Captura y Almacenamiento de CO_2

Una Opción Sustentable para el Uso de Combustibles Fósiles

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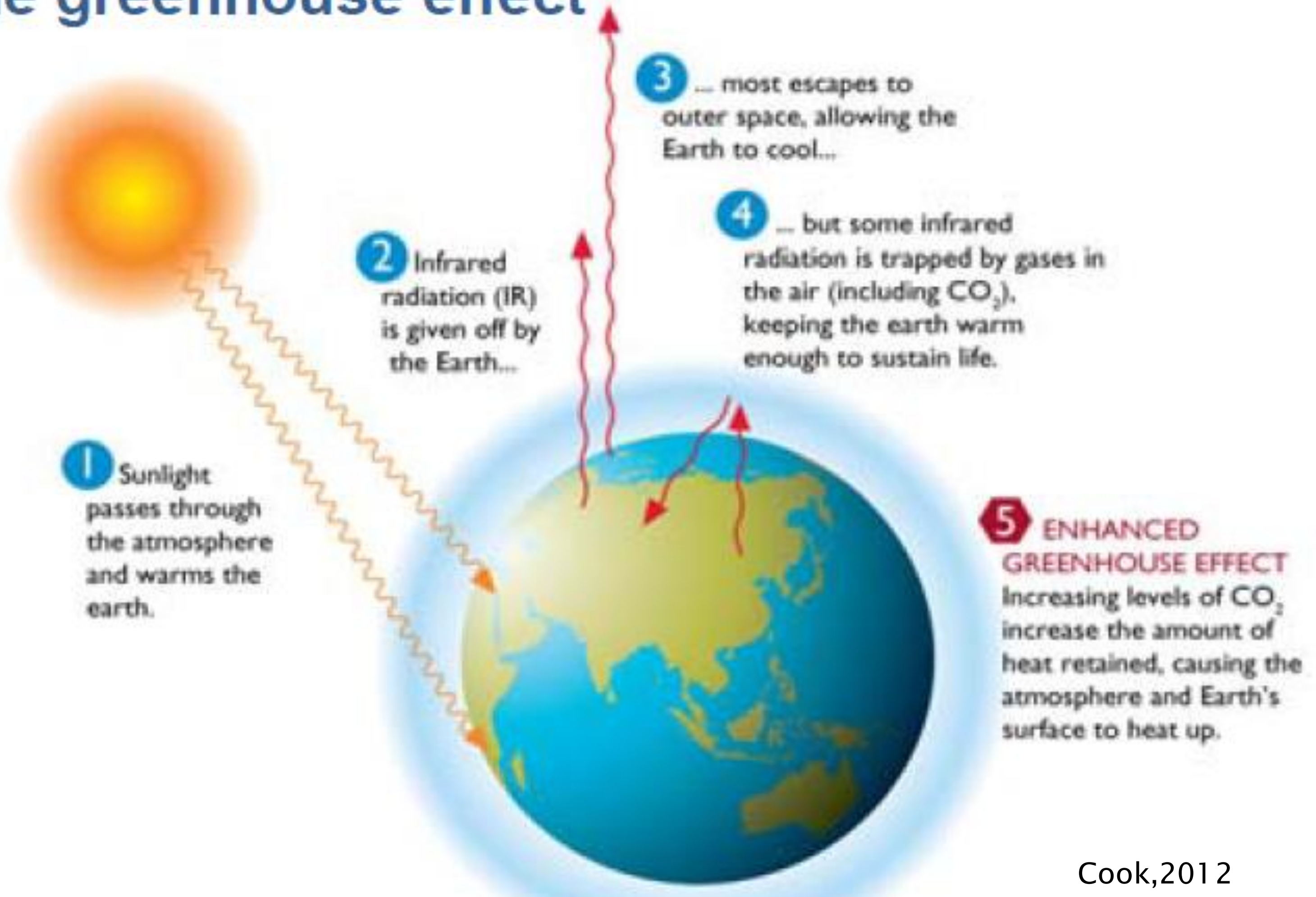
Abril de 2013

El Cambio Climático y los GEI

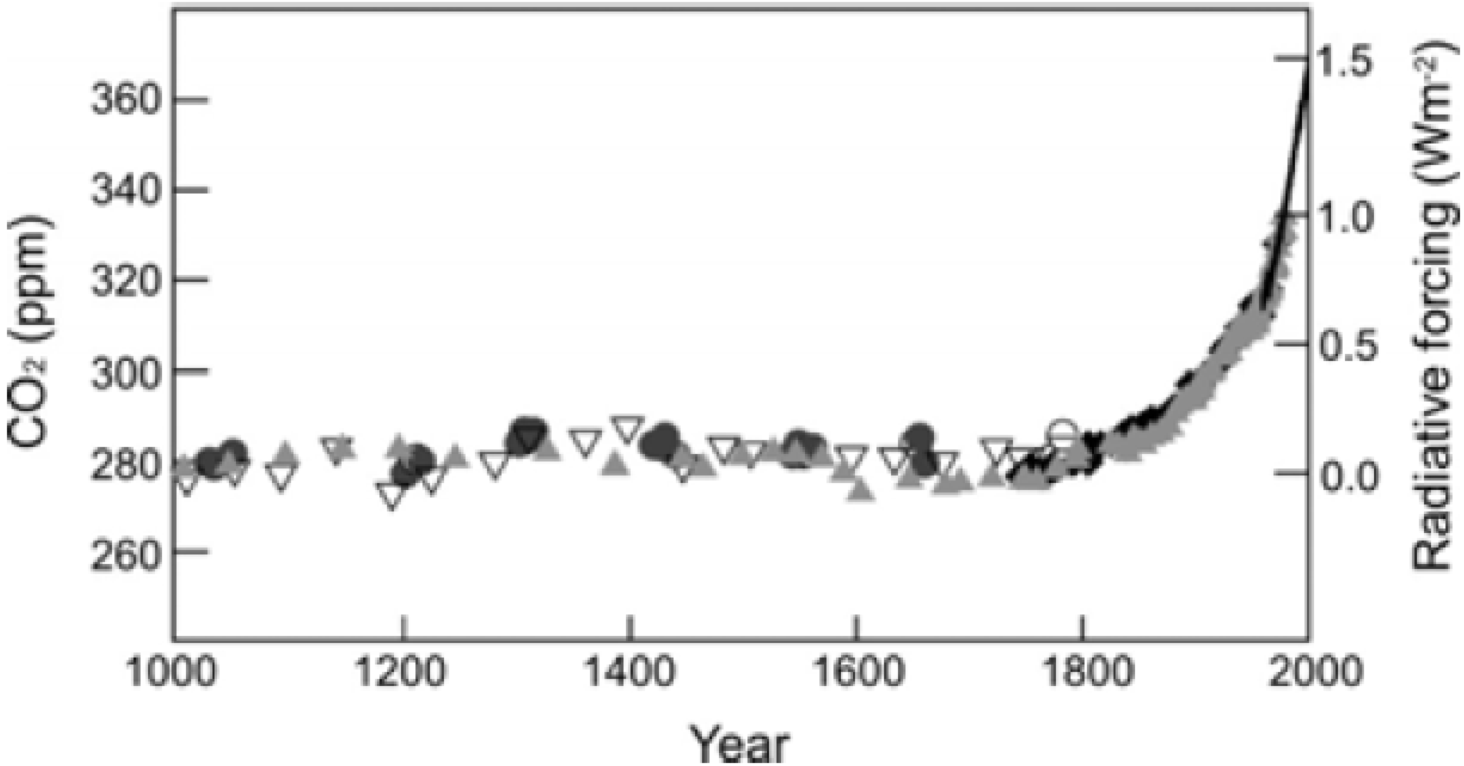
The greenhouse effect



Cook,2012

CO_2 Concentrations in Atmosphere

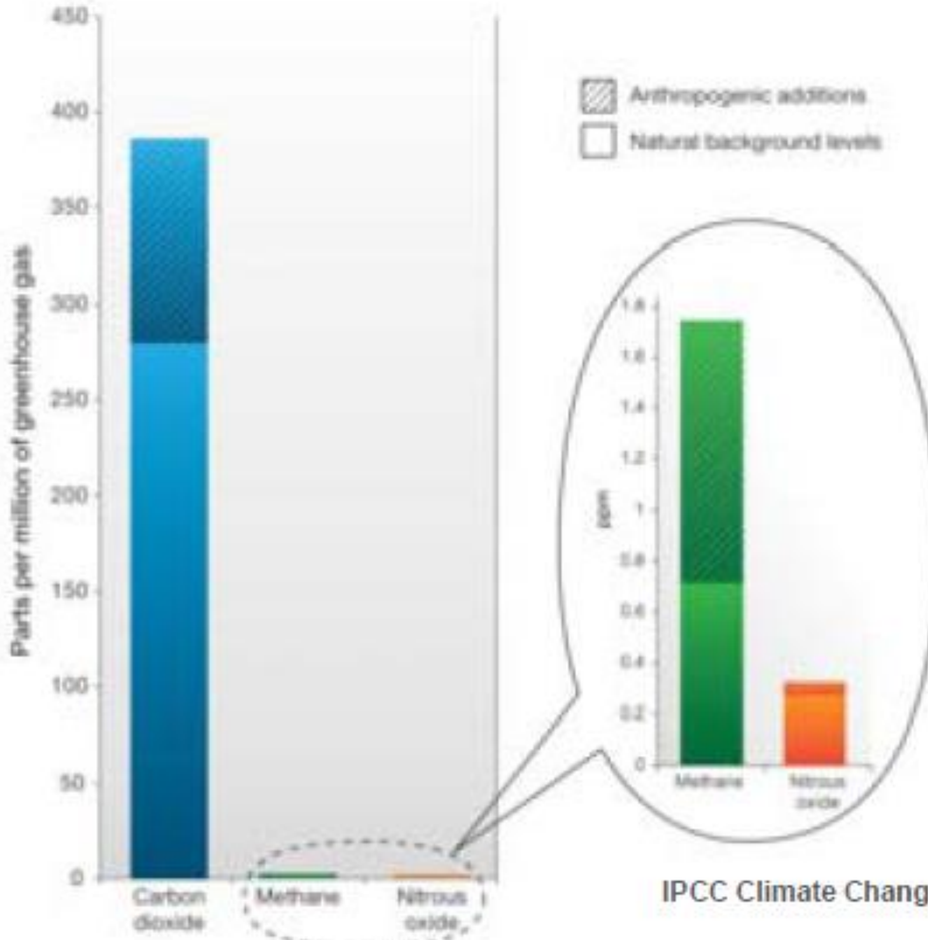
- CO_2 increased 31% since year 1750 (280 ppm to ~370 ppm)



Change in global atmospheric concentration of CO_2 over past 1000 years (IPCC, 2001)

Increase in greenhouse gases

Increase in greenhouse gases (1750 to 2005)

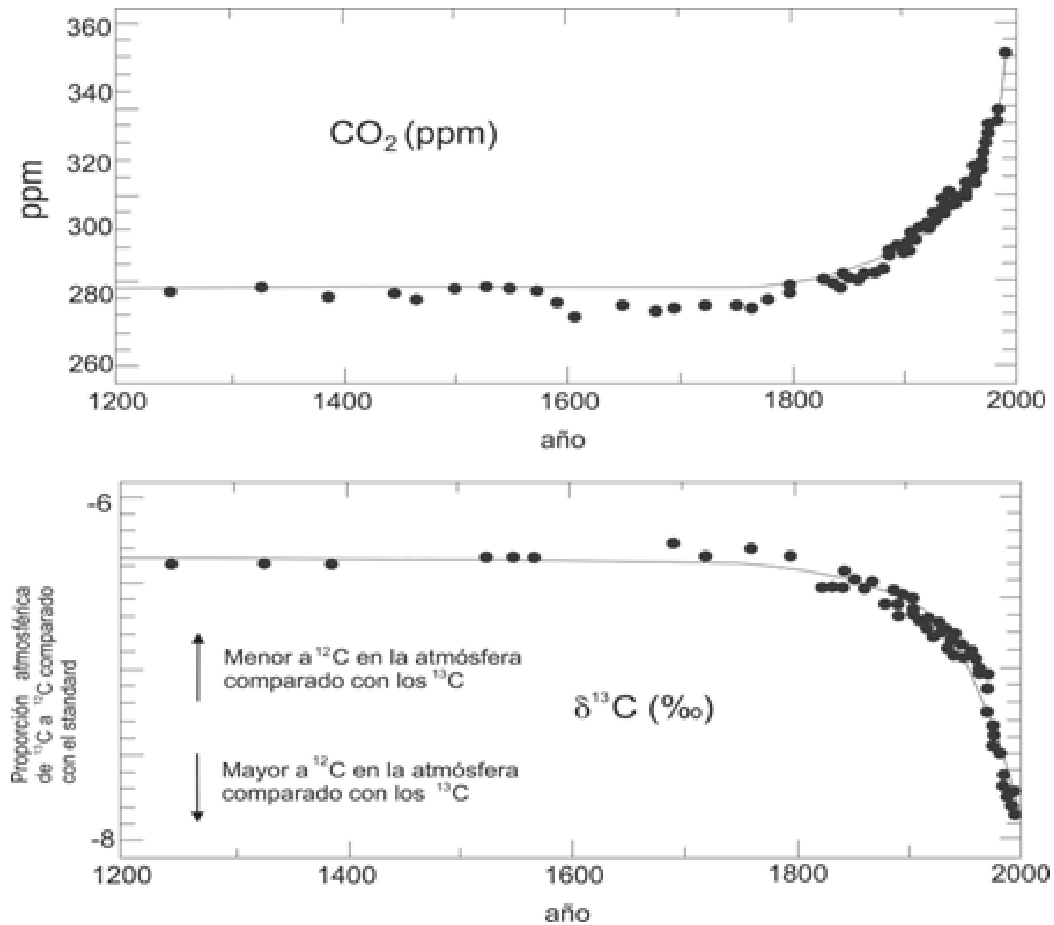


Increase in CH_4, N_2O

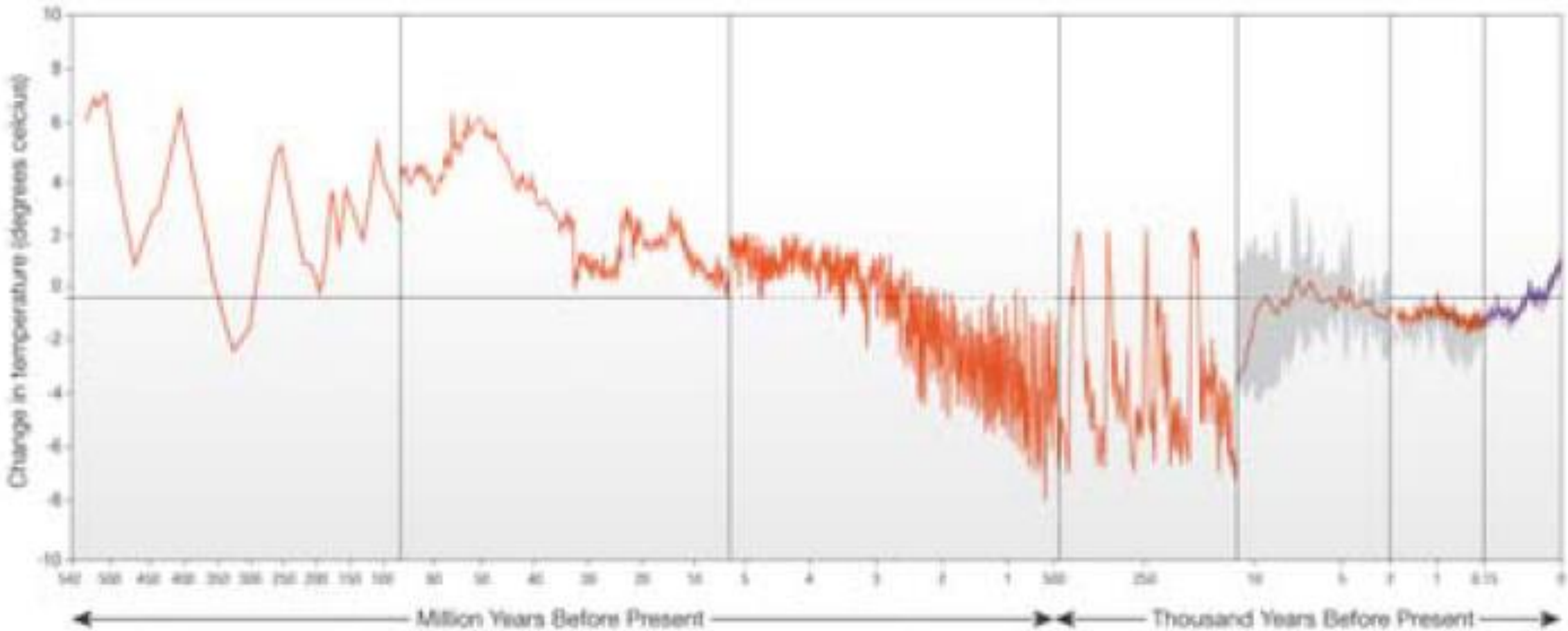
IPCC Climate Change 2007: Synthesis Report

Incremento de las concentraciones de CO_2 en el mundo en los últimos 200 años.

En la parte inferior de la figura apréciese el decaimiento de la relación $^{13}C/^{12}C$ que apoya el origen antropogénico de bióxido de carbono ya que el isótopo ^{13}C es de origen natural exclusivamente en contraparte al ^{12}C que tiene una componente antropogénica importante [Cook, 2012].

