An overview on the IEAGHG technical programme: CO_2 capture technologies for the power and industrial sectors, their integration, and potential to reduce costs

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Who are we?

Our internationally recognised name is the IEA Greenhouse Gas R&D Programme (IEAGHG). We are a Technology Collaboration Programme (TCP) and are a part of the International Energy Agency's (IEA's) Energy Technology Network.

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Evaluating technology options to mitigate greenhouse gas emissions
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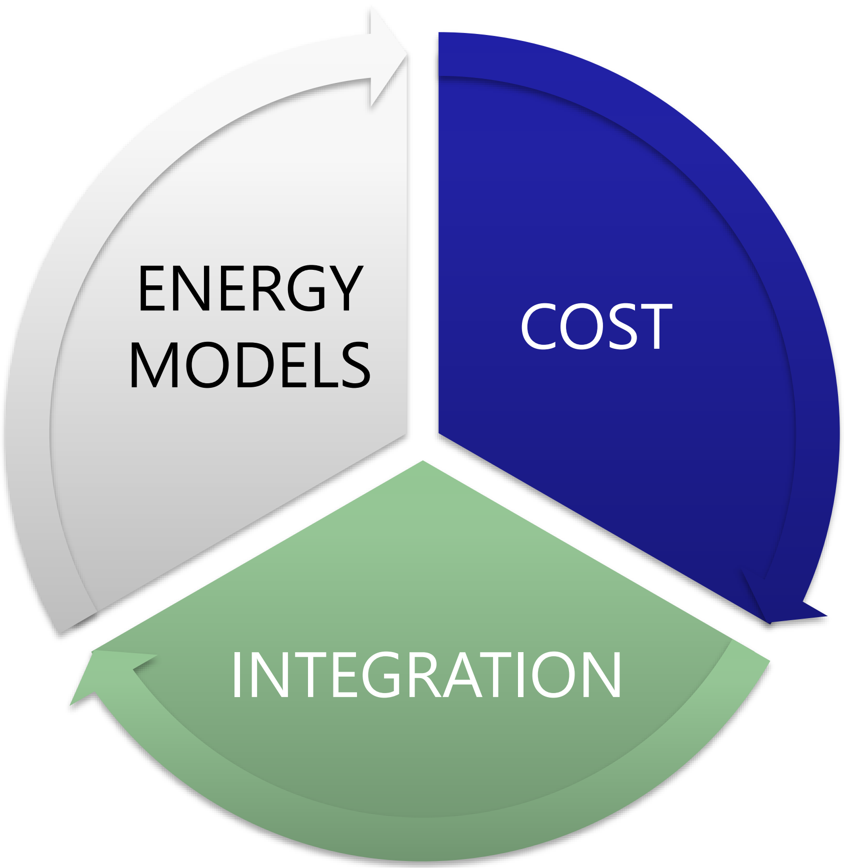
What I am going to talk about

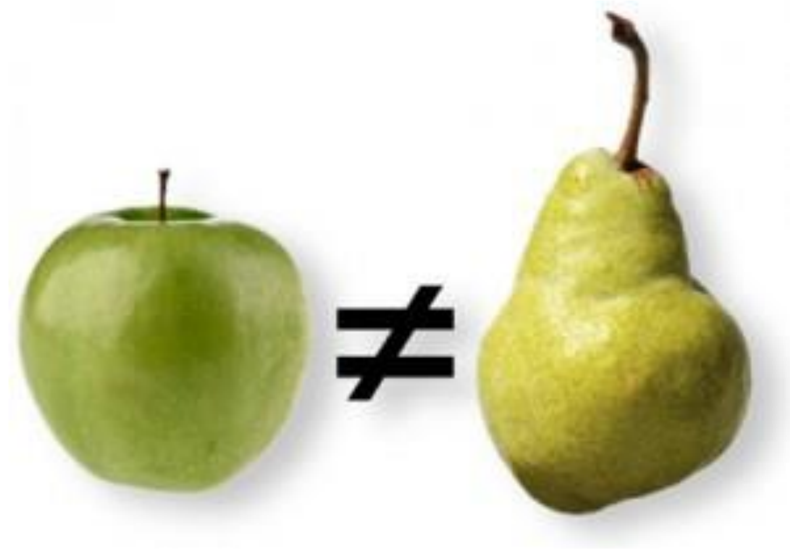
- The problem
- How we have studied the problem
  - Power
    - Towards zero emissions from fossil-fuel-fired power stations
    - Review of fuel cells with CCS
    - Valuing flexibility in CCS power plants (FlexEVAL)
  - Crosscutting issues
    - Effects of plant location on the costs of CO_2 capture
    - Further assessment of emerging CO_2 capture technologies and their potential to reduce costs **(Ongoing)**
    - Understanding the cost of reducing water usage in coal and gas fired power plants with CCS **(Ongoing)**
  - Industry
    - Cost of CO_2 capture in the industrial sector: cement and steel industries

