CCUS Technology Road Map

The Presentation

- Energy Challenge
- CO_2 Problem
- Carbon Capture Use & Storage
- Future Trends
- Costs and Hurdles
- Technology Maturity
- Conclusions

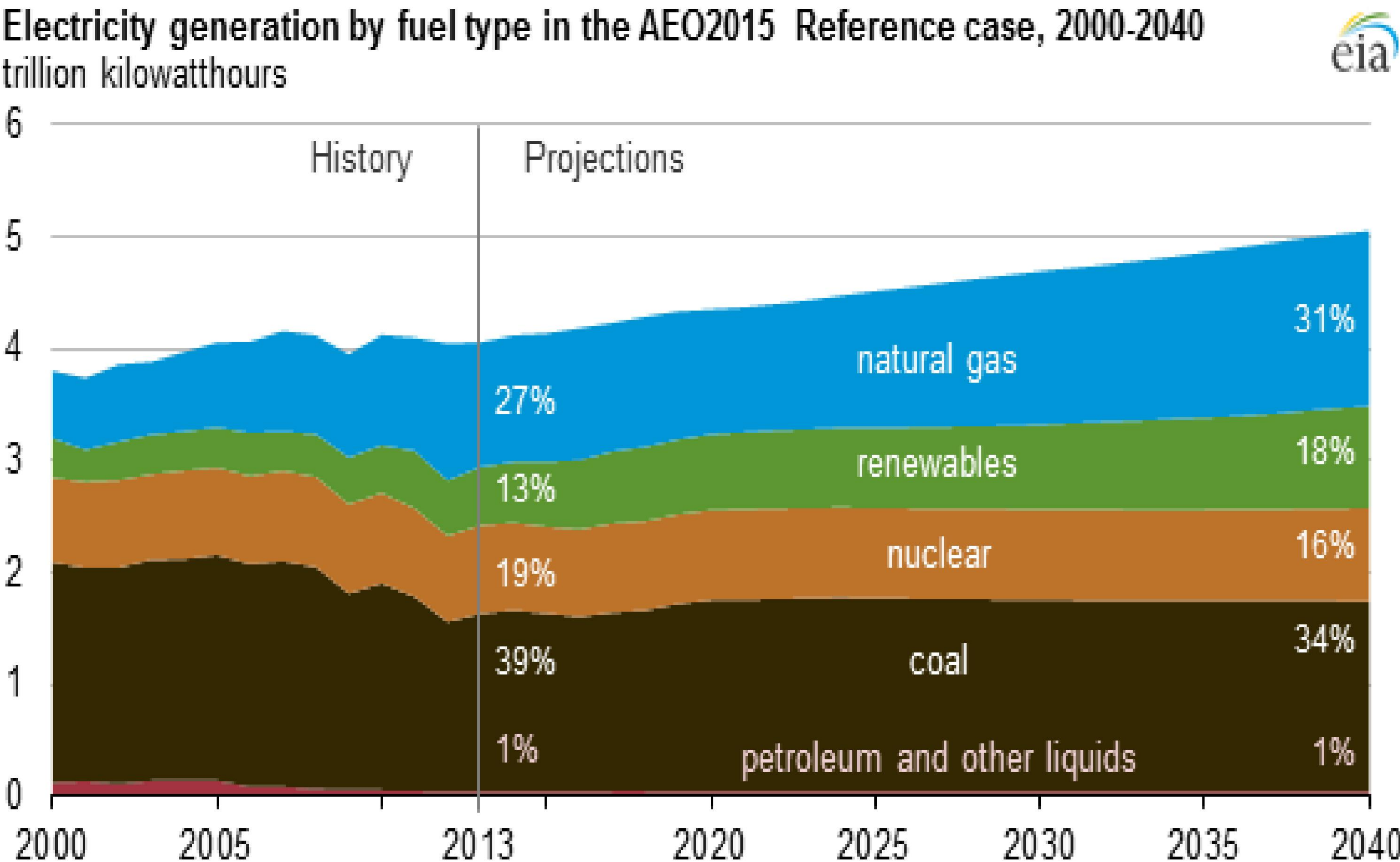
The Energy Challenge

Energy v Carbon Conflict

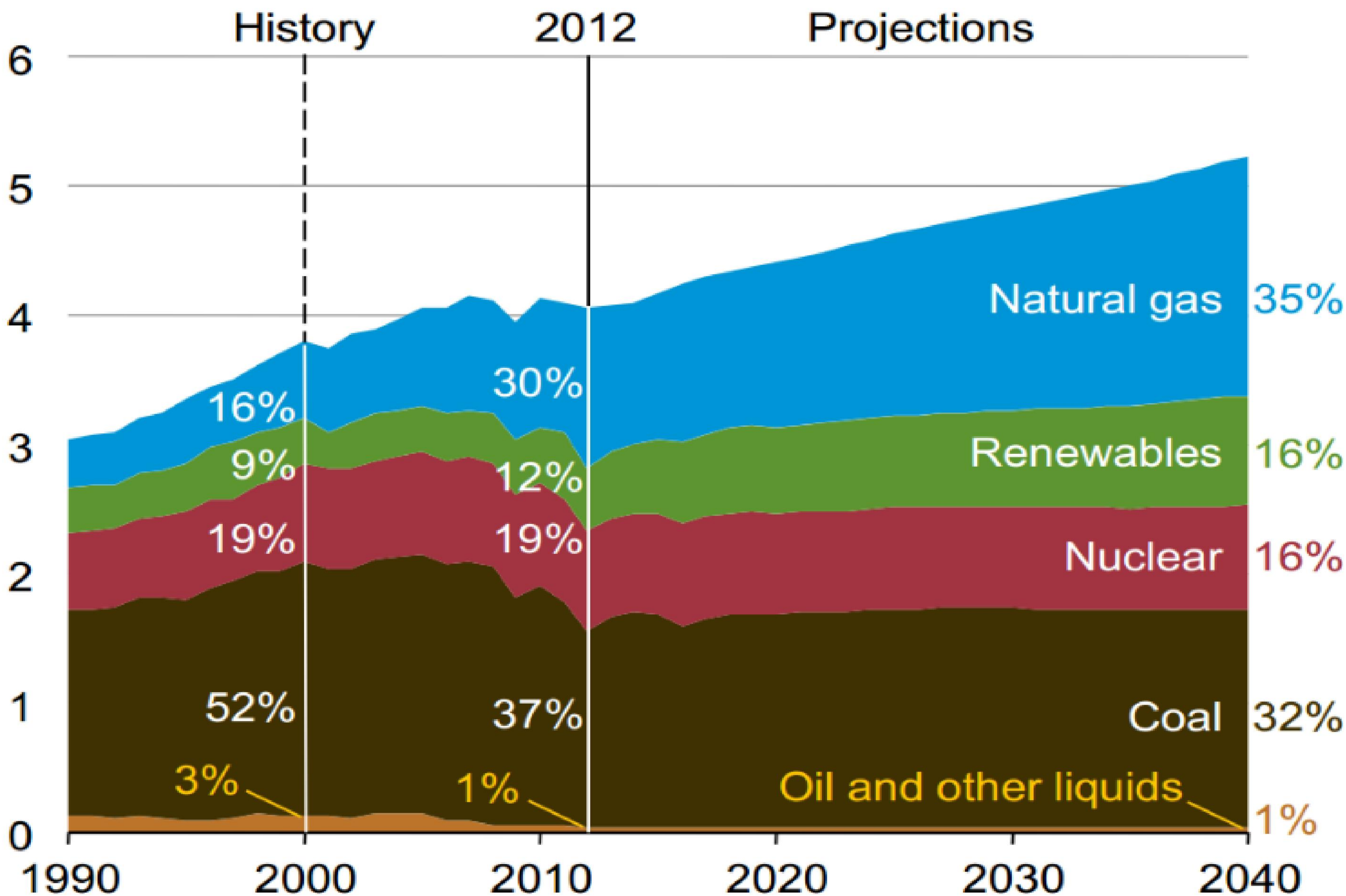
- **By 2050 World energy demand is expected to double and the world population to go from 7 to 9 Billion people.**

- **Competing factors:**
  - **Rising demand**
  - **Depletion of conventional supply stocks**
  - **Environmental and social effects**

WORLD ENERGY CONSUMPTION

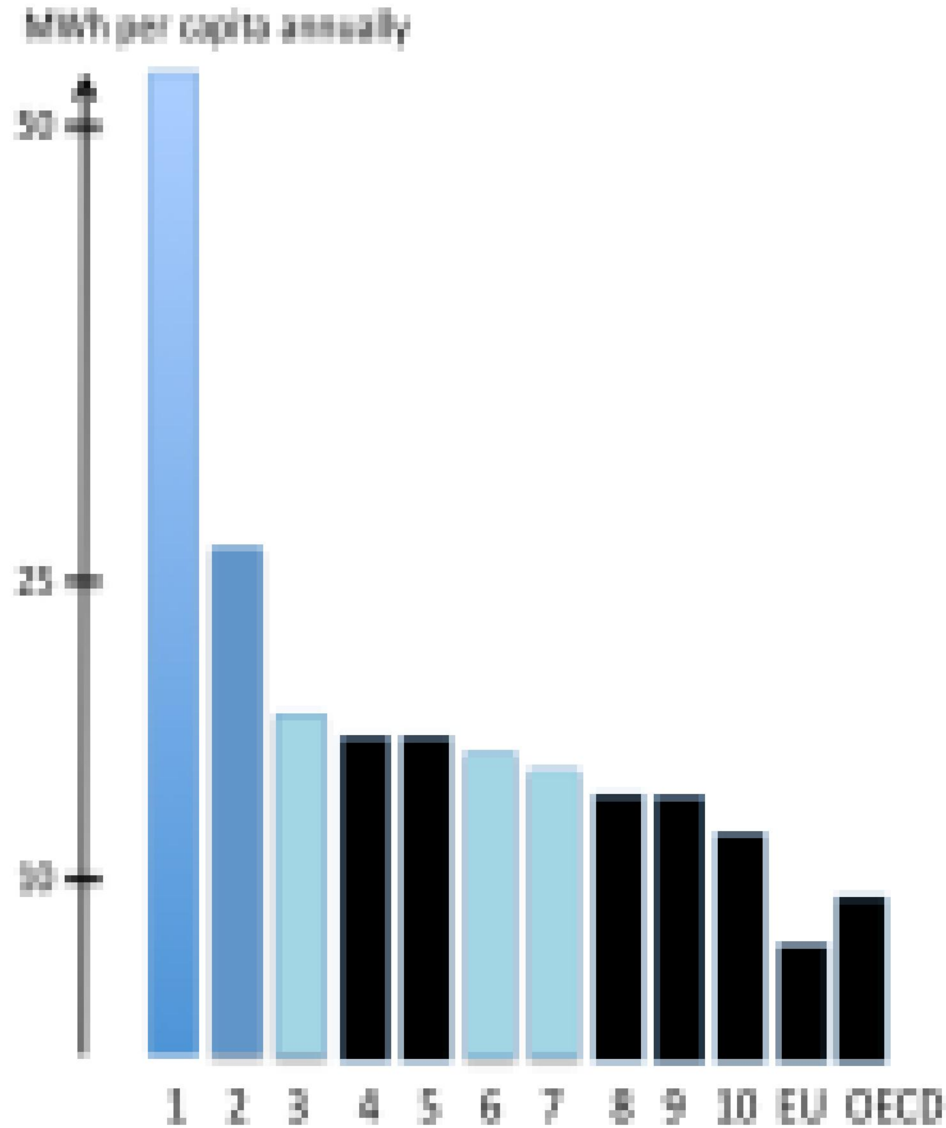


WORLD ELECTRICITY GENERATION BY FUEL 1990-2040
(Trillion kilowatt hours)



