

UK Costs for a Range of CCS Technologies

UK CCS Research Centre Biannual Conference,
Cambridge

27th March 2018



UK Costs for a Range of CCS Technologies

Agenda

1. Introduction
2. BEIS 2017 CCS Study Overview
3. Methodology
4. Key Assumptions
5. State of the Art Technology Results
6. Novel Technology Potential – 2 examples
7. Conclusions



UK Costs for a Range of CCS Technologies

Wood Overview

55,000

People

60+

Countries

400+

Offices



160+

Year history

\$10bn

Revenue (AMFW/WG) Combined

Sectors and markets we operate in:



Clean Energy



Chemical



Refining



Environment
and Infrastructure



Manufacturing



Marine
and Defence



Mining
and Minerals



Nuclear, Power
and Process



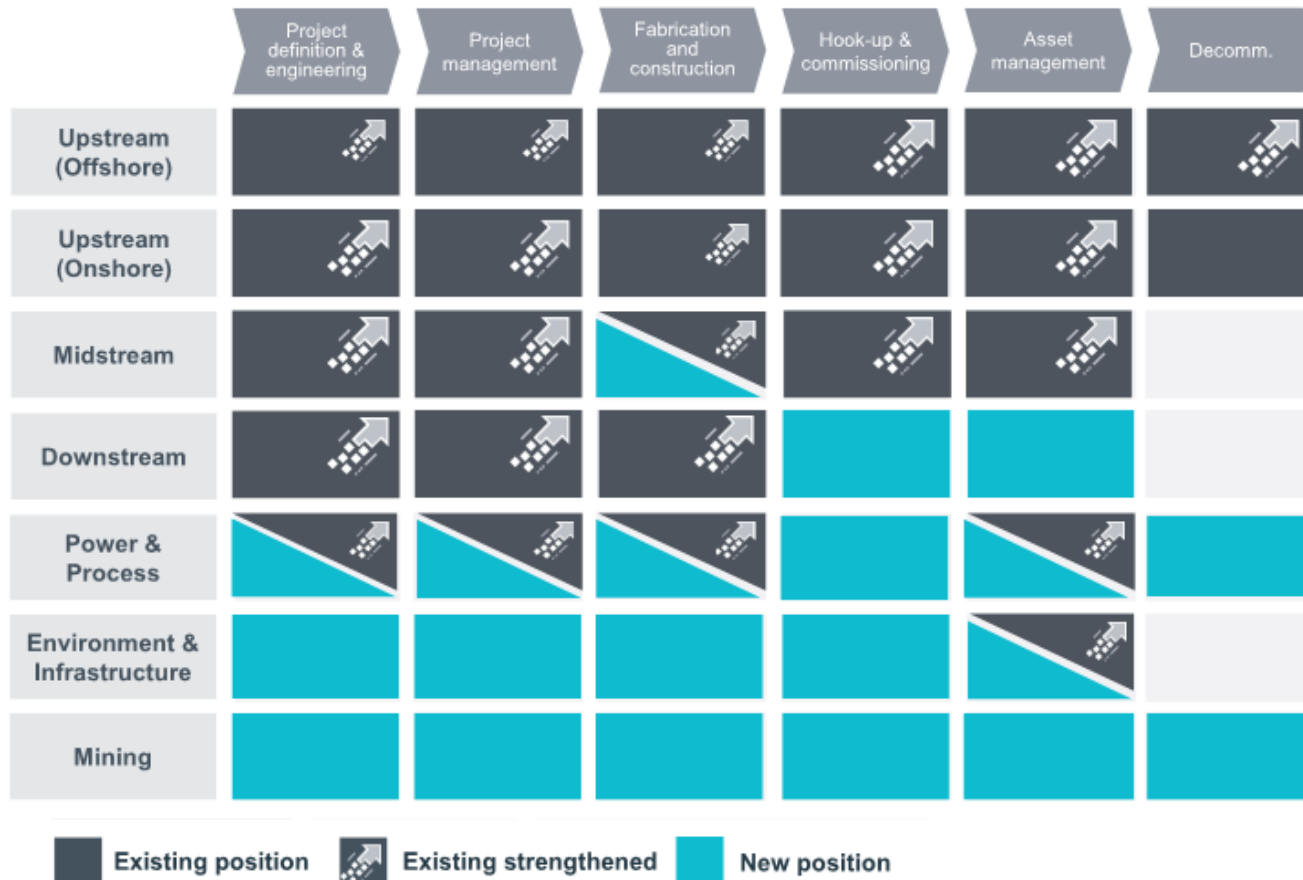
Oil & Gas



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Wood Overview

The recent combination has brought together world-class expertise from established brands, Wood Group (incl. legacy Mustang & Kenny), Amec and Foster Wheeler



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Introduction

- ▶ Wood, (formerly Foster Wheeler), has performed over 50 CCS studies since the mid-1990s.
 - ▶ Comparing state of the art technologies (benchmarking)
 - ▶ Assessing new technologies
- ▶ Performed several CCS FEEDs
 - ▶ DF-1 Peterhead
 - ▶ Hydrogen Power Abu Dhabi
 - ▶ E.ON Kingsnorth
 - ▶ Don Valley Power Project
- ▶ Various pre-FEEDs including:
 - ▶ Statoil Snøvit Train II
 - ▶ Cameroon LNG



Statoil appointed us to carry out the Pre-FEED study for a second LNG train at the Hammerfest plant

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Introduction

- ▶ Wood (formally Foster Wheeler) work has covered CCS from power generation, LNG liquefaction, refining, hydrogen production, CTL/GTL, natural gas treating, cement and steel production.
- ▶ All work incorporates equipment, construction and commissioning cost data from real projects built around the world.
- ▶ In 2017 we have been performing studies for several clients.
- ▶ This presentation will share results from a study in progress for UK Department for Business, Energy & Industrial Strategy (BEIS) with input from IEAGHG, ETI and others.



BEIS 2017 CCS Study Overview

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BEIS 2017 CCS Study Overview

- ▶ Key aims of the study included:
 - ▶ Technology performance & cost update of state of the art CCS technologies
 - ▶ Assessment of selected novel technologies, biomass & hydrogen schemes with CCS
- ▶ State of the Art CCS Technologies included:
 - ▶ Natural gas CCGT with proprietary amine-based post combustion capture
 - ▶ Natural gas reforming combined cycle with pre-combustion capture
 - ▶ Supercritical pulverised coal with proprietary amine-based post combustion capture
 - ▶ Supercritical pulverised coal with oxy-combustion capture
 - ▶ Coal gasification combined cycle with pre-combustion capture
- ▶ 2017 study aims to incorporate latest cost & technical performance:
 - ▶ improvements in the base power plants
 - ▶ further development & operational experience from CCS schemes in operation.



