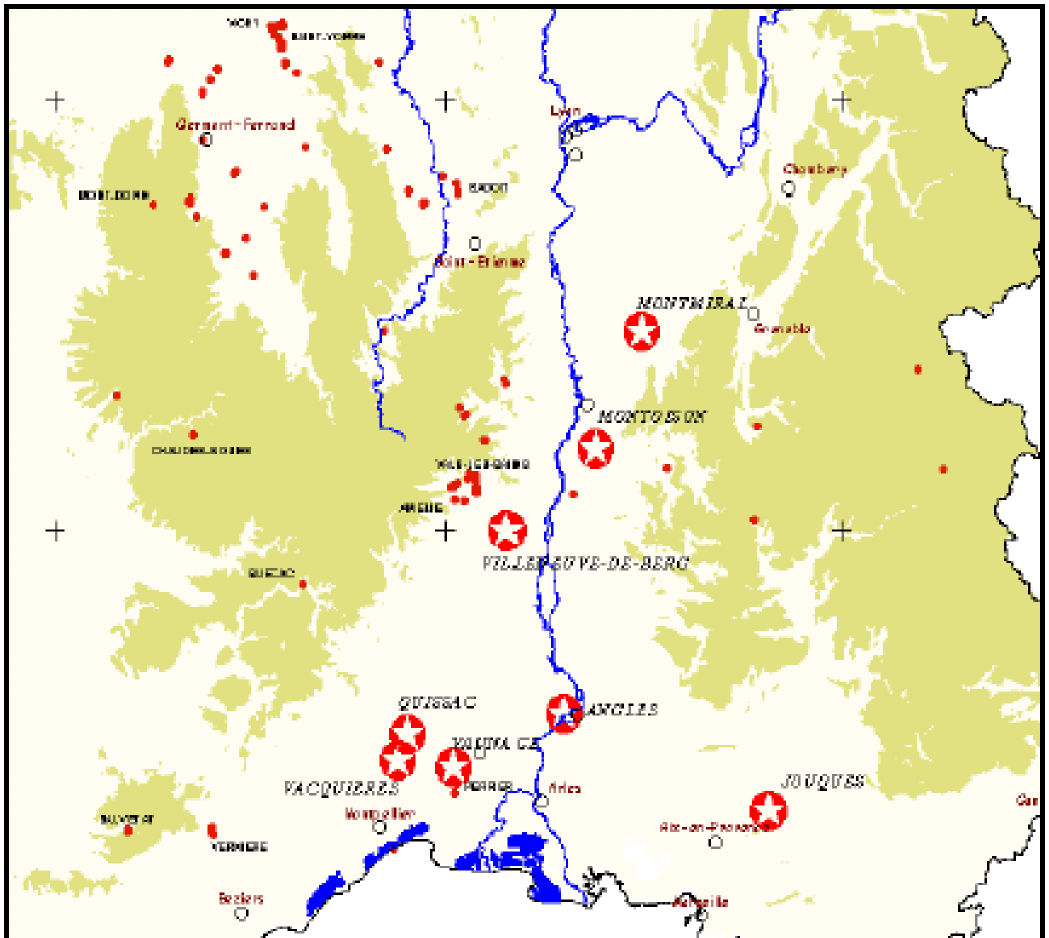
FIGURE 1. Potential pathways for leakage along an abandoned well, including flow along material interfaces (a, b, f) and through well cements and casing (c, d, e).