The problem

- CO_2 capture is recognised as an important contribution to decarbonize the electricity system and the industrial sector
- BUT: price, integration, full CO_2 reduction?
- IEAGHG commissioned 7 studies in the 2017-2019 period, linked to power and industrial plants, and the concerns above

POWER PLANTS





Review of Fuel Cells with CO_2 capture

Literature review: current status	SOFCs and MCFCs, applications and configurations Large scale projects
Comparison with the benchmark case	Cansolv-based postcombustion
Economic review of data from the literature	Homogeneised by currency, year, plant size, and location Sensitivity analysis

Case	Description
Case 1a	Supercritical Pulverised Coal (PC) boiler plant
Case 1b	PC boiler plant with CCS (Cansolv CO_2 Capture Process)
Case 2a	Natural Gas Combined Cycle (NGCC) plant
Case 2b	NGCC plant with CCS (Cansolv)
Case 3a	Integrated Gasification Combined Cycle (IGCC) plant (GEE Radiant Gasifier)
Case 3b	IGCC plant (GEE) with CCS (2-Stage Selexol)
1	Atmospheric NGFC (utilising MCFC) + cryogenic CO_2 separation
2	Atmospheric IGFC+ utilising SOFC+ oxy-combustion+ condensation
3	Pressurised IGFC (utilising SOFC) + oxidation + flash cascade
4	Pressurised NGFC (utilising SOFC) + oxidation followed by flash cascade
5	Atmospheric MCFC with Natural Gas at the anode and exhaust from PC boiler at the cathode +oxy-combustion+ condensation

Doosan Babcock

Review of Fuel Cells with CO_2 capture

Doosan Babcock

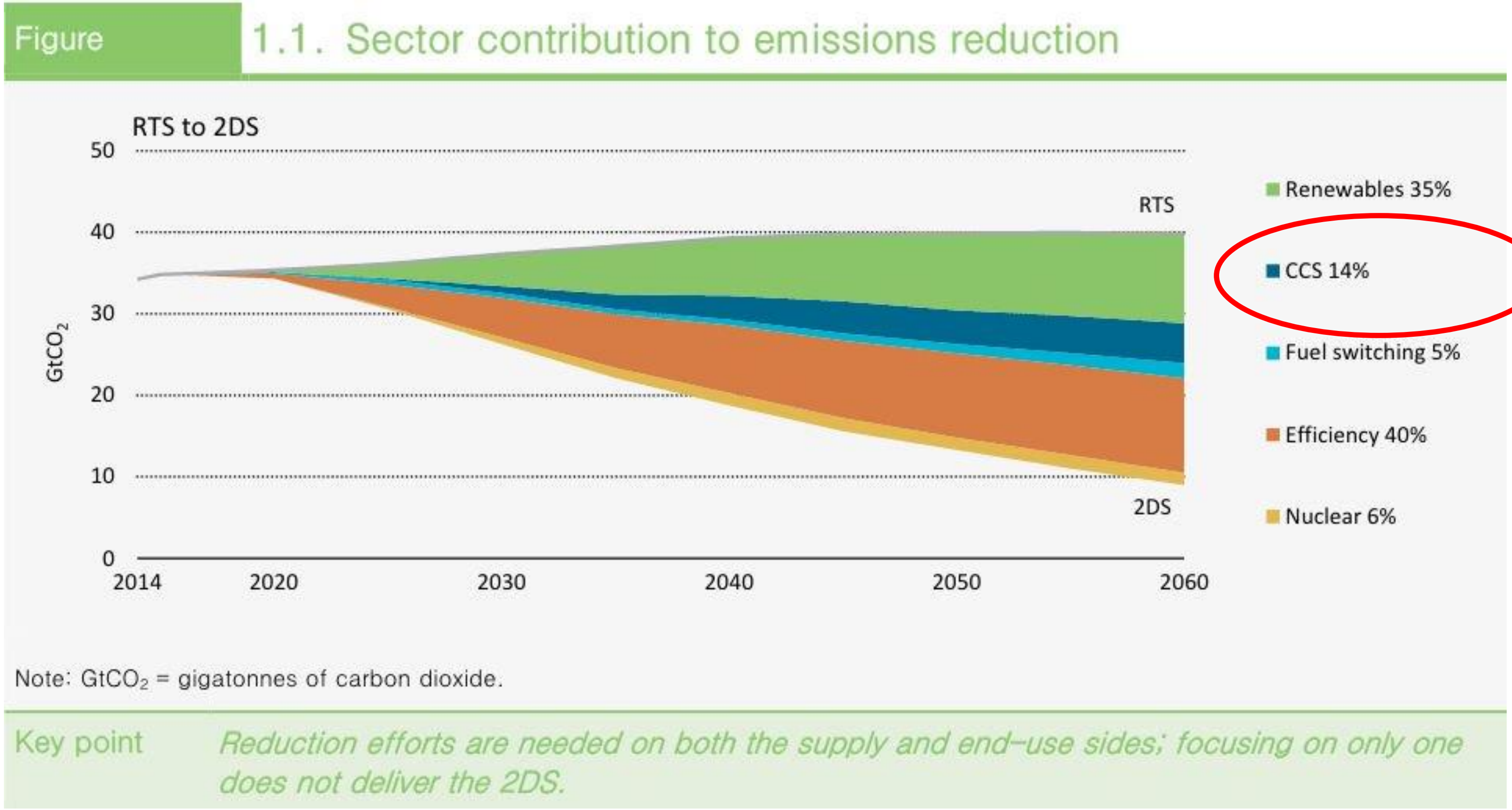
- The CO_2 avoided cost is low for case 5 (to note the methodology limitation), and still competitive LCOE