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BEIS 2017 CCS Study Overview

- ▶ Novel technologies, biomass & hydrogen CCS schemes:
 - ▶ Allam cycle natural gas oxy-combustion
 - ▶ Molten carbonate fuel cells for post combustion capture
 - ▶ Biomass CFB with post combustion capture*
 - ▶ Biomass CFB with oxy-combustion capture*
 - ▶ Biomass gasification combined cycle with pre-combustion capture*
 - ▶ Natural gas SMR hydrogen unit with post combustion capture*

*Results not included in this presentation

- ▶ Final report is not yet published, thus the results presented today are not yet set in stone.



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Methodology

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Methodology

- ▶ Source data for costs and plant performance:
 - ▶ Base power plant:
 - ▶ Simulation (Gatecycle & Hysys)
 - ▶ Published data from operating plants and vendors
 - ▶ CO₂ capture processes:
 - ▶ Developed from vendor data for similar projects or published data
 - ▶ Cansolv provided cost & performance data for all post combustion cases
 - ▶ CO₂ compression & dehydration
 - ▶ Developed from simulation & vendor data for similar projects
 - ▶ CO₂ transportation & storage
 - ▶ Applied as a cost penalty per tonne of CO₂ captured, not considered in detail.
- ▶ Material & energy balances provide basis for thermal efficiency calculation & high level equipment sizing.
- ▶ Capital & operating costs provide basis for levelised cost of electricity (LCOE).



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Key Assumptions

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Key Assumptions

- ▶ Greenfield site, coastal location in the North East of England.
- ▶ 9°C, 80% humidity, 400 ppmv CO₂ in air.
- ▶ UK grid natural gas, internationally traded bituminous coal.
- ▶ CO₂ compression to 110 bar (abs).

- ▶ Baseload power generation at:
 - ▶ 90% availability for post & oxy combustion cases
 - ▶ 85% availability for pre-combustion cases

- ▶ 1Q2017 cost figures in GBP
- ▶ Nth of a kind cost build up basis
- ▶ Equity financed
- ▶ 25 year life
- ▶ 8.9% discount rate
- ▶ Prices of feedstocks & CO₂ emissions based upon BEIS profiles



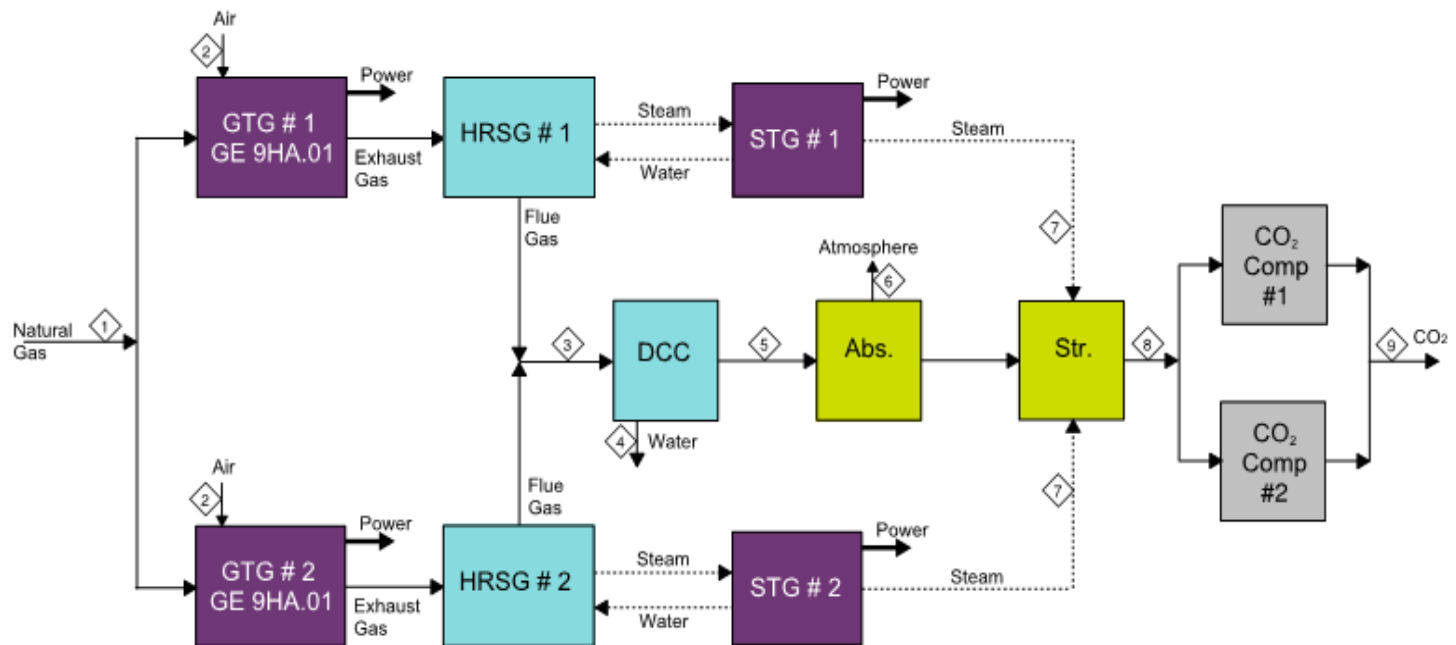
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State of the Art Technology Results

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State of the Art Technology Results

