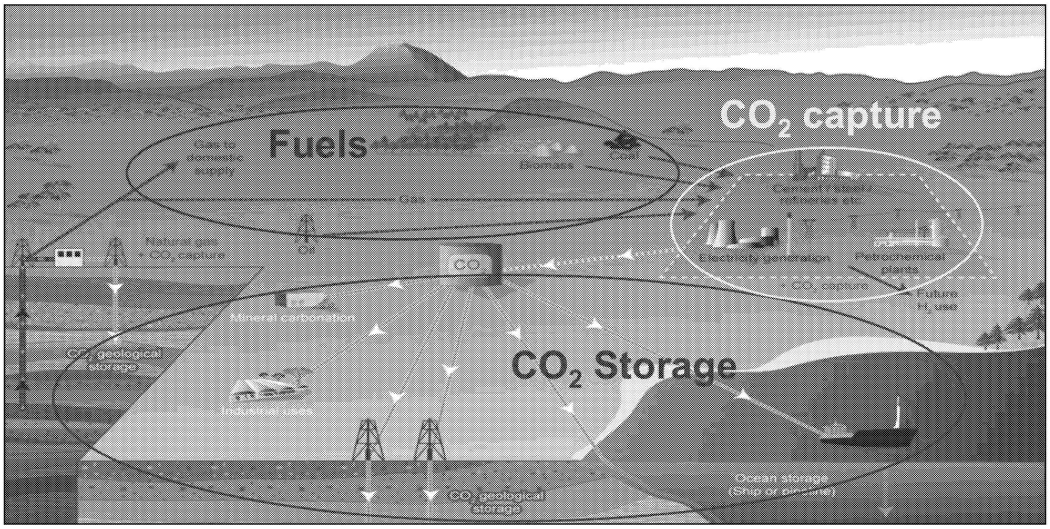
CO_2 Capture, Utilization and Storage (CCUS): Overview of the technology components, policy and value proposition

Carbon Solutions, Group Technology

15th June 2016



Fuels
CO_2 capture
Gas to domestic supply
Biomass
Coal
Gas
Oil
Natural gas + CO_2 capture
Cement / steel / refineries etc.
Electricity generation
Petrochemical plants
+ CO_2 capture
Future H_2 use
CO_2
Mineral carbonation
CO_2 geological storage
CO_2 Storage
Industrial uses
CO_2 geological storage
Ocean storage (Ship or pipeline)

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Overview

- What is CCUS?
- Technology Components
- Cost Picture and opportunity to reduce costs
- What is the value proposition for CCUS?
- BP Experience
- Competitor position and our view of drivers
- Policy – what is stopping CCUS and what needs to happen?
- What BP is working on in CCUS and with whom?

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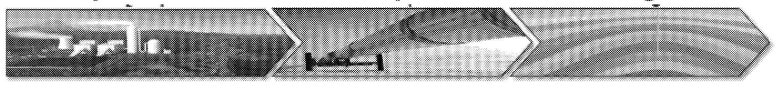
CCUS combines several technology components and operations…

Capture | **Transport** | **Storage**



CO_2 Sources

Upstream O&G
- Natural Gas Processing

Heavy industries
- Steel
- Cement

Power generation
- Coal
- Gas
- Petroleum coke
- Biomass

Industrial hydrogen production and use
- Chemicals (ammonia)
- Synthetic fuels
  - Coal-to-liquid
  - Steam methane reforming
  - Biomass-to-liquid
- Refineries (fuel upgrading)

Capture

Gas sweetening
- CO_2/CH_4 separation

Post-combustion
- CO_2/N_2 separation

Oxy-fuel combustion
- O_2/N_2 air separation unit
- Oxy-fuels boiler

Pre-combustion
- Gasification or reformers
- CO_2/H_2 separation

Additional equipment
- Compression
- Dehydration

Transport

Pipelines

Ship

Networks & hubs

Storage

Underground geological storage
- Deep saline aquifers
- Depleted oil and gas fields
- Unmineable coal seams

Beneficial reuse of CO_2
- Enhanced oil/gas recovery
- Enhanced coal bed methane
- Synthetic fuels
  - Algae biofuels
  - Formic acid
  - Synthetic natural gas
- Urea yield boosting
- Mineralization
- Polymer processing

Other options in R&D
- Storage in basaltic formations
- Ocean storage
- Working fluid for enhanced geothermal systems

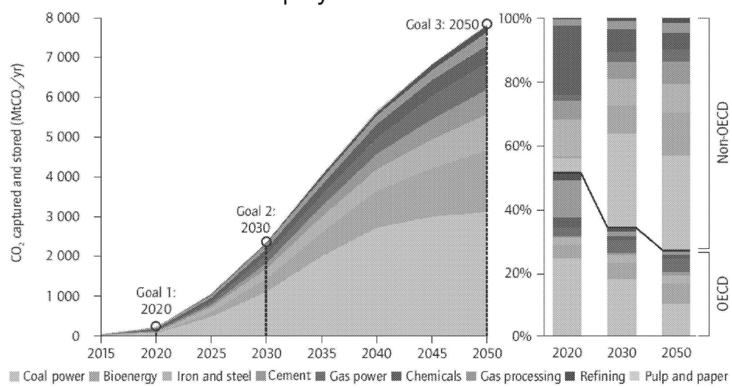
…that need integration and scale up

- CO_2 capture from any fossil fuel or biomass combustion or industrial processes, and is commercially available from technology licensors for all applications
- Transport by pipeline, ship and road all commercially practiced
- CO_2 storage has been demonstrated in saline formations and incidental storage with CO_2 EOR is commercially practiced
- CO_2 conversion and utilisation is commercially practiced for urea and methanol
- Key integrated CO_2 capture applications:
  - Coal-fired power generation – demonstrated at Boundary Dam
  - Gas-fired power generation – demonstrated at Bellingham

CCUS relies on a combination of technologies – components are proven but large-scale integrated demos are still needed to build confidence

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 CCS takes place in non-OECD countries by 2050[1]
- 1 GW coal-fired power plant generates c. $6MtCO_2$/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 CCS goal of 6GtCO$_2$/yr by 2050)

