Carbon Capture, Use and Storage (CCUS)

Briefing for Bernard Looney, July 24th 2018

Pre-read

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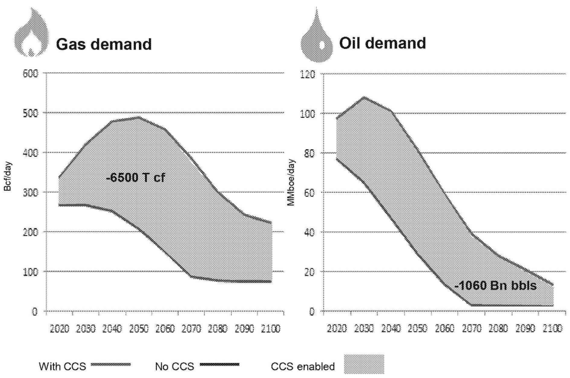
Contents

Meeting objective is to provide a briefing on CCUS, an overview of BP's high graded CCUS projects and discuss the role of Upstream

CCUS is critical for BP (and the world)

Intergovernmental Panel on Climate Change (IPCC) modelled global demand for oil and gas with and without CCUS in a 2DS. The results illustrate the important role of CCUS in decarbonising power infrastructure and energy-intensive industries that rely on the use of fossil fuels.



Source: BP Internal Analysis of 3 models from the AR5 Scenario Database for a 2DS, 2016

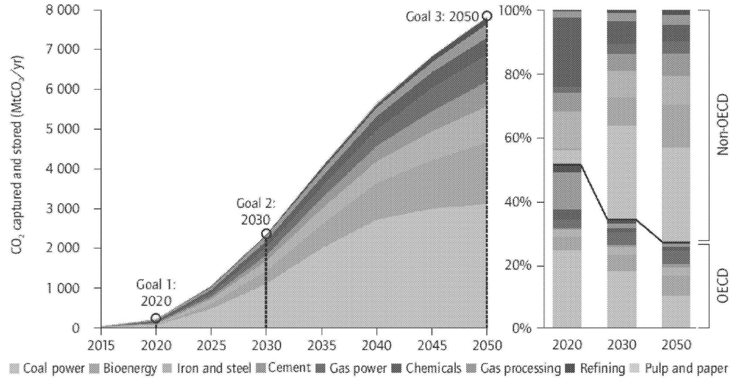
CCUS can play a critical role in...

1. Securing oil and gas assets while meeting climate change targets
2. Enabling more oil and gas over the energy transition for a given carbon budget
3. Cutting emissions, supporting license to operate
4. Pioneering BP R&D and implementation
5. Decarbonizing gas use across Upstream and Downstream
6. Complementing other BP low carbon offers and underpinning the dual energy challenge

With current fossil fuel consumption in 2015 of 8 Bn tce coal, 122.5 Tcf gas, and 35 Bn bbls oil, CCUS deployment until the end of the century in a 2 deg C enables 21 years (170 Bn tce) of continued current consumption levels of coal, 59 years (7200 Tcf) for gas, and 29 years (1040 Bn bbls) for oil. This shows the stark importance of CCUS to securing future gas demand in strict carbon and climate scenarios.
Data from the IEA ETP 2016 2°C (2DS) scenario also shows that CCS is very versatile and can be used not only on power but also in carbon-intensive industries including steel and cement that have few low carbon options aside from CCS, as well as other applications and uses
Within the CCS on power application, the same scenario showed, as a percentage of electricity generation with CCS, 67% coal with CCS, 30% natural gas with CCS, and 3% biomass with CCS
CCUS can play a vital role in helping achieve the Paris Agreement goal of keeping temperature rise to well below 2ºC and balancing emissions sources and sinks.
According to the IEA (2017)1, CCUS will need to provide 14% of all global cumulative CO2 reductions by 2060 to meet the IEA's 2ºC (2DS) scenario, and one third of the incremental CO2 reductions in the IEA's Below 2ºC (B2DS) scenario.
The IPCC (2014)2 reported that 2ºC scenarios which use alternatives to CCUS would on average cost more than twice as much (138% increase).
Every year that passes without material policy action for CCUS increases the risk of not delivering the goals, and the cost of trying to meet them.
A study by the CCS Association quantifying the value of CCUS to society suggested a five-fold return on investment to the UK economy (creation or retention of skilled jobs, avoided emissions costs, environmental benefits, and balance of trade addition).
Long-term growth of gas is partially enabled through CCUS on gas power and heat.
Wide scale CCUS deployment could leave more of the 'carbon budget' available for the use of oil for transportation where there are fewer, viable low carbon substitutes.