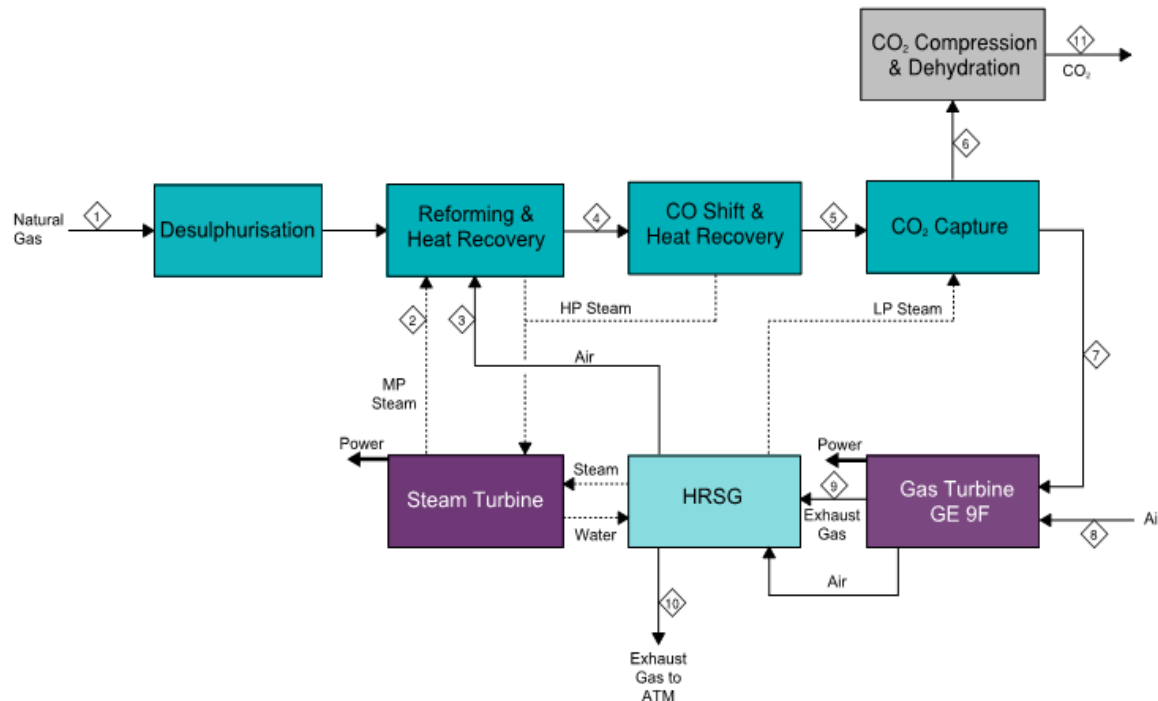
- ▶ Natural Gas CCGT with Cansolv CO₂ Capture
 - ▶ 2 x GE 9HA.01 gas turbines in combined cycle, scale 1,200 MWe nominal
 - ▶ Single train of CO₂ capture using combined concrete structure for direct contact cooler & absorber



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State of the Art Technology Results

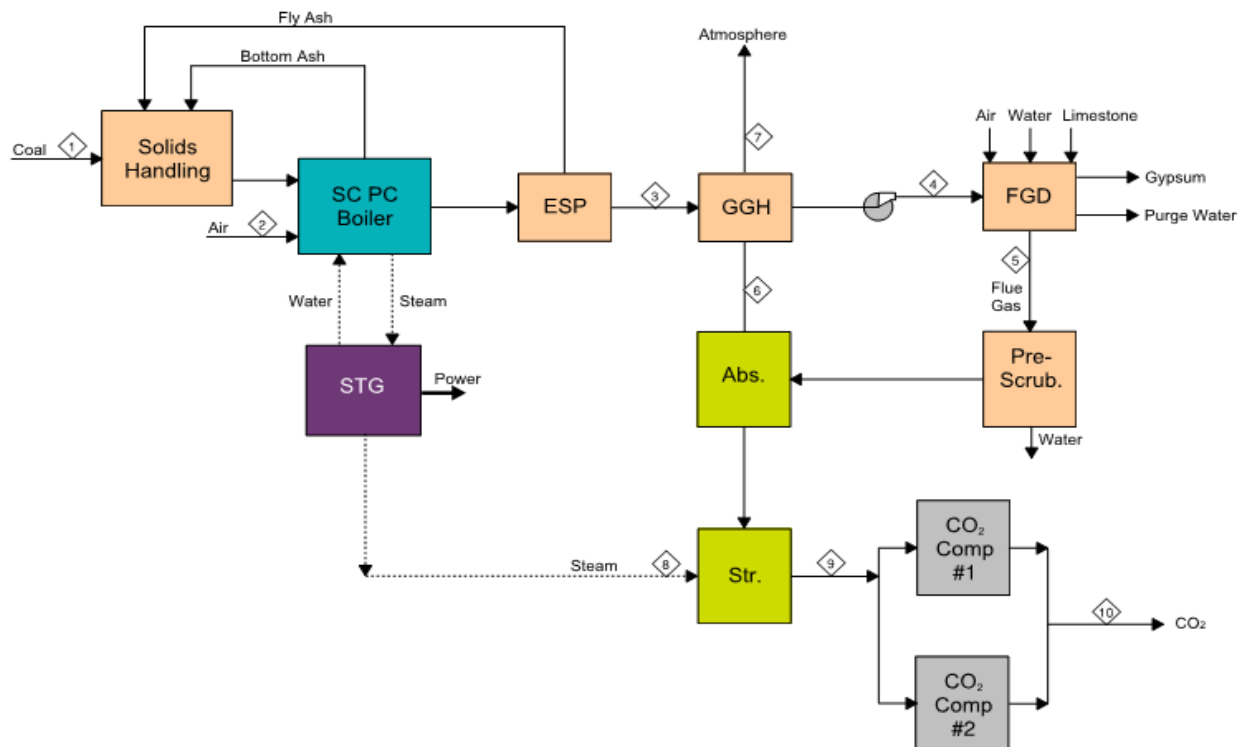
- ▶ Natural Gas reforming combined cycle with pre-combustion CO₂ capture
 - ▶ 40 bar auto-thermal reformer
 - ▶ 2 x GE 9F syngas variant gas turbines in combined cycle, scale 950 MWe nominal
 - ▶ Two trains of full system including Selexol process for CO₂ capture.