[2]Shell, OGCI CCS Workstream meeting, 2016

[3]Team analysis, 6MtCO$_2$=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

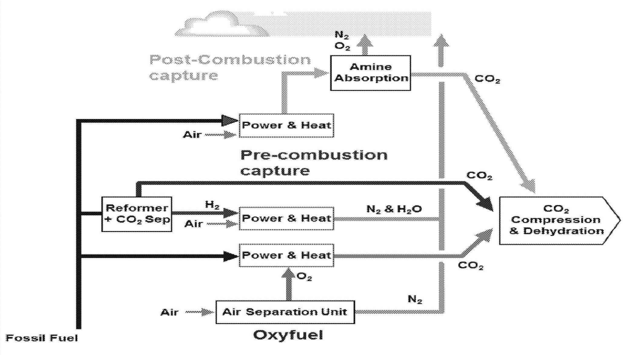
…but it has stalled and faces significant barriers

- CCUS is considered an essential component of the low carbon portfolio needed to meet global climate goals
- Gas-fired power with CCUS provides intermittent low carbon generation to balance intermittency of renewables
- CCUS is the only option for decarbonisation of certain industries and coal
- CCUS is the only technology that could enable continued large-scale use of fossil fuels in a tightly carbon-limited world
- Current commercial application of CCUS is focused on high purity CO_2 sources and EOR, but is limited in scale

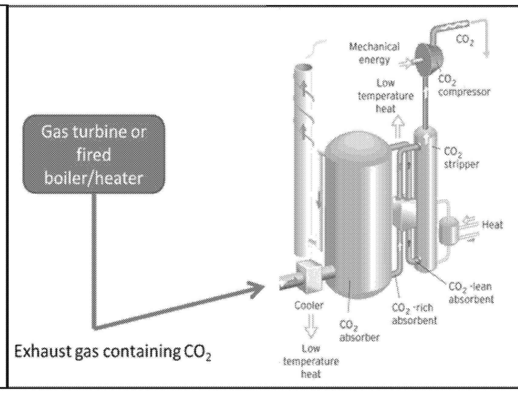
Despite its importance and ambition to meet decarbonisation goals, CCUS has stalled and commercial deployment is very limited

Proven capture technology is available for different CO_2 sources …

CO_2 Capture Types



Post Combustion CO_2 Capture



Post-combustion capture, Pre-combustion capture, Oxy-fuel

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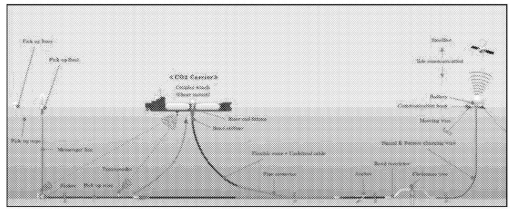
… but energy penalty & cost with existing technology is high

- In natural gas processing, CO_2 can be captured from contaminated gas
- For post-combustion processes (preferred for most applications including power generation) CO_2 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

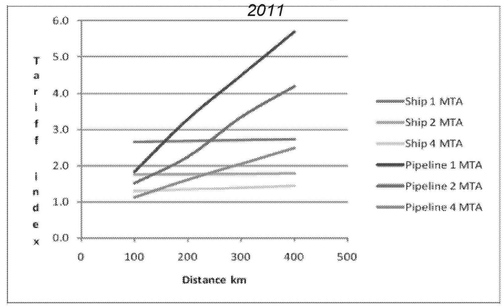
Capture is proven but integrated demos are needed to build confidence and new technologies are promising cost improvements

Shipping may have a material role in some regions …

- Small scale CO_2 shipping (ca 2kte) in operation today for food/beverage
- Larger scale ship design (ca 40-80kte) is available
- Rotterdam hub business model is being developed based on ship transport of CO_2 offshore
- 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



Source: GCCSI Prelim Feasibility Study on CO_2 Carrier for Ship-based CCS, 2011



Source: GCCSI CO_2 Liquid Logistics Shipping Concept, 2011

...whereas elsewhere new CO_2 pipeline infrastructure will be required

- ~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: IEA GHG CO_2 Pipeline Infrastructure Report, Jan 2014

CO_2 transportation infrastructure is needed to link sources with sinks

Alternative ways of using and storing CO_2…

Utilisation

CO_2 Conversion (CCC)

Currently 200 Mtpa (mostly from industrial sources) used in making Urea, inorganic carbonates, methanol

BP refineries sell 0.4 Mtpa

CO_2 stored depends on the permanency of the product

CO_2 EOR

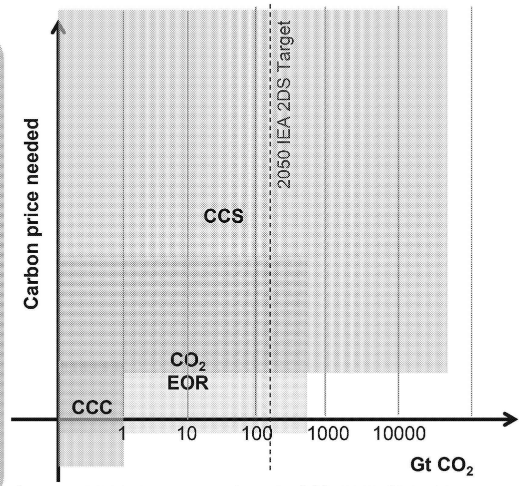
Current market mainly in US is 70 Mtpa (80% from natural sources, 20% from industry)

CO_2 goes through multiple injection and production recycles – but ultimately the vast majority of CO_2 supplied end's up stored in the reservoir

CO_2 Storage (CCS)

Currently 4 Mtpa operating geological storage projects in saline formations

2 in Norway (Sleipner/Snohvit), 1 in US (Decatur), 1 in Canada (Quest)



Sources: IEA Technology Roadmap for CCS, 2013, Global Energy Assessment, 2012, IEAGHG/ARI CO2 Storage in Depleted Oilfields, 2009, Niall McDowell, Imperial College, 2016