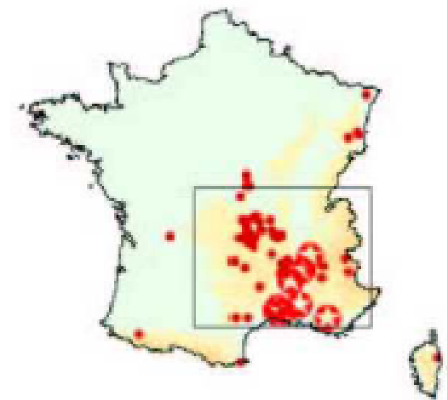


Nordbotten et al., *Environ. Sci. Technol.* 2005

Stockage durable du CO_2: analogues naturels…

La province carbogazeuse française

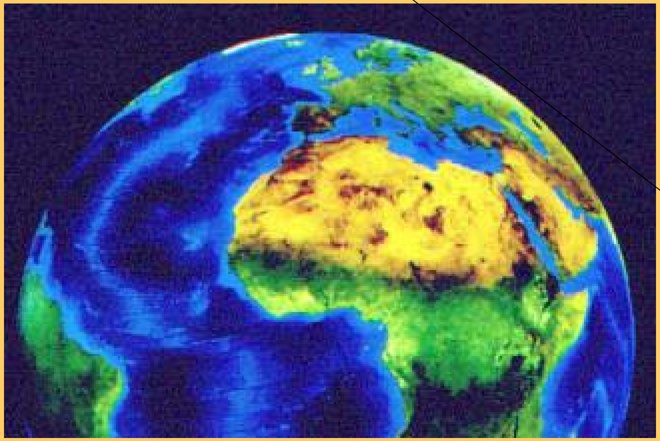




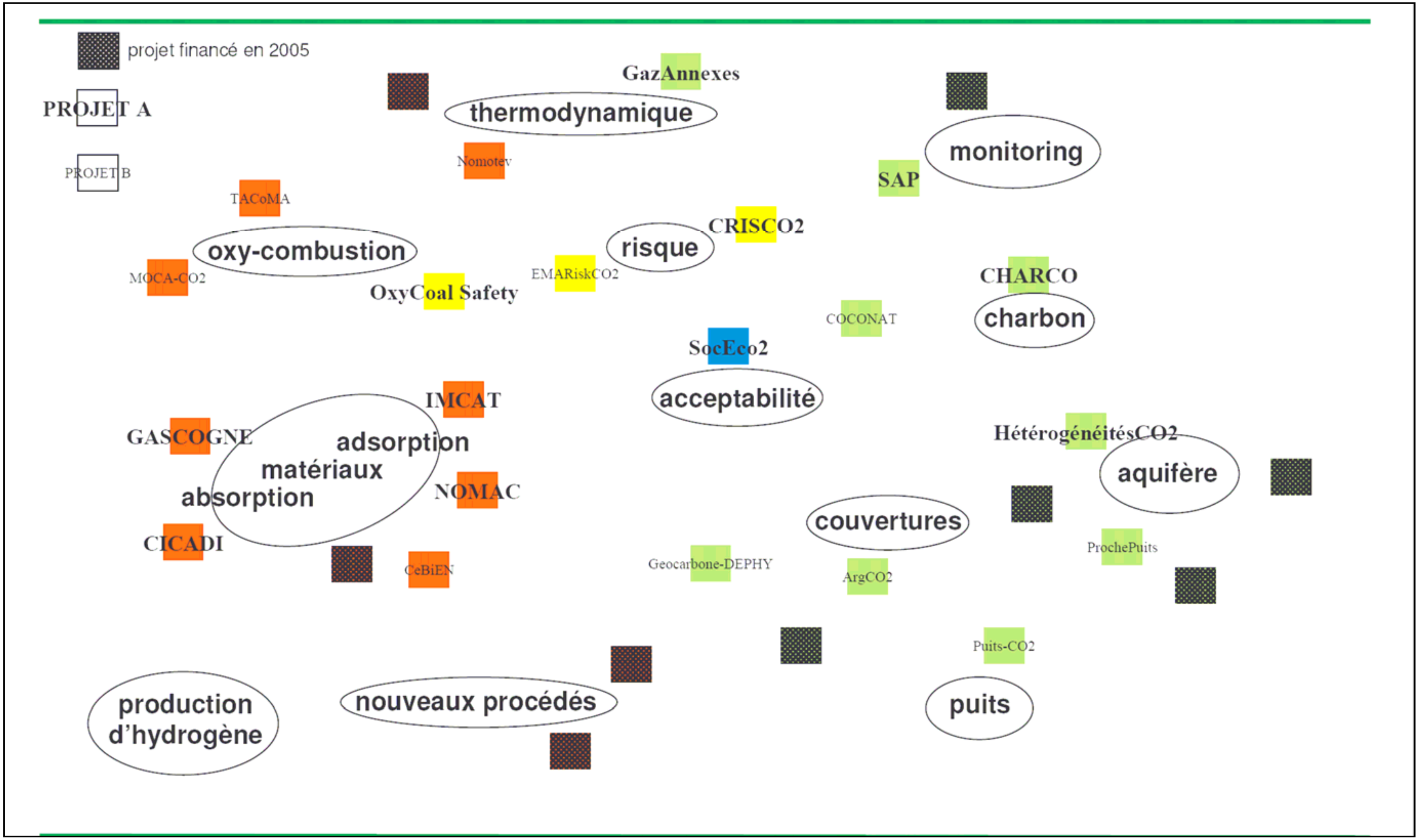
Gisements naturels de CO_2

Eaux carbogazeuses exploitées (boissons, thermalisme)

Conclusion



Les enjeux: 1. Recherche et démonstrateurs…



	Irsching, E.ON	Natural gas, 530 MWe	Pre-combustion Retrofiting towards CCGT	
Italy	To be defined, Enel	Hard coal 660 MW, of which 1/3 shall be captured	Post-combustion Currently tested at 50 MWe on Brindisi site. Storage in aquifer (near Torrevaldaliga site?)	2012
	Southern Italy, Rezia Energia Italia	Hard coal	Oxy-combustion + CFB Storage options are under investigation	
Netherlands	Eemshaven, Nuon	Hard coal, Biomass, Natural gas 1200MW	Pre-combustion IGCC MAGNUM project (initially, CCS on 400MW)	2011
	Eemshaven or Zuid-Holland, RWE	Hard coal, Biomass 1600-2200 MW	Capture ready PC (super-critical, η=46%)	2011
	Rotterdam area, E.ON	Hard coal	Post-capture Super Critical PC Construction starts in 2008	
	Rotterdam area	Natural gas	Pre-combustion	
Norway	Mongstad, Statoil	Natural Gas 280 MW elec. + 350 MW heat	Post-combustion, CHP plant Storage with EOR option in North Sea.	2014
	Karstø, Naturkraft	Natural Gas 400MW	Post-combustion amine NGCC Storage in oilfield –EOR	2011
	Tjeld-bergodden, Statoil & Shell	Natural gas 860MW	Post-combustion amine NGCC Storage in Draugen oilfield – EOR	2011
Poland	Poland, BOT/RWE/CEŽ/EDFPolska/GE/Vattenfall	Hard coal 800MW	Pre-combustion IGCC Capture >85% and storage	2013
	Lagisza / Katowice, PKE	Hard coal	Post-combustion Supplement to a SC CFB plant under construction	2012-14
	Siekierki / Warsaw, Vattenfall	Hard coal 800 MWe	Oxy-combustion Retrofitting of a CHP plant.	

Spain	North/Central Spain, Union Fenosa	Hard coal		
United Kingdom	Teeside, Progressive Energy	Hard coal (+ petcoke) 800MW	Pre-combustion IGCC + shift Storage in UK North Sea (EOR).	2009
	Hatfield, Powerfuel	Hard coal 900MWe	Pre-combustion IGCC + shift	2010
	Killingholme, Lincolnshire, E.ON UK	Hard coal (+ petcoke) 450MW	Pre-combustion IGCC + shift	2011
	Ferrybridge, Scottish & Southern Energy	Hard coal 500MWe	Post-combustion PC (super-critical retrofit)	2011
	Immingham, ConocoPhillips	Hard coal (+ petcoke) 1180MWe	Pre-combustion IGCC for CHP plant and H2 production. Storage in UK North Sea (EOR).	2012
	Tilbury, RWE	Hard coal 1600MW	Post-combustion PC super-critical retrofit	2013
	Kingsnorth, E.ON UK	Hard coal Biomass 1600 MWe	Oxy-combustion Super critical steam cycle	2015

NB 1: For some projects, details of planned storage facilities are not yet determined, as legal and commercial considerations are still pending.

NB 2: For comparison, a 400 MW coal-fired power station emits around 2.5 Mt of CO_2 per year.

Source: Communication from the Commission to the European Parliament and the Council, supporting early demonstrration of sustainable power generation from fossil fuels – Impact assessment 23.01.08

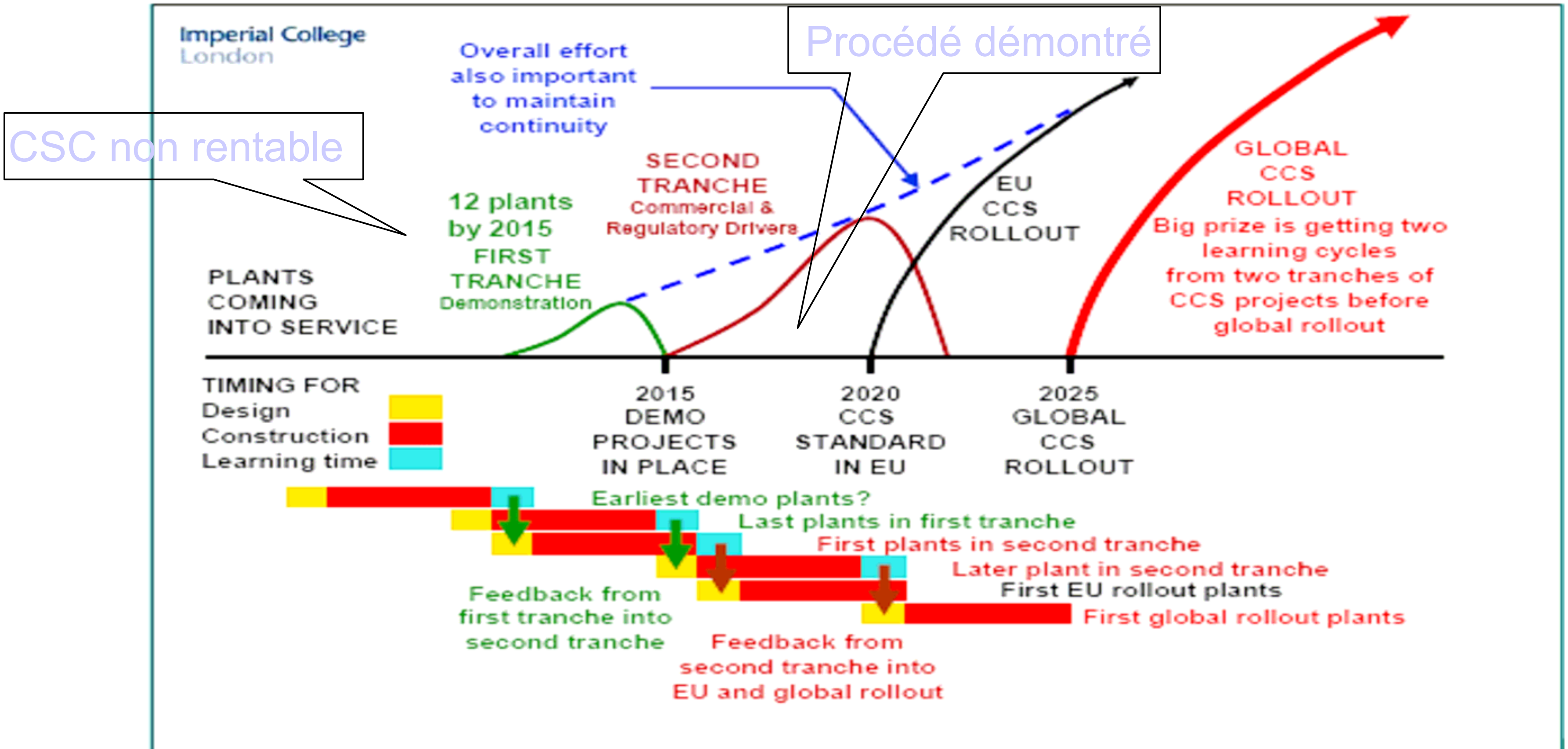
List of large scale CCS electricity generation projects in Europe (250 MW_{el} and above)