UK Costs for a Range of CCS Technologies

State of the Art Technology Results

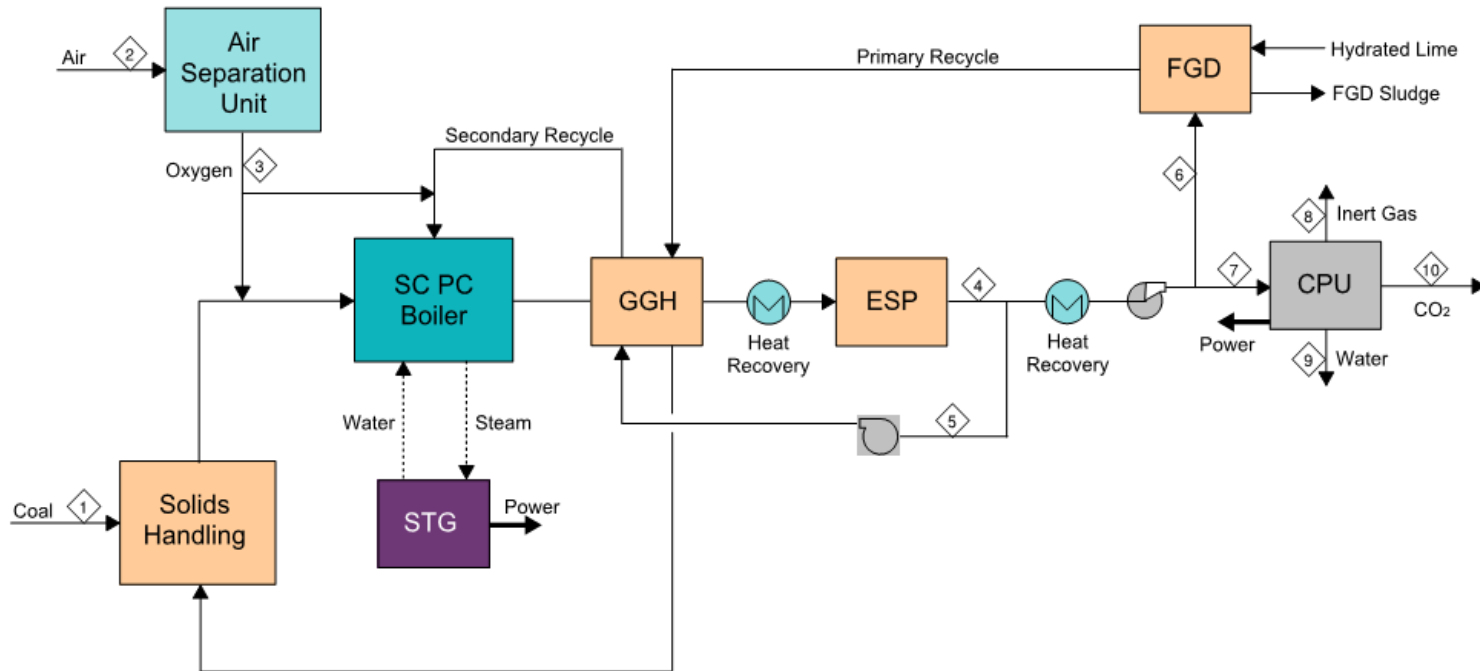
- ▶ Supercritical pulverised coal with Cansolv CO₂ capture
 - ▶ Steam generator at 620°C & 270 bar with MP reheat and a steam turbine at a 1000 MWe nominal scale.
 - ▶ Single train of CO₂ capture using combined concrete structure for pre-scrubber & absorber.



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State of the Art Technology Results

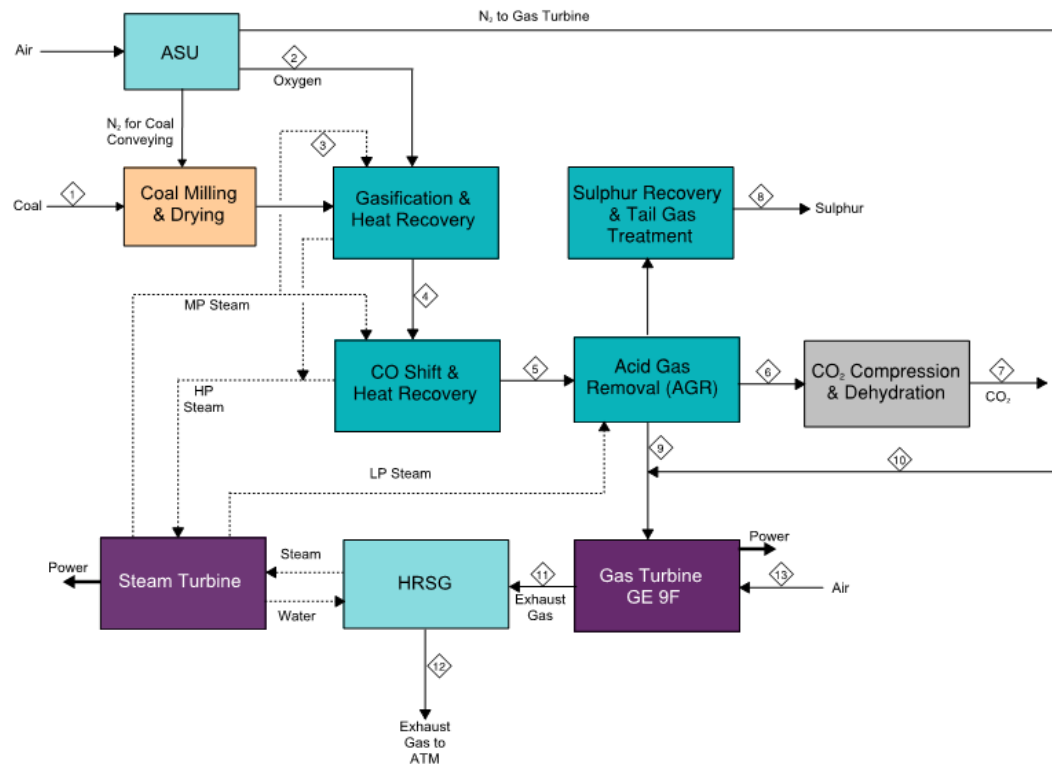
- ▶ Supercritical pulverised coal with oxy-combustion CO₂ capture
 - ▶ Steam generator at 620°C & 270 bar with MP reheat and a steam turbine at a 1000 MWe nominal scale.
 - ▶ CO₂ purification & compression based upon Air Products process.
 - ▶ Cryogenic ASU.



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State of the Art Technology Results

- ▶ Integrated gasification combined cycle with pre-combustion CO₂ capture
 - ▶ 40 barg Shell gasification process
 - ▶ 2 x GE 9F syngas variant gas turbines in combined cycle, scale 1050 MWe nominal
 - ▶ Two trains of full system including Selexol process for CO₂ capture.