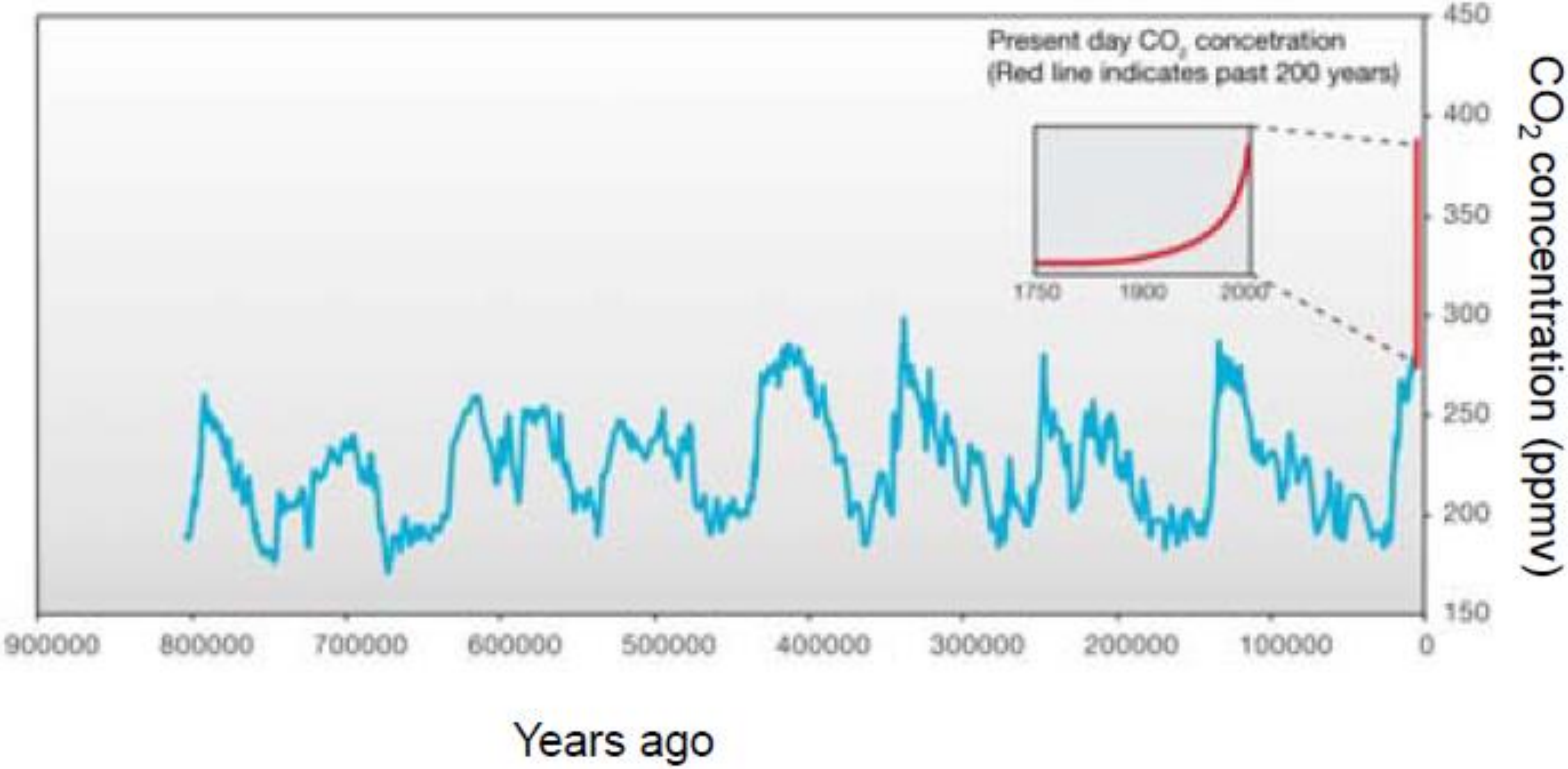


Temperature of planet Earth

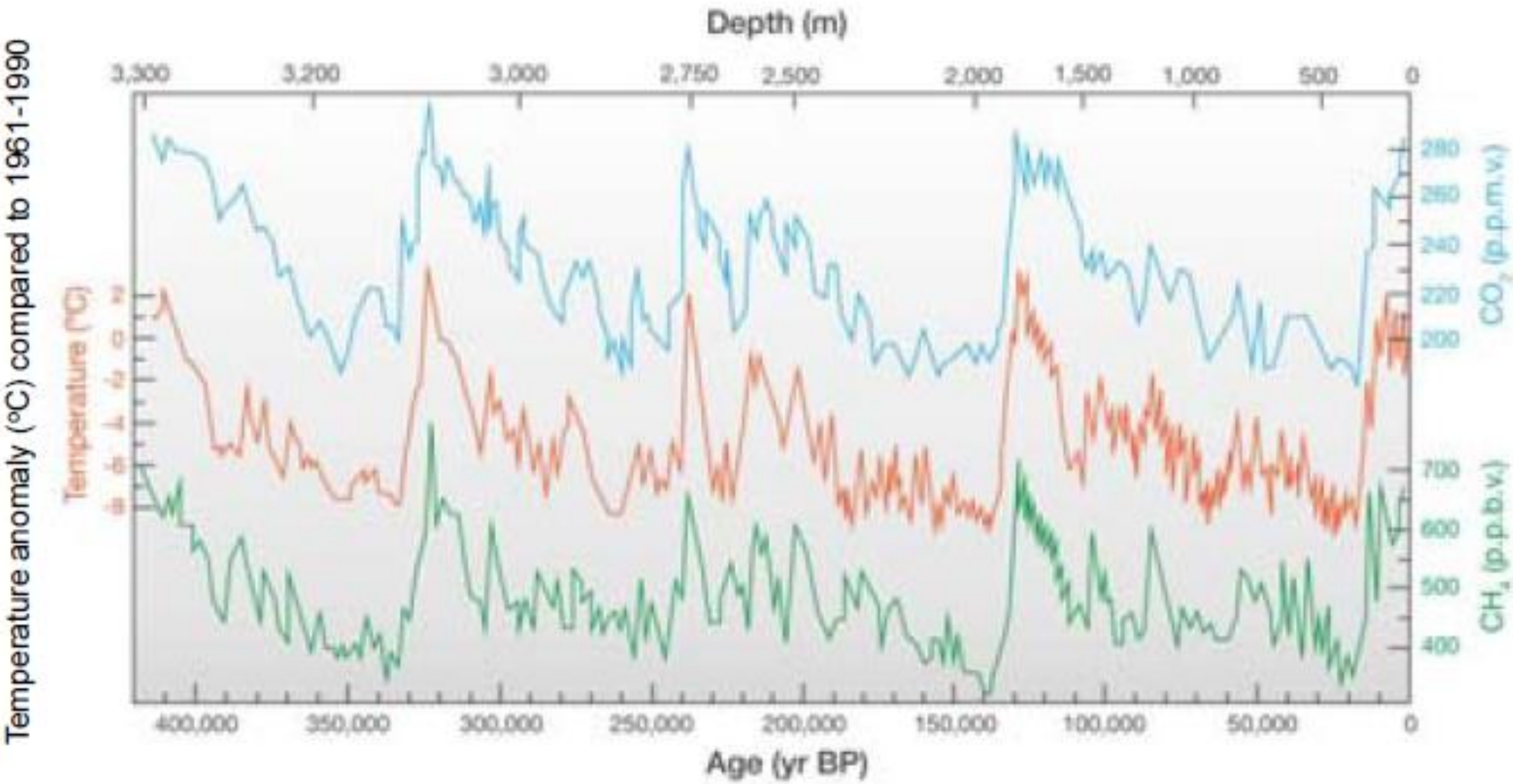


After Rohde, data compiled from Royer et al, Zachos et al, Lisiecki et al, Petit et al, Mann et al, Mann et al and Brohan.

Carbon dioxide variations: last 800,000 years

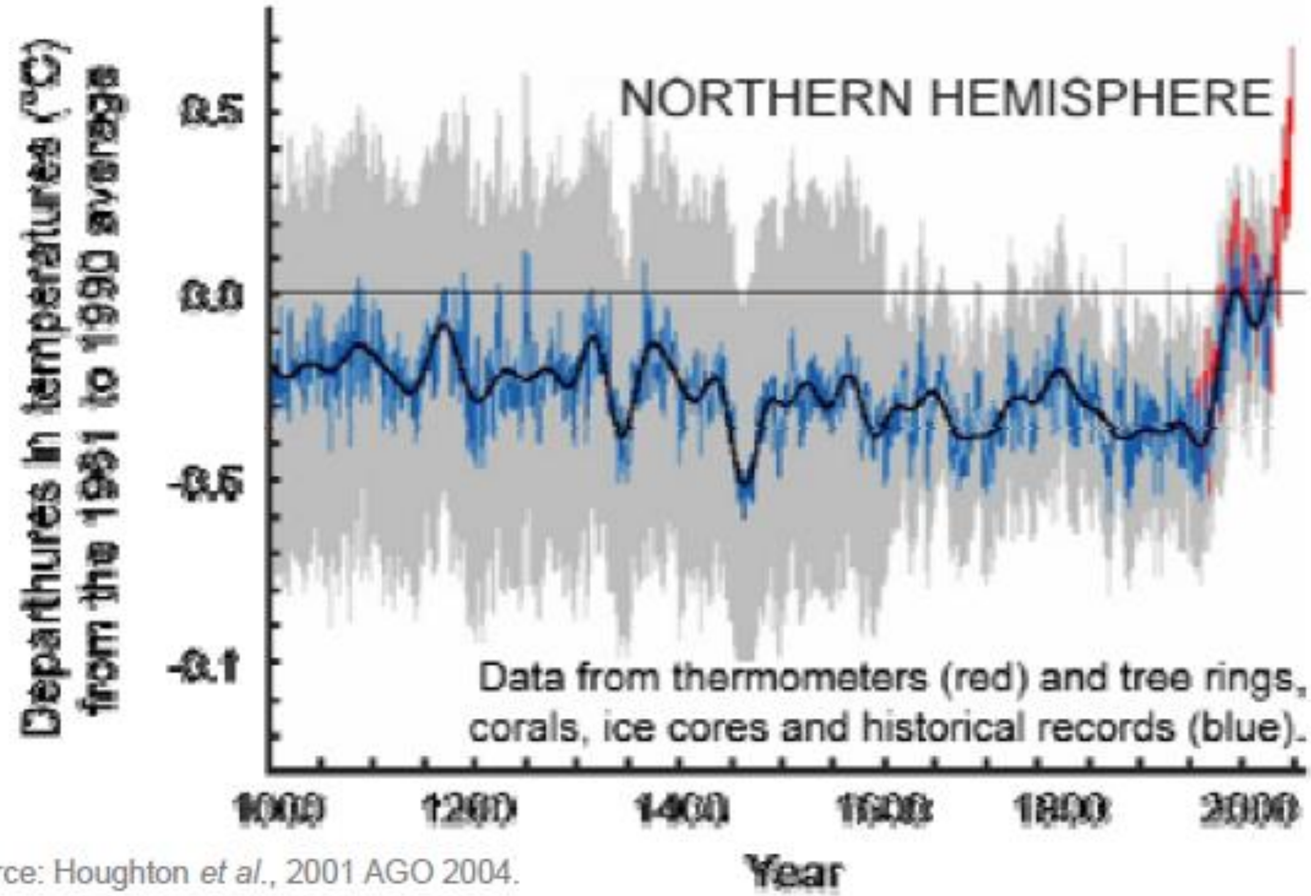


Variations of surface temperature, carbon dioxide and methane over 400,000 years



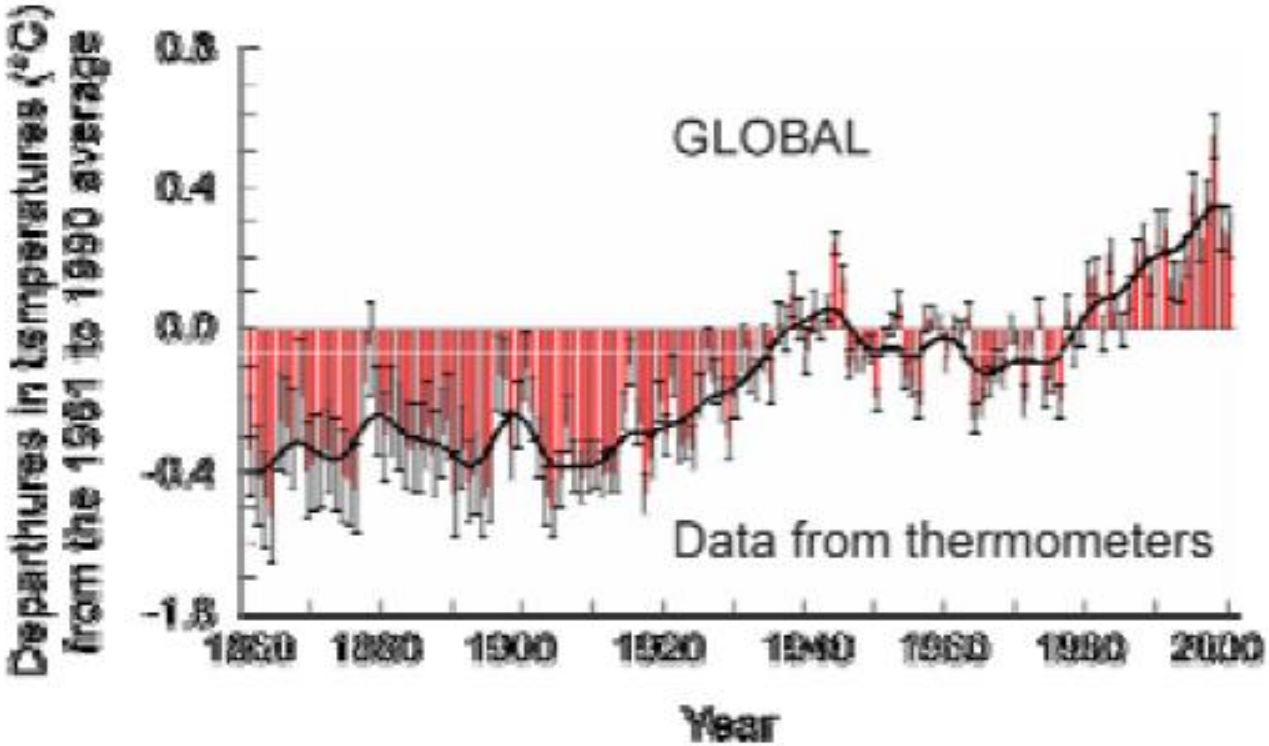
Data from Vostok ice cores, USGCRP, 1999

Earth's surface temperature variations for the last 1000 years



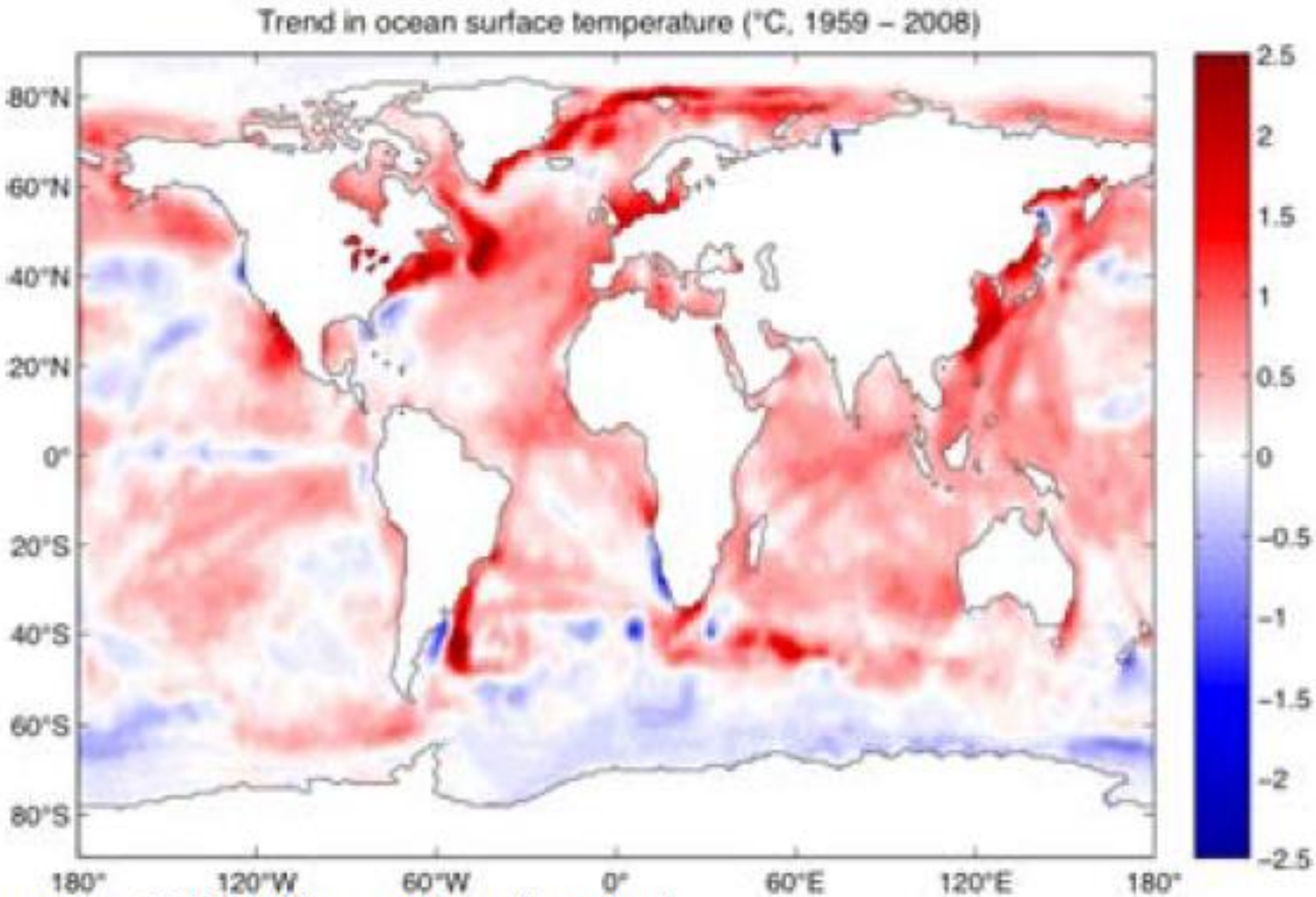
Source: Houghton *et al.*, 2001 AGO 2004.

Earth's surface temperature variations for the last 140 years



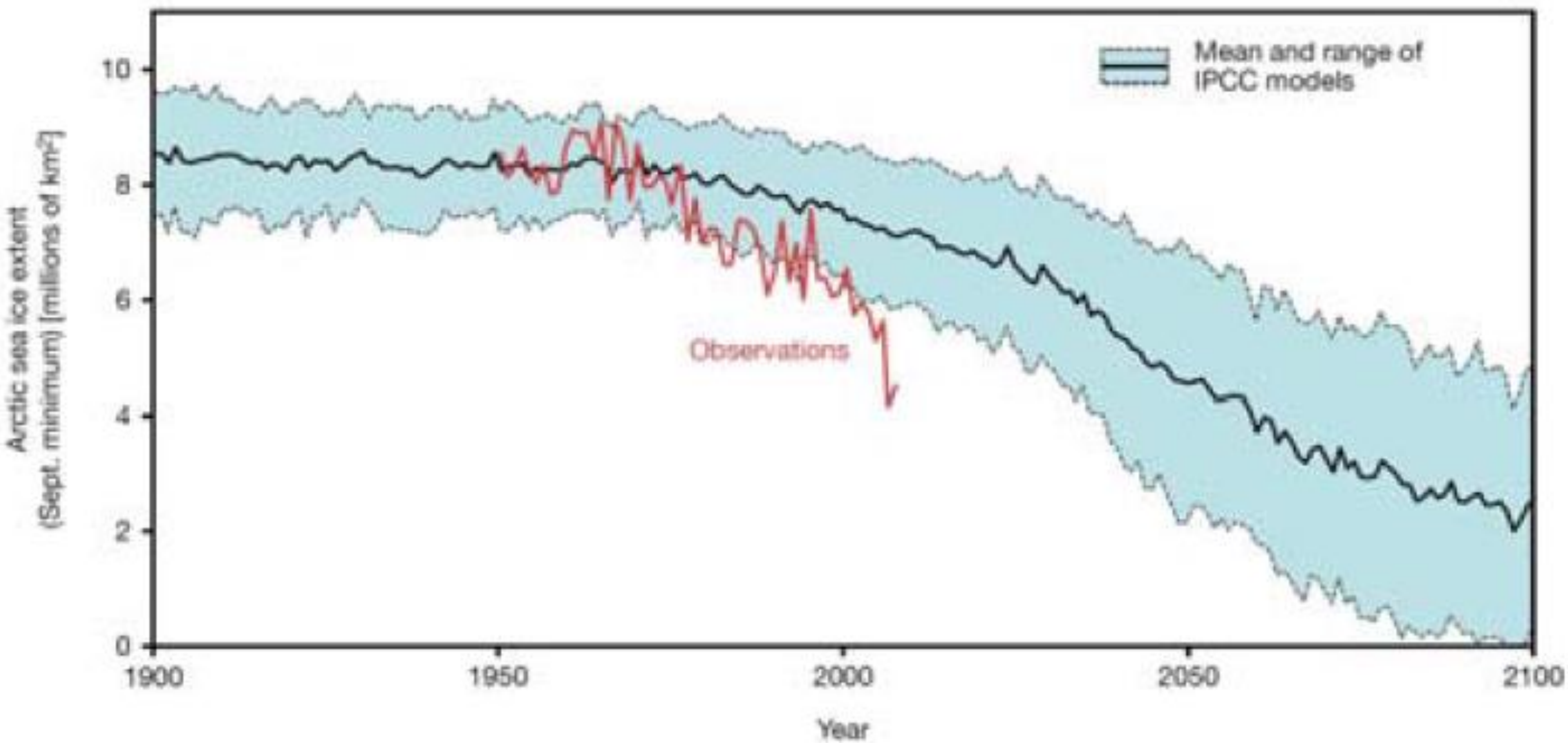
Source: Houghton *et al.*, 2001, AGO 2004.

Average ocean temperature changes



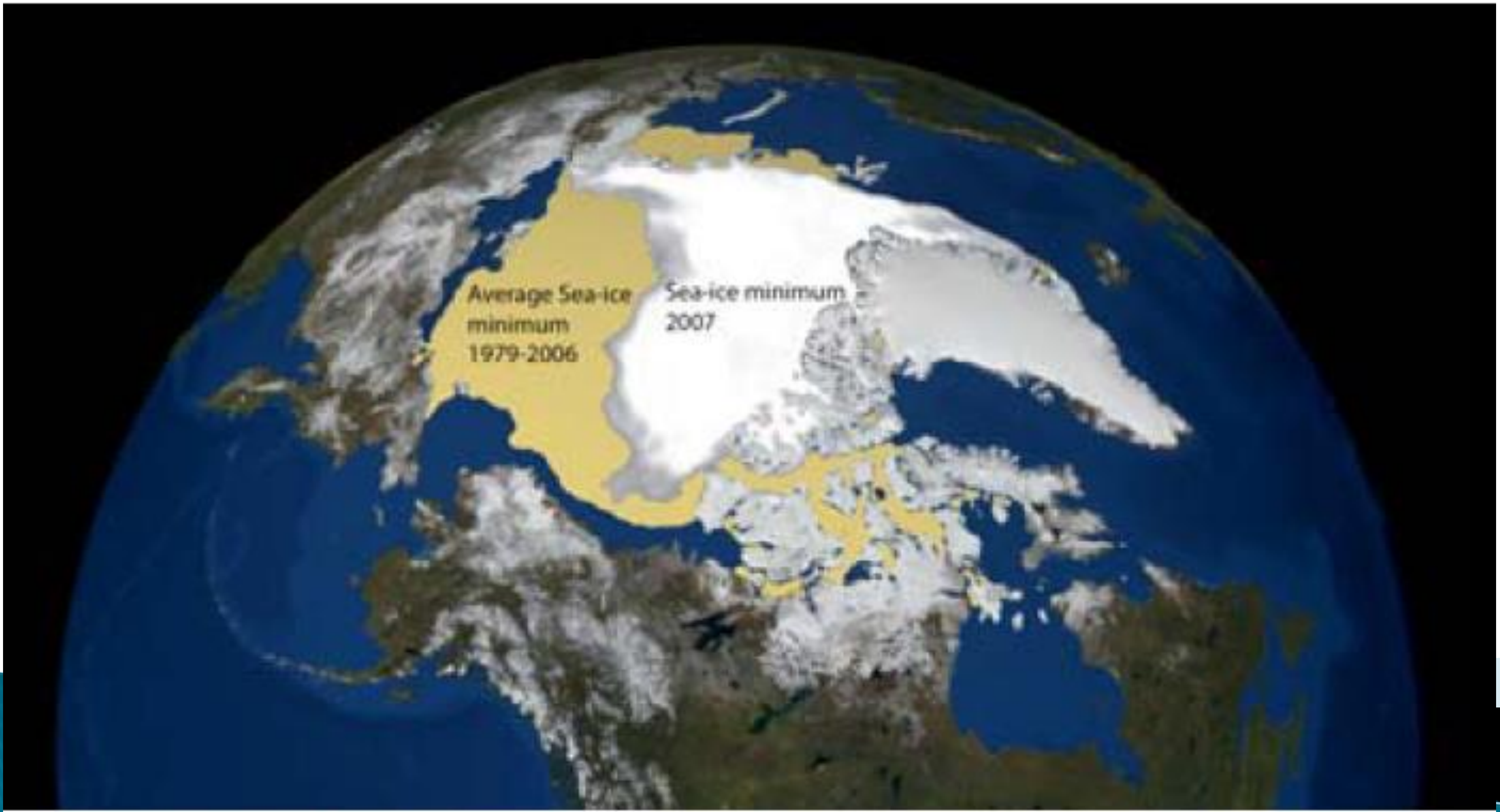
From The Copenhagen Diagnosis 2009. http://www.copenhagendiagnosis.org/

Arctic sea ice



From Strove et al. (2007) updated with 2008 data *in* The Copenhagen Diagnosis 2009. http://www.ccrc.unsw.edu.au

Arctic sea ice



Sourced from the NASA/Goddard Space Flight Center Scientific Visualization Studio *in* the Copenhagen Diagnosis 2009. http://www.ccrc.unsw.edu.au

Increases in greenhouse gases over the last century

- Fossil fuel burning – driven by energy demands
- Land use change – forests to farms and industry
- Increased agriculture – more livestock, rice growing
- Increased industry – iron, steel, cement, manufacturing

Kaldi, 2013

Suggested effects of warming

- Climate change – intensity of storms, longer droughts, biological and ecological change

- Rising sea levels

- Warming temperatures likely to increase water vapour in the atmosphere – water vapour is a greenhouse gas so it is likely that this will reinforce global warming.