Updated: 15th September 2007

Country	Location and Company	Fuel and Capacity	Technology	Start
Bulgaria	Maritsa lignite basin	Lignite 650-750 MWe	Pre-combustion IGCC + shift	
Czech Republic	North Bohemia, CEZ	660 MWe	Post-combustion Storage in deep saline aquifers	2012-14
Denmark	Kalund DONG	Hard coal 600 MWe	Post-combustion Retrofitting of a 600 MW CHP plant. Storage in Havnso aquifer.	2013
	Nordjyllandvaerket / Aalborg, Vattenfall	Hard coal with biomass co-firing 700-900 MW	Oxy-combustion in CHP. For storage, five options are under investigation.	
	Amagervaerket / Copenhagen, Vattenfall	Hard coal with biomass co-firing 350-700 MW	Oxy-combustion in CHP. For storage, two options are under investigation.	
Finland	Meri-Pori, FORTUM	Hard coal 560 MW	Oxy-combustion In SC and CFB processes. Transport of CO_2 by ship. Storage in the North Sea.	2013
France	Le Havre, Poweo			
Germany	Spreetal, Siemens	Hard coal 1000MW	Pre-combustion IGCC + shift	2011
	Schwarze Pumpe, Vattenfall	Lignite 300-600MW	Oxy-combustion EGR in Altmark region	2012
	Ludwigshafen BASF	Hard coal, Biomass 1000 - 1500MW_{th}	Capture ready IGCC + shift + poly-generation, (storage?)	2012
	Germany, RWE	Hard coal, Lignite 450MW	Pre-combustion IGCC + shift Storage in depleted gas field in Lower Saxony	2014
	To be defined, E.ON	Hard coal 400MW	Comtes700 upscale project PC Ultra super-critical Capture ready.	2014

Les enjeux: 2. Assurer le déploiement industriel

***<u>Learning curve du CCS</u>*: 2 générations de pilotes nécessaires avant de pouvoir être une norme globale.**



Source: J Gibbins, Imperial College London

Les enjeux 3. Cadre juridique du CCS…

6.3. Composition of the CO2 stream

(175) CO2 purity is desirable both to minimize transport and storage risk and to establish public confidence that CCS is not being used as a pretext to dispose of waste. It is thus necessary to impose conditions on the composition of CO2 to be accepted for storage. A requirement that no wastes or other material can be added to the stream for the purposes of disposal is widely accepted. However, a certain level of contamination, for instance by materials involved in the capture process (such as the capture solvents) is almost inevitable and should be allowed for.

(176) The main point of issue is to what extent the stream is allowed to be contaminated by air pollutants also present in the combustion exhaust, and in particular sulphur and nitrogen oxides (SOx and NOx). The Commission consulted on a position whereby the same level of denitrification and desulphurization would be required for the captured and stored exhaust as would be required under current air pollution legislation if the exhaust were vented to the air.

(177) However, respondents stressed that the current air pollution requirements are based on potential risk from venting to the atmosphere, and not on the potential risk from transport and geological storage. This is correct, and so the requirements for the composition of the CO2 stream are now to be set so as to ensure the integrity of the transport and storage network, and consequences on the environment in the case of leakage. This is in line with the approach adopted in international conventions (OSPAR and the London Convention).

COMMISSION OF THE EUROPEAN COMMUNITIES

Brussels, 23.1.2008
COM(2008) XXX

COMMISSION STAFF WORKING DOCUMENT

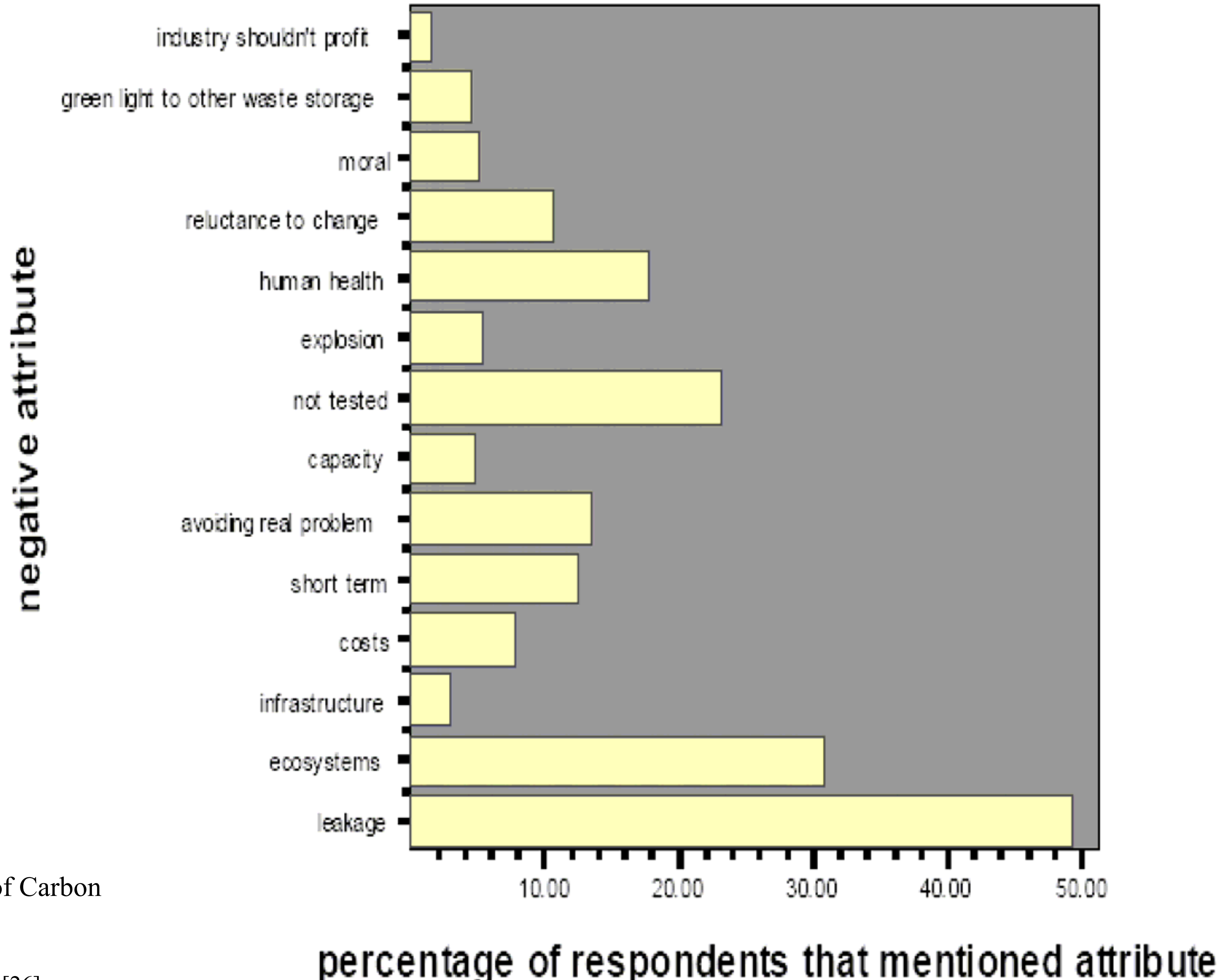
Accompanying document to the

Proposal for a

DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

on the geological storage of carbon dioxide

Les enjeux 4. Acceptabilité sociétale…



The Public Perception of Carbon Capture and Storage Technologies
(Source Shackley et al 2004) [26]