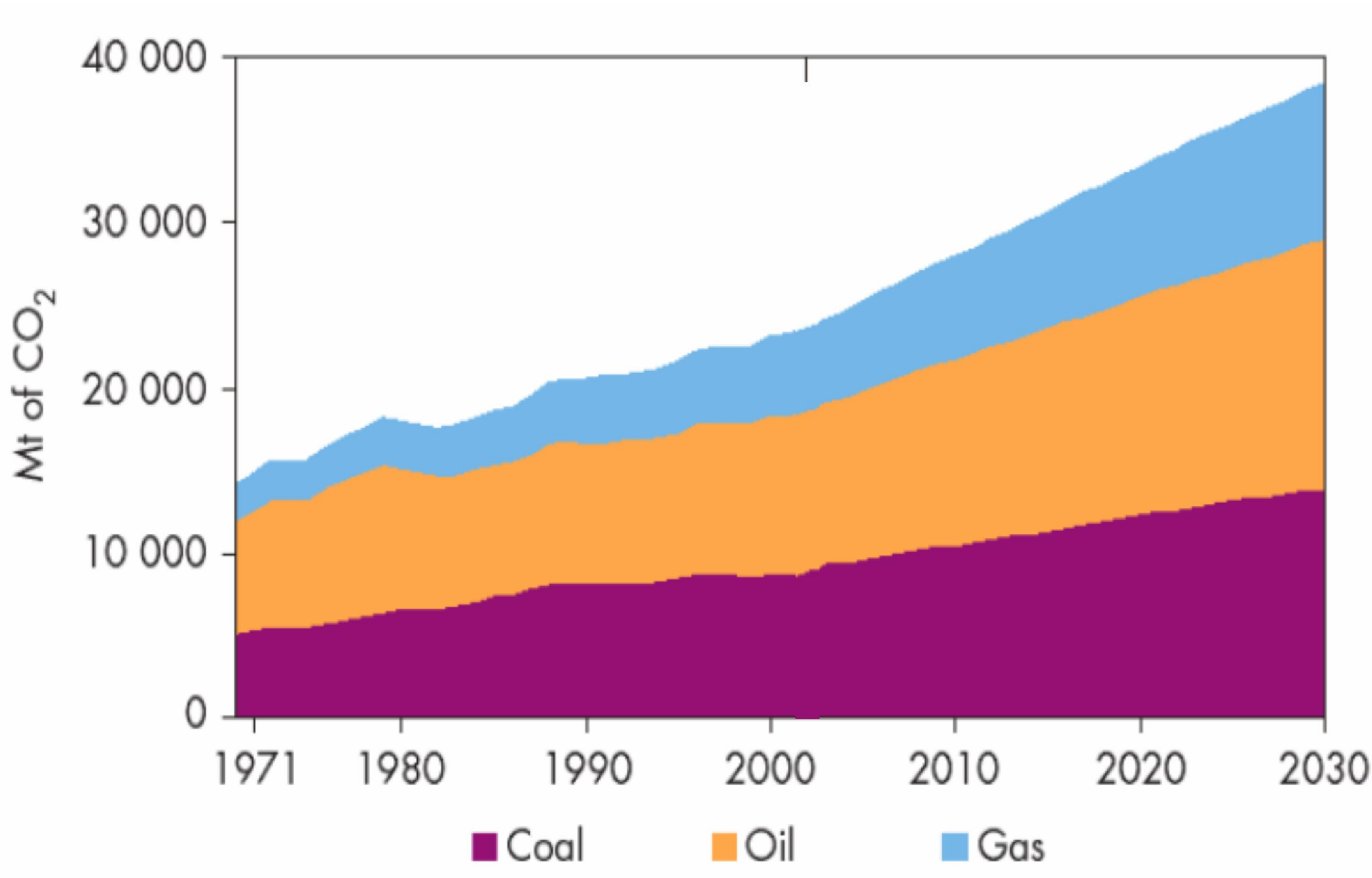
World Largest Electricity Producing Countries per capita

1.	**Iceland**	53 MWh
2.	Norway	26 MWh
3.	Canada	18 MWh
4.	Qatar	17 MWh
5.	Kuwait	17 MWh
6.	Finland	16 MWh
7.	Sweden	15 MWh
8.	USA	14 MWh
9.	UAE	14 MWh
10.	Bahrain	12 MWh
	OECD average	9 MWh
	EU average	6 MWh



