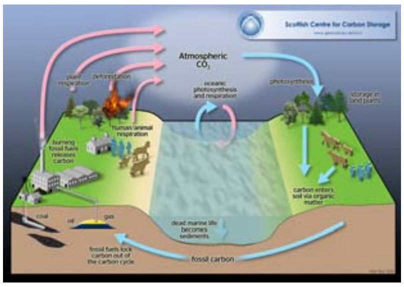
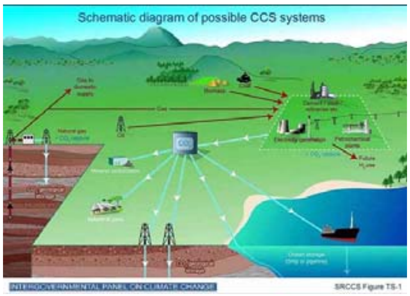
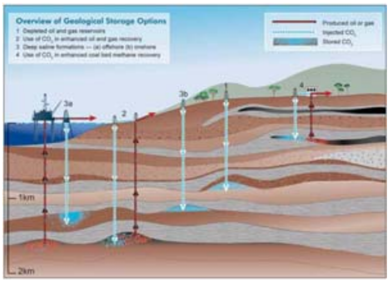
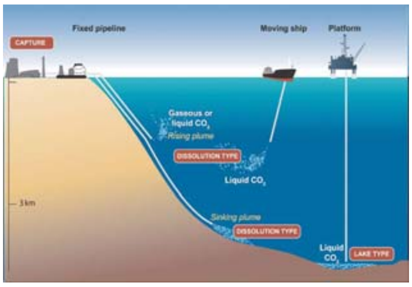
Carbon Capture and Storage