Kaldi, 2013

An alternative view:

Climate Change / Global Warming may be occurring, but if it is, it is due to natural causes that are part of normal geological processes that have been taking place for hundreds of million years. Human activities are too insignificant to result in consequences of such enormous scale!

Kaldi, 2013

What about other possible causes of warming?

- Sun activity – while there are variations in the solar radiation due to the solar cycle, the is no overall upward trend in incoming solar radiation.

- Natural cycles in the earth's motion (as explained by Milankovitch) have much longer trends – indeed would point to longer-term cooling in the Northern Hemisphere.

Kaldi, 2013

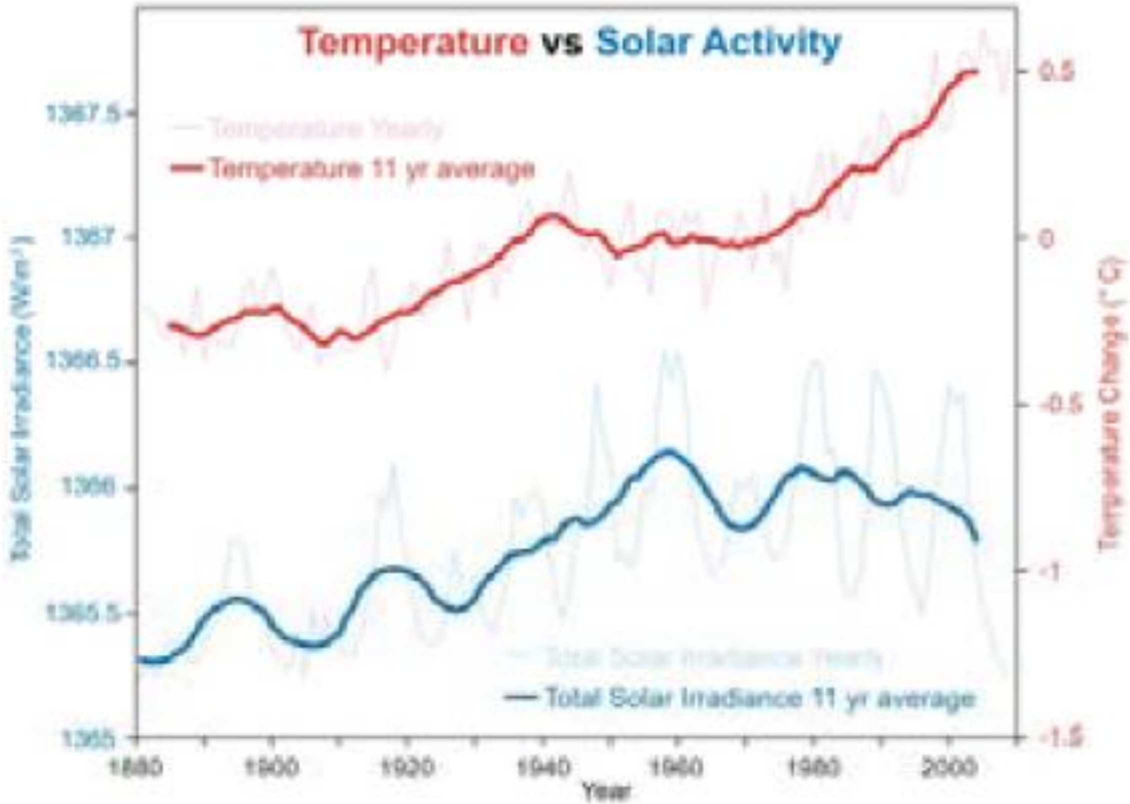
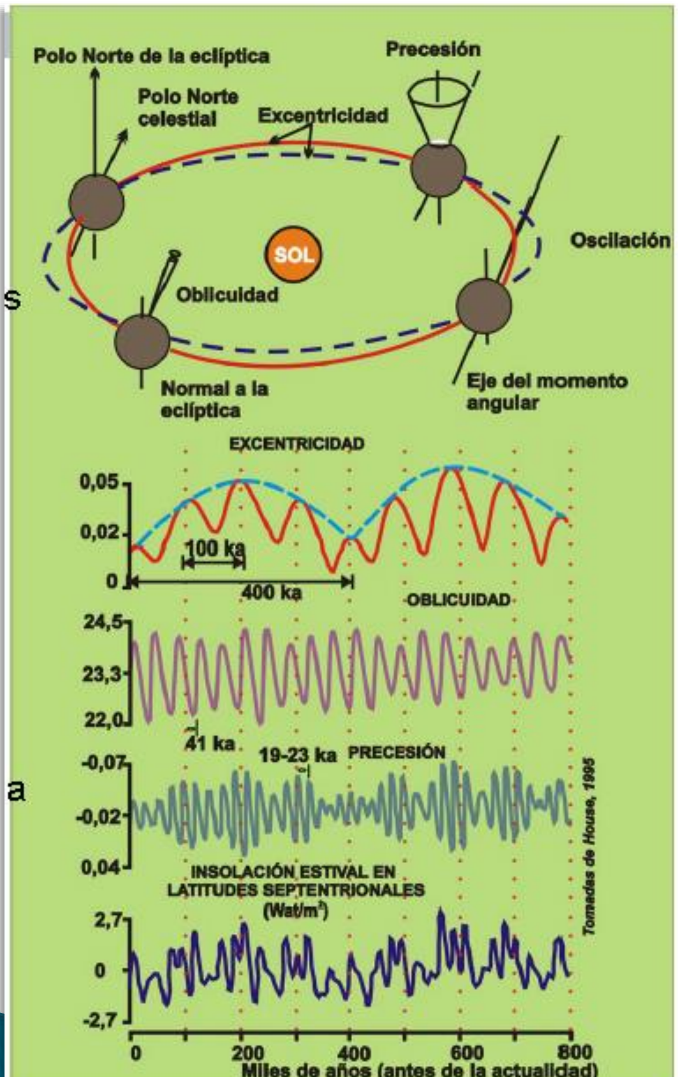
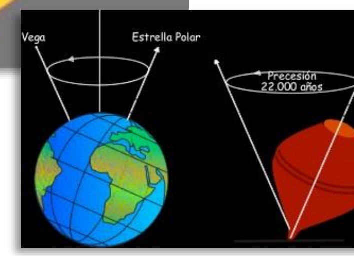
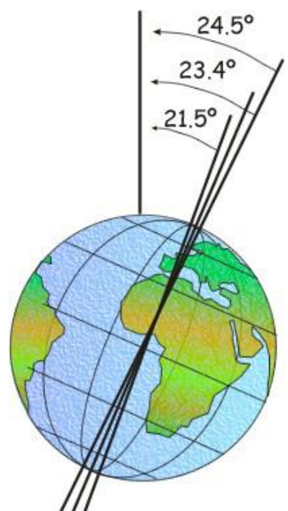


Figure 1: Annual global temperature change (thin light red) with 11 year moving average of temperature (thick dark red). Temperature from NASA GISS. Annual Total Solar Irradiance (thin light blue) with 11 year moving average of TSI (thick dark blue). TSI from 1880 to 1978 from Krivova et al 2007 (data). TSI from 1979 to 2009 from PMOD.

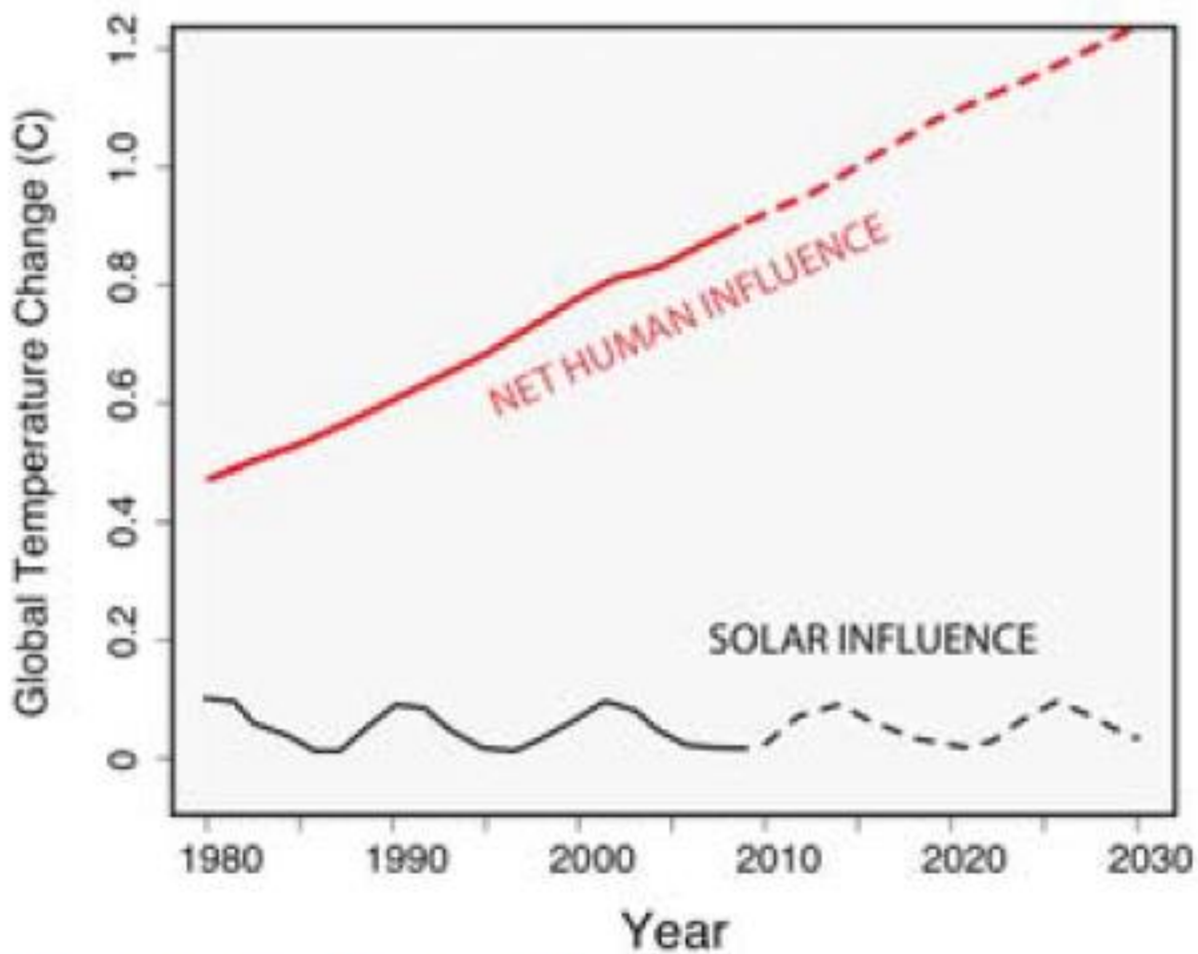
Cíclos de Milankovitch





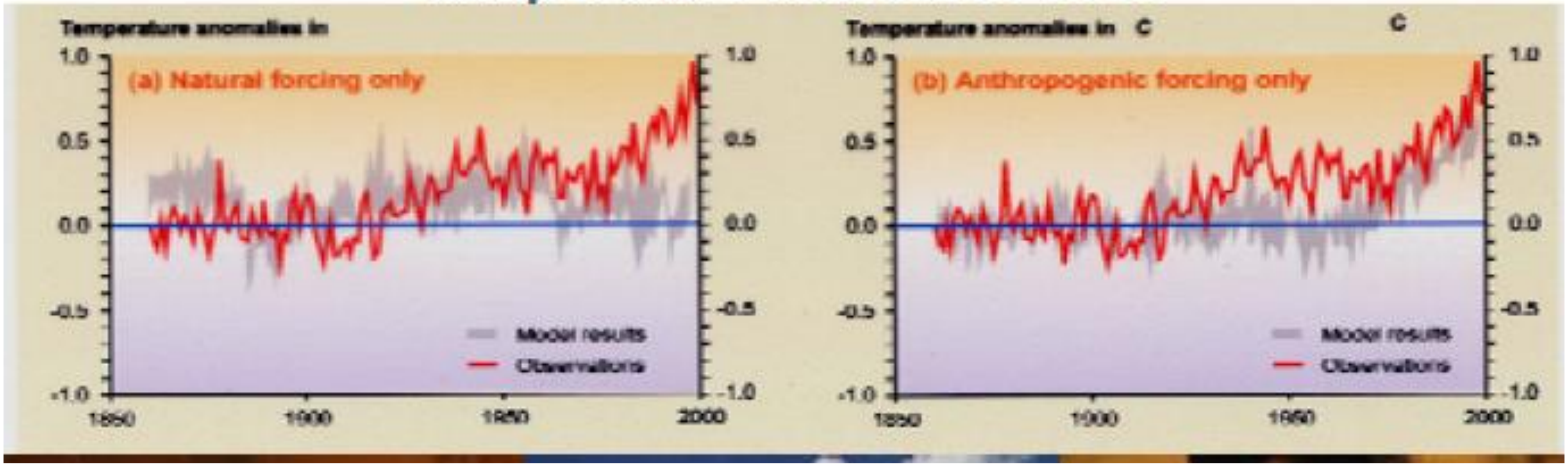


Solar radiation variations



hagen Diagnosis 2009. http://www.ccrc.unsw.edu.au

Comparison between model and observations of the temperature rise since 1860



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Is Solar Activity the Cause of Climate Change?

In recent years, several peer reviewed publications have reported on the role of the sun on climate change:

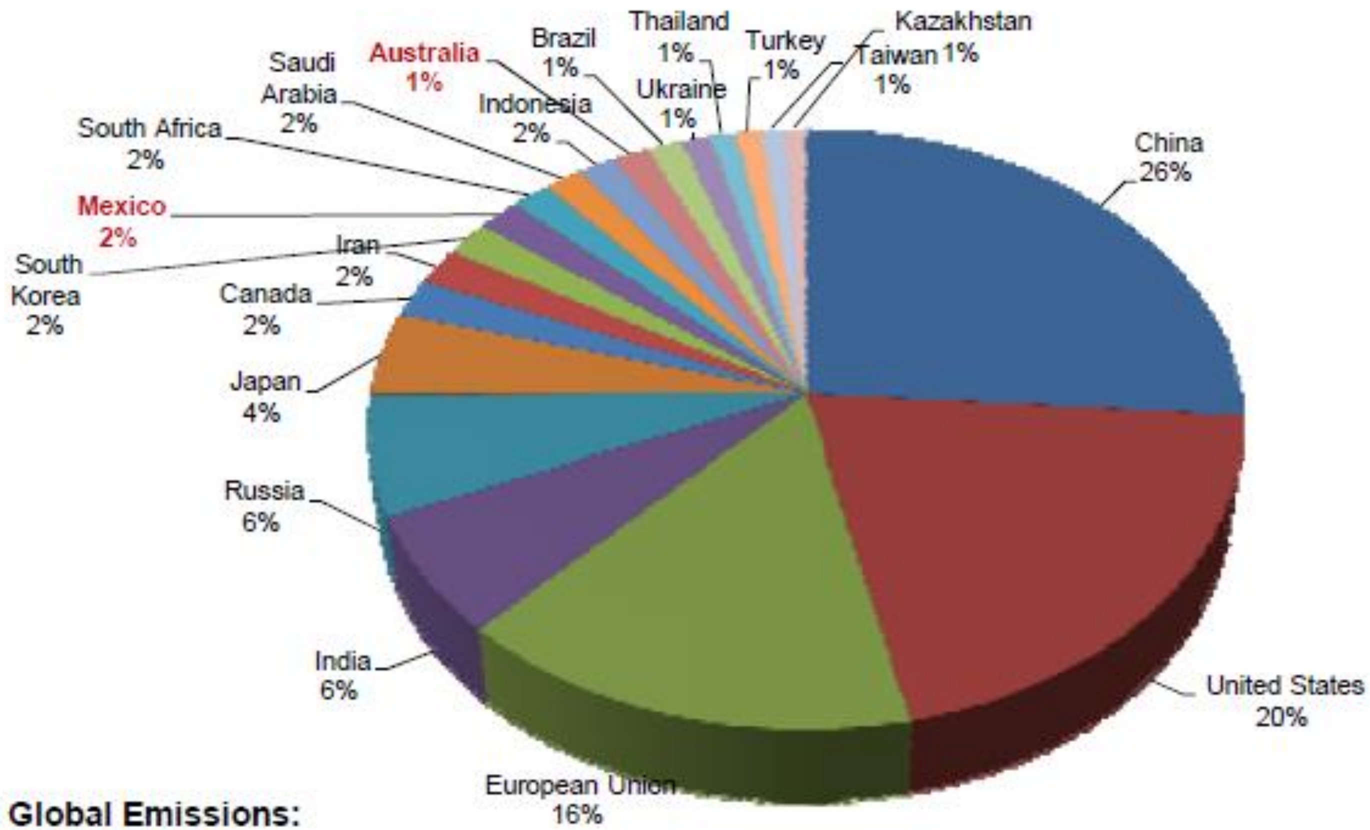
• Several studies correlated solar activity and climate over the last 11,400 years. Upon observing a recent divergence between sun and global temperature, Solanki (2004)[1] concluded *"solar variability is unlikely to have been the dominant cause of the strong warming during the past three decades"*.

• More recently, Lockwood and Frohlich (2008)[2] concluded that *"…solar forcing has declined over the past 20 years while surface air temperatures have continued to rise…"*.

[1]*http://cc.oulu.fi/~usoskin/personal/nature02995.pdf*; [2]*http://rspa.royalsocietypublishing.org/content/464/2094/136*

Emisiones, de dónde provienen ?

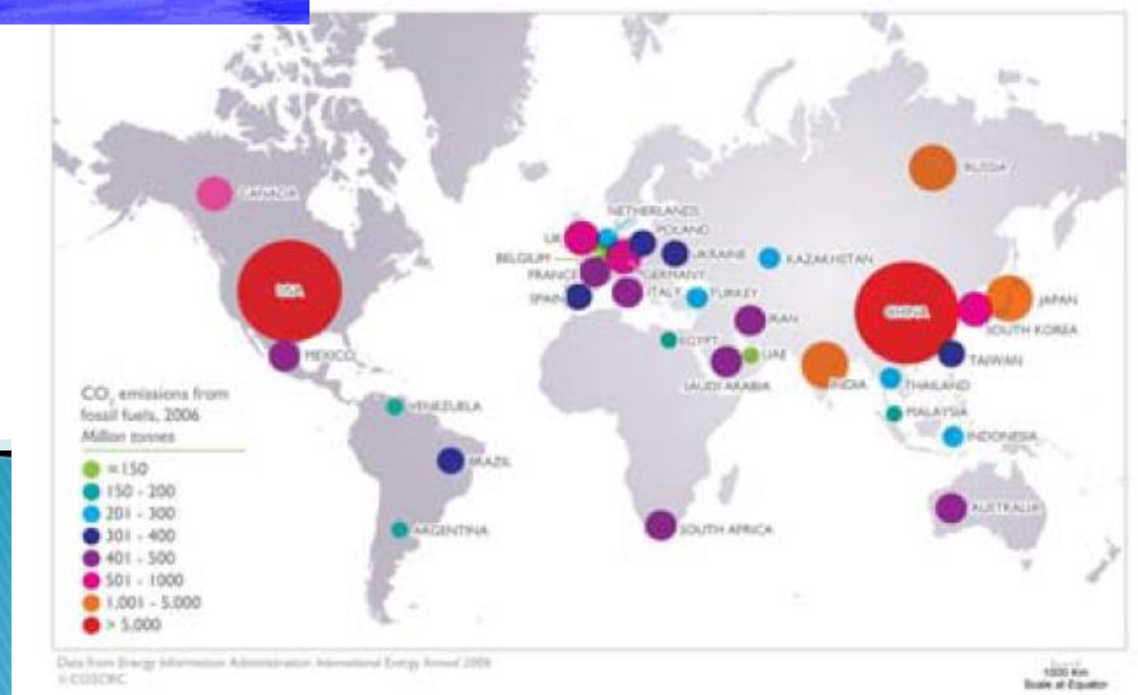
World CO_2 emissions

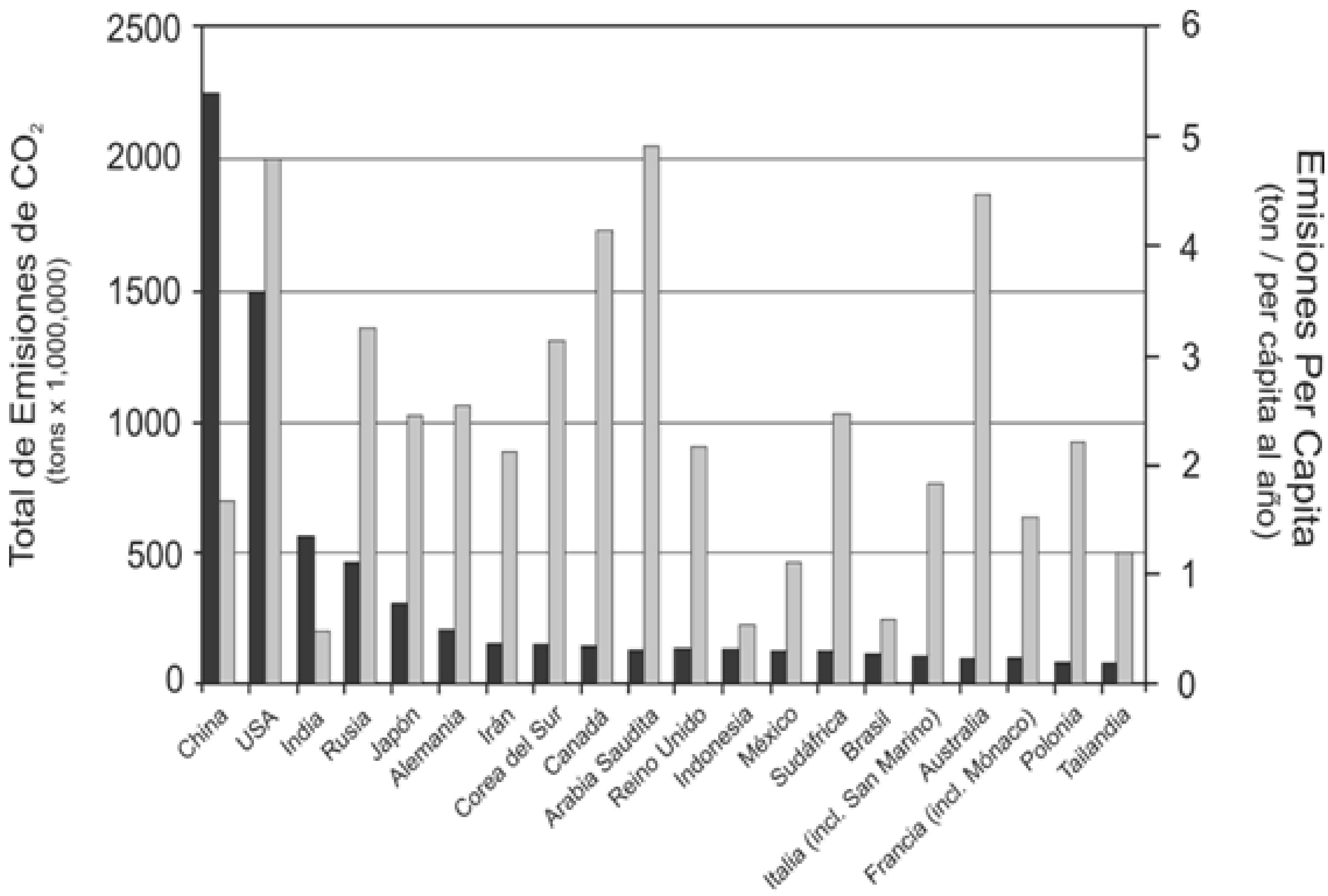


Total Global Emissions: 29.9 GT / year
(United Nations Statistics Division, 2008)