…have different storage potential and cost

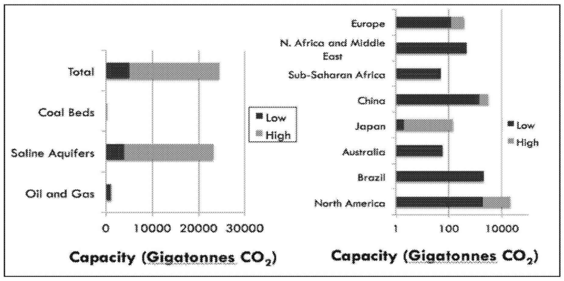
A perspective on the contribution that CCUS (will vary based on regional costs, benefits and geology) could make to climate change mitigation;

- CO_2 storage of 5,000-25,000 Gt has the largest potential but no benefit without a sufficiently high carbon price/incentive
- CO_2 EOR potential could utilize and store 65-370 Gt of CO_2 but won't be available/achievable everywhere and faces policy challenges at very large scale
- CO_2 conversion could utilize 1 Gt - is insufficient alone, but does give beneficial use

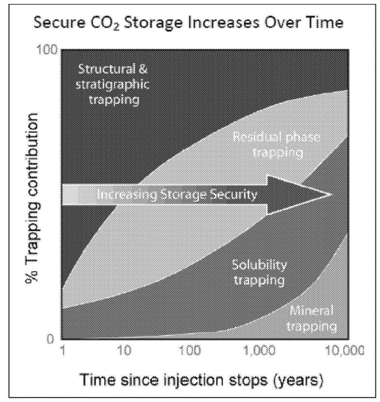
There appears to be sufficient technical storage capacity but there are a number of techno-economic constraints

CO_2 geological storage has sufficient security and scale potential to make a material contribution to climate goals…

- 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



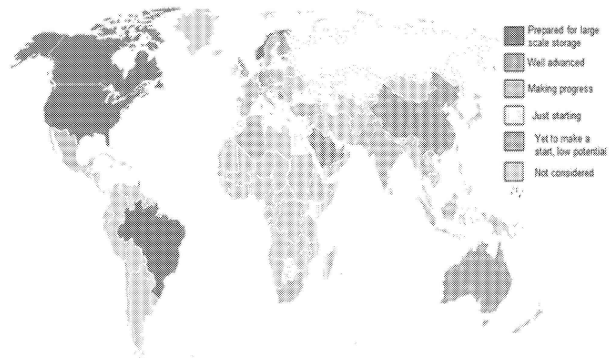
Source: Global Energy Assessment, 2012



Source: Sally Benson, Stanford University, 2008

…but storage resources are not uniformly distributed, uncertainty remains in some key areas, and little is being done to de-risk

- 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)



Source: GCCSI Global Storage Readiness Assessment, 2015

Further definition and action in reserves progression of CO_2 storage resources is needed in key areas

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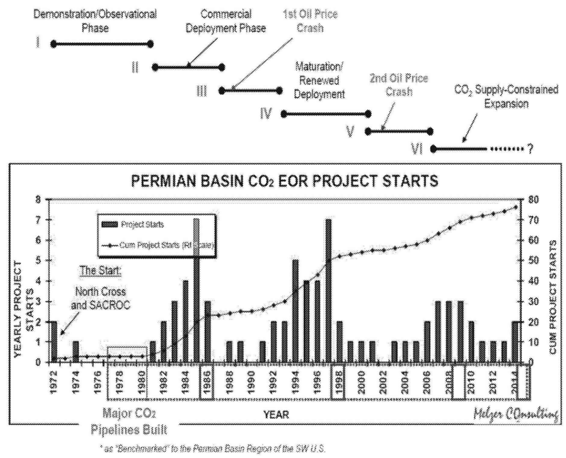
CO_2 EOR established itself in a few onshore US basins in the 1970-90's but ran out of low cost natural CO_2…

- 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).
- Demand is linked to oil price – peak in start-ups prior to 1986 and 1998 oil price shocks, but since 2005, CO_2 demand outpaced supply
- 80% of the CO_2 is from natural sources, remaining 20% from industrial sources (gas processing plant, H_2 and N_2 plant, chemical, power and other plant)



Source: Melzer Consulting, 2015

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…but the emergence of CCUS gives an opportunity to expand and deploy in other regions

- Practice will change and technologies will emerge given a value associated with 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)
- Leading to improved economics, and an increase in EOR and storage volumes

Figure 8 • Global storage potential for different CO_2-EOR practices ($GtCO_2$)

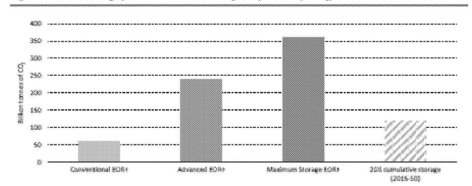
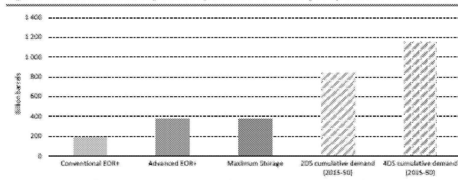


Figure 9 • Global incremental oil production potential for various CO_2-EOR practices

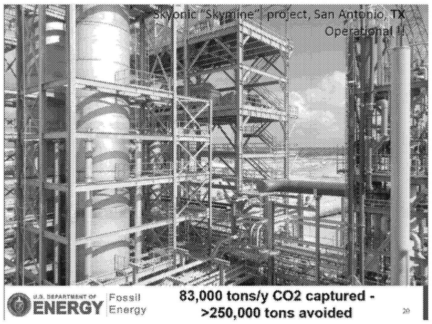


Source: IEA 2015, Storing CO_2 through EOR

CO_2 EOR performance and scale can increase if a value is attributed to CO_2 storage

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.