- *Le CCS n’est pas la solution aux limitations des gaz à effet de serre, mais il constitue un des principaux leviers pour atteindre le facteur 4*

- *Le portefeuille de technologies de première génération à mettre en oeuvre peut s’appuyer sur une expérience des industries gazières, pétrolières et d’ingénierie*

- *Le développement des technologies de deuxième génération et le lancement de démonstrateurs sont des priorités*

- *L’acceptabilité sociétale, l’impact environnemental, le cadre juridique et la volonté politique peuvent constituer des freins majeurs au déploiement de cette option*

How can we achieve the factor 4 target?

1. **Decrease energy consumption**
2. **Improve energy efficiency**
3. **Promote renewable energy sources**
4. **Achieve Carbon Capture and Storage (CCS)**
5. **Use carbon dioxide**

…..

Rapport Syrota (Septembre 2007) Extraits…

"Au plan technologique, la nouvelle source énergétique quasi gratuite, renouvelable, sûre, partagée, qui suppléerait sans dommage, sans gaz à effet de serre et sans déchet à tous les usages combinés du pétrole, du gaz et du charbon, et de l'uranium, n'existe pas, et sans doute n'existera jamais. **(...)** *La poursuite des errements actuels (scénarios " tendanciels ") est le chemin le plus court et le plus certain vers des perspectives de catastrophes mondiales* **(...).** *L'inaction ne laissera ouverte qu'une alternative à terme : changer de société par la force ou la voir disparaître."* **(p. 11)**

"Il est clair que les tendances actuelles en matières de déplacements privés, de transport de matières premières pondéreuses ou de produits manufacturés ne sauraient être durablement prolongées." **(p. 29)**

"Le captage et le stockage du CO_2 ne sont pas une solution sur laquelle la France peut raisonnablement compter pour diminuer significativement ses émissions de gaz carbonique." **(p. 91)**

	Storage Technology	Global potential	Cost	Technology status
Geological storage	Depleted gas and oil field	675 Gt CO_2	0.5-8 US$/t$CO_2$ *	Proven
	Enhanced Oil Recovery	35 Gt CO_2		Proven
	Enhanced Gas Recovery	80 Gt CO_2		Speculative**
	Enhanced Coal-bed methane Recovery	20 Gt CO_2		Speculative
	Saline Formation	1000 Gt CO_2		Speculative
Ocean Storage		NA	5-30 US$/t$CO_2$	Under research
Mineral carbonation			50-100 US$/t$CO_2$	Under research

(Source: IEA 2004 [20], IPCC 2005 [1]).

* Excluding potential revenues from EOR, EGR or ECBM.

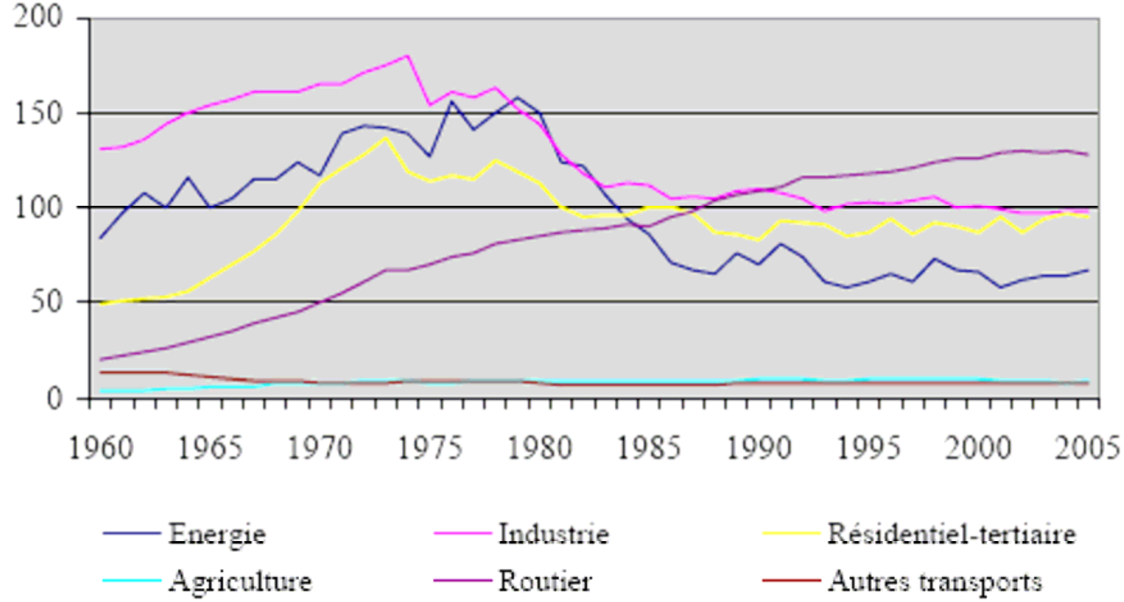
** A European project for EGR in the North Sea is in its initial stages

CO_2 EOR projects world wide

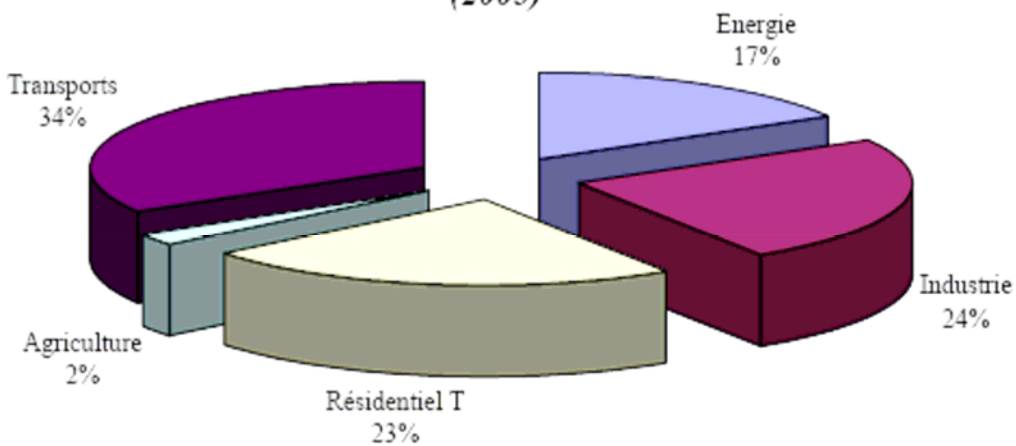
Country	**Total projects**	**Ongoing projects**
USA	85	67
Canada	8	2
Hungary	3	0
Turkey	2	1
Trinidad	5	5
Brazil	1	1
China	1	0
Total	105	76