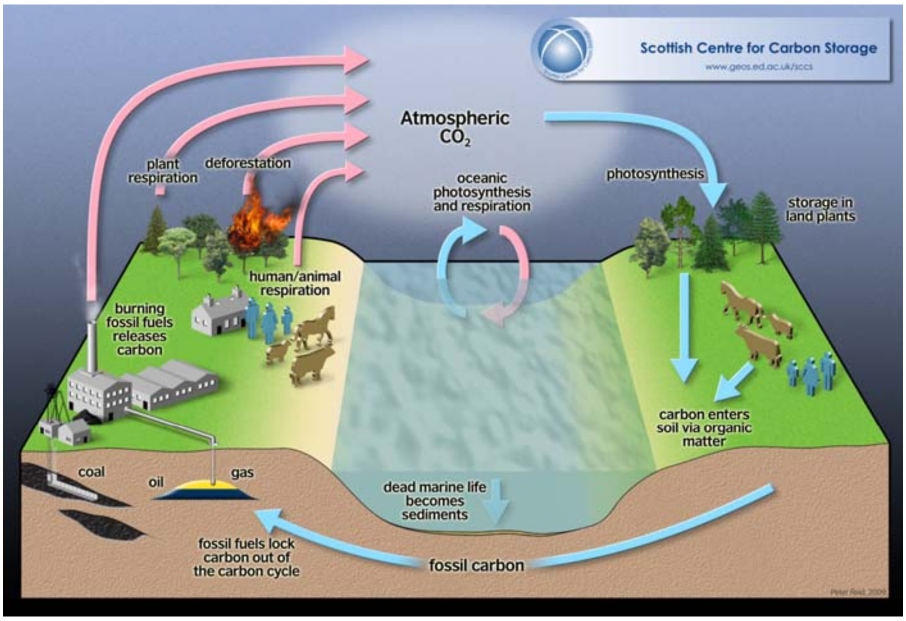






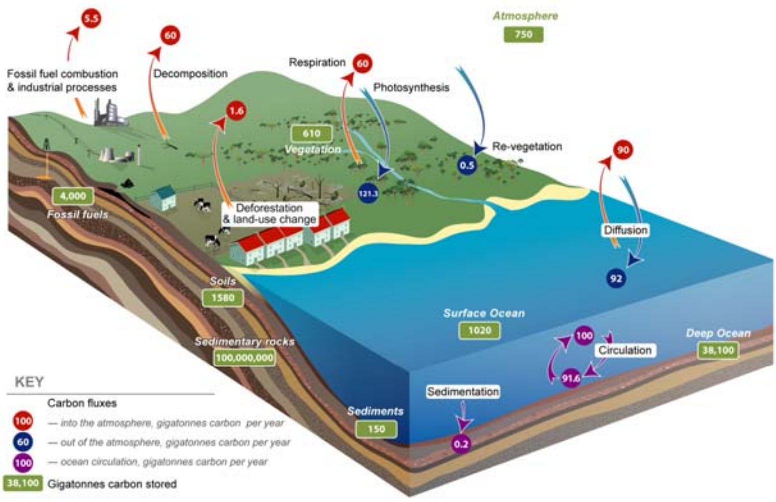


EG5066 Energy Technologies: current issues & future directions



EG5066 Energy Technologies: current issues & future directions

Carbon Capture and Storage

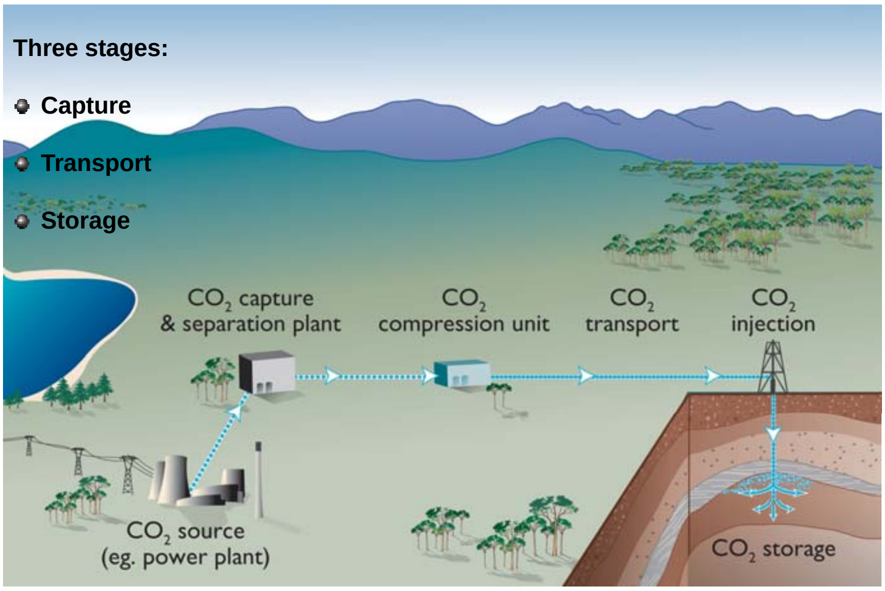


Source: CO2CRC

Carbon Capture and Storage

- Term mainly used to describe capturing CO_2 from flue gas emissions and storing it in geological structures or the oceans
- Can also be used to describe biological processes which **sequester** CO_2 through photosynthesis – trees, plankton, algae
- Another potential method is via burying biochar
- Where biological processes are utilised the S in CCS refers to **carbon sequestration** rather than storage

Carbon Capture and Storage



Source: CO2CRC

Suitable CO_2 sources for Capture

- Large stationary point source
- High CO_2 concentration in the waste, flue gas or by-product stream (purity)
- Pressure of CO_2 stream
- Distance from suitable storage sites

Global large stationary CO_2 sources with emissions of more than 0.1 $MtCO_2$/ year

Process		Number of sources	Emissions ($MtCO_2\ yr^{-1}$)
Fossil fuels	Power	4,942	10,539
	Cement production	1,175	932
	Refineries	638	798
	Iron & steel industry	269	646
	Petrochemical industry	470	379
	Oil & gas processing	Not available	50
	Other sources	90	33
Biomass	Bioethanol & bioenergy	303	91
Total		**7,887**	**13,466**

Future CO_2 Sources

CCS

Global CO_2 emissions rising – projected to range from

- 2020 29 – 44 $GtCO_2$
- 2050 23 – 84 $GtCO_2$

Technical potential of CO_2 capture estimated at:

- 2020 2.6 – 4.9 $GtCO_2$ – around 10%
- 2050 4.7 – 37.5 $GtCO_2$ (20 – 40%)