Large scale CCUS is essential to meet global climate goals

CCUS deployment to meet 2DS[1]

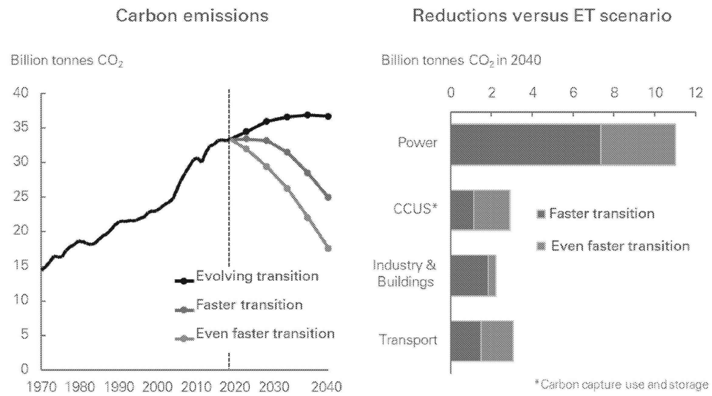


- 120 $GtCO_2$ are captured and stored by 2050 to meet 2DS[1]
- Similar infrastructure build-out to natural gas[2]
- Over 70% of all CCUS takes place in non-OECD countries by 2050[1]
- 1 GW coal-fired power plant generates c. 6$MtCO_2$/yr (equivalent of 165,000 rbpd or 2.4Blnrbbls over 40 years)[3]
- Gas-fired power plants have roughly half the CO_2 emissions per GW

Sources: [1]*IEA Technology Roadmap – Carbon Capture and Storage, 2013 (note: IEA ETP 2015 used later which has a lower CCUS goal of 6$GtCO_2$/yr by 2050)*
[2]*Shell, OGCI CCS Workstream meeting, 2016*
[3]*Team analysis, 6$MtCO_2$=310mmscfdCO_2 at downhole supercritical conditions (>800m depth)*

Notes: *rb = reservoir barrels (at downhole P, T conditions)*
Natural Gas production currently at 2.5 Gt/yr
Goal 3, 2050 = 8 Gt/CO_2/yr CCUS including 950GW power (comprising 8% of total global power capacity and 2/3 coal and 1/5 gas with CCUS)

The BP Energy Outlook 2018 considers a range of scenarios and includes large scale deployment of CCUS in the ET and EFT scenarios



Source: BP Energy Outlook, 2018

CCUS is a critical tool for meeting the Paris Climate Agreement goals at lowest cost because it enables decarbonisation of existing energy and industrial infrastructure

What is CCUS?

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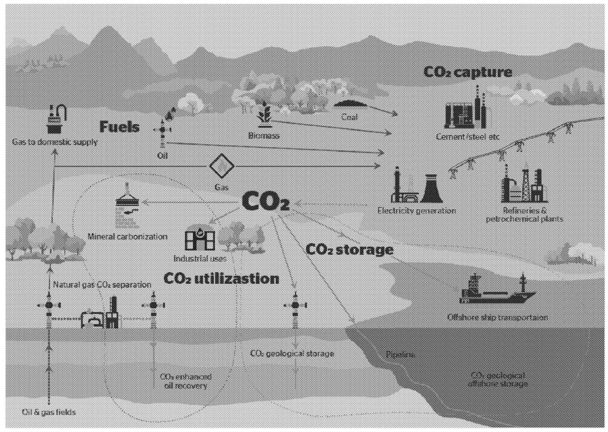
CCUS is a suite of technologies that need integration and scale up



CCUS relies on a combination of technologies – components are proven, reliable and ready – but scale-up needs to be accelerated. Capturing purer sources of CO_2 and using this in certain applications is economically viable today, e.g. in CO_2 EOR

CO2 capture from any fossil fuel or biomass combustion or industrial processes, is commercially available from technology licensors for all applications
Transport by pipeline, ship and road all commercially practiced
CO2 storage has been demonstrated in saline formations and incidental storage with CO2 EOR is commercially practiced
CO2 conversion and utilisation is commercially practiced for urea and methanol
Key integrated CO2 capture applications:
Coal-fired power generation – demonstrated at Boundary Dam and Petra-Nova
Gas-fired power generation – demonstrated at Bellingham

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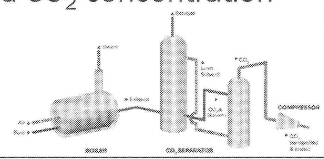
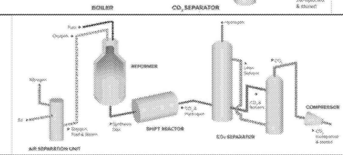
Capture accounts for 80% of the cost of CCUS with large heat and power consumption that varies with scale and CO_2 concentration

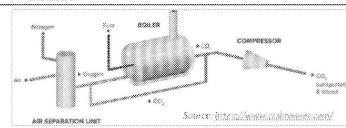
Post-Combustion Capture:
CO_2 is separated from the exhaust gases after combustion.
Low pressure, therefore large equipment,
However, often the lowest cost route to get high CO_2 capture rates.



Pre-Combustion Capture:
Fuel is chemically reformed to hydrogen
CO_2 extracted from the reformed product
Hydrogen then used as fuel, yielding water as exhaust
Capture system is at pressure so can be low cost
Interesting for refineries with hydrogen production