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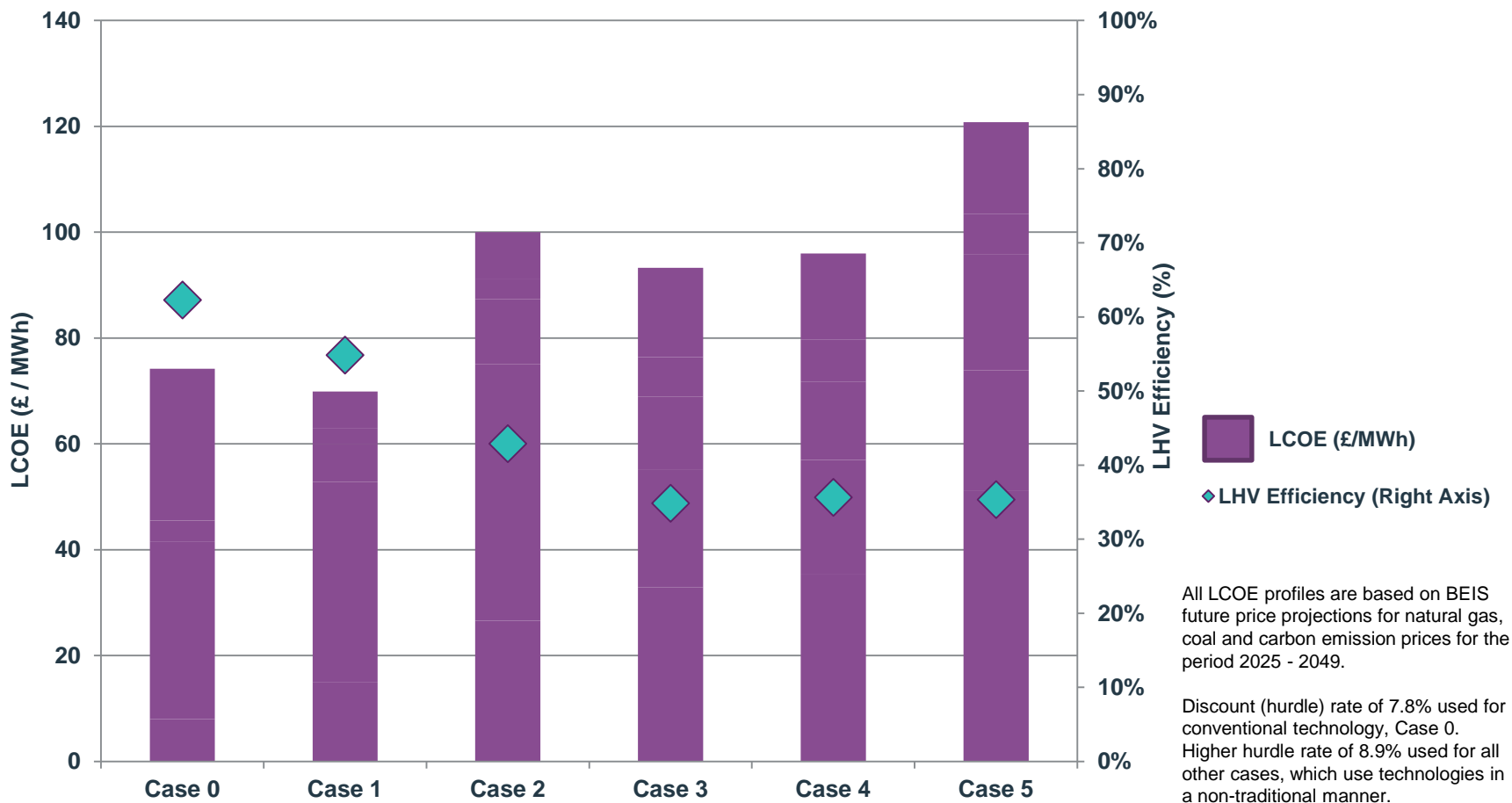
State of the Art Technology Results

		Unabated CCGT	Post-Combustion on Gas	Pre-Combustion on Gas	Post-Combustion on Coal	Oxy-Combustion on Coal	Pre-Combustion on Coal
	Units	0	1	2	3	4	5
Total gross installed capacity	MWe	1229.4	1144.3	919.1	953.5	1112.8	1062.8
Total auxiliary loads	MWe	20.9	79.7	101.3	139.4	280.2	263.0
Net Power Export	MWe	1208.5	1064.6	817.9	814.2	832.6	799.8
Net Efficiency - Year 1 (LHV)	%	62.3%	54.9%	42.9%	34.9%	35.7%	35.3%
Net Efficiency - Year 1 (HHV)	%	56.2%	49.5%	39.0%	33.3%	34.1%	33.8%
Total CO ₂ captured	kg/h	0	361539	353319	692310	685896	673147
Carbon capture rate	%	0.0%	90.8%	90.4%	90.0%	89.2%	90.3%
Carbon Footprint	kg CO ₂ /MWh	329.4	34.3	45.8	94.6	100.2	90.4
Direct Materials Cost	£M	335.3	493.5	649.6	853.1	903.7	1152.2
EPC Contract Cost	£M	583.6	845.3	1107.1	1547.4	1701.6	2151.1
Total Project Cost	£M	672.2	968.2	1,256.3	1,732.2	1,901.9	2,396.3
Total Operating Cost (excl. Fuel & Carbon)	£M pa	36.4	109.8	118.5	188.6	195.1	215.6
Income from Elec Export	£M pa	730.6	586.9	609.3	598.8	630.2	719.6
Levelised Cost of Electricity	£/MWh	74.2	69.9	100.0	93.3	96.0	120.8
Cost of CO ₂ Avoided	£/tCO ₂	0	-14.5	91.1	81.3	95.1	195.1



