CMTC 2017

An update on the state of CCS in the UK

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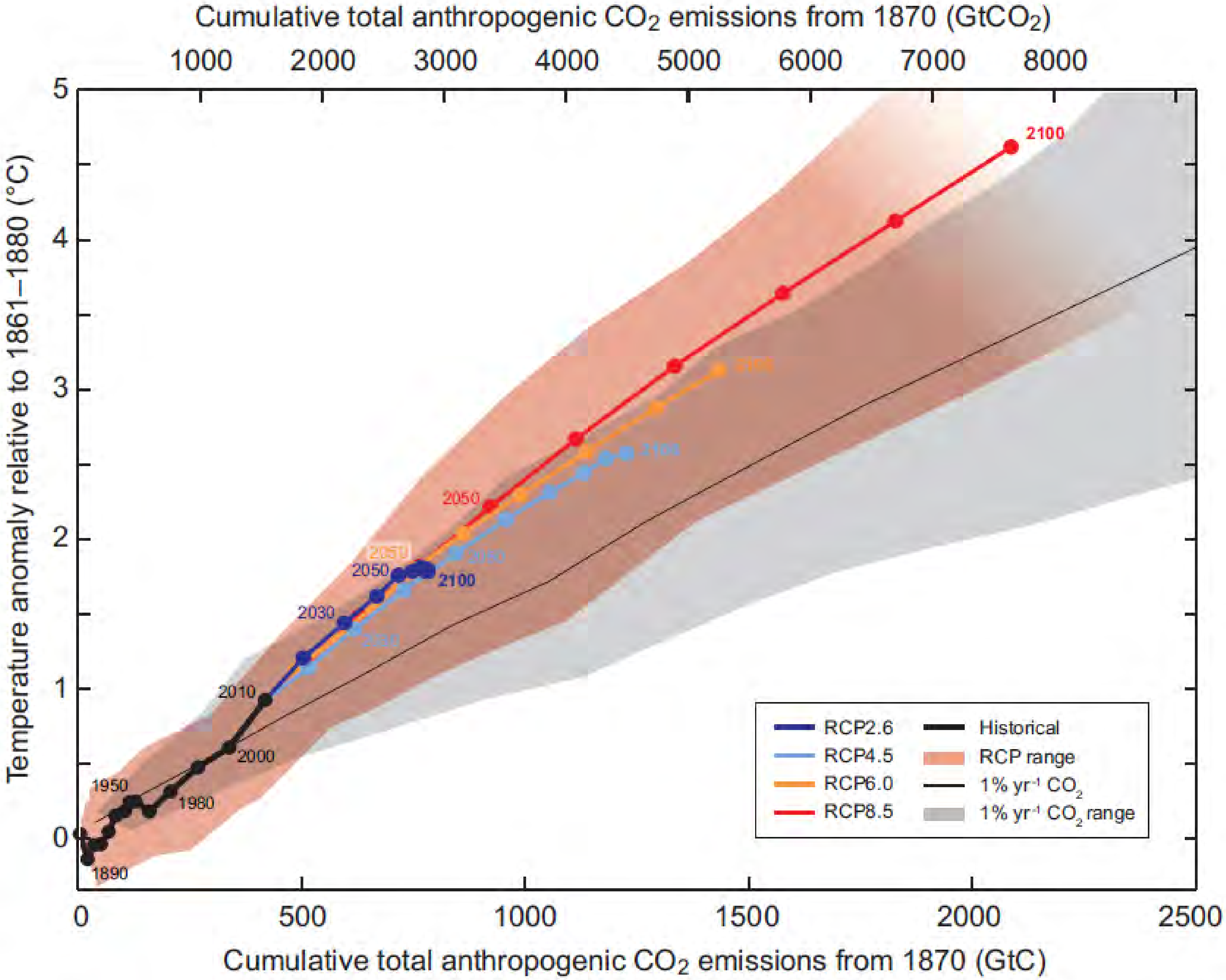
Pioneering research and skills

The Climate Problem

IPCC Climate Change 2013 'The Physical Science Basis'

http://www.ipcc.ch/report/ar5/wg1/



The Paris Agreement

http://unfccc.int/paris_agreement/items/9485.php

UNITED NATIONS
2015

Article 4

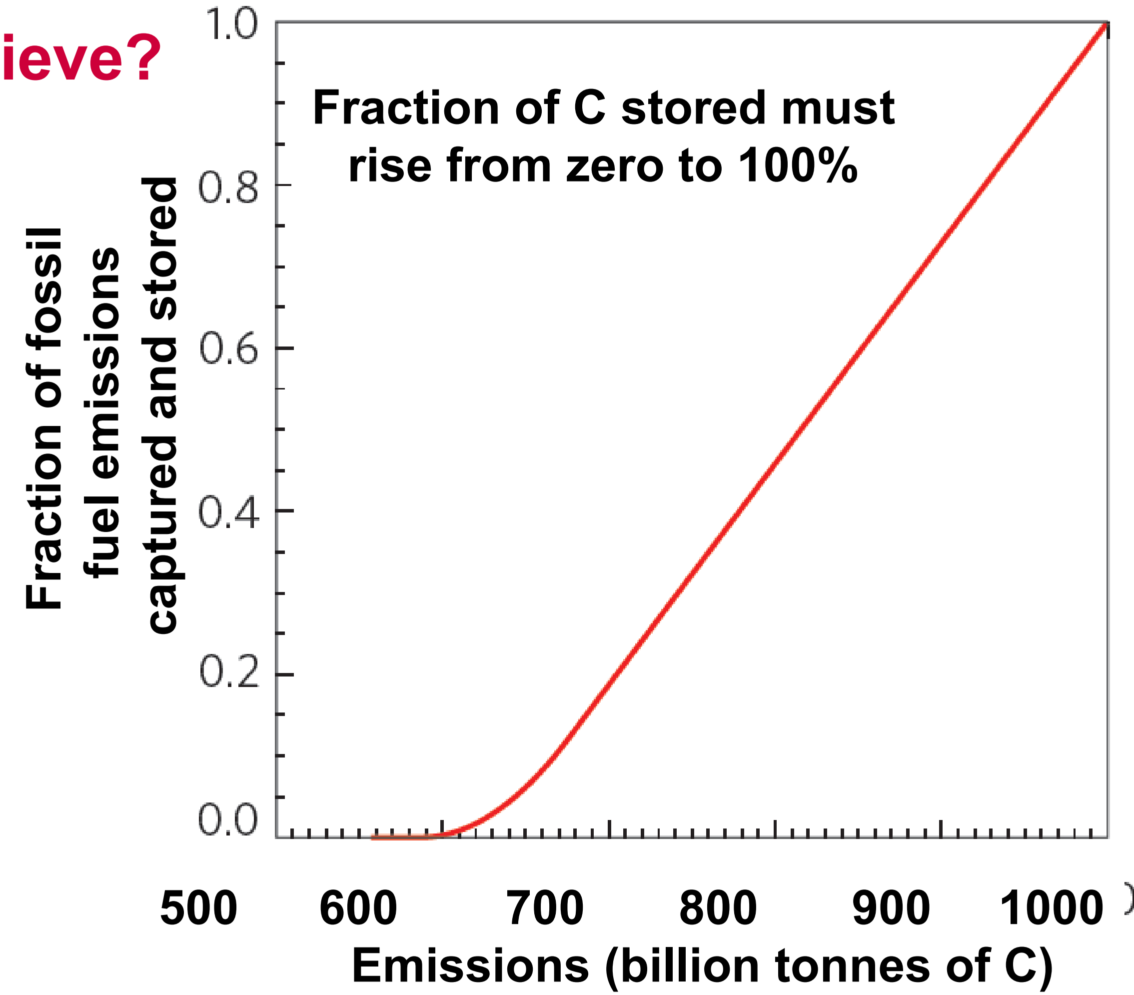
1. In order to achieve the long-term temperature goal set out in Article 2, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties, and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty.

This implies Carbon Capture and Storage on all fossil fuel use, plus minimising other anthropogenic emissions e.g. from food production.

What do we need to achieve?

The prime climate objective is not to end the use of fossil fuels.

The prime objective is to develop and deploy 100% CCS in time to cap cumulative emissions of carbon at a safe level.