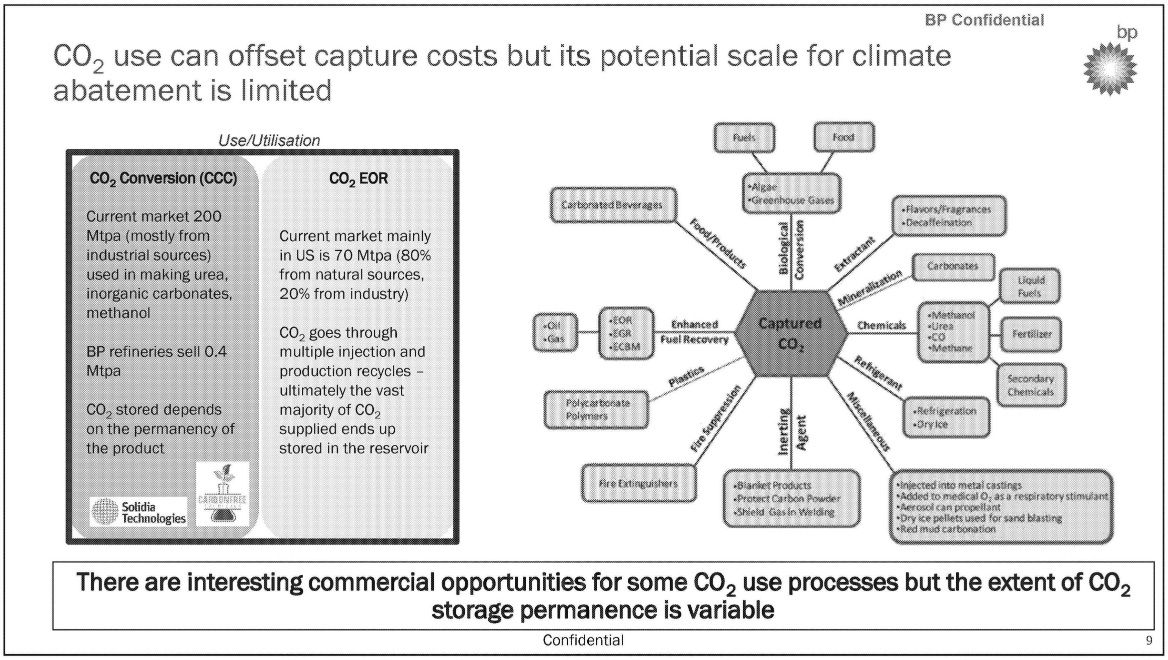


Oxyfuel Capture:
Air is separated to oxygen and nitrogen
Fuel is burnt in pure oxygen, meaning CO_2 need only be separated from water in the exhaust
Presents high costs and high electrical demand due to need for air separation unit.



New technologies promise cost improvements that could substantially increase deployment

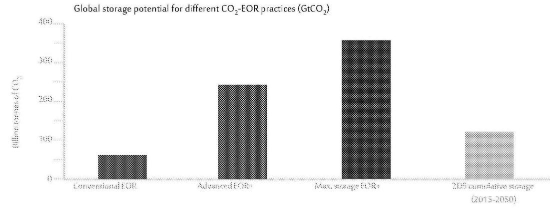
Proven capture technology is available for different CO2 sources but energy penalty & cost with existing technology is high
Capture accounts for ca 80% of the cost of CCS, with large heat and power consumption that varies with scale and CO2 concentration of the source.
Capex:Opex is ca 50:50 which results in significant economies of scale – the maximum train size of absorbers is approaching power station scale
Capture fuel (energy penalty) is split ca 50:50 for solvent regeneration and CO2 compression
The largest sources of CO2 typically have the lowest cost of capture
Most of the CO2 emissions from BP operations would have high capture cost (at least double the cost of capture from power stations)
In natural gas processing, CO2 can be captured from contaminated gas
For post-combustion processes (preferred for most applications including power generation) CO2 can be captured by chemical (amine) solvent. Post-combustion has been demonstrated on gas and coal-fired power
In the last decade, chemical absorption by aqueous amine solvent has progressed with the innovation of new amines which lower energy consumption and have less tendency to degrade and cause corrosion
Many new technologies have been proposed and evaluated experimentally – some have not lived up to promise, but there are candidates with potential to deliver significant performance improvement and cost reduction
Capture is proven but integrated demos are needed to build confidence and new technologies are promising cost improvements
Improvements in CO2 capture technology (with lower energy requirements and lower cost) could substantially improve the competitiveness of CCS

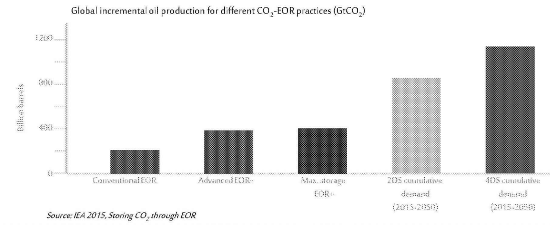


Other forms of CO2 use (materials, chemicals, fuels) are emerging …but CO2 storage is not always long-term.
Cost effective availability of low carbon/renewable hydrogen is likely to be a constraint on industrial scale deployment of many CO2 conversion technologies
However, limited opportunities might exist in;
CO2 to plastics (Bayer DREAM process)
Mineral carbonation of industrial waste
CO2 replacing H2O as a hydraulic fracturing fluid in water stressed regions
Other CO2 conversion processes may need substantial state subsidy and/or technology breakthrough
Some CO2 conversion processes may use excess/’free’ energy from renewables sources to effectively store energy through conversion processes

CO_2 EOR has potential to play a bigger role, especially if a value is attributed to CO_2 storage

- The U.S. accounts for >90% of global CO_2 EOR production (~340 mstb/d) with 136 active CO_2 EOR projects injecting 3.5 Bscf/d (68 Mte/y)
- Changes in CO_2 EOR operations and technology can result in more CO_2 storage
  - Inject less water and more CO_2
  - Optimize well design and placement
  - Improve the mobility ratio (e.g. conformance control such as BP Jupiter)
  - Extend the miscibility range (e.g. solvents, surfactants)





Source: IEA 2015, Storing CO_2 through EOR

Incentives to store CO_2 (e.g. new US 45Q tax credit) can lead to additional CO_2 storage AND additional oil production. Opportunity exists for a CO_2 EOR+ technology access offer

CO2 EOR established itself in a few onshore US basins in the 1970-90's but ran out of low cost natural CO2. The emergence of CCUS gives an opportunity to expand and deploy in other regions.