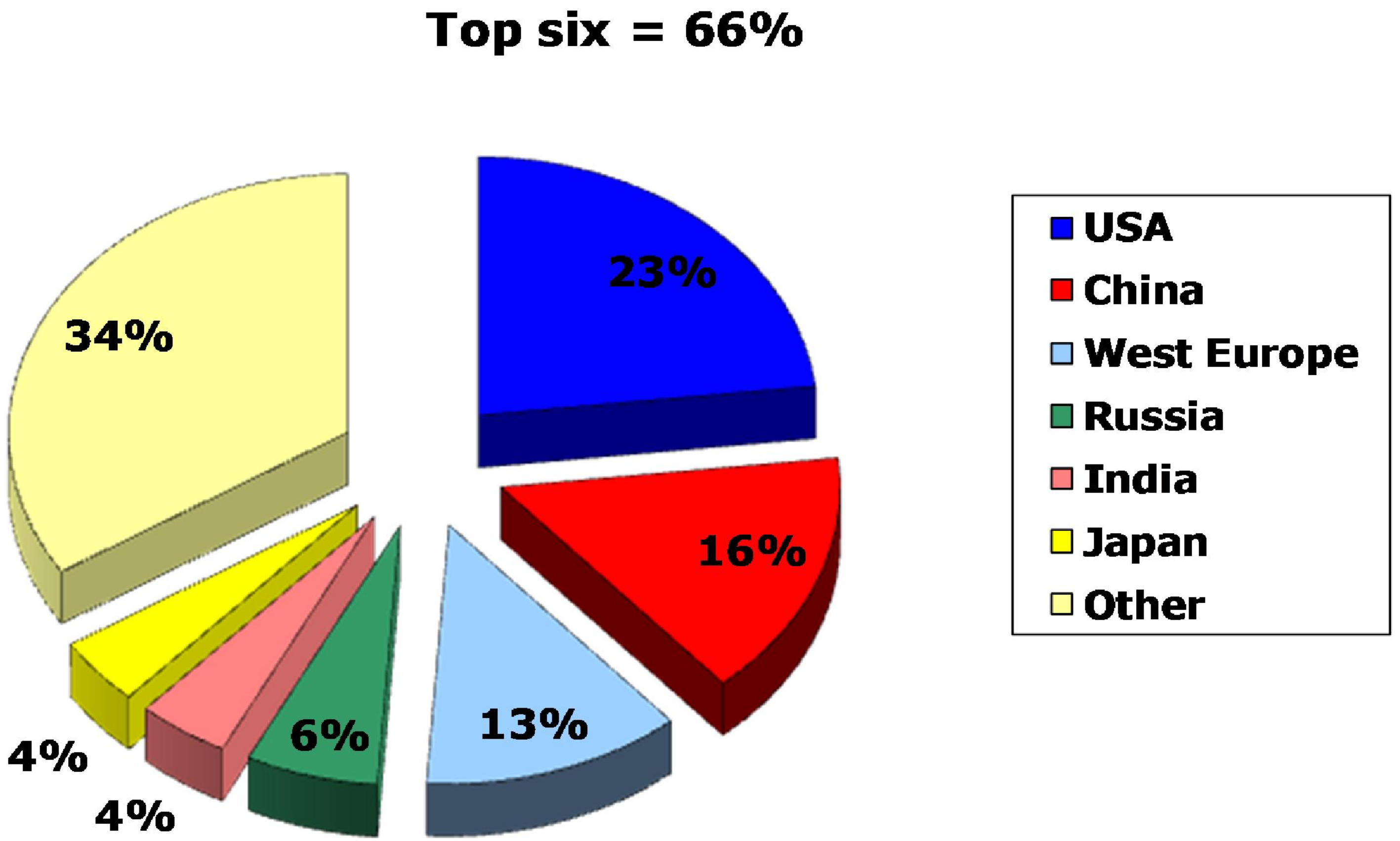
Source: IEA & OECD 2011

PROJECTED CO_2 EMISSIONS



Sources of Carbon dioxide CO_2

Biggest CO_2 Emitters 2000-2025



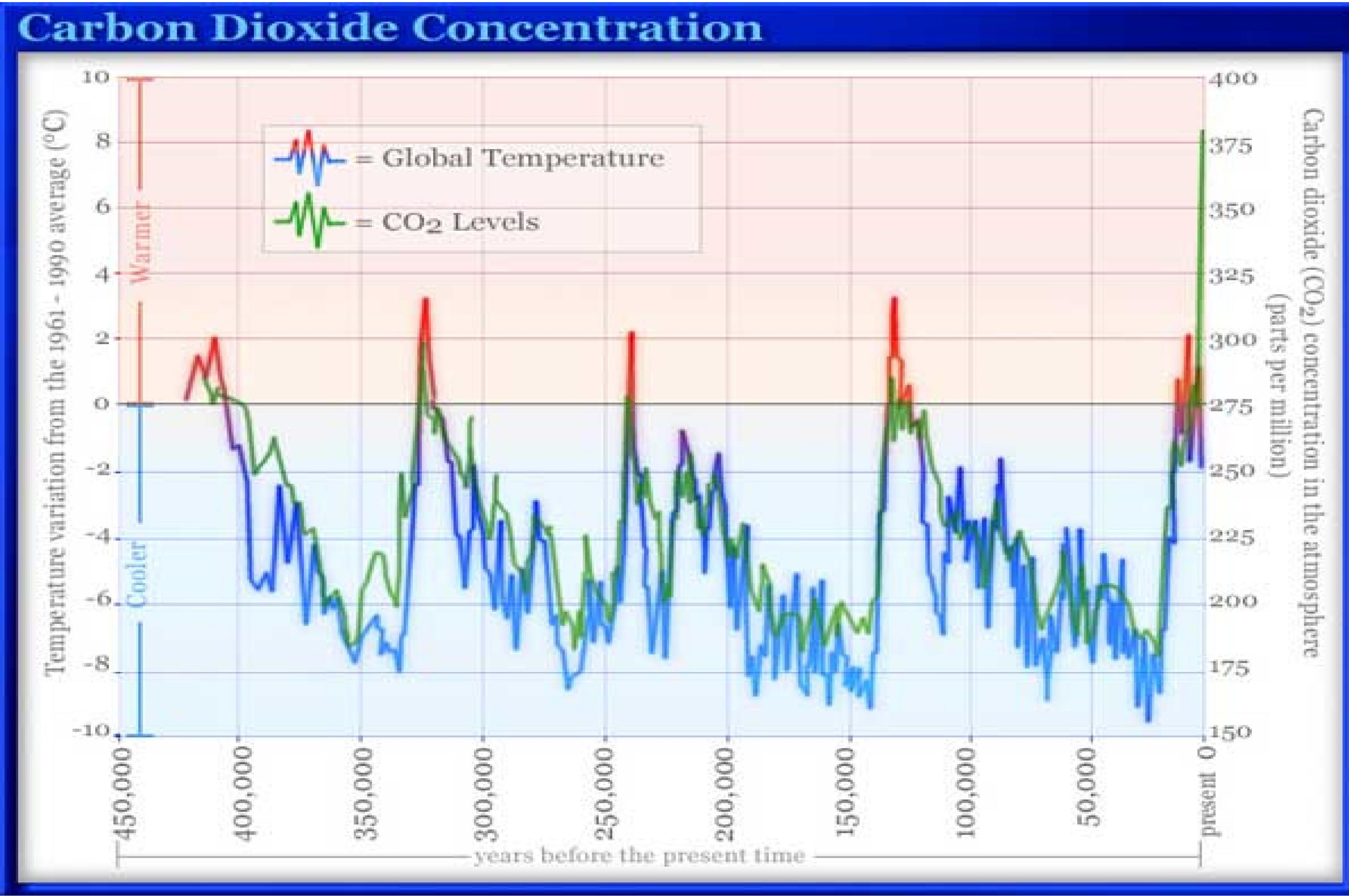
Cumulative CO2 Emissions 2000-2025, EIA, *IEA 2002*

Bahrain 5th in CO_2 Emissions/Capita

Country	Rank	Tonnes/year/capita
QATAR	1	40.12
United Arab Emirates	2	31.97
Trinidad and Tobago	3	30.00
Kuwait	4	28.88
Bahrain	5	28.86
Netherlands Antilles	6	25.10
Brunei Darussalam	7	20.30
Luxembourg	8	20.10
Australia	9	17.87
Gibraltar	10	17.26

http://www.iea.org/

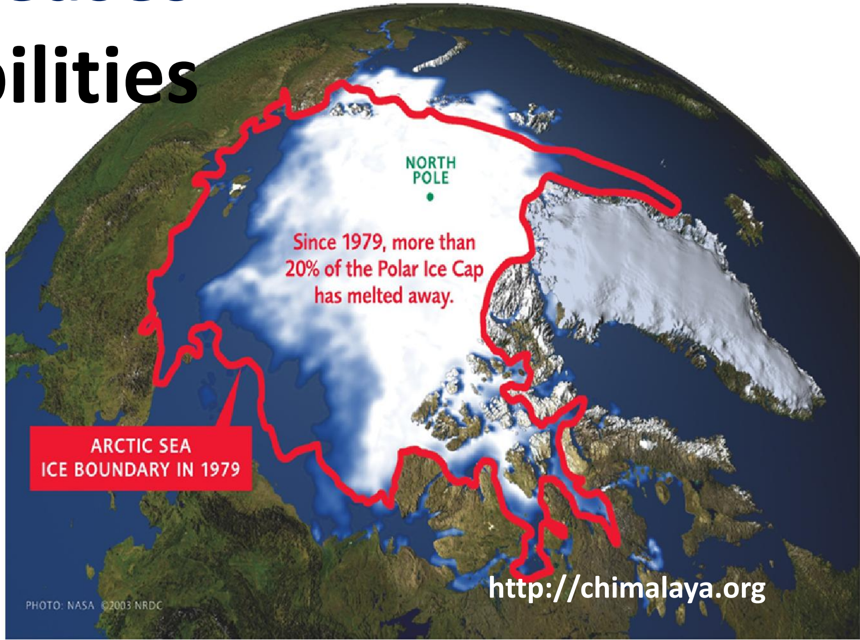
How does CO_2 affect the climate ?



Global Warming is a Reality

- Temperature rise
- Sea level rise
- Massive biodiversity loss
- Increase of extreme events
- Depletion of fresh water resources
- Increase of vector born diseases
- Economic and social instabilities

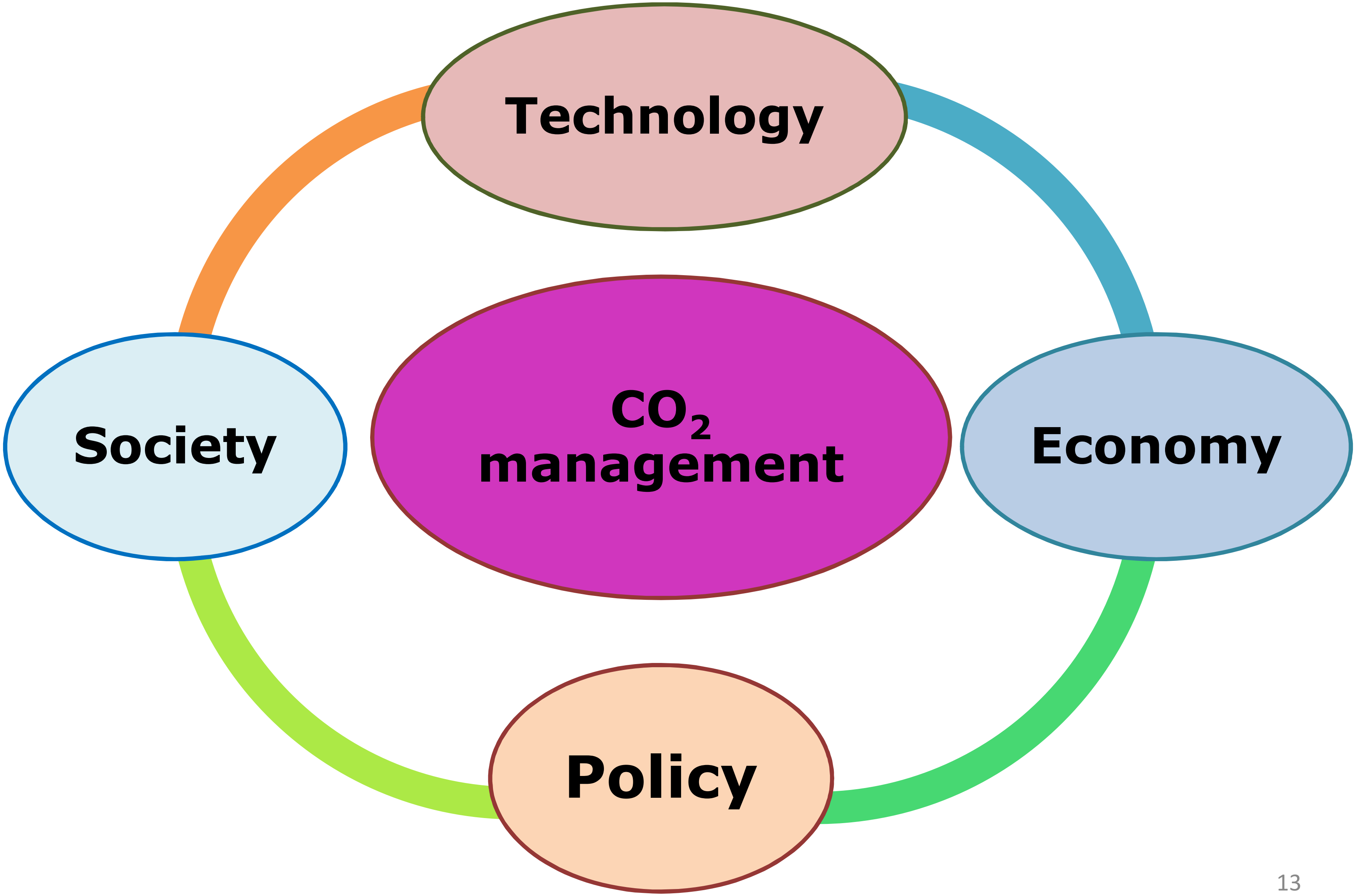
Climate change is real and represents a very serious threat to global stability



Carbon Emissions Management

- **Reduce Energy Demand**
- **Carbon Capture Use and Storage**
- **Improve Clean Coal Technologies**
- **Increase renewable Energy Use**
- **Improve efficiency of Electric Motors**
- **Improve efficiency of fossil fuel Power plants**

Elements of CCUS Management



The purpose of the roadmap

Why do we need a roadmap?