Myles R. Allen, David J. Frame & Charles F. Mason, The case for mandatory sequestration, Nature Geoscience 2, 813 - 814 (2009), doi:10.1038/ngeo709

CO_2 EOR and other applications with partial overall capture should be seen as a stage in a path from zero CO_2 capture to 100% CCS.

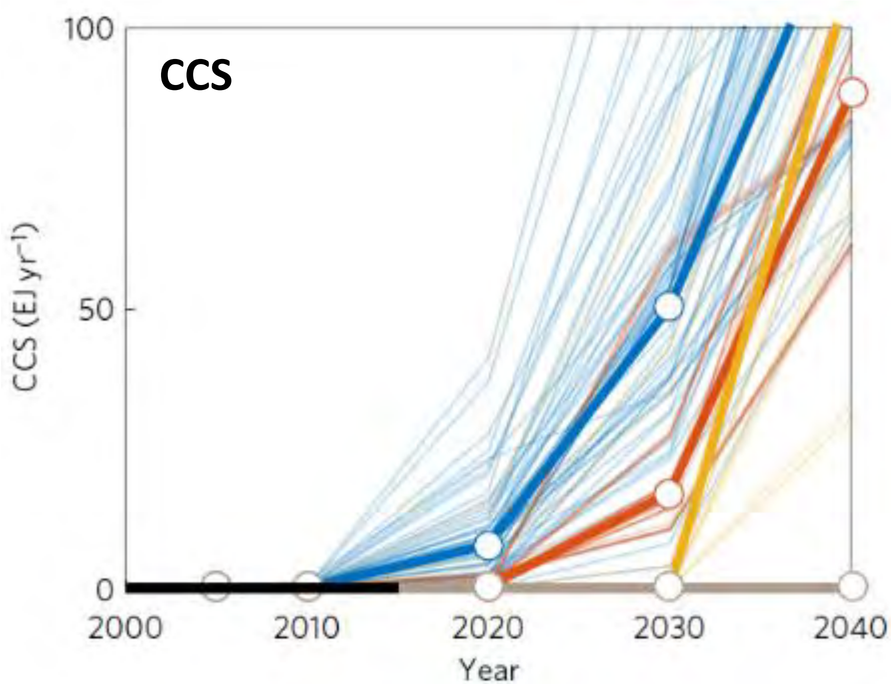
They can be a move in the right direction from where we are now – emitting 100% of fossil carbon to atmosphere.

The key factor is the extent to which technologies and/or projects can readily be adapted to get higher fractions of CO_2 stored.

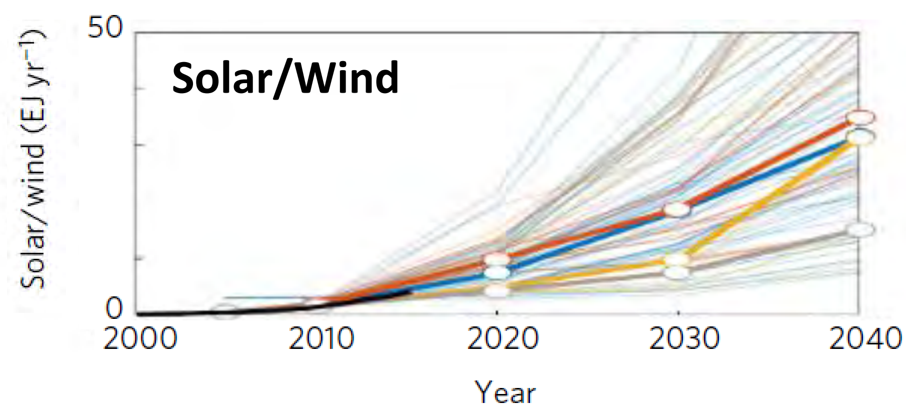
Key indicators to track current progress and future ambition of the Paris Agreement

Peters, G. P. et al. , Nature Climate Change, 2017.

… without large-scale CCS deployment, most models cannot produce emission pathways consistent with the 2°C goal. ….. **a globally coordinated effort is needed to accelerate progress,** better understand the technological risks, and address social acceptability.

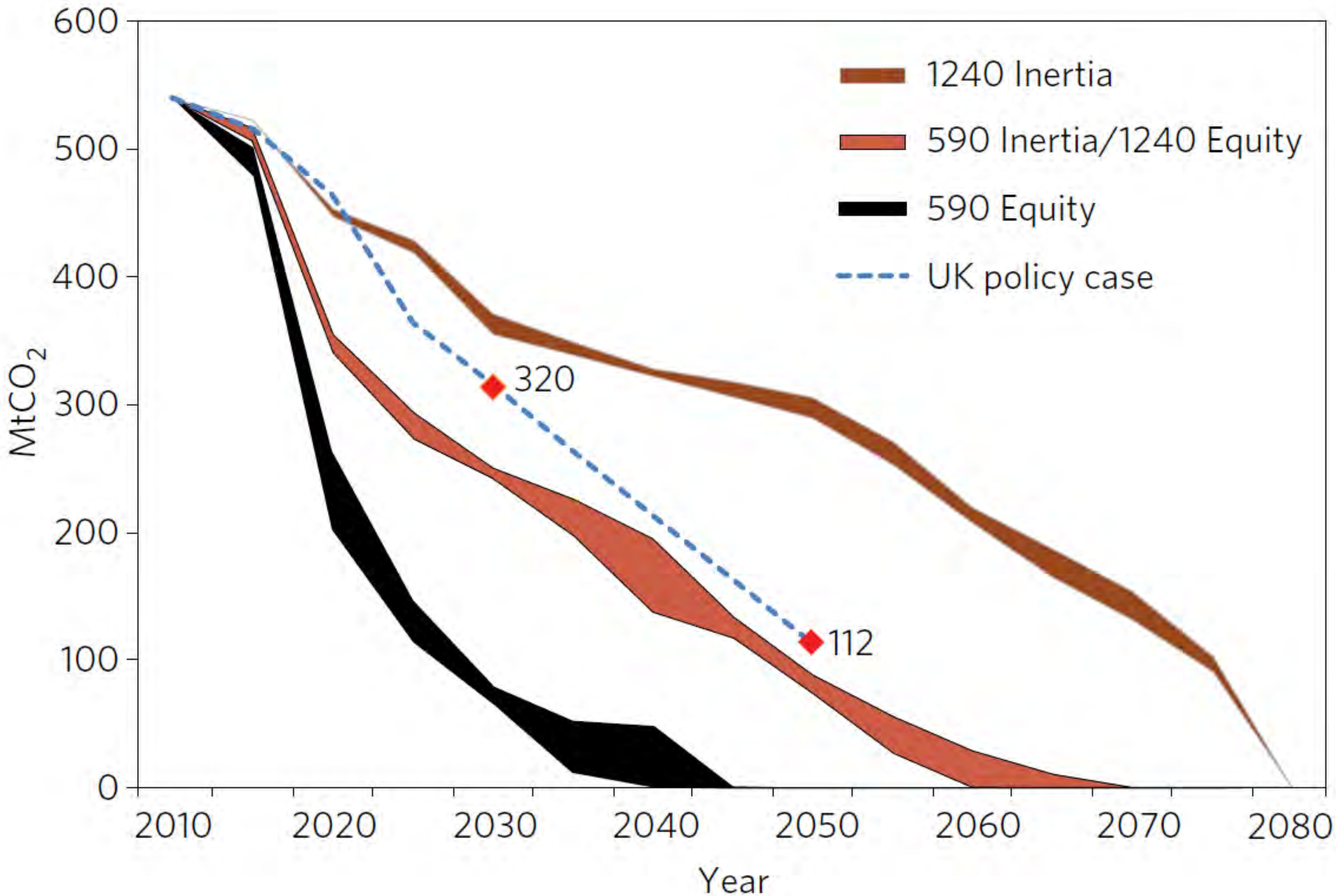


Historical trends and future pathways to 2040, assuming actions start in 2010 (blue), 2020 (red), 2030 (yellow)



Achieving net-zero emissions through the reframing of UK national targets in the post-Paris Agreement era,
Pye et al, Nature Energy, 6 March 2017.

Total remaining global CO_2 budget for 66% chance of 2^{o}C from the IPCC AR5 is 590 - 1240GtCO_2. UK shares by equity (per capita basis) and inertia (current total emissions basis) imply emissions trajectories.



