O POTENCIAL GEOLÓGICO NACIONAL:
SOLUÇÃO PARA ENRIQUECER PORTUGAL

Painel 3 – Reforço do potencial geológico

Armazenamento Geológico de CO_2 em Portugal

CO_2 Geological Storage in Portugal

Cristina Rodrigues e M. Lemos de Sousa

Associação Portuguesa de Geólogos / LNEC / 28 – 29 Novembro 2013

1. GENERAL

10 Challenges for the 21st Century

** Climate change

** Oil peak

** Clean coal

** Uranium

** Geothermics

Raw materials

Construction materials

* Water resources

* Geologic risks

** Underground space management

BRGM, 2009

Energy definition

The capacity of a system to produce external activity

(Max Planck)

Forms of energy:

- Mechanical
- Thermal
- Chemical bond
- Physical bond
- Electrical
- Electromagnetic radiation

Energy concepts

- Physical

- Economic
  - Energy as a product or commodity

Energy indicator

Energy intensity

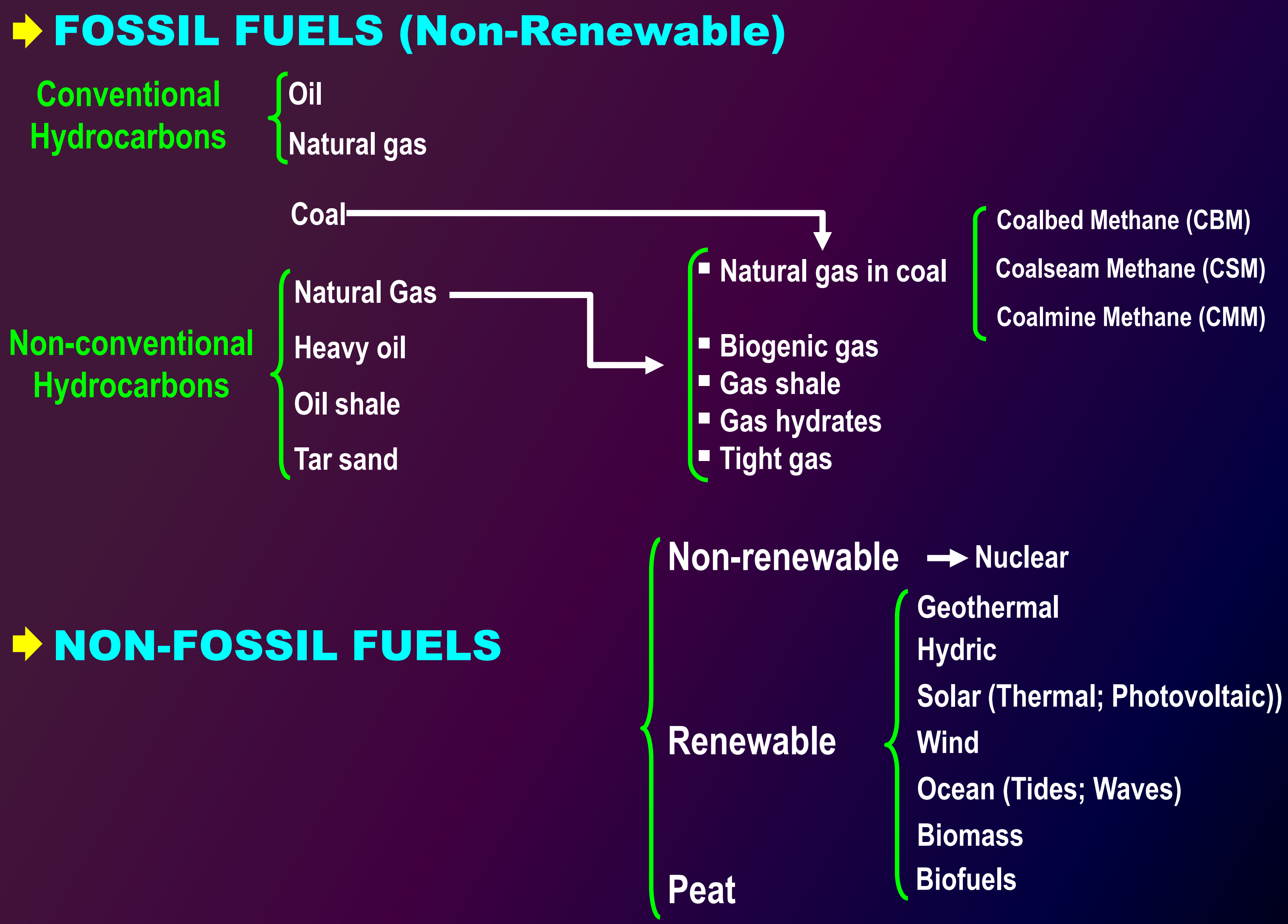
Energy balance (accounting)

Energy policy

Energy chain

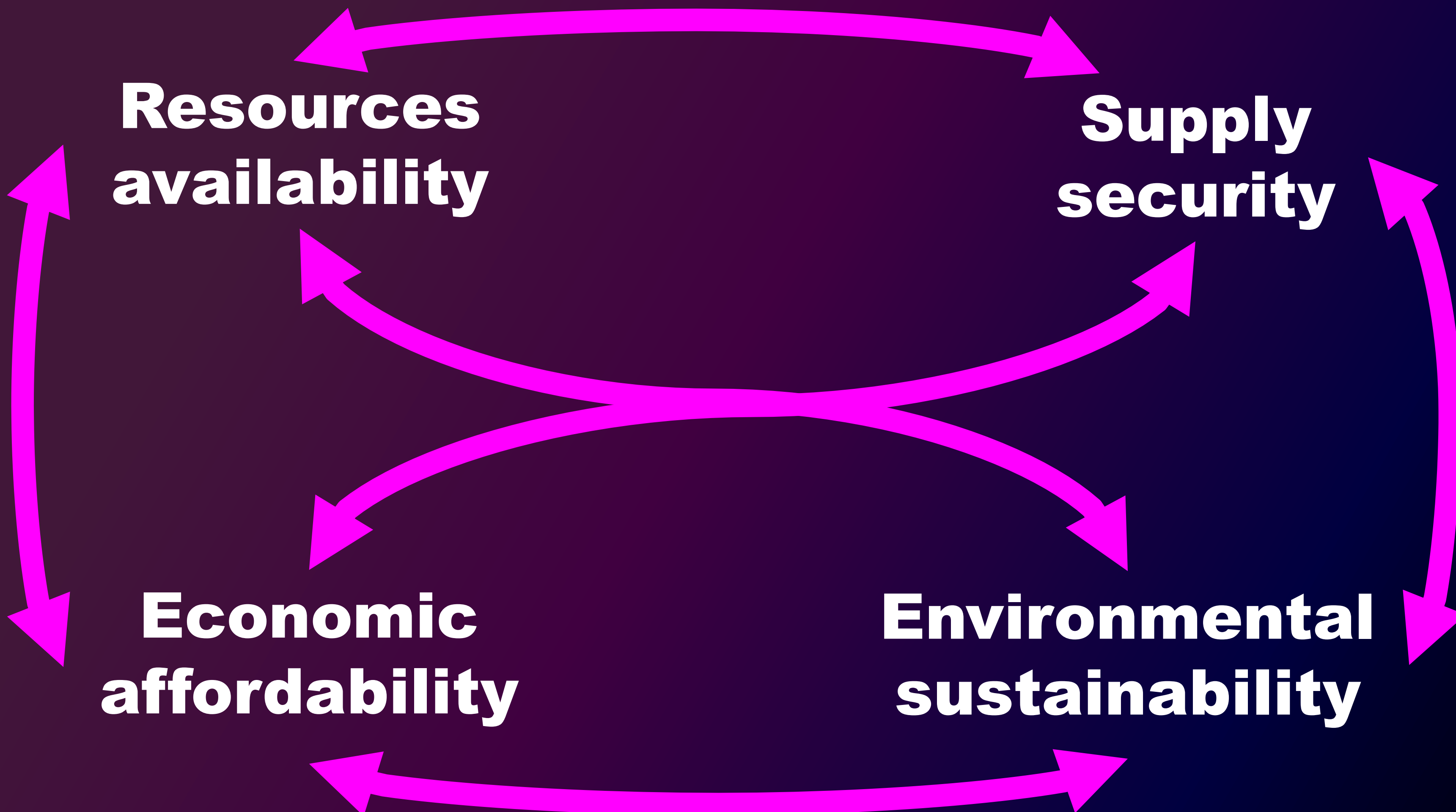
- Primary energy
  - Derived (Secondary) energy
    - Final (Supplied) energy
      - Useful energy