Give Strategic Direction

↓

Ensure Actions by Key Players are aligned

↓

Measure progress

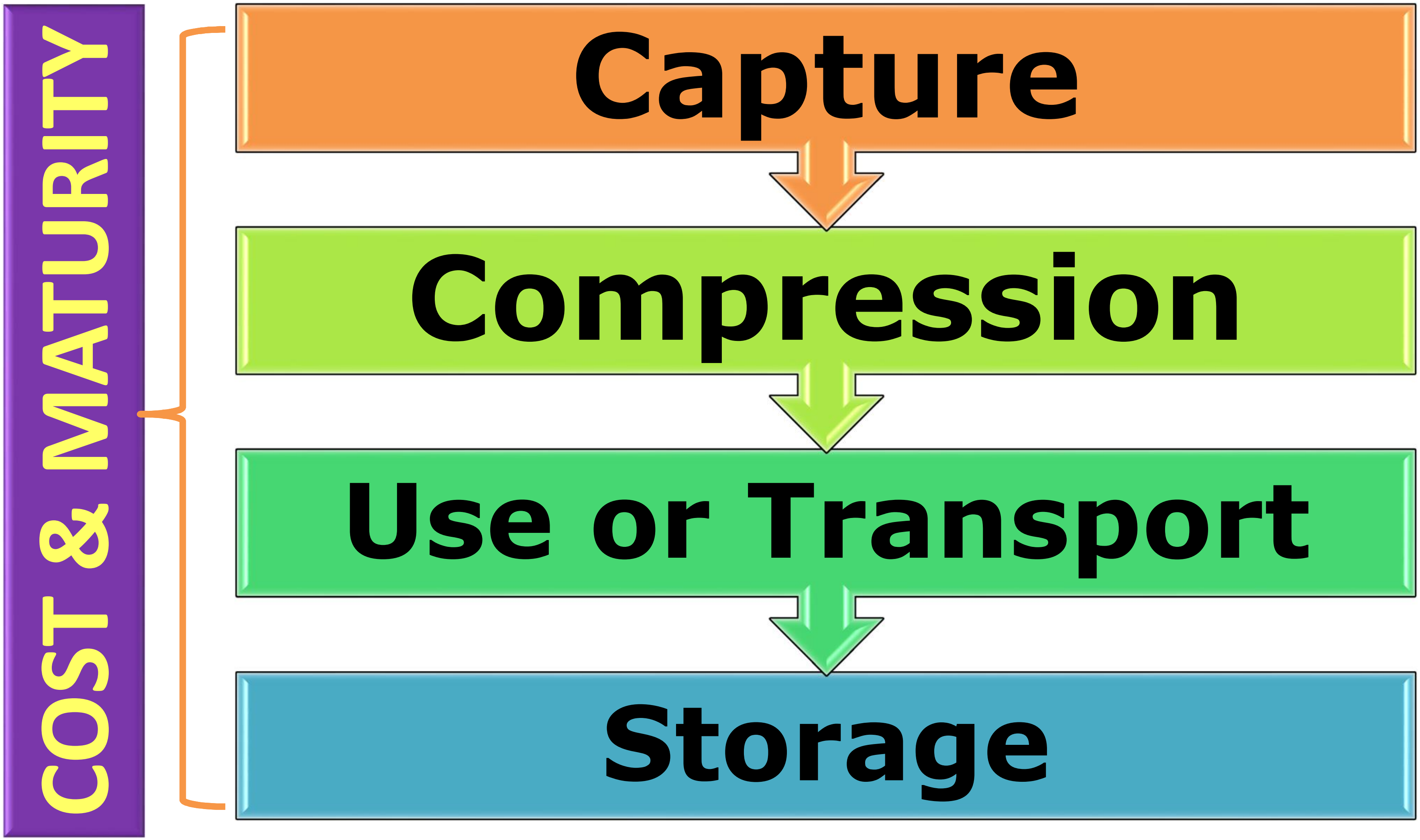
↓

Align with Government Policy

Carbon Capture Use and Storage (CCUS)

- **CCUS is needed to capture CO_2 from large point sources and subsequently storing it.**
- **Technology for capturing of CO_2 is already commercially available for large CO_2 emitters, such as power plants.**
- **Capture is meaningless without storage or exploitation.**
- **Storage of CO_2, on the other hand, is still on trial as concept.**
- **Avenues to use the captured CO_2 are still work in progress.**

Carbon Capture Use and Storage (CCUS)

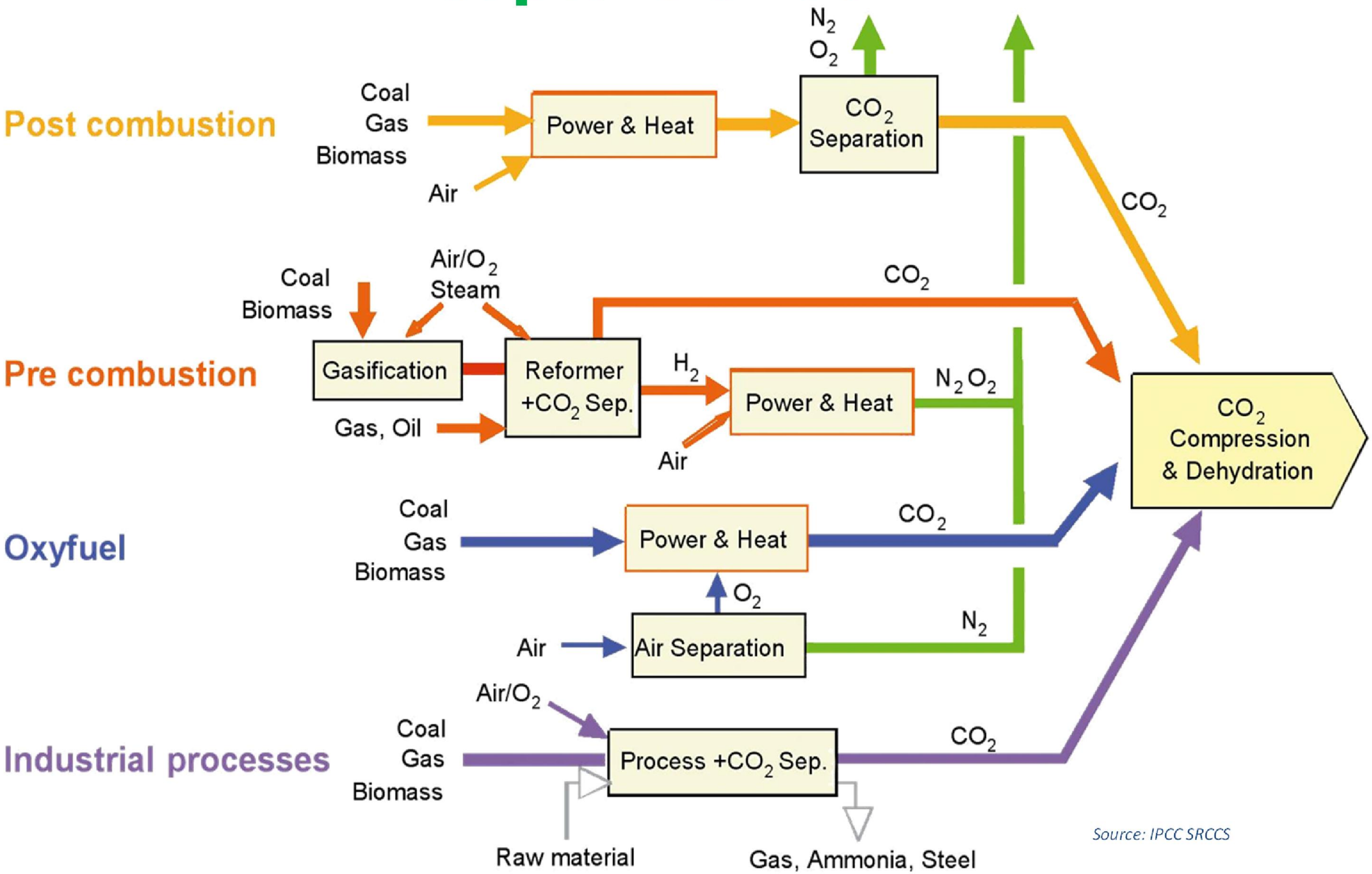


Carbon Capture Use and Storage (CCUS)
Why persist with CCUS?

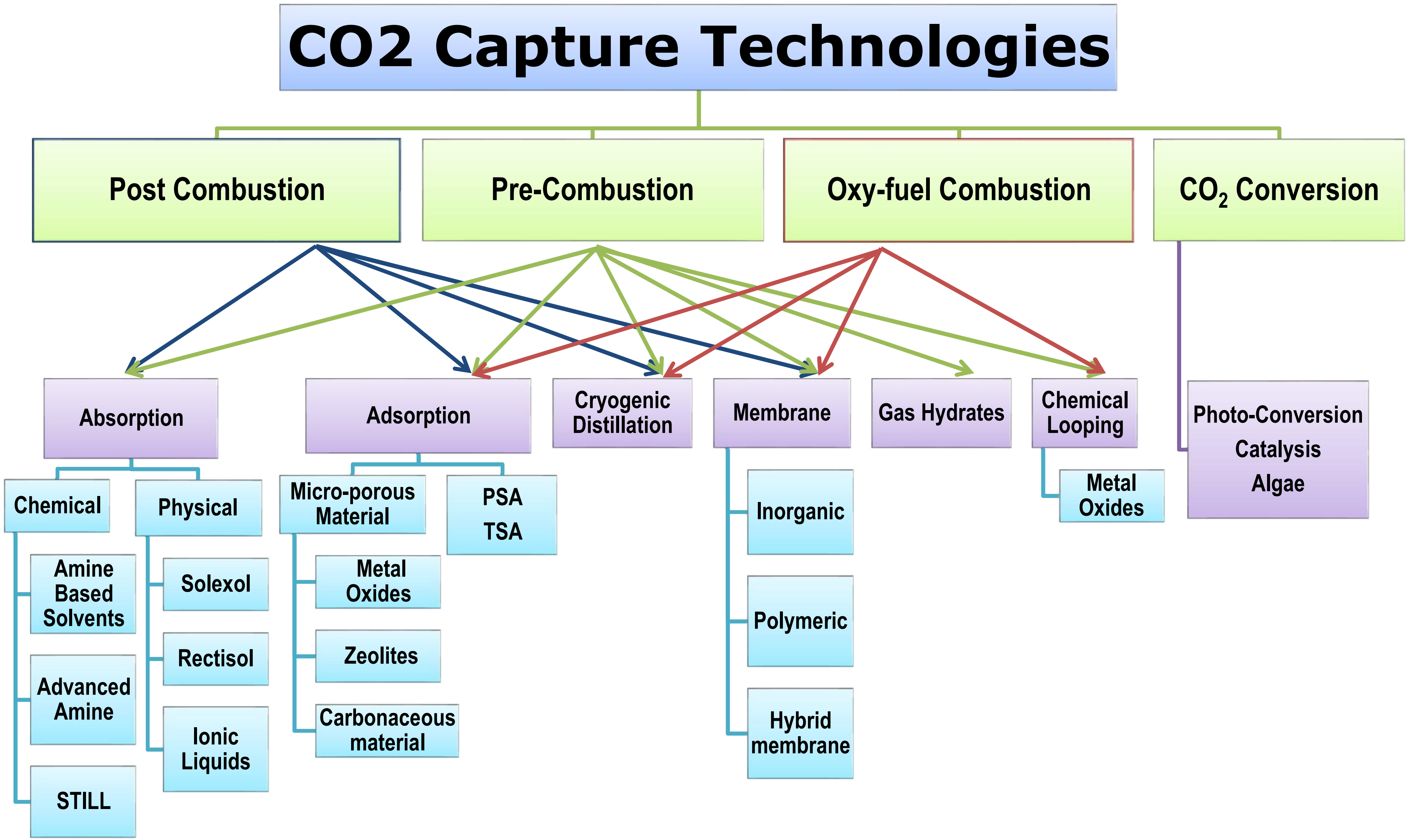
- The need to meet existing CO_2 targets
  CCUS should provide up to 20% of the CO_2 emission reductions needed by 2050.
- Capture energy efficiency needs to improve.
- Coal is dirty but some countries have it in abundance and consider it a secure supply to gas
- Large scale coal combustion in US, China and India - cleaner coal technology essential from global CO_2 perspective
- Compatible with existing grid infrastructure

