CCS Now and the Challenge Ahead Post COP21

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CCS – a key climate policy option

- The IPCC AR5 indicated - CCS is a crucial technology to meet the 2^0C target
  - Climate scenarios could not meet 2^0C without CCS
  - The costs of meeting the 2^0C will be 138% higher if CCS is not included as a mitigation option
- Post Paris CCS "lowered" the target to limit temperature rise to below 2^0C target.
- CCS is expected to be an even more crucial technology if we are to achieve below 2^0C target.

CCS – a key climate policy option (2)

- To go below 2^0C significant reductions in greenhouse gas emissions will be required in all sectors not just the power sector.
- CCS is a key technology, probably the only one, that can achieve deep emissions cuts in the industry sector.
- "Negative emission" technologies like BioCCS will likely need to be deployed from 2030 onwards.

Capture Technology Developments

- Post Combustion Capture -
- Oxy combustion
- Supercritical CO_2 cycles
- Pre –combustion capture (IGGC)

Post Combustion Capture

- Significant progress in reducing energy of regeneration for amine based process
  - Now 2.0-2.3 MJ/Kg CO_2, Cansolv 201 solvent, +others
    - Down from 4-4.5MJ/Kg in 1990
  - MEA no longer definitive baseline for c technology comparison
- Significant number of vendors testing or tested at 10MW - 100,000t scale
  - Norway, TCM – Cansolv, Aker, Carbon Clean Solutions, ….
  - Canada, Shand – Hitachi
  - China, Shanghai – Huaneng Group
  - Japan, Tomakomai – MHI, Saga City, Toshiba
- Many more at 1-2MW scale – NCC, USA

PCC Developments in Power Sector

Boundary Dam 3, Canada

- Refit of existing coal fired unit
- Operational for 1 year
- CanSolv amine based PCC technology
- 110MWe
- 95% capture
- CO_2 sold for EOR

NRG Parish, USA

- Refit of existing coal fired unit
- Now Operational
- MHI amine based PCC technology
- 250 MW slip stream
- 90% capture
- CO_2 sold for EOR

Post Combustion Capture

- Boundary Dam 3 Operational Achievements
  - March 2016 - a 90% reliability factor had been achieved for the first quarter of 2016
  - July 2016 – 1 millionth tonne of CO_2 had been captured
- Cost reduction from learning by doing
  - 30% CAPEX, 25% OPEX
- A word from the wise!

  "A capture technology must be piloted at a scale that allows for reasonable engineering scale up to a commercial size"

Oxy Combustion

- Alstom/GE
  - 35MWth test facility at Schwarze Pumpe, Germany
  - Engineering design for White Rose 426MWe (gross) – now cancelled
- B&W
  - 30MWth Burner tests, Ohio, USA
  - Engineering design for FutureGen 2.0 159MWe project – now cancelled
- HUST, China
  - 35MWth test facility in Wuhan, China
  - Lead to a 200MWe FEED design

Callide Oxy Fuel Project

Key technical achievements

- 10,200 hours oxy-firing operation and 5,600 hours of CO_2 capture plant operation
- A boiler turn-down to 50% Load Factor was demonstrated
- > 95% capture of SOx, NOx, particulates and trace metals
- A high purity of CO_2 product (> 99.9%) was produced

"The project was successful and that the technology is ready to move to the full commercial scale."

Supercritical CO_2 Cycles

- IEAGHG techno economic study has evaluated technology options
  - SCOC-CC, S-Graz, NET Power and CES.
- Cycle efficiencies , 49% to 55%
  - NGCC/CCS base case 52% efficiency
- LCOE of base-load plants were 84-95 €/MWh,
- The cost of CO_2 emission avoidance was 68-106 €/t CO_2 avoided.
- The base case was 90% capture
  - Could go to 98% without increasing the cost/t of CO_2 avoided,
  - Or essentially 100% if lower purity CO_2 was acceptable.

Supercritical CO_2 Cycles (2)

Other points

- The cycles could be net producers of water
- Cycles have small footprints
  - advantages at compact sites

Route to commercial deployment

- NET Power is constructing a 50MW power plant
- Toshiba has developed turbine component
  - Critical component
- Testing begins in 2017
- If successful will allow scale up to 295MWe

Pre-combustion capture

- Rectisol and Selexol capture technologies are commercially proven
  - Rectisol process in operation at Dakota Gasification facility since 2000
  - Selexol process to be demonstrated at Kemper County in late 2016
    - No cost overruns on capture component
- Osaki CoolGen Project - IGFC
  - Project is planned in three steps.
    - 166 MW oxygen-blown IGCC now operating
    - Add an amine based capture test facility , 2019 on
    - Add MCFC – 47-49% cycle efficiency