Other forms of CO_2 use (materials, chemicals, fuels) are emerging…



BP experience of CO_2 conversion technologies through Venturing

Conversion and utilisation technologies provide differing extent (but often minimal) and amount of storage

Process	Global Annual CO_2 Usage	Typical source of CO_2	Lifetime of storage
Urea	65-146Mt^	Industrial	6 Months
Methanol	6-8Mt	Industrial	6 Months
Inorganic Carbonates	3-45Mt #	?	Decades
Organic Carbonates	0.2Mt	?	Decades
Polyurethanes	10Mt	?	Decades
Technological	10Mt	?	Days to Years
Food and drink	8Mt	?	Days to Years
TOTAL	**102 – 227Mt**		

Notes:
^, # The demand for CO_2 in Urea and Inorganic Carbonate production is particularly uncertain. Various sources have quoted figures with orders of magnitude differences.

…but CO_2 storage is not always long-term

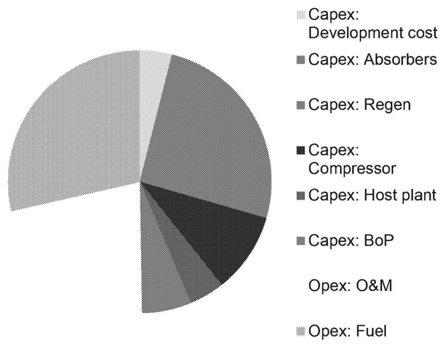
- Cost effective availability of low carbon/renewable hydrogen is likely to be a constraint on industrial scale deployment of many CO_2 conversion technologies
- However, limited opportunities might exist in;
  - CO_2 to plastics (Bayer DREAM process)
  - Mineral carbonation of industrial waste
  - CO_2 replacing H_2O as a hydraulic fracturing fluid in water stressed regions
- Other CO_2 conversion processes may need substantial state subsidy and/or technology breakthrough
- Some CO_2 conversion processes may use excess/'free' energy from renewables sources to effectively store energy through conversion processes

There are interesting opportunities for some CO_2 conversion processes but the extent of CO_2 storage is variable

Data from Wilcox, Carbon Capture

Capture accounts for ca 80% of the cost of CCS…

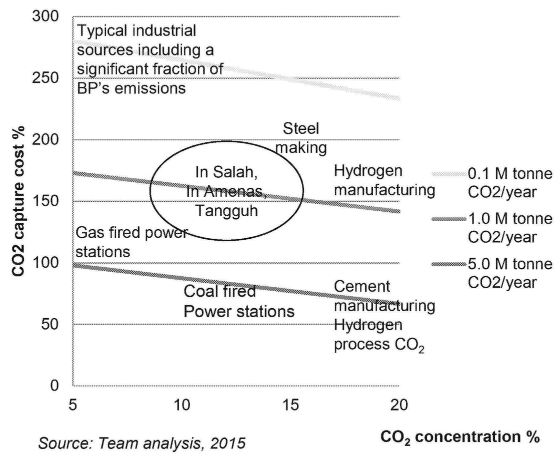
Capture cost breakdown



*Notes: * post-combustion 85% capture rate applied to natural gas fired power plant located in the UK*
Sources:

Source: UK CCS Cost Reduction Taskforce, 2014

Capture cost by scale and concentration*



Source: Team analysis, 2015

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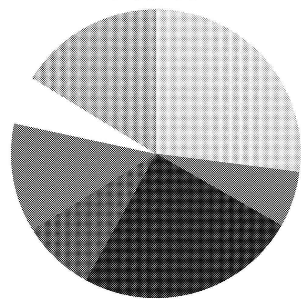
… with large heat and power consumption that varies with scale and CO_2 concentration of the source

- 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 CO_2 compression
- The largest sources of CO_2 typically have the lowest cost of capture
- Most of the CO_2 emissions from BP operations would have high capture cost (at least double the cost of capture from power stations)

Improvements in CO_2 capture technology (with lower energy requirements and lower cost) could substantially improve the competitiveness of CCS

Transport and storage cost…

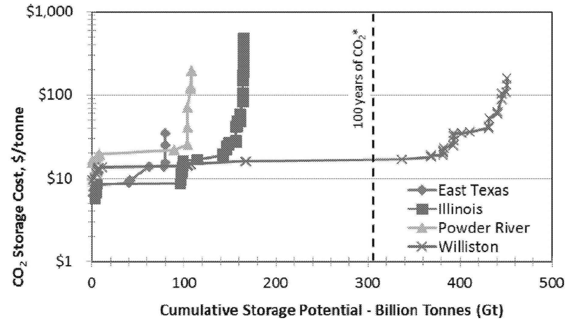
CO_2 transport and storage cost breakdown



Notes: assuming CO_2 transport by pipeline and storage of the CO_2 in a depleted oil and gas reservoir in the North Sea

Source: UK CCS Cost Reduction Taskforce, 2013

Storage costs vary by formation



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

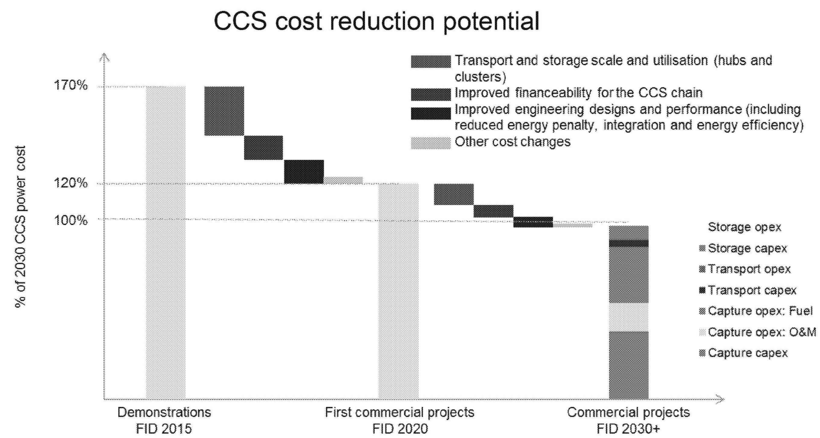
Source: US NETL, Quality Guidelines for Energy System Studies: Carbon Dioxide Transport and Storage Costs in NETL Studies, 2014