The U.S. accounts for >90% of global CO2 EOR production (~340 mstb/d) with 136 active CO2 EOR projects injecting 3.5 Bscf/d (68 Mte/y).
Demand is linked to oil price – peak in start-ups prior to 1986 and 1998 oil price shocks, but since 2005, CO2 demand outpaced supply
80% of the CO2 is from natural sources, remaining 20% from industrial sources (gas processing plant, H2 and N2 plant, chemical, power and other plant)

Practice will change and technologies will emerge given a value associated with CO2 storage:
Inject less water and more CO2
Optimize well design and placement
Improve the mobility ratio (e.g. conformance control such as BP Jupiter)
Extend the miscibility range (e.g. solvents, surfactants)
Leading to improved economics, and an increase in EOR and storage volumes
Increasing the volume of CO2 injected into the oil reservoir: this involves increasing CO2 injection volumes from 1.0 hydrocarbon pore volume (HCPV), currently used in "state-of-the-art", to 1.5 HCPV. Higher HCPV's of injected CO2 enable more of the reservoir's residual oil to be contacted (and even multiple contacted) by the injected CO2.
Optimizing well design and placement: this includes adding infill wells to achieve increased contact between the injected CO2 and the oil reservoir and using physical or chemical diversion materials to divert CO2 into previously poorly contacted portions of the reservoir.
Improving the mobility ratio between the injected CO2/water and the residual oil: this assumes an increase in the viscosity of the injected water as part of the CO2-WAG process (increasing the viscosity of CO2 with CO2-philic agents could theoretically further improve performance) . The viscosity of the injected water can be changed by adding polymers or other viscosity enhancing materials.
Extending the miscibility range: this helps more reservoirs achieve higher oil recovery efficiency. It assumes that "miscibility extenders" are added to CO2-EOR process that reduce minimum miscibility pressure requirements and use of other (to be developed) miscibility pressure or interfacial tension reduction agents.

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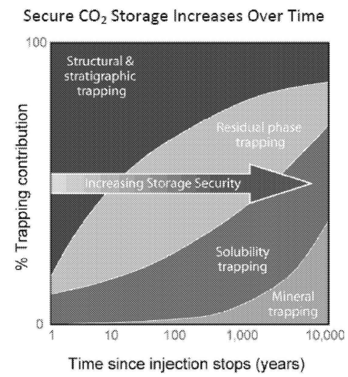
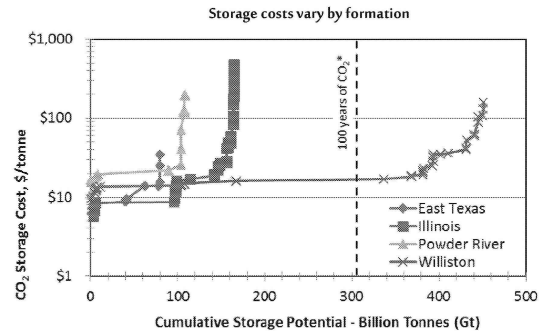
CO_2 storage has sufficient technical capacity and multiple mechanisms to ensure security, but there are regional techno-economic constraints



Source: Sally Benson, Stanford University, 2008



*90% capture of CO_2 emissions from U.S. electric power and industrial sectors

Source: US NETL, Quality Guidelines for Energy System Studies: Carbon Dioxide Transport and Storage Costs in NETL Studies, 2014

Improvements in CO_2 storage technology can improve storage performance but securing the best geology is fundamentally important to storage economics

CO2 geological storage has sufficient security and scale potential to make a material contribution to climate goals…but storage resources are not uniformly distributed, uncertainty remains in some key areas, and little is being done to de-risk.

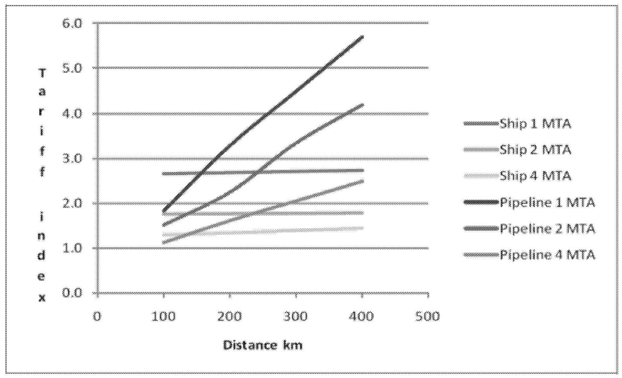
Storage security increases over time but operational and lengthy post closure monitoring, measurement and verification (MMV) is required to satisfy regulators
Sufficient storage capacity is available at global scale for CCS to make material contribution to emissions reductions
Site access, risks, injection rates and costs have to be taken into account to progress from resource to reserves
Initial injection rates and pressure dissipation are key cost uncertainties that require either:
proactive site characterization (stratigraphic wells and well testing), and/or
reactive operational management (stimulation, injection wells, water production)