(Source: IEA, 2004) [20]

Evolution des émissions de CO_2 par secteur (1960-2005)

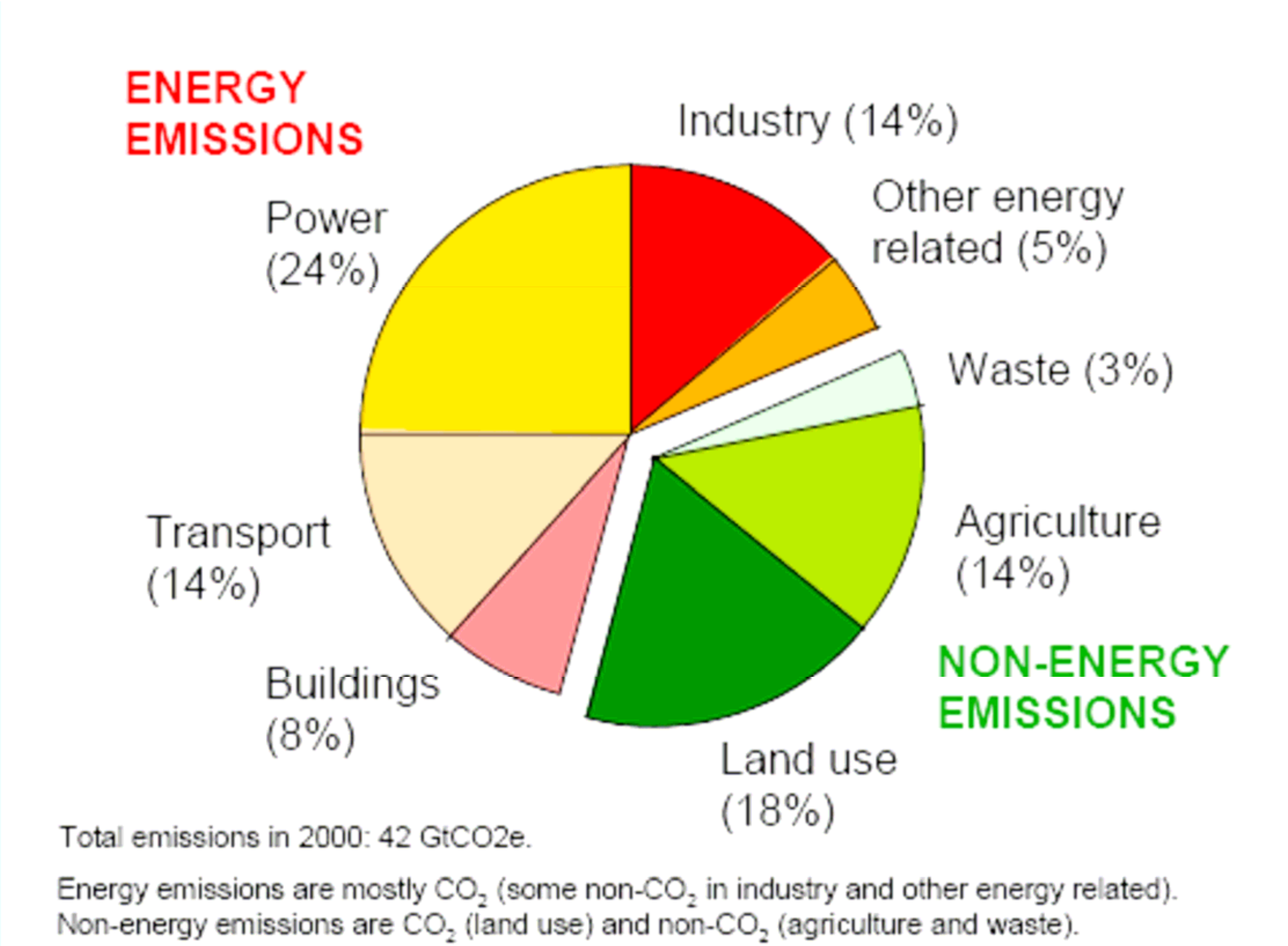


Poids des différents secteurs dans les émissions de CO_2 (2005)



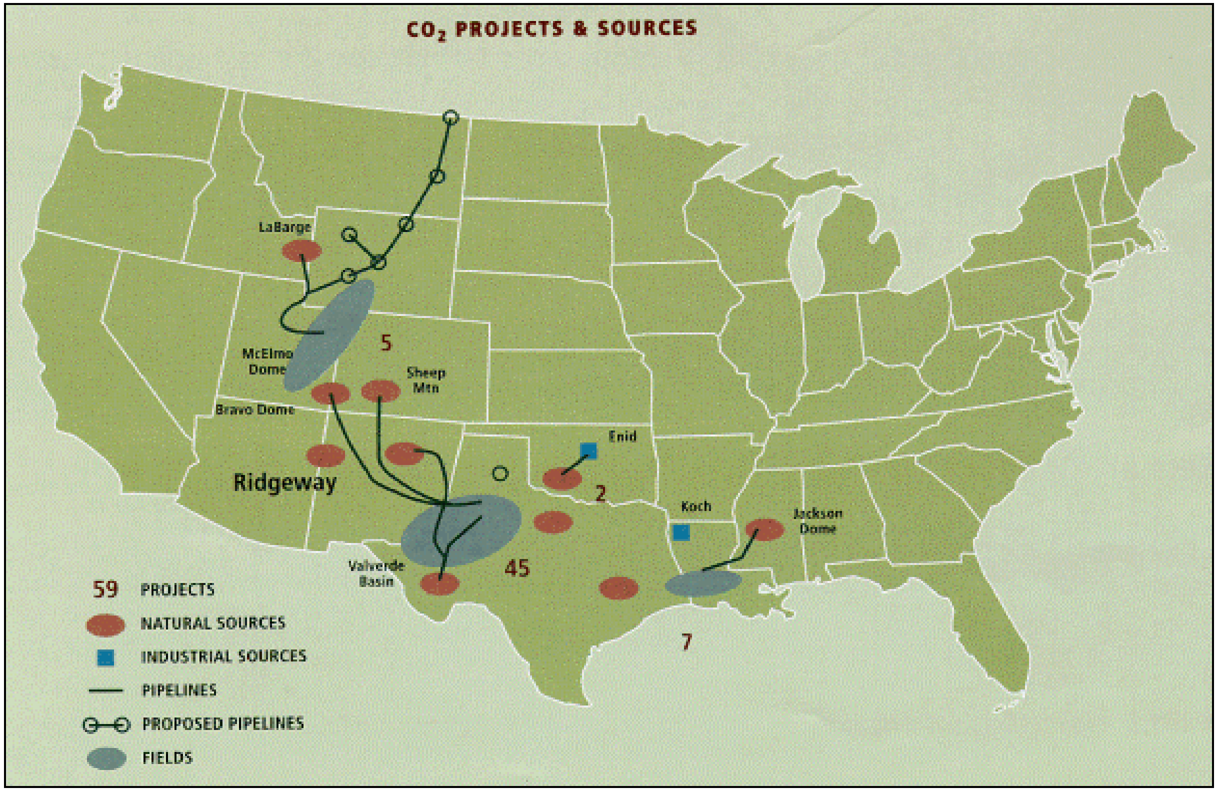
Source : CITEPA

CO_2 sources: World



Source: Prepared by Stern Review, from data drawn from World Resources Institute Climate Analysis Indicators Tool (CAIT) on-line database version 3.0.