…can be optimised at scale

- Compressed CO_2 is transported by pipeline – cost is proportional to length (ca 1.5 M$/km)
- The cost and economies of scale for CO_2 storage are formation specific
- There is a technology dimension to optimising storage economics, but there is no substitute for accessing the best geology
- If CO_2 is used for EOR then CO_2 value can help offset CO_2 supply costs, and in some cases can achieve an economic value chain

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

Plausible incremental cost reduction pathway…



Sources: UK CCS Cost Reduction Taskforce

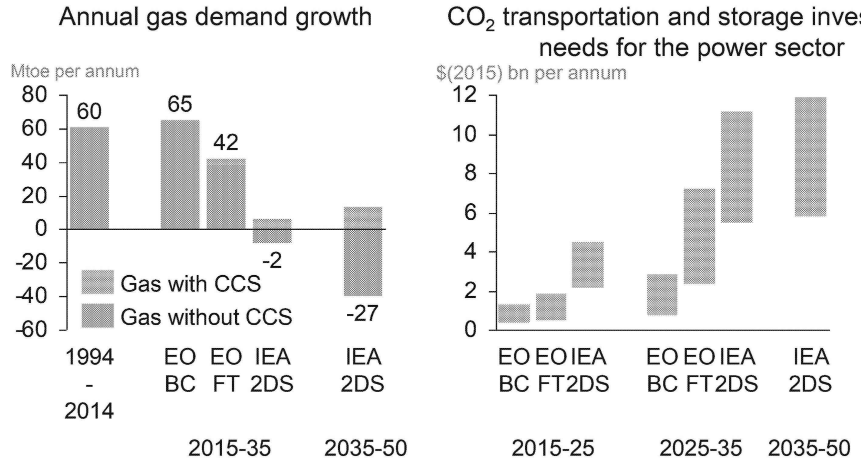
Note: No account for cost reduction associated from potential utilization revenues have been made. These are CCS not CCUS costs.

… for existing technologies to achieve competitive CCS costs at full-scale

- Reaching commercial stage requires the build-out of infrastructure and proving of the integrated value chains
- Optimising transport and storage infrastructure for large-scale CCS is important to driving cost reduction
- Developing the ability of the supply chain, managing risk and accessing low-cost finance is also important for cost reduction
- Technology innovation could deliver substantial further cost reduction - particularly from capture

Early demo projects have high cost but a pathway for cost reduction is possible

CCUS creating value for natural gas and ...



Index
EO – Energy Outlook
BC – Base case
FT – Faster transition
IEA – International Energy Agency
2DS – Two Degrees
CCS – Carbon Capture & Storage

Sources: BP Energy Outlook 2035, IEA Energy Technologies Perspective 2015, Team analysis

… as a potential new investment opportunity

- The charts illustrate the importance of CCUS to the scale of gas-fired power and therefore the incremental gas demand growth (or decline) across tightening carbon scenarios.
  - To meet carbon policy requirements without CCUS, even oil demand could be lower as compensating greater levels of abatement are potentially sought by transport sector
- Large scale global deployment of CCUS for the power sector would require $4-12bn/year of Transport and Storage investment from 2020 to 2050
  - An 800 MW gas-fired combined-cycle plant with CCUS could require investment of up to $1 bn in the early stages of a CO_2 transportation & storage network.
  - CO_2 transport and storage market is not currently financeable

CCUS could help sustain gas demand growth for longer, supporting gas markets, the value of gas and potentially liquid fuels

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CCUS may be needed to reduce BP's CO_2 emissions …

High purity CO_2 sources offering lowest cost CCUS possibilities for BP

Segment	Process	Applicable Sources
Upstream	Gas separation	North Africa, Tangguh, Alaska, L48, Brazil & Angola (Pre-salt)
Refining	Hydrogen production – 95% purity	Gelsenkirchen, Cherry Point, Toledo*
	Hydrogen production – 50% purity	Whiting*, Lingen, Castellon, Rotterdam
Biofuels	Fermentation	Brazil (Tropical, ITB, ITT)

Source: Provisional 2016 update of BP AE Study, 2009
*Notes: * Third Party supply*

… driven by regulations and license to operate in near term and increasing carbon prices in longer term

- In some regions CCUS deployment in reducing BP's emissions may be required.
- The focus is likely to be on high purity CO_2 sources with >90% CO_2 concentration such as upstream gas processing and hydrogen plants.
- These plant types have relatively low incremental capture costs (e.g. < $25/tonne), but would increase cost of supply
- Industry precedents include Gorgon (Australia) and Lula (Brazil) for upstream gas processing

Deployment of CCUS may be required in BP assets to reduce emissions as climate policy strengthens or becomes a license to operate requirement

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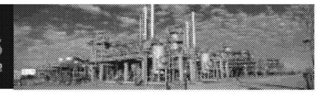
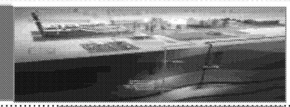
BP was an early mover in CCUS and has broad experience ….

Research	Fundamental science & policy/regs	CMI; Zep Zero emissions platform; CCSa Carbon Capture & Storage Association
Technology development	Programmes to reduce risk/costs of CCUS	CO_2 Capture Project; energy technologies institute; OGCI OIL AND GAS CLIMATE INITIATIVE
Technical demonstration	Assurance framework & risk assessment (In Salah JIP Ph 1 & 2)	In Salah Gas Stockage de CO_2
Commercial-scale projects	Project experience across full value chain	Hydrogen Power projects; Peterhead, HECA, HPAD, etc.
Venturing	Access and insight into CO_2 utilization	Skyonic – converts carbon dioxide emissions to solids for long-term storage; Solidia Technologies – developing next generation building materials that consume, not generate, CO_2 in the production process





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… but we have greatly reduced our CCUS resources and technology effort following the demise of Hydrogen Power

- Our experience spans from 2000 with the CMI and CCP projects leading on climate science and technology research and development
- In Salah has provided valuable "learning by doing" even although this is a sub-optimal reservoir for CO_2 storage
- The Hydrogen Power (H2P) business provided "full value chain" experience as well as work to understand a case for CO_2 storage business
- Withdrawal from H2P has precipitated a loss of BP experience on projects, technology development and people capability
- Venturing have identified a few examples of CO_2 utilization, but it is of limited scale