CCS in the UK

National Importance for UK Decarbonisation and CCS

24 January 2017, Westminster Hall Debate

The Parliamentary Under-Secretary of State for Business, Energy and Industrial Strategy, Jesse Norman

CCS has a wide range of potential applications in which it could contribute to the reduction of carbon in our environment. Those include not merely decarbonising **heating** and **transport**, but providing a pathway for low-carbon **hydrogen** and producing **negative emissions** when **biomass is combined with CCS** in power generation. ….

It has been rightly noted that it has the potential to help **energy-intensive industries** in this country to remain competitive. ……

The Government absolutely believe that CCS has a potential role in long-term decarbonisation, but it must be affordable. …… we are taking the time to look hard at CCS to … find a cost-effective pathway.

https://hansard.parliament.uk/commons/2017-01-24/debates/242BBBF1-396C-463D-8861-CCC547E011D0/UKDecarbonisationAndCarbonCaptureAndStorage

Committee on Climate Change

Report 'UK climate action following the Paris Agreement', October 2016.

Carbon capture and storage is very important given its potential to reduce emissions across heavy industry and the power sector, open up new decarbonisation pathways (e.g. based on hydrogen) and remove CO_2 when coupled to bioenergy. **Estimates by the Committee and by the ETI indicate that the costs of meeting the UK's 2050 target could almost double without CCS.**

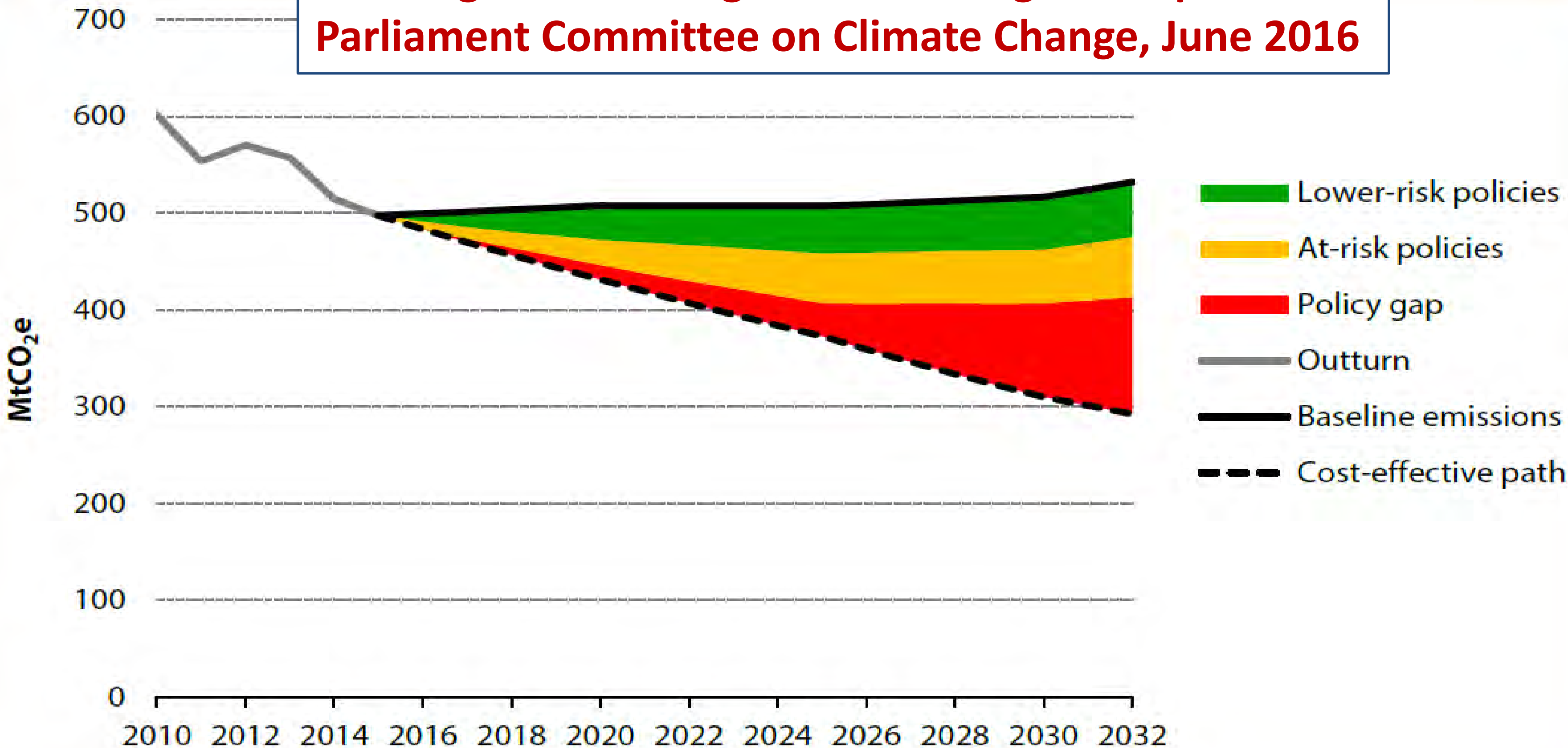
Energy Technology Institute

Report 'Carbon capture and storage: Building the UK carbon capture and storage sector by 2030', 2015

A complete failure to deploy CCS would imply close to a doubling of the annual cost of carbon abatement to the UK economy from circa 1% to 2% of GDP by 2050 (or roughly an extra £1000 on annual average household bills for energy and transport services).

Figure 2. Assessment of current policies against the cost-effective path to meet carbon budgets and the 2050 target

Meeting Carbon Budgets - 2016 Progress Report to Parliament Committee on Climate Change, June 2016



Source: DECC (2015) *Updated energy and emissions projections*; CCC analysis.

Notes: 'Lower-risk policies' (green) are those that aim to address known barriers and have sufficient funding and ambition to deliver with reasonable confidence. 'At-risk policies' (amber) either lack sufficient funding, do not address known barriers or have important design elements still to be confirmed. No funded policies exist to close the 'policy gap' (red), even though the Committee's scenarios identify abatement options to do so that are on the lowest cost path to meet the carbon budgets and the 2050 target. 'Baseline emissions' is the likely path of emissions in the absence of policy effort.

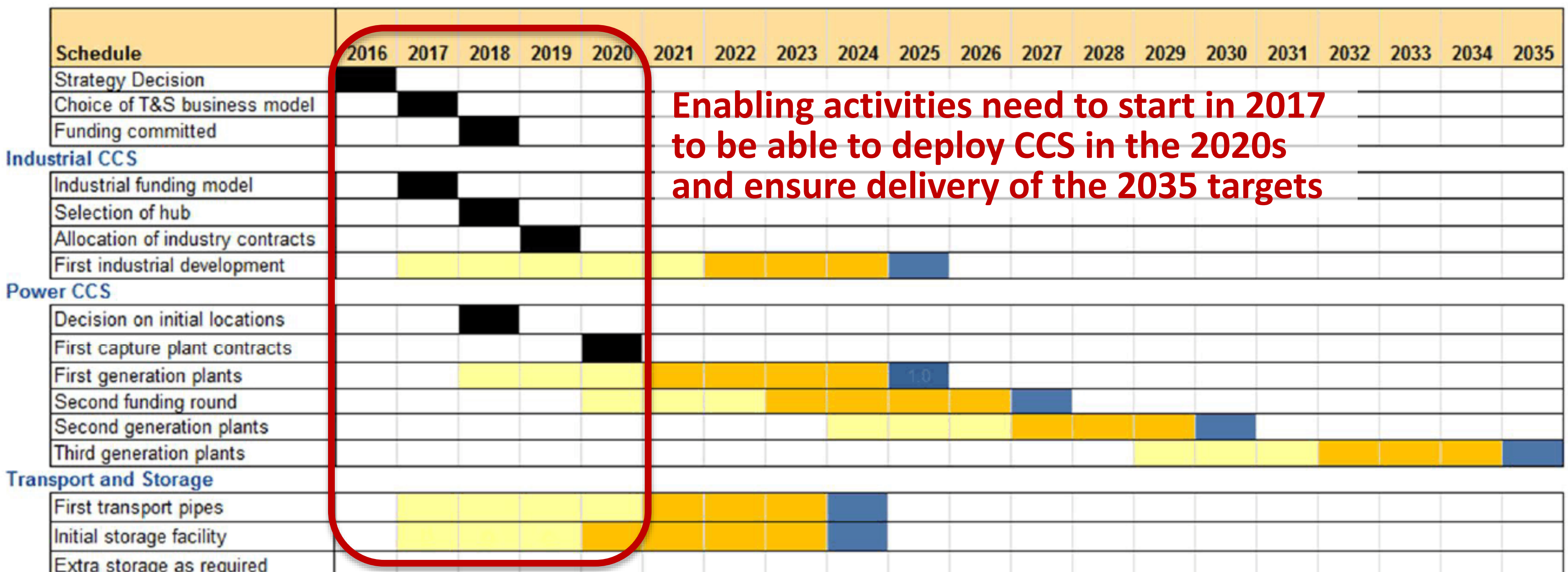
Committee on Climate Change

May/June 2016: A strategic approach for developing CCS in the UK

https://www.theccc.org.uk/wp-content/uploads/2016/07/Poyry_-_A_Strategic_Approach_For_Developing_CCS_in_the_UK.pdf
https://www.theccc.org.uk/publication/meeting-carbon-budgets-2016-progress-report-to-parliament/