Capture et transport CO_2: Technologie appliquée pour le traitement de gaz de combustion (11 sites industriels) et injection pour RAP (84 sites dont 72 aux USA)



Réseaux de transport, de stockage, compression et production de gaz naturel au 1er janvier 2005

Source : Observatoire de l'Énergie d'après GDF.

Coût d'ensemble de la filière

*(par tonne de CO_2 évitée)**

- **Capture: 25 – 65 $**
- **Transport: 0.5 $ (pour 100km)**
- **Séquestration: 6 – 26 $**

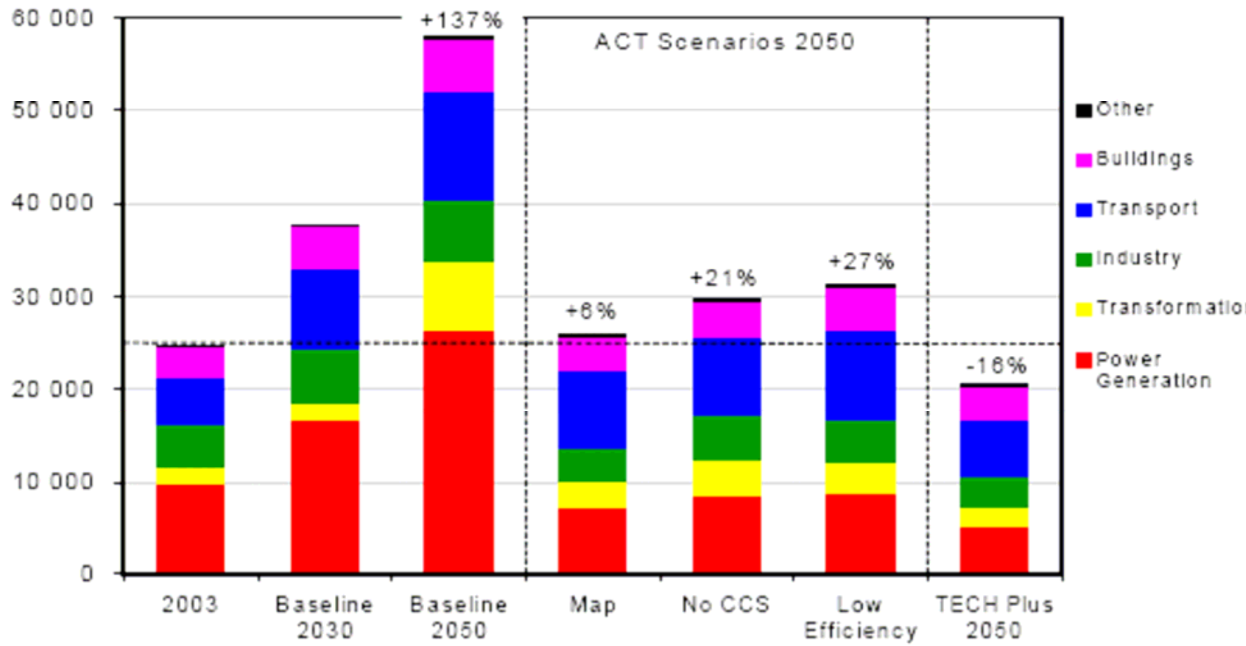
Coût total : 40 – 91 $

** D'après "CO_2 Capture, reuse and storage technologies: a white report" DOE (1997)*

CCS: a key issue in factor 4 achievement…

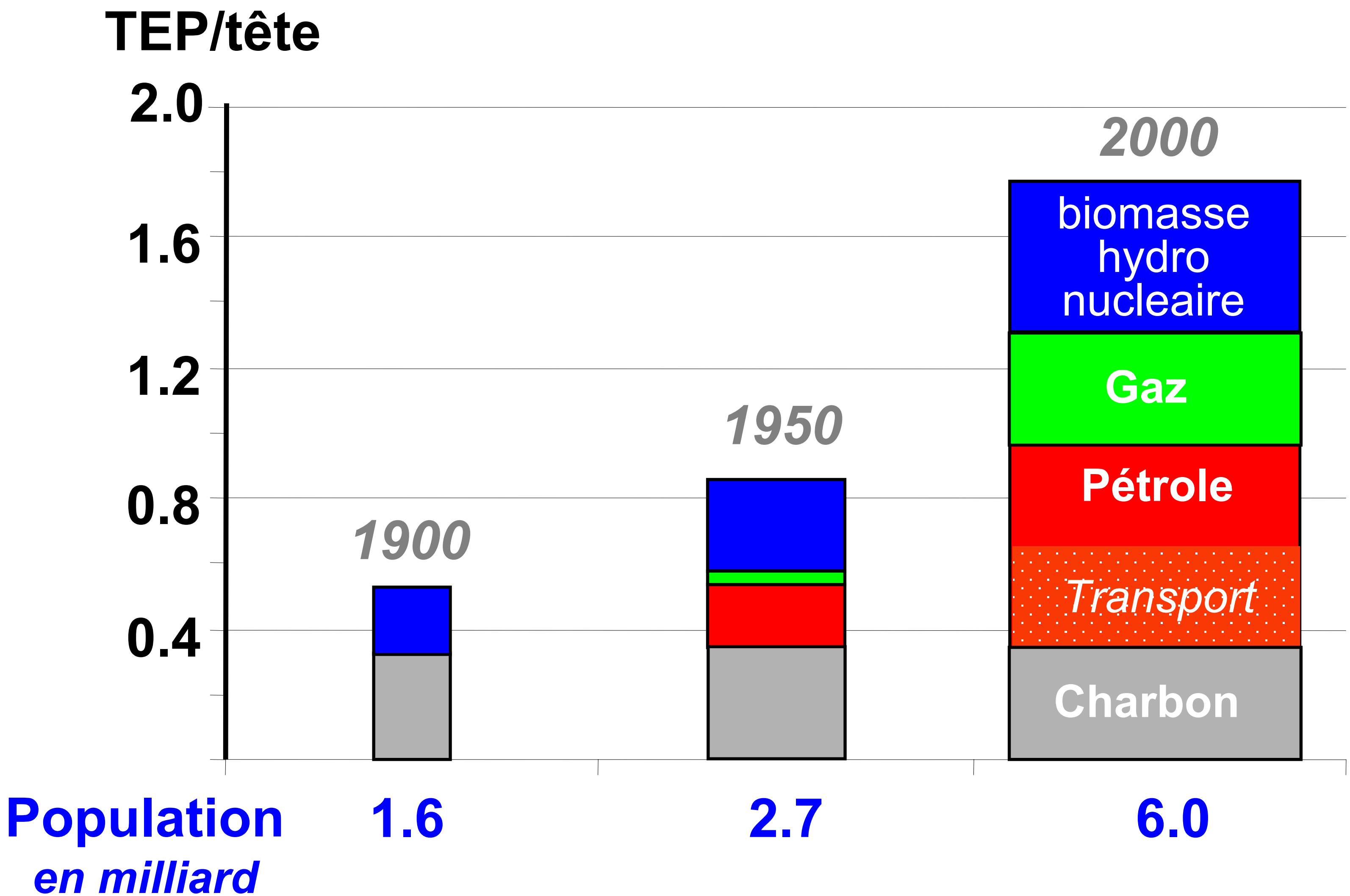
Émissions mondiales de CO_2 dans différents scénarios élaborés par l'AIE

("base line", 3 scénarios ACT/Accelerated technology, "Tech plus")



[CCS = Carbon capture & storage [captage et stockage géologique du CO_2] *Source : Agence internationale de l'énergie*

Le scénario « Baseline » (tendanciel de base) correspond à la poursuite des errements actuels. Il aboutit en 2050 à un niveau d'émissions inadmissible. Le scénario « Map » suppose la mise en œuvre réussie des technologies dont on peut raisonnablement penser disposer à horizon 2050. Le scénario « No CCS » (capture et stockage du carbone non disponible) permet de mesurer l'impact d'un échec du développement des techniques de capture/séquestration du carbone. Le scénario « Low efficiency » (basse efficacité) correspond à une moins bonne amélioration de l'efficacité énergétique. Enfin le scénario « Tech plus » suppose le développement important de nouvelles technologies (pile à combustible, photovoltaïque, hydrogène), hypothèse loin d'être assurée à cet horizon.