Global emissions predicted to increase by 50% by 2030, with main growth from developing countries

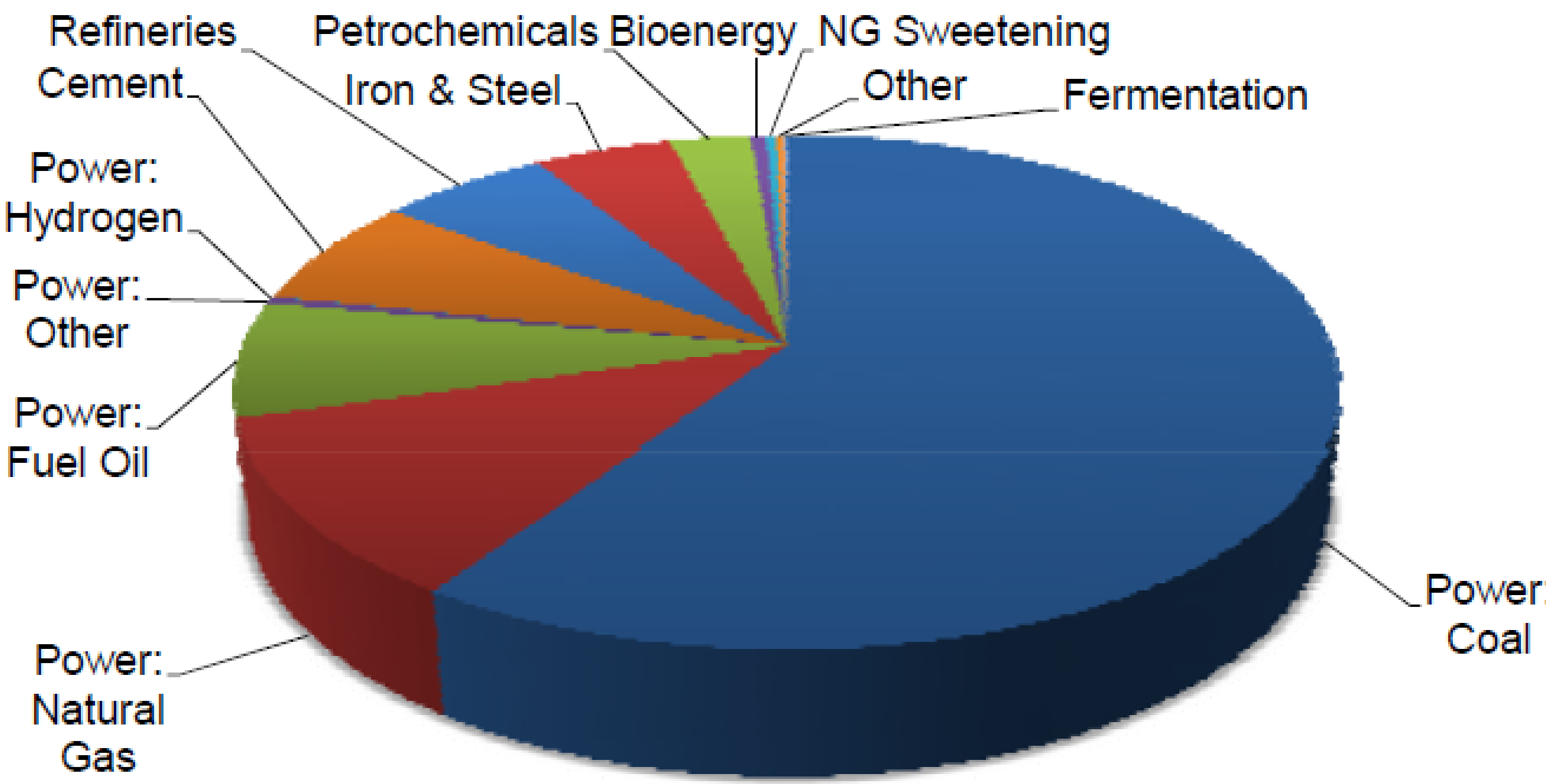
World CO_2 emissions





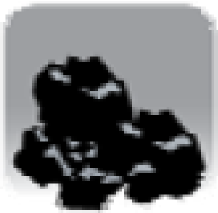
Principales países emisores de CO_2 en el mundo y su desempeño per cápita [Geoscience Australia, 2012]

Global stationary CO_2 emissions (2002)



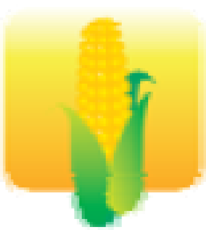
Adapted from: IPCC Special Report (2005) 'Carbon dioxide capture and storage', Cambridge University Press

Fuel types



- Fossil fuels
  - non-renewable natural resources (e.g. coal)
  - man-made from non-renewable natural sources (e.g. gasoline)

- Synthetic fuels
  - man-made from non-renewable resources



- Biofuels
  - direct use (e.g. wood burning)
  - man-made from renewable natural sources (e.g. algal fuel, ethanol)

Wiley,2013

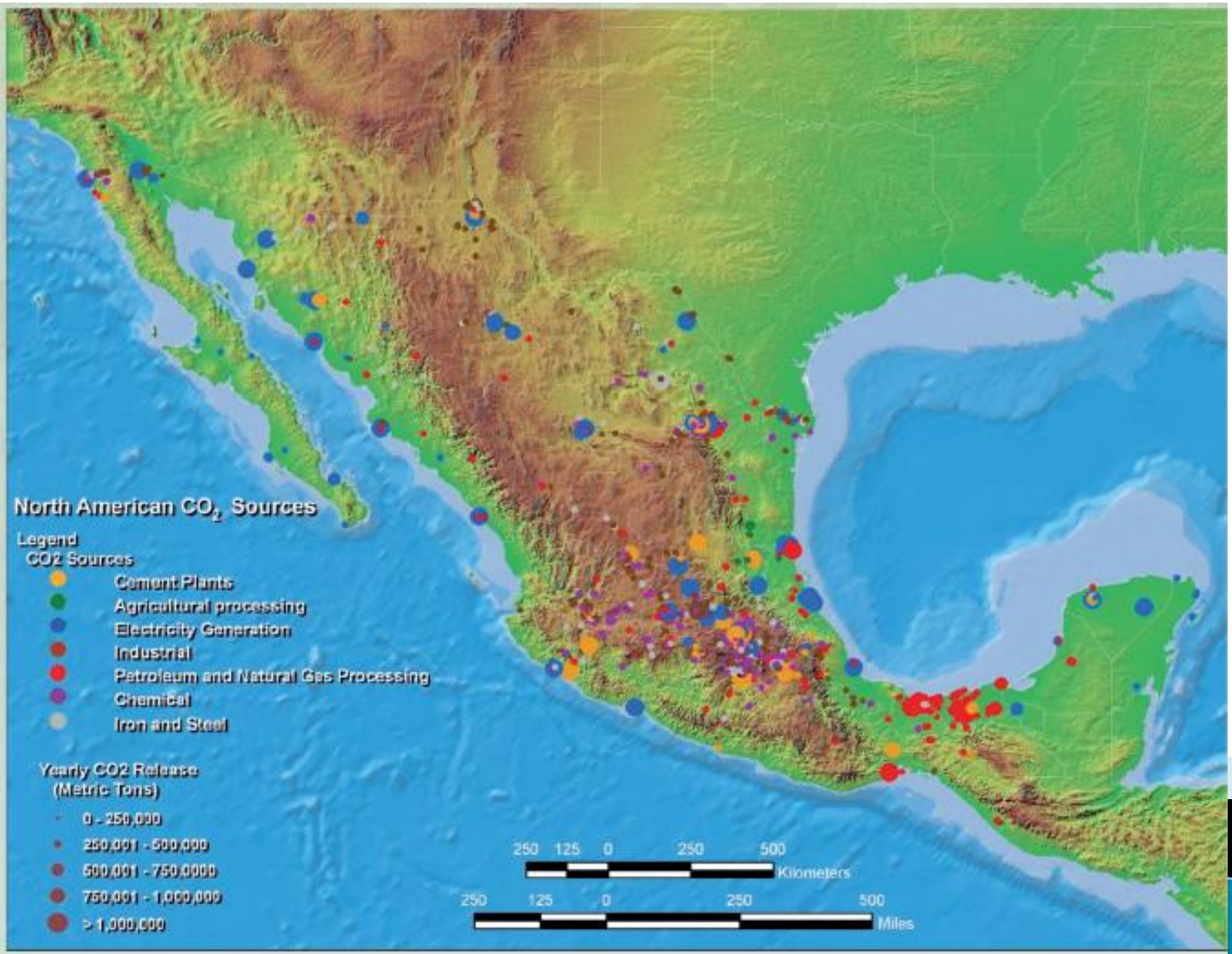
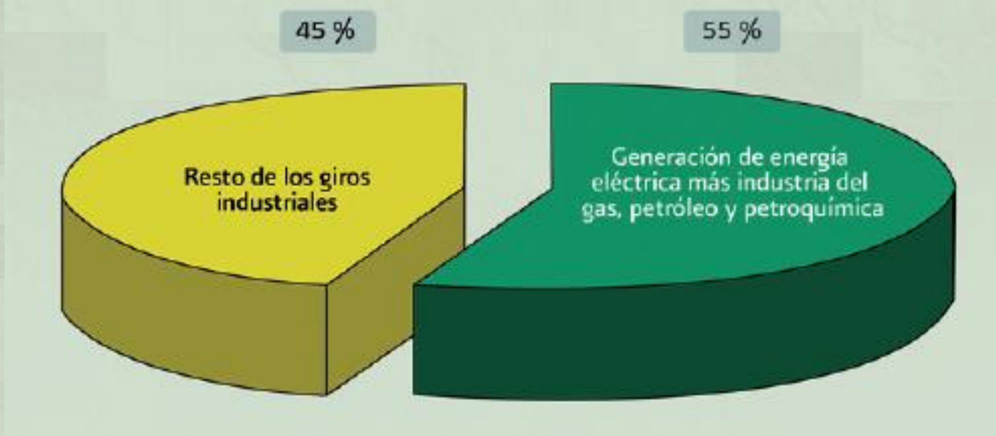


Figura 4 - Ubicación y magnitud relativa de las fuentes fijas que emiten CO_2 (Con datos de la versión preliminar de la base de datos RETC 2010).

Giro Industrial	Fuentes Fijas	Emisiones (ton CO_2)
Generación de energía eléctrica	99	84,231,501.34
Industria del gas, petróleo y petroquímica	311	50,062,131.08
Industria del cementony la cal	63	24,512,692.34
Industria metalúrgica, siderúrgica y metalmecánica	387	19,333,279.83
Industria Química	506	6,750,632.33
Bebidas fermentadas y alimentos	69	3,369,485.06
Industria de la celulosa y el papel	74	3,072,017.41
Industria del vidrio	26	1,901,168.77
Industria Automotriz	206	1,670,321.61
Industria de pinturas y tintas	49	415,978.42
Explotación de minerales no metálicos	6	241,108.62
Textiles, plásticos e impresos	8	144,907.77
Centros logísticos y de atención hospitalaria	11	83,010.98
Eléctricos, electrónicos y electrodomésticos	45	79,762.36
Agropecuaria	15	48,977.07
Maderera	3	38,866.52
Tratamiento de residuos peligrosos	45	23,544.72
Industria del asbesto	12	12,242.85



SENER,2011

Where's the CO_2?

Source: http://www.power-technology.com/contractors/materials/ibau-hamburg/ibau-hamburg2.html

CO_2 Emissions From Electricity Generators:

(Tonnes/MWhr):