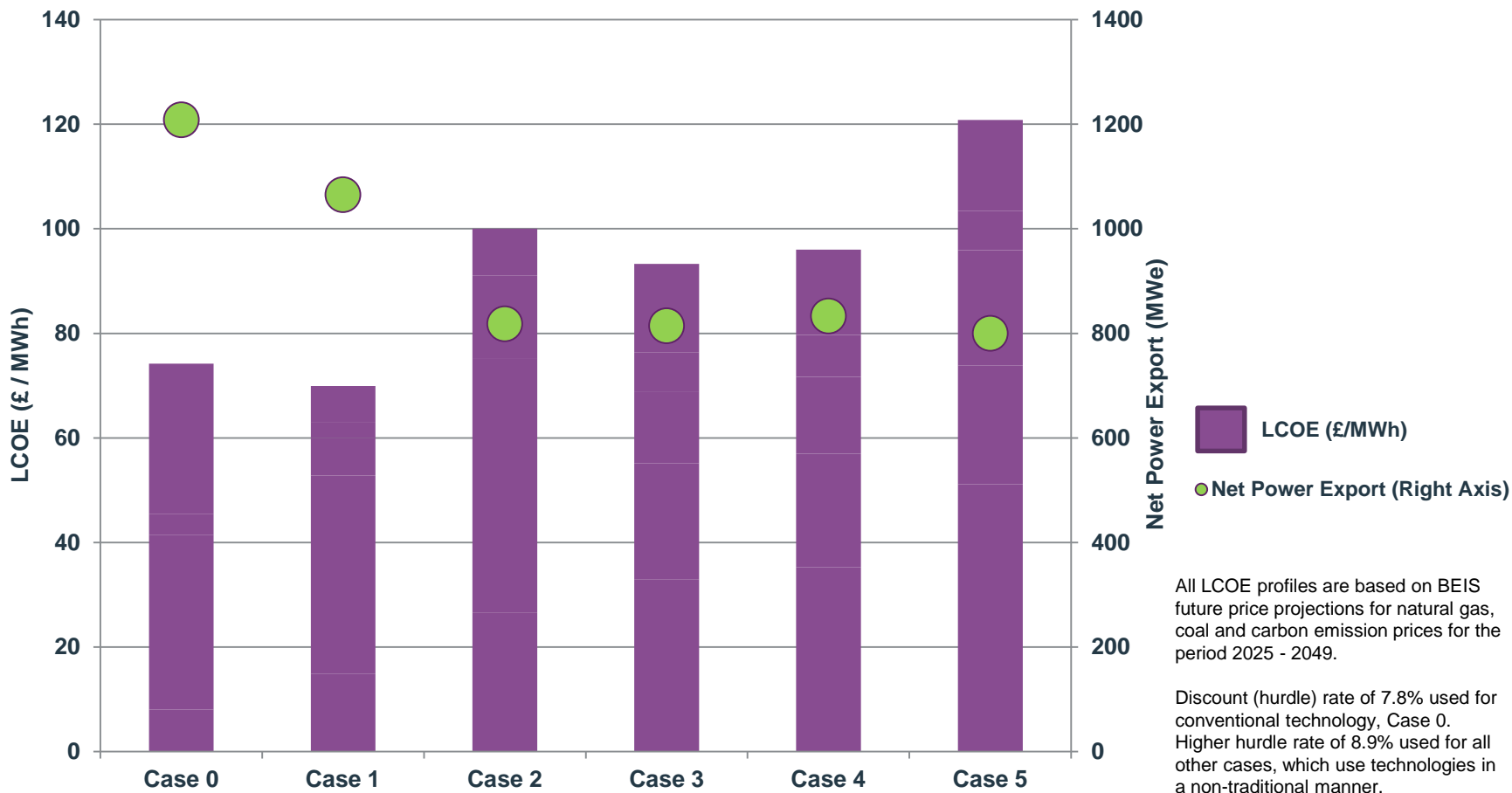
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State of the Art Technology Results



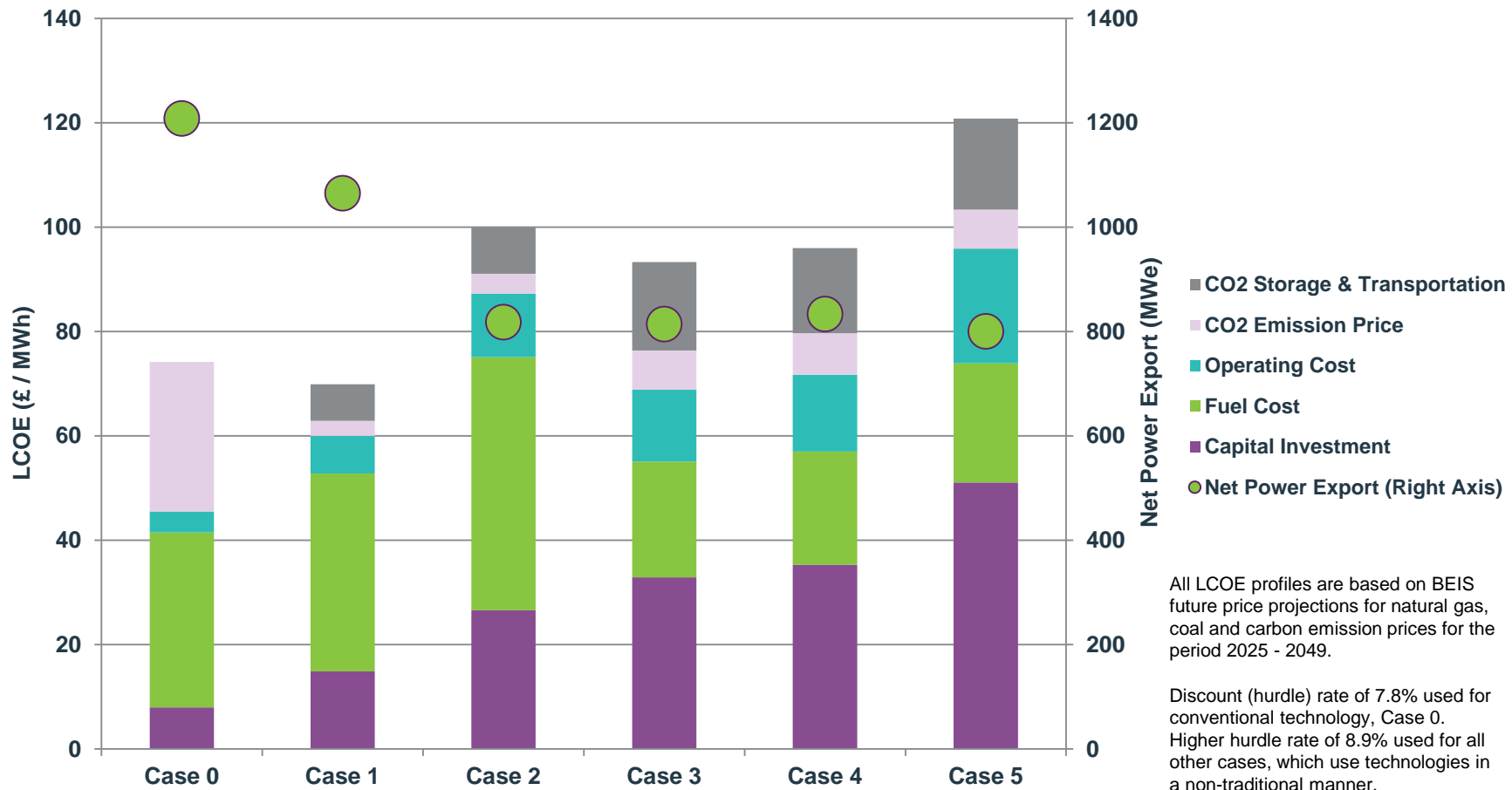
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State of the Art Technology Results