Primary Energy

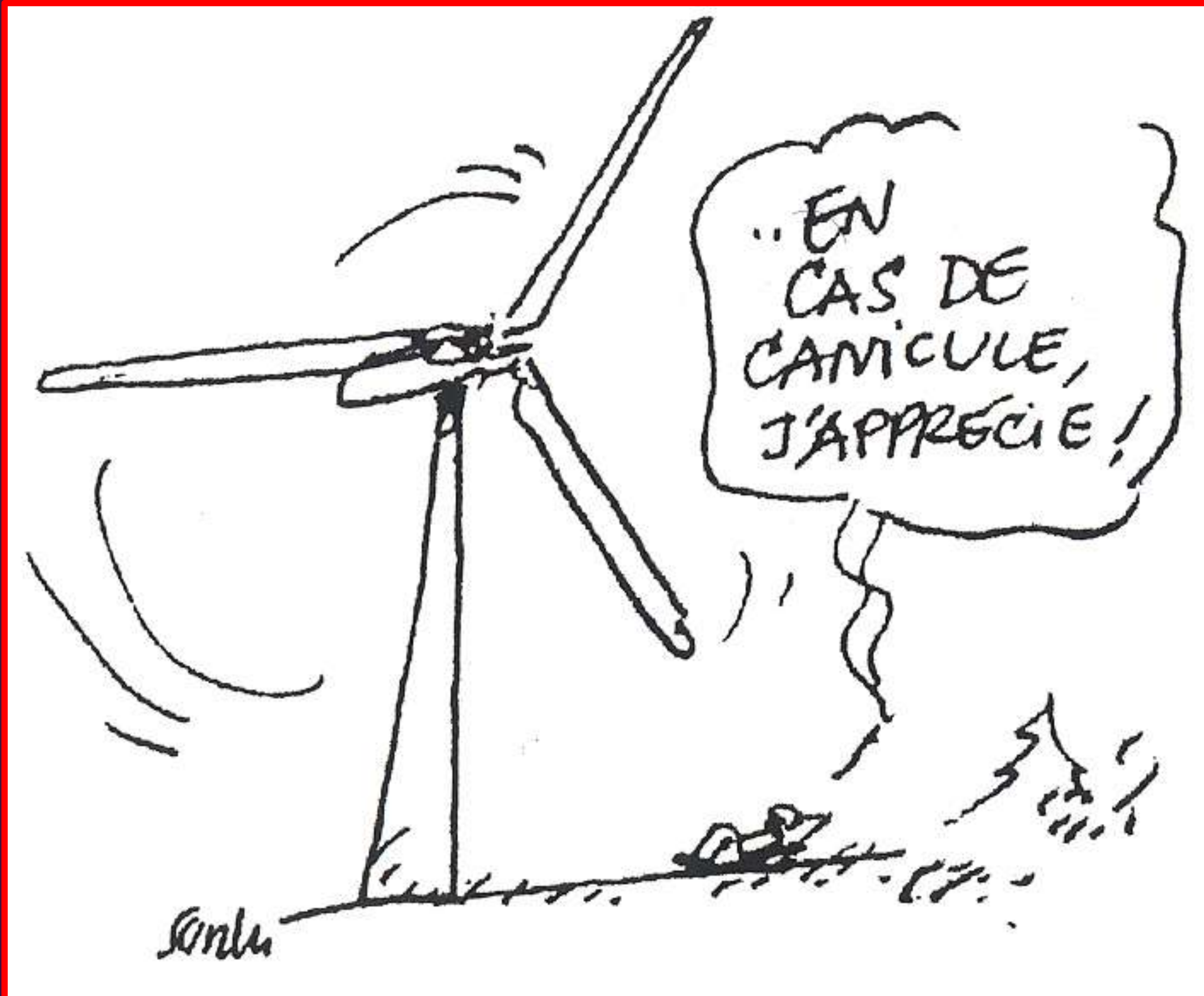


M. Lemos de Sousa and C.F. Rodrigues, UFP – CIAGEB, 2012

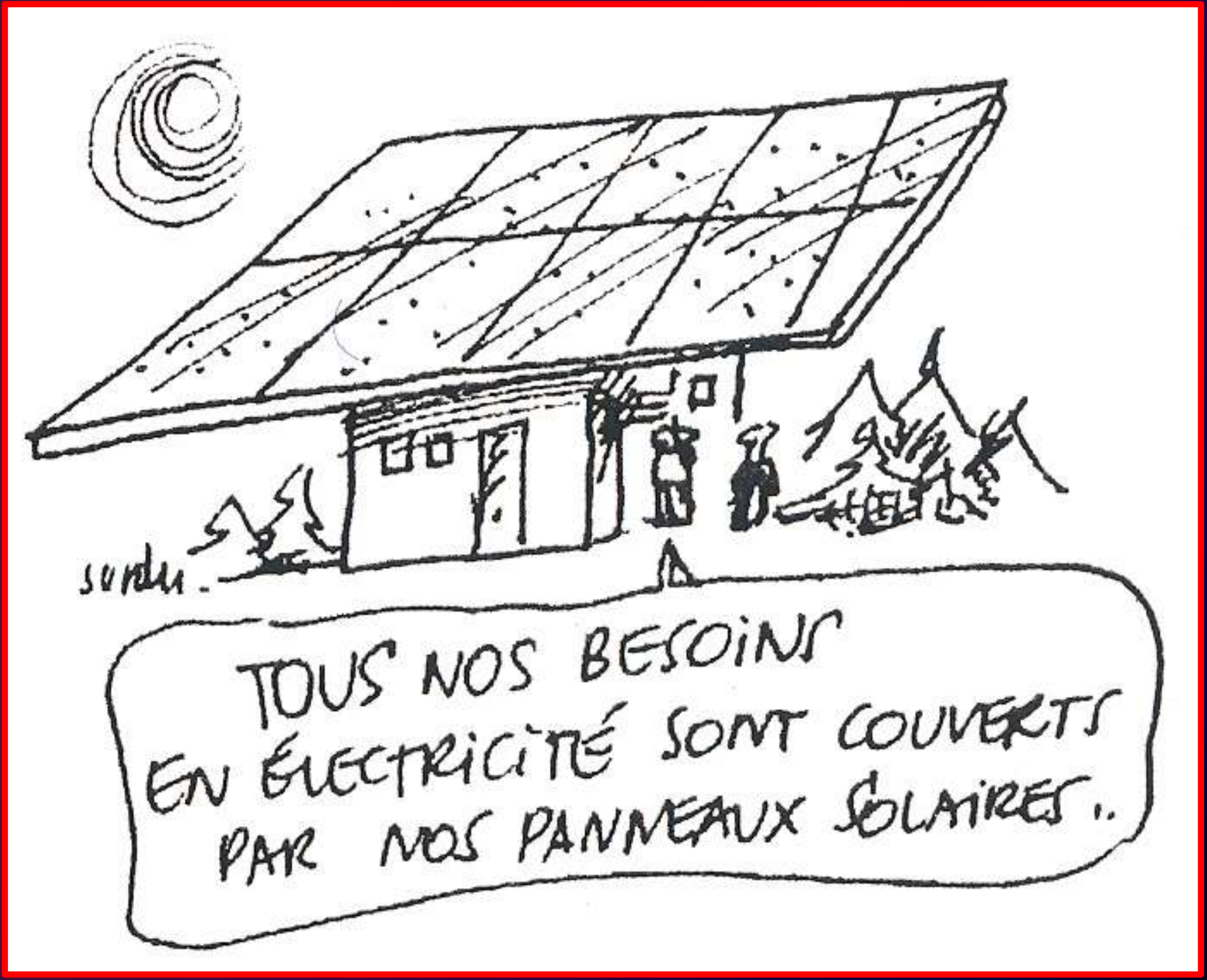
Energy essentials



G.M. Oliveira, UFP – CIAGEB, 2012



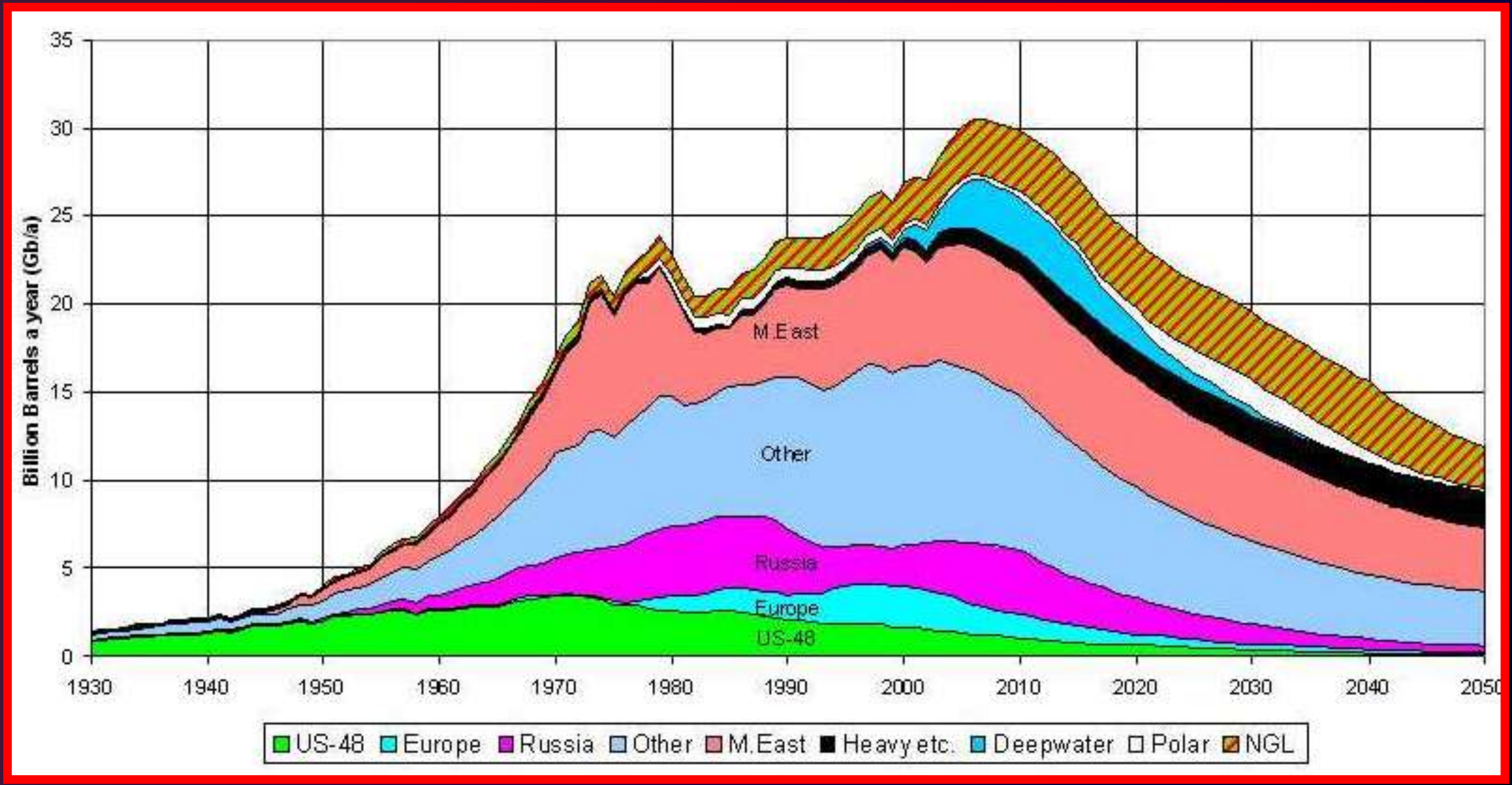
Serdu in Wautelet, 2007



Serdu in Wautelet, 2007

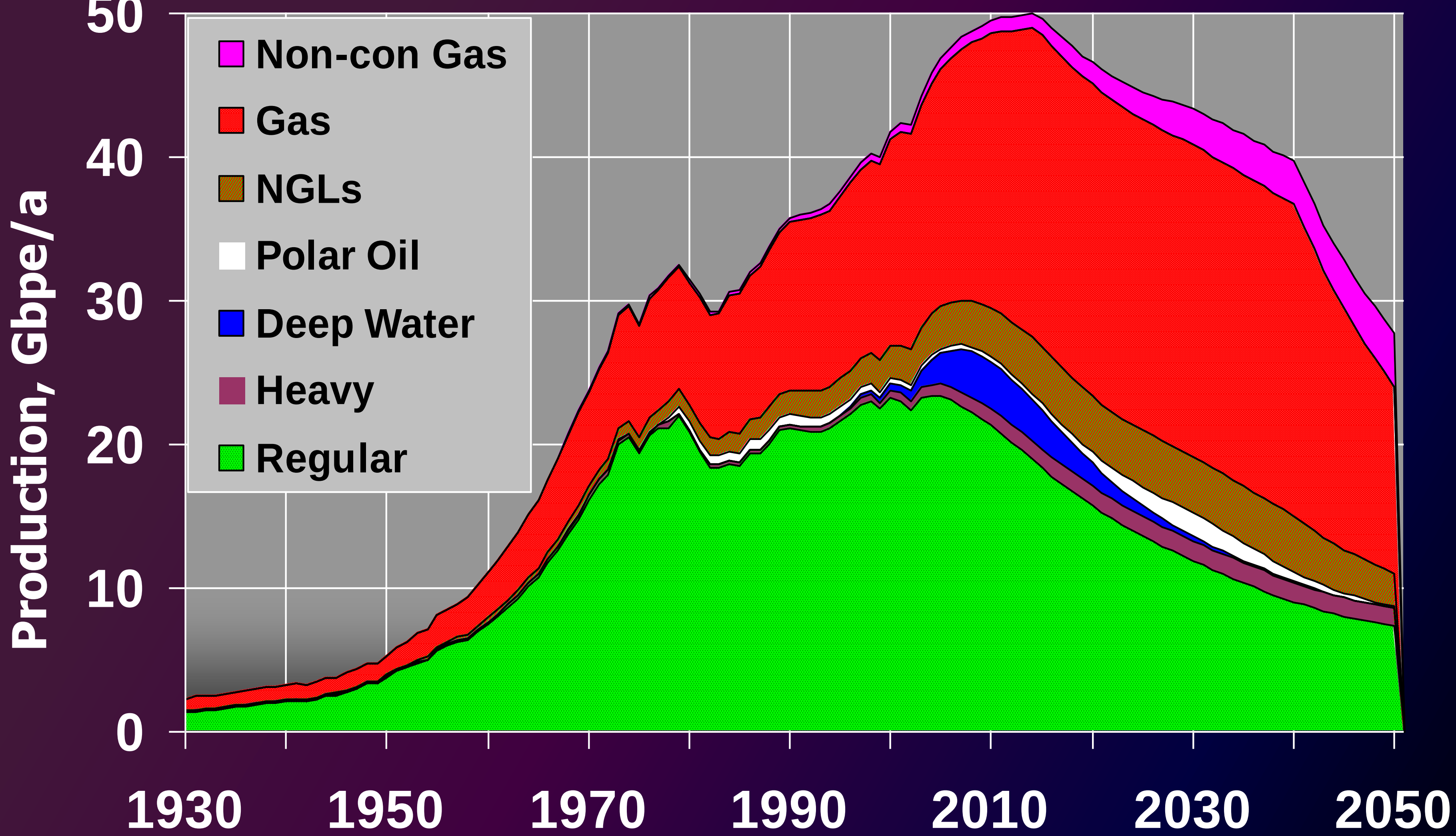
Serdu in Wautelet, 2007

Oil and NLG - 2004 Scenario

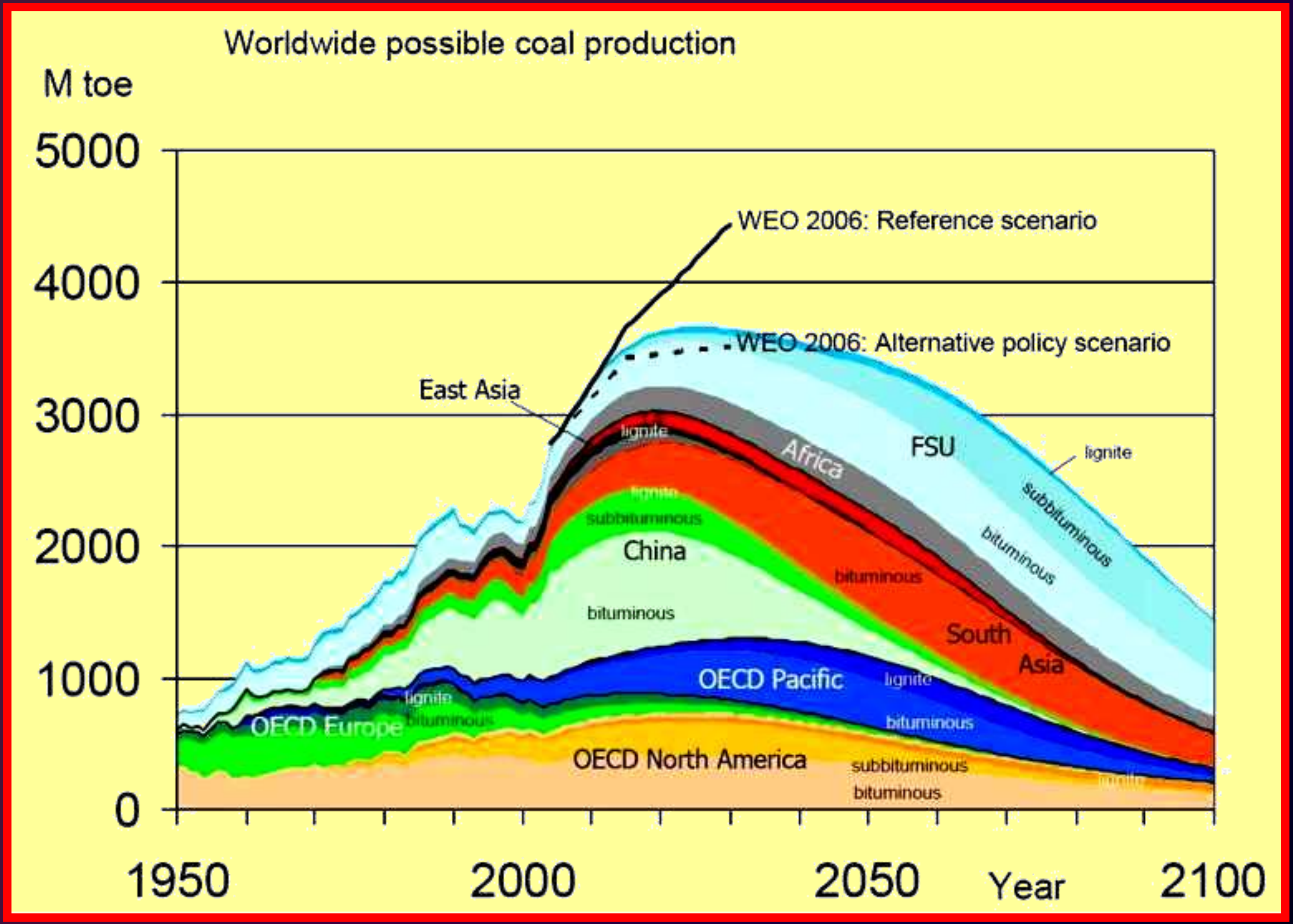


Campbell 2005, ASPO Lisbon Meeting

Oil and Gas - 2005 Scenario

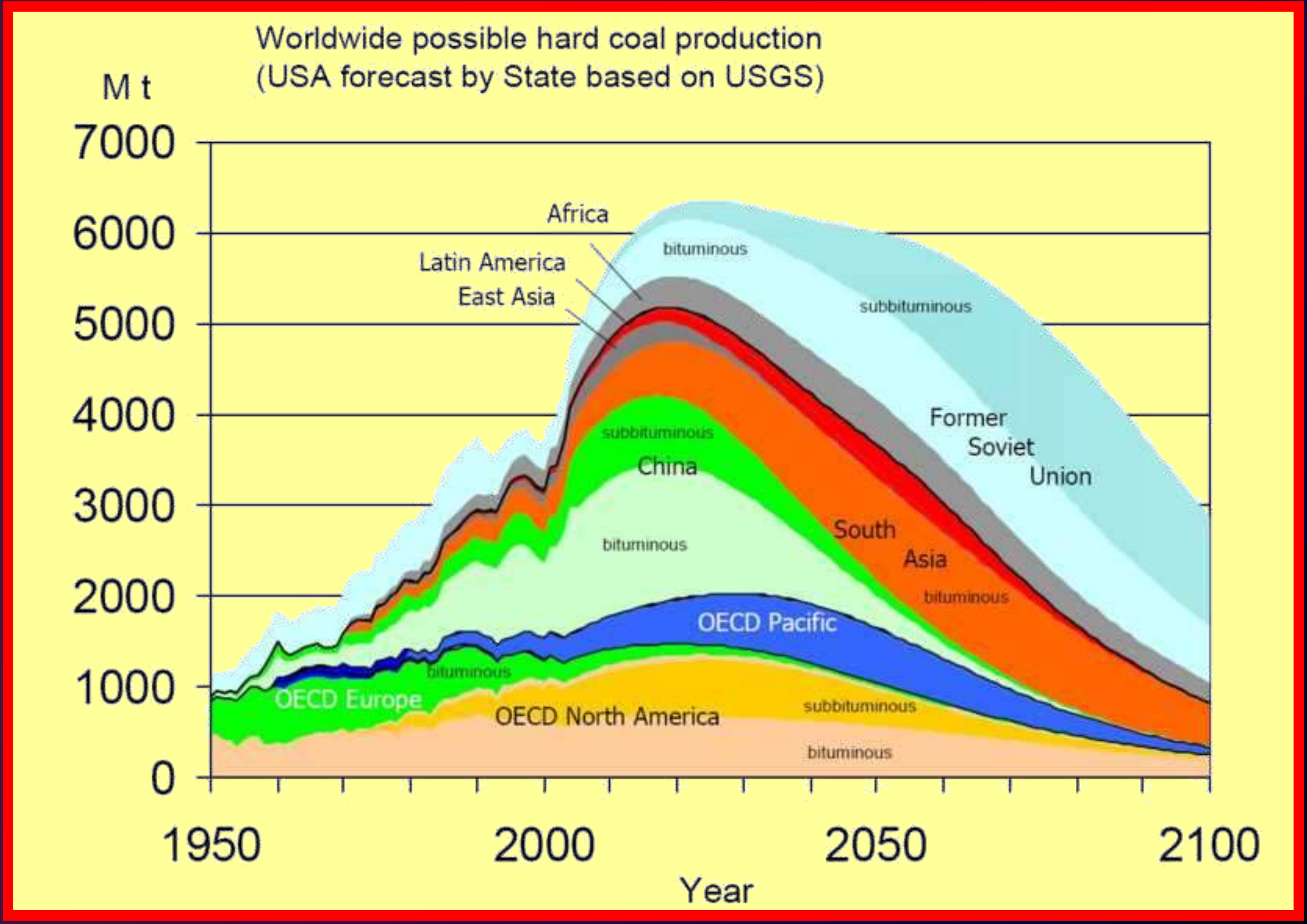


"Peak Coal" – 2007 Scenario



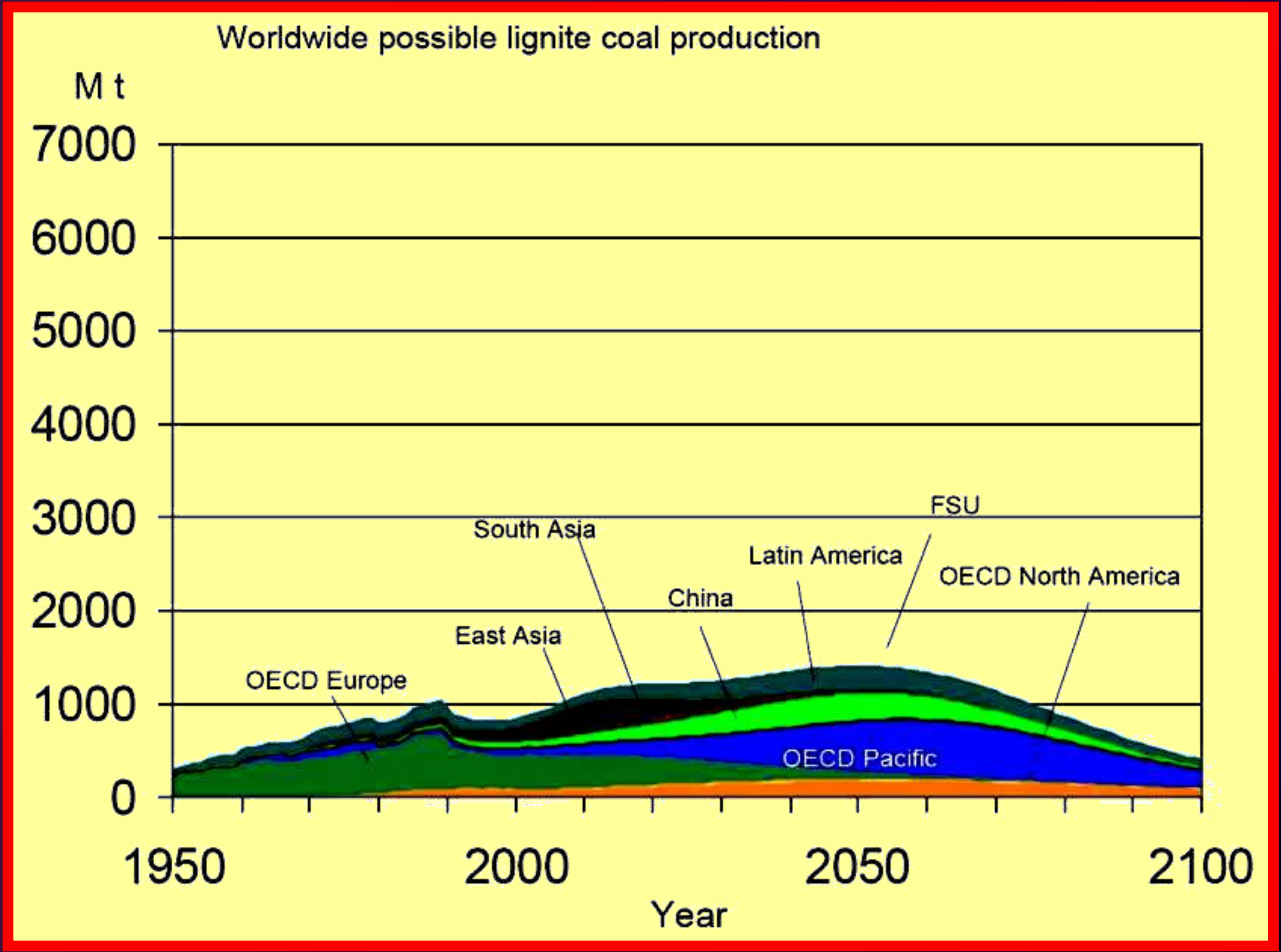
EWG 2007 and Laherrère 2007

"Peak Coal" – 2007 Scenario Hard and Subbituminous Coals



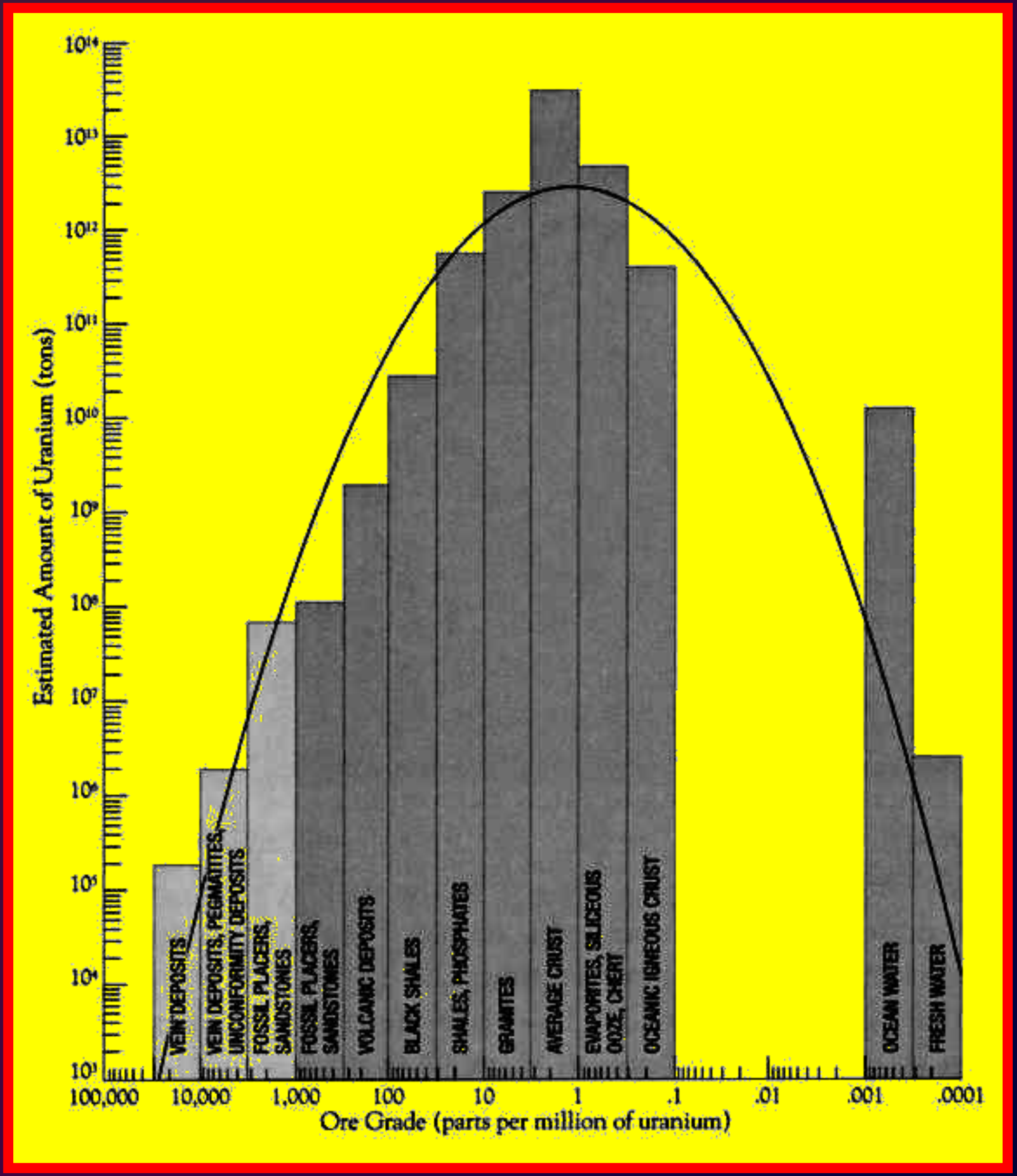
EWG 2007

"Peak Coal" – 2007 Scenario Lignite



EWG 2007

Uranium Distribution in Earth Crust

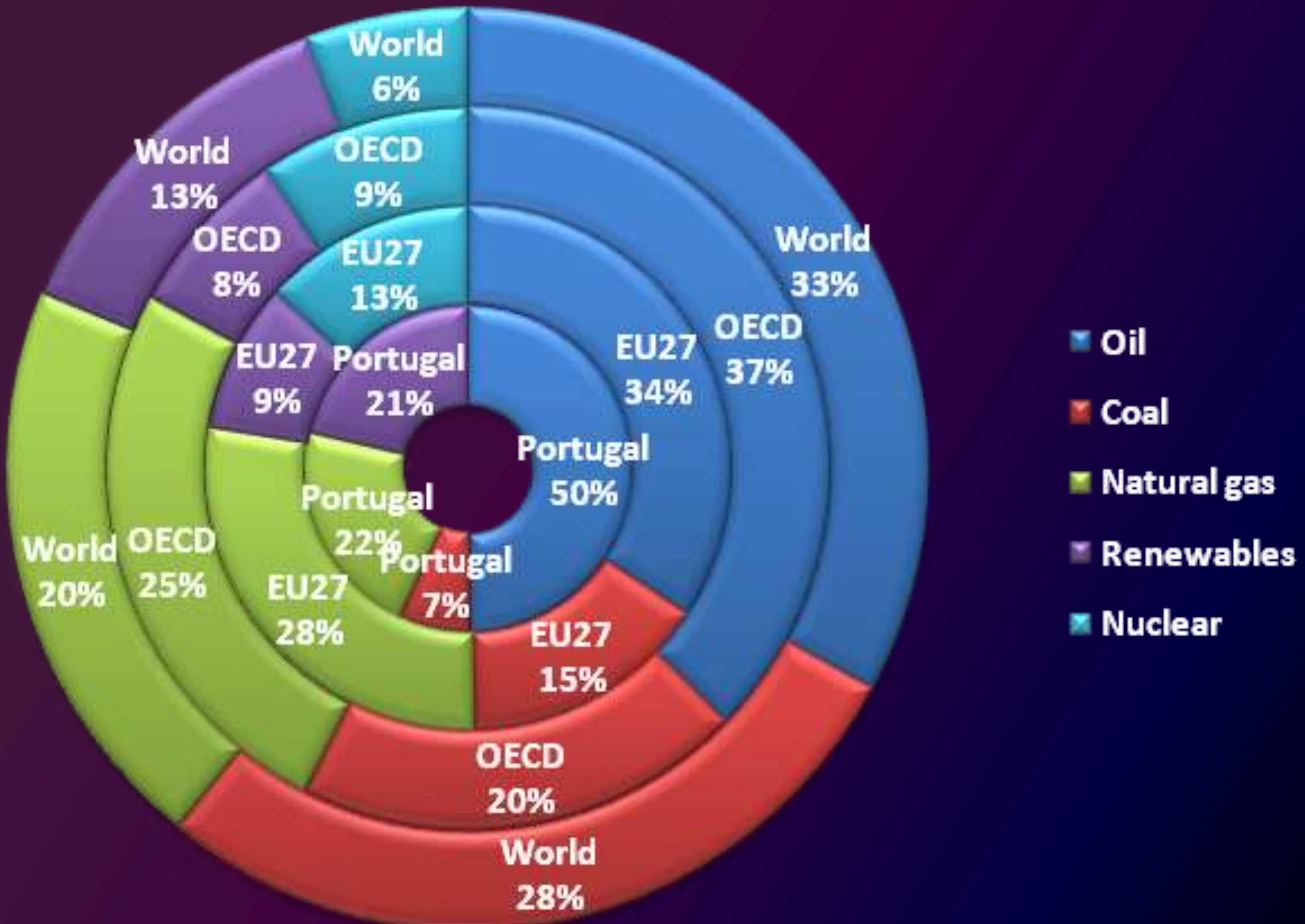


Deffeyes 2005

Energy Scenario

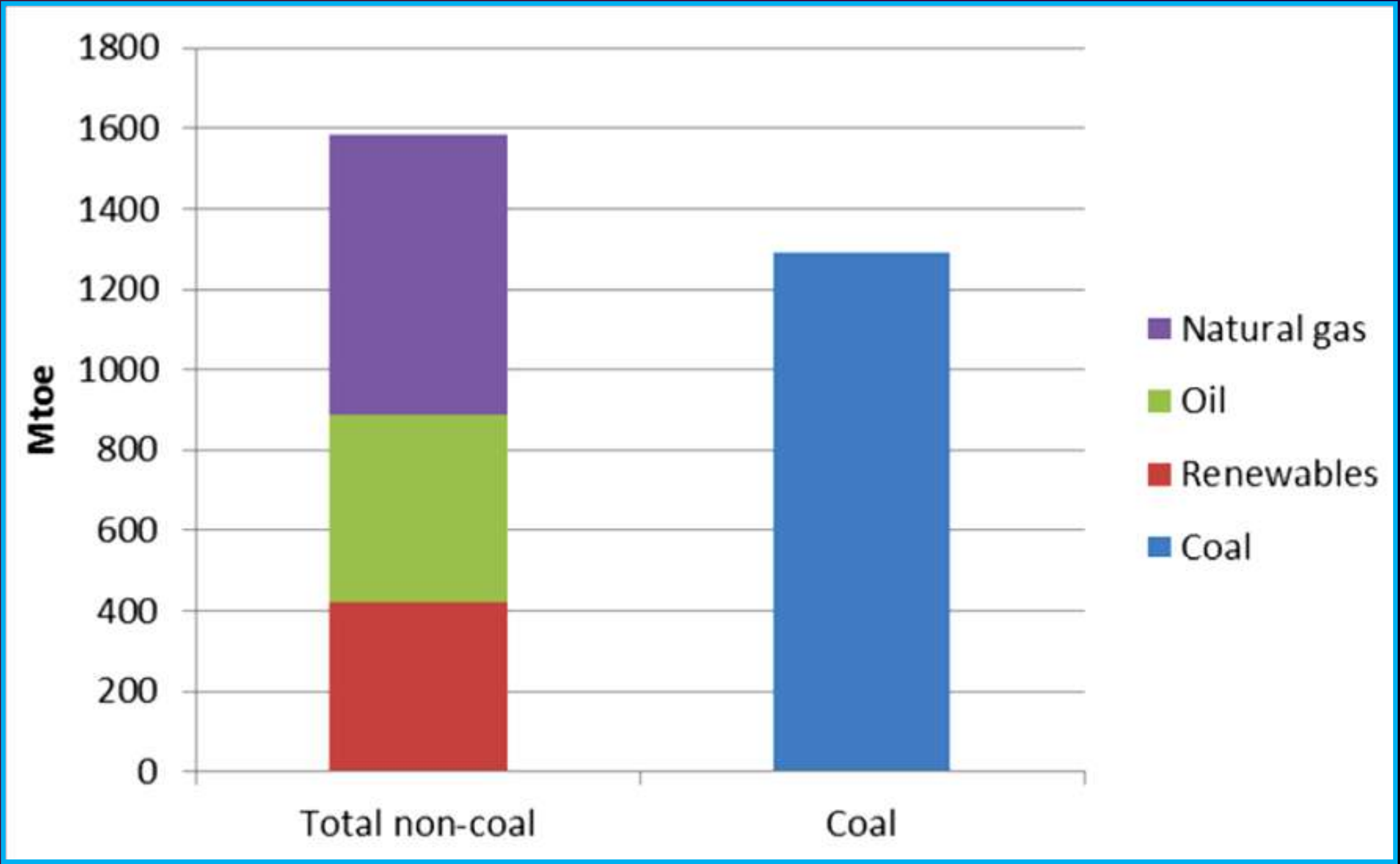
WORLD

Primary Energy Supply - 2010



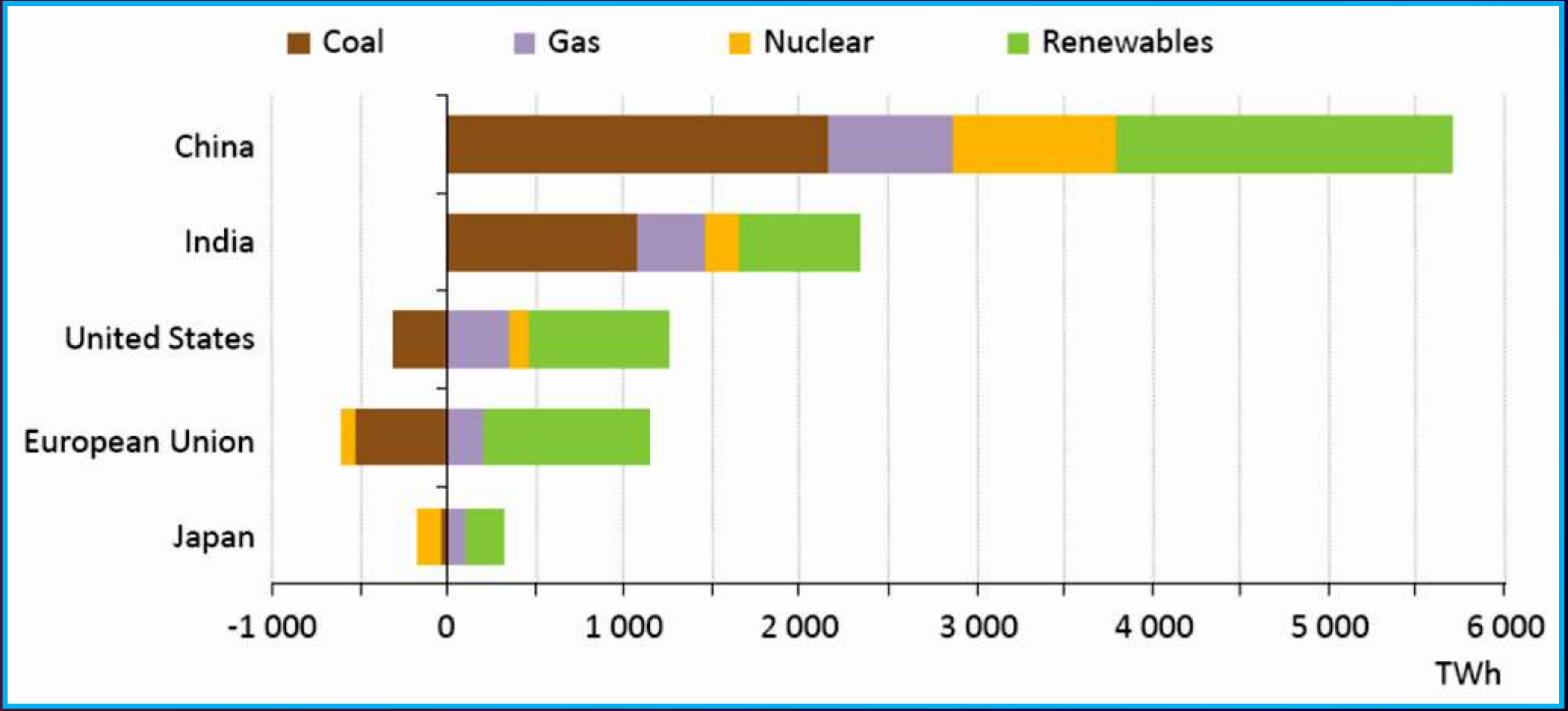
Source: DGGE, Eurostat, IEA, OECD and EIA/DOE (2011)
G.M. Oliveira, UFP – CIAGEB, 2012

INCREMENTAL WORLD PRIMARY ENERGY DEMAND BY FUEL, 2001-2011



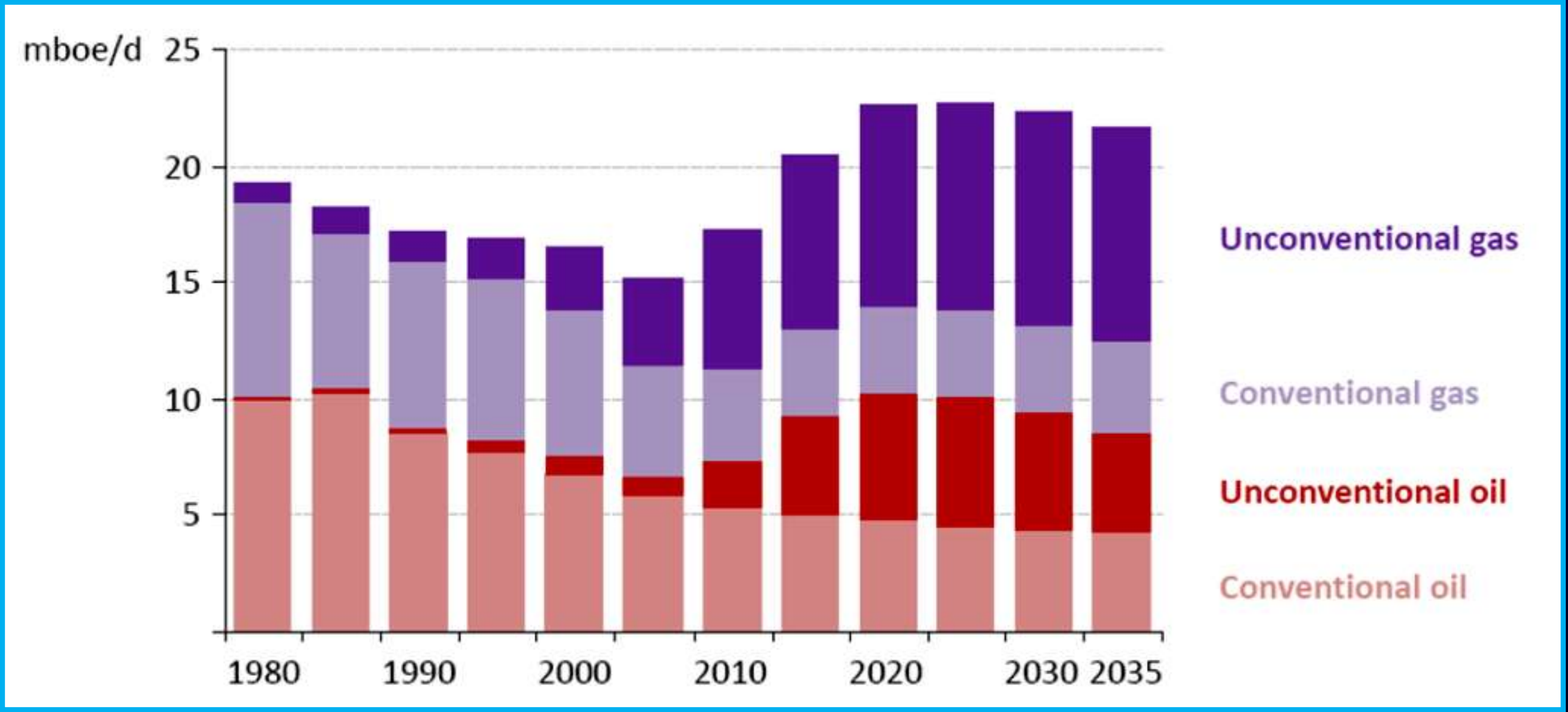
IEA World Energy Outlook, 2012

CHANGE IN POWER GENERATION FOR SELECTED PARTS OF THE WORLD, 2010 – 2035



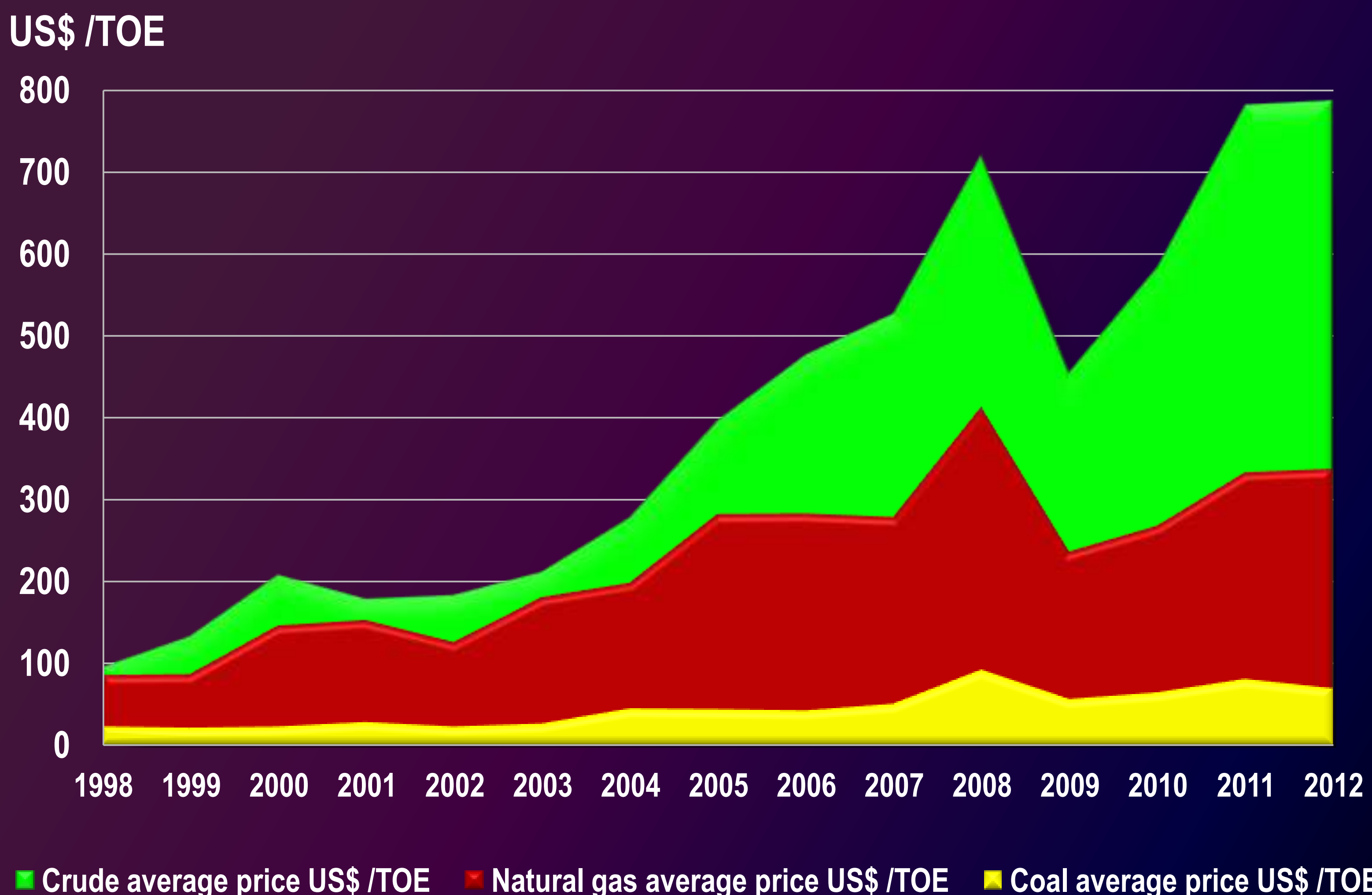
IEA World Energy Outlook, 2012

HISTORIC AND FORECASTED US OIL AND GAS PRODUCTION



IEA World Energy Outlook, 2012

COMPARISON OF FOSSIL FUELS AVERAGE PRICES



G.M. Oliveira, UFP – CIAGEB, 2013

Data from BP - *British Petroleum* (2013). BP Statistical Review of World Energy - June 2013. BP statistical review

Energy Scenario

EUROPE

Energy New Scenario

The energy sector enters in a **TOTAL NEW STRATEGIC CYCLE**

SUSTAINABLE GLOBAL ENERGY SUPPLY

REDUCTION OF GREENHOUSE GASES (GHG) EMISSIONS

CARBON Dioxide (and other GHG) TRADING SYSTEM

CARBON (Climate) EXCHANGE MARKETS

- GHG Allocation Plans
- Monitoring GHG Emissions
- Standardised and Secure System of GHG Emissions Registries

✓ UNFCCC
✓ Kyoto Protocol

- ED 2003/87/EC October 13
- ED 2004/101/EC October 27 (“Linking Directive”)

Diverse Decisions, Regulations, etc

Correspondent National Legislation

“European GHG Emissions Allowances Trading Scheme”

Additionally, in Europe

- The **2020** EU Energy Policy Target and Objectives – The need for action
- Europe's Climate Change Opportunity
- Energy for a Changing World

20(30) 20 20 → 2020

"Proposal for a Directive … on Geological Storage of Carbon Dioxide …" (Jan 2008)

P. Russ, T. Wiesenthal, D. van Regemorter and J.C. Ciscar
"Global Climate Policy Scenarios for 2030 and beyond; Analysis of Greenhouse Gas Emission Reduction Pathway Scenarios with the POLES and GEM-E3 models"
European Commission 2007

"Limiting Global Climate Change to 2 degrees Celsius – The way ahead for 2020 and beyond"
January 10, 2007

European Council Climate – Energy Legislative Package

April 6, 2009

Directive 2009/31/EC

of the European Parliament and of the Council of 23 April 2009 on Geological Storage of Carbon Dioxide

(Official Journal June 5, 2009)

Portugal: DL 60/2012, March 14

European strategy evolution

20 20 20 to 2020

An Energy Policy for Europe (2007)

Limiting Global Climate Change to 2 degrees Celsius – The way ahead for 2020 and beyond (2007)

Energy 2020

The Energy 2020: A strategy for competitive, sustainable and secure energy (2007)

Energy Roadmap 2050

The Energy 2020: Energy Roadmap to 2050 (2011)

EUROPEAN UNION LEGAL FRAMEWORK ENERGY – CLIMATE

2008

Climate Action
Energy for a Changing World

2010

2011

Strategy 2020
"20 20 20 by 2020"

Goals:

- **20% reduction of GHG emissions (1990)**
- **20% reduction of energy consumption by energy efficiency gain**
- **20% of energy by renewable sources**

Energy Strategy 2020
Europe 2020 Strategy

Goals:

2008 objectives are included in a global development scenario for sustainable competitivity and energy security

Energy Roadmap 2050

Goals:

- **40% reduction of GHG emissions until 2030**
- **60% reduction of GHG emissions until 2040**
- **80 – 95% reduction of GHG emissions until 2050**

EU MOVING FORWARD (1)

EUROPEAN
COMMISSION

Brussels, 27.3.2013
COM(2013) 169 final

GREEN PAPER

A 2030 framework for climate and energy policies

EU MOVING FORWARD (2)

EUROPEAN
COMMISSION

Brussels, 27.3.2013
COM(2013) 180 final

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

on the Future of Carbon Capture and Storage in Europe

EU MOVING FORWARD (3)

EUROPEAN COMMISSION

MEMO

Brussels, 27 March 2013

Consultative Communication on the future of Carbon Capture and Storage in Europe

EUROPEAN STRATEGY

Europe 2020 initiative - Energy 2020

"A strategy for competitive, sustainable and secure energy"

http://ec.europa.eu/energy/strategies/2010/2020_en.htm

European Commission and Directorate-General for Energy, 2011. Energy 2020 - a strategy for competitive, sustainable and secure energy. Publications Office of the European Union, Luxemburg, pp. 28.

http://ec.europa.eu/energy/publications/doc/2011_energy2020_en.pdf

Communication from the commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "Energy 2020: A strategy for competitive, sustainable and secure energy", Brussels, 10.11.2010. COM(2010) 639 final, pp.21.

http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0639:FIN:EN:PDF

EUROPEAN STRATEGY

Europe 2020 initiative - Energy 2020

Targets

- Employment
- R&D / Innovation
- Climate change / Energy
- Education
- Poverty / Social exclusion

The new energy strategy focuses on five PRIORITIES

- Achieving an energy efficient Europe;
- Building a truly pan-European integrated energy market;
- Empowering consumers and achieving the highest level of safety and security;
- Extending Europe's leadership in energy technology and innovation;
- Strengthening the external dimension of the EU energy market.