Case	Ref 1a	Ref 1b	Ref 2a	Ref 2b	Ref 3a	Ref 3b	1	2	3	4	5
Performance											
Net Power Output (MWe)	634	634	634	634	634	634	634	634	634	634	634
Net Plant HHV efficiency (%)	40.7	32.5	51.5	45.7	39.0	32.6	58.9	49.4	44.8	74.0	45.6
HHV Thermal Input (MWth)	1557.7	1950.8	1231.1	1387.3	1625.6	1944.8	1076.8	1283.4	1415.2	856.8	1389.7
CO_2 emissions (g/kWh)	774	97	357	40	782	93	98	1	0	0	113
CO_2 Capture (%)	0	90	0	90	0	90	72	>99	100	100	88
Cost											
Installed cost (2017 M€)	1653.4	2875.1	558.6	1208.7	1974.2	2761.3	800.7	3164.7	3234.2	3367.3	1185.1
LCOE (2017 € cent/kWh)	9.61	15.20	6.05	9.09	11.01	14.74	6.92	19.18	18.75	19.55	8.62
Cost of CO_2 avoided (2017 € /t CO_2)	N/A	82.6	N/A	96.0	N/A	54.2	33.5	104.7	99.0	378.2	-15.0

Review of Fuel Cells with CO_2 capture

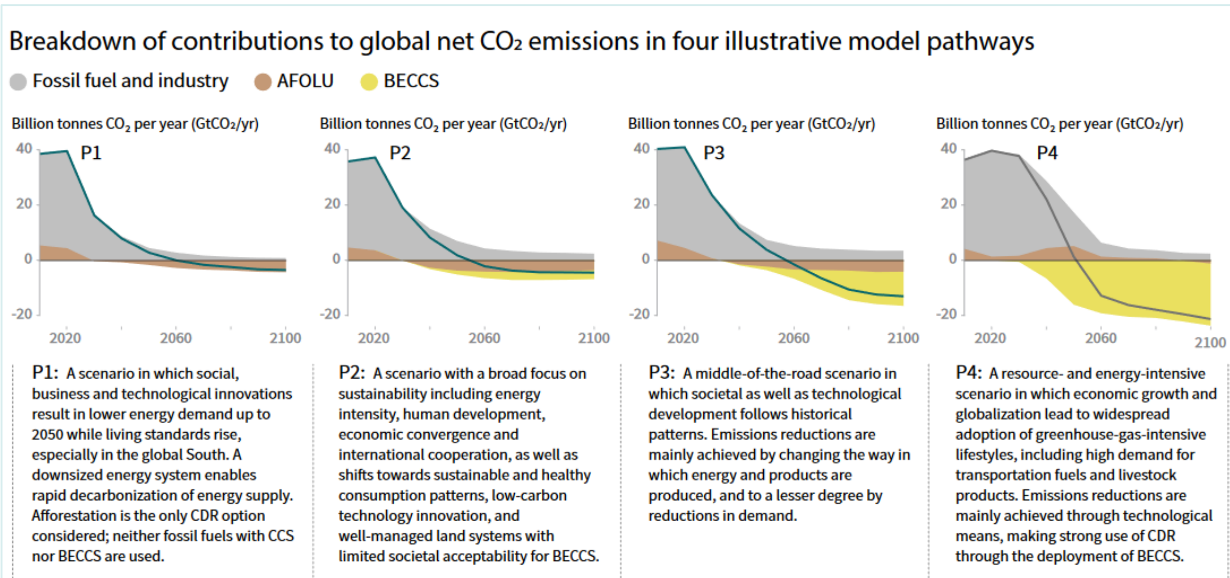
- The results of this study show that FC with CCS hybrid cycles have the potential to be competitive with current state of the art carbon capture technology but not yet there.