Transport and storage cost can be optimized at scale

Compressed CO2 is transported by pipeline – cost is proportional to length (ca 1.5 M$/km)
The cost and economies of scale for CO2 storage are formation specific
There is a technology dimension to optimising storage economics, but there is no substitute for accessing the best geology
If CO2 is used for EOR then CO2 value can help offset CO2 supply costs, and in some cases can achieve an economic value chain

Shipping may have a material role in some regions, whereas elsewhere new CO_2 pipeline infrastructure will be required

- Small scale CO_2 shipping (ca 2kte) in operation today for food/beverage. Larger scale ship design (ca 40-80kte) is available
- EU, US and Japan have looked at return cargo options – LPG out, CO_2 return
- Source/sink flexibility, operational expense, and re-use are key advantages, but does require some buffer storage at hubs
- ~4000 miles of CO_2 pipeline operational in the onshore L48; ~ 810 miles of CO_2 pipeline operation in Europe
- Good operational safety record
- Requires large capital investment but networks and re-use can save considerable cost



Source: GCCSI CO_2 Liquid Logistics Shipping Concept, 2011

CO_2 transportation infrastructure is needed to link sources with sinks

CCUS Policy Support

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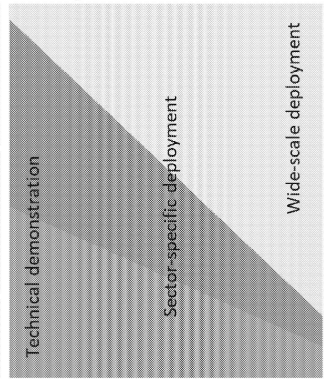
A range of CCUS policy options and incentives exist, varying in type/scale over the demonstration to deployment period

Objective	Example
Reducing emissions	Cap & trade Carbon tax Baseline and credit Feebate Emission performance standard CO_2 purchase contract
Technology learning	Capital grant Production subsidy Investment tax credit Production tax credit Feed-in tariff Premium feed-in tariff Portfolio standard
Access to capital markets	Co-investment equity Provision of debt Credit guarantees Insurance products

Importance over time

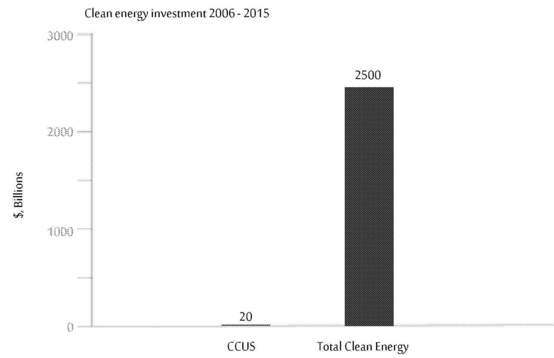


An ambitious and collaborative approach is required to enable wide-scale CCUS deployment, and should include targeted transitional incentives prior to a carbon price

A robust carbon price is needed to stimulate CCUS deployment
Until the carbon price is high enough, transitional incentives are required to underpin investment
A variety of policy instruments are being considered, from performance standards, to Feed in Tariffs, to CCUS mandates (e.g. no new coal without CCUS)
CCUS will not happen without government policy support
Perhaps the appetite for significant policy support for CCUS is reducing, since it supports continued use of fossil fuels?

CCUS interest and policy varies between regions.
Interested countries appear to be USA, Canada, Norway, Europe, China, Australia and Middle East
10 Countries list CCUS as part of their Intended National Determined Commitments (INDC's)
There is limited interest in CCUS from other countries but then CCUS is not applicable everywhere
Policy focus is mainly R, D&D - pilot and demonstration projects have been implemented in some interested countries
Regulatory framework for storage has been developed in North America and Europe and ISO is underway for CCUS

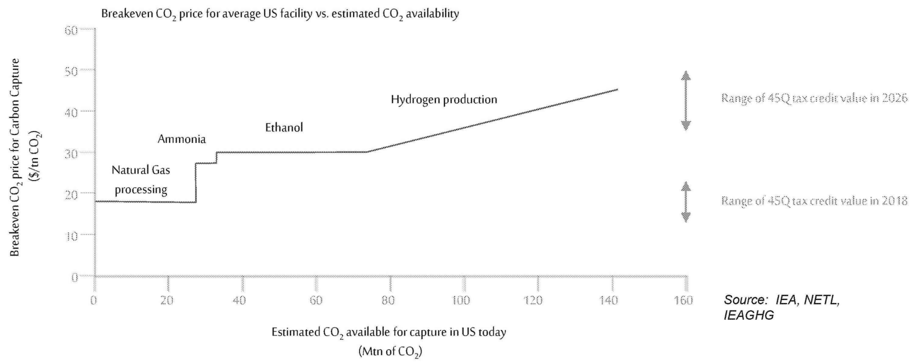
Policy parity with incentives provided to other forms of low carbon energy is now being considered



Sources:
GCCSI, 2016
Clean energy data sourced from Bloomberg New Energy Finance, 2016. Clean Energy Investment by the numbers – End of Year 2015
CCS data sourced from IEA, 2015. Tracking Clean Energy Progress 2015 Energy Technology Perspectives 2015 Excerpt IEA Input to the Clean Energy Ministerial, Paris. OECD/IEA

Significant targeted policy support has already been afforded to other low carbon energy technologies to achieve cost reductions

US IRS Enhanced 45Q tax credit will enable commercial application of CCUS to non-power sectors