Priority 4

Extending Europe's leadership in energy technology and innovation

Action 1: Implementing the SET Plan without delay

The European Strategic Energy Technology Plan - Towards a low-carbon future
http://ec.europa.eu/energy/technology/set_plan/set_plan_en.htm

CCS Technologies

Technology Roadmaps for 2010-2020

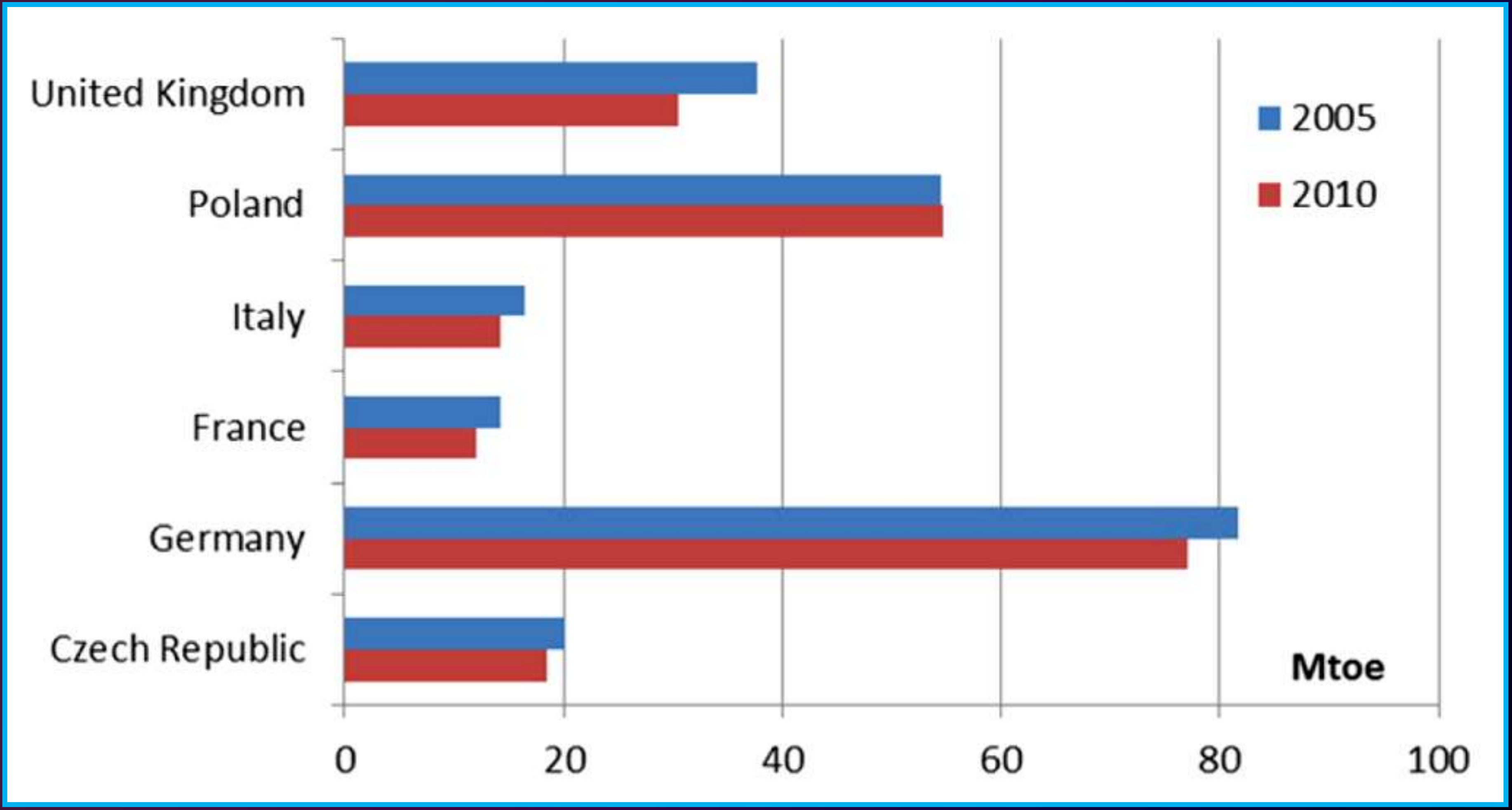
EUROPEAN STRATEGY

Energy Roadmap 2050

"Forecasting the long-term future is not possible. The scenarios in this Energy Roadmap 2050 explore routes towards decarbonisation of the energy system. All imply major changes in, for example, carbon prices, technology and networks. A number of scenarios to achieve an 80% reduction in greenhouse gas emissions implying some 85% decline of energy-related CO2 emissions including from transport, have been examined."

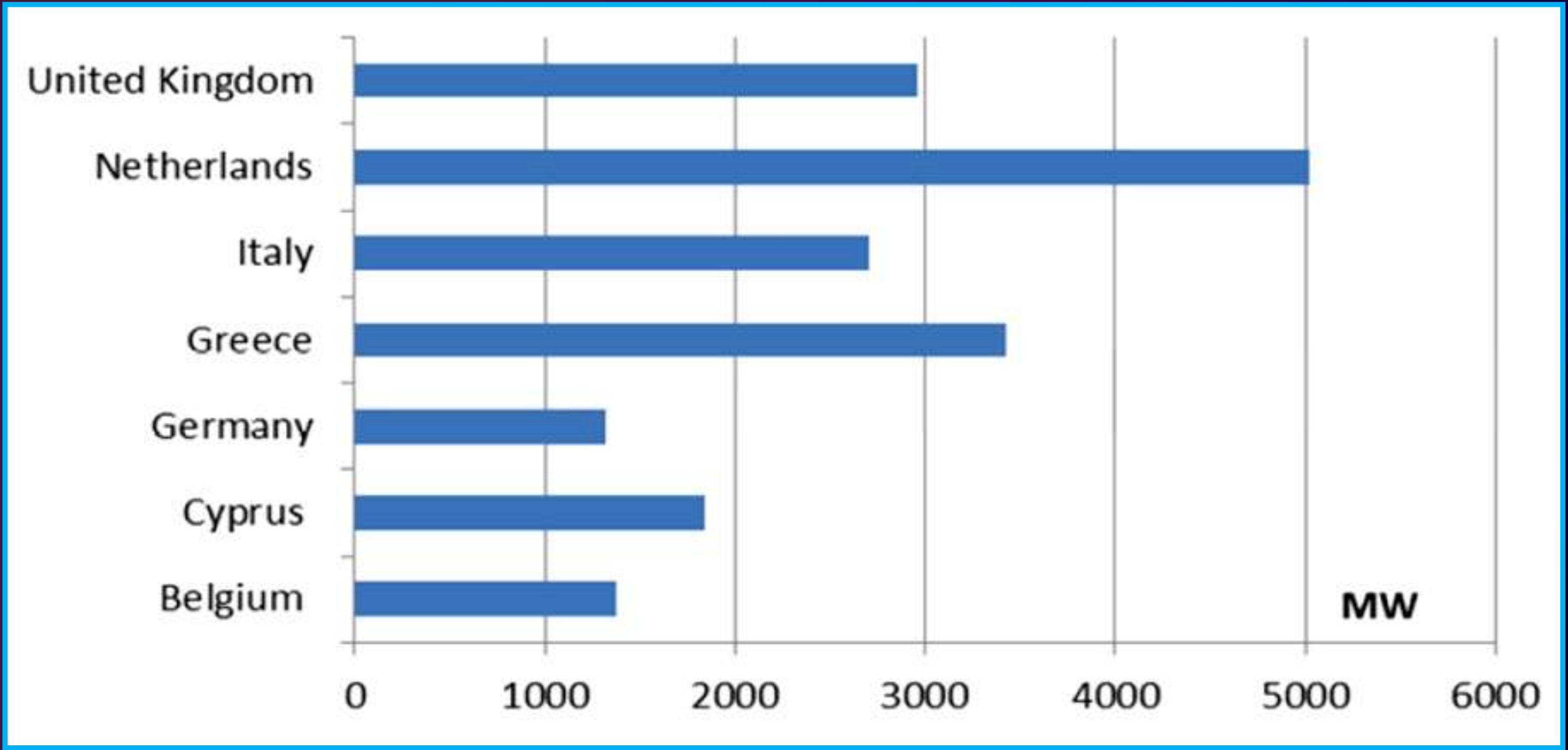
"Coal in the EU adds to a diversified energy portfolio and contributes to security of supply. With the development of CCS and other emerging clean technologies, coal could continue to play an important role in a sustainable and secure supply in the future."

MAIN CONSUMERS OF COAL IN THE EU FOR 2010



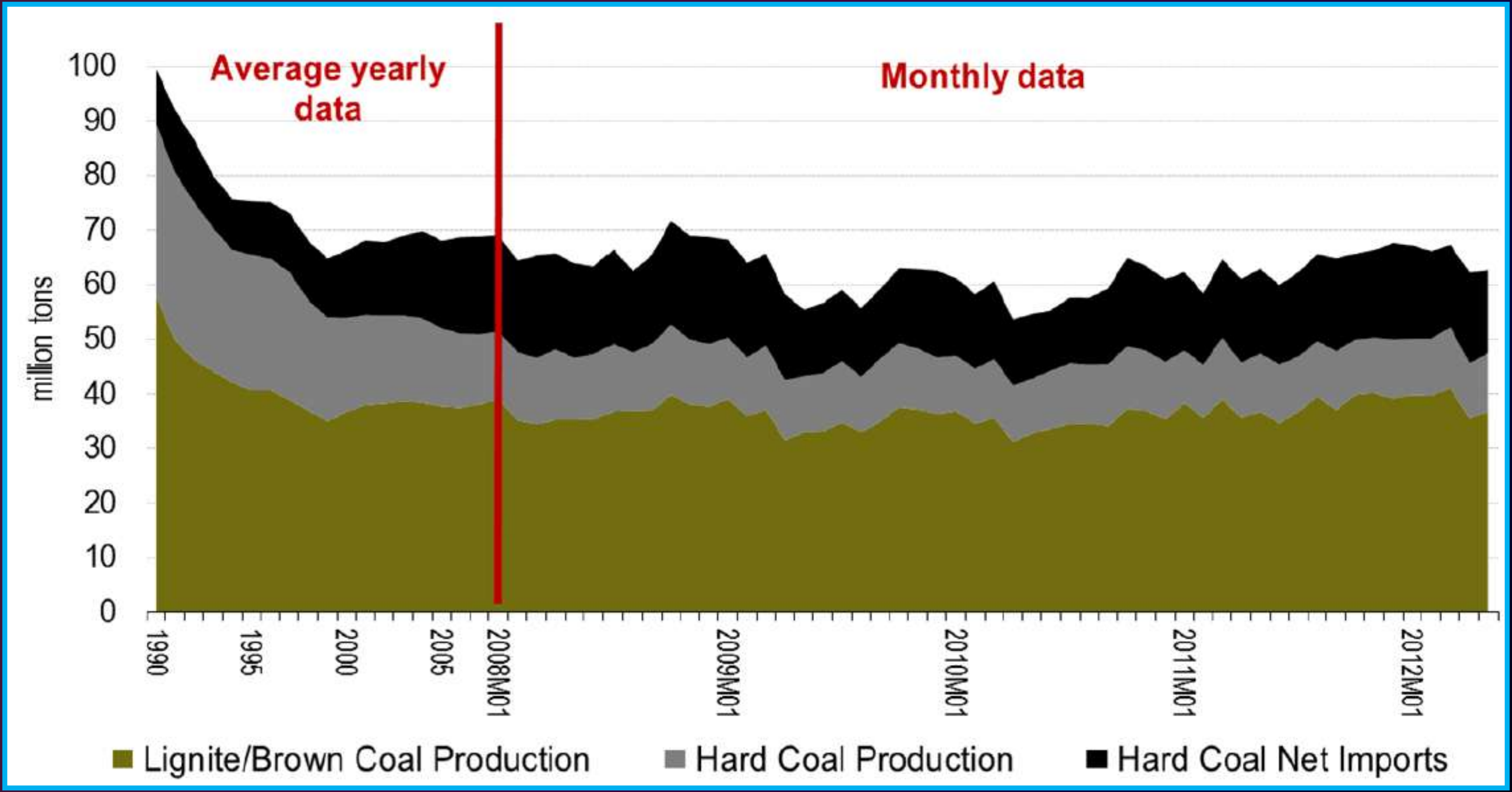
Eurostat

MAIN MEMBER STATES WHERE GAS POWER PLANTS ARE UNDER CONSTRUCTION



EU Member States' notifications

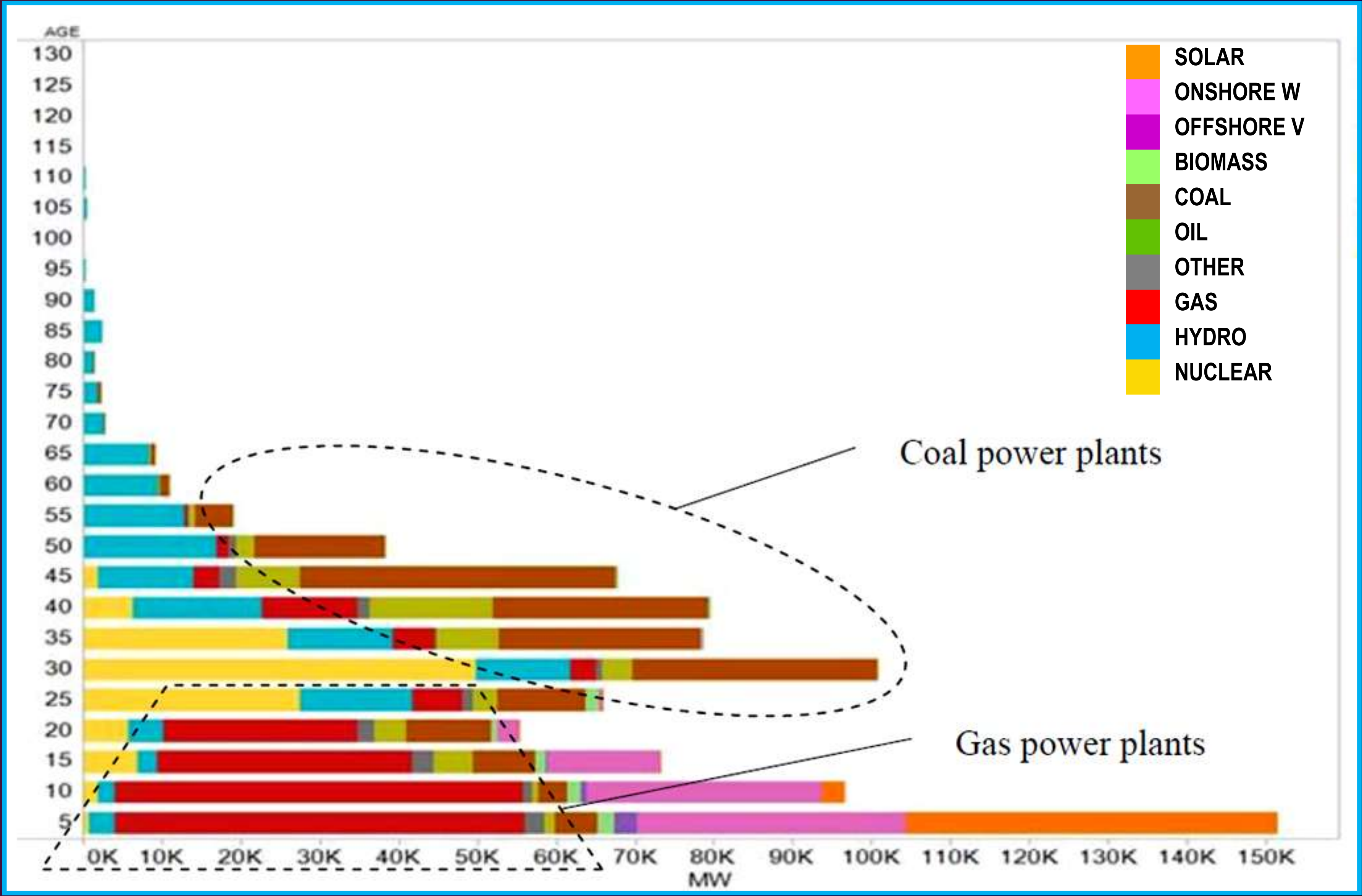
COAL CONSUMPTION DEVELOPMENTS IN THE EU OVER THE LAST 20 YEARS (including May 2012)



IEA World Energy Outlook, 2012

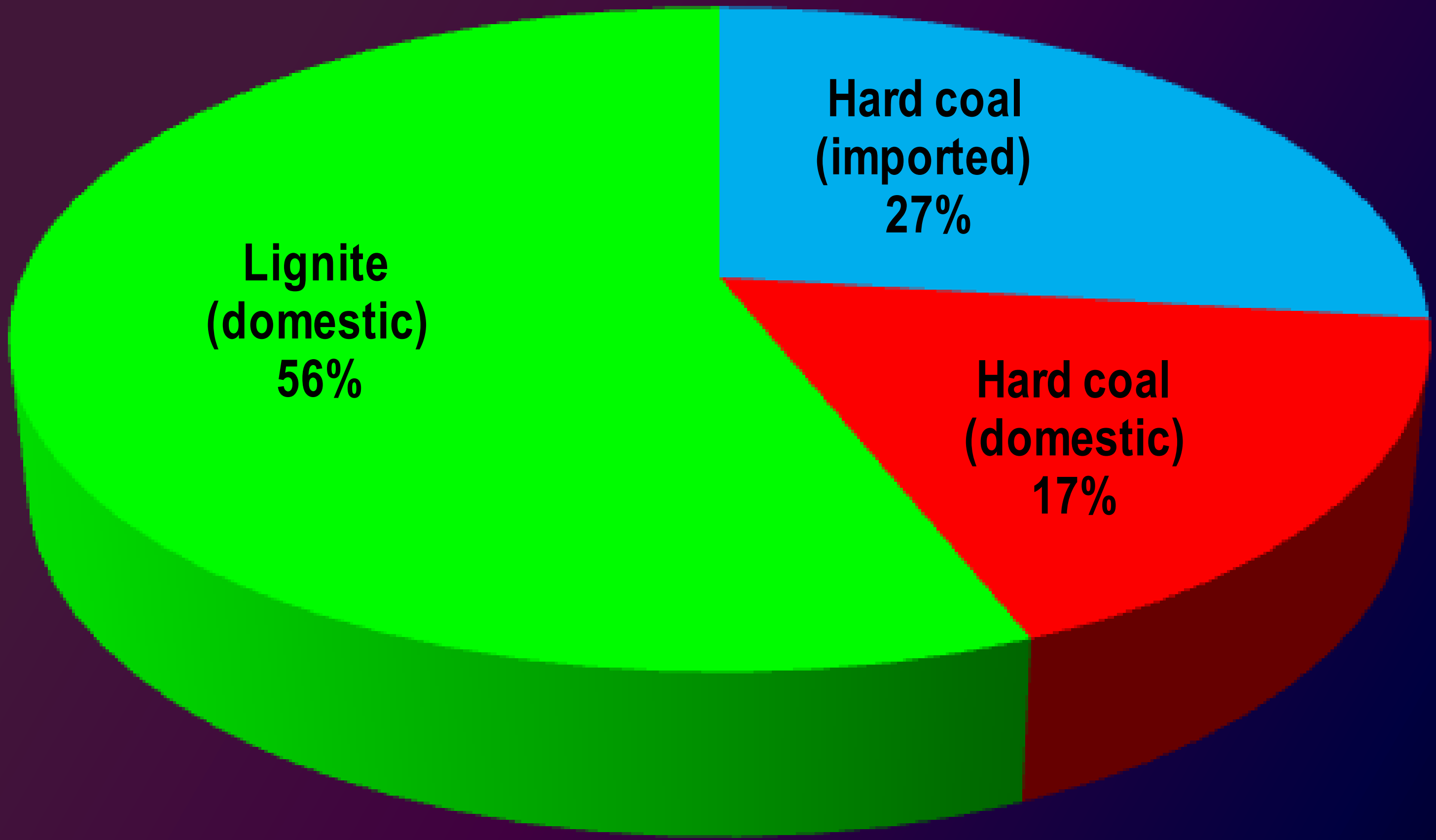
Note that to the left of the bar are yearly data back to 1990, while monthly data are shown for the period after 1/01/2008 to the right.

AGE STRUCTURE OF EUROPE'S ELECTRICITY GENERATION



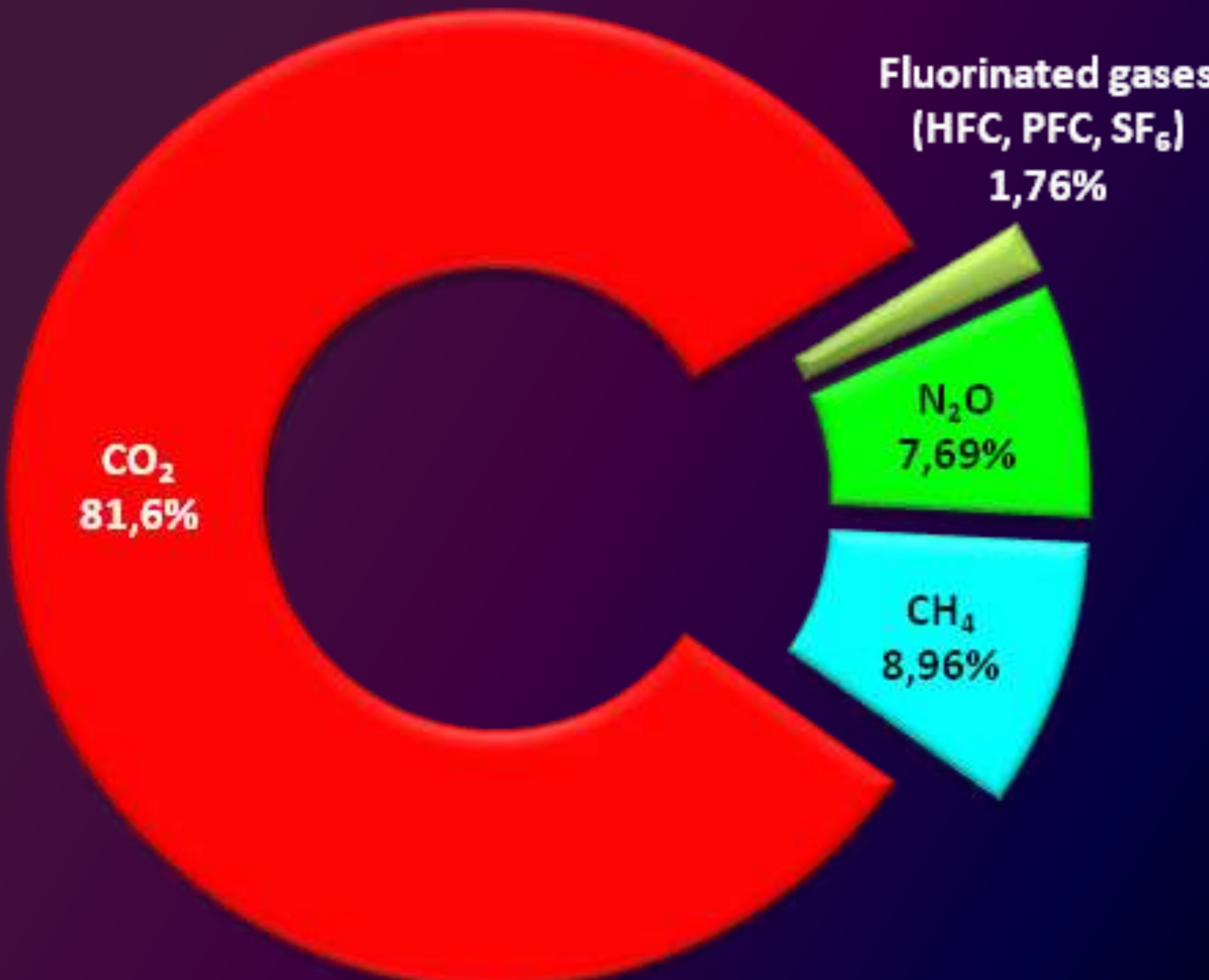
Platts

COAL USE IN THE EU IN 2010



Eurostat

Share of total greenhouse gases EU27 - 2009



Source: EEA (2012)

THE REAL PROBLEM

Is the European Union able to:

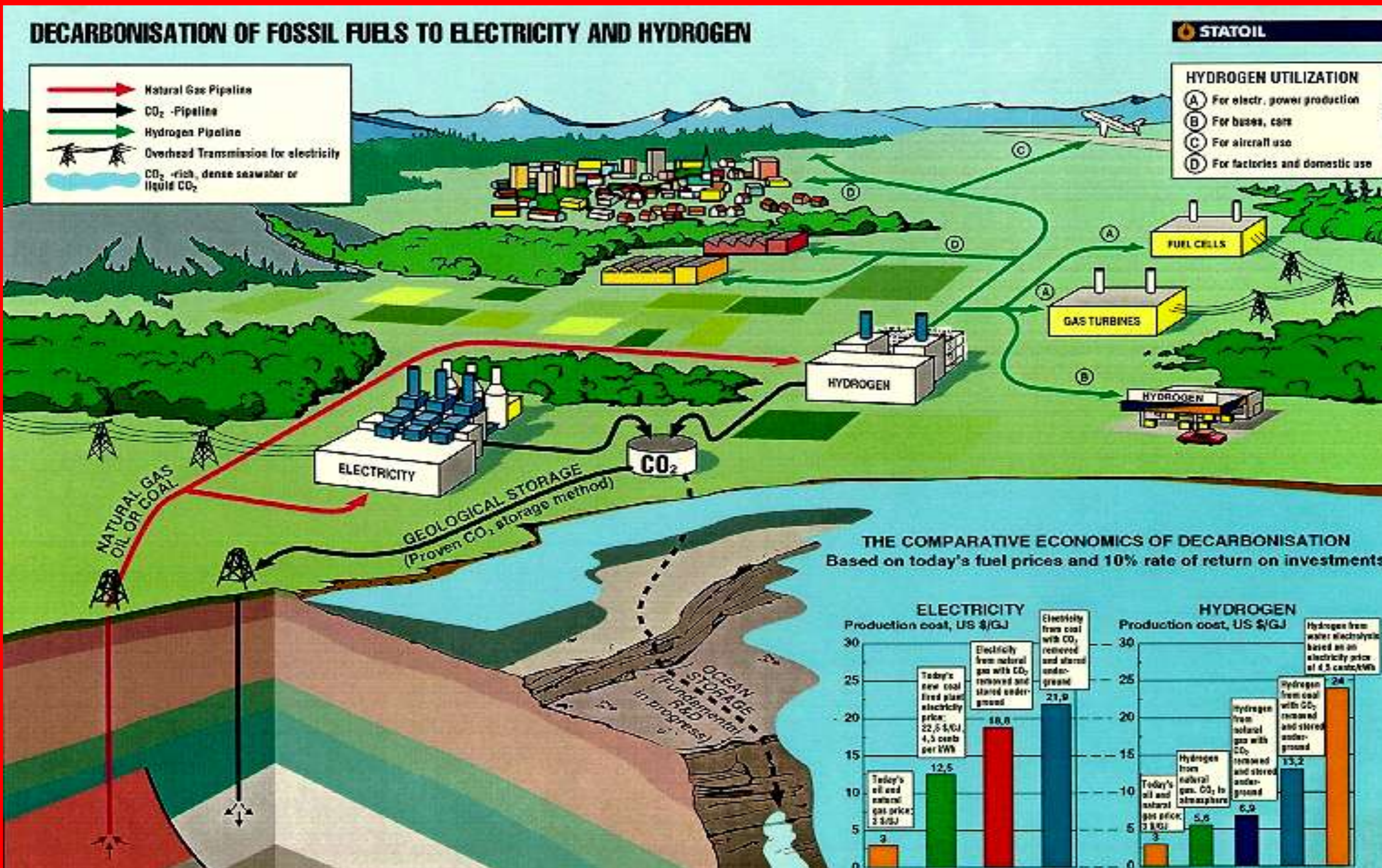
- **reduce fossil fuel industrial emissions by CO_2 capture + sequestration/storage, and**

- **implement CO_2 capture + storage technologies economically, i.e., in a competitive way with the emissions allowance trading system of the EU Directives 2003/87/EC and 2004/101/EC,**

thereby permitting medium and long term sustainable competitiveness, both in energy production and industrial development ?