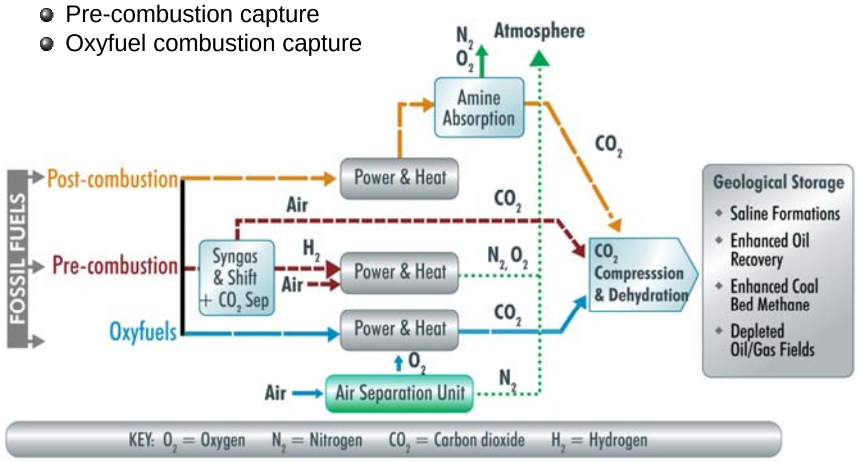
Source: IPCC

Carbon Capture Technologies

CCS

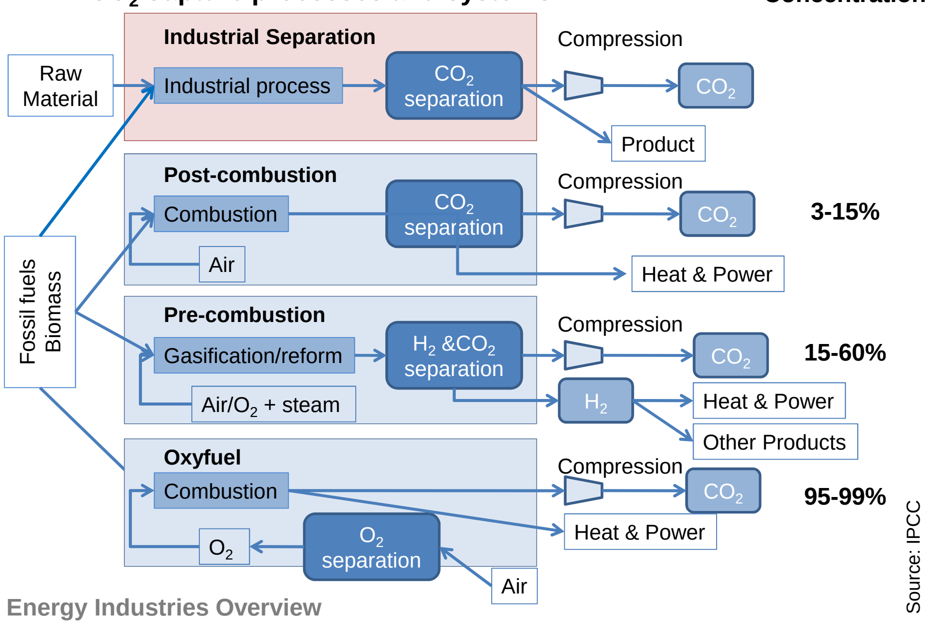
Three main technological solutions

- Post-combustion capture
- Pre-combustion capture
- Oxyfuel combustion capture



Carbon Capture & Storage

CO_2 Capture processes and systems



Maturity of capture technology

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Technology	Research	Demonstration	Economically feasible	Mature Market
Post-combustion			X	
Pre-combustion			X	
Oxyfuel combustion		X		
Industrial separation				X

Source: IPCC

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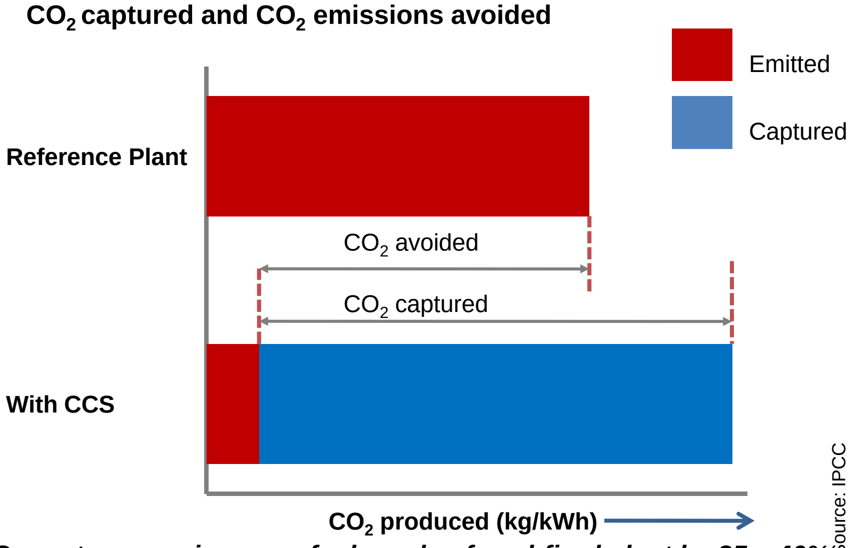
Carbon Capture & Storage

Difference between CO_2 captured and CO_2 emissions avoided



CO_2 capture may increase fuel needs of coal-fired plant by 25 – 40%

Energy Industries Overview

Post-Combustion Capture

CCS

Before CO_2 can be removed from flue gas first need to remove:

- Particles – electrostatic precipitator
- Contaminant gases such as SOx and NOx – flue gas desulpherisation

- Particle and contaminant free flue gas passed through chemical sorbent (amine-based) which absorbs CO_2
- Other methods – membranes or solid sorbents – not as efficient/cost effective

Post-Combustion Capture

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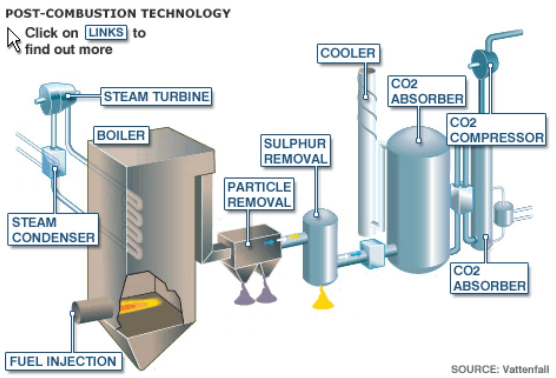


- Flue gas cooled & brought into contact with amine solution
- CO_2 bound to amine solution & transported to stripper
- Chemical reaction binding CO_2 with amine reversible
- Amine solution regenerated in scrubber
- Captured CO_2 compressed & dehydrated

Post-Combustion Capture

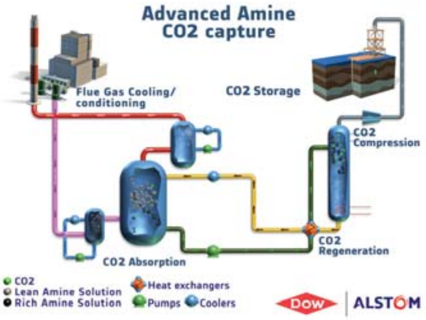
CCS

Pros:

- Feasible to retrofit to current industrial plants and power stations
- Existing technology - 60 years experience with amine solvents - but needs 10x scale-up.
- Currently in use to capture CO_2 for soft drinks industry.