BP has extensive experience, but corporate know-how is at risk of being lost while competitors continue to build

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BP experience and expertise has been established in gas EOR…

1 Patent
1* Miscible Gas Project (TX)

1 Patent
2 Immiscible Gas Project (TX/LA)
2 CO_2 Projects (TX)

1 Miscible Gas Project Study (Venezuela)
1 Immiscible Gas Project (TX)
2 CO_2 Projects (CA)

CO_2 Lab Studies (TX)
CO_2 Pilots (TX)
1 CO_2 Project (TX)

1 Gas EOR Lab Study (Abu Dhabi)
1* Arctic Miscible Gas Pilot (AK)
1 Immiscible Gas Pilot (AK)
1* Offshore Miscible Gas Project (LA)
1 Miscible Gas Project (AK)
1 Immiscible Gas Project (CA)
6 CO_2 Projects (OK, TX)

Gas EOR Lab Studies (Abu Dhabi)
Gas EOR Project Studies (Abu Dhabi)
1 Miscible Gas Pilot (AK)
1 Conformance and Injectivity Pilots (AK)
2 Miscible Gas Projects (AK, Offshore Norway)
2 CO_2 Projects (TX)

2 CO_2 Lab Studies (Abu Dhabi)
2 Miscible Gas Pilots (AK)
1 Conformance Pilots (Offshore Norway)
4 Miscible Gas Projects (AK, Offshore UK)
2 Immiscible Gas Projects (AK)
1 CO_2 Storage Demo Project (Algeria)

1 CO_2 Pilot (TX)

* World first
Intellectual Property
Studies/Pilots
Operational gas EOR

1940s 1950s 1960s 1970s 1980s 1990s 2000s 2010s?

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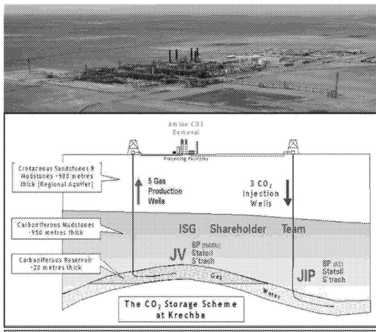
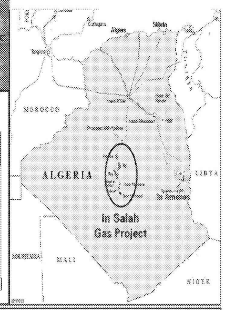
….and a recent BP CO_2 commercialization study shows this offers the potential for new opportunities for BP

- BP has been involved in miscible gas EOR for 70 years, e.g. BP led the development of CO_2 EOR in the U.S. (divested in 2003) and currently operate the world's largest enriched hydrocarbon gas EOR project at Prudhoe Bay
- Pioneered innovative Designer Gas^{TM} technologies in Alaska & involved in sweep-enhancing technologies
- Deployment limited by access to an economic source of miscible gas
- New opportunities may be commercial: renewal/abatement in the L48 and Alaska, access opportunities in the Middle East, and large-scale EOR deployment may be enabled with an appropriate price on CO_2

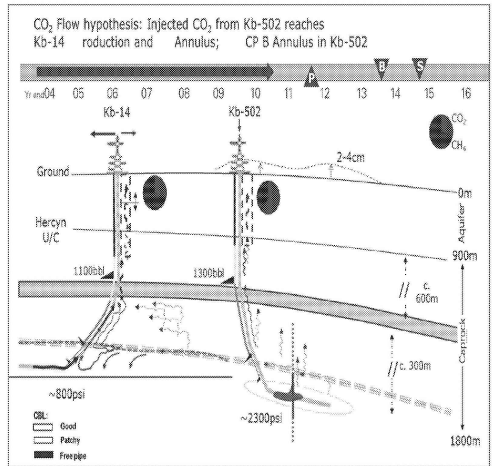
A price on CO_2 could make CO_2 EOR an interesting opportunity that also enables CCUS

In Salah was a first of a kind technical demonstration project for CO_2 storage at industrial scale …





- Industrial Scale Demonstration of CO_2 Geological Storage (Conventional Capture)
- Deep Saline Storage Formation common; Offset & downdip from Krechba Field GWC
- Storage started August 2004 via 3 Injectors; ended June 2011
- 3.7 $MMtCO_2$ Stored to date @ cost of ~$50-60/t
- No CCS Policy or Regulation hence no commercial benefit
- Test-bed for CO_2 Monitoring Technologies $30mm Research Project: BP leverage 1:3.5



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… that has not performed as expected, requiring early P&A and liability uncertainty

- Development and operational key learnings include:
  - Exceeding the recommended maximum CO_2 injection pressure, resulted in CO_2 migrating into the cap rock and accessing the annuli of nearby wells
  - Poorly abandoned wells exposed to the CO_2 plume offer a potential leak path
  - The importance of an integrated subsurface view/model to recognise presence of natural fractures in the system should include the overburden
  - CCS must be fully integrated into Field Development Plan and Operations
  - In the absence of regulations, the relationship with regulator is critical

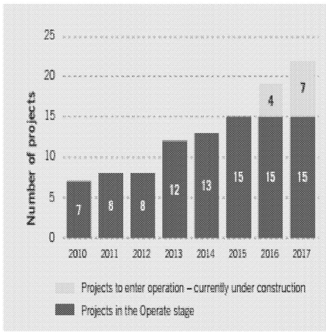
- The final phase of site closure and preparing the terms by which we hand responsibility of the stored CO_2 back to the state will be another leading edge learning project

CCS is doable, but needs careful site selection and operational management

Limited progress in large-scale CCUS deployment …

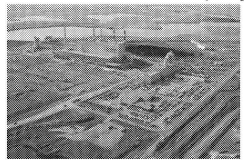
CCUS project deployment

TWh per annum

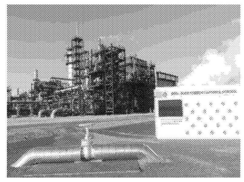


Sources: GCCSI, Saskpower, Shell, Saudi Aramco

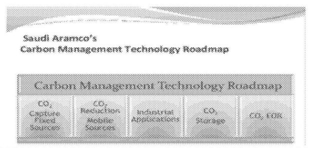
2014/15 CCUS project additions



<u>Saskpower Boundary Dam Project</u>
Alberta, Canada
125 MW coal-fired power
1 Mt/year CO_2 for EOR, partly aquifers