M. Lemos de Sousa and C.F. Rodrigues, UFP – CIAGEB 2008

Vision of a Clean Future



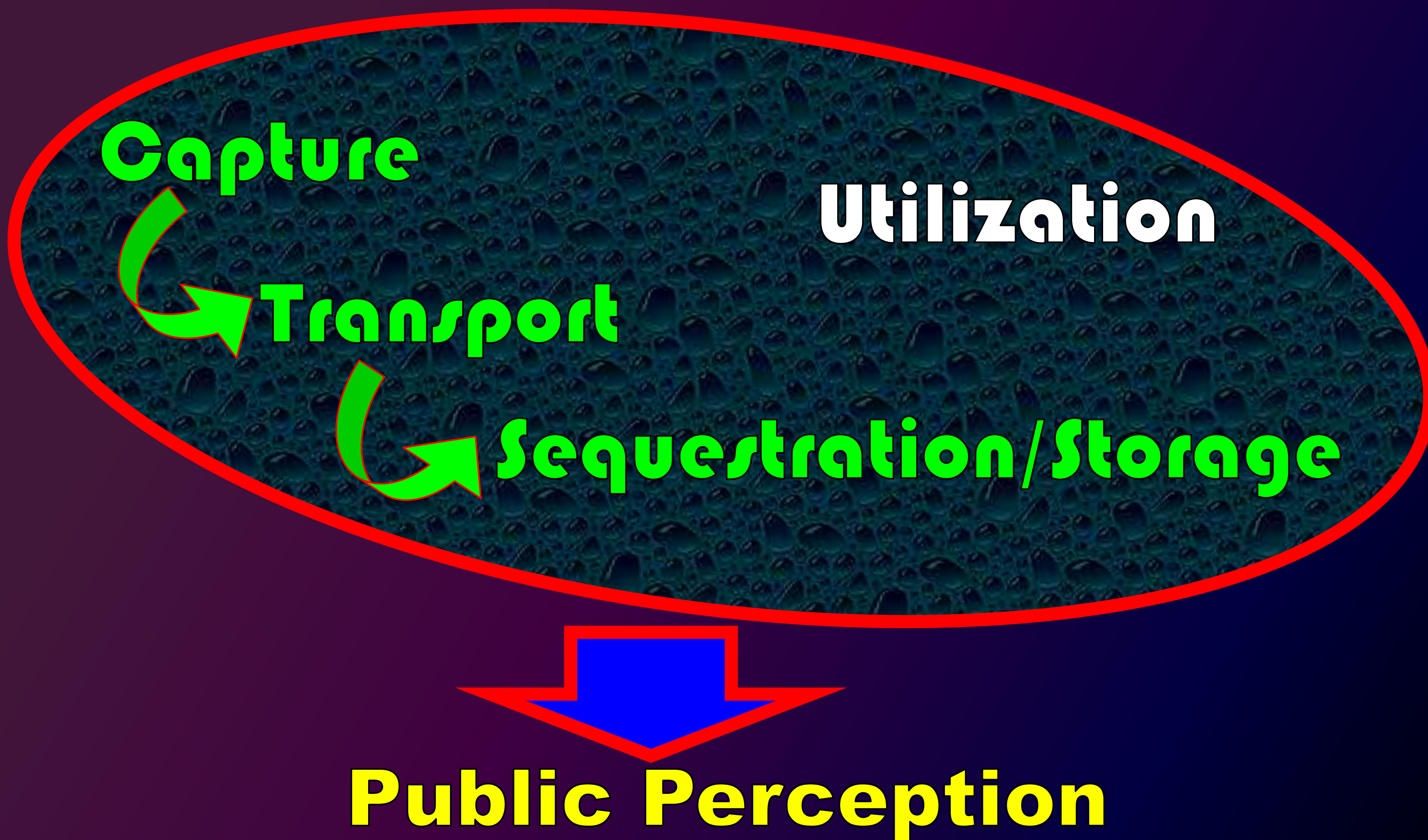
European Commission DG TREN / C: Conventional Energy

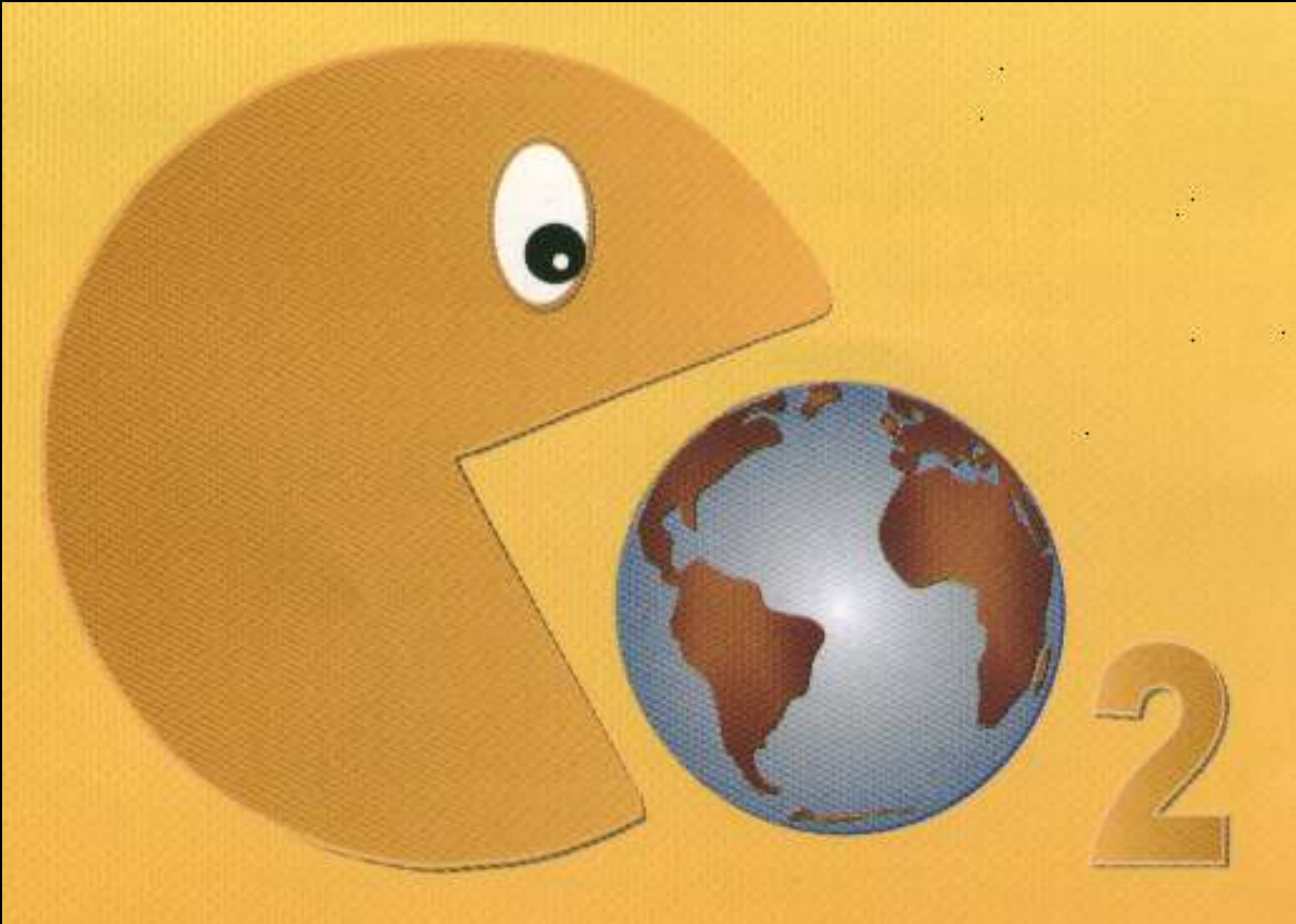
2. CCS TECHNOLOGIES

THE GENERAL PROBLEM

Reducing CO_2 emissions a major focus of EU energy policy

CC(U)S TECHNOLOGIES




2

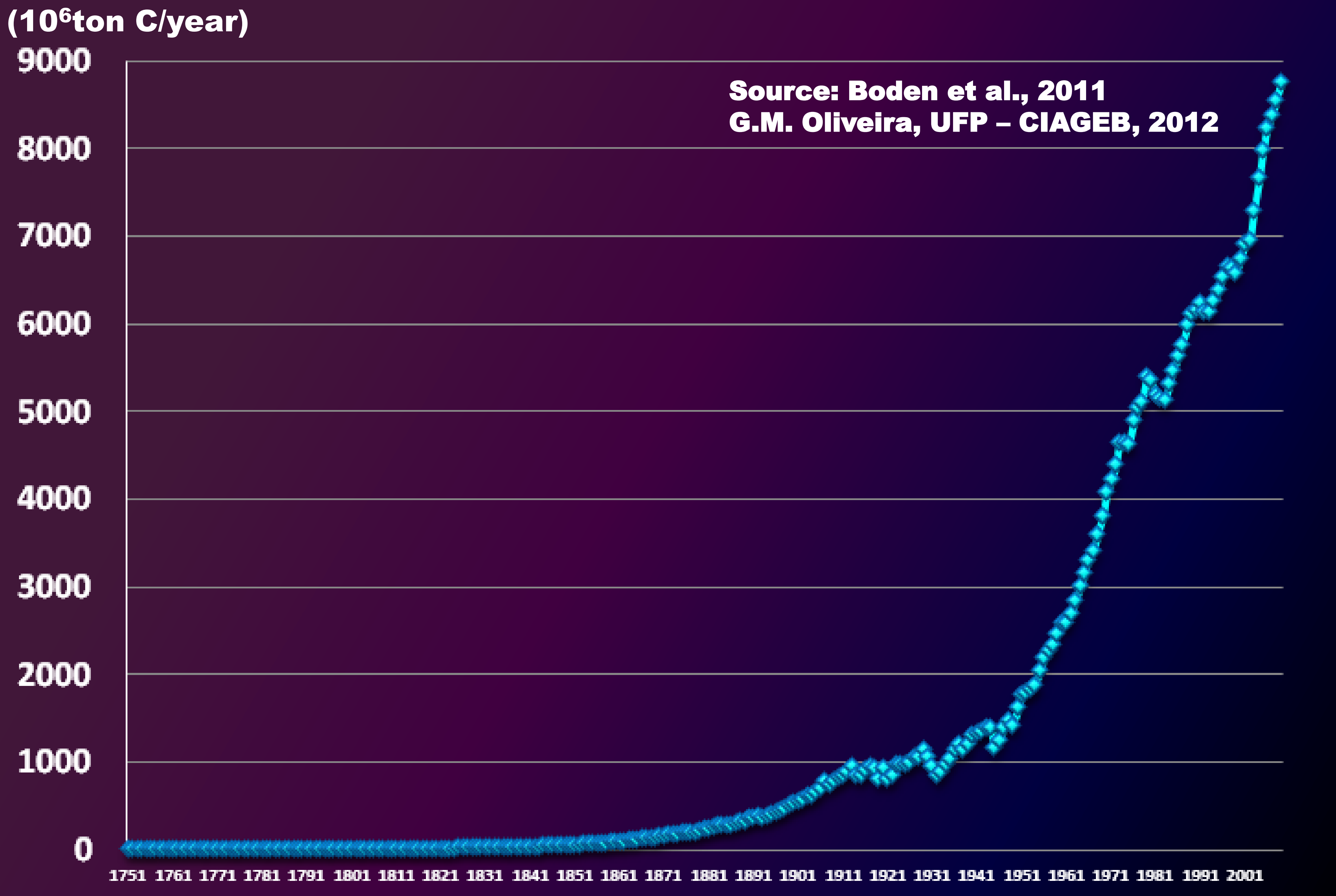

The Economist
JULY 6TH–12TH 2002
Vivendi's fall from grace
PAGES 12 AND 62
The politics of America's scandals
PAGE 43
Why Arab countries have failed
PAGES 24-26
THE GLOBAL ENVIRONMENT
SURVEY, AFTER PAGE 52
CO_2AL
Environmental enemy No.1


I ♥
CLEAN COAL

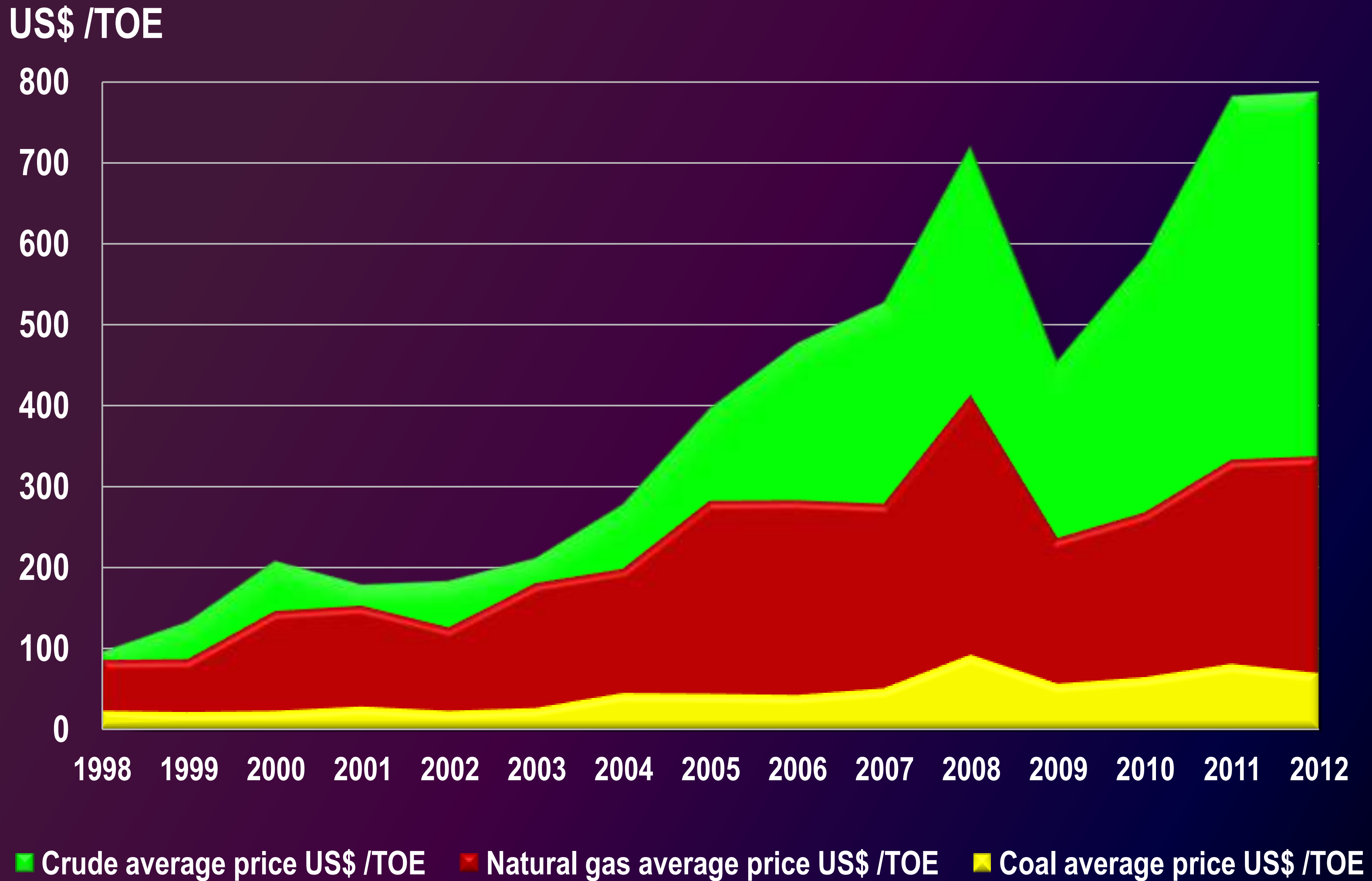

I
CLEANER
COAL

Global average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding.

GHG concentration in atmosphere and CCS



COMPARISON OF FOSSIL FUELS AVERAGE PRICES



G.M. Oliveira, UFP – CIAGEB, 2013
Data from BP - *British Petroleum* (2013). BP Statistical Review of World Energy - June 2013.
BP statistical review

ENVIRONMENTAL

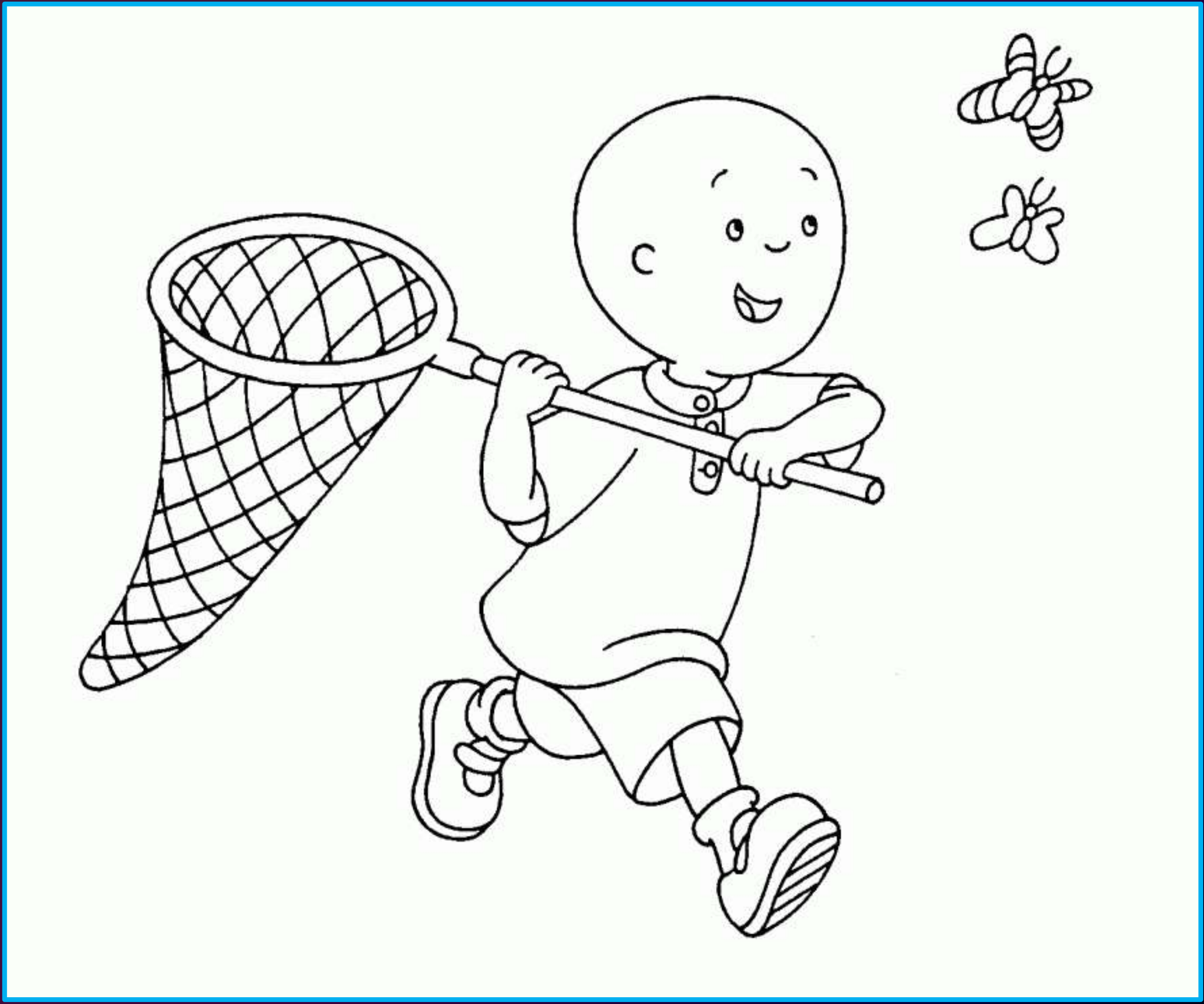
POLITICS

CO_2 ABATEMENT

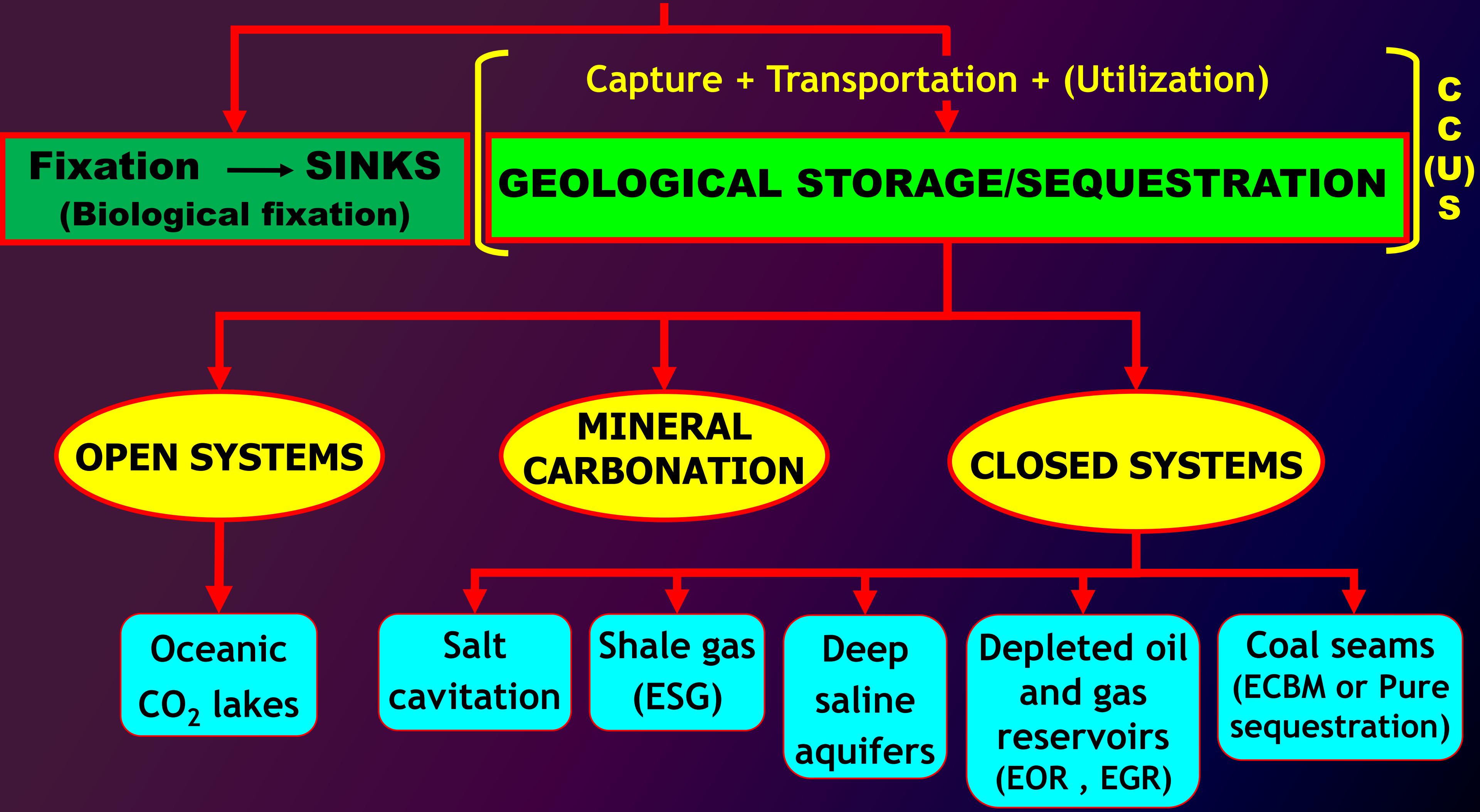
SOCIAL

ECONOMICS

REMOVING CO_2 FROM THE ATMOSPHERE

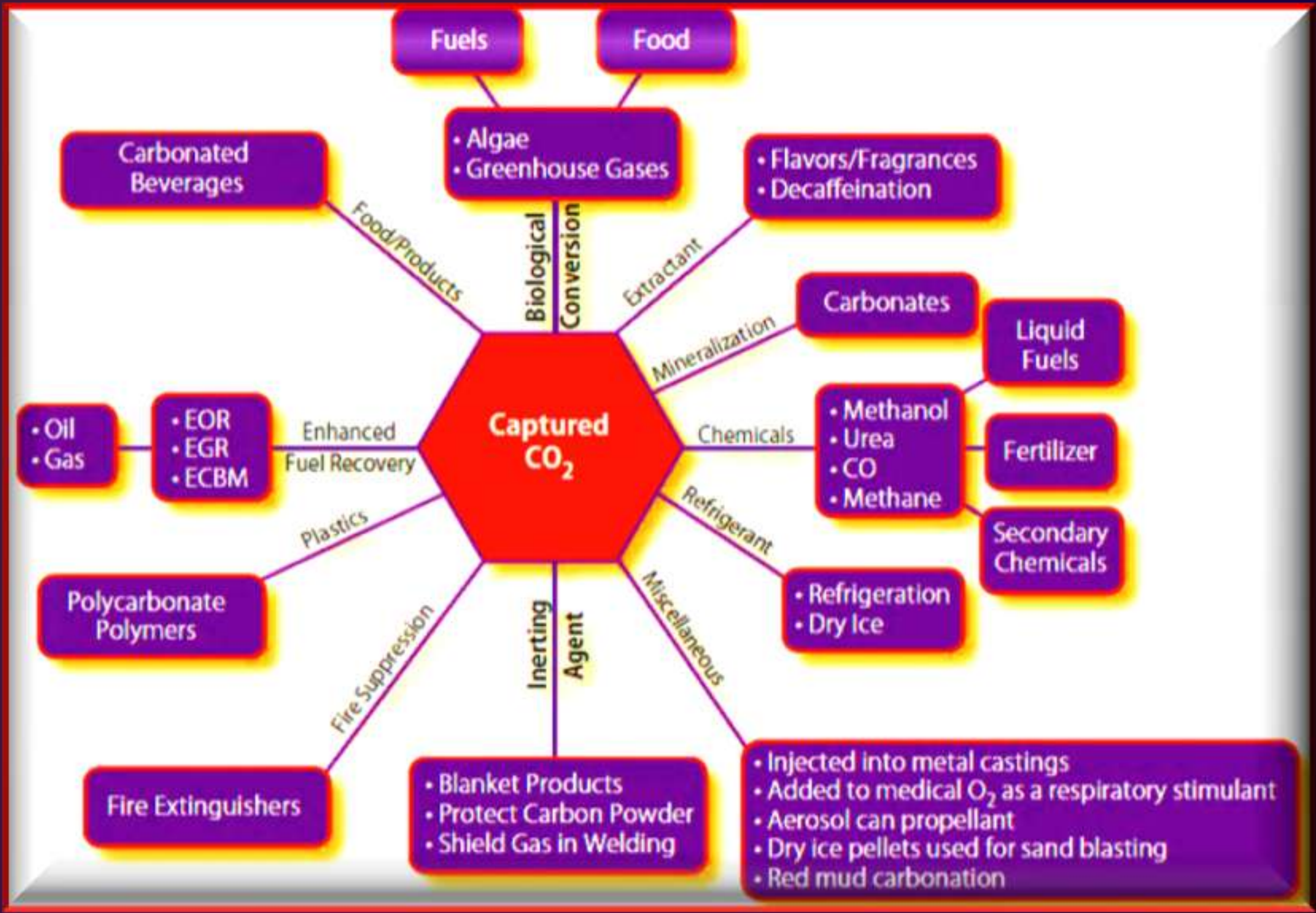


CO_2 ABATEMENT: State-of-the-art



M. Lemos de Sousa and C.F. Rodrigues, UFP – CIAGEB, 2012

DIAGRAM SHOWING THE VARIED AND PLENTIFUL CURRENT AND POTENTIAL USES OF CO_2

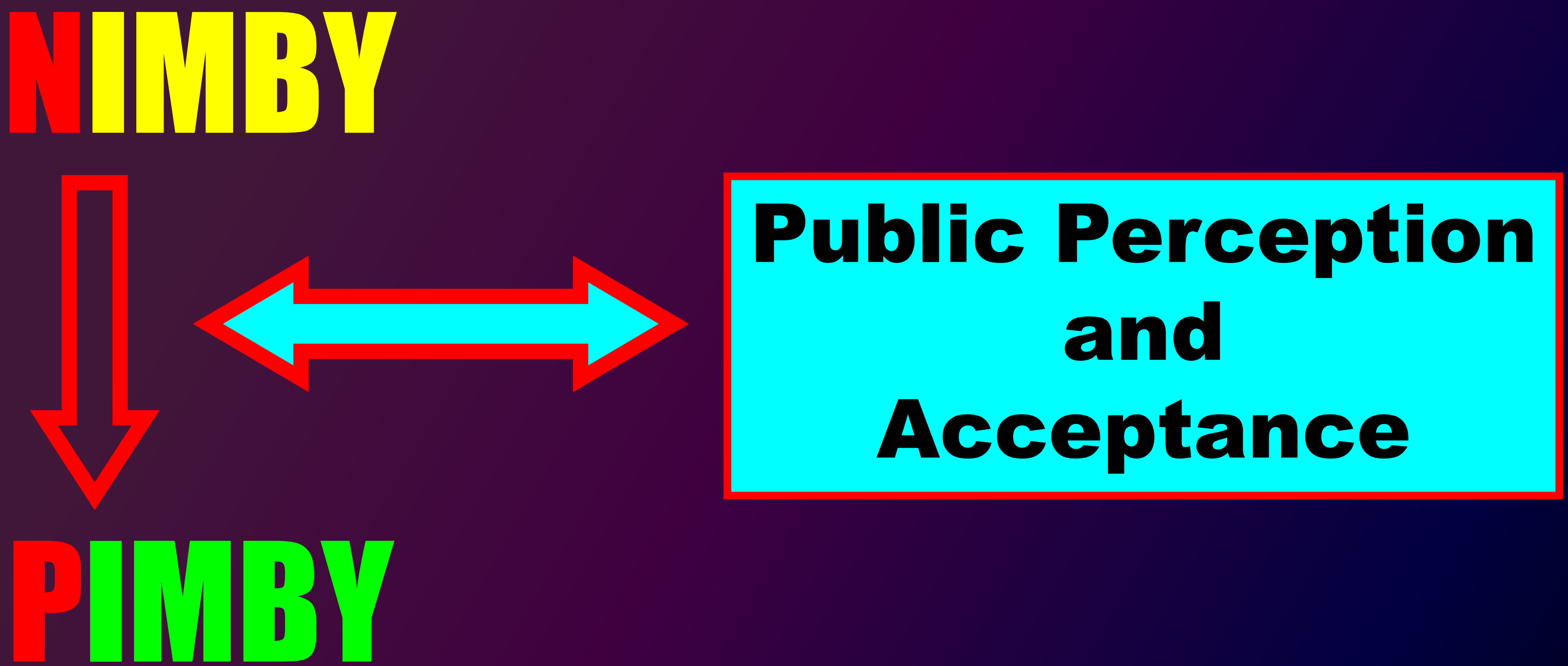


CSLF, 2011

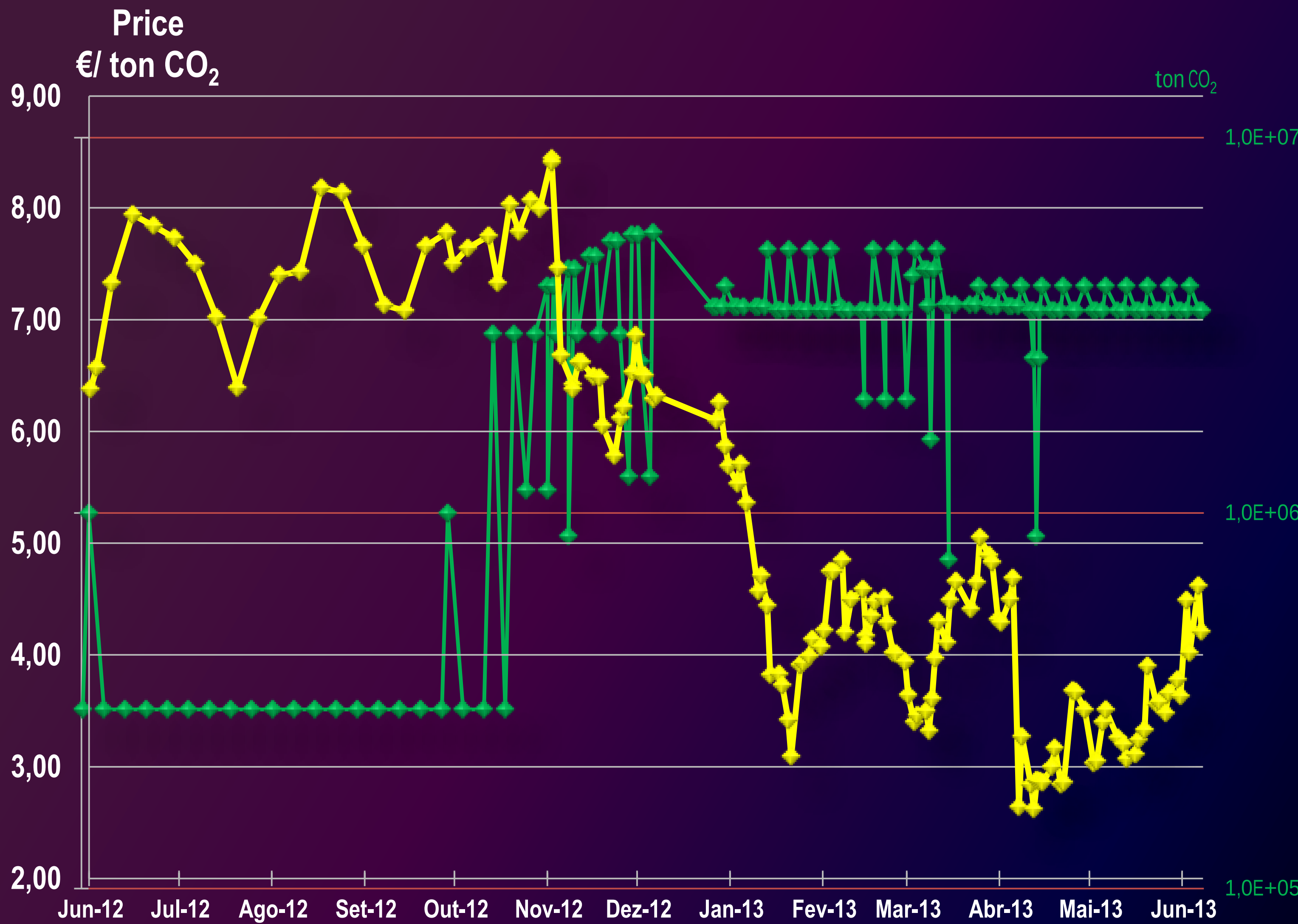
carbon
sequestration leadership forum

IEA GREENHOUSE GAS R&D PROGRAMME

CO2CRC


NIMBY
PIMBY
Public Perception
and
Acceptance

EVOLUTION OF CO_2 AUCTION PRICES AND QUANTITIES



G.M. Oliveira, UFP – CIAGEB, 2013

Data from EEX – European Energy Exchange, available online:

https://www.eex.com/en/Download/Market-Data/EU%20Emission%20Allowances%20-%20EEX

- **Feasibility - Pilot Projects (100% risk)**
  - ✓ **Technical viability** → Field Scale / → Laboratory Scale
  - ✓ **Modeling** → Model validation
  - ✓ **Implementation – Security of storage by:**
    - Estimation of storage capacity potential
    - Long term Risk Assessment
  - ✓ **Economic viability** (Technology costs *vs* Allowances trading costs)
- **Commerciality - Industrial Project**

M. Lemos de Sousa and C.F. Rodrigues, UFP – CIAGEB 2009

CO_2 Geological Sequestration

The FEASIBILITY of any project depends on:

1. Public Perception and Acceptance	
2. Security of Storage ➢ Estimation of storage capacity potential Standards Screening of sites ➢ Long term risk assessment	Technical viability
3. Natural Analogues	Technical viability
4. Commercial Analogues	Economic viability

Adapted from DOE-NETL/CSLF and CO2CRC main concepts

M. Lemos de Sousa and C.F. Rodrigues, UFP – CIAGEB 2009

ANALOGUES are data compilations or case studies of areas with high quality data (modern, outcrop or subsurface), which can be used to provide levels of expected heterogeneity for a reservoir of a given depositional setting.