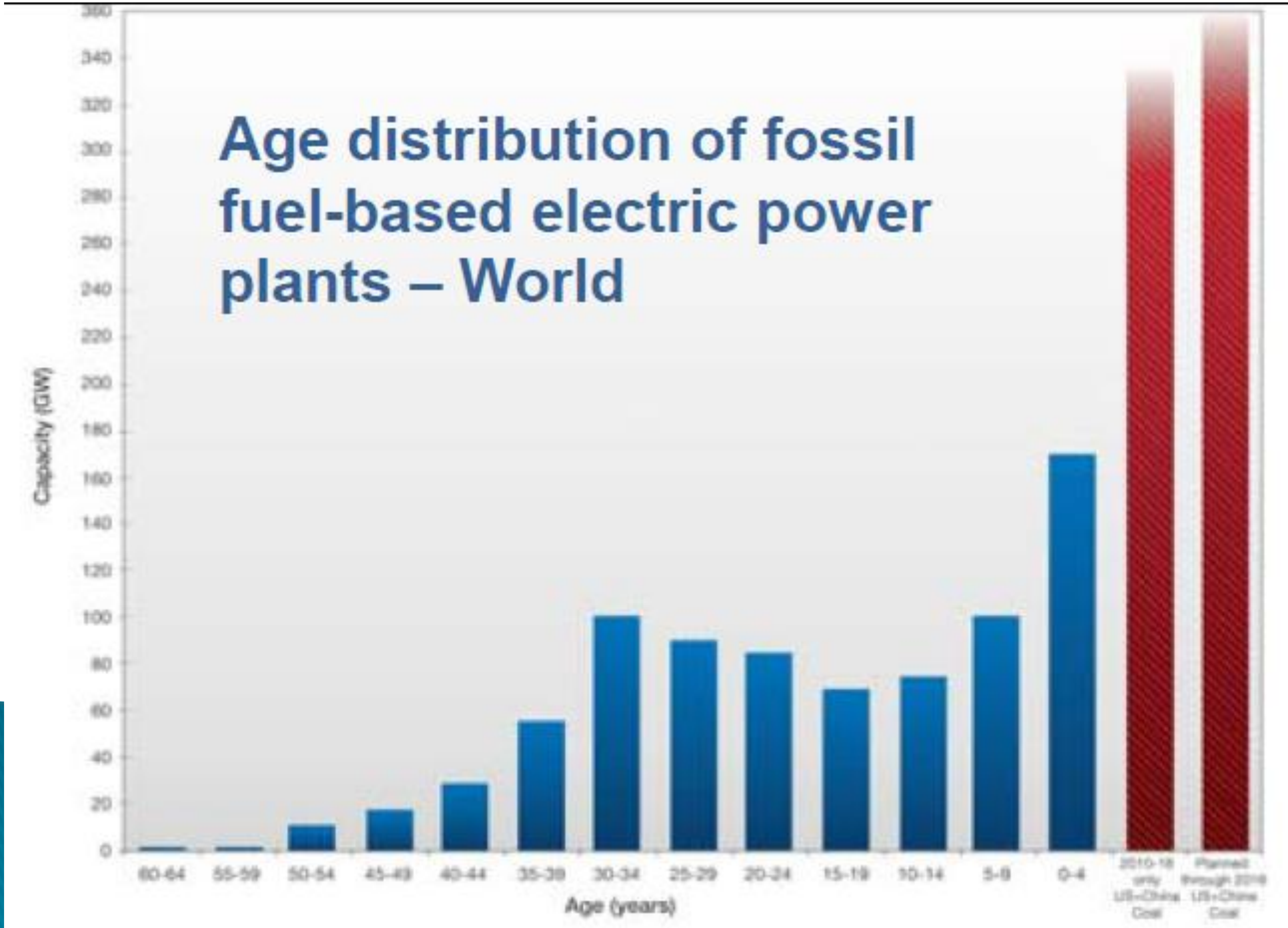
Brown Coal: 1.2

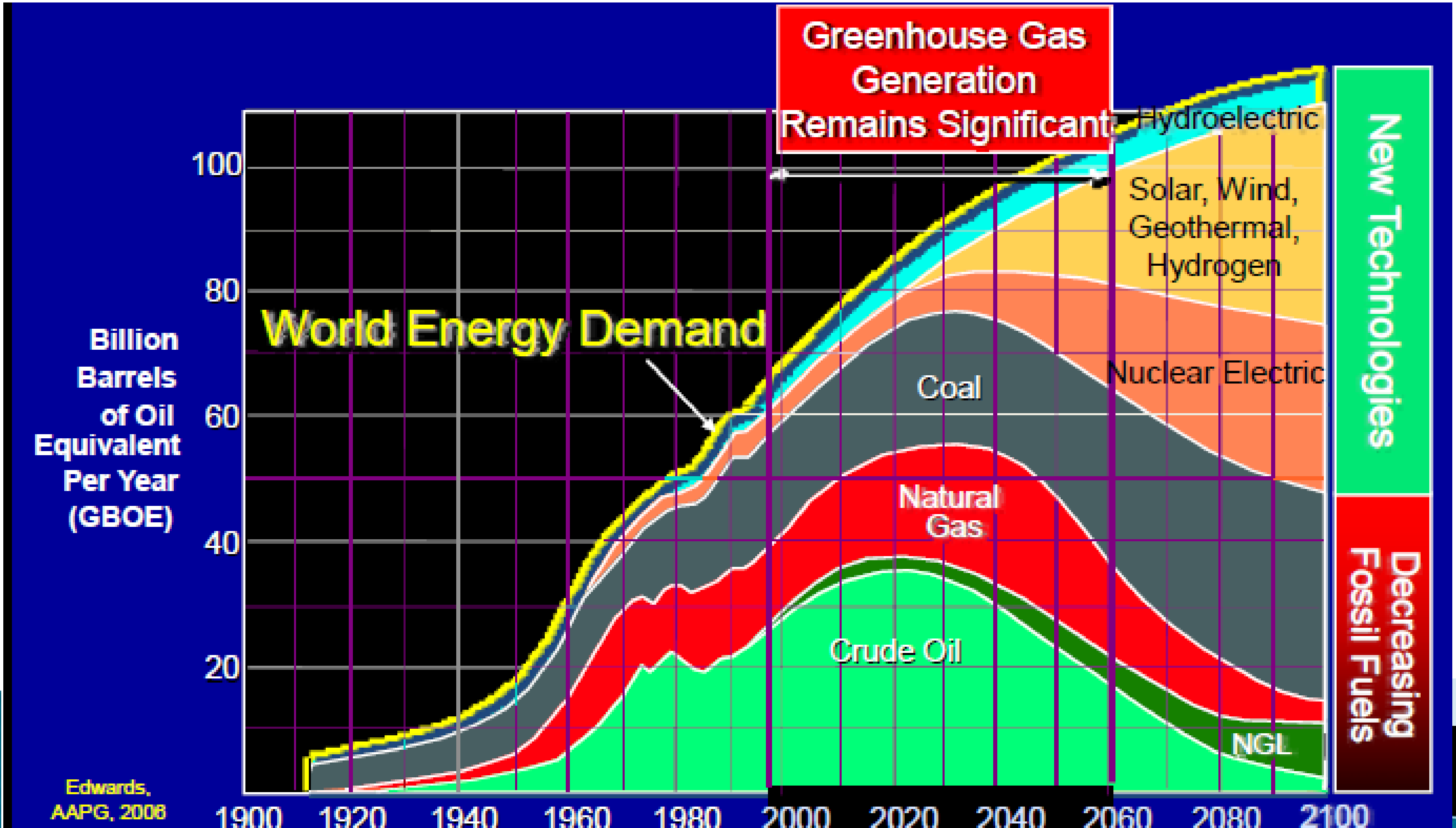
Black Coal: 0.8

Gas (CH_4): 0.4

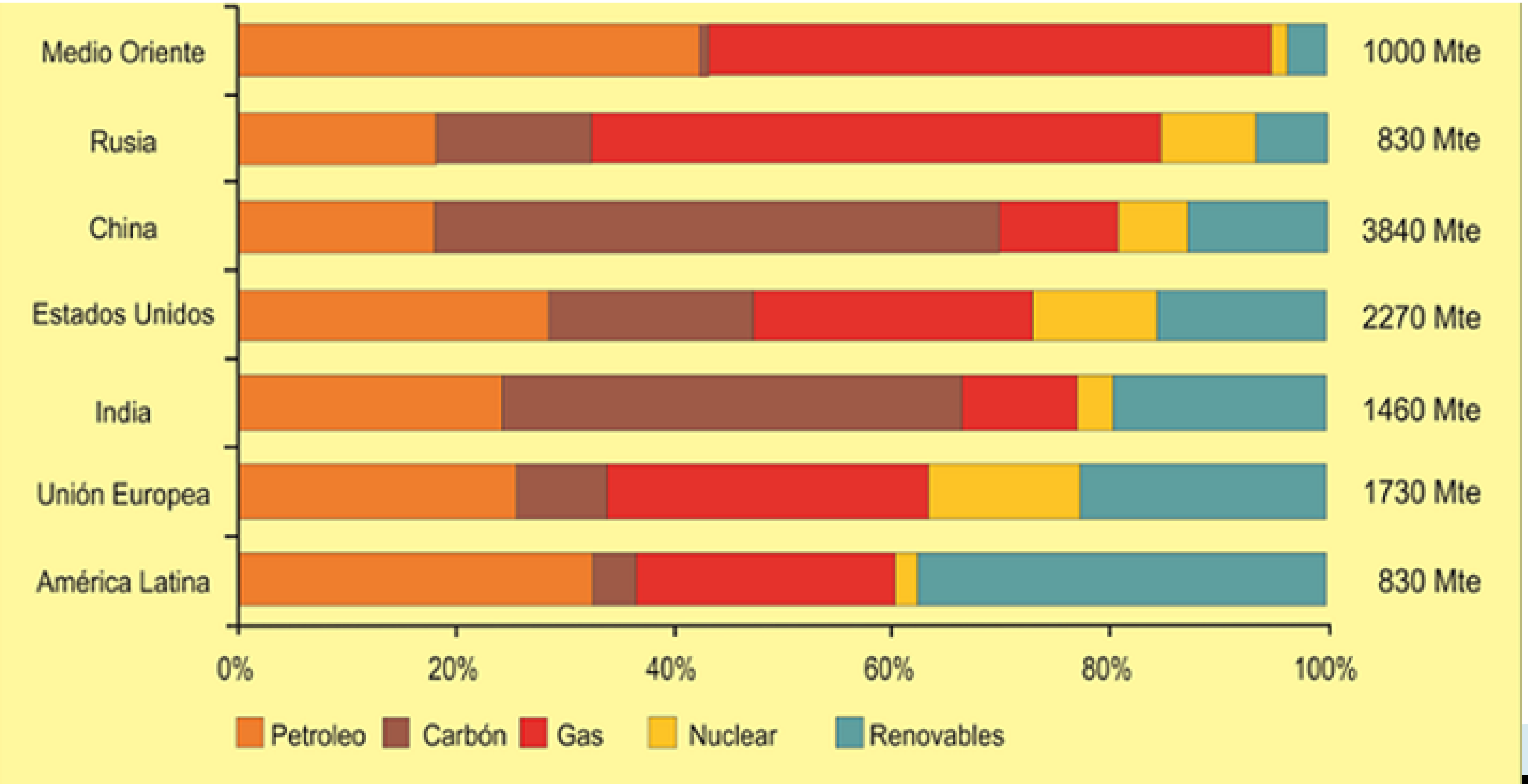
(1 Tonne ~ 19 mmcf)

Global CCS Institute;CO2CRC, 2013


Age distribution of fossil fuel-based electric power plants – World
Capacity (GW)
Age (years)
60-64
55-59
50-54
45-49
40-44
35-39
30-34
25-29
20-24
15-19
10-14
5-9
0-4


Greenhouse Gas Generation Remains Significant
World Energy Demand
Billion Barrels of Oil Equivalent Per Year (GBOE)
100
80
60
40
20
Hydroelectric
Solar, Wind, Geothermal, Hydrogen
Nuclear Electric
Coal
Natural Gas
Crude Oil
NGL
New Technologies
Decreasing Fossil Fuels
Edwards, AAPG, 2006
1900
1920
1940
1960
1980
2000
2020
2040
2060
2080
2100

Wiley, 2013

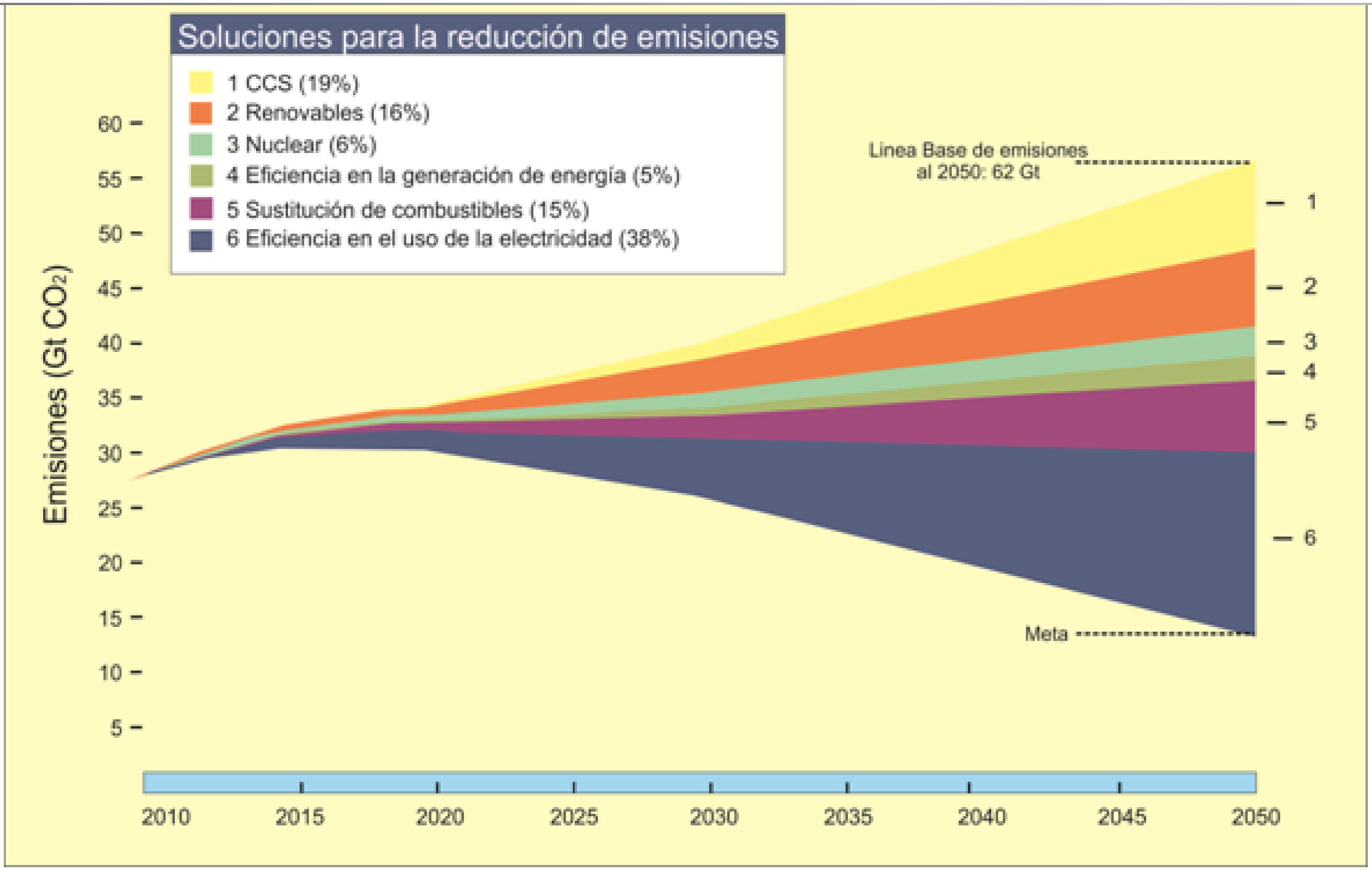


Escenario al 2035 en lo que se refiere a las tecnologías de producción de energía en los principales países y regiones del mundo [IEA, 2012].

Cuáles son la alternativas que tenemos ?

Contextual Framework

- Public view: climate change / global warming is real
  - is happening now (geological time too abstract)
  - caused by greenhouse gas (GHG) emissions
  - GHG from anthropogenic activities
  - fossil fuel industry is main contributor
  - "something" can be / must be done
- Lawmakers responsive to public sentiments
- Lenders under pressure to fund "clean" energy
- Industry positioning for carbon constrained world
- But what about the cost?



Cartera de opciones para reducir las emisiones de CO_2 relacionadas a la industria fija al año 2050 [IEA, 2010].

WHAT is carbon capture and storage?

CCS is an integrated process involving CO_2 ***capture*** of from a point source of emission, CO_2 ***transportation***, and CO_2 injection and ***storage*** in a geologic formation.

Capture

Carbon capture is the separation of CO_2 from the other gases produced when fossil fuel is burnt for power generation and in other industrial processes.

Transport

Once separated, the captured CO_2 is usually compressed and transported via truck, rail, ship or pipeline to a suitable site for geological storage.

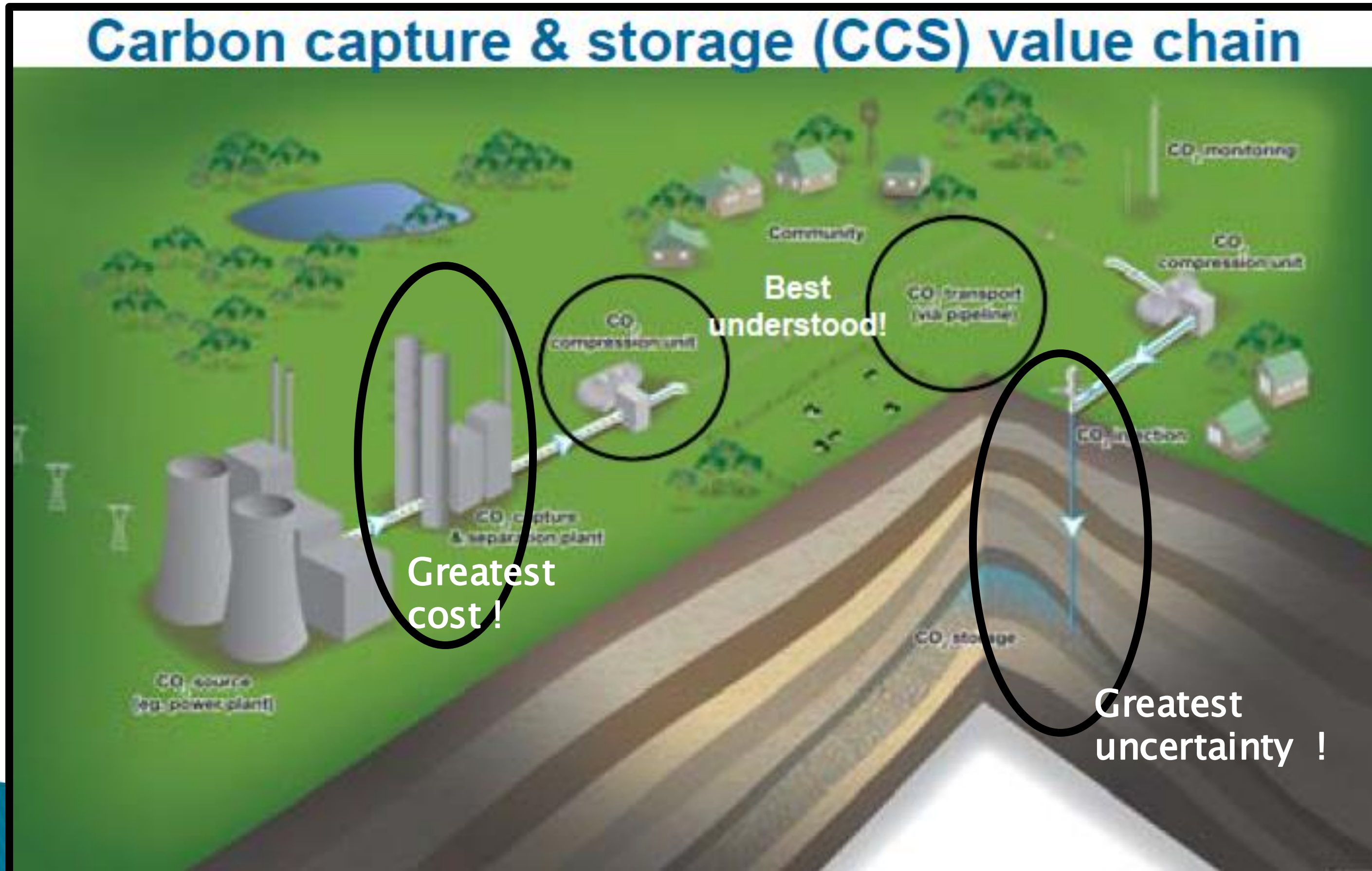
Storage

At the storage site CO_2 is injected into geologic formations, generally at depths of one kilometre or more. **Utilisation** of CO_2 for enhanced oil recovery (EOR) may be considered storage under certain conditions.

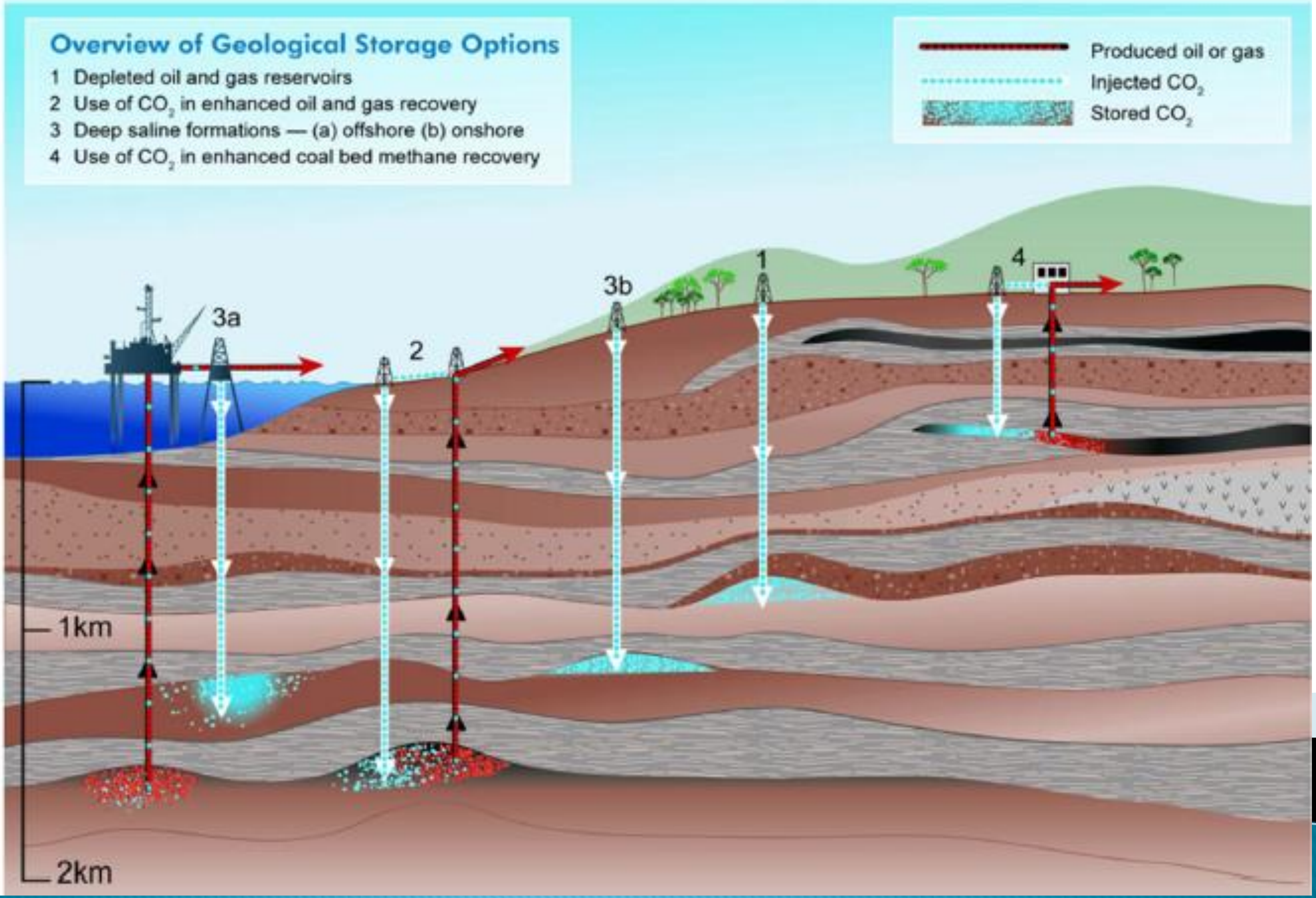
Withaker,2012

Carbon Capture & Storage (a simple solution)

Cook,2012


Carbon capture & storage (CCS) value chain
Community
Best understood!
Greatest cost !
Greatest uncertainty !
CO compression unit
CO transport (via pipeline)
CO capture & separation plant
CO source (eg. power plant)
CO monitoring
CO storage

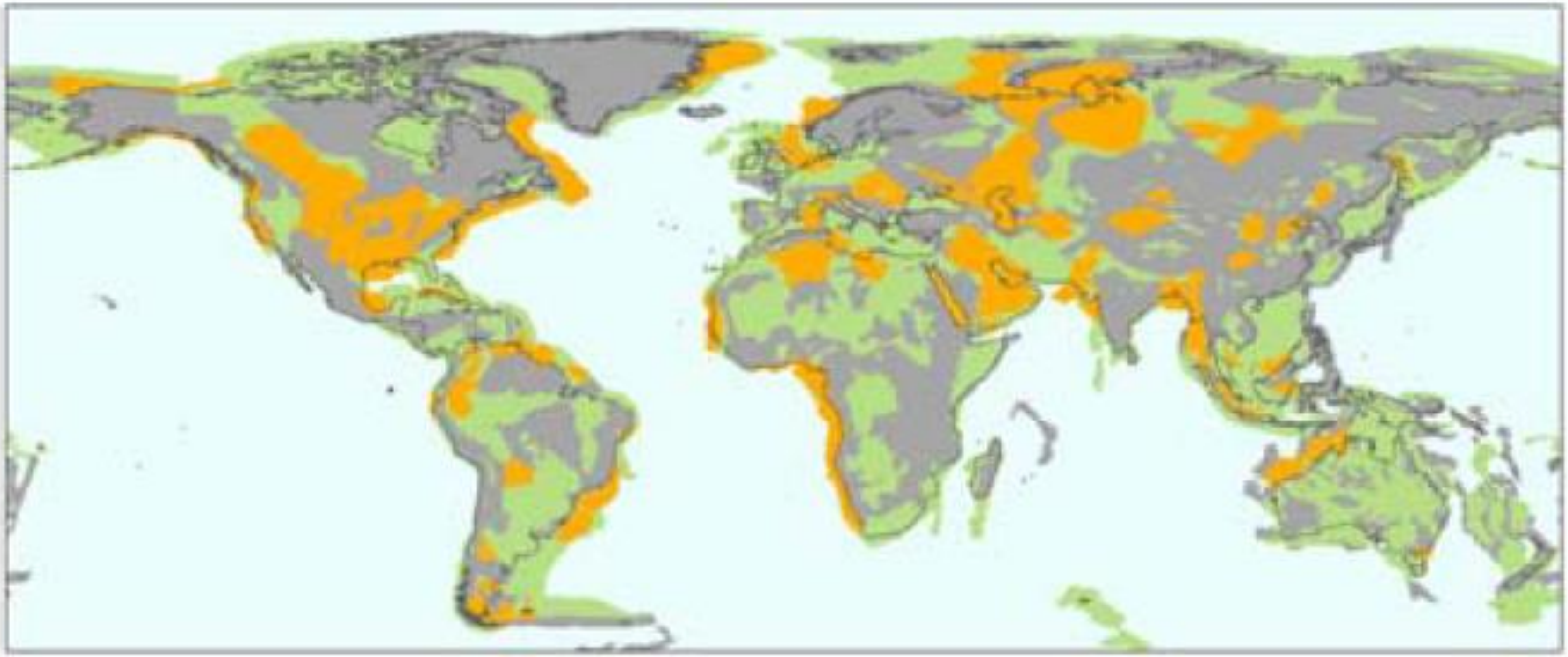
Kaldi,2013



Overview of Geological Storage Options
1 Depleted oil and gas reservoirs
2 Use of CO_2 in enhanced oil and gas recovery
3 Deep saline formations — (a) offshore (b) onshore
4 Use of CO_2 in enhanced coal bed methane recovery
Produced oil or gas
Injected CO_2
Stored CO_2
3a
2
3b
1
4
1km
2km