'**Sufficient scale of targeted roll-out**: 4-7 GW of power CCS and 3-5 Mt captured CO_2 from industrial plants by 2035 ….. to commercialise CCS and facilitate subsequent wide-scale deployment.'

'**An initial focus on one or two strategic clusters**: clusters in areas of industrial activity around storage sites that have been identified and successfully characterised.'



UK Committee on Climate Change Greenhouse gas removal

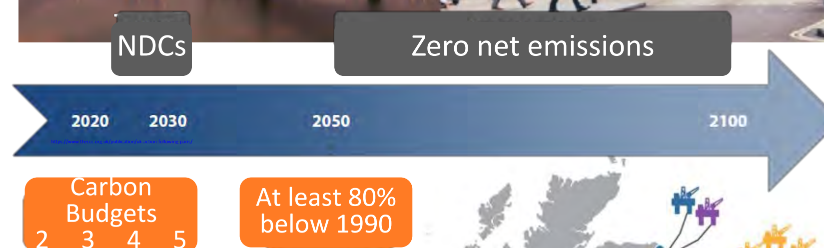
- *The UK 2050 target to reduce emissions at least 80% from 1990 levels (i.e. less than around 160MtCO_2e/yr) is challenging and requires significant action across the economy, but can be met in various ways using currently known technologies.*

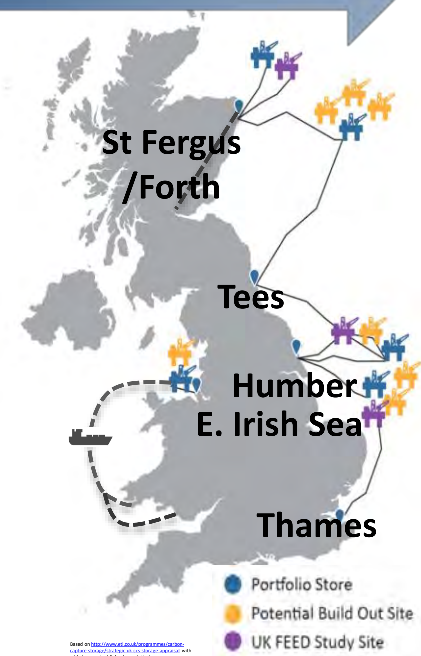
- *Our UK scenarios to 2050 include up to 67 MtCO_2/yr removals from three GGR options: afforestation, BECCS and wood in construction. ……. BECCS could become capable of reducing emissions at a comparable cost to other technologies in the 2030s. This would require the Government to implement an effective new approach to CCS development and development of sustainable bioenergy supplies without locking these into alternative uses. Our scenarios include up to 47 MtCO_2/yr removed by BECCS while generating energy.*

https://www.theccc.org.uk/wp-content/uploads/2016/10/UK-climate-action-following-the-Paris-Agreement-Committee-on-Climate-Change-October-2016.pdf

UK CCS 2008/2009

UK CCS 2016/2017





October 11,2009

Peterhead CCS Project

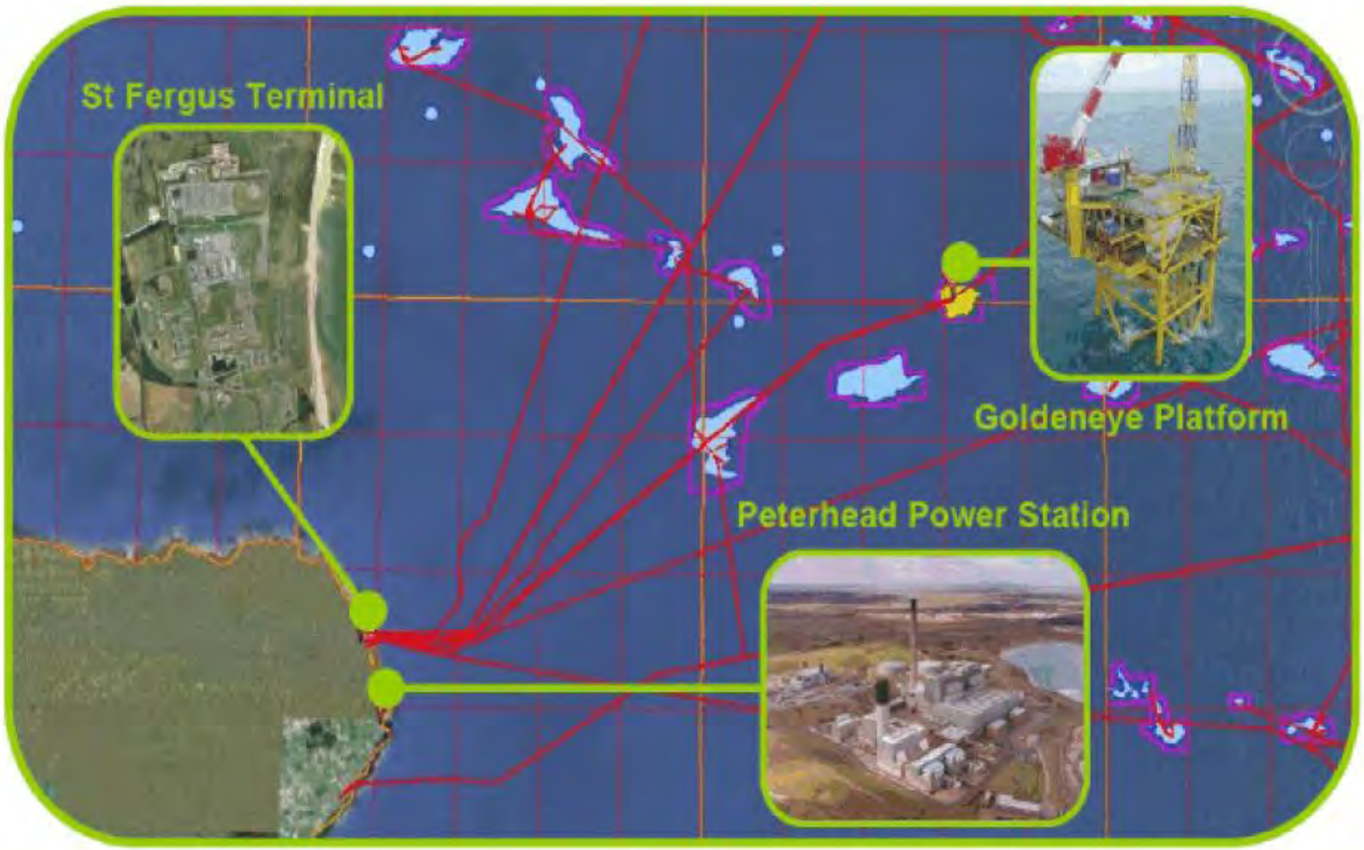
Shell UK Limited and SSE

Post-combustion capture on one of three existing GT units

Approximately 400MW equivalent capacity and 1MtCO_2/yr

Peterhead Geography

Jeremy Carey, Technology Manager, SSE, *CCS Deployment in SSE Peterhead and Beyond…,* IPA / UKCCSC CCS Conference 1st September 2011