UK Costs for a Range of CCS Technologies

State of the Art Technology Results



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Novel Technology Potential – 2 Examples

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Novel Technology Results – 2 Examples

- ▶ Modelled from public domain data
- ▶ Higher degree of technical risk
- ▶ Modelled as Nth of a kind to assess future potential once commercialised
 - ▶ Allam cycle natural gas oxy-combustion
 - ▶ Natural gas is combusted with oxygen at high pressure & temperature
 - ▶ Hot combustion products drive a turbine
 - ▶ Integrated heat recovery systems
 - ▶ Cryogenic ASU & CO₂ purification
 - ▶ Molten carbonate fuel cells for post combustion capture
 - ▶ Natural gas combined cycle power plant (2 x GE 9HA.01s)
 - ▶ Flue gas used as oxidant stream in natural gas fed MCFCs
 - ▶ MCFCs generate power while capturing CO₂ from the flue gas
 - ▶ Unconverted fuel returned to MCFC fuel inlet
 - ▶ Cryogenic CO₂ purification



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Novel Technology Results – 2 Examples

		Unabated CCGT	Post- Combustion on Gas	Allam Cycle on Gas	MC Fuel Cell on Gas	Post- Combustion on Coal
	Units	0	1	6	7	3
Total gross installed capacity	MWe	1229.4	1144.3	1263.9	1645.0	953.5
Total auxiliary loads	MWe	20.9	79.7	415.5	136.4	139.4
Net Power Export	MWe	1208.5	1064.6	848.4	1508.6	814.2
Net Efficiency - Year 1 (LHV)	%	62.3%	54.9%	55.2%	59.7%	34.9%
Net Efficiency - Year 1 (HHV)	%	56.2%	49.5%	50.2%	43.2%	33.3%
Total CO ₂ captured	kg/h	0	361539	283546	477597	692310
Carbon capture rate	%	0.0%	90.8%	90.0%	92.1%	90.0%
Carbon Footprint	kg CO ₂ /MWh	329.4	34.3	37.1	27.1	94.6
Direct Materials Cost	£M	335.3	493.5	583.2	815.8	853.1
EPC Contract Cost	£M	583.6	845.3	1067.9	1392.0	1547.4
Total Project Cost	£M	672.2	968.2	1,213.2	1,569.6	1,732.2
Total Operating Cost (excl. Fuel & Carbon)	£M pa	36.4	109.8	98.8	180.4	188.6
Income from Elec Export	£M pa	730.6	586.9	535.5	840.4	598.8
Levelised Cost of Electricity	£/MWh	74.2	69.9	80.1	70.7	93.3
Cost of CO ₂ Avoided	£/tCO ₂	0	-14.5	20.0	-11.7	81.3



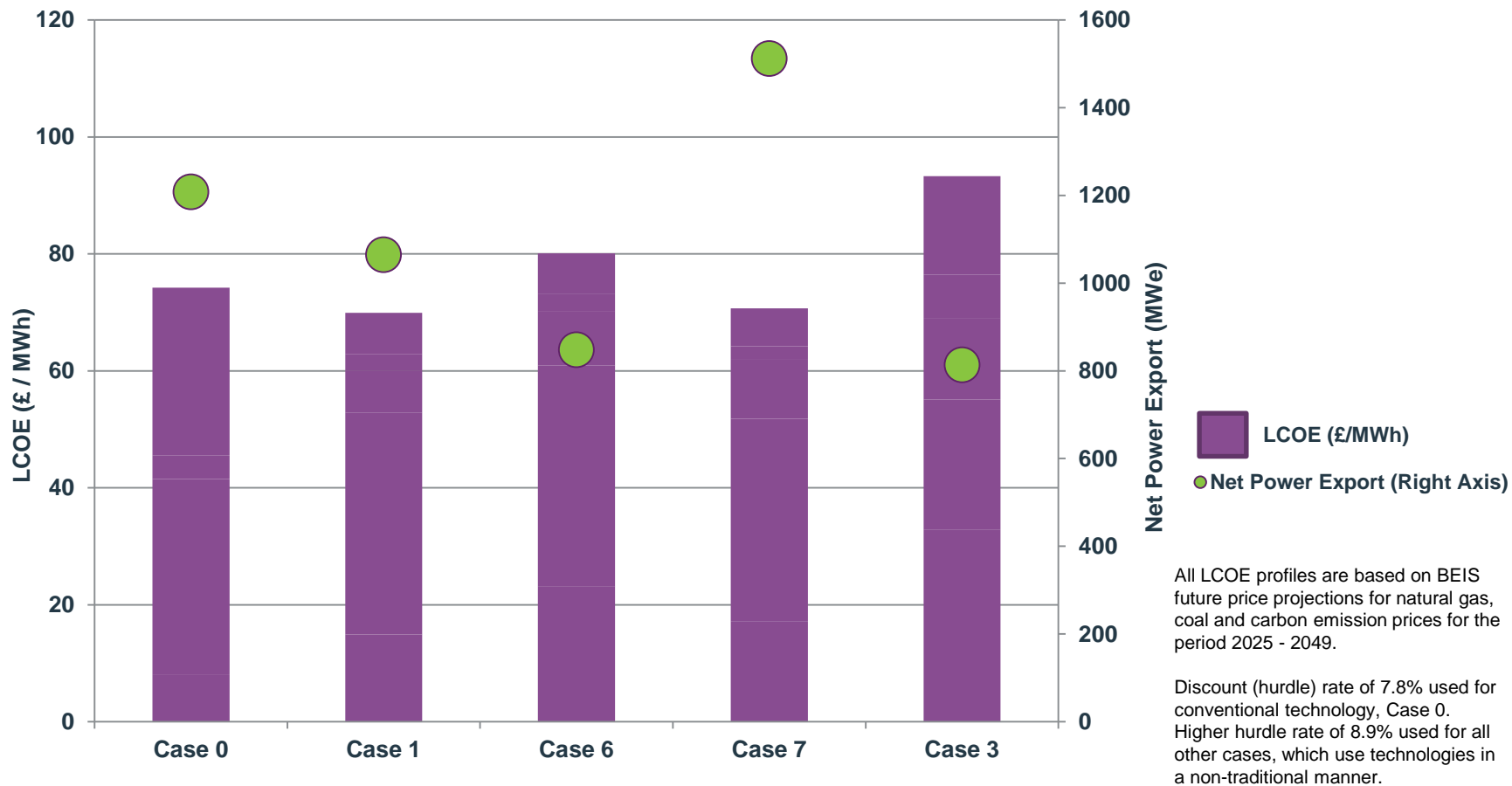
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Novel Technology Results – 2 Examples