IPCC,2005

Global CO_2 storage potential



Bradshaw and Dance, 2004

3000 km

Sedimentary basins with high storage potential

Sedimentary basins with unknown storage potential

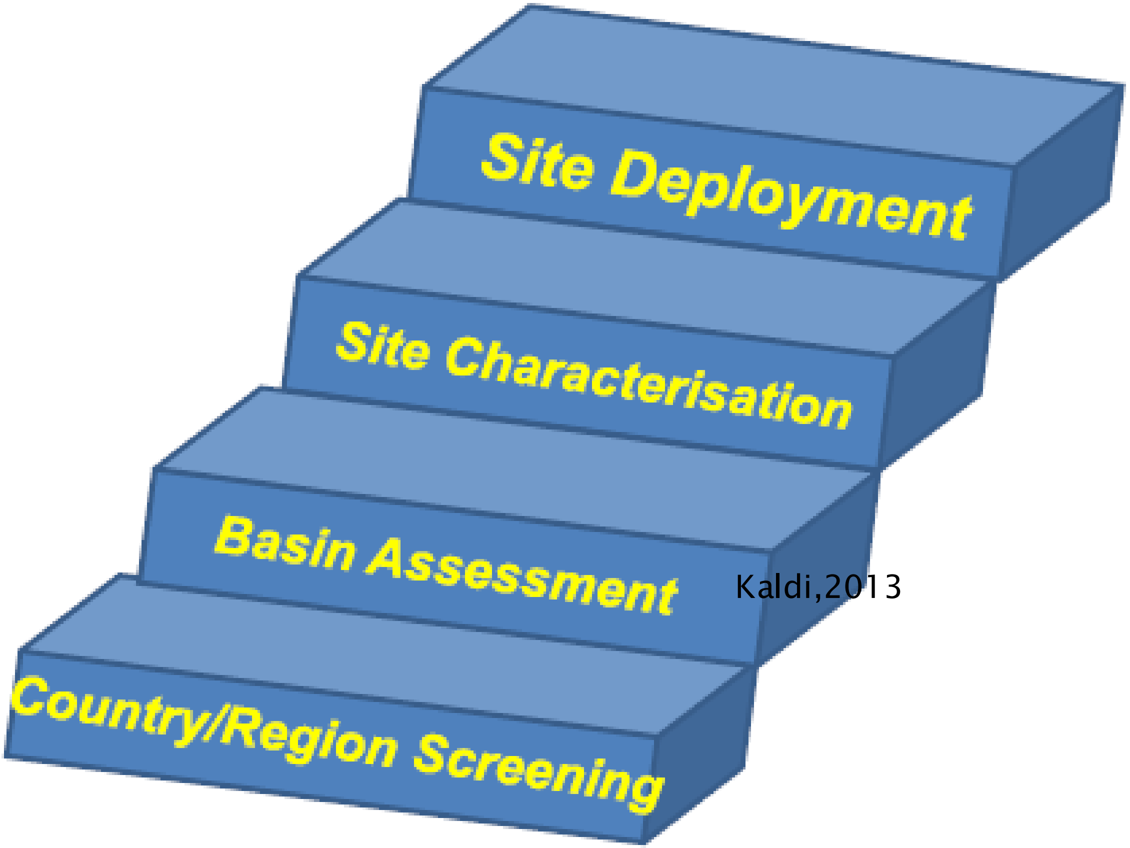
Geology with no storage potential

Etapas del Desarrollo de la Tecnología de CCS

Periodo	Características
1970 a 1980	Creación del Concepto e investigación aislada
1990´s	La mitigación de emisiones por CF es una preocupación mundial. Primeros proyectos demostrativos de CCS
2000-2006	Primeros sistemas integrados de CCS nacionales e internacionales. El CCS se expresa como medida esencial para continuar usando CF.
2007-2100	Programas públicos creados para acelerar la tecnología . Detonan innumerables proyectos pilotos y demostrativos
2010 al presente	Fondos públicos para financiar el desarrollo de la tecnología CCS para que sea considerada masiva operacional a partir del 2015

Markusson et al,2012

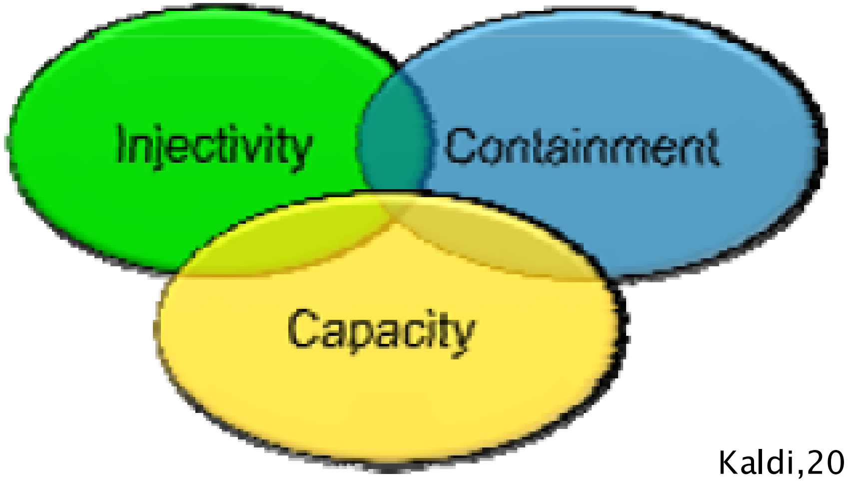
Reducing uncertainty for site selection critical steps



Kaldi,2013

Criteria for site characterisation:

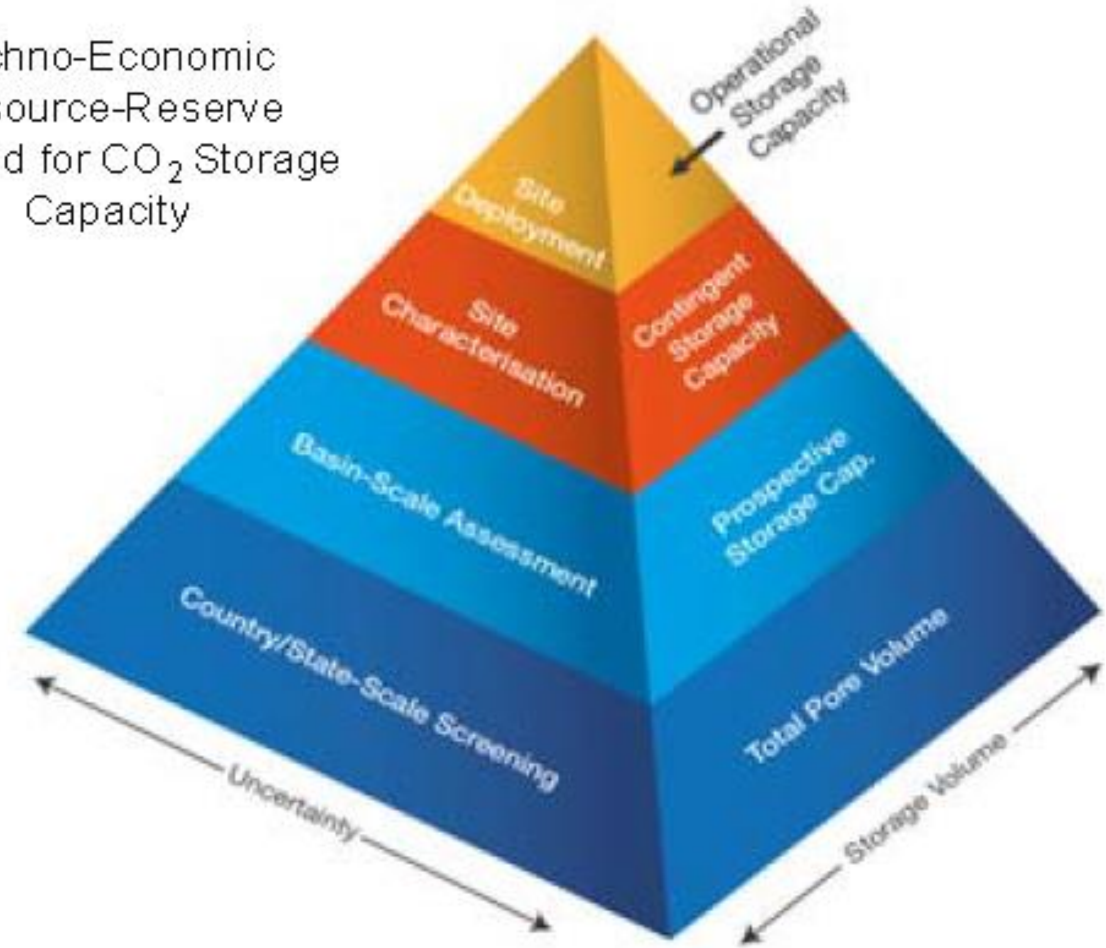
- Injectivity (can we put the CO_2 into the rock?)
- Containment (can we keep the CO_2 in the rock?)
- Capacity (what volume of CO_2 can the rock hold?)



Kaldi,2013

Storage capacity estimation

Techno-Economic Resource-Reserve Pyramid for CO_2 Storage Capacity



CO2CRC, 2011

Volumetric equation for capacity calculation

$$G_{CO_2} = A\, h_g\, \phi\, \rho\, E$$

G_{CO_2} = Volumetric storage capacity

A = Area (Basin, Region, Site) being assessed

h_g = Gross thickness of target saline formation defined by A

ϕ = Avg. porosity over thickness h_g in area A

ρ = Density of CO_2 at Pressure & Temperature of target saline formation

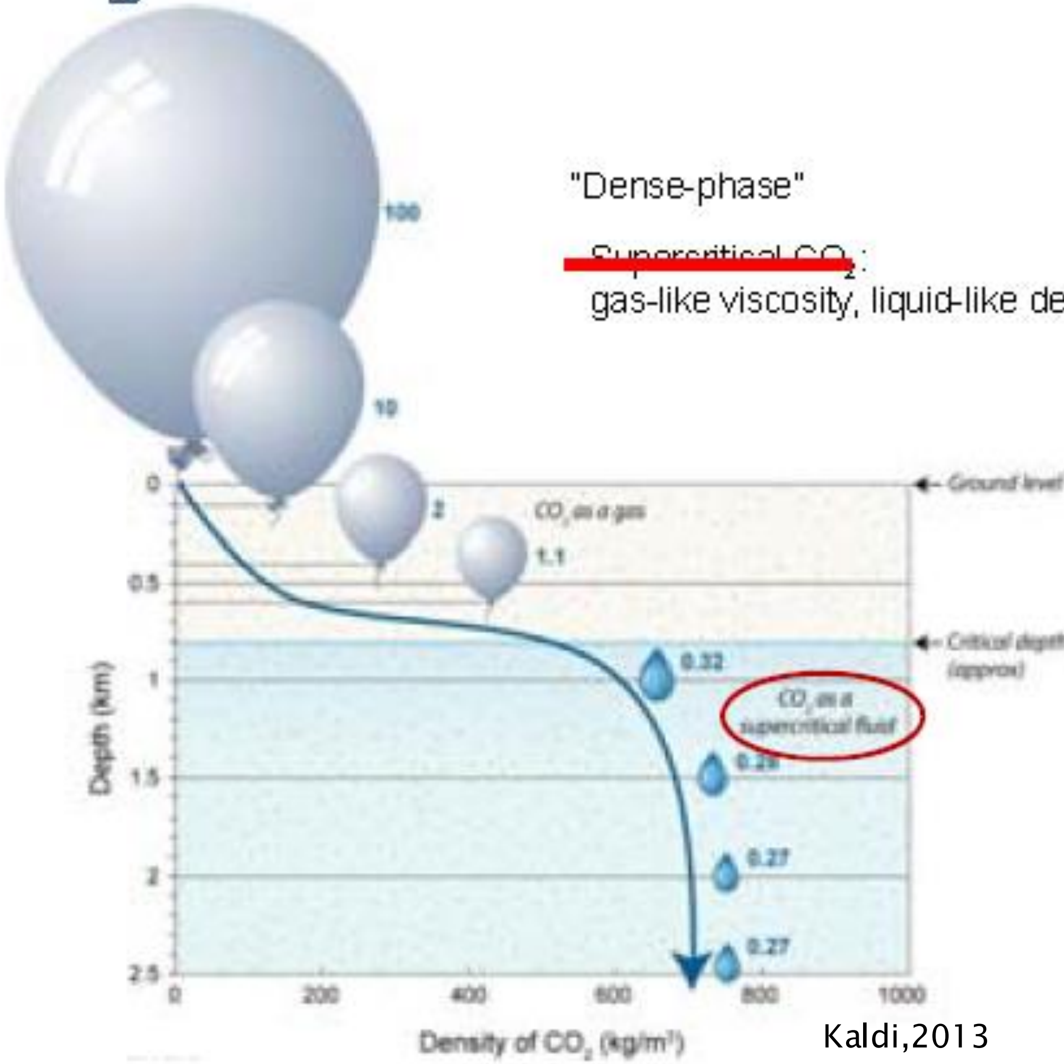
E = Storage "efficiency factor" (fraction of total pore volume filled by CO_2)

NETL DOE, 2006

CO_2 storage effectiveness increases with depth

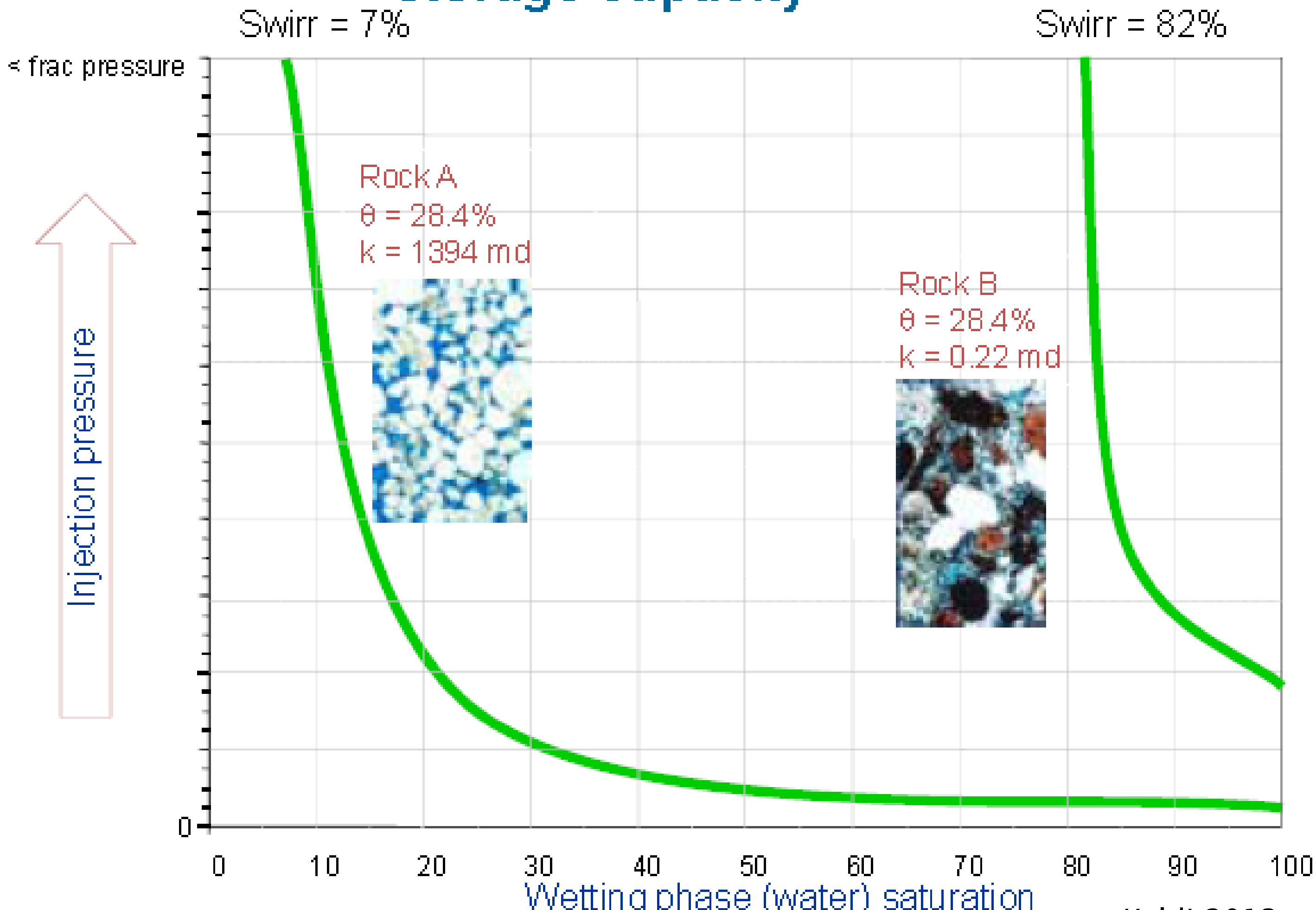
"Dense-phase"

~~Supercritical CO_2~~:
gas-like viscosity, liquid-like density



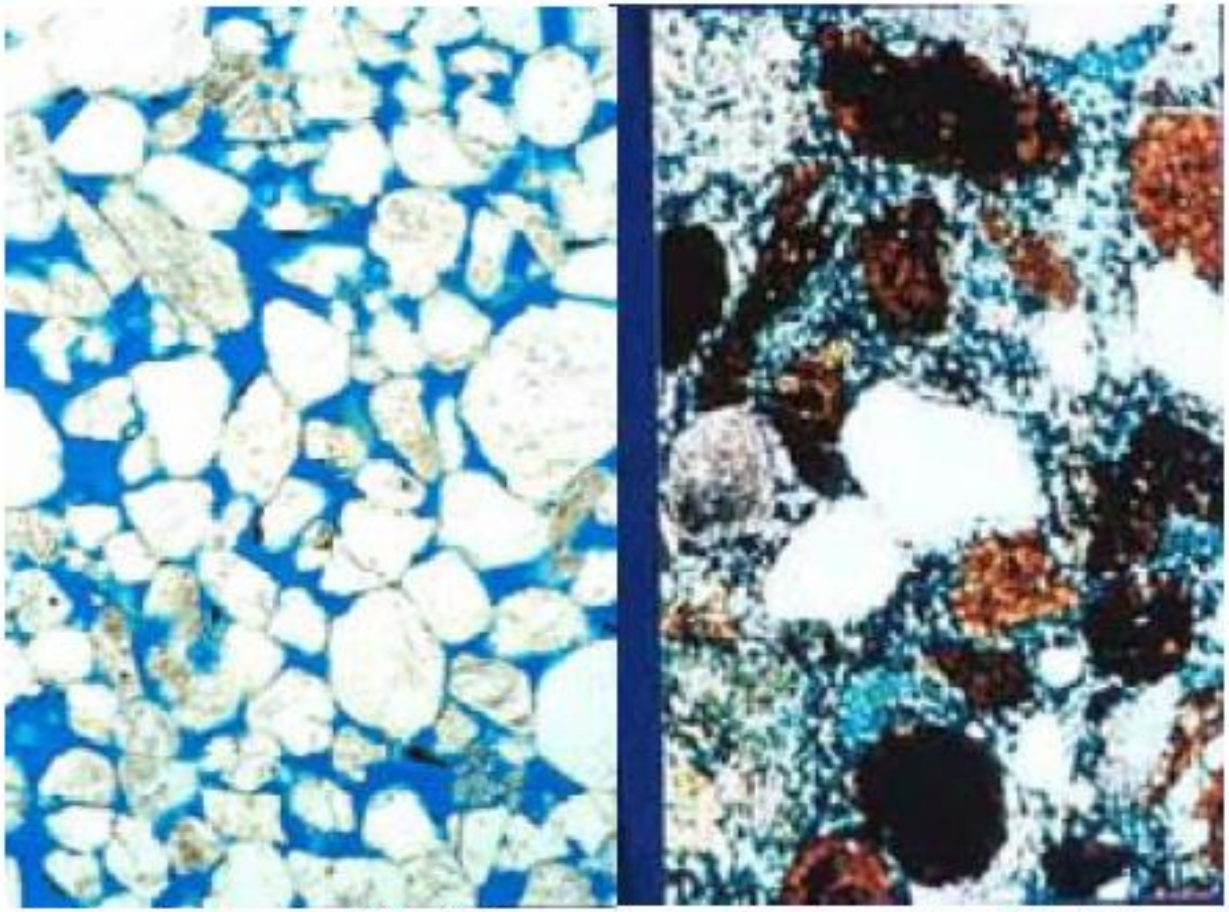
Kaldi,2013

Irreducible water saturation: a critical control on storage capacity



Kaldi,2013

Storage capacity controlled by permeability (not just porosity)