Carbon Capture Use and Storage (CCUS)

Capture of CO2



Carbon Capture Use and Storage (CCUS)



Carbon Capture Use and Storage (CCUS)

Post-combustion capture

Future Direction of Research / Key Issues

Cost and energy reduction

- **Cost and process optimisation of the current MEA based technologies**
  - **Design of the absorption column**
  - **Reduction of energy consumption of the regenerative column**

Solvent Improvement

- **Improvement of Current solvents**
  - **Improving kinetics**
  - **Improving additives to reduce degradation**
- **Lower solvent losses**
- **Development of new types of solvents :**

  …

Carbon Capture Use and Storage (CCUS)

Post-combustion capture

Future Direction of Research / Key Issues

Corrosion

- **Stainless steel v carbon steel**
- **Inhibitors can contain V, Sn, Sb (antimony)**

Contacting Equipment

- **Development on column design and packing**
- **Reducing the equipment**

Environmental Impact Assessment

- **Impact assessment due to solvent degradation**
- **Fugitive emissions (especially NH_3 as one of the by-product of degradation)**

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<table>
<tr><th></th><th>Research Pathways</th><th>Cross Cut Pathways</th></tr>
<tr><td>Post Combustion</td><td><u>Chemical Solvents</u>
• Amines[c]
• Advanced amines[p]
• Aqueous ammonia[L]
<u>Physical Solvents</u>
• Ionic liquids[L]
<u>Membranes</u>
• Membrane/amine hybrids[L]
• Enzymatic CO2 processes[L]
<u>Chemical Sorbents</u>
• Amine-enriched sorbents[L]
• Metal organic frameworks[L]
<u>Physical Sorbents</u>
• Metal organic frameworks[L]</td><td rowspan="3">• Heat and pressure integration with base power plants
• CO2 compression
• CO2 capture
• O2 quality (for oxy and post combustion)
• CO2 quality (for transportation)
• Post combustion capture: CO2 recycle to concentrate flue gas.

Key:
L: laboratory scale/conceptual
P: Pilot scale
C: Commercially available</td></tr>
<tr><td>Pre-Combustion</td><td><u>Chemical Solvents</u>
• Amines[C]
<u>Physical Solvents</u>
• Glycol[C]
• Methanol[C]
• Ionic liquids[L]
<u>Chemical Sorbents</u>
• Metal organic frameworks[L]
<u>Physical Sorbents</u>
• Metal organic frameworks[L]
<u>Membranes</u>
• Polymeric, Ceramic, Hollow fiber, Membrane supports[L]
<u>Novel</u>
• Hydrates[L]</td></tr>
<tr><td>Oxy-Combustion</td><td>Conventional oxyfuel with recirculation[C]
Oxygen transport membranes[L]
Cemical looping[L]</td></tr>
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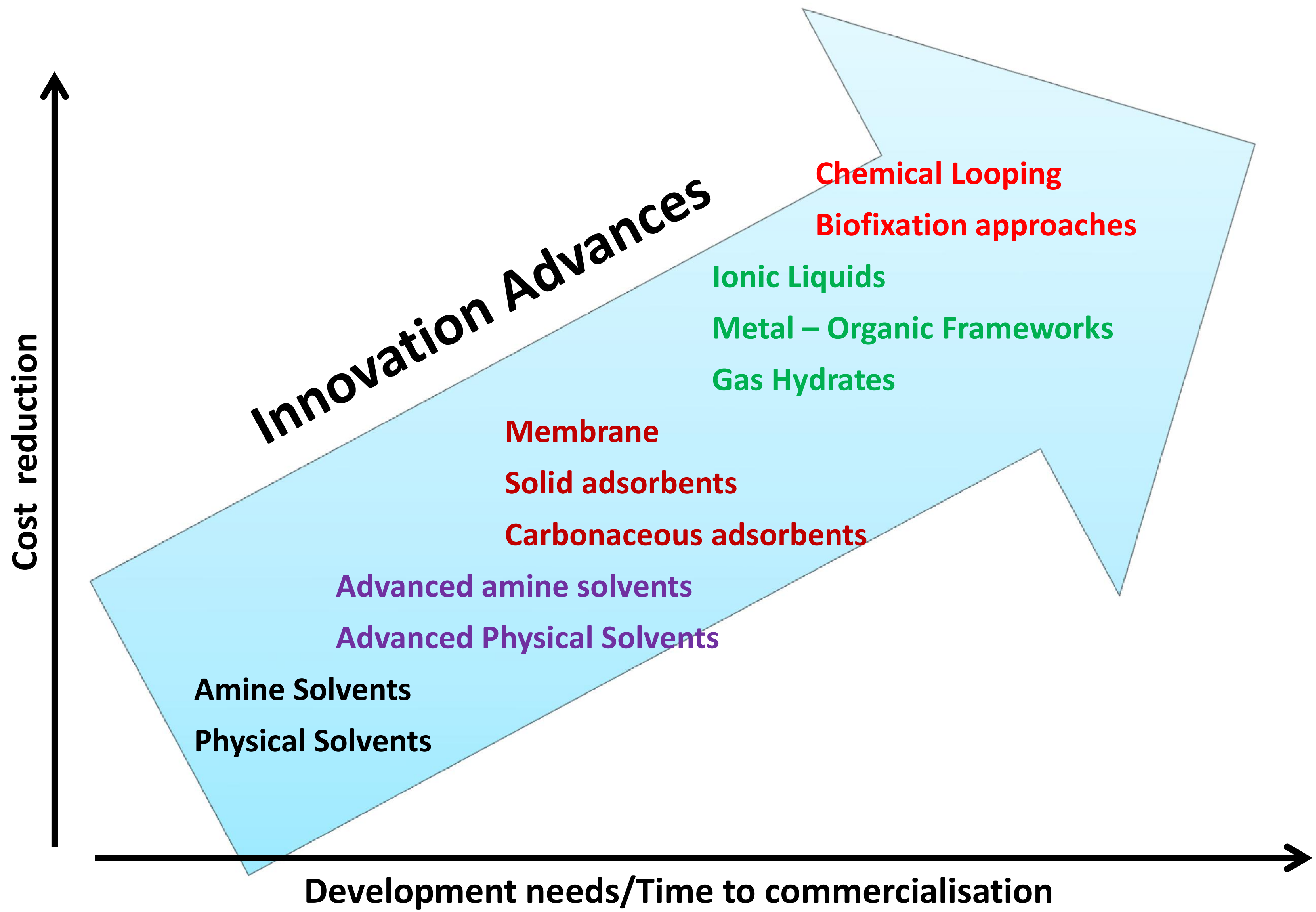
Carbon Capture Use and Storage (CCUS)

Future Direction of Research



Angew. Chem. Int. Ed. 2010, 49, 6058 – 6082

Carbon Capture Use and Storage (CCUS)

Future Direction of Research

- **Conventional solvents**
  - **Steam requirement: 1.8 ton steam/ton CO_2**
  - **e.g. MEA, etc.. CO_2**
- **Currently avialable solvents**
  - **Steam requirement: 1.4–1.2 ton steam/ton CO_2**
  - **e.g. MHI, Fluor, etc.**
- **Up and coming solvents**
  - **Steam requirement: 1.0-0.8 ton steam/ton CO_2**
- **Game-changer**
  - **Steam requirement: ~ 0.5 ton steam/ton CO_2**
  - **(or less)**

Carbon Capture Use and Storage (CCUS)

Efficiency Targets

Efficiency penalty estimates (IEA targets)

Technology	Current state-of-the-art	Target for 2020
CCUS-post combustion	~12 % efficiency loss	~8 % efficiency loss
CCUS-oxy fuel	~10 % efficiency loss	~8 % efficiency loss
CCUS – pre combustion	~7 -9 % efficiency loss	~5 -6 % efficiency loss
CCUS gas – post com	~ 8 % efficiency loss	~7 % efficiency loss
CCUS gas –oxy-fuel	~11 % efficiency loss	~8 % efficiency loss

Source: IEA GHG studies

Carbon Capture Use and Storage (CCUS)

Storage Methods

- **In plants and soil ‘ terrestrial sequestration’. Natural storage by plants through photosynthesis or as carbon in biomass and soils. Forestation is needed**
- **Underground geological sequestration. Depleted oil and gas fields or coal seams.**
- **Deep in Ocean Sequestration**
- **Solid material generation**