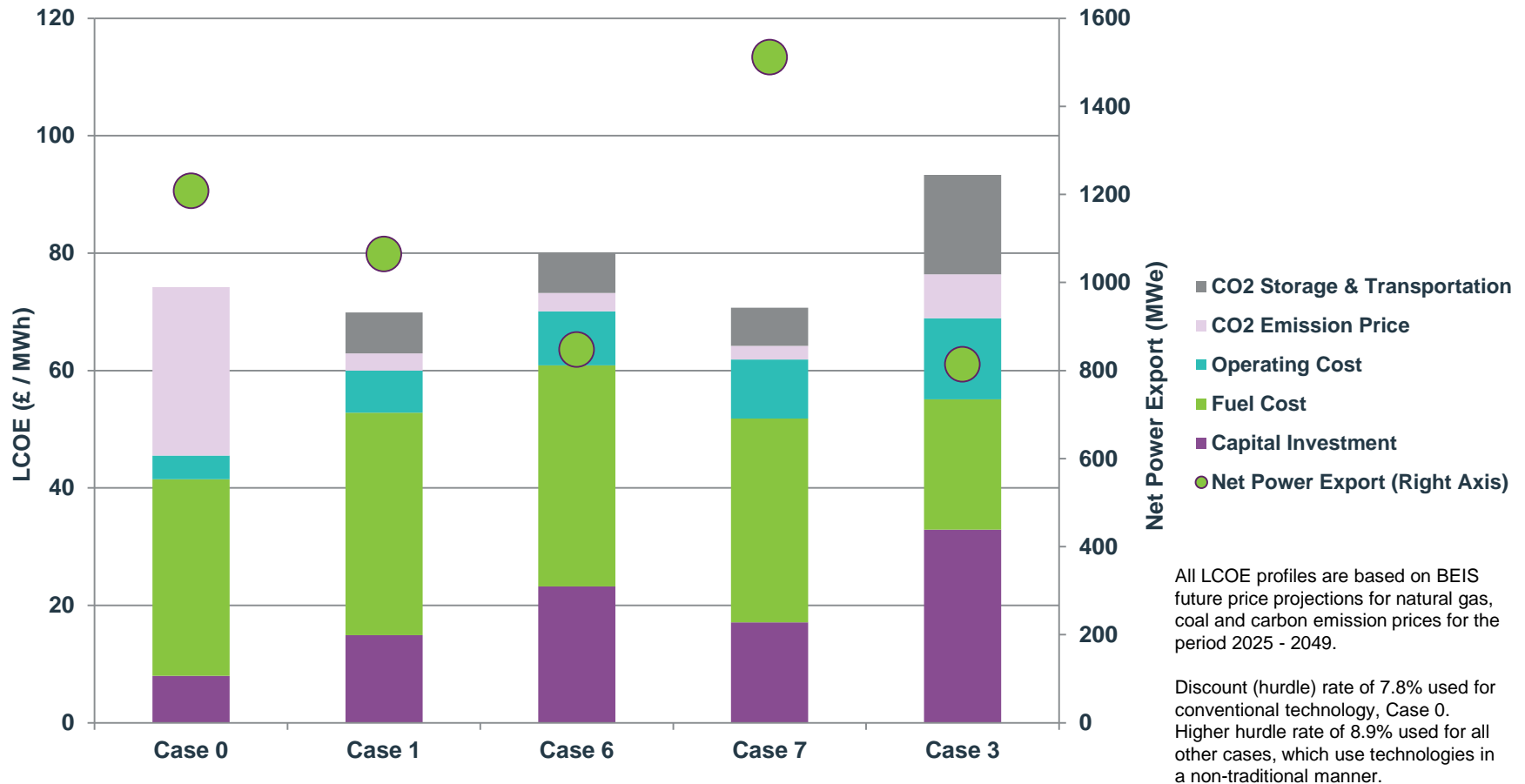
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Novel Technology Results – 2 Examples



UK Costs for a Range of CCS Technologies

Novel Technology Results – 2 Examples



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Conclusions

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Conclusions

- ▶ Lowest cost LCOE with carbon capture is still CCGT with proprietary solvent by a significant margin, results suggest this is due to;
 - ▶ high efficiency & low capital cost of base plant
 - ▶ clean fuel results in CO₂ capture conditions less challenging than some
 - ▶ less carbon to be captured and compressed per unit of electricity generated
- ▶ Post combustion routes appear most attractive (with oxy not far behind)
 - ▶ For baseload operation producing power, flexibility advantages of pre-combustion routes (e.g. hydrogen production) cannot be quantified.
- ▶ Two of the leading novel technologies appear well positioned to compete with proprietary solvents for base load power generation if they can reduce their capital costs or improve efficiencies further.
- ▶ **LCOE with carbon capture could be achieved at:**
 - ▶ **£69.9/MWh on gas at a carbon footprint of 34 kg CO₂/MWh**
 - ▶ **£93.3/MWh on coal at a carbon footprint of 95 kg CO₂/MWh**



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Thank you!

Questions?

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