Industrial CCS

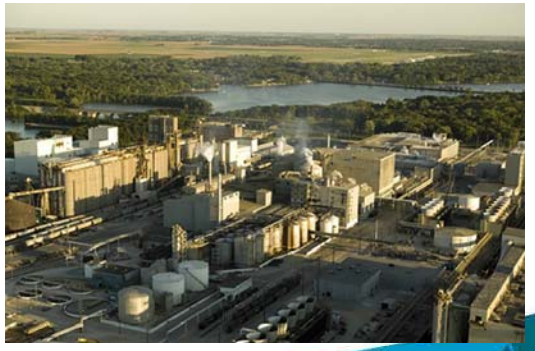
- Studies have shown us the adding CCS to industry processes is very site specific
- Standalone plants will have waste heat available for use
  - 50% capture may be limit in these cases
- Alternative to add new steam generator – costs start to increase

Industry CCS Developments

- Gas Processing sector - >20 years operational experience
  - PCC established technology (Sleipner, Snohvit)
  - Lula Project offshore Brazil demonstrating membrane technology at scale
    - Advantages for offshore applications using floating platforms
  - Gorgon, Australia – next project to come on stream – 3 X 1Mt/day PCC units

Industry CCS

- CCS now deployed in:
  - Hydrogen refining/upgrading
    - Quest – solvent based technology
      - 1Mt injected into on shore saline aquifer
    - Air Products, PSA technology
      - Over 3 Mt – used for CO2-EOR
  - Steel sector
    - Emirates Steel – Amine based capture
      - Now operational
      - 800,000 tonnes CO2 for CO2-EOR
  - Bioethanol production
    - ICCS Project, Illinois USA
    - Start up Q2 2017
    - 1Mt/y - deep saline aquifer



CO_2 Utilisation

- Emotive topic at GHGT-13
- Not a mitigation option
- Except for CO_2-EOR options do not permanently remove CO_2 from the atmosphere
- Can it help to build CCS infrastructure?

CCU Value

- 3 new PCC vendors
  - Linde 500tpd plant at Jubail Industrial City, Saudi Arabia.
    - First demonstration of CO_2 capture on ethylene glycol production
  - Carbon Clean Solutions – 10tpd unit plant in India
    - First demonstration of CO_2 capture on coal power plant in India
  - Toshiba, 10tpd PCC on waste incinerator at Saga City, Japan
    - First CO_2 capture demonstration on waste incinerator
- Limited pipeline infrastructure development to date
  - Unlike CO2-EOR in USA which added extensive pipeline network for reuse for CCS
- CCU unlikely to assist pipeline infrastructure development in Europe – need policy drivers

What Next?

- Next projects on horizon
  - Fluor to demonstrate at ROAD in 2018?
  - Capture at bio-CCS power plant in Japan in 2018?
  - Industry CCS project(s) in Norway 2010?
- Options and costs of 99-100% capture
  - Higher capture rates important to reduce residual emissions from CCS in future
  - Higher capture process rates or combination with biomass co-firing?
- Valuing CCS
  - Move beyond LCOE comparisons to system based assessments
  - Flexible CCS plants could complement flexible renewables

The Challenges for CCS (1)

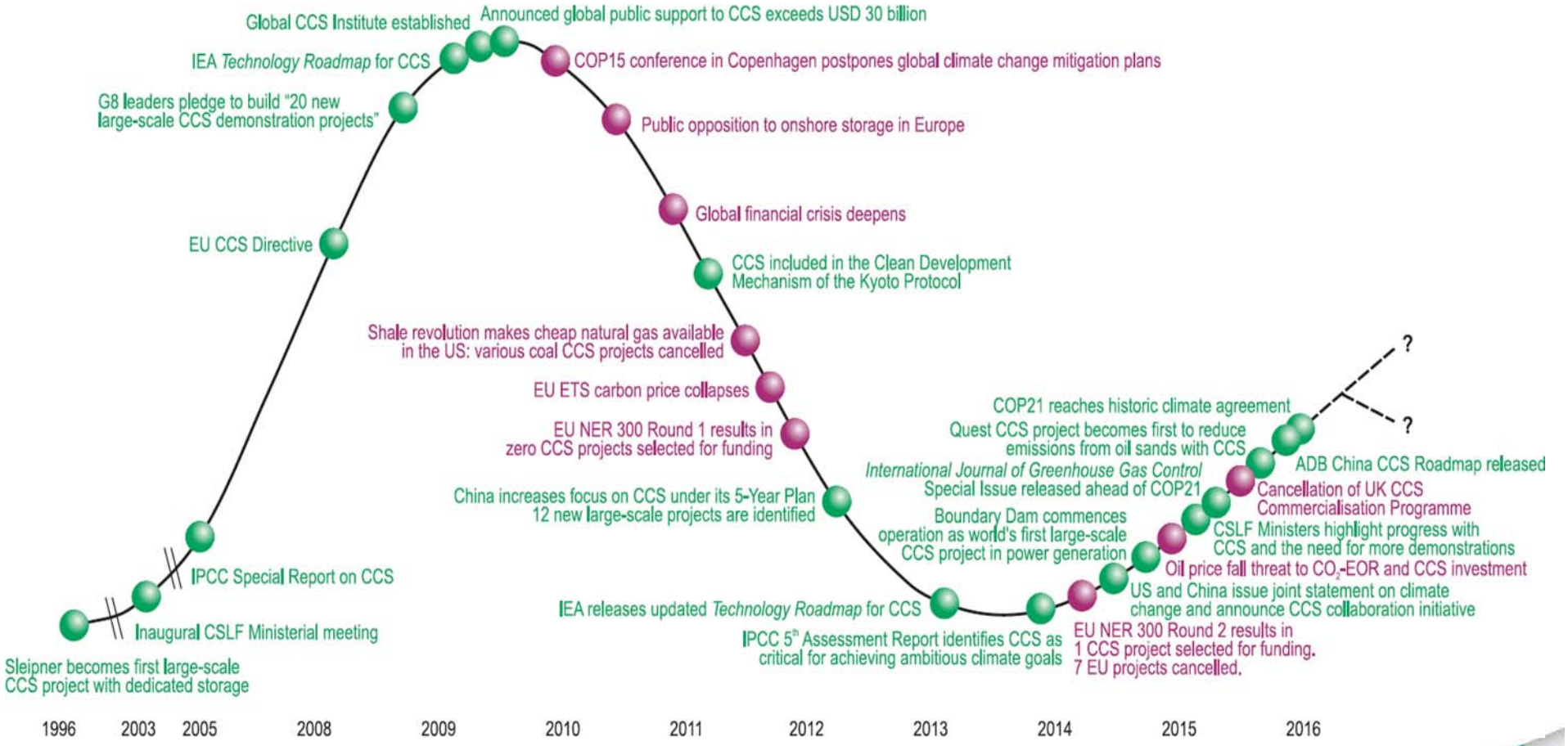
- Raise its profile (positively) on international stage – COP/IEA Ministerials, CEM etc
- CCS included in 11 NDC's (+USA) at COP21
    - 62% of CO2 emissions in 2013
- In particular with Developing Countries that will continue to use fossil fuels