An indicative illustration of the White Rose Carbon Capture and Storage Project

ALSTOM drax BOC A Member of The Linde Group CAPTURE POWER

- New standalone power plant at the existing Drax Power Station site near Selby,
- State-of-the-art coal-fired power plant with the potential to co-fire biomass.
- 426MWe (gross) oxyfuel power and carbon capture and storage
- 90% of all CO_2 emissions captured
- Capturing approximately 2 million tonnes of CO_2 per year
- Anchor project for Yorkshire CO_2 transportation and storage network

http://www.whiteroseccs.co.uk

CCS ‘demonstrations’ in retrospect

The target for CCS in the UK:

- Has to achieve multiple >10 MtCO_2/yr projects for meaningful impact on national emissions
- And deploy CCS across the UK to achieve 2050 and subsequent targets

CCS demonstration programme so far:

- Has stipulated small ~300MW power plant projects processing 1-2 MtCO_2/yr (inherited from coal plant approach)
- No clear plans have existed for further deployment to use T&S fully
- Unit costs for sub-scale ‘demonstrations’ are therefore very high
- And a solution to the main problem of building and successfully operating >10 MtCO_2/yr T&S networks with multiple inputs would not be demonstrated

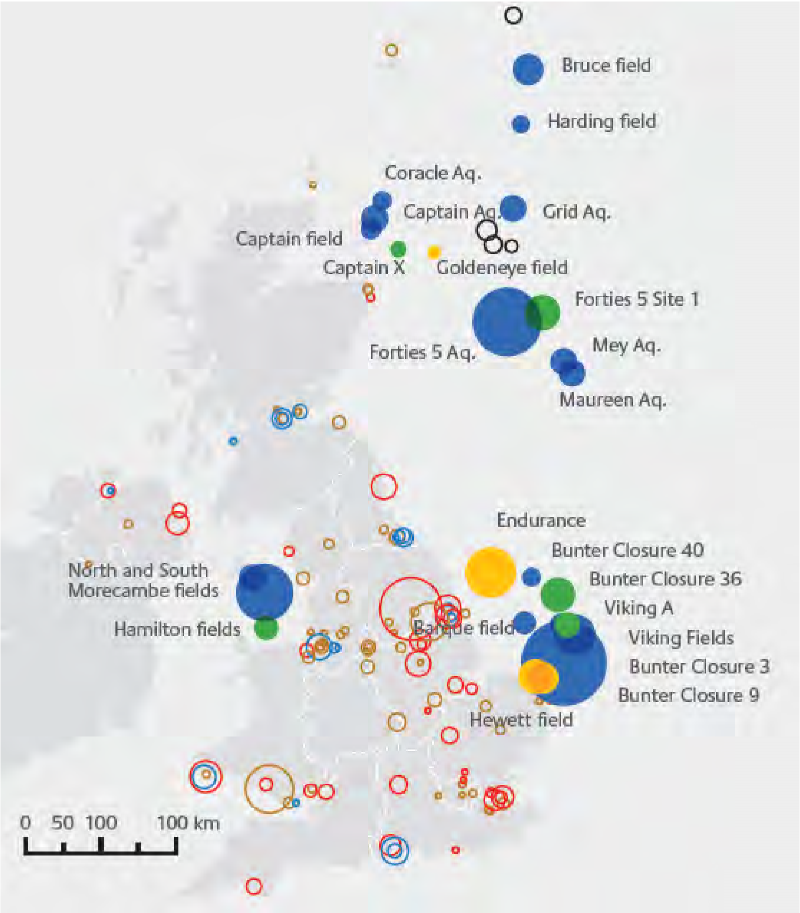
Future CCS developments:

- Need scale to be cost-effective, suggested role for government in implementing T&S infrastructure (e.g Oxburgh Report*)
- National strategy for interlinked regional clusters, including shipping
- Multiple CO_2 sources: power, industry, hydrogen, BECCS
- Technology needs to be capable of net zero emissions

* http://www.ccsassociation.org/news-and-events/reports-and-publications/parliamentary-advisory-group-on-ccs-report/

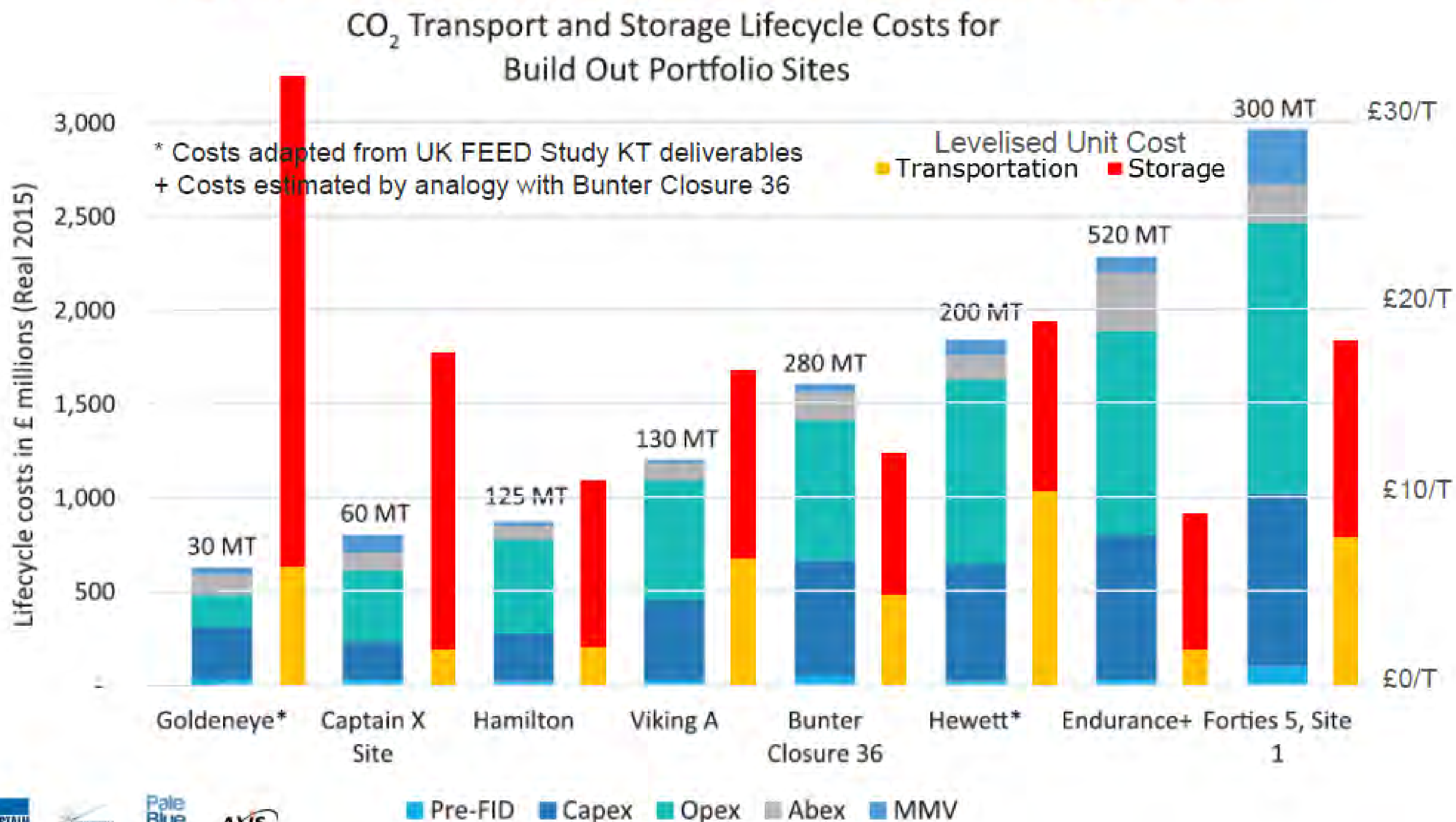
Taking Stock

- Peterhead – project looked landable – simple chain.
- White Rose – assigning risks across several chain companies was too difficult.
- 3 CO2 stores have been appraised , plus 5 partially appraised - 8 sites totalling 1600MT - enough for many decades, at "10 GW" - 40MT/a+ CO_2.
- Top risk of leakage is abandoned oil and gas wells.
- Transport and storage costs are £8-16/te – about £7/MWh for a gas fired power plant.
- Data is publically available on BEIS and ETI websites.
- Storage accessible to the South East and East England arguably the largest, and best.