<u>Shell Quest Project</u>
Alberta, Canada
1 Mtpa CO_2 capture capacity
CO_2 stored in saline aquifer



<u>Saudi Aramco Uthmaniyah Project</u>
Kingdom of Saudi Arabia
0.8 Mtpa CO_2 capture capacity
CO_2 used for EOR pilot in Uthmaniyah field

… though notable recent projects on power and by oil and gas companies

- The charts illustrate that globally there are 15 large-scale CCUS projects in operation, with the capacity to capture up to 28 Mt of CO_2 per year, with a further seven under construction
- The majority of projects in operation to date have been gas processing with over half of these in turn linked to EOR
- Most of the projects in operation or execute are in North America
- The world's first large-scale power sector CCUS project – the Boundary Dam Carbon Capture and Storage Project on a coal –fired power plant became operational in October 2014

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

Oil and gas supermajors are active in CCUS projects …

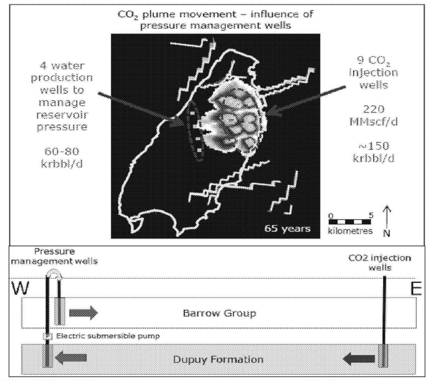
Project Name	Location	Company	Capture	Storage	Size (Mtpa)	Duration
Schute Creek	WY, USA	ExxonMobil	Gas Processing	EOR	7	1986-
Weyburn	Canada	Cenovus and Apache	Pre-combustion (Synfuel Gasification)	EOR	3	2000-
Gorgon	Australia	Chevron (47.3%), ExxonMobil (25%), Shell (25%), others	Gas Processing	Saline Aquifer (with water production)	4	2016-
Lost Cabin	WY, USA	ConocoPhillips	Gas Processing	EOR	1	2013
In Salah	Algeria	JV (BP, Sonatrach, Statoil)	Gas Processing	Saline Aquifer	1	2004-2012
Sleipner	Offshore Norway	Statoil, ExxonMobil, Total	Gas Processing	Saline Aquifer	1	1996-
Quest	Canada	Shell (60%), Marathon (20%), Chevron (20%)	Pre-combustion (Oil sands SMR upgrader)	Saline Aquifer	1	2015-2025+
Lula	Offshore Deepwater Brazil	Petrobras (65%), BG (25%), others	Gas Processing	EOR	0.7	2013-
Snøhvit	Offshore Norway	Statoil, Petoro, Total, GDF Suez, Hess	Gas Processing	Saline Aquifer	0.7	2008-
Lacq	France	Total	Oxy-fuel combustion	Saline Aquifer	0.1	2009-2017

Source: IOGP, 2015
Notes: This is a subset (10) of all (15) projects currently underway.

…where it supports core business in CO_2 separation from gas processing and CO_2 EOR

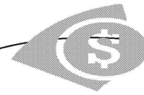
- Once leader, BP has been overtaken by Shell, ExxonMobil, Statoil, Petrobras and Chevron
  - Shell only are promoting saline aquifer storage and CCS on gas-fired power
- Shell & ExxonMobil have strong IP positions
  - Controlled Freeze-Zone (Exxon), Fuel-Cells (Exxon) and Cansolv (Shell)
- Case-study – Gorgon
  - 4Mtpa CO_2 separation from produced gas prior to LNG at an additional ~$1.5-2 bn cost
  - LtO requirement
  - Compression and injection into a saline aquifer immediately below the plant

Gorgon: Injection of produced CO_2 for low cost LNG carbon abatement

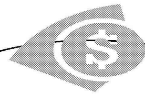


Our competitors are progressing CCUS for core business needs, but not at a pace to offer CCUS as a climate solution

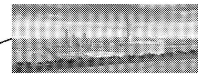
Policy support is key to accelerating CCUS deployment …



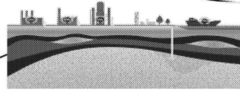
Lack of Carbon price



Cost and pace uncertainty

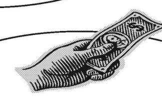


Integrating the technology at scale

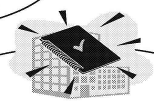


Putting the right infrastructure in place

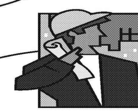
Public perception



Commercial structures – along whole value chain



Policy and regulations for post-demo phase



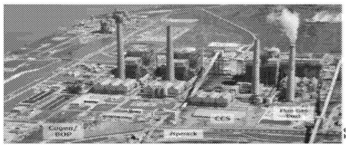
Building the right capability

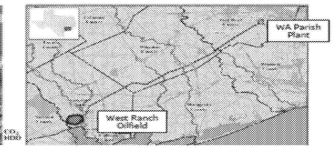
... as commercialising CCUS is not a technical challenge

- CCUS has not been afforded sufficient policy support, especially when viewed in terms of its ability to achieve deep CO_2 emissions reductions
  - Since 2007, total CCUS investment has been less than US$20 billion, ~100 times less the amount for renewable energy technologies over the same timeframe
- Application of the principle of 'policy parity' can strengthen the foundations for widespread deployment by an equitable level of consideration, recognition and support being given to CCUS
  - Specific areas in the application of this principle include:
    - Predictable and enduring policy arrangements
    - Extending CCUS law and regulation across the globe
    - Incentivising storage site selection to support project development
    - Continuing research & development to reduce costs