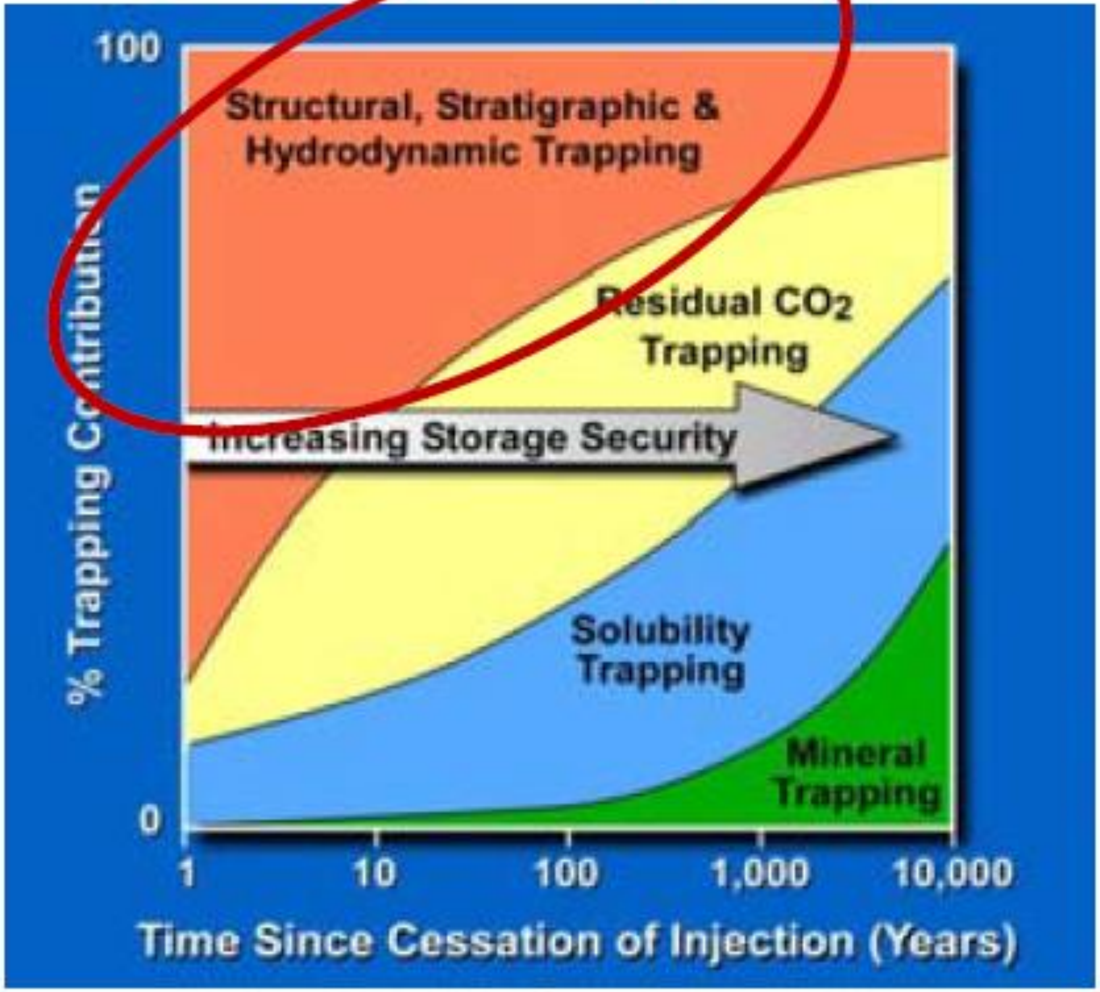


Rock A: ϕ = 28.4%
k = 1394 md

Rock B: ϕ = 28.4%
k = 0.22 md

Kaldi,2013

CO_2 storage trapping mechanisms



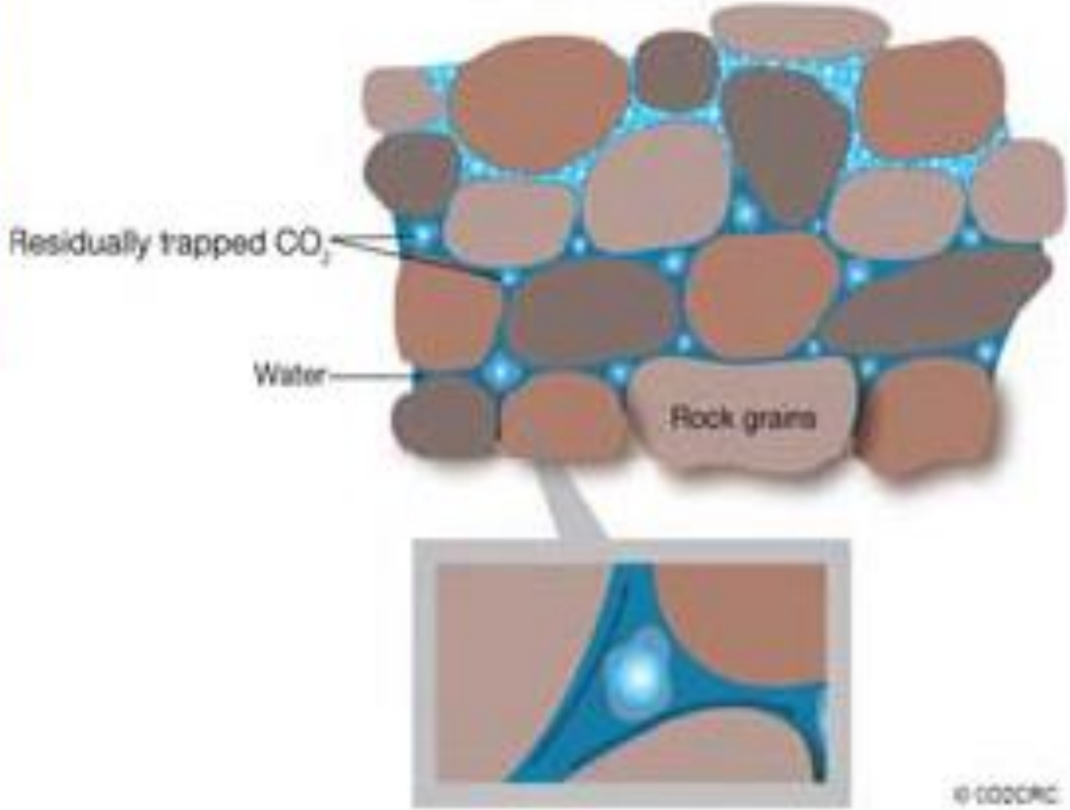
From IPCC SRCCS, 2005

Structural / Stratigraphic Trapping (SST)

Most familiar; best understood; lowest risk

CO_2 Trapped in solution

CO_2 Trapped as a mineral



CO_2 Trapped in rock pores as Residual Saturation (Sgr_{CO2})

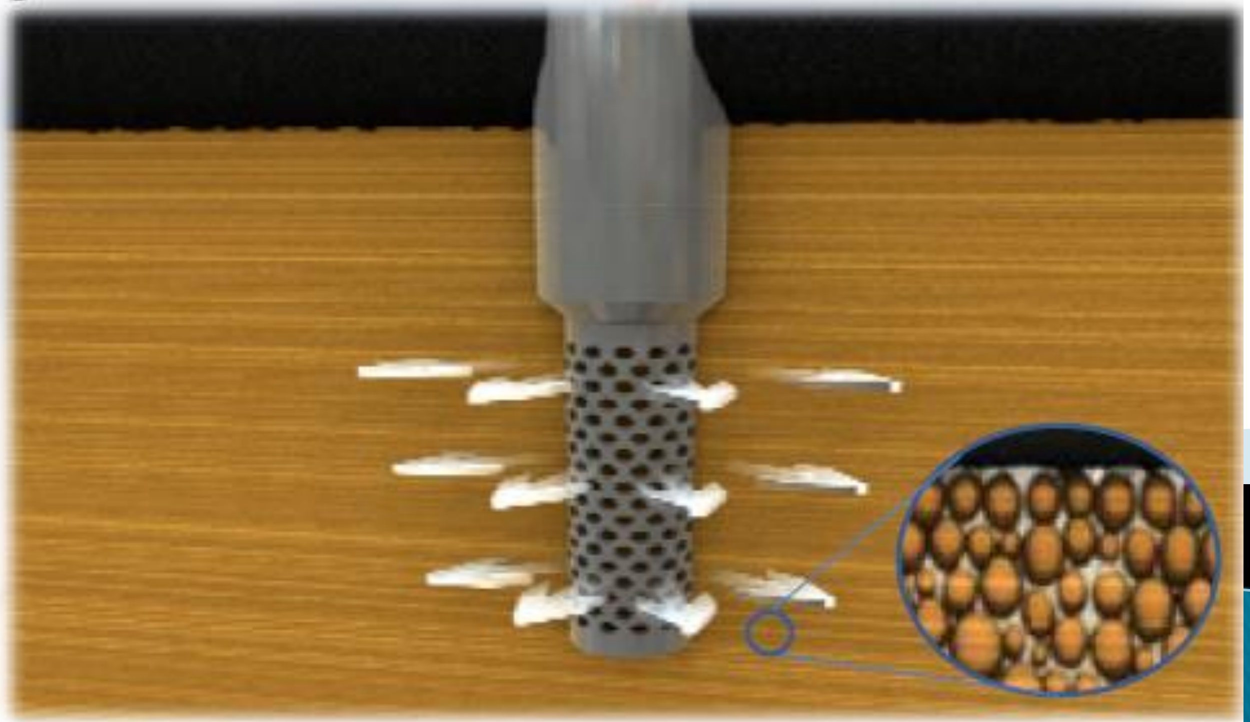
Kaldi,2013

Injectivity

$I_{v/t}$ depends on A * P_i * k

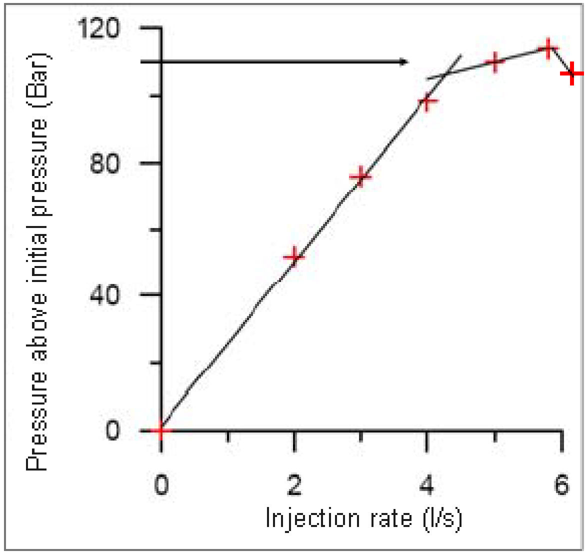
$I_{v/t}$ = Injection rate
A = Area (of wellbore in contact with formation)
P_i = injection pressure (below frac)
k = permeability

($I_{v/t}$ is proportional to number of wells)

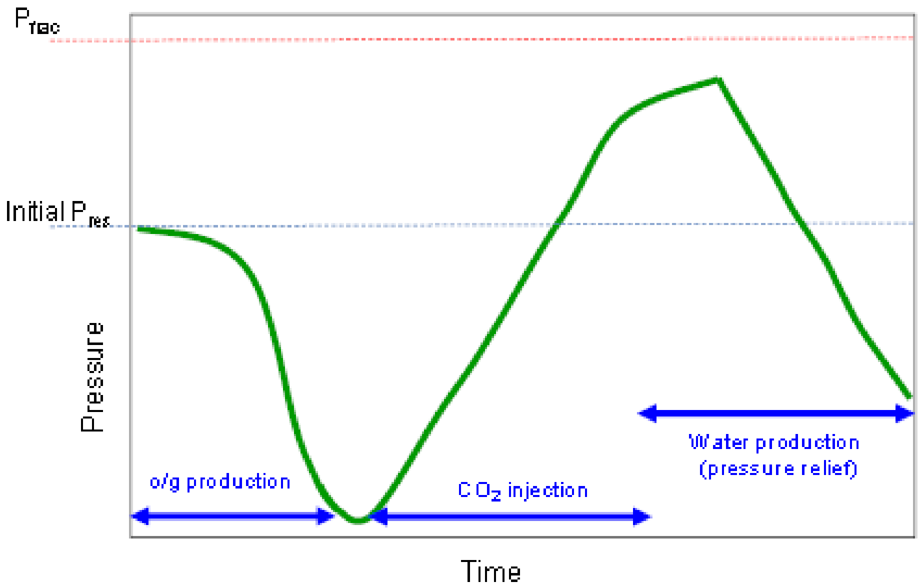


Kaldi,2013

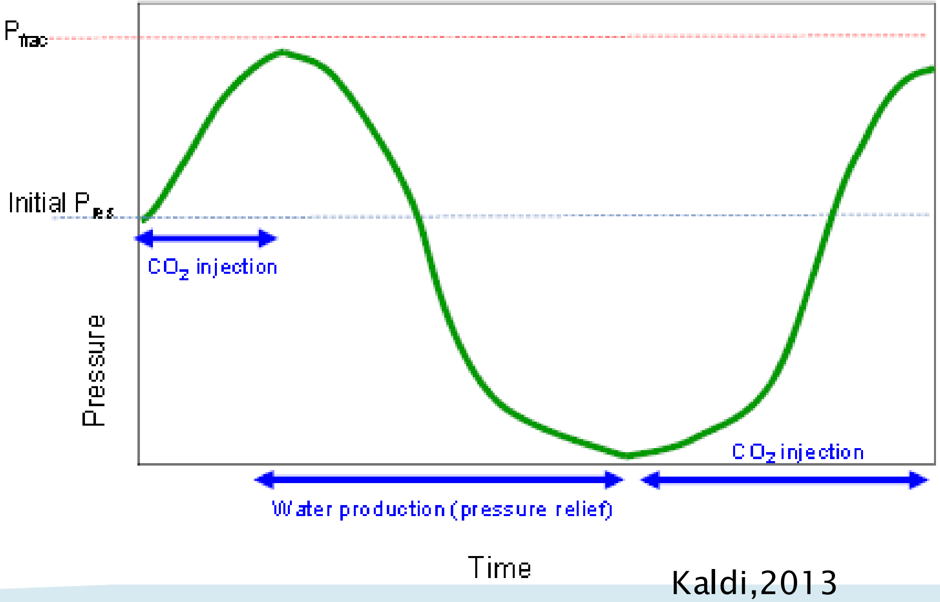
Frac pressure (P_{frac})



Depleted field (pressure v. time)

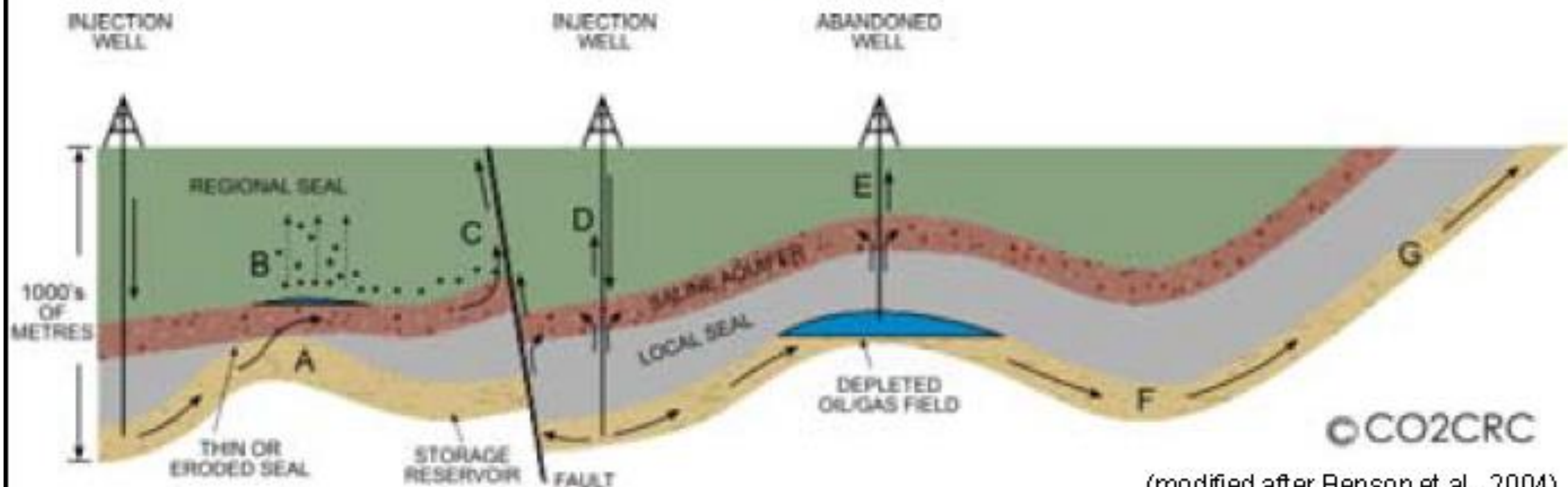


Saline formation (pressure v. time)



Kaldi,2013

Potential CO_2 escape mechanisms



(modified after Benson et al., 2004)

A: CO_2 escapes through thin or eroded section of seal,

B: CO_2 buoyancy pressure exceeds capillary pressure and passes through the seal,

C: CO_2 migrates from reservoir and up transmissive fault,

D: CO_2 escapes up wellbore via poorly completed injection well and into shallower formation,

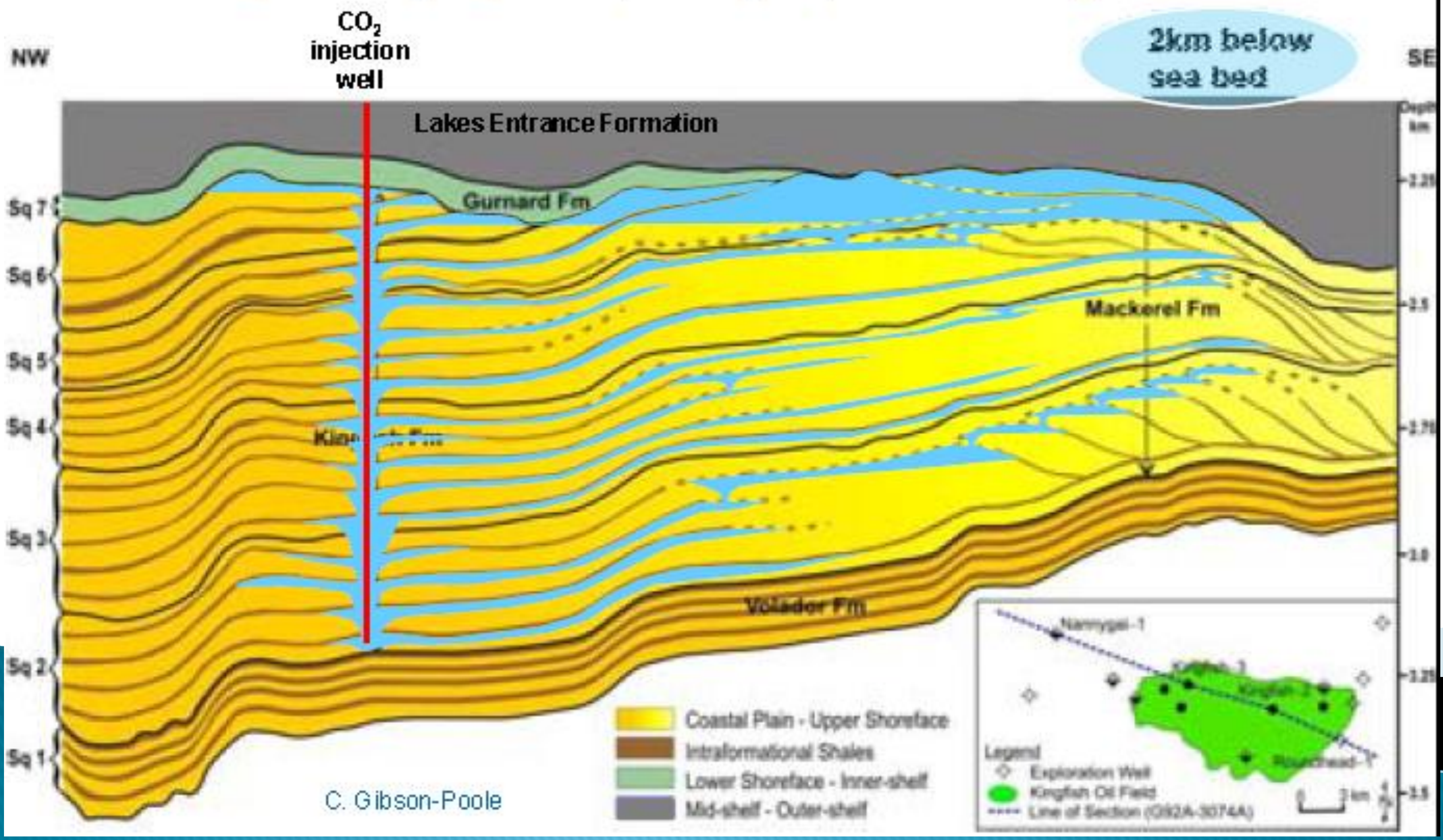
E: CO_2 escapes up wellbore and into shallower formation via poorly plugged old abandoned well,

F: Hydrodynamic flow transports dissolved CO_2 out of closure,

G: CO_2 migrates updip beyond influence of regional seal

Intraformational seals (baffles)

increase length of CO_2 migration pathways & potential for Sgr and dissolution



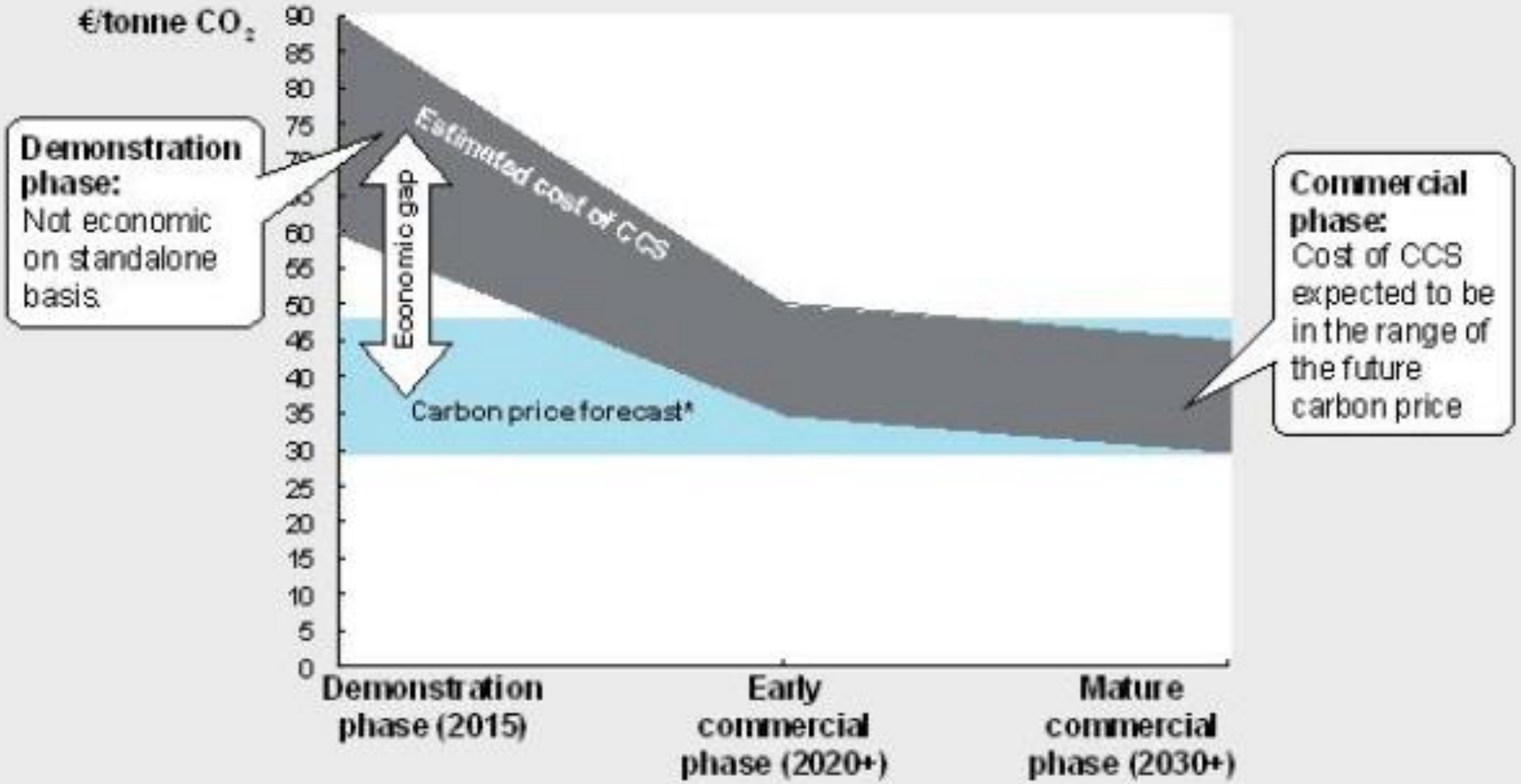
Perspectiva Económica y Social

The most common objections to CCS are…

- Cost
- Not enough storage capacity
- No clarity on regulations / liability
- Public acceptance
- It's only a ploy to keep coal going
- It's unproven technology