See also https://ukccsrc.ac.uk/about/delivering-cost-effective-ccs-2020s-new-start

UK has a wide range of offshore storage sites



COSTAIN energy technologies Pale Blue Dot. AXIS

See also https://ukccsrc.ac.uk/about/delivering-cost-effective-ccs-2020s-new-start

ETI – Taking stock of UK CO_2 storage

ETI – Taking stock of UK CO_2 storage

Example of key economic indices for different development options.

CASE	Source	CO_2 Flow	Duration	Store	Up Front T&S Capex	Levelised T&S	Levelised Capture +T&S	Levelised Power Cost
		MT/a	Years		£M	£/Te	£/Te	£/MWh
Base Case – 2.6 GWe	Power	7.5	25	Endurance	592	11	58	78
Case A Ammonia Unit	Industrial	0.33	8	Hamilton	324	256	300	
Case B Single GT	Power	1.5	25	Hamilton	255	33	63	95
Case C Expansion of Case B	Power	4.5	25	Hamilton	390	17	62	82
Case D Add Ammonia Unit to Case C	Industrial	0.33	20	Hamilton	56	37	80	

National Audit Office

https://www.nao.org.uk/report/carbon-capture-and-storage-the-second-competition-for-government-support/

UK CCS RESEARCH CENTRE

Key findings - The role of CCS

CCS could make a significant contribution to decarbonising the economy, but there are challenges which increase the costs to deploy it in the UK. CCS has the potential to contribute to the decarbonisation of the power, industrial, transport and heating sectors. Together these make up around 83% of the UK's CO_2 emissions.

Recommendations

In developing its next phase of supporting CCS, the Department should:

a. **Maximise the potential value from the competition by incorporating the lessons it and the key stakeholders have learned into any new CCS strategy.**

b. **Ensure it understands, from the outset, the position of CCS developers and their ability or willingness to carry certain risks and applies this in its approach.**

c. **Assess options for how it can make early projects more affordable to taxpayers and consumers.**

d. **Agree early with HM Treasury any affordability constraints**.

More generally, the Department should:

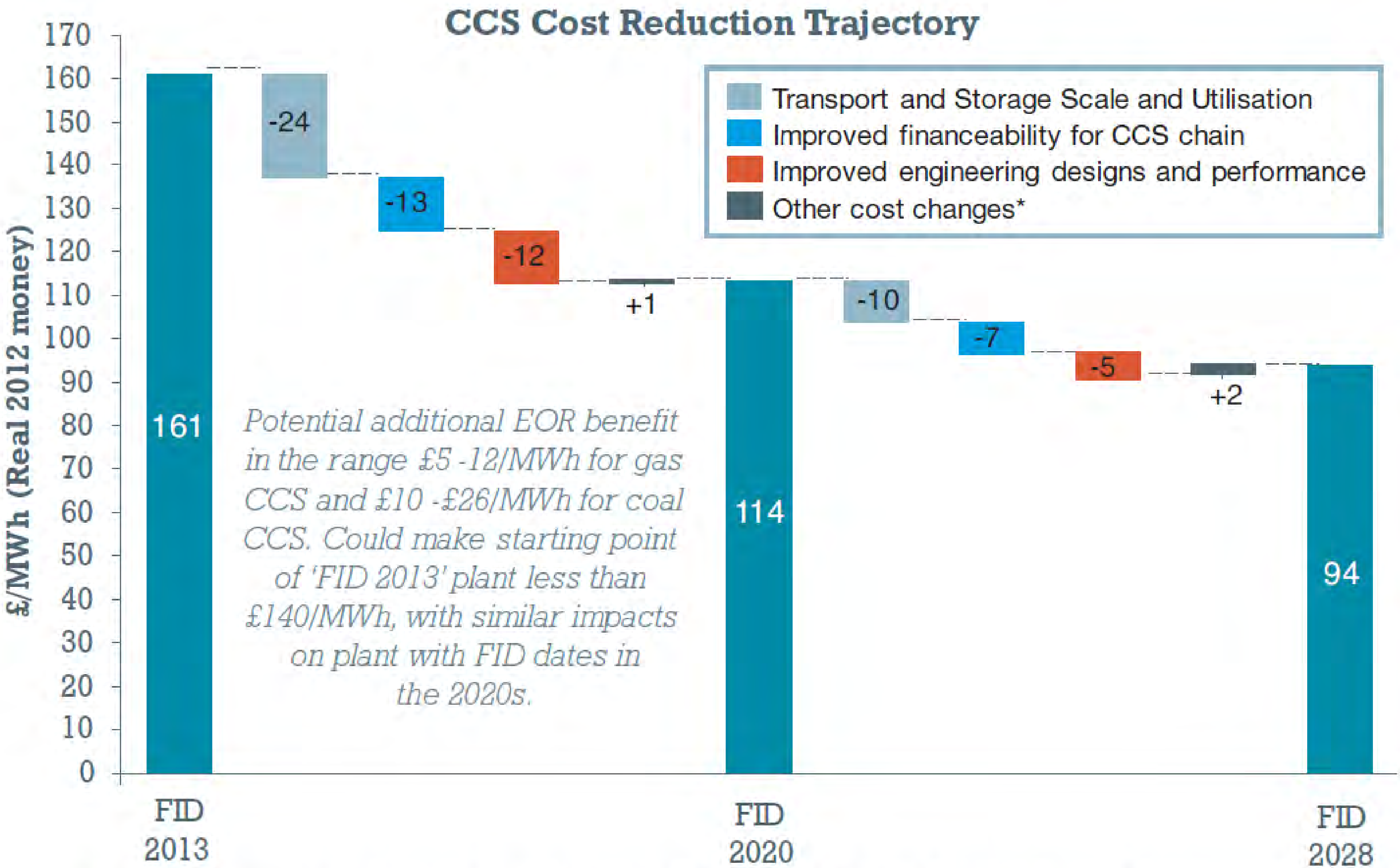
e. **Work with HM Treasury to establish and use a consistent way of measuring the value of investments in different generating technologies that enable meaningful comparisons**.

f. **Regularly revisit its commercial strategy and the value-for-money case in light of the evolving understanding of the delivery environment and market conditions.**

g. **Consider the possible consequences of, and its risk appetite for, scenarios that are outside its central forecast or expectation when it develops a new project or programme.**