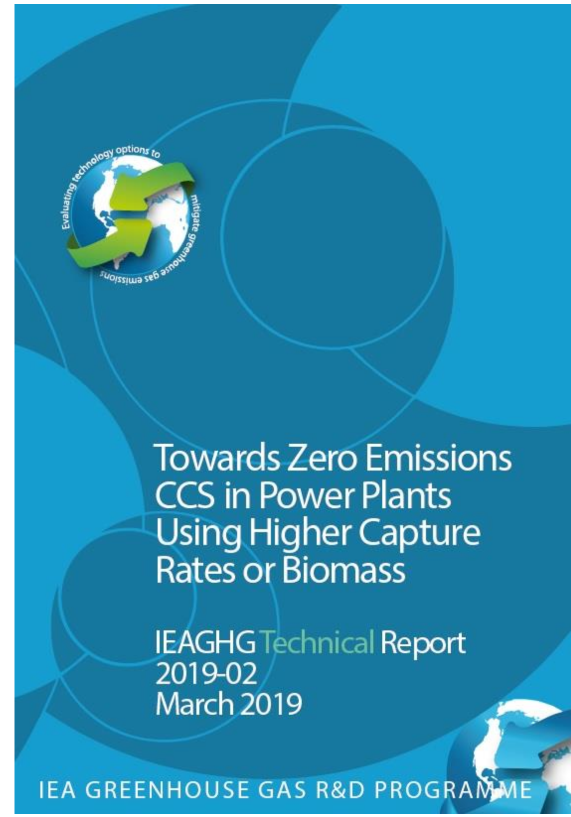
90% CAPTURE RATE… WHY?



https://www.iea.org/reports/energy-technology-perspectives-2017

Towards zero emissions from fossil-fuel-fired power stations





- **IEAGHG Note: IAMs typically assume Capture rate of 90% - this is a limiting factor for CCS deployment from IAMs later this century.**
  - https://www.ipcc.ch/report/sr15/

Towards zero emissions from fossil-fuel-fired power stations

Review of current energy models

Impact of 100% capture rate

Meaning in the B2DS

Review of capture rate of capture technologies

Theoretical performance

Experimental performance at large scale

Extract barriers to achieve capture rate >90%

Why capture rate has been limited to 90%

Recommendations, analysis of incentives

Techno-economic assessment for 90-99.7% capture rate

Towards zero emissions from fossil-fuel-fired power stations

More attention is needed on zero emission fossil fuel power plants using CCS in research and development: DEPLOYMENT

Increasing capture rate to 99.7% on USC coal plant with CCS, LCOE increased by 7% and CO_2 avoidance cost 3% (essential to demonstrate in practice)

DOES IT FIT?

Valuing flexibility in CCS power plants (FlexEVAL)

Identify the role of flexibility in UK electricity

It is not CCS alone that will achieve the decarbonisation of the power sector, but rather a well-balanced combination of technologies

Develop a metric to evaluate the wide benefit of technologies

LCOE is an intuitive metric BUT does not account for price and production variability of vies an indication for the impact a technology has on the energy economics or flexibility

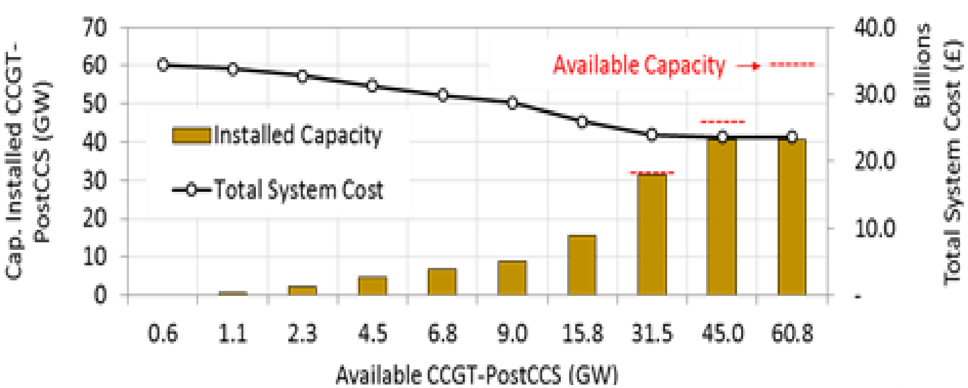
Quantify the value of CCS on the UK electricity system

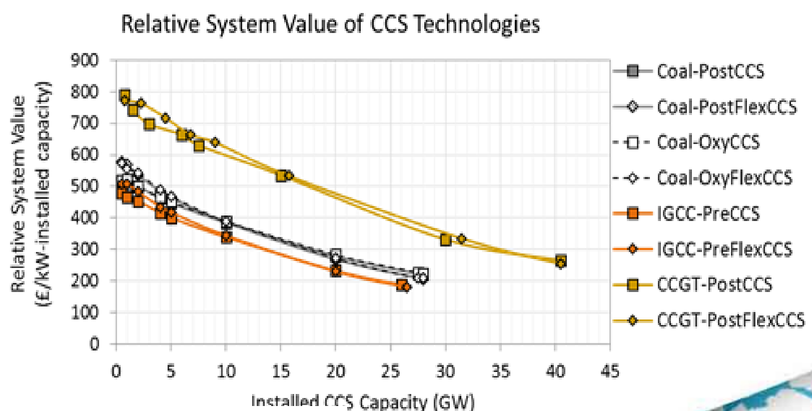
System Value (SV): marginal change in total electricity generation cost from integrating an additional unit of that technology