Cons:

- High running costs – absorber and degraded solvents replacement.
- Limited large scale operating experience.



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Post-Combustion Capture

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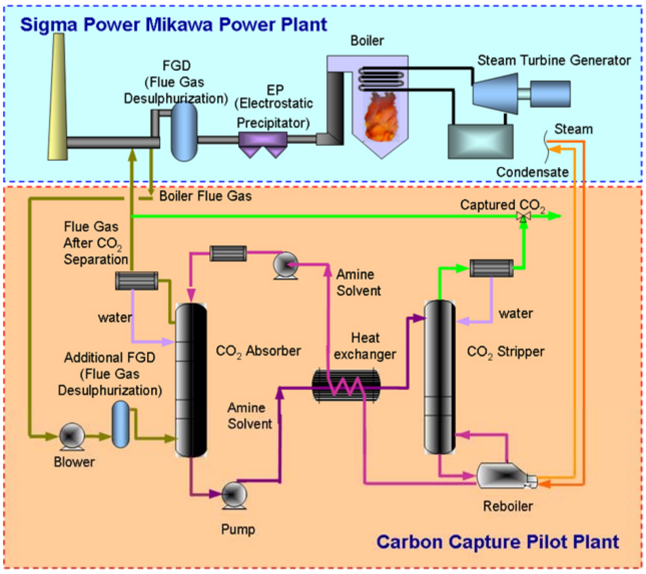

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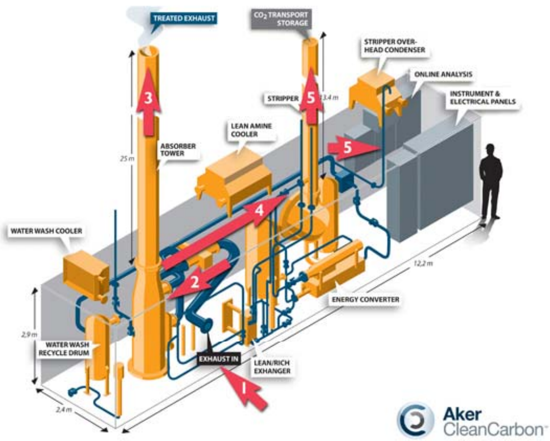
Carbon Capture & Storage

Post-Combustion Capture

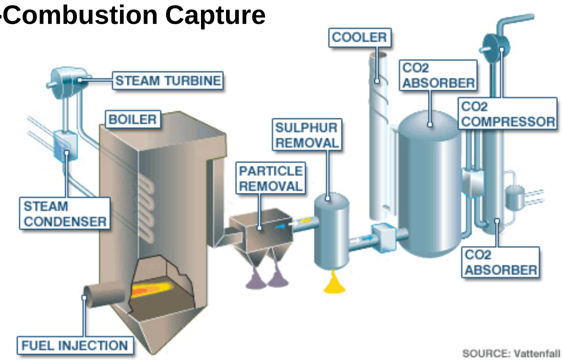
Scottish Power - Longannet



Energy Industries Overview

Carbon Capture & Storage

Post-Combustion Capture



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Energy Industries Overview

Carbon Capture & Storage

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CCS

Pre-combustion Capture

1st stage – to produce syngas (H_2 + CO)

Two routes:

Steam reforming – steam added to primary fuel

$$CxHy + xH_2O \leftrightarrow xCO + (x + y/2)H_2$$

Partial oxidation of gaseous fuels (gasification)

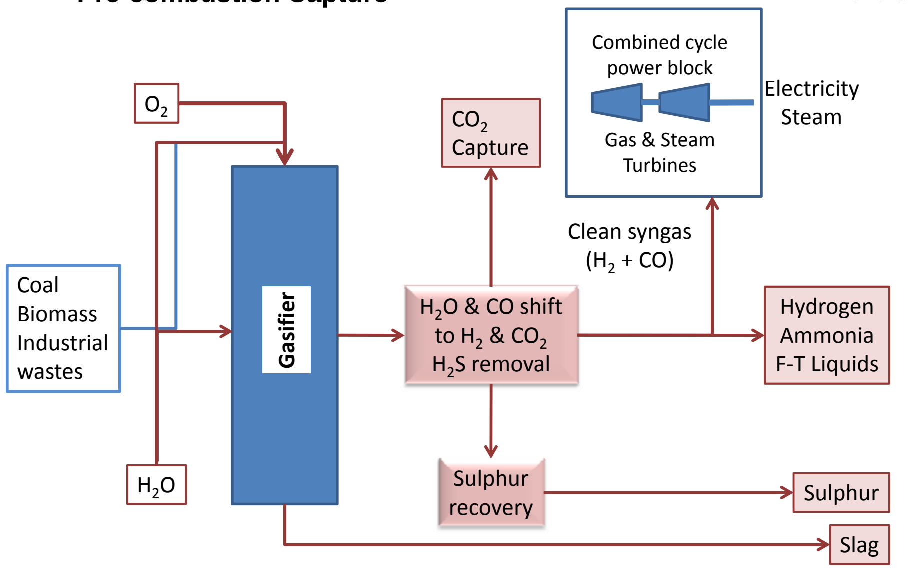
$$CxHy + x/2O_2 \leftrightarrow xCO + (y/2)H_2$$