Kaldi & Gibson-Poole 2008

Unconventional Reservoir Efficiency for long term CO_2 storage

Reservoir Characteristics

		Coal	Saline Aquifer
Reservoir	Gas storage (gas state)	Adsorption (surface area) + Absorption (cleat) (Naturally in "liquid like" state) + (gaseous or liquid)	Absorption (pore volume) (Liquid or gaseous depending on P and T)
	Gas flow	Diffusion (Low) + Laminar (Low)	Laminar (High)
Caprock/seal		Coal is simultaneously source-rock, reservoir, caprock and trap	**Independent** caprock (pelitic sediments and/or structural features)
Trap		Ibid	**Independent** trap (vital to avoid gas leakage)
Depth		Any depth	Depth compatible with the presence of saline water

C.F. Rodrigues and M.J. Lemos de Sousa, UFP – CIAGEB 2009

Unconventional Reservoir Efficiency for long term CO_2 storage

(continuation)

Technological Characteristics

	Coal	Saline Aquifer
Leakage risk	2% - 5% of gas injected, depending on "cleat system"	Wide range of variation, depending mainly on tectonic settings and/or seal characteristics
Gas injection state	Gaseous (except for seams at high depths)	Liquid
Reservoir water behaviour	Water disposal corresponds to free moisture, mostly in the "cleat system" (2% - 5%)	Water disposal volume similar to CO_2 injected volume; only 5% to 7% will dissolve (long term) in water
Frequent Criticism about reservoir eventual future use	New Coal Technologies ???	Needs of fresh water obtained by desalination !!!

C.F. Rodrigues and M.J. Lemos de Sousa, UFP – CIAGEB 2009

2. THE EASAC REPORT

easac European Academies Science Advisory Council

EASAC CCS Working Group

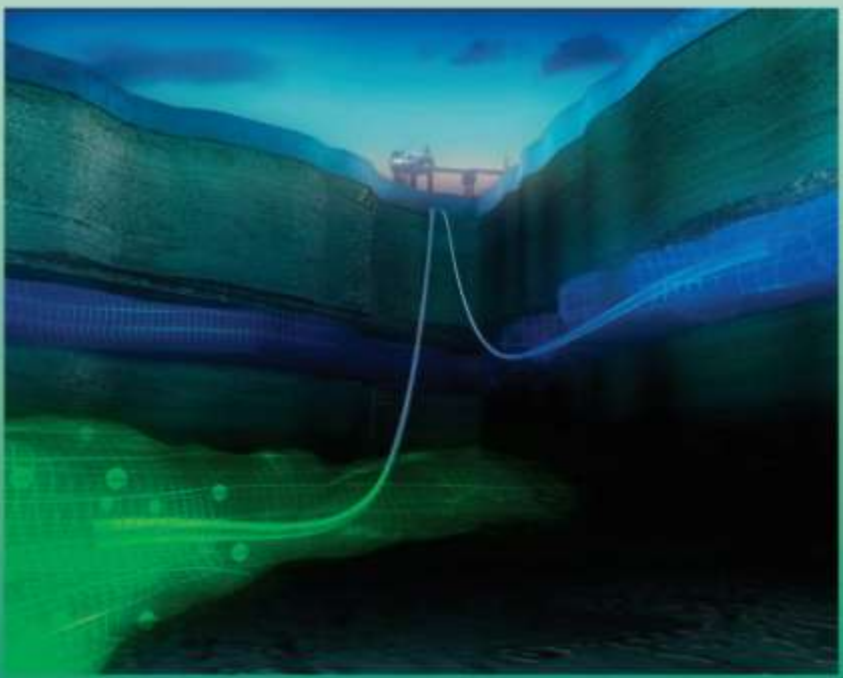
1st meeting, 26-27 October 2011, University of Cambridge

European Academies

easac

Science Advisory Council

Carbon capture and storage in Europe



EASAC policy report 20

May 2013

ISBN: 978-3-8047-3180-6

This report can be found at www.easac.eu

building science into EU policy

THE EASAC CCS TECHNOLOGIES WG

- Professor Per Aagaard, University of Oslo, Norway
- Professor Peter Balaz, Slovak Academy of Sciences, Slovakia
- Professor Vicente Cortes, University of Seville, Spain
- Professor Hans Hasse, University of Kaiserslautern, Germany
- Dr John Holmes, Secretary to the EASAC Energy Programme
- Professor Herbert Huppert (Chair), University of Cambridge, UK
- Professor Marek Jarosinski, Polish Geological Institute, Poland
- Dr Francois Kalaydjian, IFP Energy Nouvelles, France (from February 2012)
- Professor Stefan Kaskel, Fraunhofer Institute for Materials and Beam Technology, Germany (to March 2012)
- Dr Ben Laenen, VITO, Belgium (from January 2012)
- Professor Manuel Lemos de Sousa, University Fernando Pessoa, Porto, Portugal
- Professor Marco Mazzotti, ETH Zurich, Italy
- Dr John Morris, Geological Survey of Ireland, Ireland (to June 2012)
- Professor Auli Niemi, University of Uppsala, Sweden
- Professor Rudy Swennen, Katholeike University of Leuven, Belgium (to January 2012)
- Dr Sebastian Teir, VTT Technical Research Centre of Finland, Finland
- Professor Stefan Wiemer, ETH Zurich, Switzerland

Special contributions of Dr. Cristina Rodrigues (University Fernando Pessoa, Porto, Portugal) and Ms Inga von Harbou (University of Kaiserslautern, Germany)

EASAC CCS TECHNOLOGIES WG MEETINGS

- **Meeting 1**

  Kings College, Cambridge: 26–27 October, 2011

- **Meeting 2**

  ETH, Zurich: 28–29 February, 2012

- **Meeting 3**

  Royal Belgian Academy of Sciences, Brussels: 16 May, 2012

- **Meeting 4**

  Frankfurt Airport Conference Centre: 5 July, 2012

EASAC REPORT ON CCS TECHNOLOGIES IN EUROPE

LAUNCH EVENTS

► **Brussels**

Royal Belgian Academy of Sciences, 22 May, 2013

► **London**

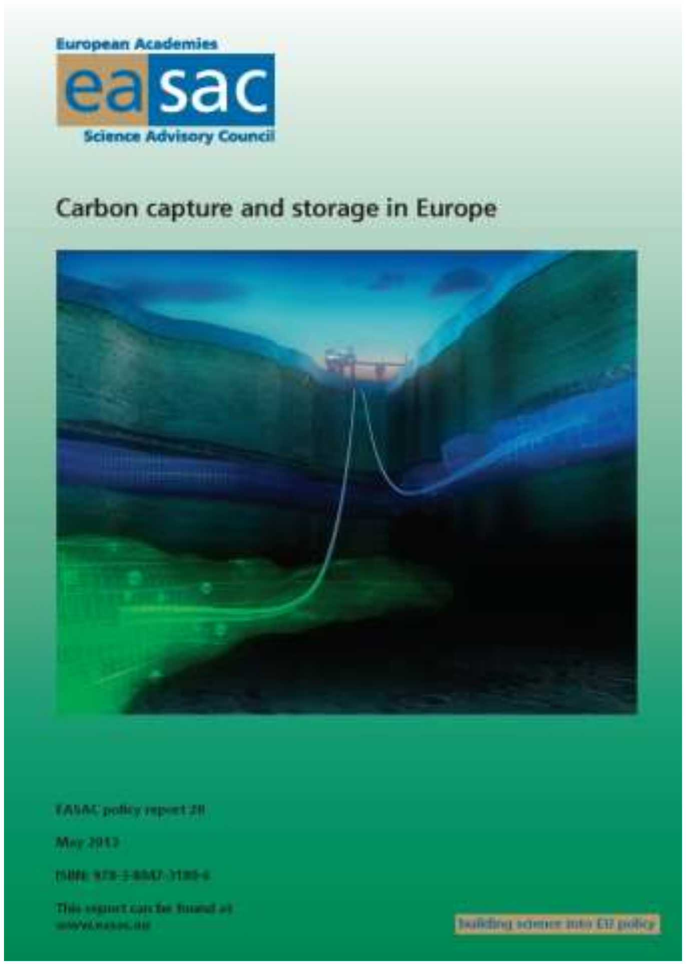
The Royal Society, 12 June, 2013

► **Lisbon**

Academia das Ciências de Lisboa, 4 July, 2013

Objectives of EASAC Study:

European Academies
easac
Science Advisory Council



- How can costs be reduced: what R&D is needed?
- How demonstrate the long term safety of storage?
- Alternative approaches to carbon sequestration?
- What contribution of CCS in Europe up to 2050?

Conclusions:

1. Capture

2. Transport

3. Storage

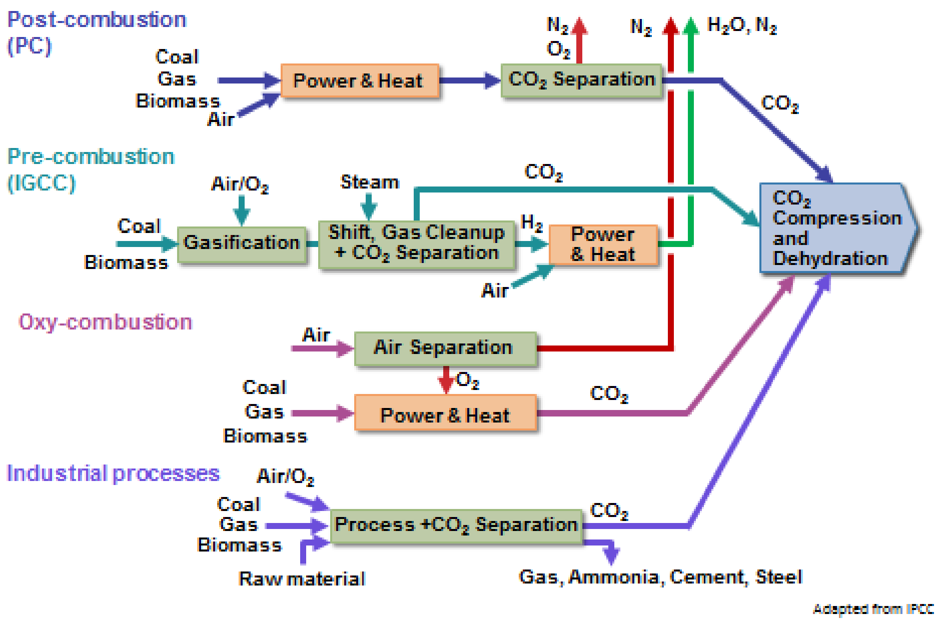
4. Alternatives

5. Public engagement

6. Prospects to 2050

Conclusions: Capture

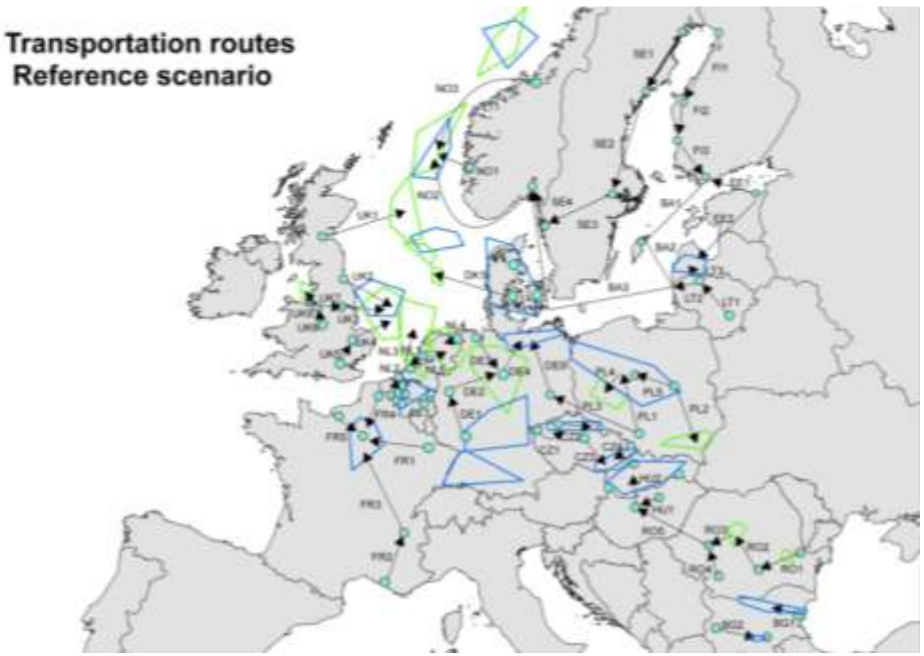
European Academies easac Science Advisory Council



Capture before or after combustion with air, or by burning with oxygen

- All feasible but commercial scale operation remains to be demonstrated
- +50% on power generation costs: developments should bring this down to +30 to 45% over next 20 years
- Adaptation for industry: beware ‘carbon leakage’

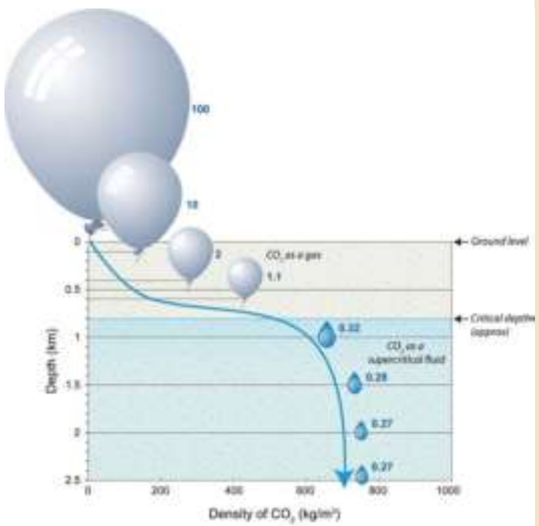
Conclusions: Transport



Source: Neele, F, Koenen, M, Seebregts, A, van Deurzen, J, Kerssemakers, K and Mastenbroek, M, 2010. *Development of a large-scale CO_2 transport infrastructure in Europe: matching captured volumes and storage availability*. CO_2 Europipe

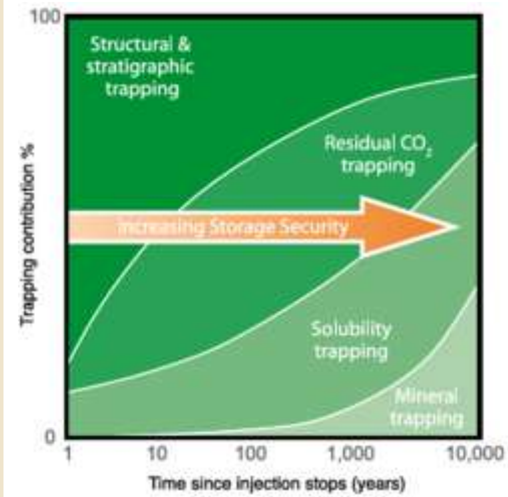
- Pipelines or ships
- Ships: demonstrate scale-up
- Pipes: impurities/operational regimes => 5-10 years R&D to underpin large scale deployment
- European CO_2 transport network: major investment needing strategic EU level approach

Conclusions: Storage



Source: *IPCC, 2005*.

- Storage processes broadly understood, but significant uncertainties remain
- Iterative process of confidence building with regulators and public
- Understanding geological processes takes time: constraint on roll out of CCS
- Storage capacity in Europe:
  - 80% saline aquifers
  - 19% depleted oil & gas fields
  - 1% un-mineable coal beds



Source: *IPCC, 2005*.

Conclusions: Alternative approaches

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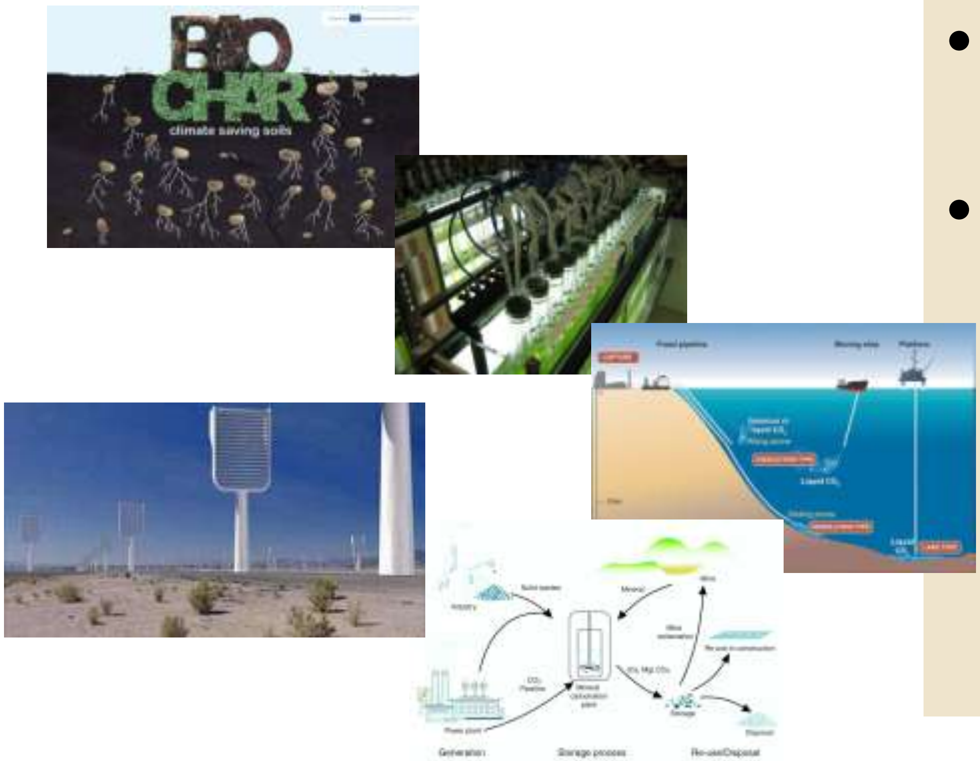

- None with potential contribution of CCS
- At pilot or demonstration scale and modest potential:
  - Biochar
  - Biomass with CCS
  - Waste carbonation
  - Algae cultivation
  - CO_2 utilisation for chemicals

Conclusions: public engagement

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- Need for public debates at EU, national and local levels about CCS to tackle climate change
- Social setting should be given greater weight in locating CO_2 storage facilities
- Important role of demonstration projects in building familiarity with the technology

Conclusions: Prospects to 2050

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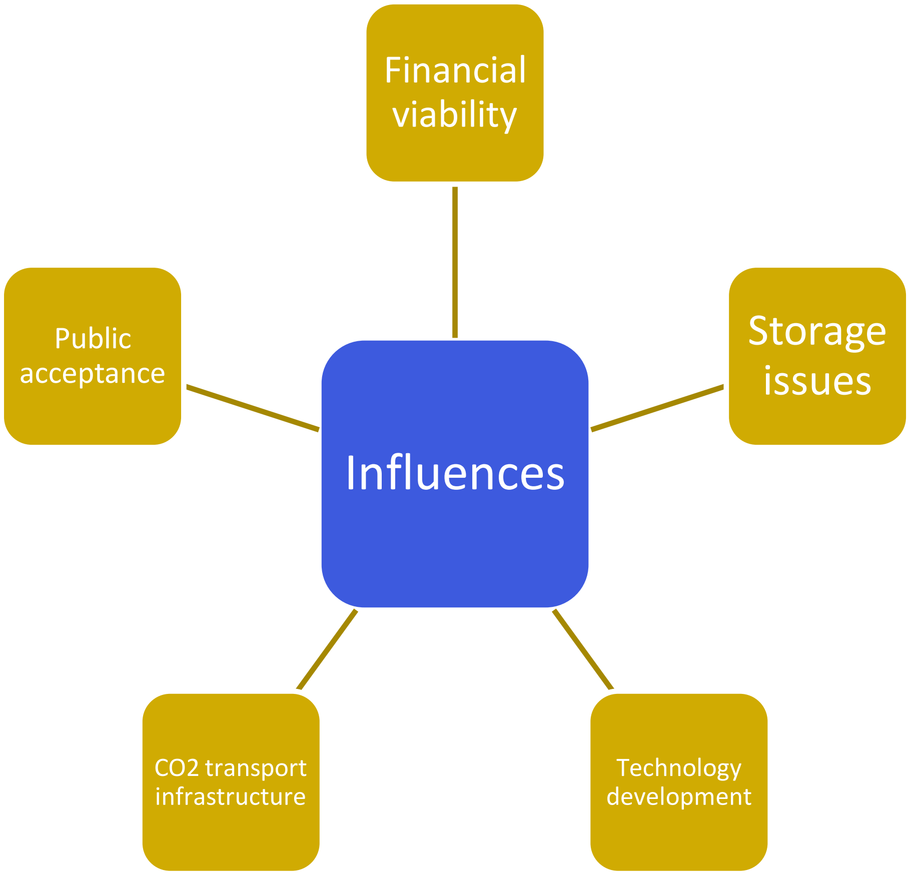

From: Professor Herbert Huppert presentation, EASAC, Brussels – 22 May, 2013

Conclusions: Prospects to 2050

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Challenges to economic viability

Difficulties of public acceptance

Delays

Confidence in storage will build slowly

Present position

Conclusions: Prospects to 2050

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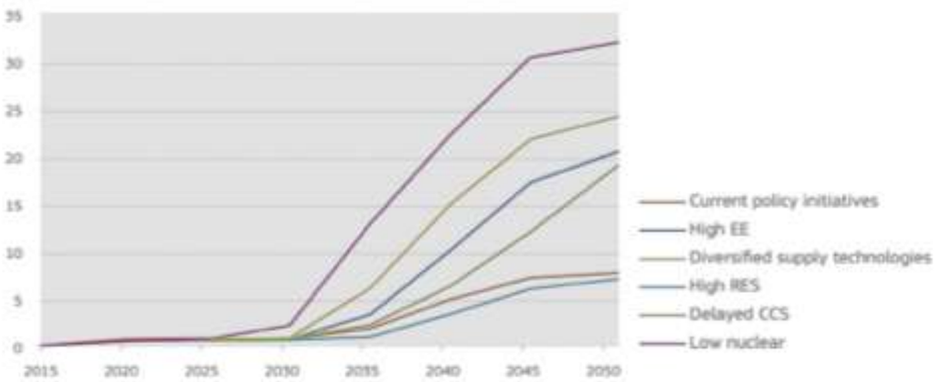
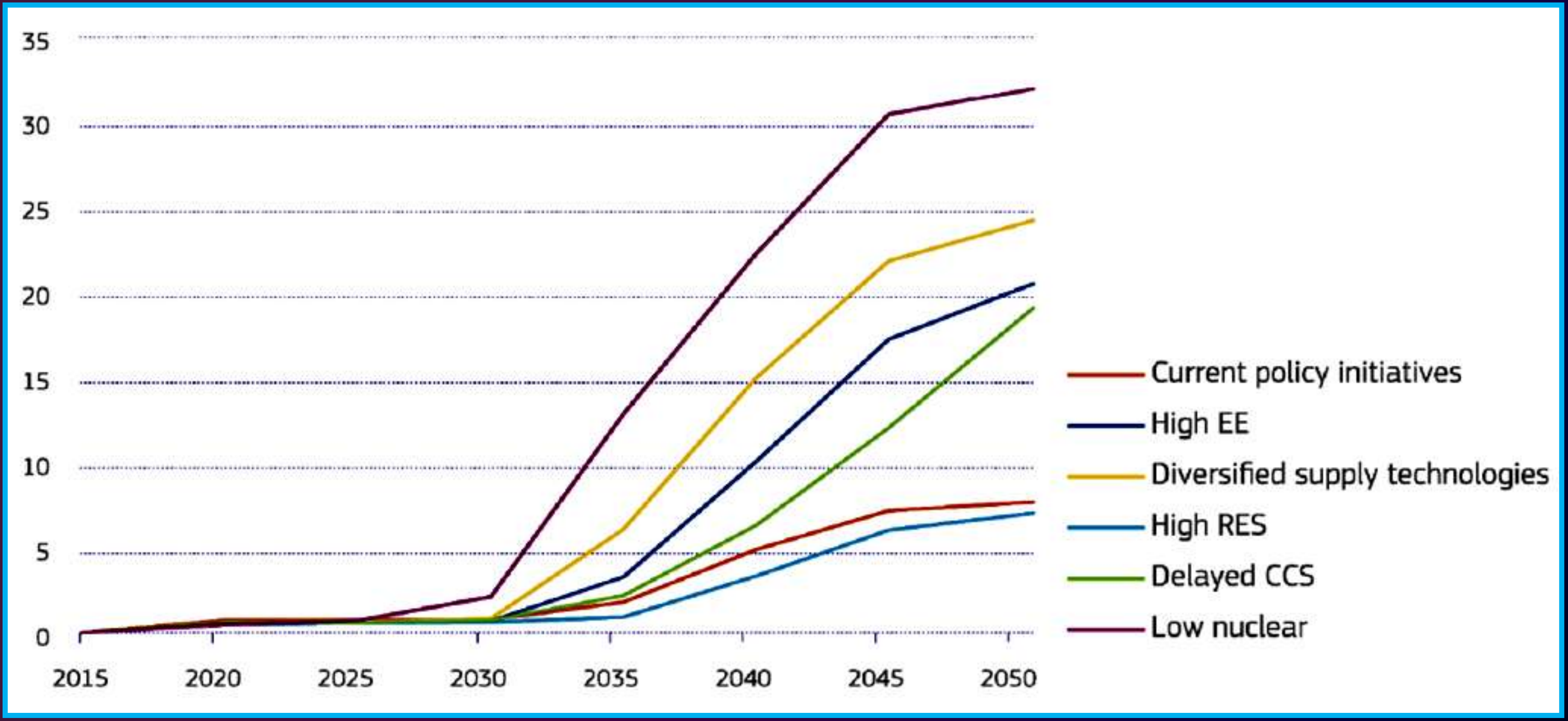


Energy Roadmap 2050: contribution of power generation using CCS (7 to 32%)

Source: *Lowe, 2012; European Commission, 2013a.*

- Contribution at lower end of Energy Roadmap projections
- Favourable juxtapositions of sources, sinks and public acceptance
- Fossil-fired power generation with CCS: important balancing role
- Allowing continuance of steel, cement production etc.
- Such positioning may help to build acceptance

SHARE OF CCS (%) IN POWER GENERATION TOWARDS 2050 IN THE ENERGY ROADMAP



2050 Energy Roadmap

Recommendations: financial viability

- Enhanced funding of demonstration plants
- Commercial rollout: Correct and augment Emissions Trading Scheme
- Include key alternatives in ETS
- Avoid ‘carbon leakage’

Recommendations: Storage

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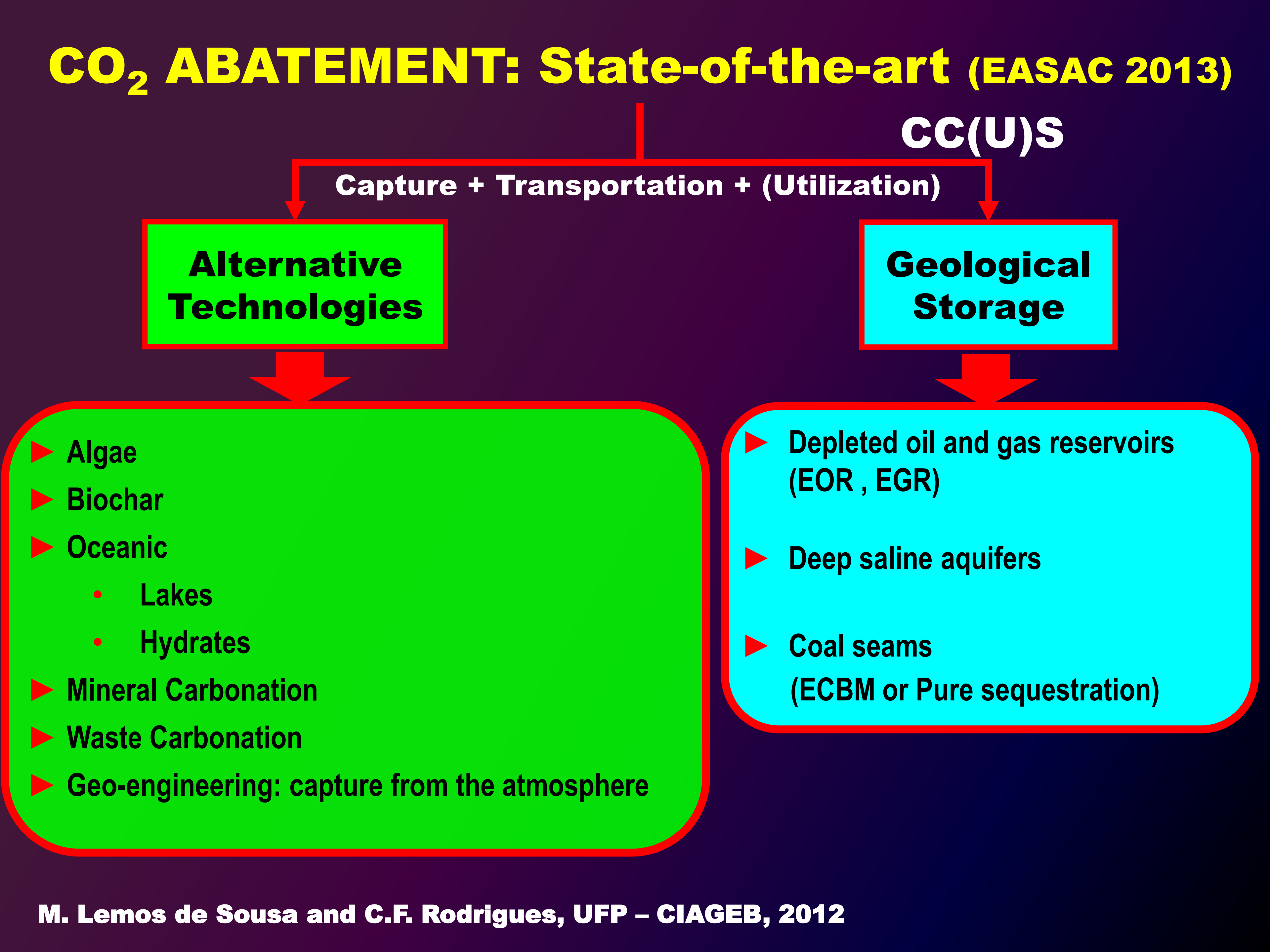
- Locate & characterise Europe's storage capacity
- Activities to accelerate confidence building in storage
- Pilot plants to complement demonstration plants

In the scope of CCUS...