Source: IEA, NETL, IEAGHG

Source: IEA, 2018 https://www.iea.org/newsroom/news/2018/march/commentary-us-budget-bill-may-help-carbon-capture-get-back-on-track.html

Value and volume enhancement was passed into US law on 9th Feb 2018. Projects need to be in construction by January 1st 2024 to qualify and can claim for a 12 year duration

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Existing CCUS Projects

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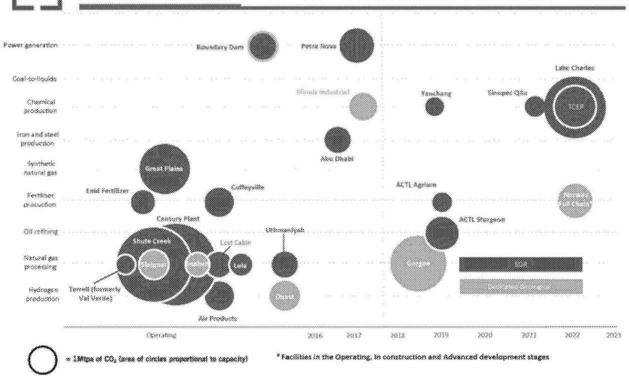
Despite its importance in meeting climate goals, commercial deployment of CCUS is very limited

LIMITED SUCCESS
- Focus on large, integrated projects
- Count on government incentives or regulations

PROVEN SUCCESS
- Stand-alone commercial cases facilitated by low capture cost and/or CO_2 sales
- Less frequently, license to operate or technology development pre-investment

ENABLERS (not drivers of success)
- Partnerships, when they pull together key operational experience
- Government incentives/regulations

Actual and expected operation dates up to 2022 for large-scale CCS facilities by industry and storage type#



* Assessing CCS possibilities from ammonia production, from cement production and from waste-to-energy sources

To date only 0.5% has been deployed of the total amount projected to 2050 in the IEA 2DS Scenario. No projects are currently associated with natural gas power generation

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CCUS industry is in its infancy, to date only 0.5% has been deployed of the total amount projected to 2050 in the IEA 2DS Scenario
Currently there are 18 active large scale integrated CCUS projects around the world that capture and store a total of 32 Mtpa CO2.
17 are operational and 1 is in post injection closure.
An additional four are in construction and 21 in planning.
The oil and gas industry participates in 17 projects.
9 active projects involve CO2 capture from natural gas processing.
13 operational projects have CO2 use and storage with Enhanced Oil Recovery (EOR).
Only two active projects are related to power generation, both coal.
15 are onshore, with 11 in North America and 3 in the Middle East and North Africa.
3 are offshore, with 2 in Norway and 1 in Brazil (deepwater).
By comparison in 2010 there were 8 large scale CCUS projects in operation capturing and storing 23 Mtpa CO2, but a total of 69 in planning.
The slowdown in progress since 2010 can be attributed to lack of adequate policy support, significant upfront capital investment needs, power sector fuel switching to cleaner natural gas, and specific incentives underpinning the growth of renewables and associated cost reductions.

BP's CCUS activity was middle of the pack but leadership is in reach

Company	Activity Summary	Technology Development	Projects Development	Policy & Regs Development	New Business Development
Statoil	- Historically very active; operational leader - Ramping up in adding R&D and new projects	Some evidence	Clear leader	High evidence	High evidence
	- Historically most active, especially in project development, but many false starts - Most active in publishing on CCUS - Expanding low-carbon investment portfolio	Some evidence	High evidence	Clear leader	High evidence
Exxon	- Technology R&D leader - Consistent approach, but doesn't collaborate - Aggressive marketing of CCUS technology	Clear leader	High evidence	Some evidence	Some evidence
bp	- Track record of support and engagement - Operational experience through JVs - Ramping up with a diverse project portfolio and multi-functional staff capability	Some evidence	Some evidence	Some evidence	Some evidence
TOTAL	- Ramping up from previously being a passive supporter - Pursuing projects and internal R&D	Some evidence	Some evidence	Some evidence	Some evidence
OXY	- EOR operator seeking to protect and grow business - Only CCUS involvement is regulatory, advocacy	Low/no evidence	High evidence	Some evidence	Some evidence
Chevron	- Scaled back CCUS engagement, now a quiet supporter - Gaining execution expertise with Gorgon	Low/no evidence	Some evidence	Some evidence	Low/no evidence
eni	- Generally a non-player in the CCUS space - Current involvement limited to OGCI	Low/no evidence	Low/no evidence	Low/no evidence	Low/no evidence

Legend

All ratings are relative and based on an external viewpoint

- ★ Clear leader
- ● High evidence
- ● Some evidence
- ● Low/no evidence

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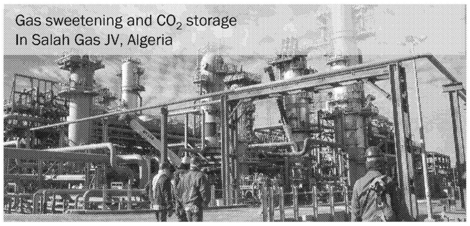
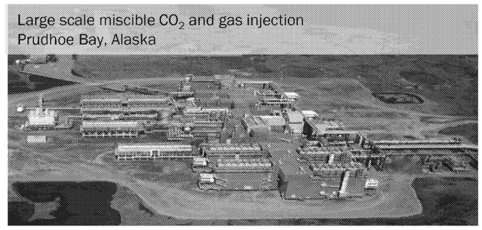
BP has operational experience in CCUS