2nd stage water gas shift reaction to convert the CO into CO_2

$$CO + H_2O \leftrightarrow CO_2 + H_2$$

Pre-combustion Capture

CCS



Pre-combustion Capture

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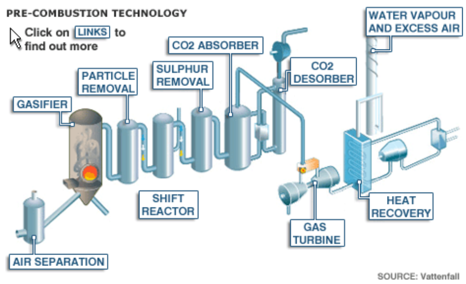


Pros:

- Proven industrial scale technology in oil refineries, but needs 3x scale-up for power plants.
- 90-95% of CO_2 emissions can be captured.
- Applicable to natural gas, and to coal fired IGCC power plants.
- Lowest technology risk, and may become the most efficient method.
- Can produce H_2 as transportable energy vector, or liquid fuels from coal - but penalties on efficiency

Cons:

- Requires a chemical plant in front of gas turbine
- High investment cost of dedicated new-build plant.
- High NOx emissions – will require expensive scrubbers.
- Efficiency of H_2 burning turbines is lower than conventional turbines.
- May be less flexible under varying electricity generation market requirement, so base load preferred

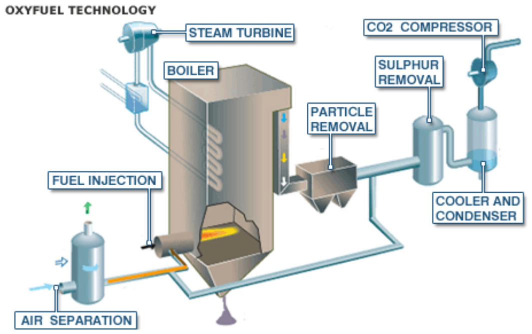
Oxyfuel Combustion Capture

CCS

- Eliminates nitrogen from the flue gas by combustion in pure oxygen or mixture of pure oxygen and flue gas so NOx production reduced
- Combustion temperature of fuel in pure oxygen is too high so temp controlled by proportion of process heat being recycled back to combustion chamber
- Combustion products mainly CO_2 + water vapour + O_2
- Combustion products cooled to condense water vapour giving 80 – 98% CO_2 depending on process & fuel
- Concentrated CO_2 compressed, dehydated, purified before transport & storage

Oxyfuel Combustion Capture

CCS



Pros

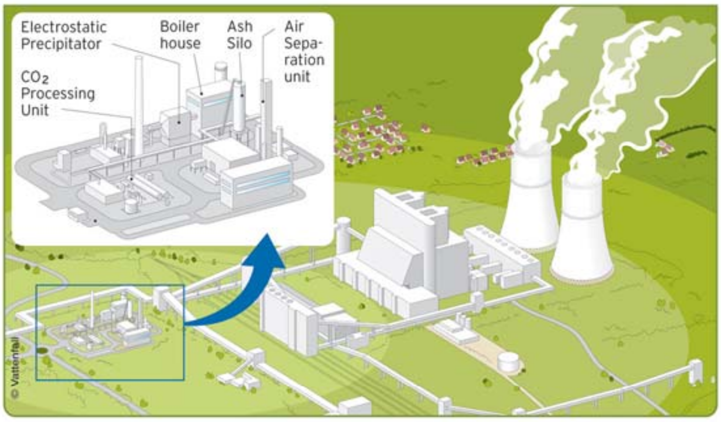
- Potential for 100% CO_2 capture.
- Few other harmful emissions due to more complete combustion.
- May be possible to retro-fit the oxy-fuel burners onto modified existing coal power plant

Cons

- High energy penalty without chemical looping combustion.
- Only at large development stage in 2007 - first Demonstration plants in planning

CCS

Oxyfuel Combustion Capture



Vattenfall demonstration plant - Schwarze Pumpe in Germany

- 30MW oxyfuel pilot plant attached to 1600MW lignite-fuelled power plant
- 90% CO_2 capture rate

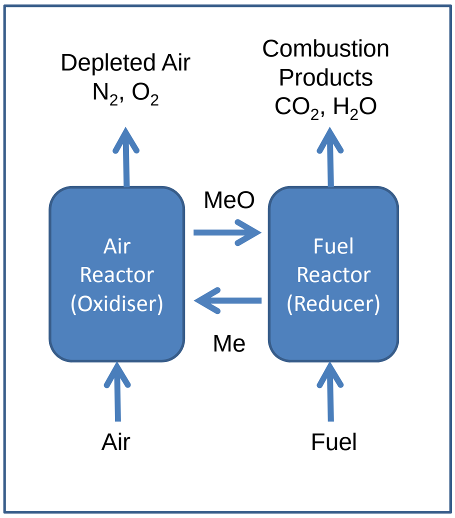
CCS

Chemical Looping Combustion

2 stage reaction of hydrocarbon combustion in 2 separate reactors:
- Air (oxidiser) Reactor
- Fuel (reducer) Reactor