CCS Cost Reduction Taskforce

Final Report, May 2013

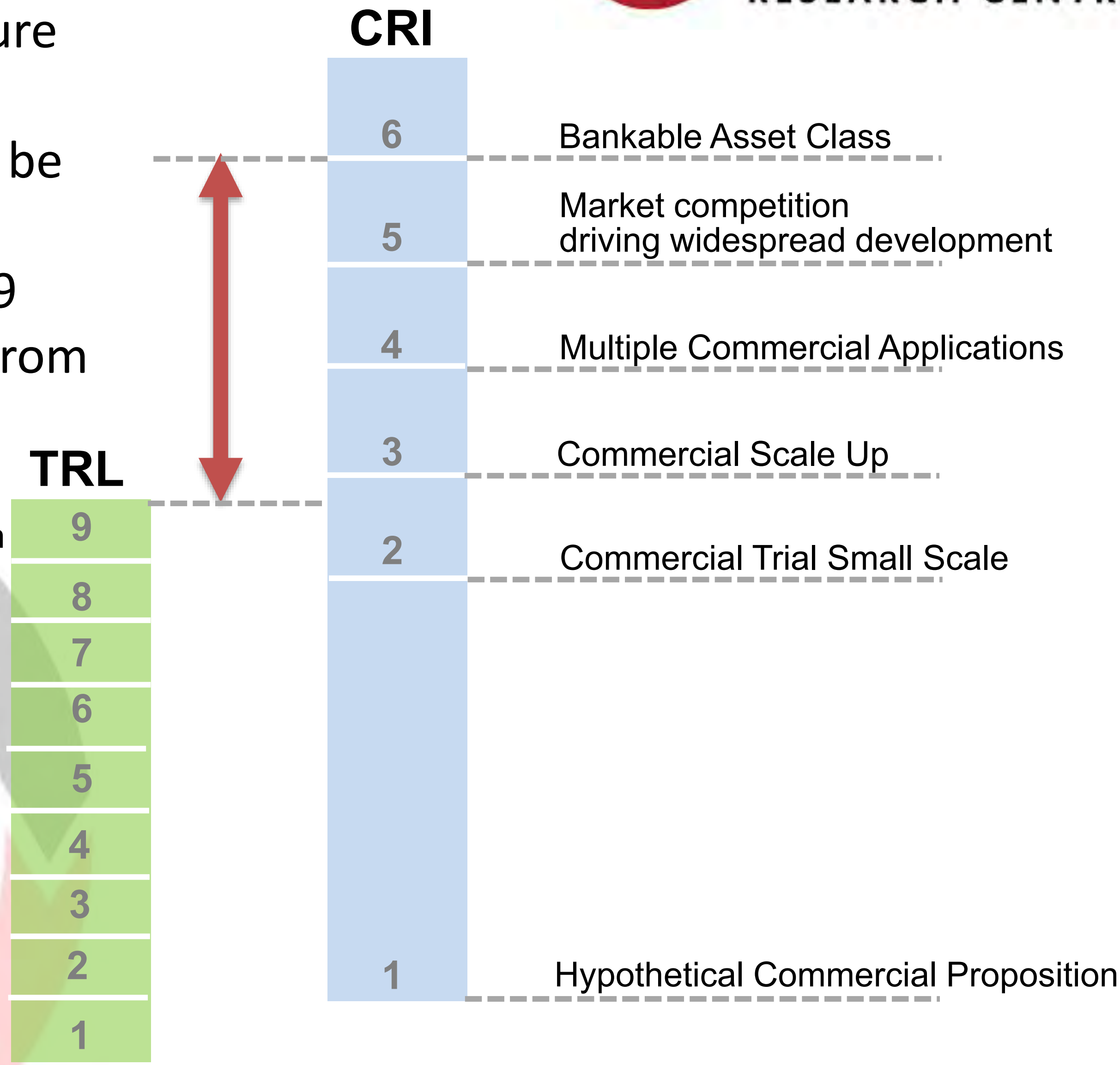


Note: Shows average costs across technologies. *E.G. Increasing CO_2 price, falling storage abandonment costs

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/201021/CCS_Cost_Reduction_Taskforce_-_Final_Report_-_May_2013.pdf

Fundamental research needed to increase Commercial Readiness as well as TRL

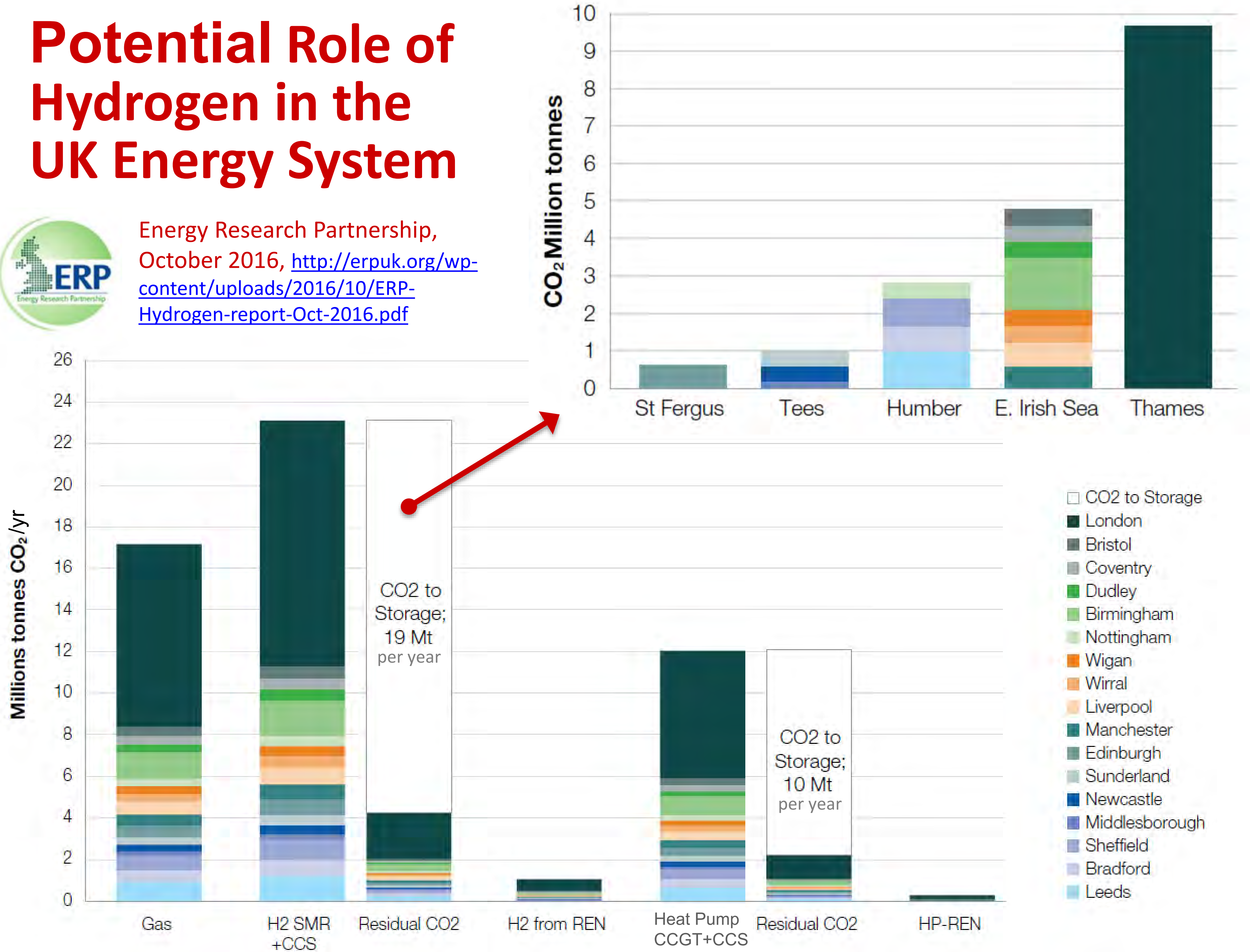
For technologies to mature to be a "bankable asset class" this gap must also be bridged. Nuclear, Wind, Solar, Marine are all TRL9 and are still benefitting from fundamental research.



Faraday discussion, 2016, http://pubs.rsc.org/en/content/articlelanding/2016/fd/c6fd00046k#!divAbstract, based on http://arena.gov.au/files/2014/02/Commercial-Readiness-Index.pdf

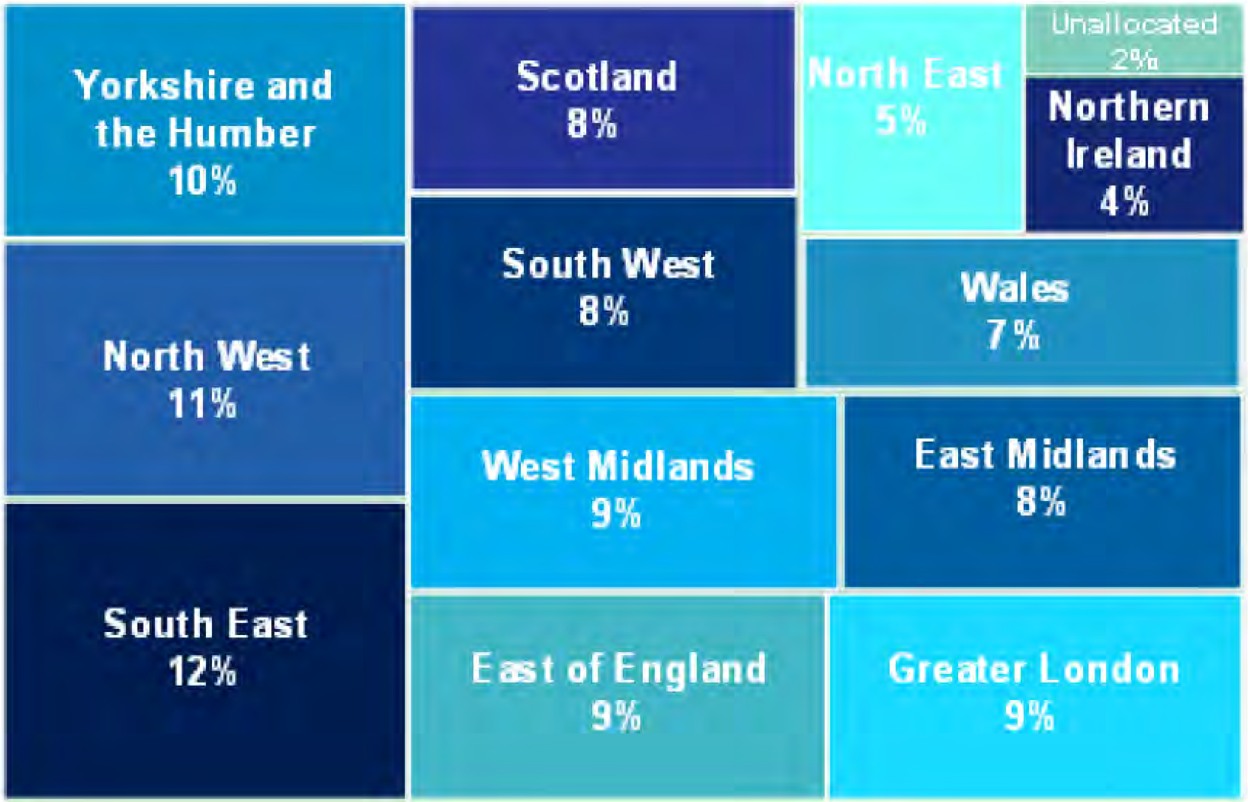
Potential Role of Hydrogen in the UK Energy System