Transport of Captured Carbon

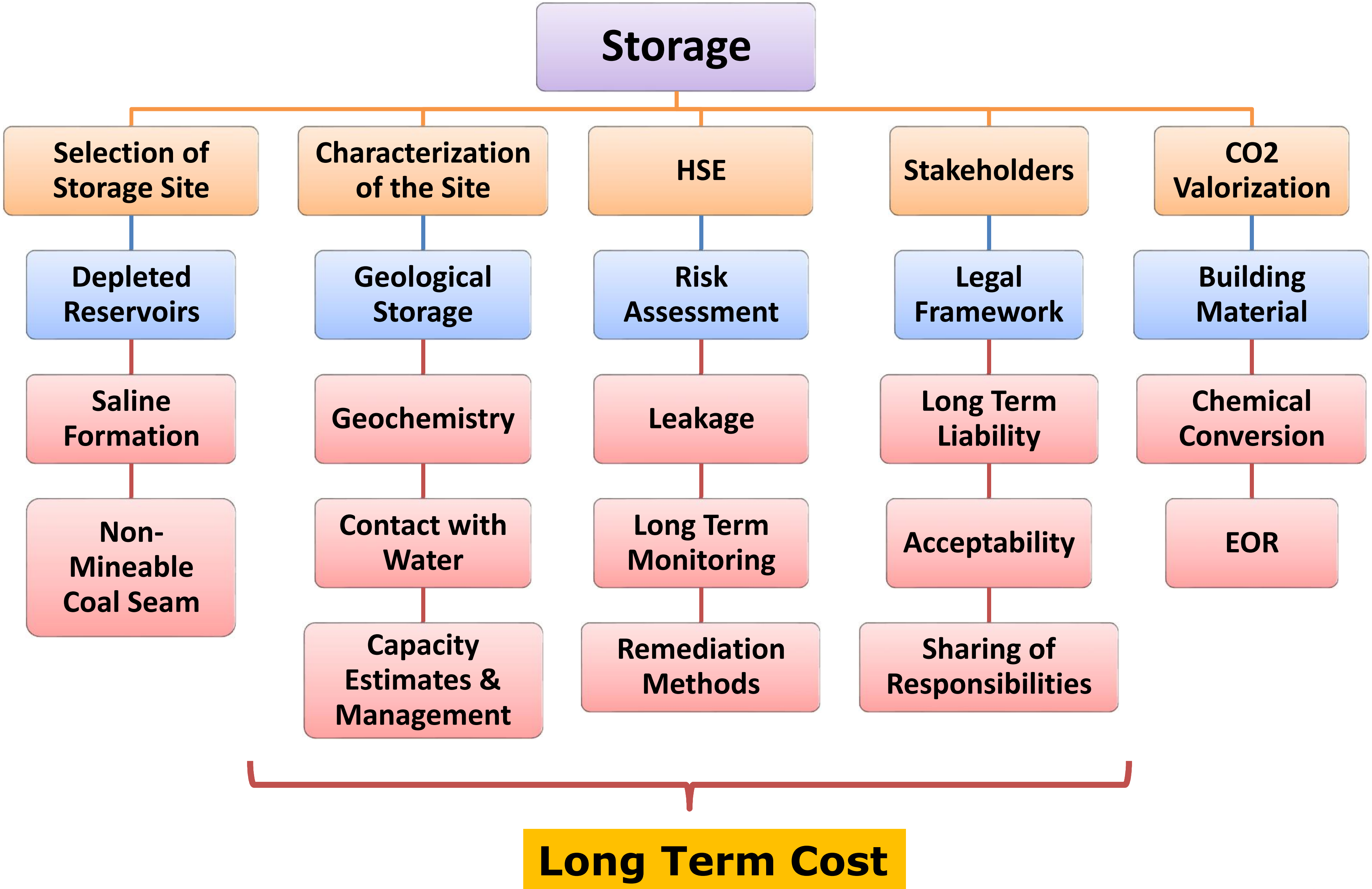
- The captured CO_2 is compressed and dehydrated for transport or storage
- Transport by pipeline at high pressure 80 to 150 bar to ensure it is in dense phase, is the cheapest.
- Tankers are also used (14 to 17bar and around – 30^{o}C. Good for long distance but high cost due to need for liquefaction.

Delivery and Storage of Captured CO_2

- gaseous storage in various deep geological formations .
- liquid storage in the ocean.
- solid storage by reaction of CO_2 with metal oxides to produce stable carbonates

- Capture process removes up to 90% of emissions
- Transported to location via pipeline or tankers
- Main storage sites usually disused oil (EOR) and gas fields (EGR) and offshore saline aquifers
- It should remain in storage for many centuries

Carbon Capture Use and Storage (CCUS)



Carbon Capture Use and Storage (CCUS)

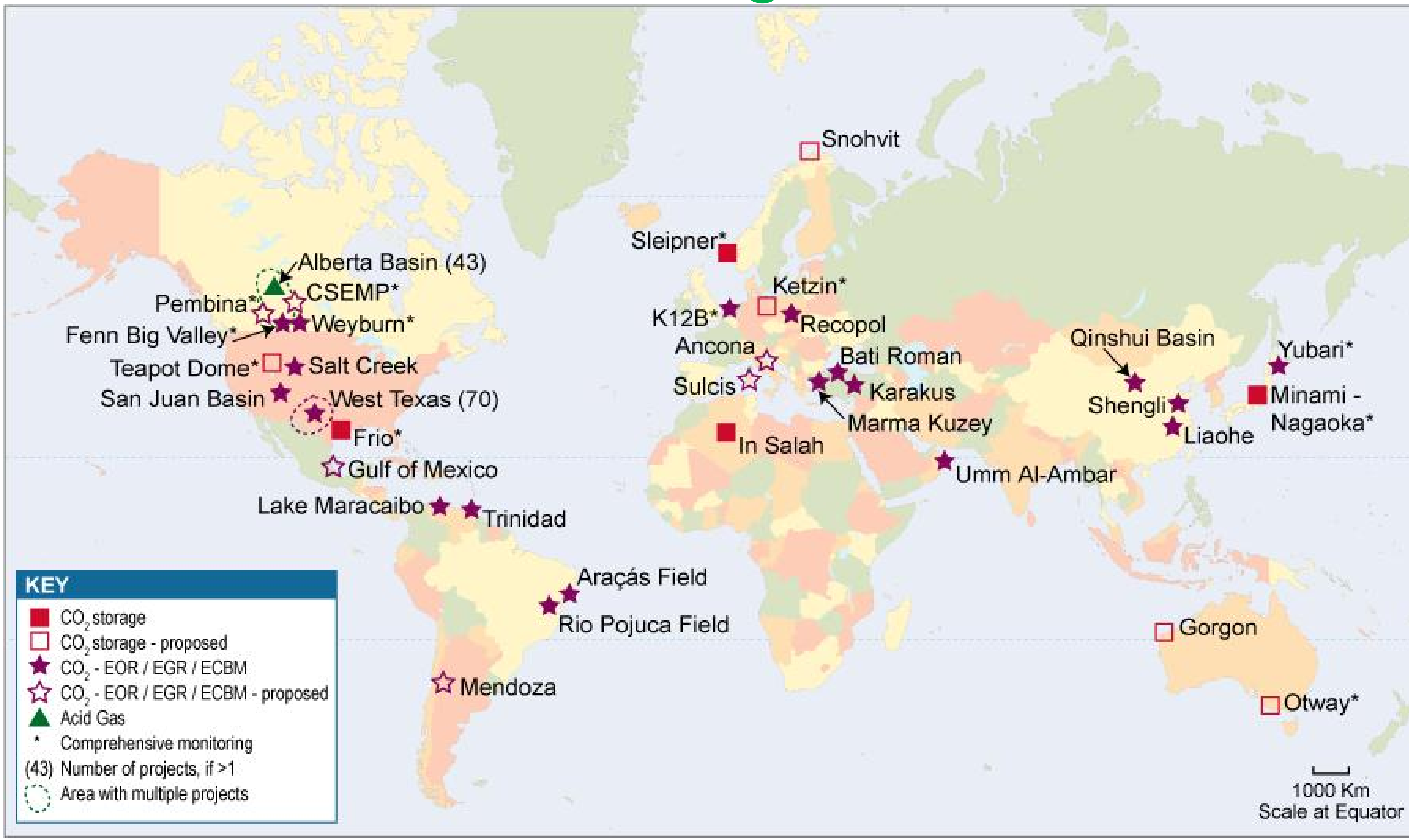
Screening Candidate Oil Reservoirs

- **Reservoir pressure and temperature**
- **Composition of the oil in the reservoir**
- **Composition of CO_2 stream available**
- **Determination of Minimum Miscibility Pressure (MMP): The minimum pressure, at reservoir temperature, that oil becomes miscible with the injected stream of CO_2**

90% Reservoir Fracture Pressure should be equal or greater than MMP

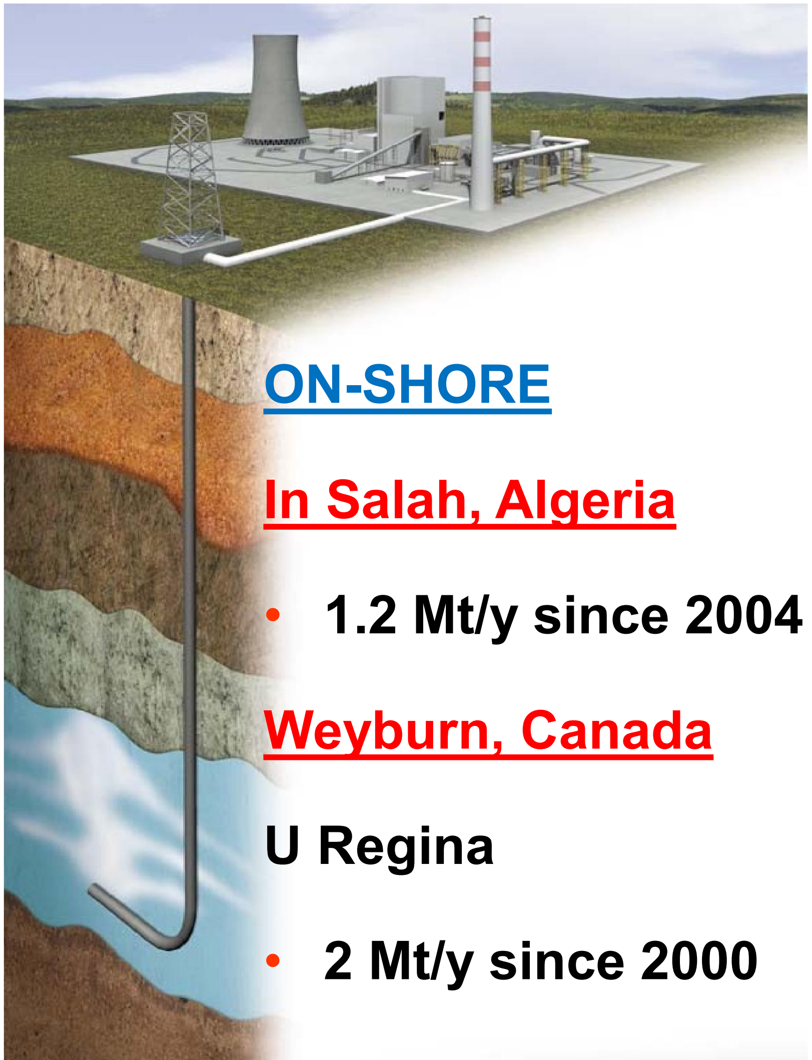
Carbon Capture Use and Storage (CCUS)