*Fuel burns in reducer therefore does not come into contact with air and avoids need for post-combustion capture

Uses metal oxide as a hydrogen carrier
- Metal particles reacted with air to give metal oxide
- Metal oxide particles react with fuel on fluidised bed reactor to produce:
  - Metal particles
  - CO_2 and water vapour
- Water vapour condensed leaving pure CO_2



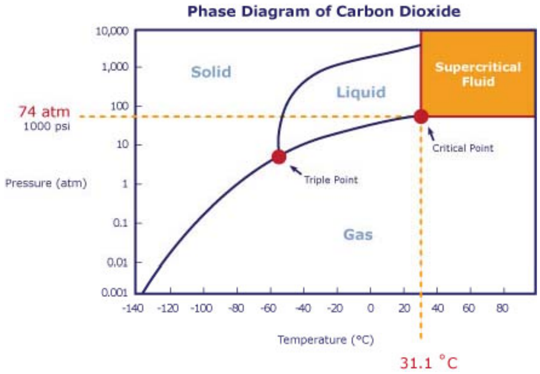
Transport

CCS

The main complication with CO_2 transport is that CO_2 behaves differently under varying pressures and temperatures and therefore transport of CO_2 must be carefully controlled to prevent solidification and blockages occurring.

At temperatures & pressures higher than the critical point CO_2 is in a supercritical state where it behaves as a gas but has a very high density similar to that of water

- Pressure - 74 bar
- Temperature - 31°C



Two main methods:

- Pipeline
- Ship

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Transport by pipeline

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- Common in USA – in 2008 there were some 5800km of CO_2 pipelines used since 1970s for EOR projects
- Designed for supercritical/dense phase CO_2 transport.
- Avoids solidification of the CO_2 and to be pumped as a liquid.
- Pressures are kept above 10 MPa
- CO_2 must be dried before transportation because:
  - CO_2 dissolved in water creates an acidic solution that attacks metal pipelines.
  - CO_2 hydrate crystals can form when CO_2 and water mix causing pipeline blockages

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Ship Transport

- Limited to food & brewing industry – 100, 000 tonnes/y
- Similar to Liquefied Petroleum Gas (LPG)
- Liquid CO_2 at -25 to -35^oC; pressures of 1.4 to 1.7 Mpa
- Carry 850 to 1,400 t CO_2
- Need more carrying capacity to make difference

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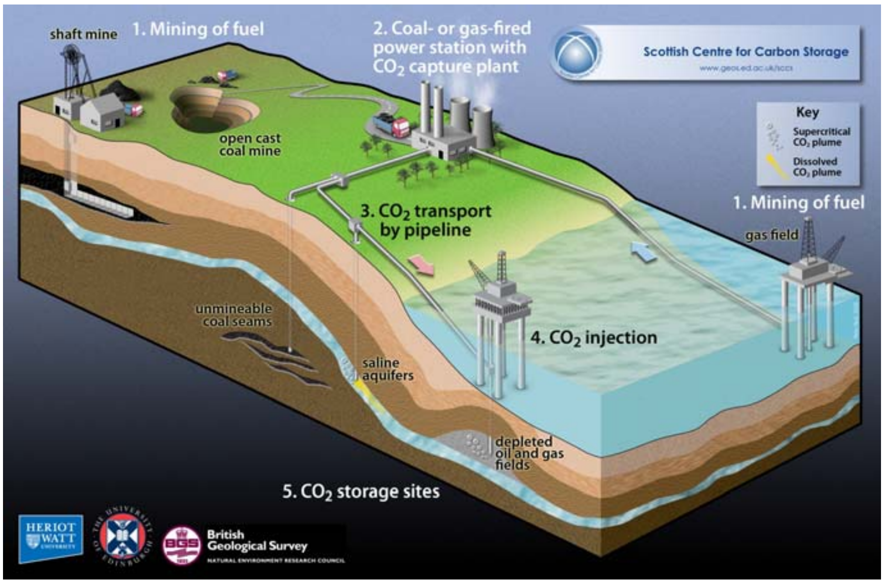

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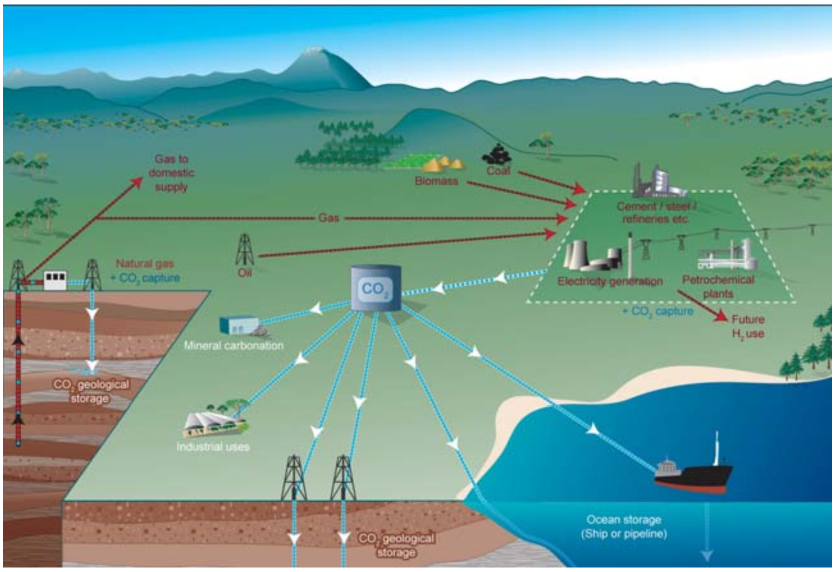