Intended to create a complete understanding for the system synergy and challenges

Valuing flexibility in CCS power plants (FlexEVAL)

- Flexible CCS provide and added VALUE by accommodating high level of intermittent renewable capacity, reducing Total System Cost. It reduces the interconnection capacity, reducing the electricity imports (also limited)
- The interaction of CCS technologies with renewable capacity is decisive. However, lower CCS use due to high use of renewables could disincentivise investment





Imperial College London

cep

Centre for Process Systems Engineering

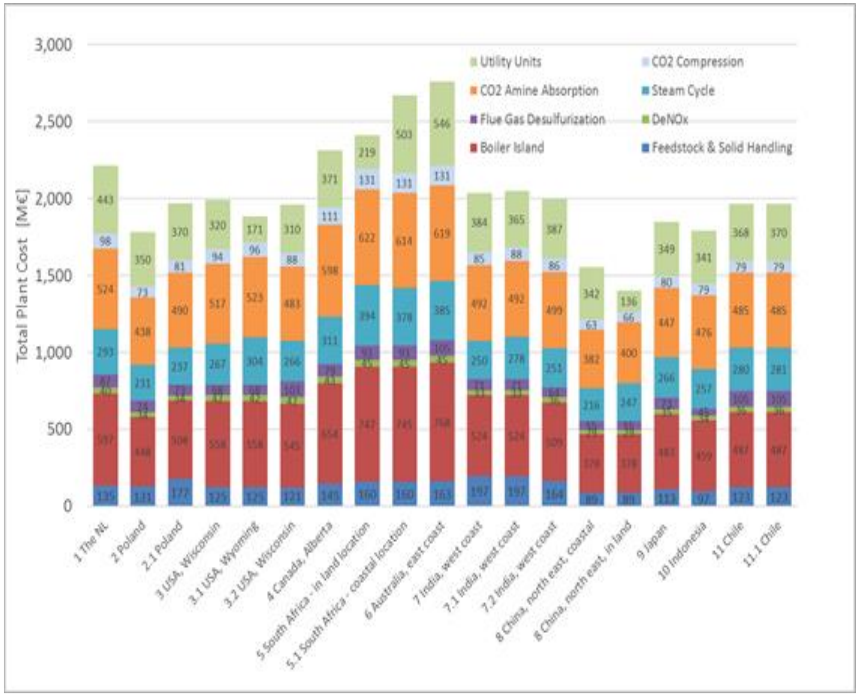
CROSSCUTTING ISSUES

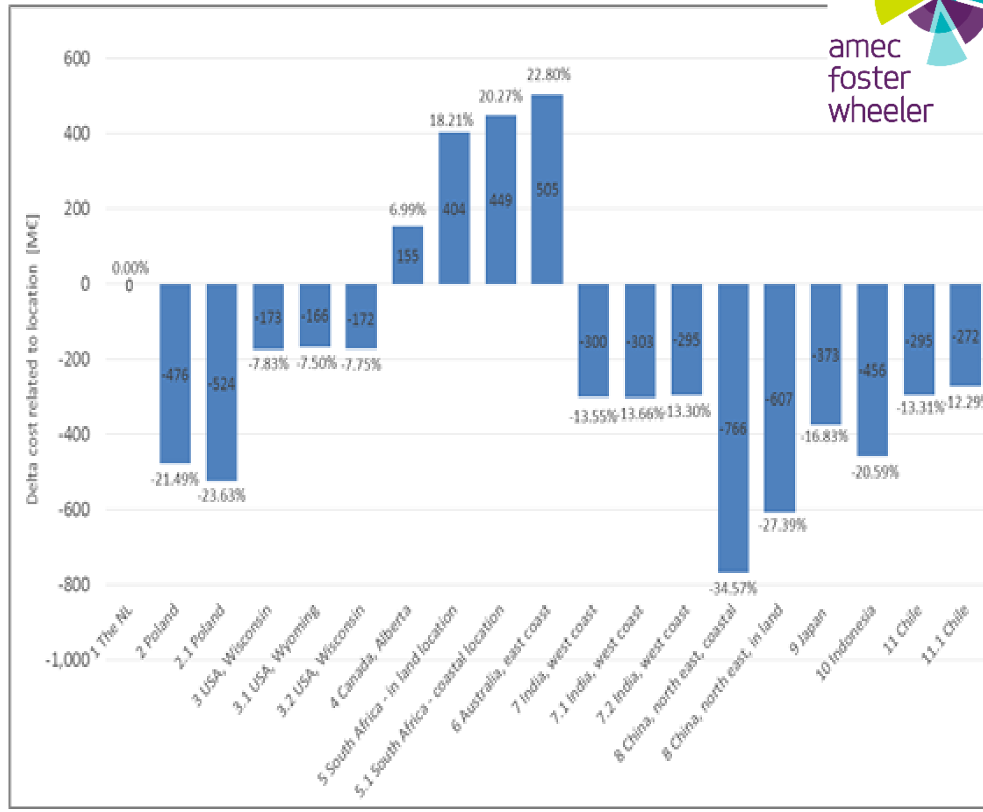
SAME SOLUTION WHEREVER YOU ARE?