Planned and current locations of geological storage



Carbon Capture Use and Storage (CCUS)

Large Scale Storage Examples



ON-SHORE

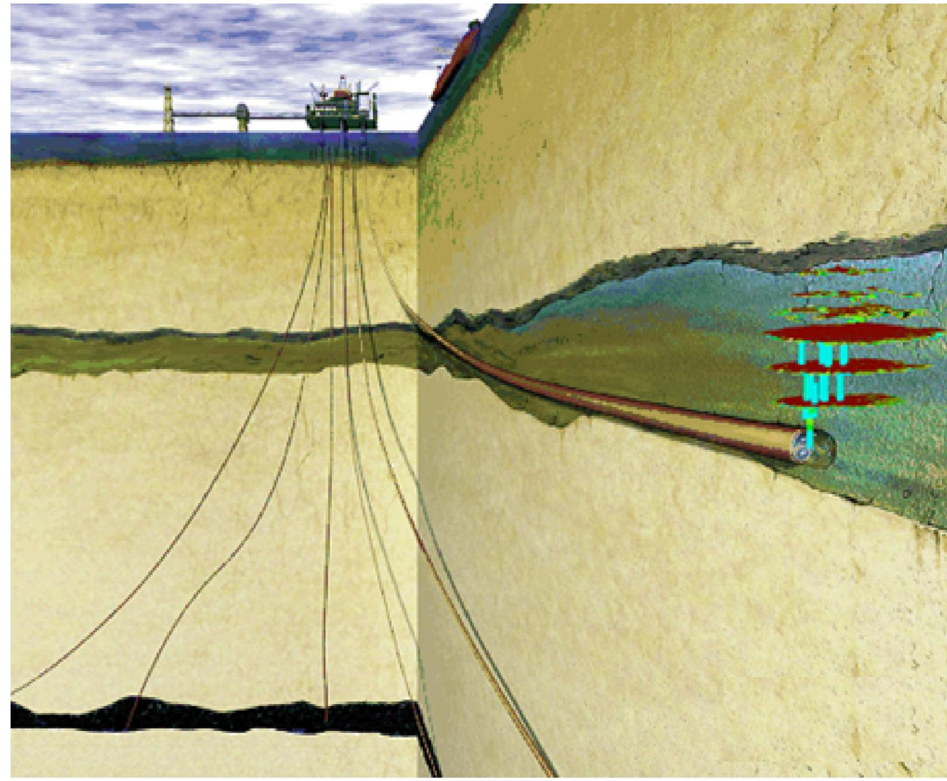
In Salah, Algeria

- 1.2 Mt/y since 2004

Weyburn, Canada

U Regina

- 2 Mt/y since 2000



OFF-SHORE

Sleipner, Norway: 1 Mt/year since 1996

Snovit, Norway: 0.7 Mt/year since 2007

Carbon Capture Use and Storage (CCUS)

Mineral carbonation through Peridotite

- **Mineral carbonation will return CO_2 as a usable harmless object in our world.**
- **a potential "carbon capture" material: is peridotite where contact between carbon dioxide and peridotite causes a chemical reaction which, over time, converts them into minerals such as calcite**
- **This rock material is present in the GCC region and particularly in Oman, UAE and Saudi Arabia.**
- **Resources on the Arabian Peninsula could suffice for capturing 10% of total human CO2 emissions/year**

Carbon Capture Use and Storage (CCUS)

Economics

- **CCUS applied to a modern conventional power plant could reduce CO_2 emissions to the atmosphere by approximately 80-90%.**
- **Seen as parasitic load in power generation as capturing and compressing CO_2 requires more energy and increases the fuel needs of a plant by about 10-40%.**
- **These and other system costs are estimated to increase the cost of energy from a power plant with CCUS by 30-60% depending on the specific circumstances.**
- **It is estimated that the cost of capture, transport and storage from power plants is around \$60/t of CO2 but recently \$23/t was quoted.**

Carbon Capture Use and Storage (CCUS)

Natural and Synthetic CO_2 conversion

- **The deforestation of the planet must be reversed through natural and synthetic forestation.**
- **Synthetic trees combine the CO_2 with Sodium hydroxide (NaOH) to produce Na_2CO_3 liquid which can be pumped to sediments below oceans where it can be stored for millions of years.**
- **A synthetic tree remove 1000 times more CO_2 that a real tree.**
- **CO_2 and water can also be converted photosynthetically to produce methanol, which can then be used directly in fuel cells or combustion engines, thus utilizing solar energy to convert CO_2 to a renewable power by means of a neutral carbon cycle process.**
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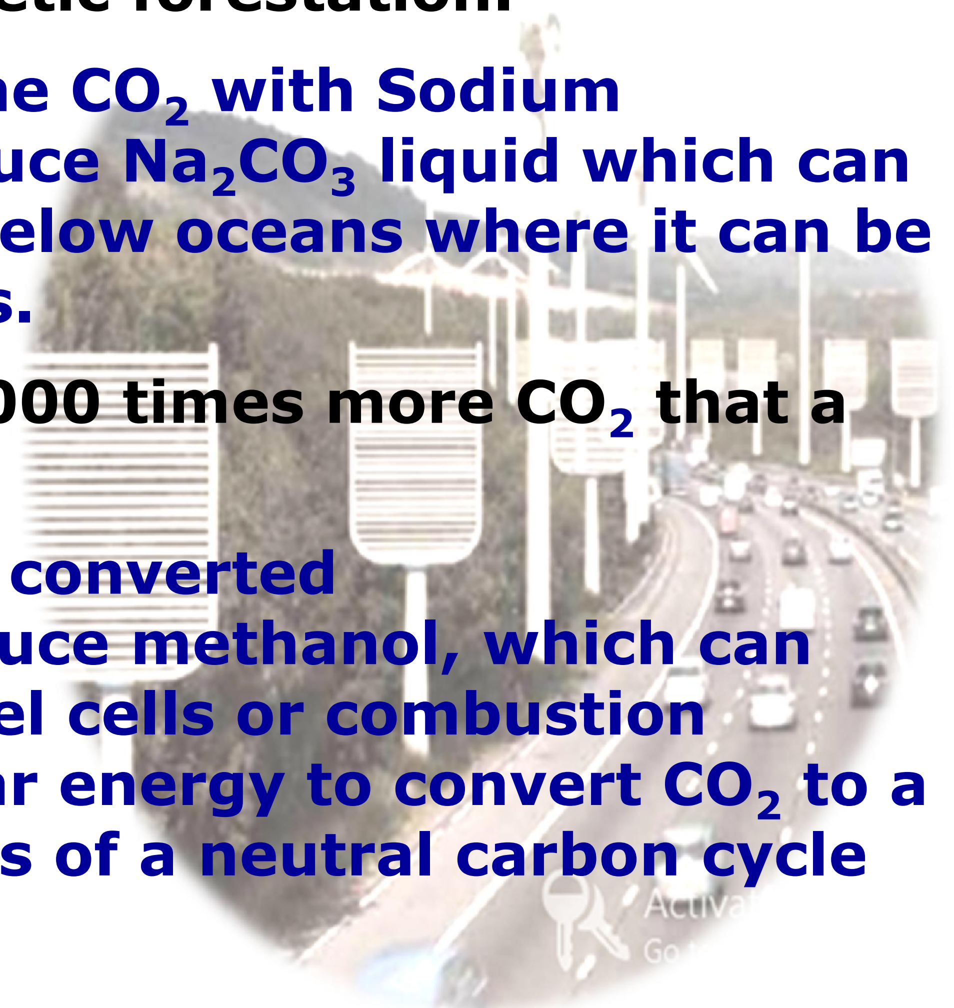
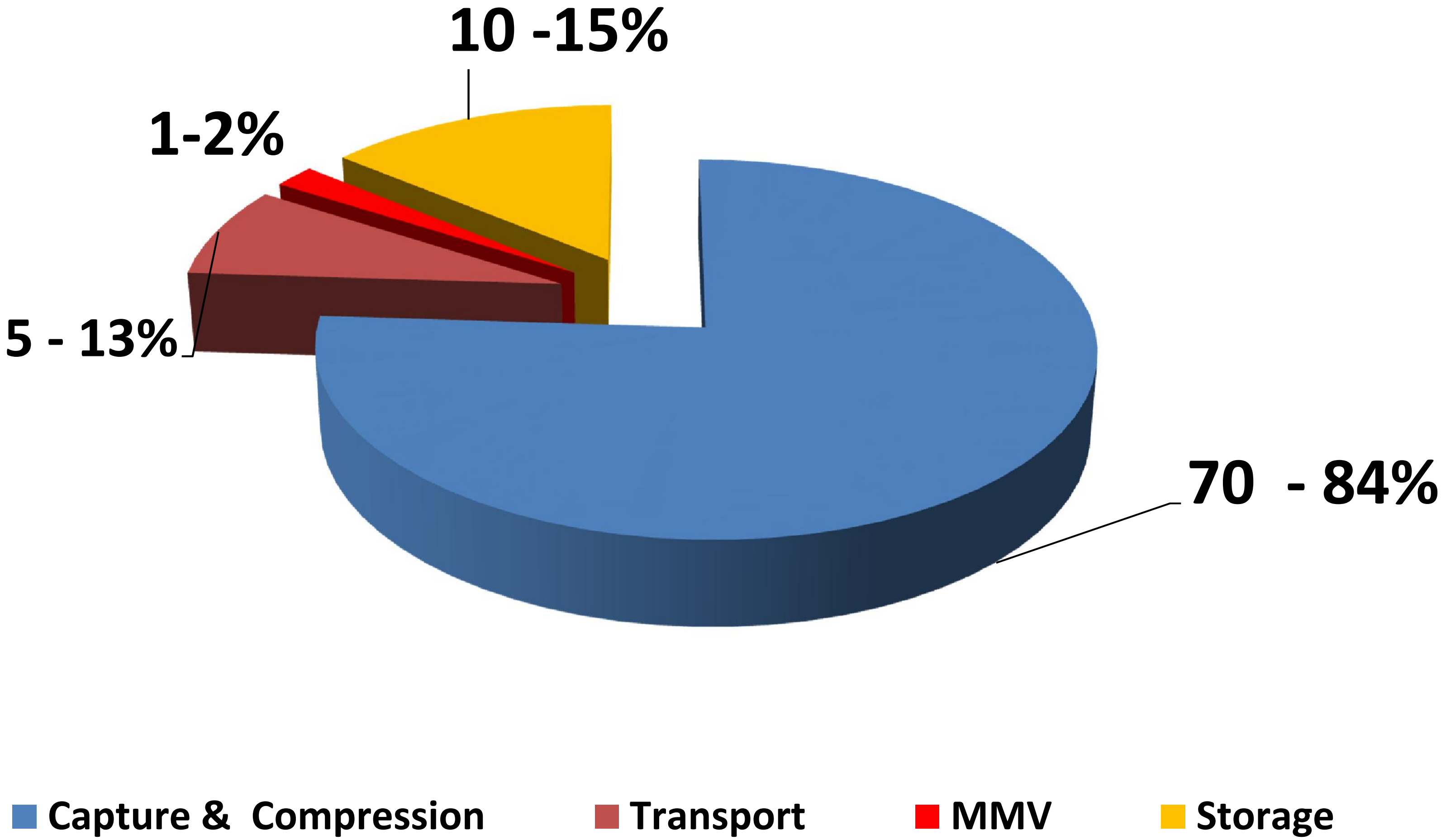