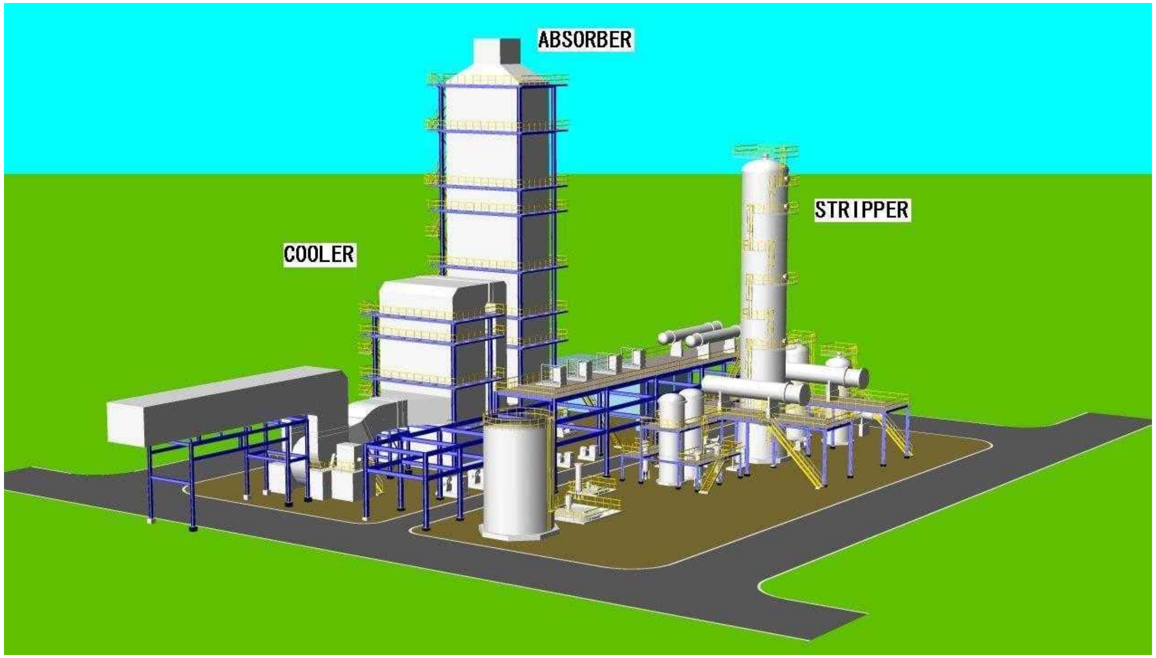
Ressources énergétiques mondiales: *Fossiles 85%*

Nucléaire 14%

Renouvelables 1%

Absorption gaz liquide conventionnelle pour la capture à partir de gaz de combustion: Synthèse

- ✪ *Reste le procédé de référence (CCP = Fluor Econamine©)*
- ✯ *Limitations:* *Sensibilité aux oxydants (O_2, SOx, NOx)*
  Entraînement (environ 10^{-3})
  Engorgement
  Taille des installations
  Coût énergétique de la régénération
  Production de CO_2 secondaire



More about costs….

European Union

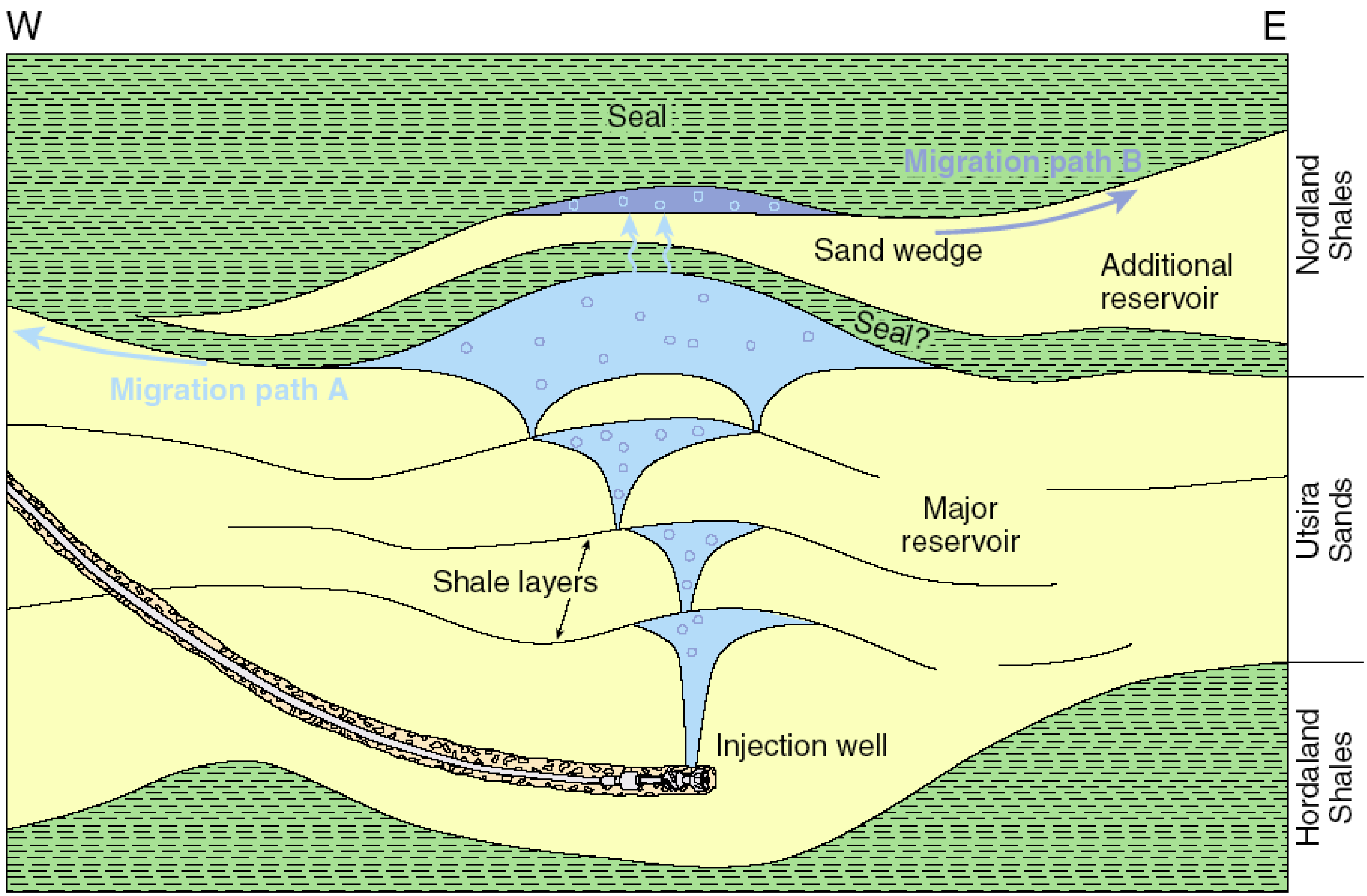
- **Current capture costs: 50 - 60 €/ton CO_2**
- **UE target : 15 (FP7) – 20 (FP6) €/ton CO_2**
- **March 2005 fine: 40 €/ton CO_2**
- **Trading price mid 2003 : 13 €/ton CO_2**
- **Trading price end 2004 : 8.5 €/ton CO_2**