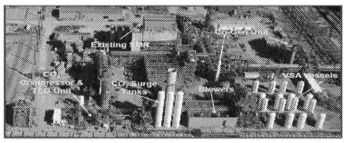
CCUS at scale is not commercial today and requires policy support that underpins a commercial investment decision

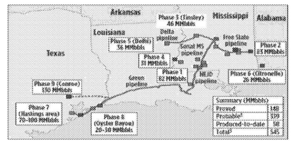
Demonstration projects require substantial capital investment which have largely been provided by governments …



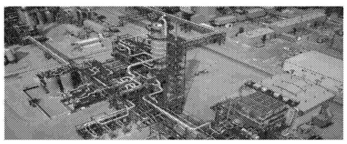


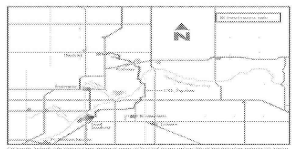
USA, West Parish – NRG/JXNippon/Hilcorp
1mmtpa post-combustion capture from coal power w/ CO_2 EOR
US DOE Capital Grant of **$167Mln**





USA. Port Arthur – Praxair/Denbury
1mmtpa CO_2 capture from H2 SMR w/ CO_2 EOR
US DOE Capital Grant of **$284Mln**





Canada. Scotford Upgrader – Shell
1mmtpa CO_2 capture from oil sand upgrader w/ saline aquifer storage
Canadian Federal and Alberta Province Capital Grant of **$425Mln,** plus double carbon credits

Average capital grant = $300Mln/mtpa capacity

…yet much of this has been withdrawn and the policy window is closing

- A series of large scale CCUS demonstration projects around the world are considered necessary as a stepping stone to large scale deployment. Early projects require government incentives and financial support, typically grant funding
- Efforts have been made to develop large integrated CCUS demonstration projects through public private partnerships in USA, Canada, Australia, Middle East, Europe including UK
- Progress has been slower than anticipated and many projects have been cancelled ahead of investment, including BP's DF projects
- Costs have been cited as a reason for cancellation of the UK demonstration programme where £1bn of public capital had been earmarked to support 2 commercial scale integrated power and CCS projects

Integrated CCUS demonstration projects have been enabled by specific government funding for demonstrations, but government funding is wavering

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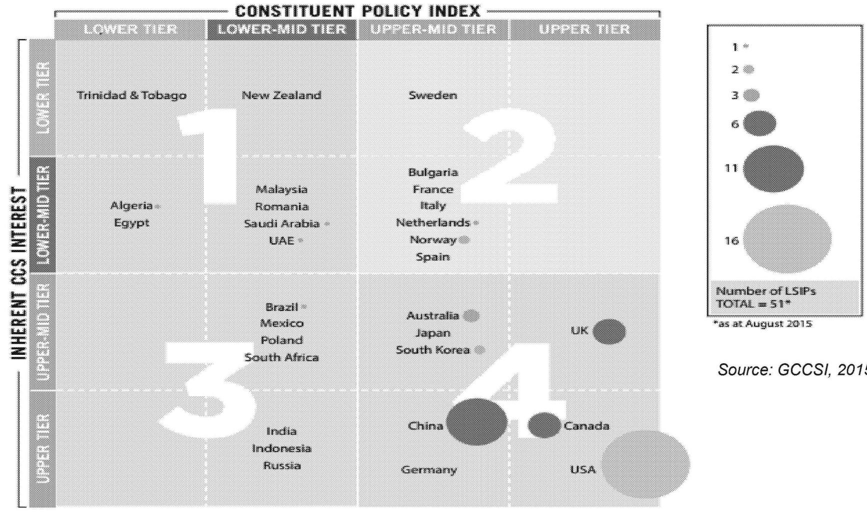
GCCSI 2015 Policy Indicator shows the variance in CCUS interest and policy between regions …



Source: GCCSI, 2015

… interest is focused on a few countries, and on demonstration rather than deployment

- 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

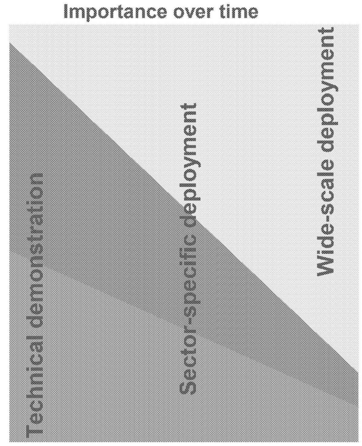
- Regulatory framework for storage has been developed in North America and Europe and ISO is underway for CCUS

Interest in CCUS varies considerably by region and the emphasis is mostly on Research, Development & Demonstration

CCUS incentives will vary 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



... and a range of policy options exist

- 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?

An ambitious and collaborative approach will be required to develop effective policy frameworks that enable CCUS deployment

BP maintains a reduced but relevant capability …

Research	Fundamental science & policy/regs	CMI; Zep Zero emissions platform; CCSa Carbon Capture & Storage Association; Harvard; Tufts University
Technology development	Programmes to reduce risk/costs/uncertainty of CCUS	CO_2 Capture Project; energy technologies institute; OGCI Oil and Gas Climate Initiative
Technical demonstration	Risk management and site closure planning	
Venturing	Access and insight into CO_2 utilization	Skyonic – converts carbon dioxide emissions to solids for long-term storage; Solidia Technologies – developing next generation building materials that consume, not generate, CO_2 in the production process

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… to manage a growing GHG risk that may require CCUS for some businesses and to support CO_2 EOR opportunities

- Based around a focused technology programme and working in partnerships
  - CCUS programmes have reduced in the last 5 years, though activity levels have grown considerably over the last 12 months, with the addition of OGCI focus on CCUS and Methane
  - Our technology focus is on reducing CCUS costs, identifying and managing risk and performance prediction around storage

- Business interest and awareness has also grown, with new opportunities in Alaska (LNG and CCUS) and the Middle East (CO_2 EOR) being supported

- New work at integrating and leveraging CMI with Harvard and Tufts on Climate change technology/policy interface will also have a CCUS dimension

BP is taking a collaborative approach integrating new activities with the current programme to take full advantage of synergies and reduce duplication