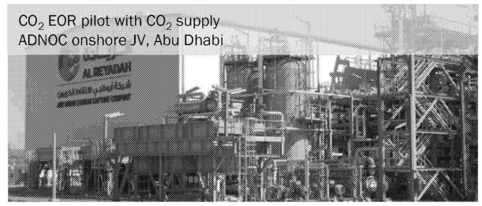


Gas sweetening and CO_2 storage
In Salah Gas JV, Algeria



Large scale miscible CO_2 and gas injection
Prudhoe Bay, Alaska

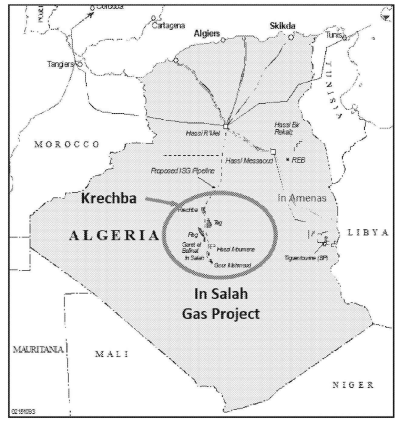
CO_2 capture technology pilots and demos
CO_2 Capture Project, Global



CO_2 EOR pilot with CO_2 supply
ADNOC onshore JV, Abu Dhabi

BP has experience across the CCUS full project life cycle at In Salah

- Industrial scale demonstration of CCUS operated by the In Salah Gas JV
  - Gas processing to reduce CO_2 to gas contract spec
  - Industry standard amine CO_2 removal technology
- ~3.7Mt CO_2 stored via three horizontal wells at Krechba
- No CCUS policy or regulation in place and no commercial incentives/support received
- CO_2 injection operations from 2004 to 2011:
  - CO_2 safely stored, notwithstanding technically challenging reservoir conditions
  - Injection features seen on 2009 seismic in deep overburden and injection stopped to investigate



Experience highlights the importance of performance based regulation, and application of well and reservoir operating limits

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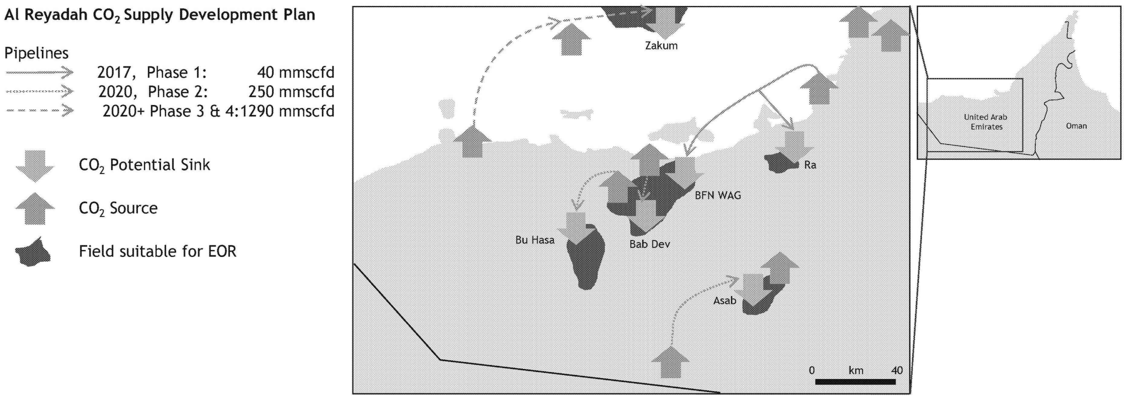
We are currently gaining additional CO_2 supply and EOR insight in ADNOC onshore



BP as asset leader for Bab has a role to evaluate commercial options that expand CO_2 supply for EOR from an existing pilot (Phase 1) to future large scale deployment (Phase 2)

BP is working collaboratively to leverage investment, with CCUS activity focused on commercialisation, storage and investments

OIL AND GAS CLIMATE INITIATIVE

A coalition of 10 companies:
BP, CNPC, Eni, Pemex, Petrobras, Repsol, Saudi Aramco, Shell, Statoil, Total

$1 billion dollar investment over ten years

Focus by investment in:

- Carbon capture, use and storage (CCUS)
- Methane reduction emissions

Current investments:

- Clean Gas Project
- Solidia Technologies

CCUS activity in OGCI is now focused on policy and value, storage and investments, and has already delivered a number of catalyzing activities:

Policy & Value Working Group:
Completed the Value of CCUS in the UK paper, based on authoritative external sources.
Developed policy recommendations for scale-up of CCUS in the UK, including the separation of transport & storage policy from CO2 capture. OGCI have offered to convene a CO2 capture policy workshop with energy intensive industries.
The 2018 work plan includes development of value and policy proposals for the Netherlands, Middle East and China. In addition a new CCUS narrative and communications plan will be developed.
Storage Working Group:
OGCI is testing the newly agreed SPE Storage Resources Management System (SRMS) on four major aquifers and on a regional CO2 storage capacity assessment.
OGCI will contribute to technical guidelines for SRMS. It will also deliver a multi-faceted stakeholder map for CO2 storage in India to assist with decision making.
Climate Investment (CI) activity:
CI Clean Gas Project now focused on Teesside, UK, where a new gas power plant would co-locate with industrial emitters to broaden CO2 capture potential in alignment with UK Government ambitions. Transport and storage options are being evaluated. Ongoing work will further de-risk storage, develop business models and a commercial investment strategy.
OGCI company peer reviews planned for 24 – 26th January.
CI has invested in Solidia, a low CO2 cement technology.