USA

- **DOE target: 10 - 15 $ /ton CO_2**

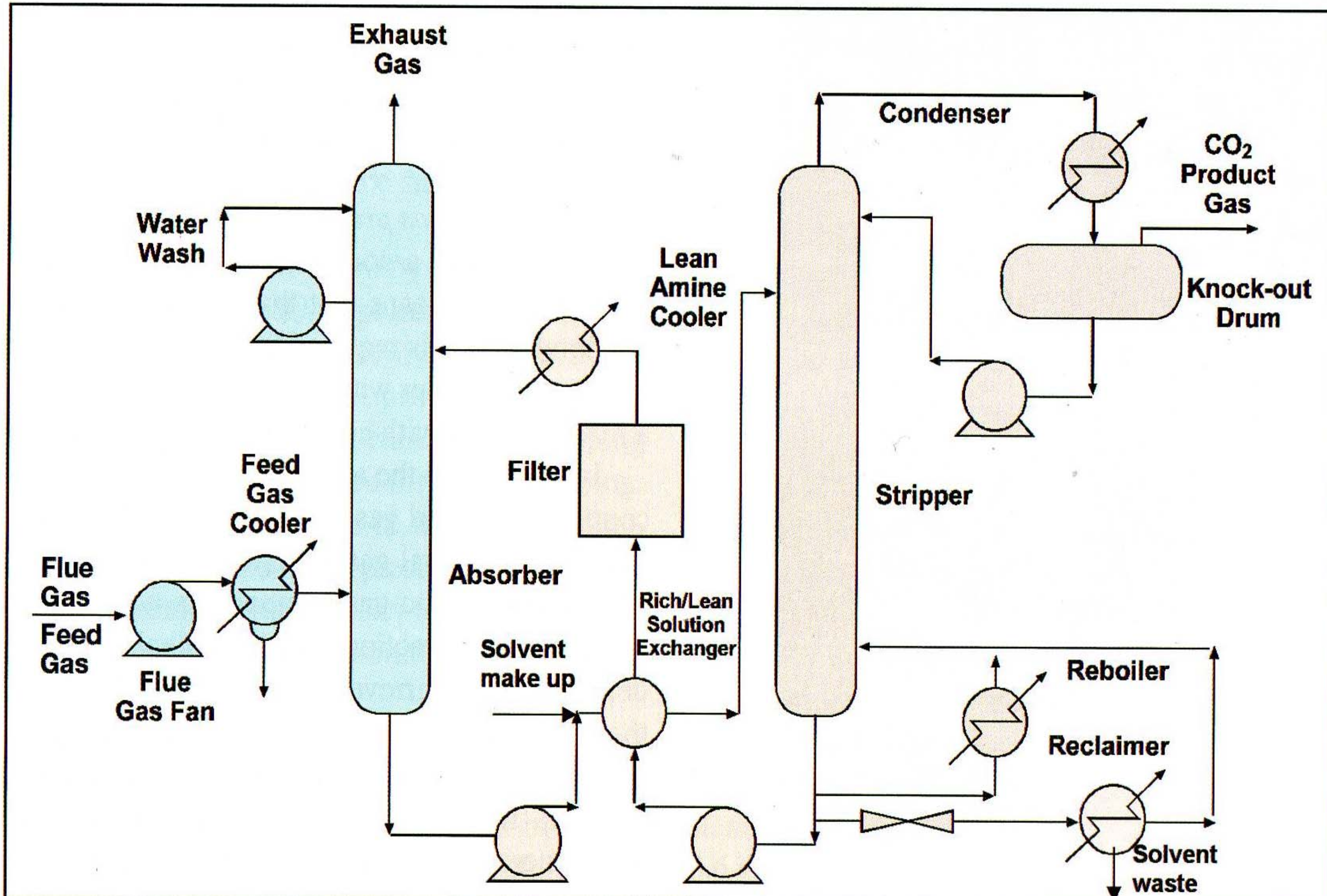
Source:
Greenhouse Issues (2003), 69, 2
Greenhouse issues (2005), 76, 9

Sleipner: architecture géologique du site



Commercial CO_2 capture plants

Operator	Location	Capacity (tonnes/day CO_2)	Fuel Sources	CO_2 Use	Technology	Status
IMC Global	Trona, CA	800	Coal boiler	Carbonation of brine (soda ash)	Kerr-McGee MEA	Operational since 1978
Mitchell Energy	Bridgeport, TX	493	Gas heaters, engines, turbine	EOR	Inhibited MEA	Operational since 1991
Northeast Energy Associates	Bellingham, MA	320	Gas turbines	PURPA (food-grade)	Fluor Daniel	Operational since 1991
Applied Energy Systems	Poteau, OK	200	Coal boiler (fluidized bed)	PURPA (food grade)	Kerr-McGee MEA	Operational since 1991
Sumitomo Chemicals	Chiba, Japan	165	Gas boilers plus oil/ coal boiler	Food-grade	Fluor Daniel	Operational since 1994
Luzhou Natural Gas	China	160	NH_3 plant reformer exhaust	Urea	Fluor Daniel	Operational since 1998
Indo Gulf Fertilizer Co.	India	150	NH_3 plant reformer exhaust	Urea	Dow MEA	Operational since 1988
Prosint	Rio de Janeiro, Brasil	90	Gas boiler	Food-grade	Fluor Daniel	Operational since 1997
Liquid air Australia	Australia	2 x 60	Gas boiler	Food-grade	Dow MEA	Operational since 1985
AES, Shady Point Power Station	Panama, OK	190	Coal fired CFB boiler	Food-grade	ABB Lummus	Operational since 1991
AES, Warrior Run Power Station	Cumberland, MA	150	Coal fired CFB boiler	Food-grade	ABB Lummus	Operational since 1999


Exhaust Gas
Condenser
CO_2 Product Gas
Water Wash
Lean Amine Cooler
Knock-out Drum
Filter
Stripper
Feed Gas Cooler
Flue Gas
Feed Gas
Absorber
Rich/Lean Solution Exchanger
Solvent make up
Reboiler
Flue Gas Fan
Reclaimer
Solvent waste

Composés gazeux et effet de serre

$$GWP_C^g = \frac{AGWP(g)}{AGWP(CO_2)} = \frac{\int_0^{TH} a_g f^g(t)dt}{\int_0^{TH} a_C f^C(t)dt}$$

	Efficacité radiative ($Wm^{-2}ppb^{-1}$)	**GWP**		
		20 ans	100 ans	500 ans
CO_2	1.55×10^{-5}	1	1	1
CH_4	3.7×10^{-4}	62	23	7
N_2O	3.1×10^{-3}	275	296	156
HFCs	0.02 to 0.40	40 to 9400	12 to 12000	4 to 10000
SF_6	0.52	15100	22200	32400