Effects of plant location on the costs of CO_2 capture

Cost of CO_2 capture: general assessments	Regardless of design, ambient conditions or location
To provide technical and economic differences	Net efficiencies were changed per location (different efficiency penalties due to the PCC) Local costs were adjusted: CAPEX, OPEX and LCOE varied
Key factors	Where it is more convenient to install PCC in the power sector The impact on CAPEX, OPEX and LCOE

Effects of plant location on the costs of CO_2 capture





The design accounts for 20% of the plant cost and 25% on the specific plant cost

Lowest costs were found in China, highest cost in Australia and South Africa due to higher labour cost and lower productivity respectively (20% increase)

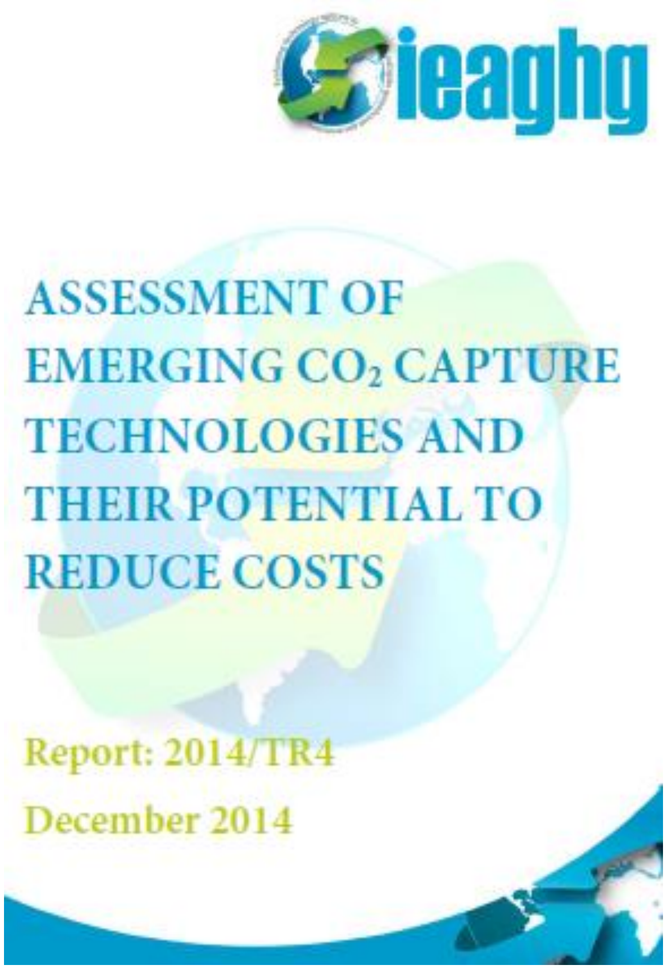
Understanding the cost of reducing water usage in coal and gas fired power plants with CCS

Overview of technologies, regulations and management techniques	Analysis of the global context
Assess the water usage with and without CCS and different cooling systems	The reuse of water from the geological storage on the power plant as a mitigation option
Techno-economic assessment	Analyse the techno-economic impact on the facilities

Understanding the cost of reducing water usage in coal and gas fired power plants with CCS

- It is possible to mitigate the water consumption increase due to a CO_2 capture system
- The re-use of extracted water can be convenient under specific conditions
- Regulations are key
- Challenges: option of reusing O&G infrastructure, design of the CCS system, salinity, distances

Further assessment of emerging CO_2 capture technologies and their potential to reduce costs



- Post-combustion was assessed as the most advanced system
- LCOE and the prospects for its reduction were assessed
- Cost-drivers, energy requirements were analysed
- This report needs continuous updates

Further assessment of emerging CO_2 capture technologies and their potential to reduce costs

Update on the benchmarking technology

- MEA-based chemical absorption is obsolete
- Other technologies are at commercial scale
- Emerging technologies should be compared to well stablished enhanced technologies