BP's New CCUS Projects

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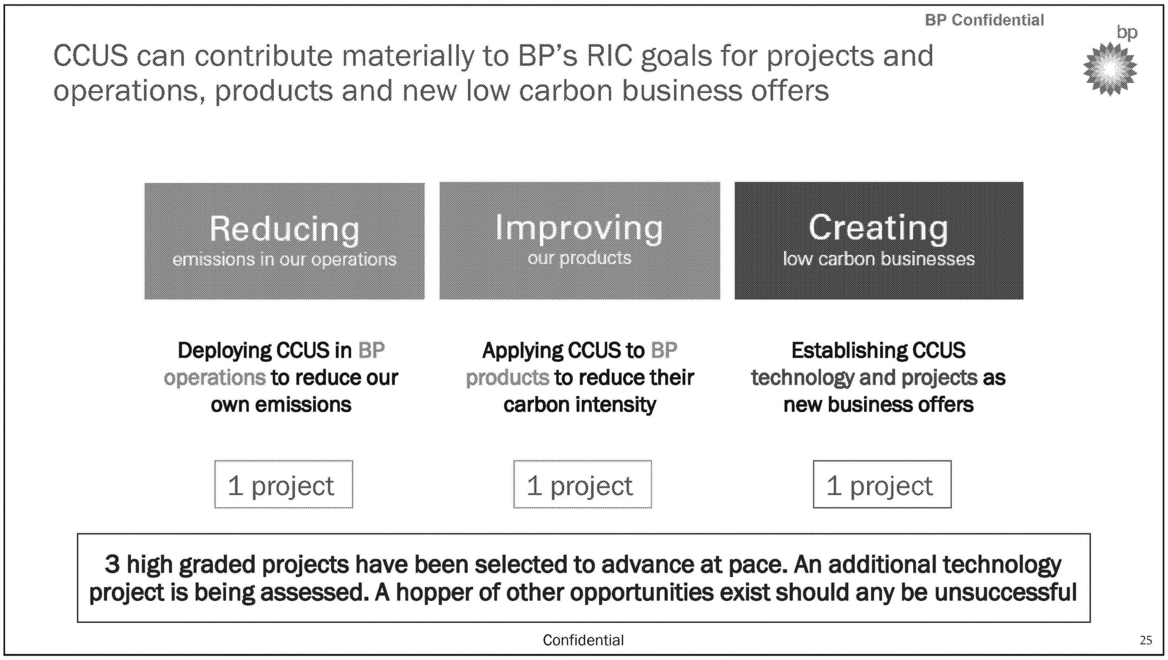
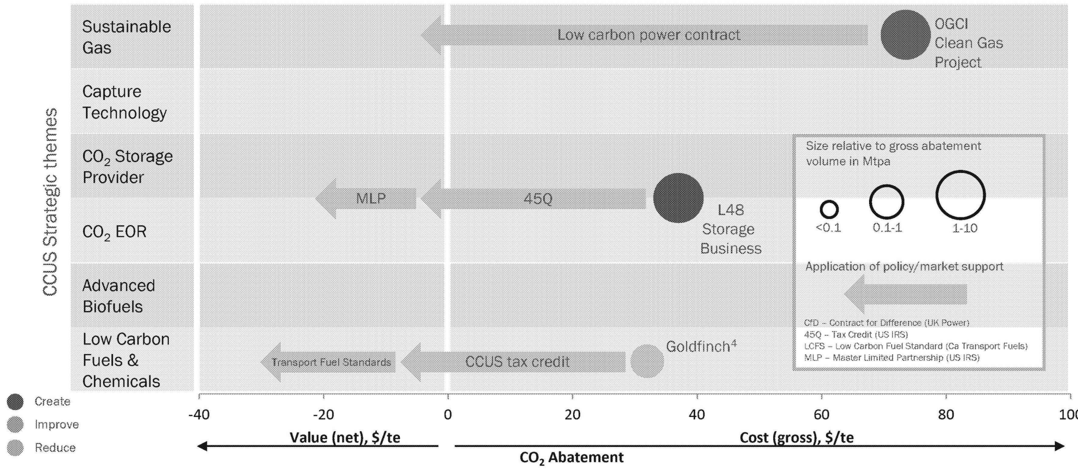


We are embedding CCUS into segment ALC and business plans, as well as holding options at a strategic level as part of New Energy Frontiers portfolio to cover our projects, operations, and products.
Within segment ALC and businesses we are working on 'low hanging fruit' options such as applying CCUS to high purity CO2 sources in Upstream gas processing, Downstream crude oil refining, and Alternative Energy biofuels fermentation.
These provide a tactically important capability and reputational platform.
Within NEF are working with external partners on new business opportunities.
These provide strategic growth aligned with existing BP capabilities, assets and markets, at a controllable pace and scale.
With recent CCUS project announcements by Exxon, Shell, Statoil and Total there are indications that this is becoming a more competitive area.

BP's high graded CCUS projects have available policy and market support mechanisms to offset abatement costs and be value accretive



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