Wiley, 2013

CCS Costs vs Carbon Price Projection



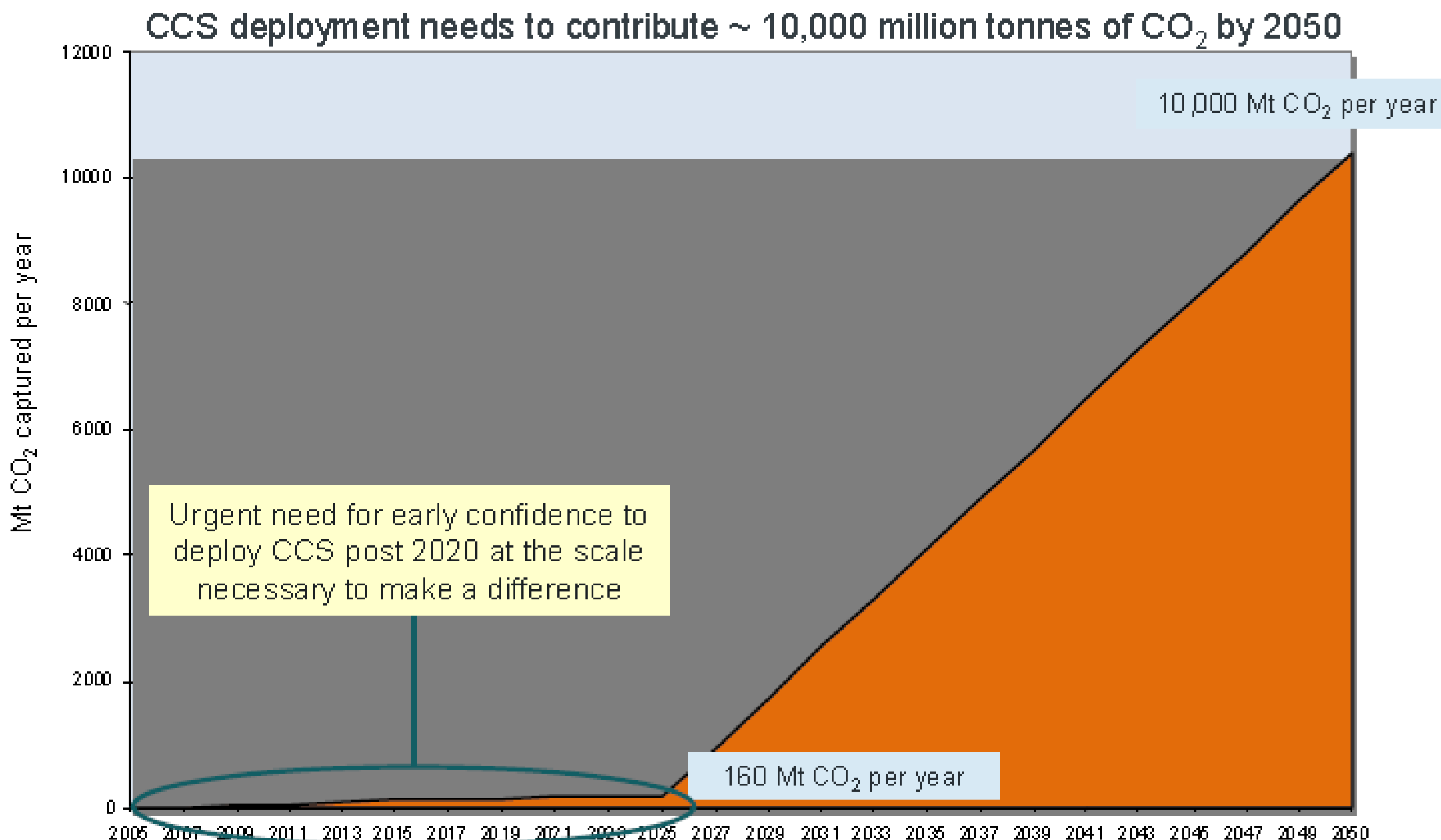
Wiley,2013

* Carbon price for 2015 from 2008-15 estimates from Deutsche Bank, New Carbon Finance, Point Carbon, Soc Gen, UBS,

Deeper monitoring options

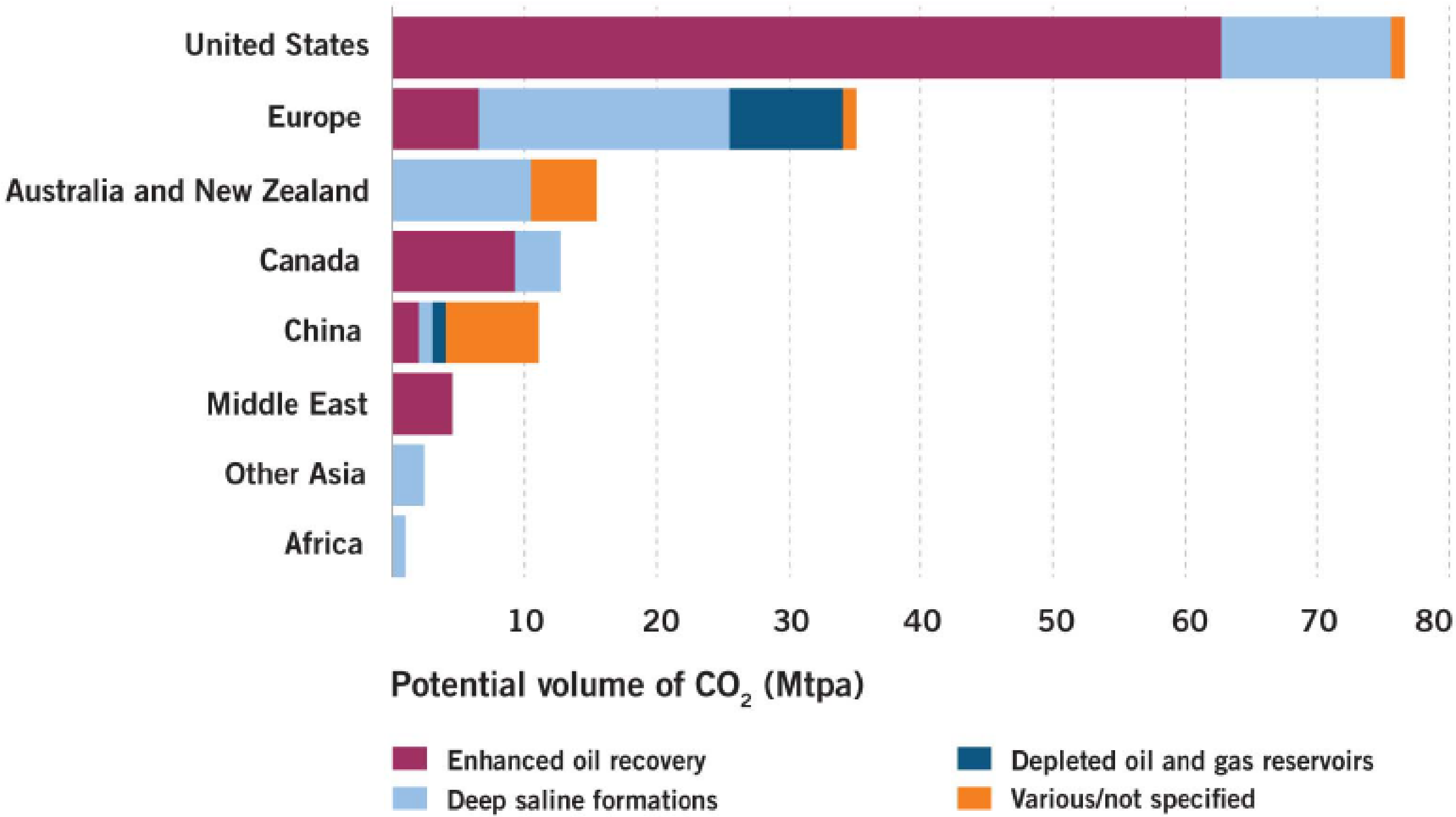
Geochemical	• Fluid sampling, pH, Chemistry • Tracer Injection
Geophysical	• Reflection Seismic 2D & 3D • Passive seismic (micro-seismic) • Electrical Resistivity • Gravity
Remote	• InSAR (Geomechanical monitoring)
Wells	• Repeat Well logging • Pressure, Temperature sensors (fibre optic) • Dedicated Observation Wells

Withaker,2012



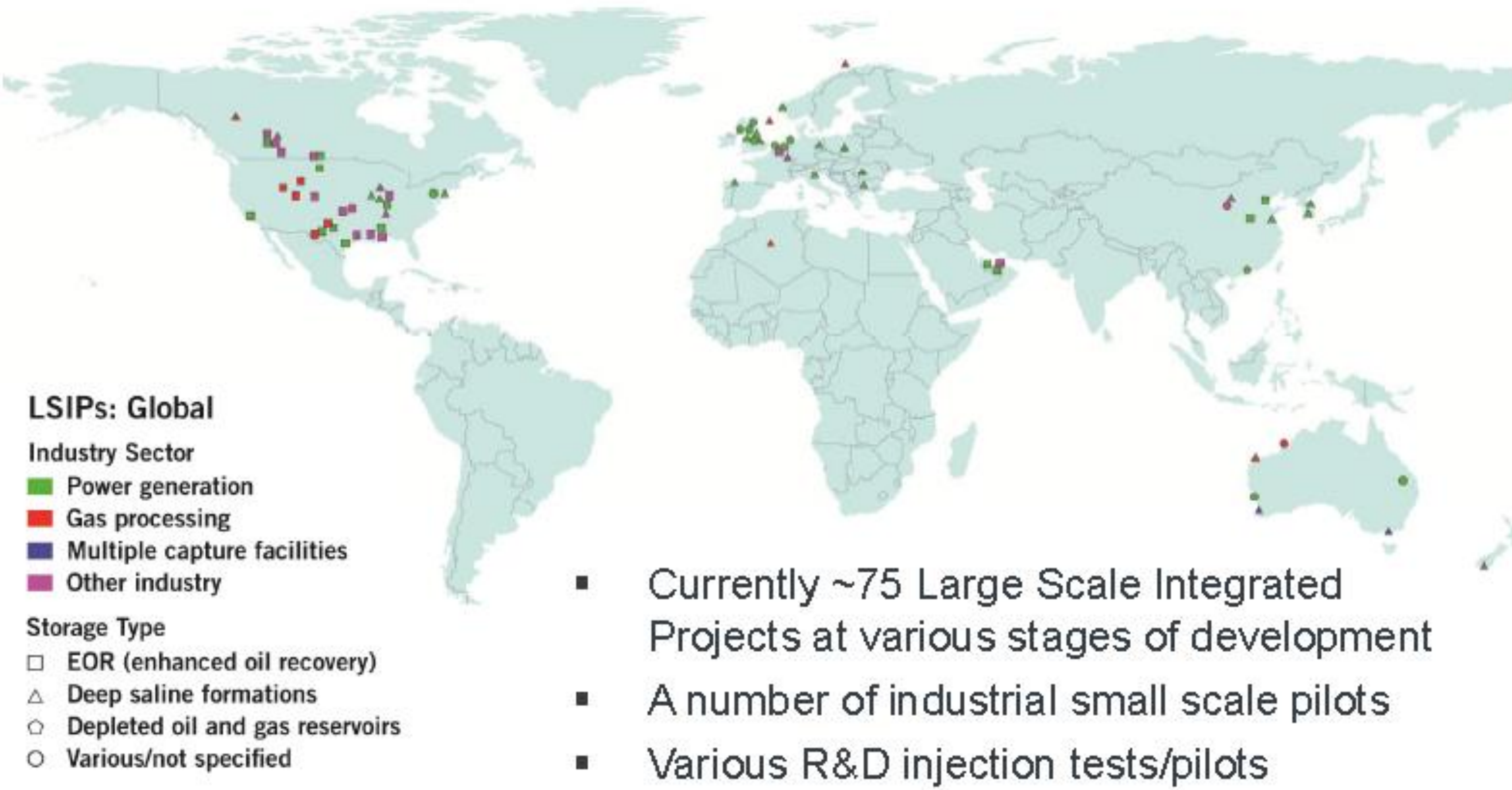
Withaker, 2012

Regional bias towards storage selection



Withaker,2012

Global Spread of CCS Projects

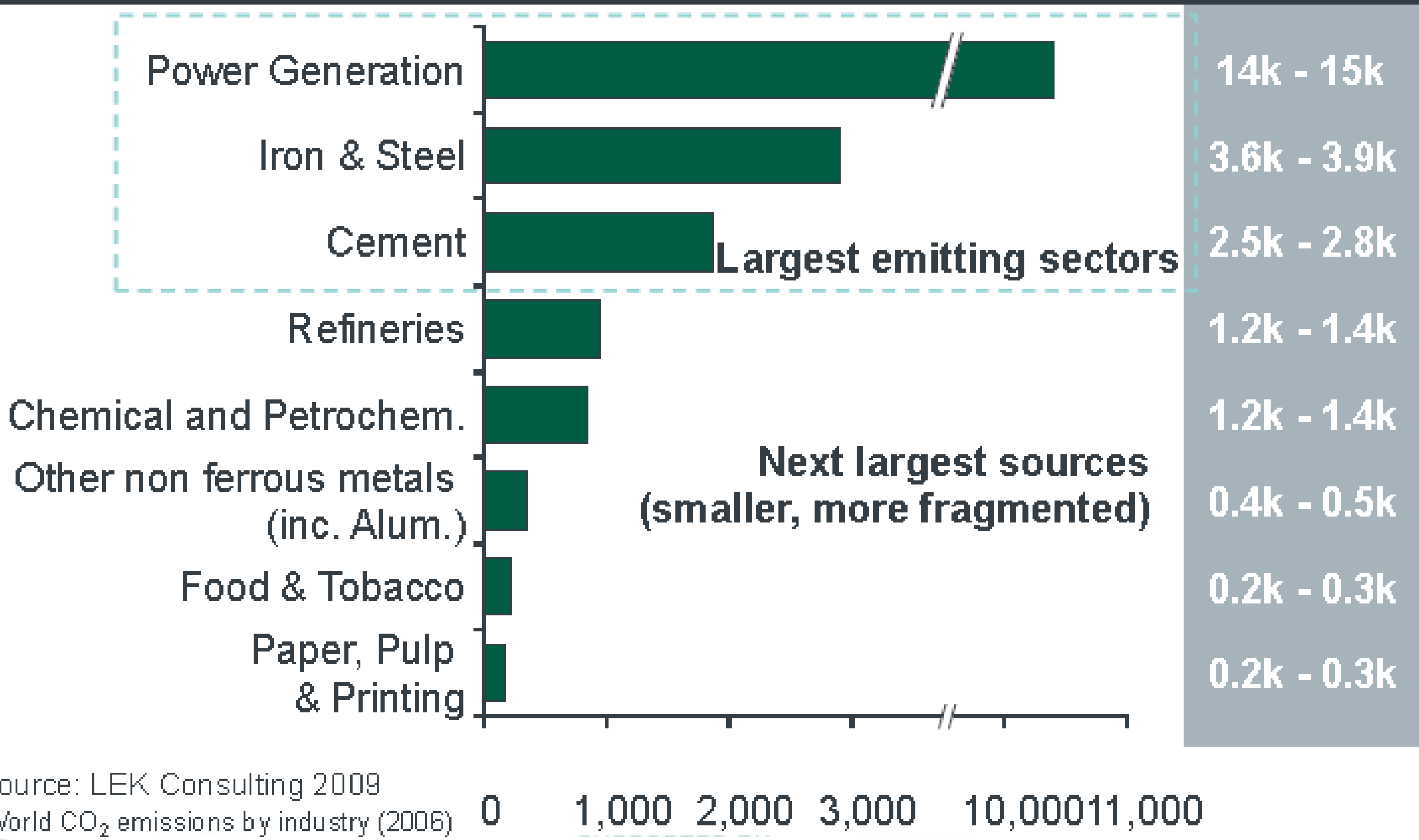


- Currently ~75 Large Scale Integrated Projects at various stages of development
- A number of industrial small scale pilots
- Various R&D injection tests/pilots

Withaker,2012

Where and How to Capture CO_2

large stationary point sources are best targets



Source: LEK Consulting 2009
World CO_2 emissions by industry (2006)

Withaker,2012

Percepción de la Sociedad

Hammond y Shakley, 2010

Tema	Derivaciones
Fugas Importantes de CO_2 del reservorio	• Preocupaciones de la seguridad del almacén. • Falta de Información sobre los fluidos "supercríticos". • Posibilidades de "explosiones" de Burbujas de CO_2 presurizadas. • Riesgos de salud para la población local • Impactos ecológicos • Sismicidad inducida • Impactos sobre los acuíferos
Fugas de los gasoductos	• Riesgos de Explosión • Peligro a la salud • Impactos ecológicos a los ecosistemas locales
Evasión de una forma real de cambio a una cultura energética verdaderamente sustentable	• Una medida a corto plazo solamente • Tecnología de "fin del tubo" • Fomenta una forma de cultura insostenible. La del uso de combustibles fósiles • Puede captar recursos que debieran ser para desarrollar las formas de energía renovable • Roba la atención de la eficiencia energética • Da paso a otras formas de contaminantes al ocultarlos en el subsuelo • Podría traer efectos de rebote

Percepción de la Sociedad

Hammond y Shakley, 2010

Tema	Derivaciones
Factibilidad y Costo	• Caros • Quién paga ? • Tecnología no lista aún • Hay suficiente capacidad de almacenamiento ? • Requiere de infraestructura que aun no existe.
Uso del CO_2	• Hay una forma tal de que el CO_2 se use y tenga un valor ? • Preferencia por hacer uso de algo que cuesta mucho dinero remover
Confianza	• La industria no debería lucrar con esta tecnología • Las motivaciones de la industria y la clase política involucrada no dan confianza • Cuando los argumentos de la industria y las organizaciones son contrarios la confianza decrece • Discrepancias entre ONG´s, gobiernos y compañías • Quien se responsabiliza en el largo plazo ?
Aspectos estratégicos	• El CCS es sólo un puente mientras otras tecnologías se desarrollan • Depende de subsidios gubernamentales • Hay mejores opciones para reducir GHG
Aspecto moral	• Estamos jugando a se “Dios” ?

Percepción de la Sociedad

Hammond y Shakley, 2010

Tema	Derivaciones
Beneficios locales	• Aspectos importantes para la economía local como creación de empleo, afluencia de capitales a la zona, prestigio por el desarrollo de una tecnología avanzada, centro de visitas para atraer el turismo • Mantiene el *core business* de la industria local y los combustibles estratégicos como el carbón • Uso potencial del CO_2 en el EOR o con otros usos importantes de la localidad • Diversifica usos energéticos
Aspectos locales y posibles preocupaciones	• Impacto en el consumo y disponibilidad del agua • Producción de agua salobre • Costos de la energía • Disturbios en el área por vivir en un “parque industrial” • Derechos en el uso de la tierra • Desmantelamiento • Monitoreo
Derechos de Propiedad	• Compensación apropiada granjeros y rancheros • Afectación de precios de tierras • Experiencias negativas del pasado como en gasoductos p . ej.

Percepción de la Sociedad

Hammond y Shakley, 2010

Tema	Derivaciones
El papel de la información	• Más información mejor entendimiento • Seminarios pero como parte de planes bien organizados • Los modelos físicos ayudan a mejorar la compresión del tema • Los medios locales con opinión positiva • Deficiencias en la opinión de "expertos"
Compromiso de los *Stakeholders*	• Compromiso activo con las partes involucradas locales y regionales , dirigida por una adecuada opinión de las autoridades
Justicia	• Desconfianza en el gobierno y la iniciativa privada • Experiencias negativas con la industria petrolera • Desconfianza en la trasparencia • El empoderamiento debería incrementar la aceptación • Preocupación por que los proyectos de CCS se instalen en comunidades pobres y sin importancia • Dudas sobre el apoyo si algo sale mal • Dudas sobre ser considerados "conejillos de indias" • Desconfianza en la fase de monitoreo • Dudas sobre quien escuchará sus dudas si el monitoreo no es claro

Gracias