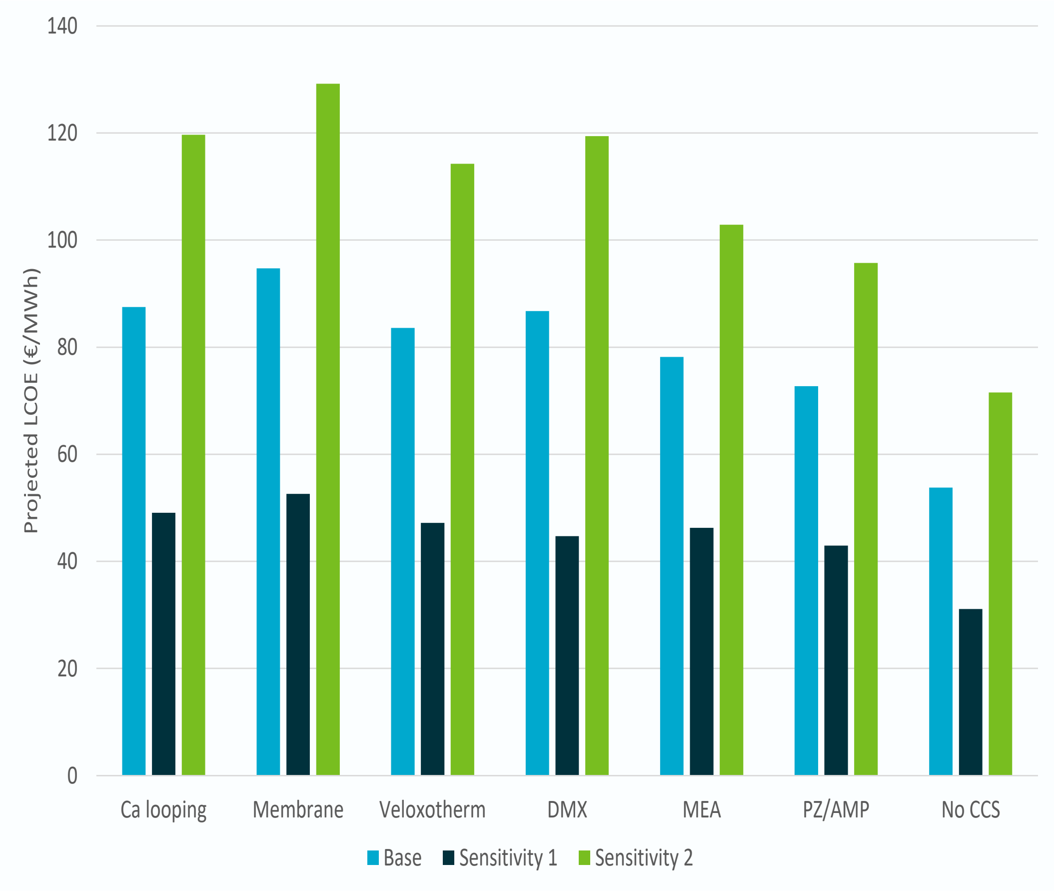
Review of TRL of current technologies

- Emerging and advanced technologies
- Evolution of its performance, costs, since 2013

Techno-economic assessment of technologies at high TRL

- Selection of the most advanced technologies
- Economic assessment under same framework and assumptions

Further assessment of emerging CO_2 capture technologies and their potential to reduce costs



Lowest cost showed by the new benchmark solution (chemical absorption)

BUT under specific conditons, others such as MEA, Veloxotherm, DMX or Ca-looping can be just slightly more expensive (perhaps under the limitations of this assessment)

Figure 2 Comparison of levelised cost of electricity (LCOE) of coal-fired technologies
CCS = carbon capture and storage; DMX = proprietary process developed at French Petroleum Institute Energies Nouvelles; MEA = monoethanolamine; PZ/AMP = piperazine/amino-methyl-propanol

INDUSTRY

Different fluegas, conditions, and integration….

Cost of CO_2 capture in the industrial sector: cement and iron and steel industries

Screening of publications

- Selection of transparent studies

Standardization of key input parameters

- North West European context
- Materials and energy flows for an average plant (plant size, capacity factor, grid CO_2 intensity, CO_2 compression outlet)
- CAPEX, OPEX
- Cost metrics

Thanks to the external reviewers

Assessment of technologies under three scenarios

- As in the literature
- No waste heat
- No selling electricity to the electricity grid