UNFCCC Side event: "CCS Opportunities for Africa". 8th Nov 2016

Speakers from BHP/SaskPower, S.Africa, Nigeria, Ghana, UT BEG, CO2GeoNet, and IEAGHG (introducing and chairing).

Challenges for CCS (2)

- Consistent Policy support needed



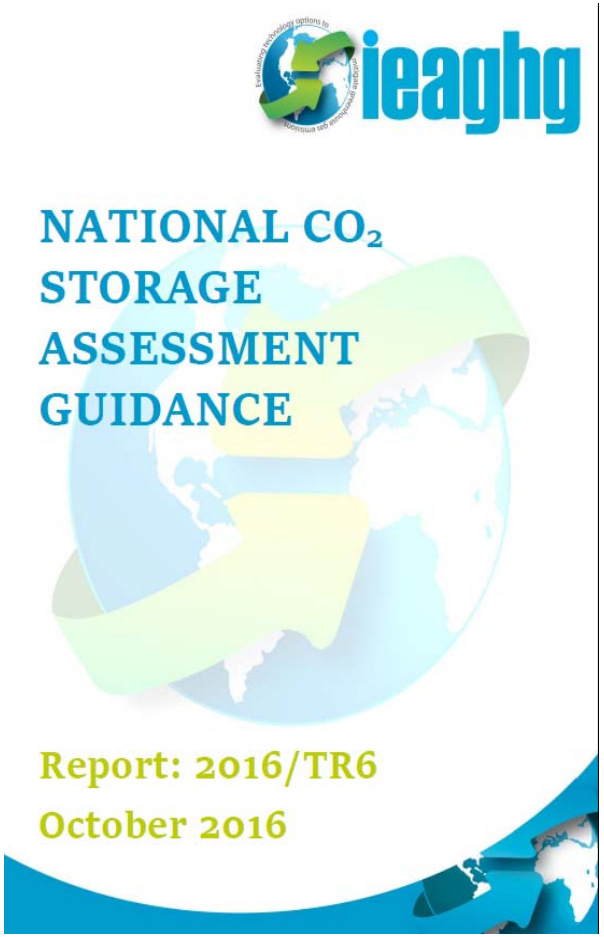
Source: **IEA (2016), *20 years of CCS: Accelerating Future Deployment*.**
Adapted from SBC Energy Institute (2016), *Low Carbon Energy Technologies Fact Book Update: Carbon Capture and Storage at a Crossroads*.

Challenges in Europe

- Focus on industry CCS
- Need to separate capture and transport/storage
  - Norwegian model/UK Competition learnings
- Build out from industrial hubs
  - UK – Teesside
- Build transport infrastructure into North Sea
  - Use EU Infrastructure Funds
- Is there the political will to start this process now?

Challenges for Developing Countries

- Prove their geological storage resource
- Knowledge transfer essential
- Financing for storage assessments required
  - Governments like Norway, USA etc co-ordinated by CSLF?
  - Clean Technology Centre and Network?
  - Global CCS Institute?
  - Oil and Gas Climate Initiative?



Summary

- Paris Agreement provides an opportunity window for CCS
- Significant progress made on CCS deployment around the globe
  - Positive Messaging needed
    - *You will never change entrenched mind-sets*
- Need to maintain momentum on CCS deployment but needs political support
- Europe we need to build out from industrial centres and get transport network in place
- Developing countries need help to start work on storage assessments now.

"*it all starts and ends with the rocks*"

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