- Deep Saline Aquifers
- Shale gas
- Coal seams
- Depleted Oil and Gas Reservoirs

Geological solutions which have already proven to be technologically feasible in terms of permanent CO_2 disposal and at the same time allow the production of large quantities of oil and gas



CO2 ABATEMENT: State-of-the-art (EASAC 2013)
CC(U)S
Capture + Transportation + (Utilization)
Alternative Technologies
Geological Storage
Algae
Biochar
Oceanic
Lakes
Hydrates
Mineral Carbonation
Waste Carbonation
Geo-engineering: capture from the atmosphere
Depleted oil and gas reservoirs (EOR , EGR)
Deep saline aquifers
Coal seams (ECBM or Pure sequestration)
M. Lemos de Sousa and C.F. Rodrigues, UFP – CIAGEB, 2012

RESERVOIR CHARACTERIZATION

Conventional reservoirs

CO_2 STORAGE
Absorbed/free states

CO_2 CIRCULATION
Laminar flow

Unconventional reservoir

CO_2 STORAGE
Adsorbed and Absorbed/free states

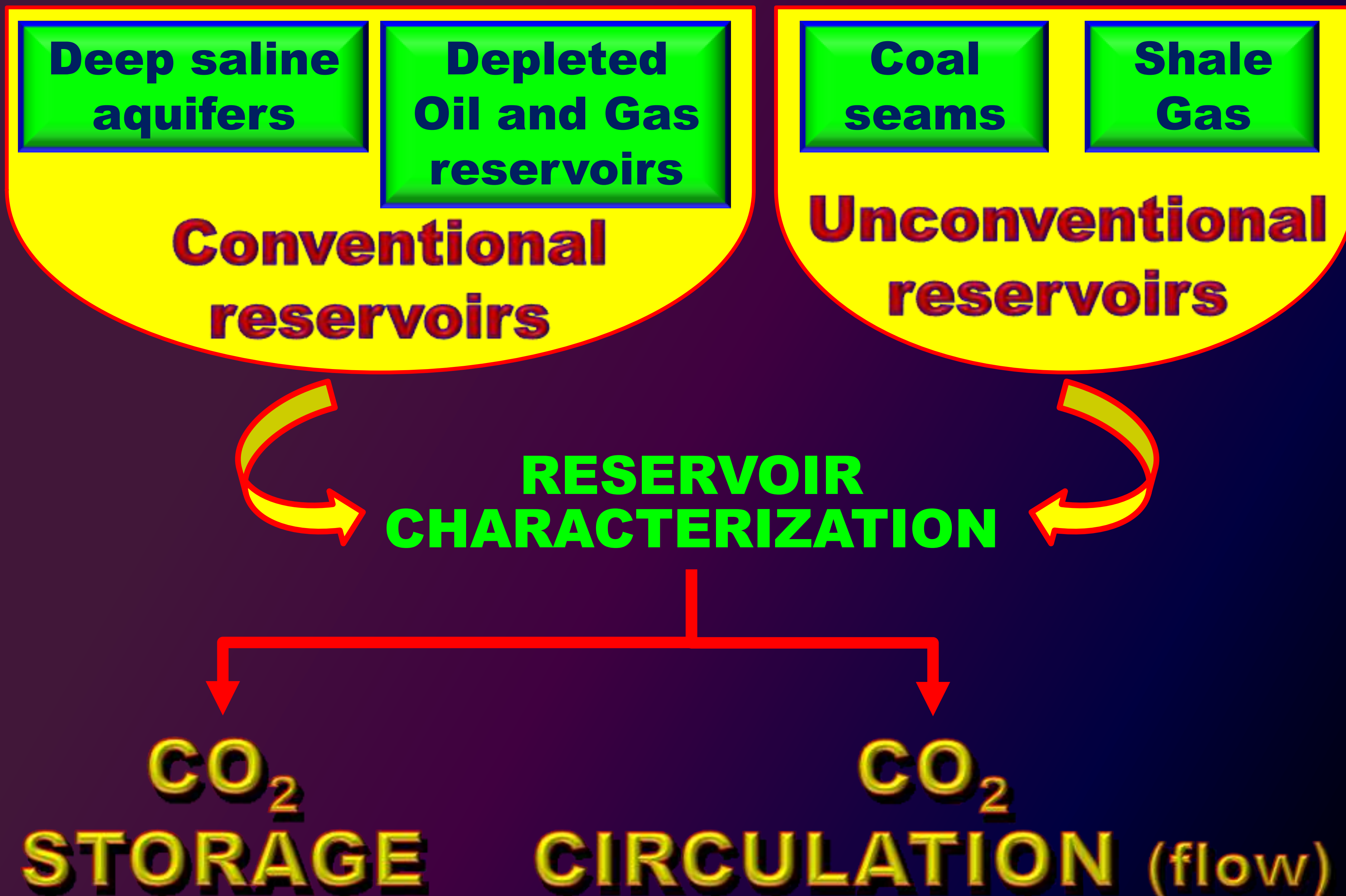
CO_2 CIRCULATION
Diffusion
Laminar flow

GEOLOGICAL PARAMETERS TO PROMOTE A PERMANENT CO_2 DISPOSAL

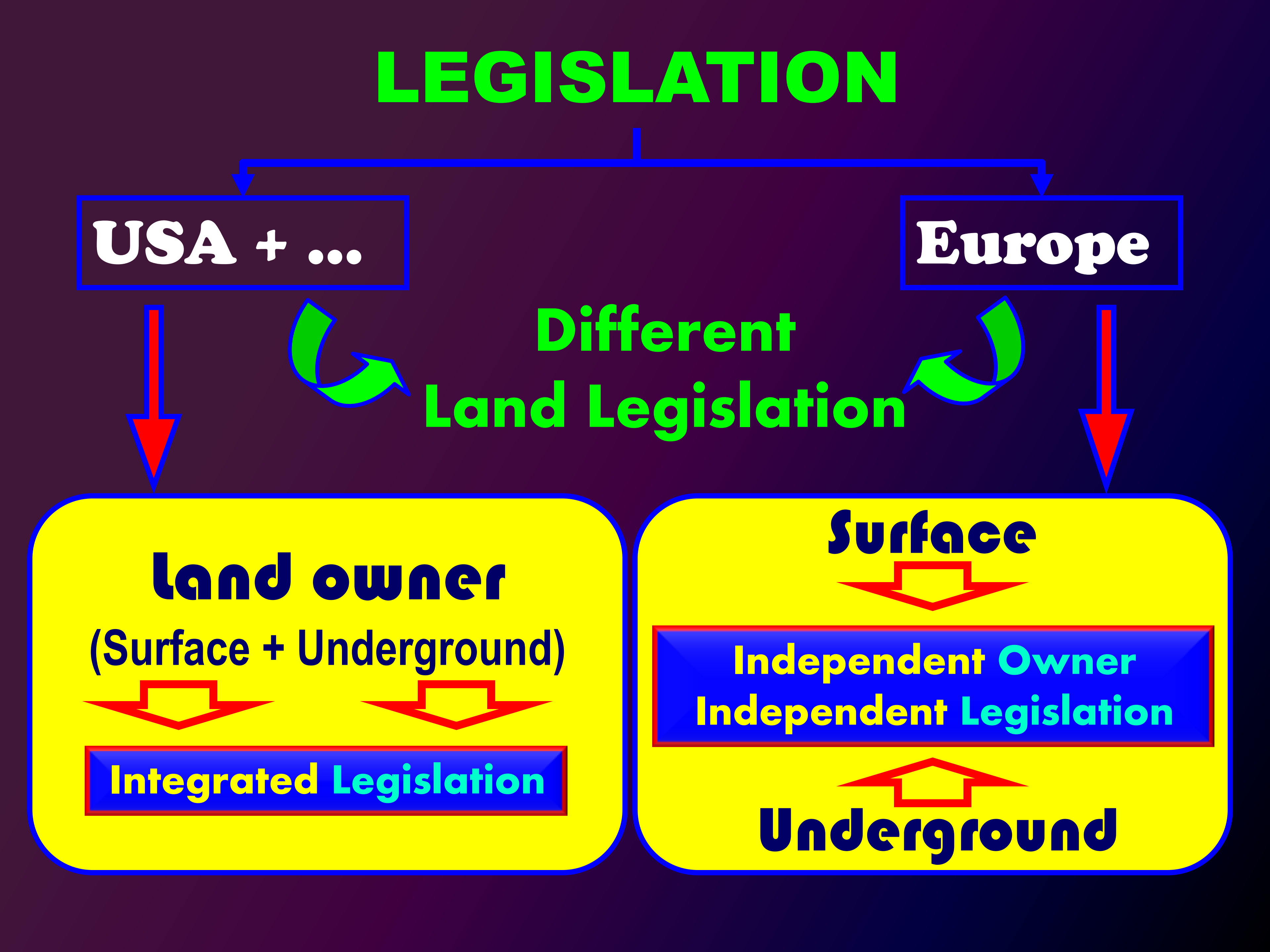
CONVENTIONAL RESERVOIRS *vs* UNCONVENTIONAL RESERVOIRS

Geological parameters	Conventional reservoirs (CR)	Unconventional Reservoirs (UCR)
Trap	Present	Entrapment by adsorption in matrix of organic matter (trap not necessary)
Seal	Present	Entrapment by adsorption in matrix of organic matter (seal not necessary)
Reservoir Porosity	High > 10%	Low < 10%
Reservoir Permeability	High > 100 mD	Low < 0.1 mD

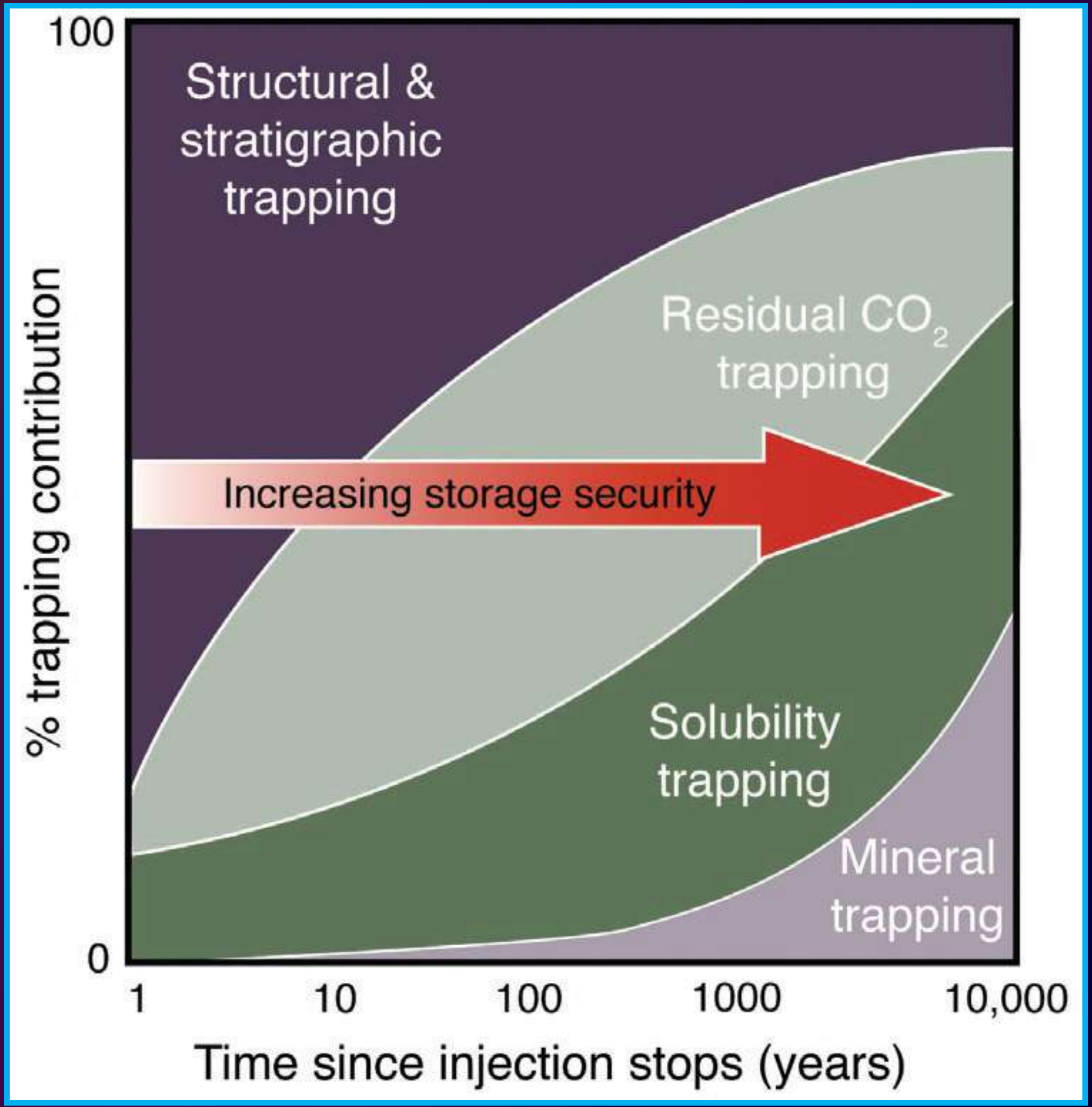
CR - Depleted Oil and Gas reservoirs, Deep Saline Aquifers; UCR- Coal seams, Shale gas



Deep saline aquifers
Depleted Oil and Gas reservoirs
Conventional reservoirs
Coal seams
Shale Gas
Unconventional reservoirs
RESERVOIR CHARACTERIZATION
CO_2 STORAGE
CO_2 CIRCULATION (flow)

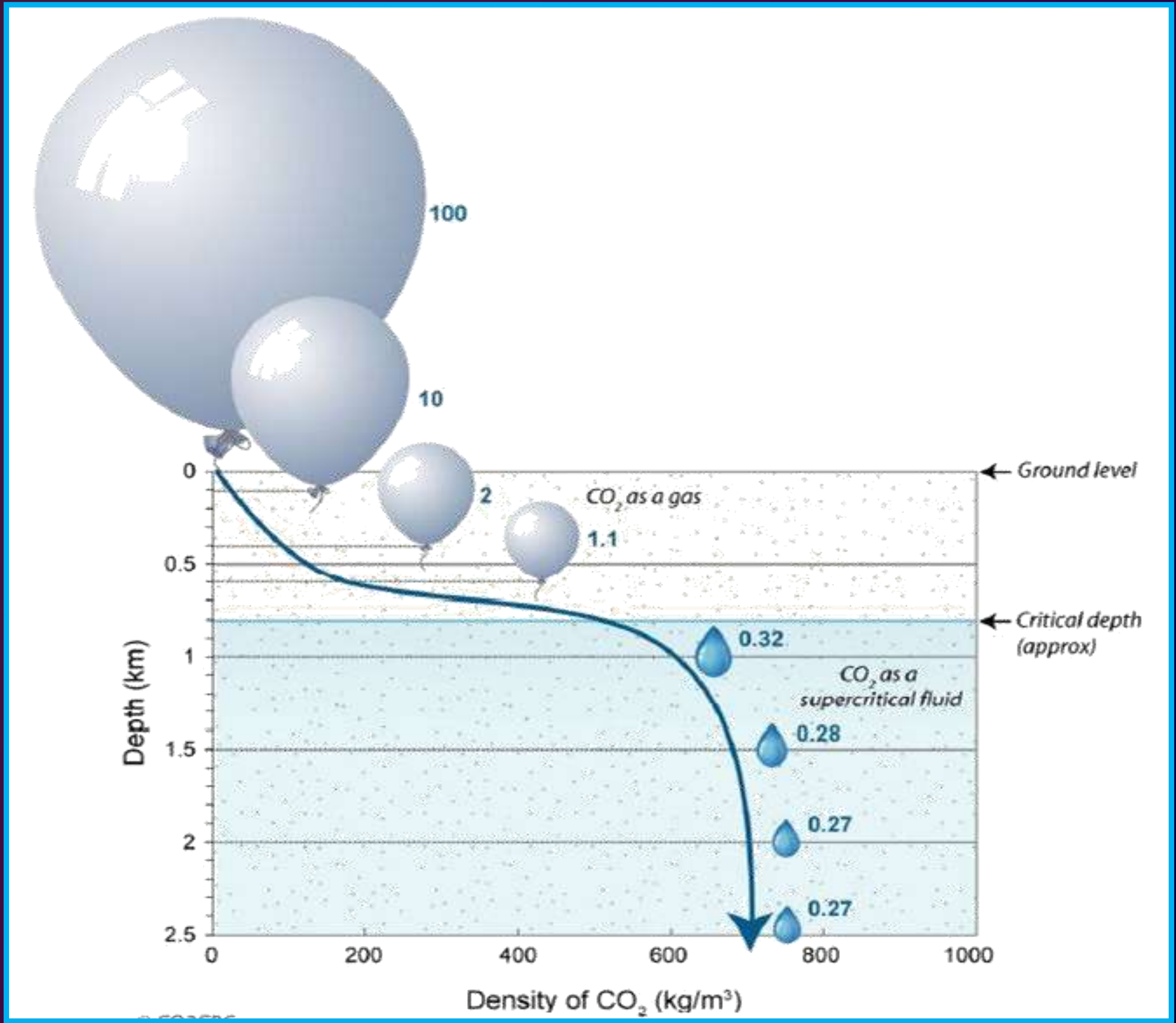

LEGISLATION
USA + ...
Europe
Different
Land Legislation
Land owner
(Surface + Underground)
Integrated Legislation
Surface
Independent Owner
Independent Legislation
Underground

EVOLUTION OF TRAPPING MECHANISMS OVER TIME



IPCC, 2005

ILLUSTRATIVE DEPENDENCE OF DENSITY OF CO2 ON DEPTH



IPCC, 2005

COAL SEAMS *VS* DEEP SALINE AQUIFERS

Efficiency for long term CO_2 storage

Reservoir Characteristics

Reservoir Characteristics		Coal seams	Saline Aquifer
Reservoir	CO_2 storage (gas state)	Adsorption (surface area) + Absorption (cleat) (Naturally in liquid state) + (gaseous or liquid)	Absorption (pore volume) (Liquid or gaseous depending on P and T)
	CO_2 flow	Diffusion (Low) + Laminar (Low)	Laminar (High)
Caprock/seal		Coal is simultaneously source-rock, reservoir, caprock and trap	**Independent** caprock (pelitic sediments and/or structural features)
Trap		Ibid	**Independent** trap (vital to avoid CO_2 leakage)
Depth		Any depth	Depth compatible with the presence of saline water

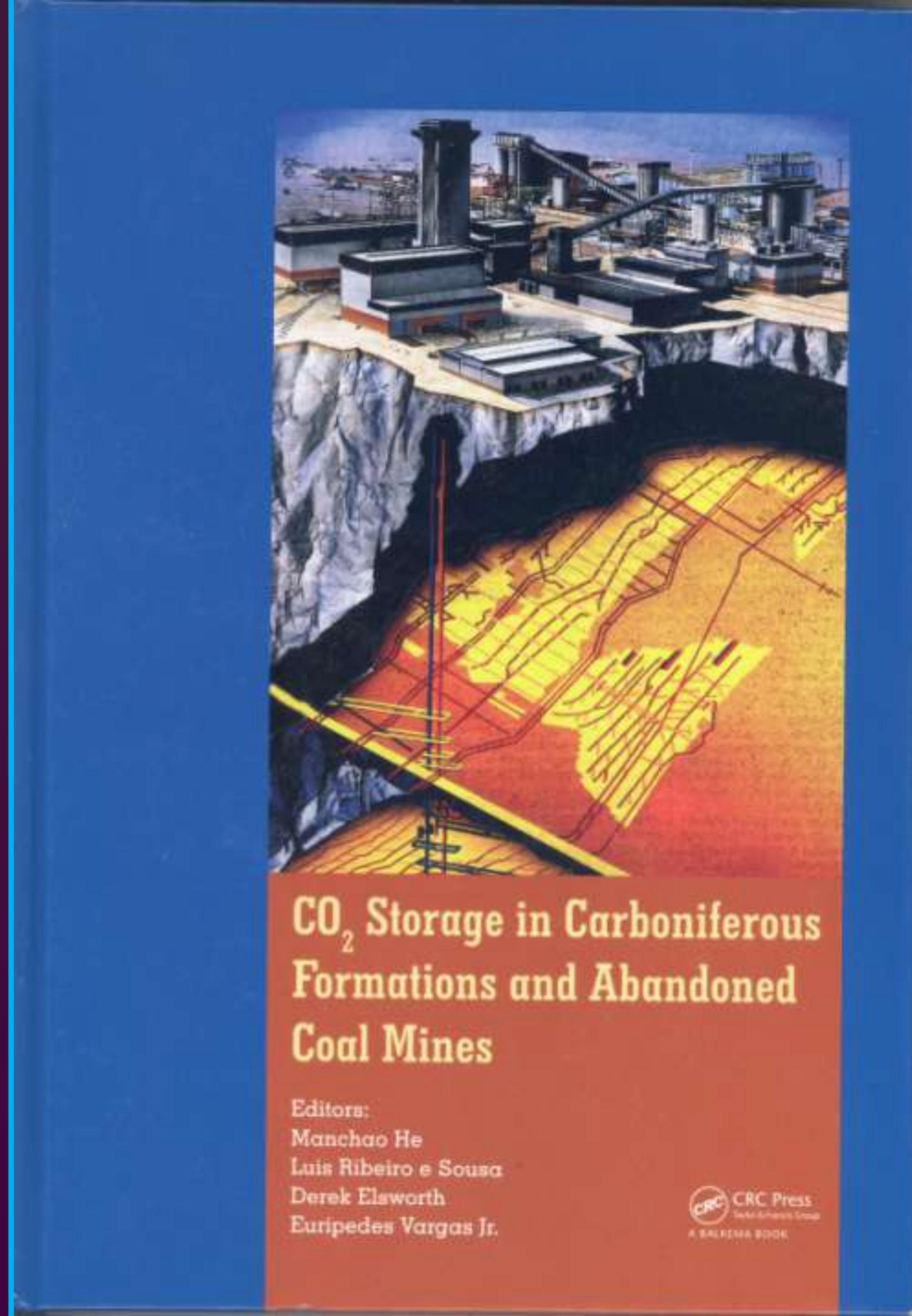
COAL SEAMS *VS* DEEP SALINE AQUIFERS

Efficiency for long term CO_2 storage

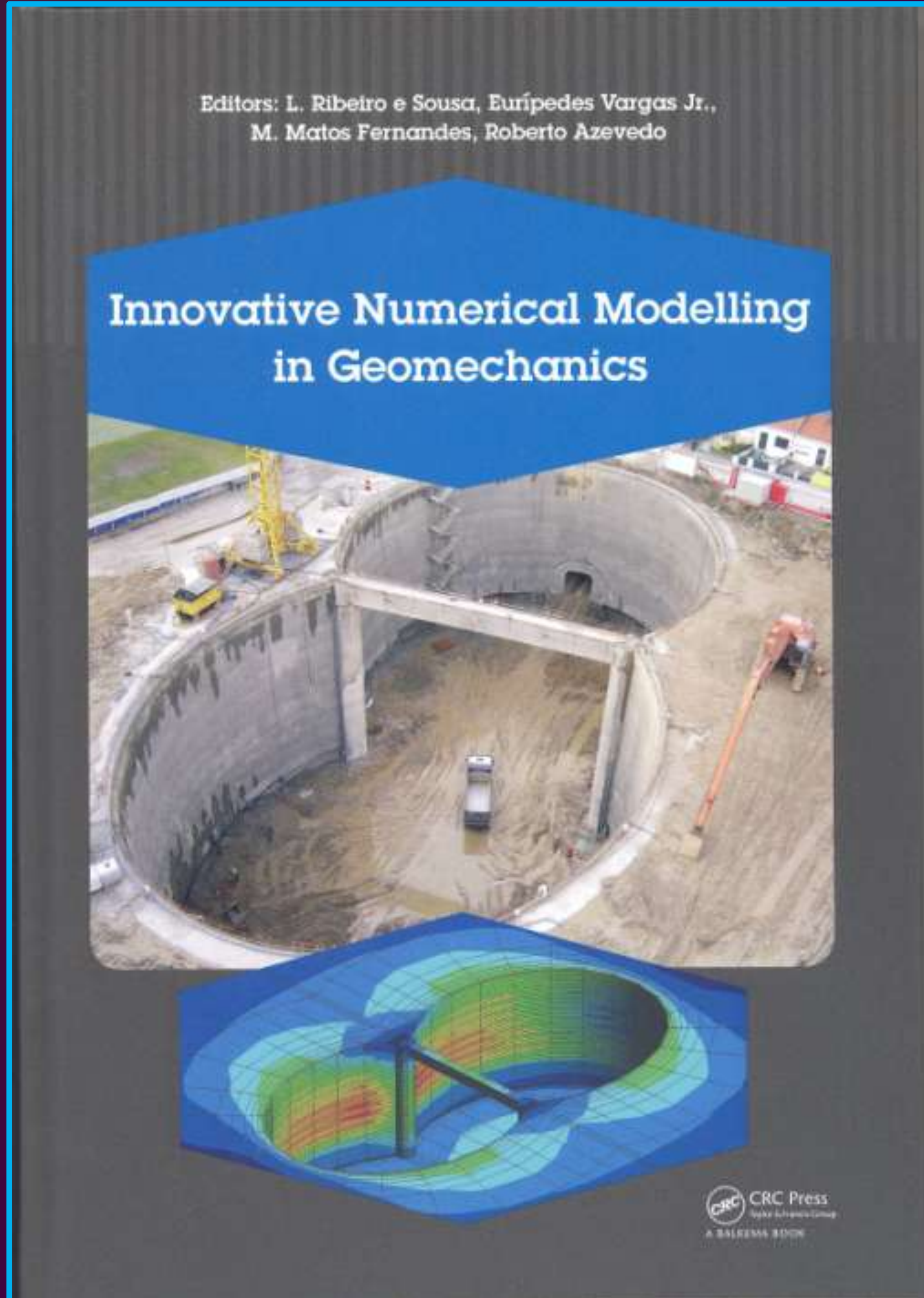
(continuation)

Technological Characteristics

Technological Characteristics	Coal seams	Saline Aquifer
Leakage risk	2% - 5% of gas injected, depending on "cleat system"	Wide range of variation, depending mainly on tectonic settings and/or seal characteristics
Gas injection state	Gaseous (except for seams at high depths)	Liquid
Reservoir water behaviour	Water disposal corresponds to free moisture, mostly in the "cleat system" (2% - 5%)	Water disposal volume similar to CO_2 injected volume; only 5% to 7% will dissolve (long term) in water
Frequent Criticism about reservoir eventual future use	New Coal Technologies ***???***	Needs of fresh water obtained by desalination ***!!!***


CO_2 Storage in Carboniferous Formations and Abandoned Coal Mines
Editors:
Manchao He
Luis Ribeiro e Sousa
Derek Elsworth
Euripedes Vargas Jr.
CRC Press
A BALKEMA BOOK

2012


Editors: L. Ribeiro e Sousa, Eurípedes Vargas Jr.,
M. Matos Fernandes, Roberto Azevedo
Innovative Numerical Modelling
in Geomechanics
CRC Press

2012

PROCESSOS DE INJECÇÃO DE CO_2 EM FORMAÇÕES CARBONÍFERAS

ANA ISABEL MOREIRA ANDRADE GOMES

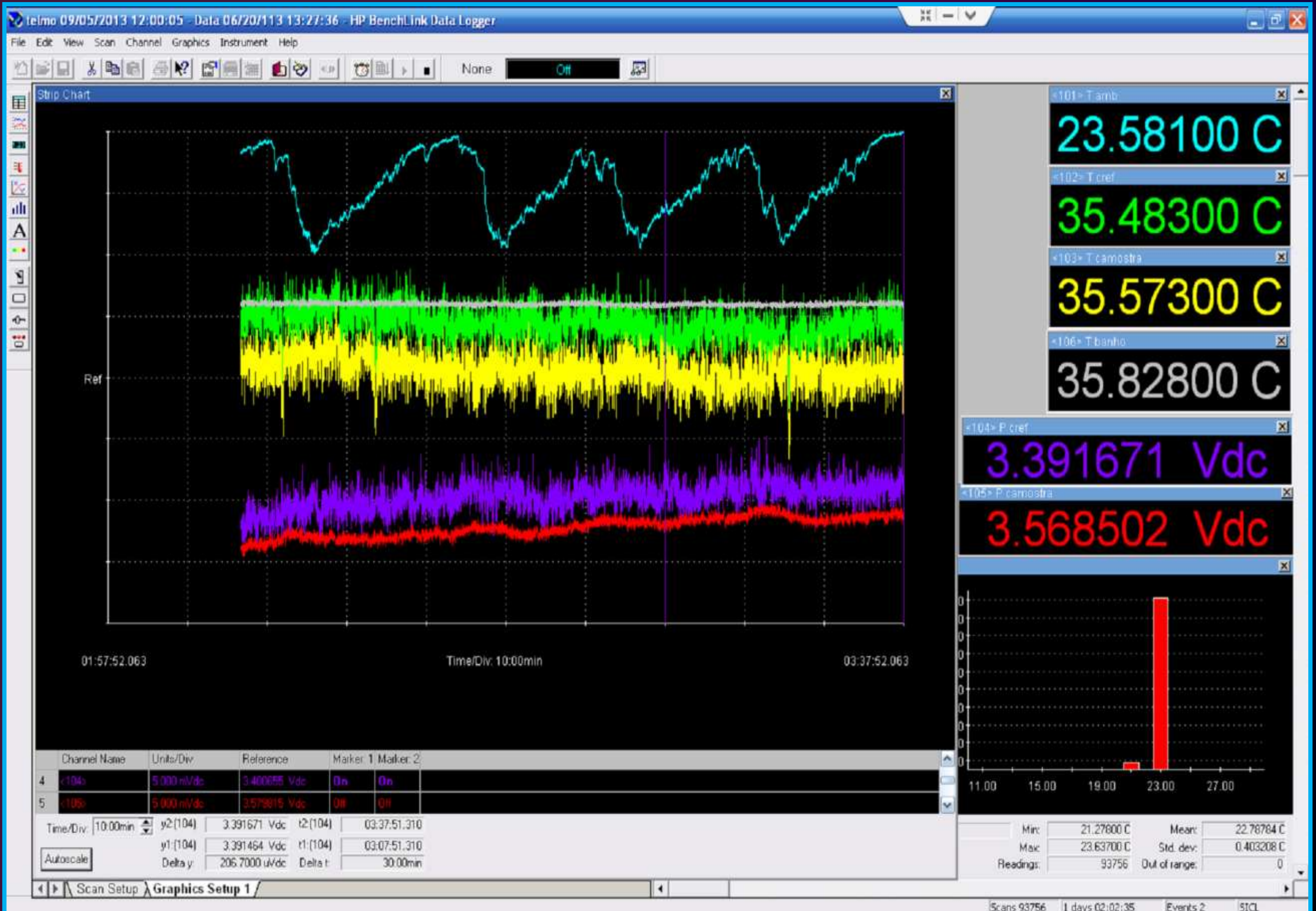
Dissertação submetida para satisfação parcial dos requisitos do grau de