Source: CO2CRC

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Storage

Geological

- Geological storage capacity at least 2,000 $GtCO_2$ mainly in oil and gas fields and in formations bearing saline water
- Upper limit uncertain, especially in saline formations
- Specific site characteristics need closer evaluation
- CO_2 injection and reservoir engineering technology for depleted oil & gas fields and saline formations is mature and available
- Monitoring of subsurface movement of CO_2 is being successfully conducted at several sites

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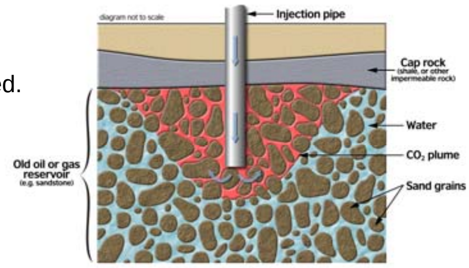
Carbon Capture & Storage

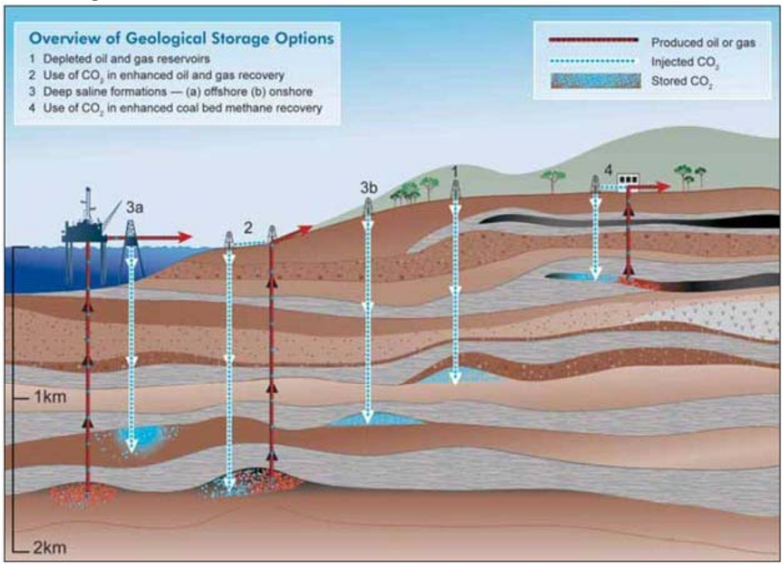
Basic Criteria for CO_2 Geological Storage Site

- Reservoir – good porosity and permeability. Usually sandstone but can be carbonate
- Seal/caprock – low permeability, low porosity, preferably unfractured. Usually a salt of shale
- Structural closure (although not essential)
- Formation below 800m – CO_2 exists in its dense phase
- Geologically stable area



Carbon Capture & Storage

Storage



Source: IPCC

Storage

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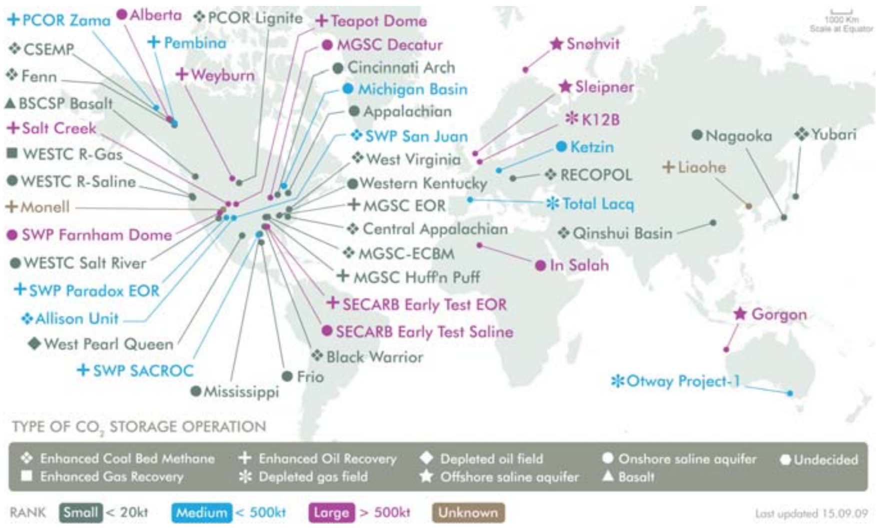

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Examples of CCS Projects

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Project name	Country	Injection start (year)	Approximate average daily injection rate (tCO_2 day^{-1})	Total (planned) storage (tCO_2)	Storage reservoir type
Weyburn	Canada	2000	3,000-5,000	40,000,000	EOR
In Salah	Algeria	2004	3,000-4,000	17,000,000	Gas field
Sleipner	Norway	1996	3,000	20,000,000	Saline formation
Snøhvit	Norway	2006	2,000	unknown	Saline formation