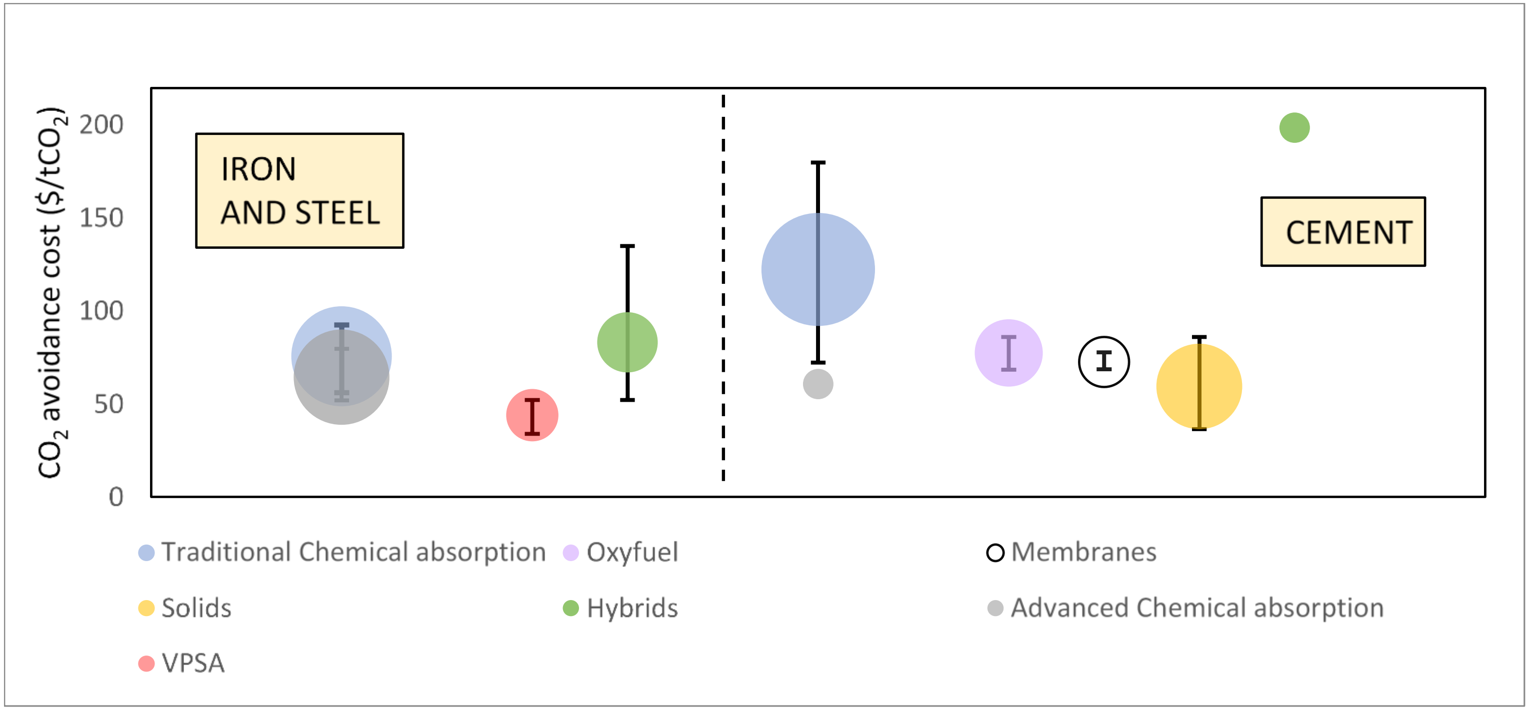
Sensitivity analysis

- Select technologies to go under analysis
- Under basic scenario: still differences on how the technologies were assessed

Cost of CO_2 capture in the industrial sector: cement and iron and steel industries

COST PARAMETER	SCENARIO	Cement						Iron and Steel[g]			
		Traditional chemical absorption	Advanced chemical absorption	Membrane	Oxy-	Solids-based	Hybrid[d]	Traditional chemical abs.	Advanced chemical abs.	VPSA	Hybrid[e]
CO_2 avoidance cost ($\$_{2016}$/ t CO_2 avoided)	BASIS	72-180	61	69-78	69-86	38-86	199	56-82	52-80	34-52	65-135
	No-heat-recovery	77-215	91	69-78[a]	69-86[a]	64-348	261	56-119	28-70	34-52[a]	81-135
	No electricity export	72-215	61	69-78[b]	69-86[b]	38-91	199[b]	69-93	12-37[f]	34-52[b]	52-90
CO_2 captured cost ($\$_{2016}$/ t CO_2 captured)	BASIS	34-79	45	51-57	50-63	11-63	146	16-21	7-16	11-14	23-66
	No-heat-recovery	34-93	59	51-57[a]	50-63[a]	21-68	171	17-30	7-18	11-14[a]	33-66
	No electricity export	36-101	45	51-57[b]	50-63[b]	20-67	146[b]	7-23[f]	3-9[f]	11-14[b]	33-44
Increase of manufacturing cost [c] ($\$_{2016}$/ t cement or steel)	BASIS	46-116	20	39	38-39	26-40	94	54-93	74-76	30-45	69-86
	No-heat-recovery	46-116	26	39[a]	38-39[a]	37-65	110	54-117	77-78	30-45[a]	69-86[a]
	No electricity export	49-116	20	39[b]	38-39[b]	40-74	94[b]	39-117[f]	36-37[f]	30-45[b]	69-86[b]

Cost of CO_2 capture in the industrial sector: cement and iron and steel industries



We cannot select the BEST technology for each sector. The review covered a wide range and the cost is very site-specific

Conclusions

- **THE DEVIL IS IN THE DETAILS**
- CCS must be evaluated individually for each region.
- LCOE does NOT represent the value of the technology within a complex electricity grid
- Any tool to achieve the decarbonised scenario must be implemented. **Reaching a CO_2 emissions reduction > 90% is essential**
- Chemical absorption is still the most advanced CO_2 capture technology. However, new systems are emerging
- Water consumption is an issue but can be mitigated
- Large demonstrations projects in the power and industrial sectors **are still needed**

ASK US FOR MORE INFORMATION!

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