MESTRE EM ENGENHARIA CIVIL — ESPECIALIZAÇÃO EM GEOTECNIA

Orientador: Professor Doutor Luís Manuel Ribeiro e Sousa

JUNHO DE 2010

RESERVOIRS SIMULATOR - DATA ACQUISITION



Recommendations: Technology

- EU funding of R&D: ensure results made public
- Tie R&D closely to commercial application
- Test range of options in demonstration plants
- Information exchange with developments elsewhere

Recommendations: CO_2 Transport

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- Integrated & strategic approach to developing Europe's CO_2 transport infrastructure
- Consider ownership and funding of transport network
- Role of demonstration plants
- Fully incorporate ship transport into provisions of CCS Directive

Recommendations: Public perception

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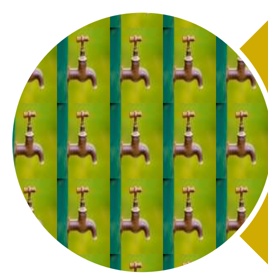
- Enhance emphasis on public debates on role of CCS in mitigating climate change
- CCS for biomass CHP
- Transparency and communication of demonstration plants

In Summary:

European Academies easac Science Advisory Council

Decisive policy action needed

Steady development and greater urgency



Not a tap that can simply be turned on

EASAC Report

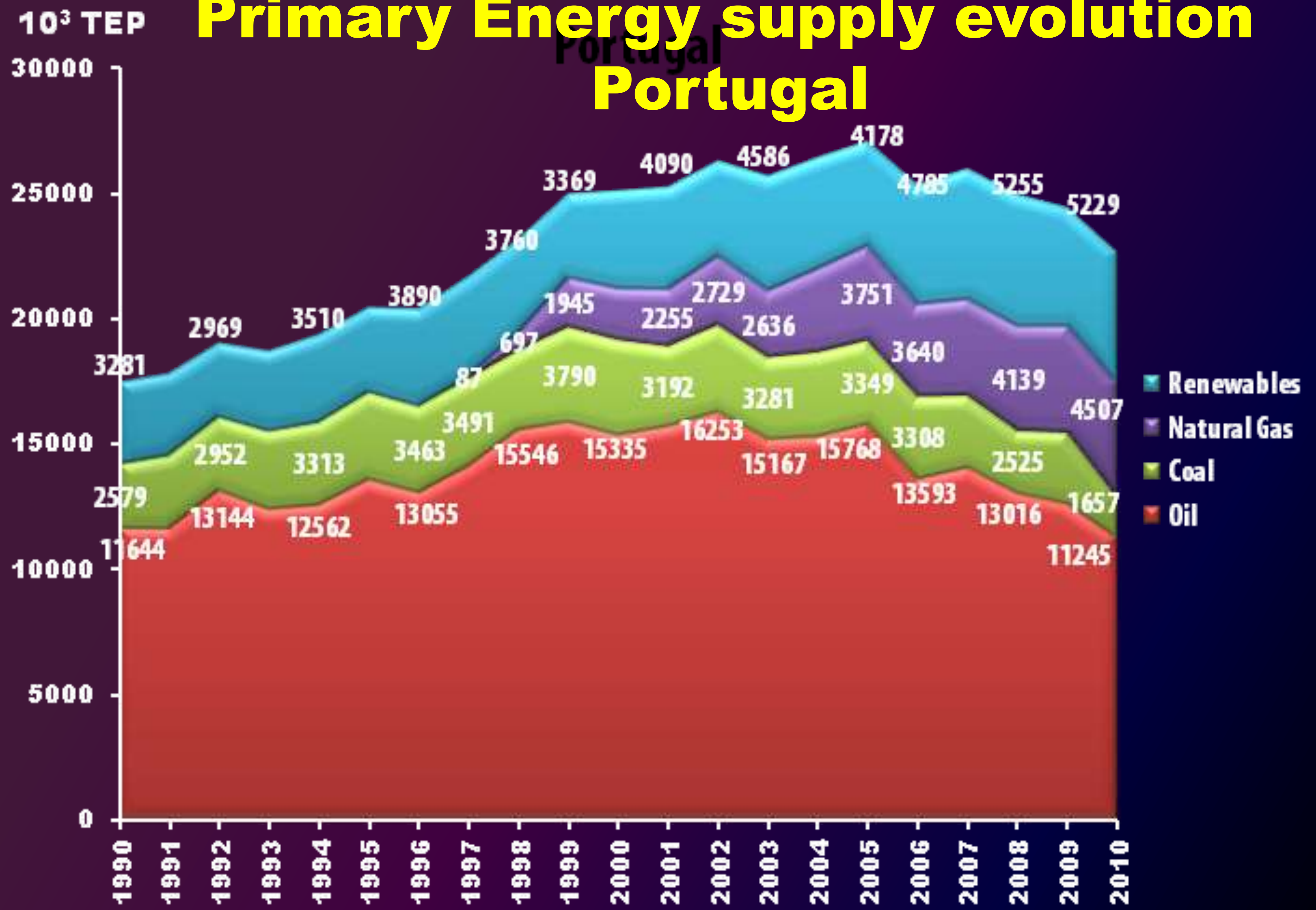
CARBON CAPTURE AND STORAGE IN EUROPE

Available at:

http://www.easac.eu/home/reports-and-statements/detail-view/article/easac-report.html

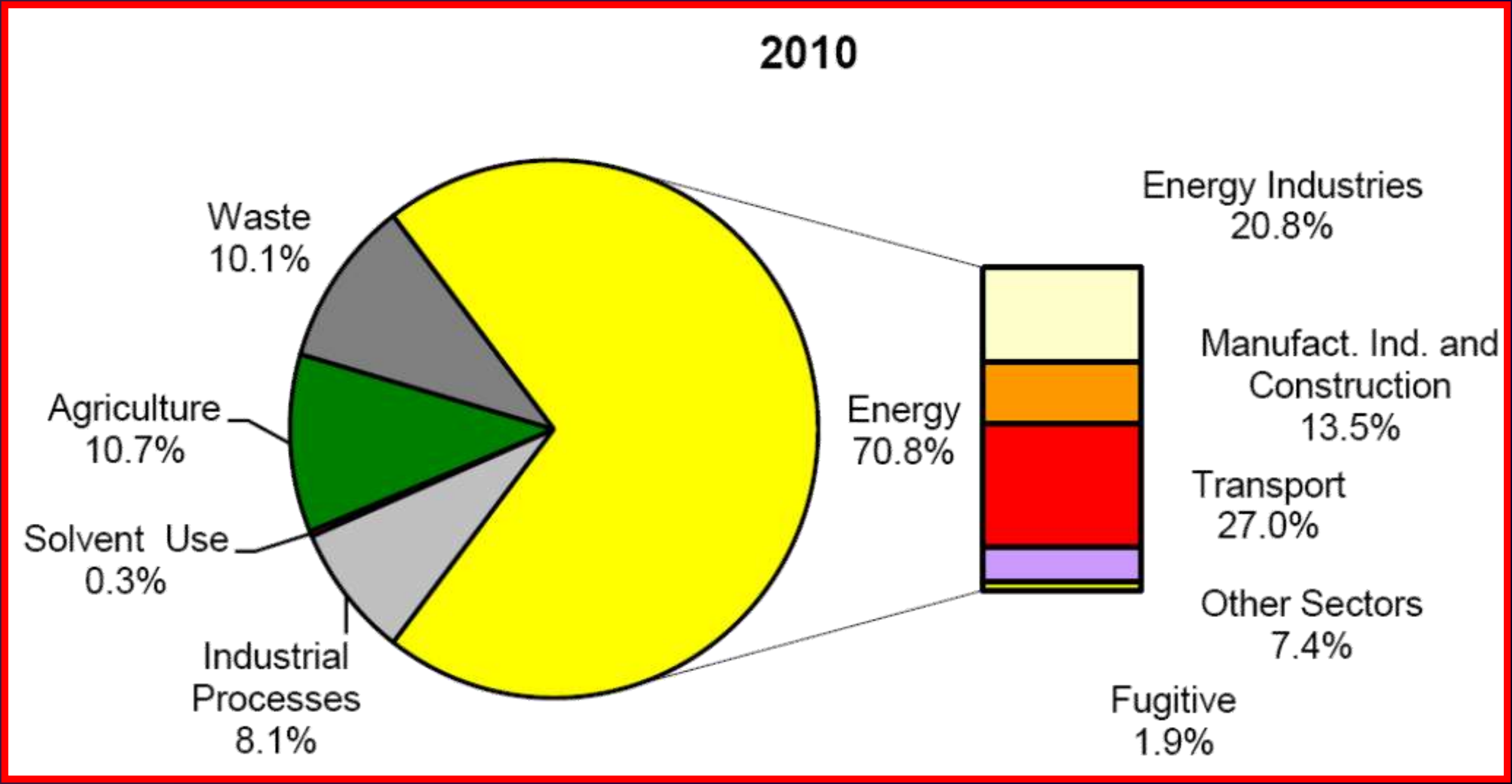
4. PORTUGAL

Primary Energy supply evolution Portugal



Source: Eurostat (2011)
G.M. Oliveira, UFP – CIAGEB, 2012

Origin of greenhouse gases in Portugal



Source: APA (2012)

CO_2 main production sites

1 – Central Termoeléctrica do Pego (Tejo Energia)
2 – Central Termoeléctrica de Sines (CPPE)
3 – Central Termoeléctrica do Ribatejo (CPPE)
4 – Central de Ciclo Combinado da Tapada do Outeiro (Turbogás)
5 – Central Termoeléctrica de Setúbal (CPPE)

6 – Refinaria de Sines (Petrogal)
7 – Refinaria do Porto (Petrogal)

8 – Sines (Repsol)

9 – Sines (Repsol Polímeros - Olefinas)

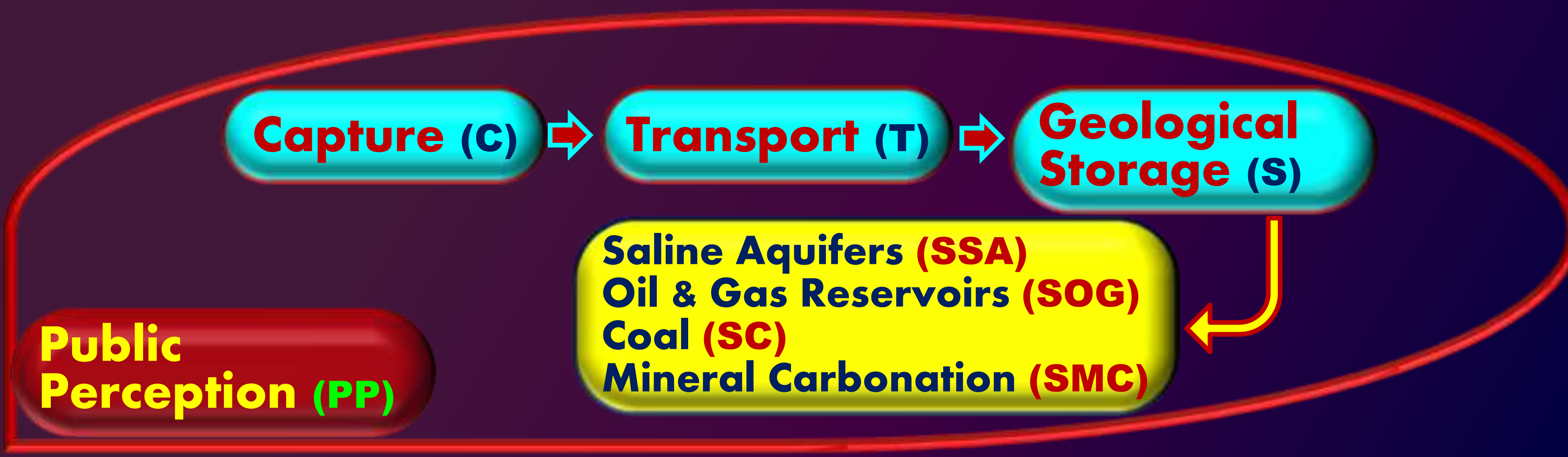
10 – Macieira – Liz (CMP)
11 – Secil – Outão (Secil)
12 – Alhandra (Cimpor)
13 – Loulé (Cimpor)
14 – Souselas (Cimpor)
15 – Cibra (Pataias)

Total Allowances for the sites represented in the map: 23 241 306 (72.2%)

Total Portuguese Allowances: 30 500 000 (100%)

CIAGEB – UFP 2009 (Geographic basis: Google Earth)

THE PORTUGUESE RESEARCH COMMUNITY IN CCS



FCUL - Faculdade de Ciências, Universidade de Lisboa	SMC
FEUP - Faculdade de Engenharia, Universidade do Porto	C
IST - Instituto Superior Técnico	C, SSA, SC
LNEG (INETI) - Laboratóri Nacional de Energia e Geologia	C, T, SSA, PP
UE - Universidade de Évora	C, SSA, PP
UFP - Universidade Fernando Pessoa	SSA, SOG, SC, PP
EDP - Energias de Portugal	C, SSA
TEJO ENERGIA, PEGOP - Pego Coal Power Plant	C, SSA
ACL – Academia das Ciências de Lisboa	

Main Portuguese CCS Projects

COSEQ (SC) ---- UFP + IST

KTEJO (C, SA) ---- Tejo energia, Pegop + LNEG + UE
http://www.ktejo.cge.uevora.pt/

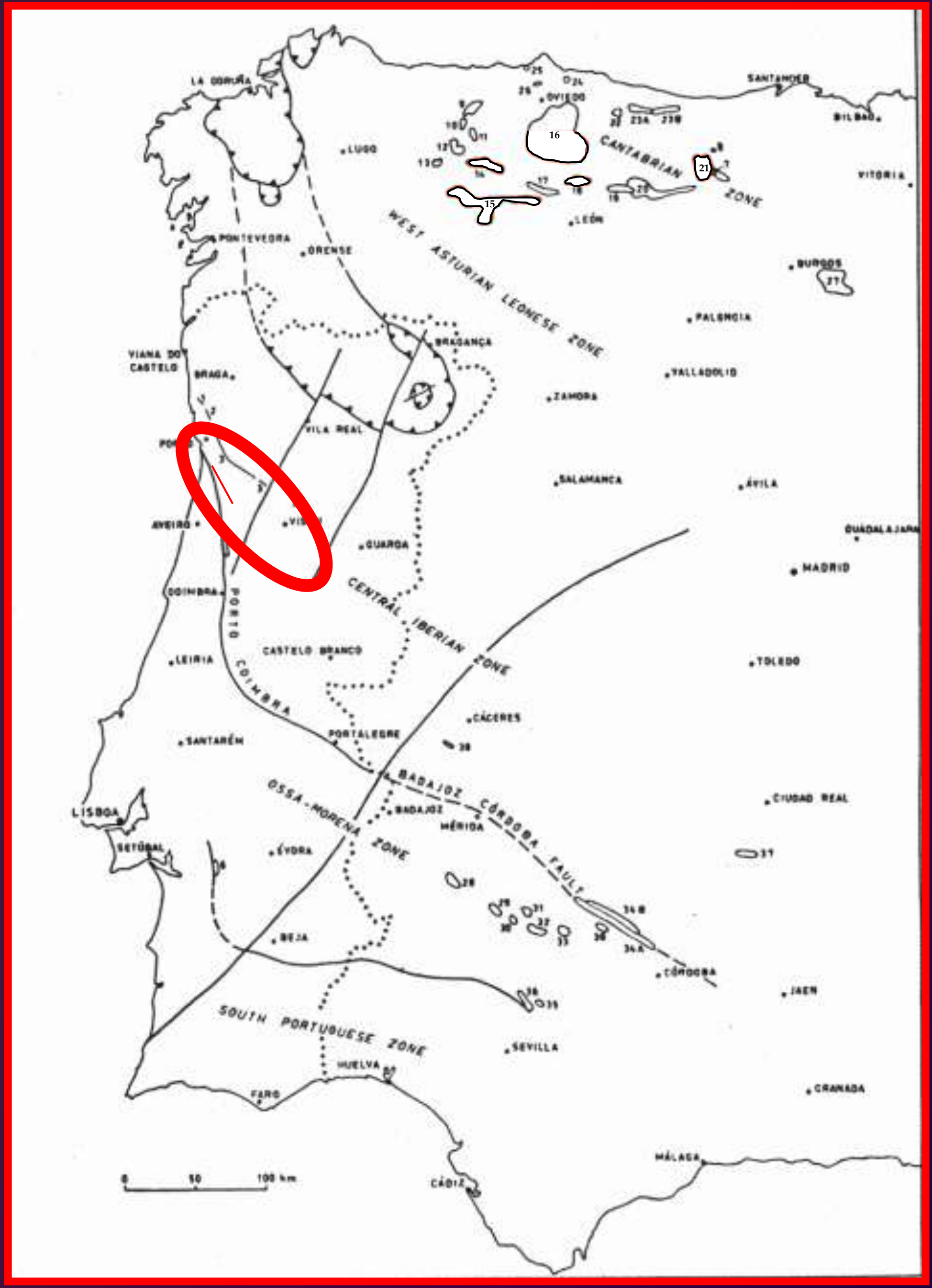
NanoGLOWA (C) ---- EDP
http://www.energy-enviro.fi/index.php?PAGE=1073
http://www.nanoglowa.com/index.html

COMET – CO2 Transport & Storage (T, SA) ---- LNEG + International Consortium

The COSEQ Project

CO_2 Geological Sequestration in Douro Coalfield Meta-anthracites

M.J. Lemos de Sousa and Cristina Rodrigues



Wagner 1983

CO_2 geological sequestration sites Coal basins

Terrestrial Carboniferous and Lower Permian Occurrences in the Western Part of the Iberian Peninsula

3 – Douro Coalfield

COSEQ Project (UFP)

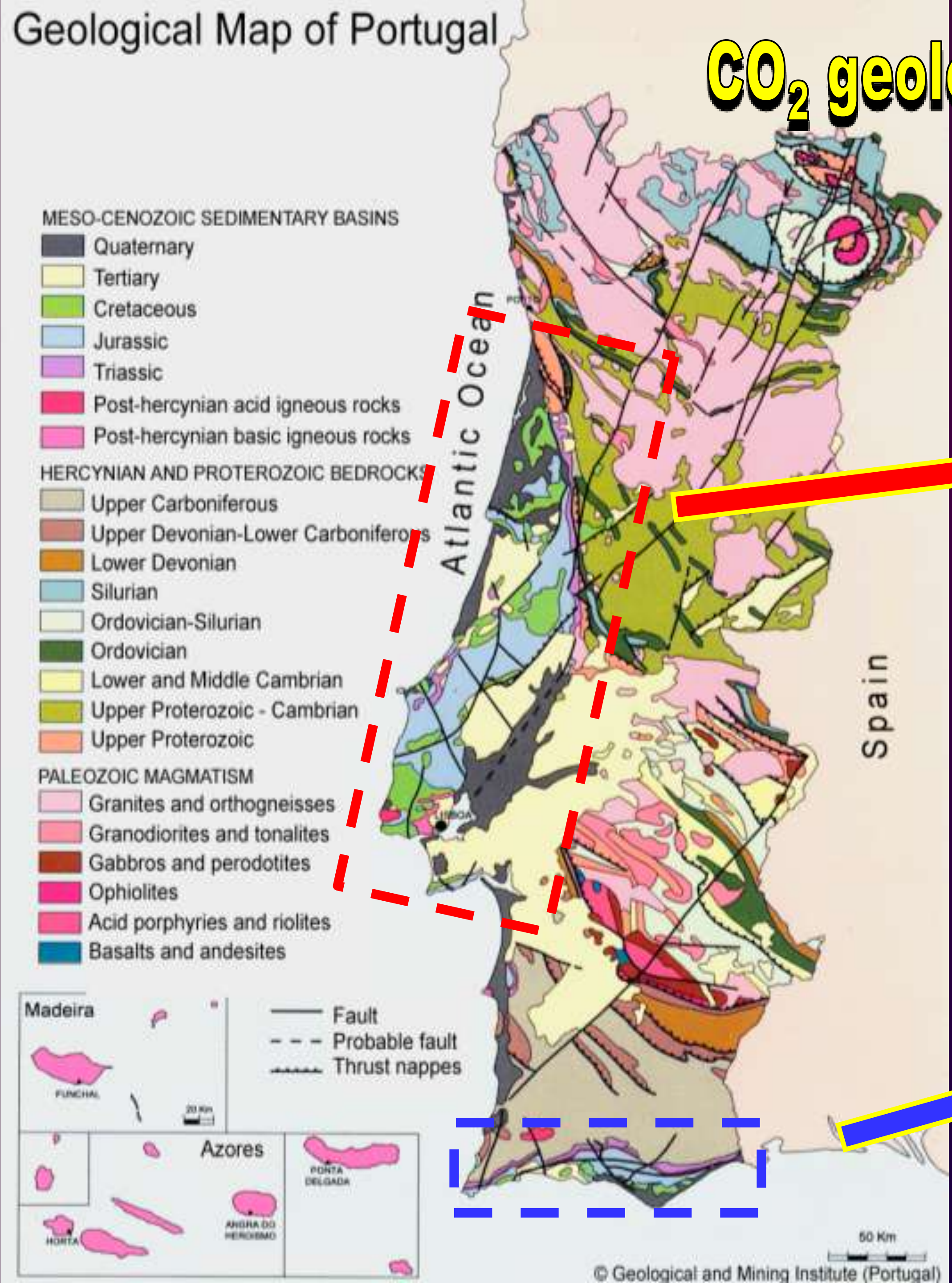
POTENTIAL USE OF SALINE AQUIFERS FOR GEOLOGICAL STORAGE OF CO_2 IN PORTUGAL

M.J. Lemos de Sousa, C.F. Rodrigues,
A. Mouraz Miranda, J.M. Marques, F. Monteiro Santos,
M.A.P. Dinis and H. Eggenkamp

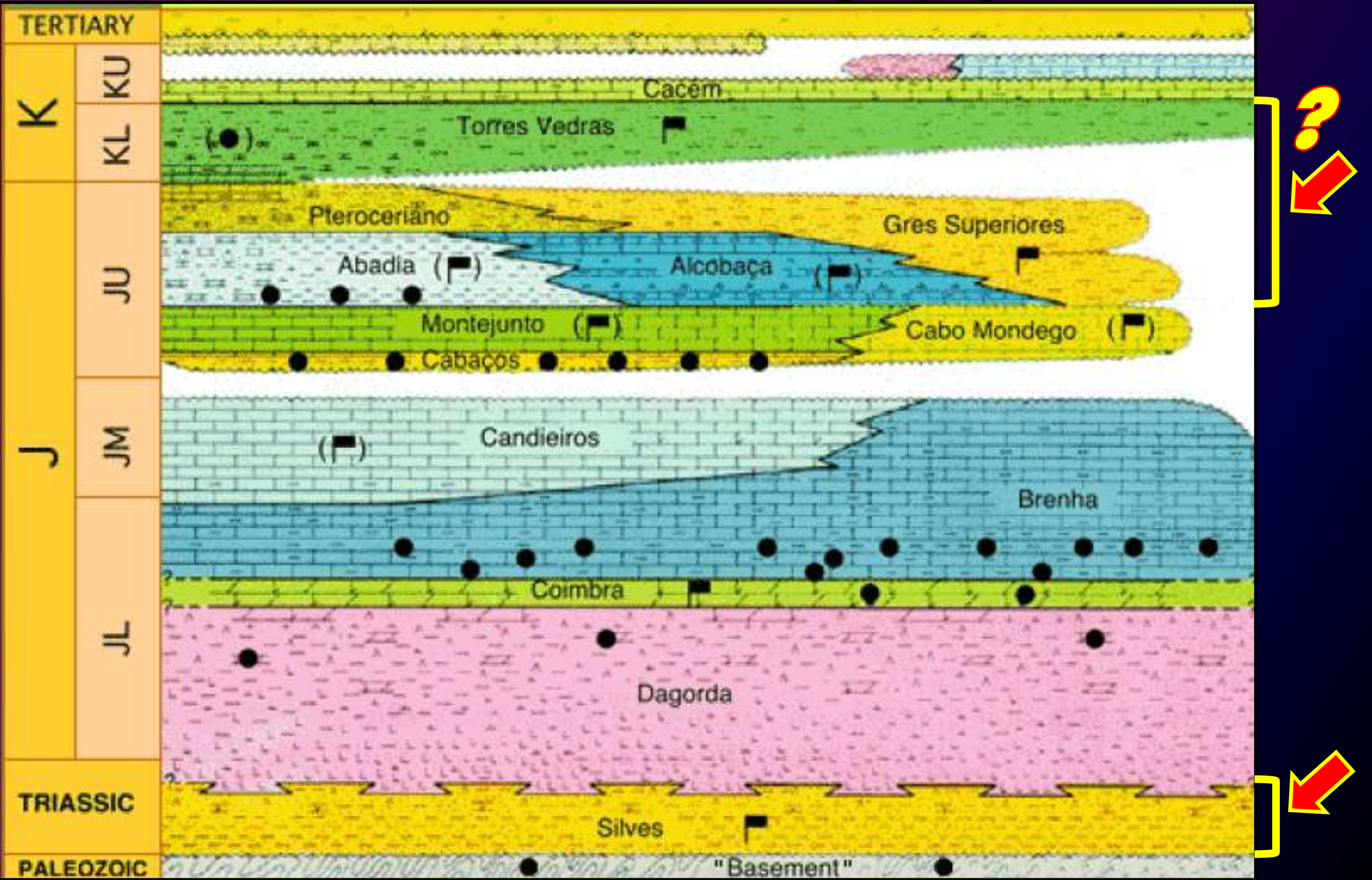
On behalf of UFP *Saline Aquifers Group*

CIAGEB - Universidade Fernando Pessoa, Porto, Portugal

CO_2 geological sequestration sites
Saline aquifers

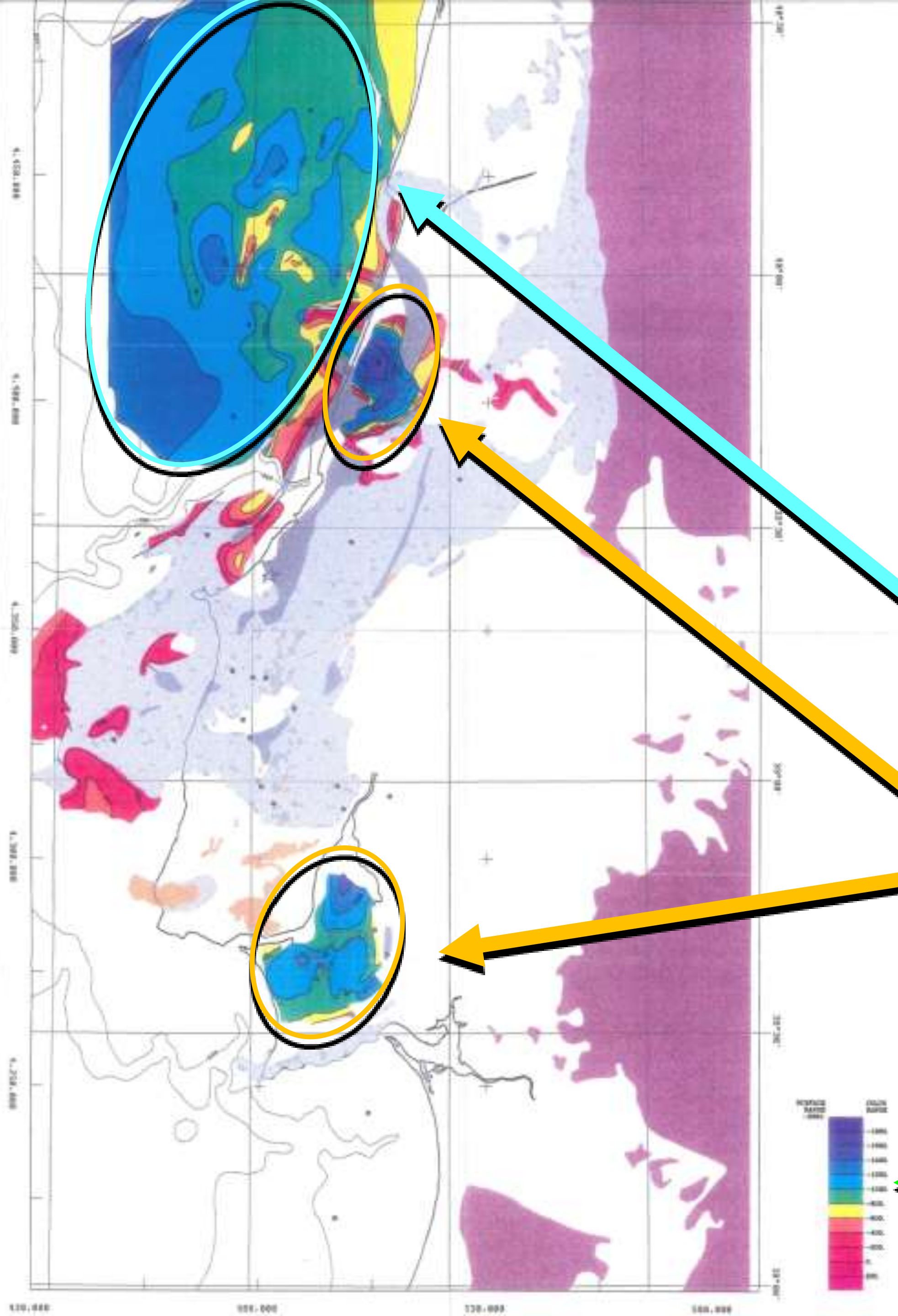


Lusitanian Basin Stratigraphy



Lomholt et al 1995

Lusitanian Basin



Top Jurassic

Potential Reservoir ?