Note all separating CO_2 from natural gas or lignite-fired gasifier (Weyburn)

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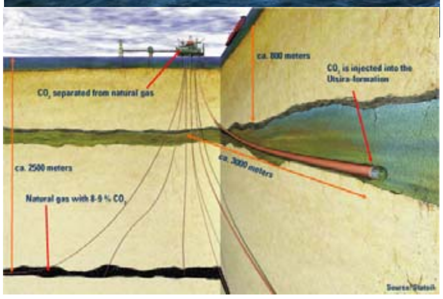
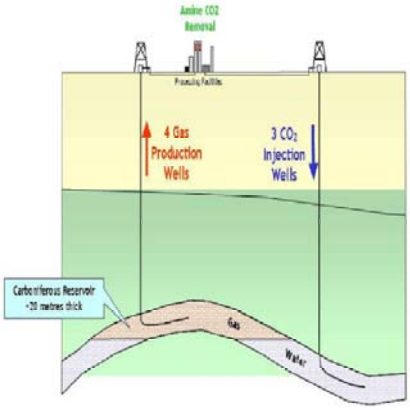
Sleipner - Norway



Krechba gas production plant - Algeria



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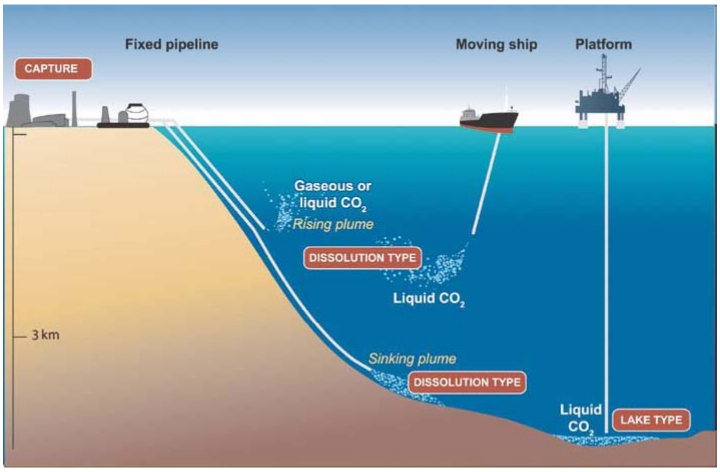
Storage - Ocean

Ocean Storage – proposed solution but it will make them more acidic and now no longer consider viable



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Biochar

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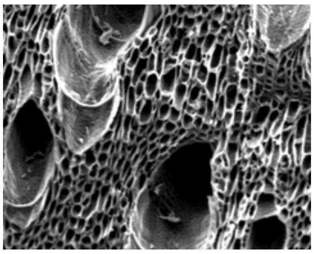
- Carbon-rich product of thermal decomposition of biomass under limited oxygen supply and relatively low temperatures (<700ºC)
- Similar to charcoal, but produced to improve soil productivity and C storage
- Can sequester carbon in soil for hundreds of thousands of years
- Promoted by James Hansen & James Lovelock to mitigate GHG emissions

- Pre-Columbian Amazonian Natives used biochar to enhance soil productivity – so-called *Terra Preta de indio*
- Used a pit or trench method to produce biochar resulting in *terra preta* or dark soil

Biochar - characteristics

CCS

- High carbon content (60 – 95% C)
- Resistant to biodegradation
- Significant adsorptive qualities (similar to activated carbon)
- Nutrients (& contaminants) essentially lock on to the structure
- Increases moisture holding capacity
- Enhances microbial biomass



Biochar - production

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- Original method was to produce a soil additive in the pit or trench method
- Modern method involves pyrolysis:
- Fast pyrolysis (seconds) yields 60% bio-oil; 20% char, 20% syngas
- Slow pyrolysis (hours) gives ~50% char – uses the syngas as fuel
- The lower the temperature the more biochar produced

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Biochar - production

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As temperature increases:

- Biochar yield decreases
- Fixed carbon increases
- Surface area increases
- Ash content increases

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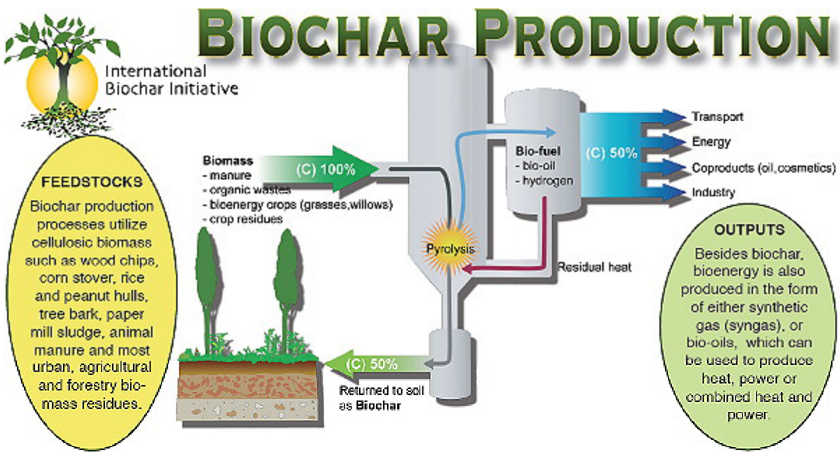

Carbon Capture and Storage