Carbon Capture Use and Storage (CCUS) Costs

CCS Cost Breakdown



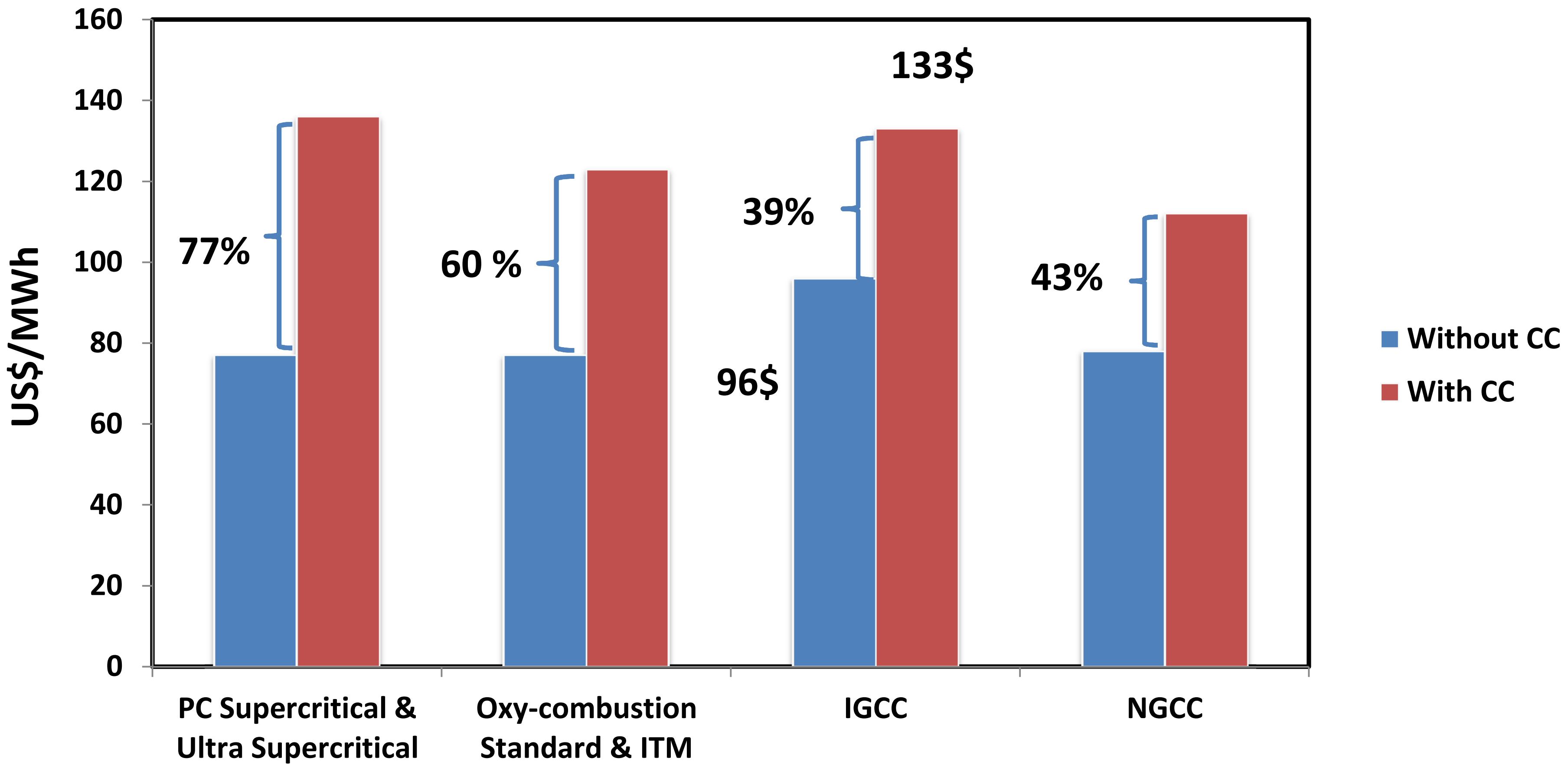
MMV - Measuring, Monitoring and Verification

Cost data: The Costs of CO_2 Capture, Transport and Storage, Zero Emission Platform, http://www.zeroemissionsplatform.eu/library/publication/125-sdd.html

Carbon Capture Use and Storage (CCUS)

Economics

Levelised Cost of Production (LCP) with Various CC Options



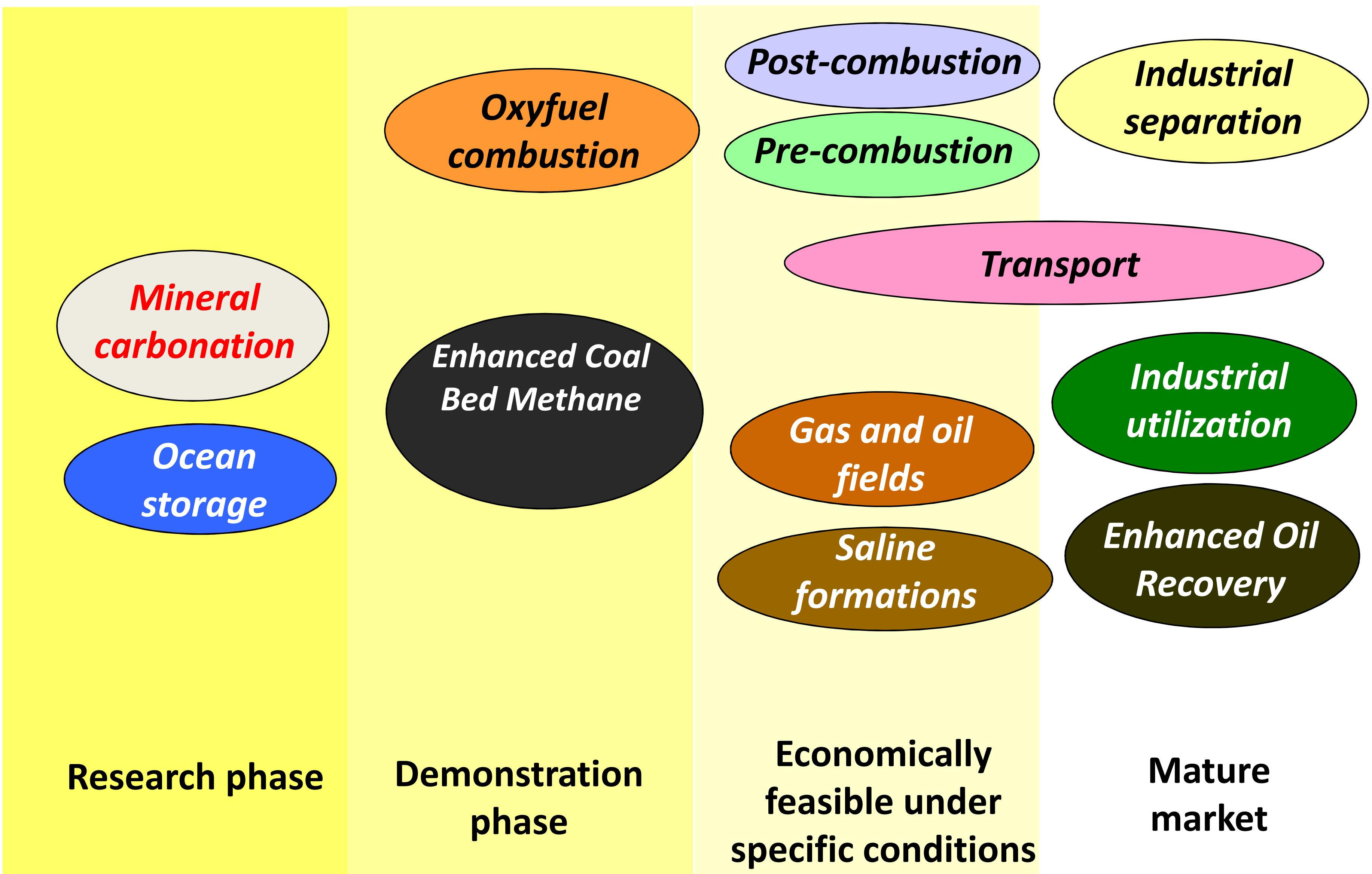
Source: Global CCS Institute 2009

Carbon Capture Use and Storage (CCUS)
Technology Maturity for Deployment

- **Research and Development**
  - **Laboratory Work**
  - **Bench Scale**
- **Technology Demonstration**
  - **Pilot Scale**
- **Deployment**
  - **Large or Semi-Commercial Scale**
  - **Wide Commercial Deployment**

Carbon Capture Use and Storage (CCUS)

Technology Maturity



THANK YOU