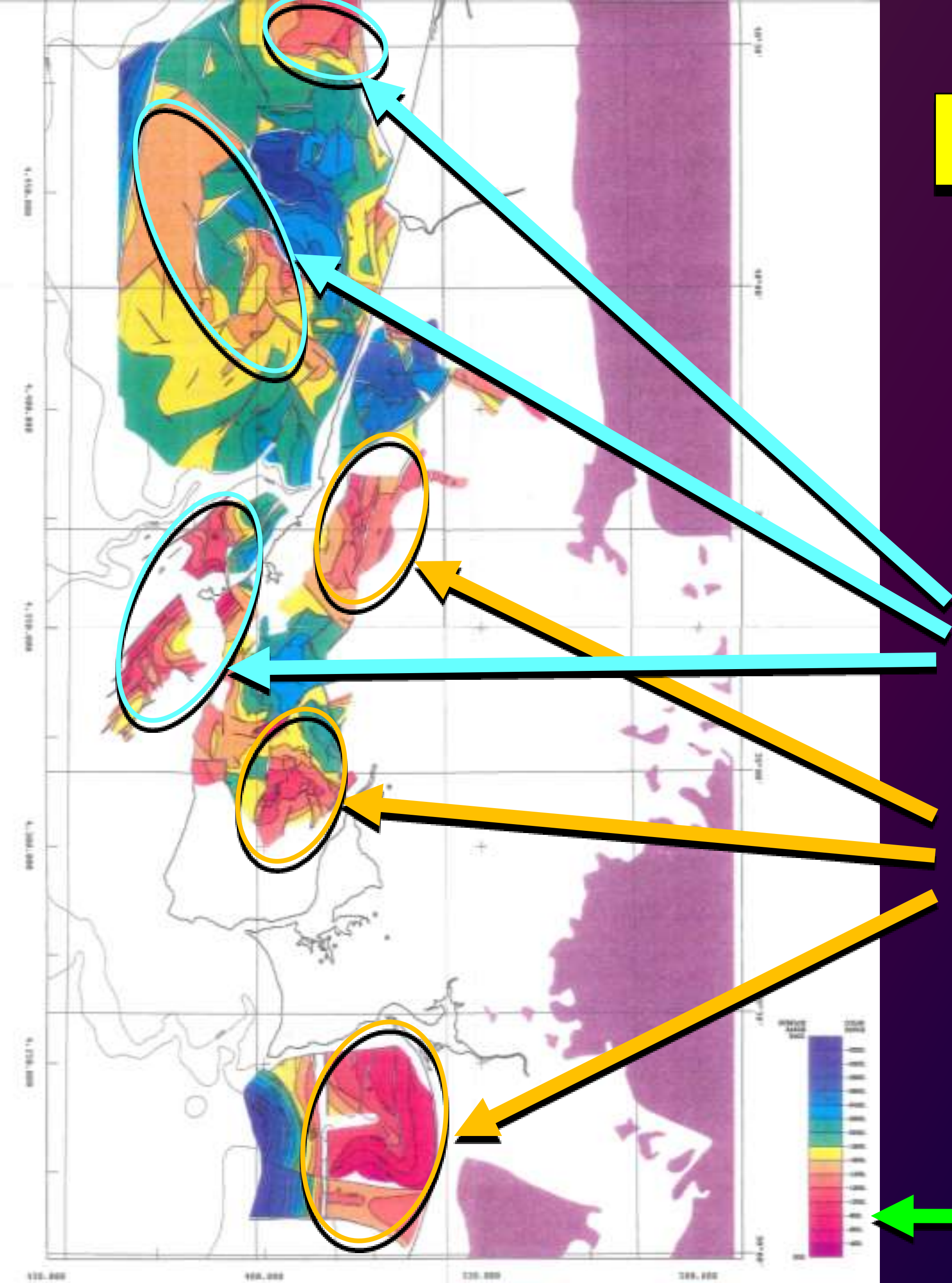
(> 1000 m)

Offshore

Onshore

- 1000 m

Lomholt et al 1995



Lusitanian Basin

Top Triassic

Potential Reservoir

(> 800 m)

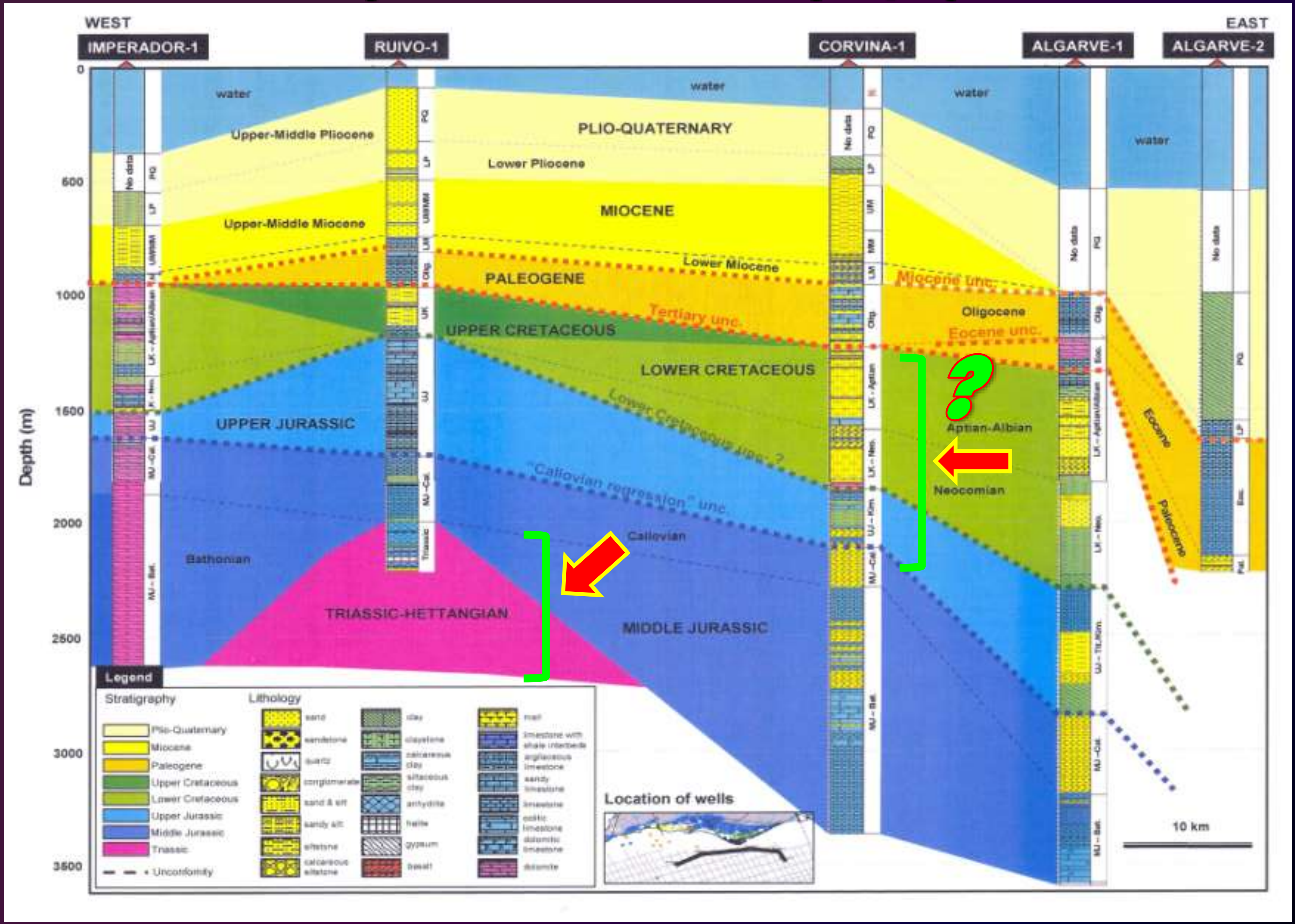
Offshore

Onshore

- 800 m

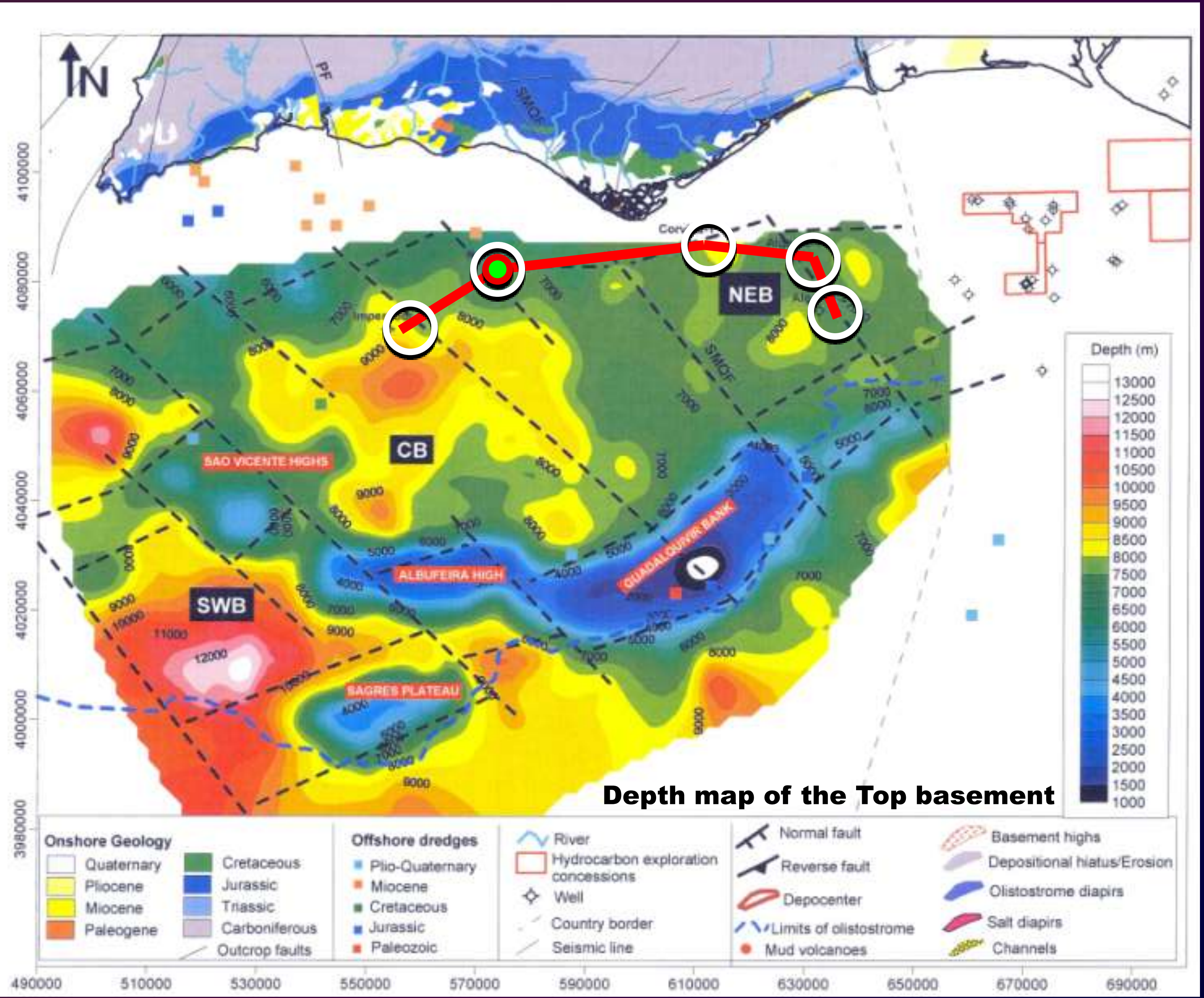
Lomholt et al 1995

Algarve Basin Stratigraphy



Matias 2007

Algarve Basin



Matias 2007

Onshore ?

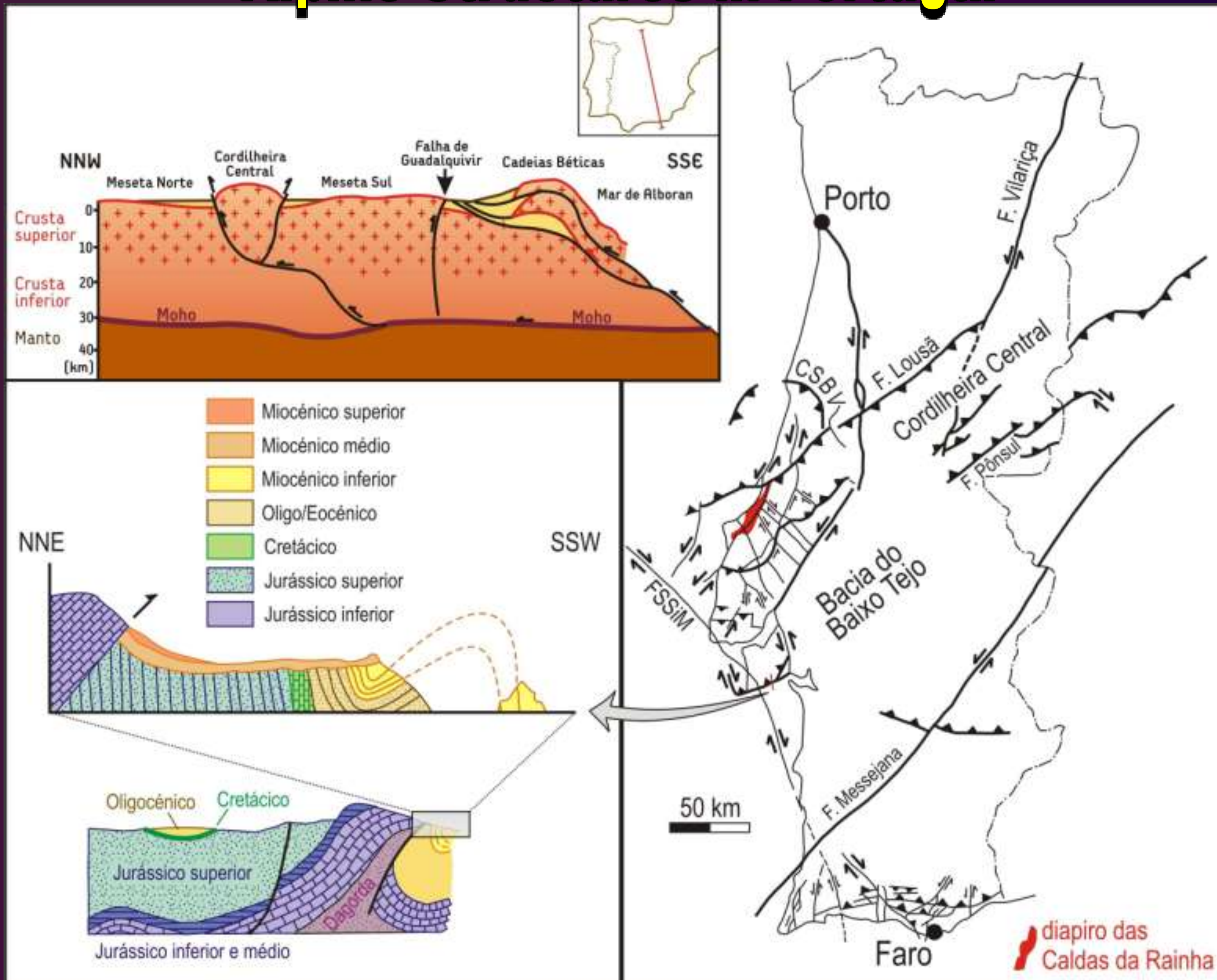
Offshore

Potential Reservoir

Upper Jurassic (> 1500 m)

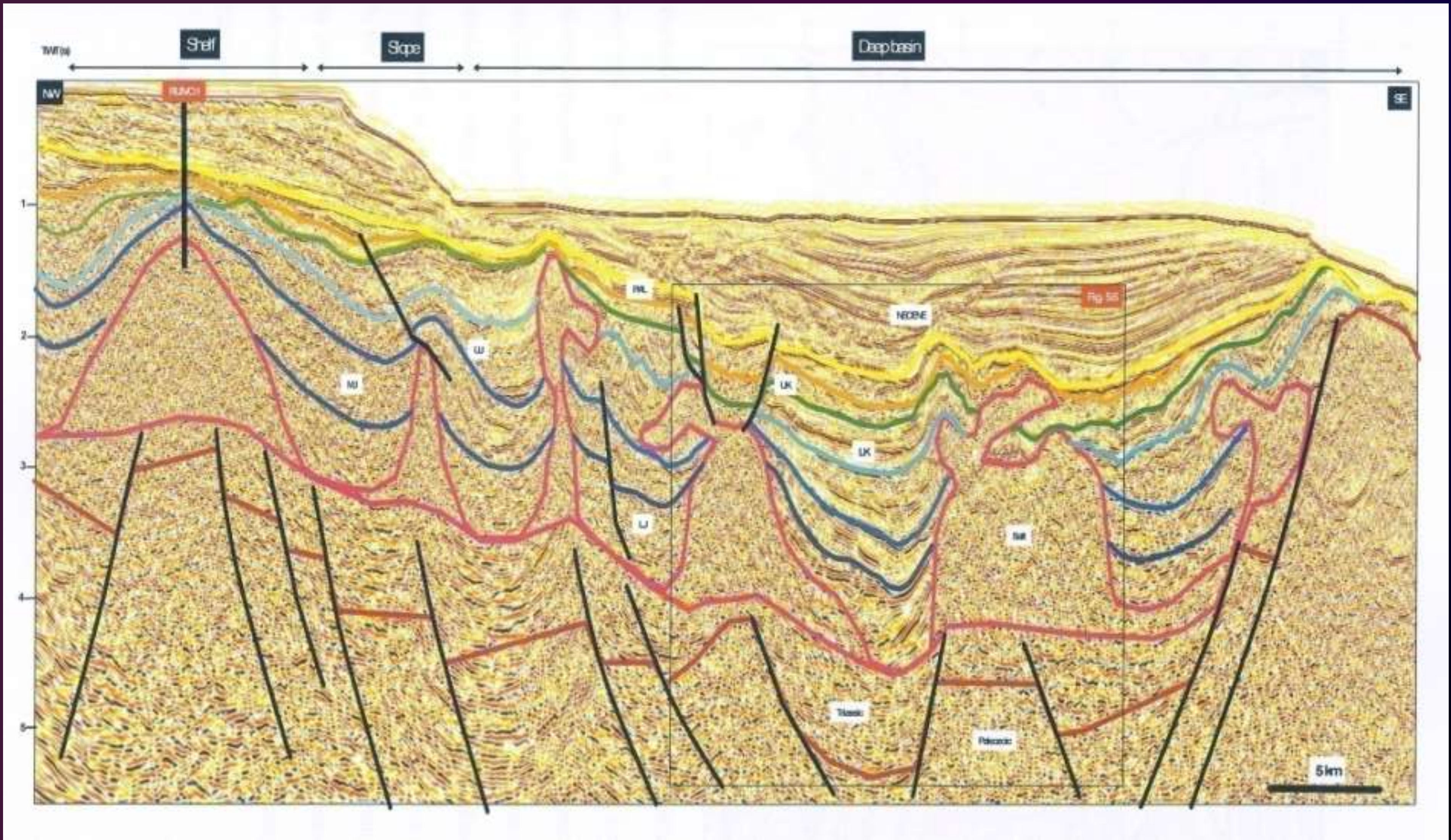
Triassic (> 2000 m)

Alpine Structures in Portugal



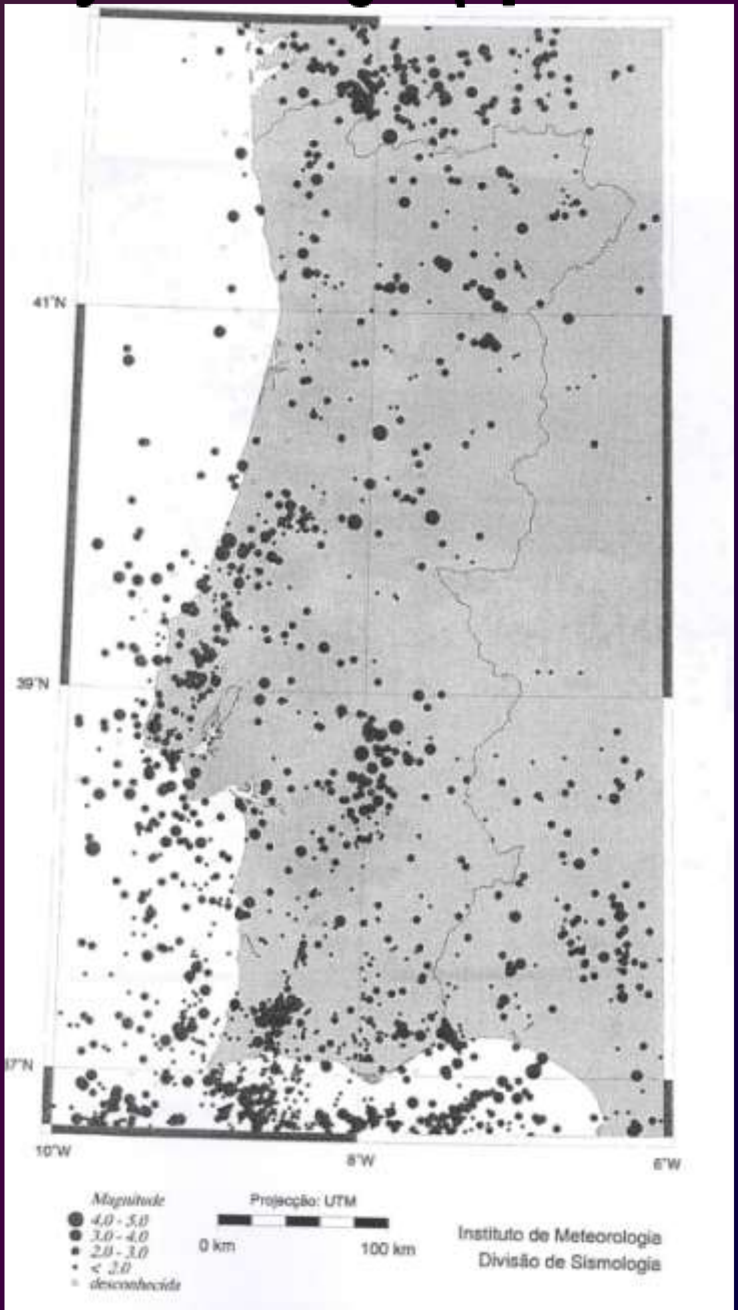
Ribeiro 2006 in R. Dias et al 2006

Algarve Basin
Regional Seismic line



Matias 2007

Seismic Activity in Portugal (epicentres 1970 - 2000)



Senos et al 2004

CIAGEB

“Energy” Research Group

Current PhD Programme

- **PhD in “EARTH SCIENCES”**

Scientific and Research Domains:

- ✓ “Petroleum Systems and Energy Problems”
- ✓ “GHG Emissions and CO2 Geological Sequestration”
- ✓ Geo-Engineering and Geo-Hazards

CIAGEB

"Energy" Research Group

European Patent EP 1 801 346 A1

https://data.epo.org/publication-server/getpdf.jsp?cc=EP&pn=1801346&ki=A1

"Process for gaseous phase Carbon dioxide sequestration by injection in coal seams."

Inventors:

A. Mouraz Miranda (IST),
C.F. Rodrigues (UFP)
M.J. Lemos de Sousa (UFP)

December 21, 2006

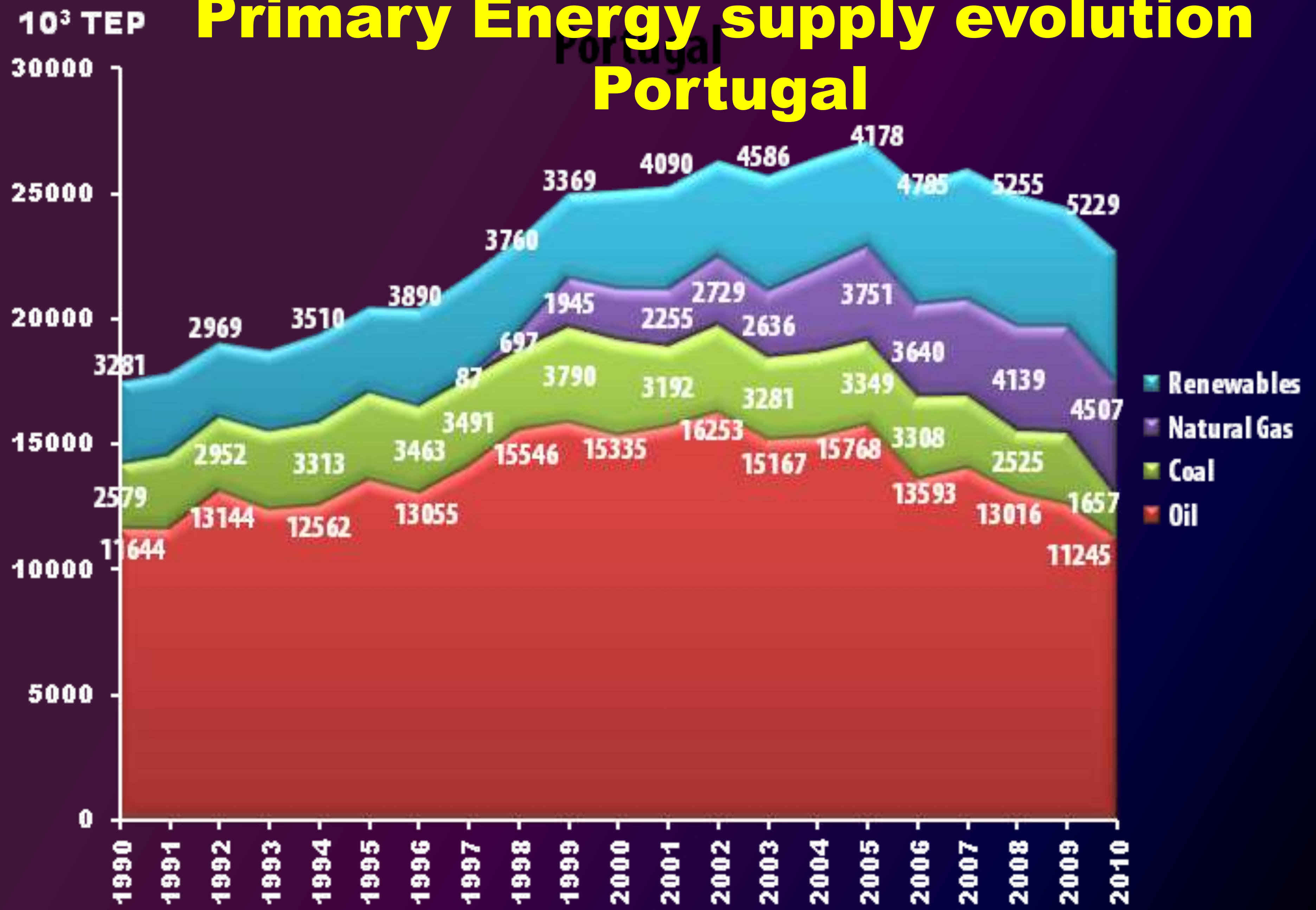
Reservoir Simulator

Maria Alzira Pimenta Dinis

ESTUDO DO PROCESSO DE DIFUSÃO DE GASES EM CARVÕES COM BASE EM ISOTÉRMICAS DE LANGMUIR

Universidade Fernando Pessoa
Porto 2010

Primary Energy supply evolution Portugal



Source: Eurostat (2011)
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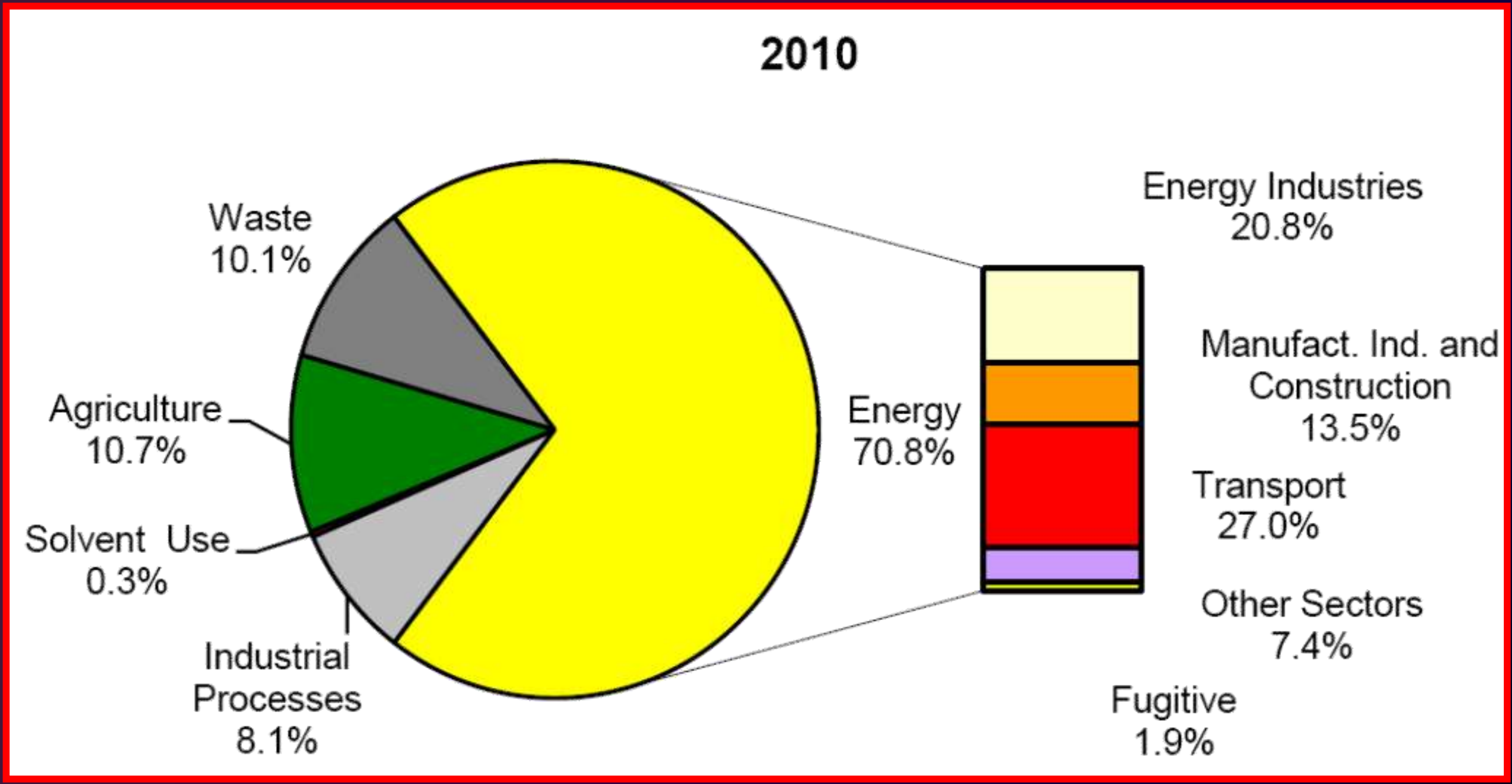
Origin of greenhouse gases in Portugal



Source: APA (2012)

Thank you very much