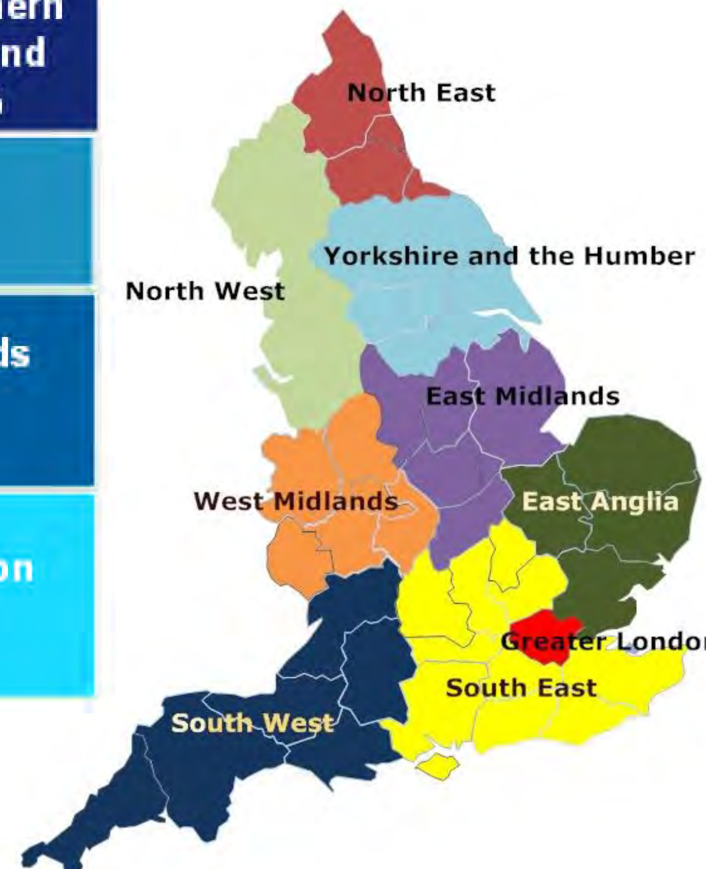
Energy Research Partnership, October 2016, http://erpuk.org/wp-content/uploads/2016/10/ERP-Hydrogen-report-Oct-2016.pdf



LOCAL AUTHORITY CARBON DIOXIDE EMISSIONS ESTIMATES 2014

Statistical Release: National Statistics, 30 June 2016

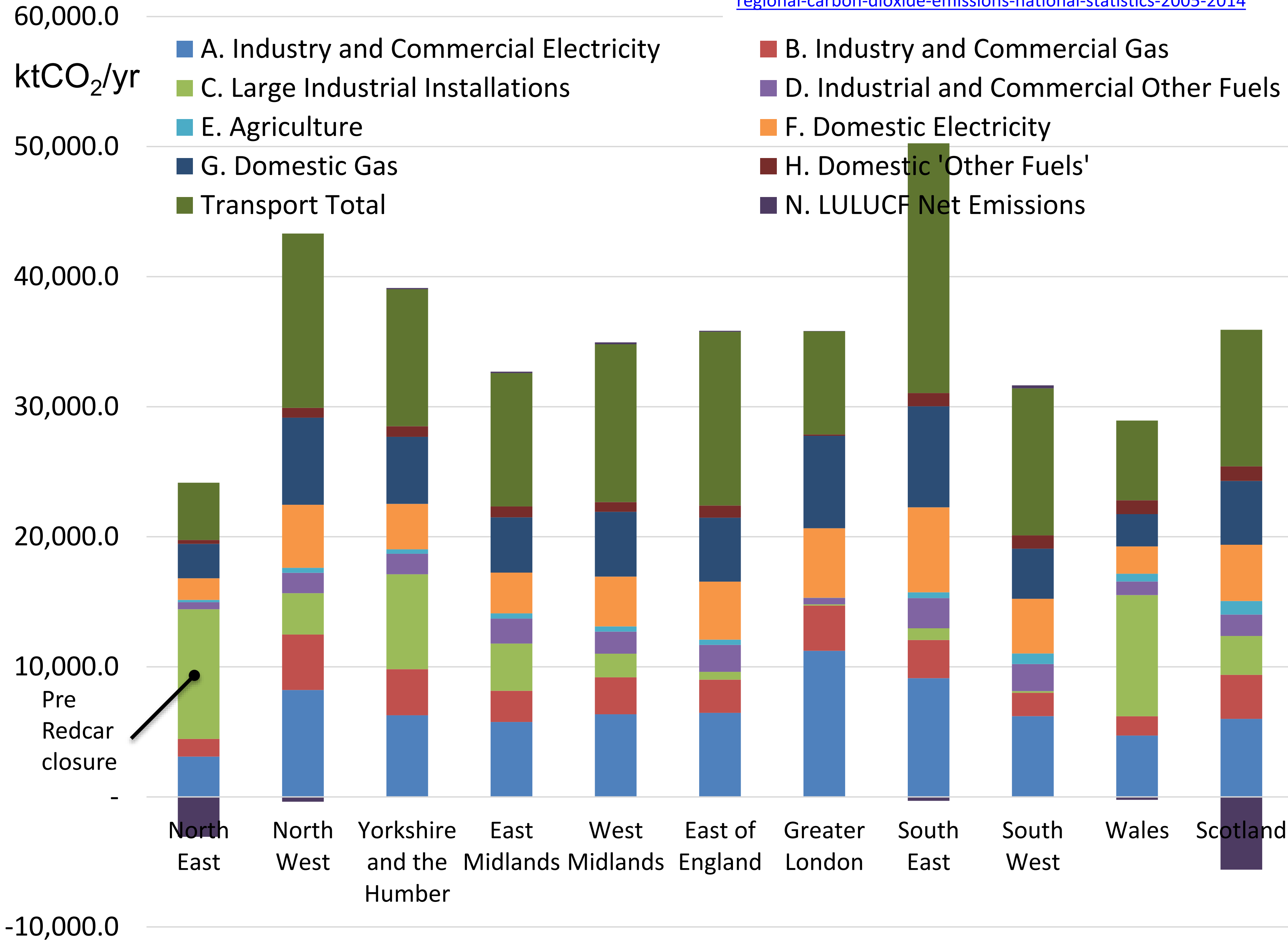




http://www.britaingallery.com/england_regions.php

2014 UK CO_2 emissions by region and source

https://www.gov.uk/government/statistics/uk-local-authority-and-regional-carbon-dioxide-emissions-national-statistics-2005-2014



DECC & BIS – March 2015 - Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050

https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050

A series of eight reports that assess the potential for a low-carbon future across the most heat-intensive industrial sectors in the UK.

The roadmap project aimed to:

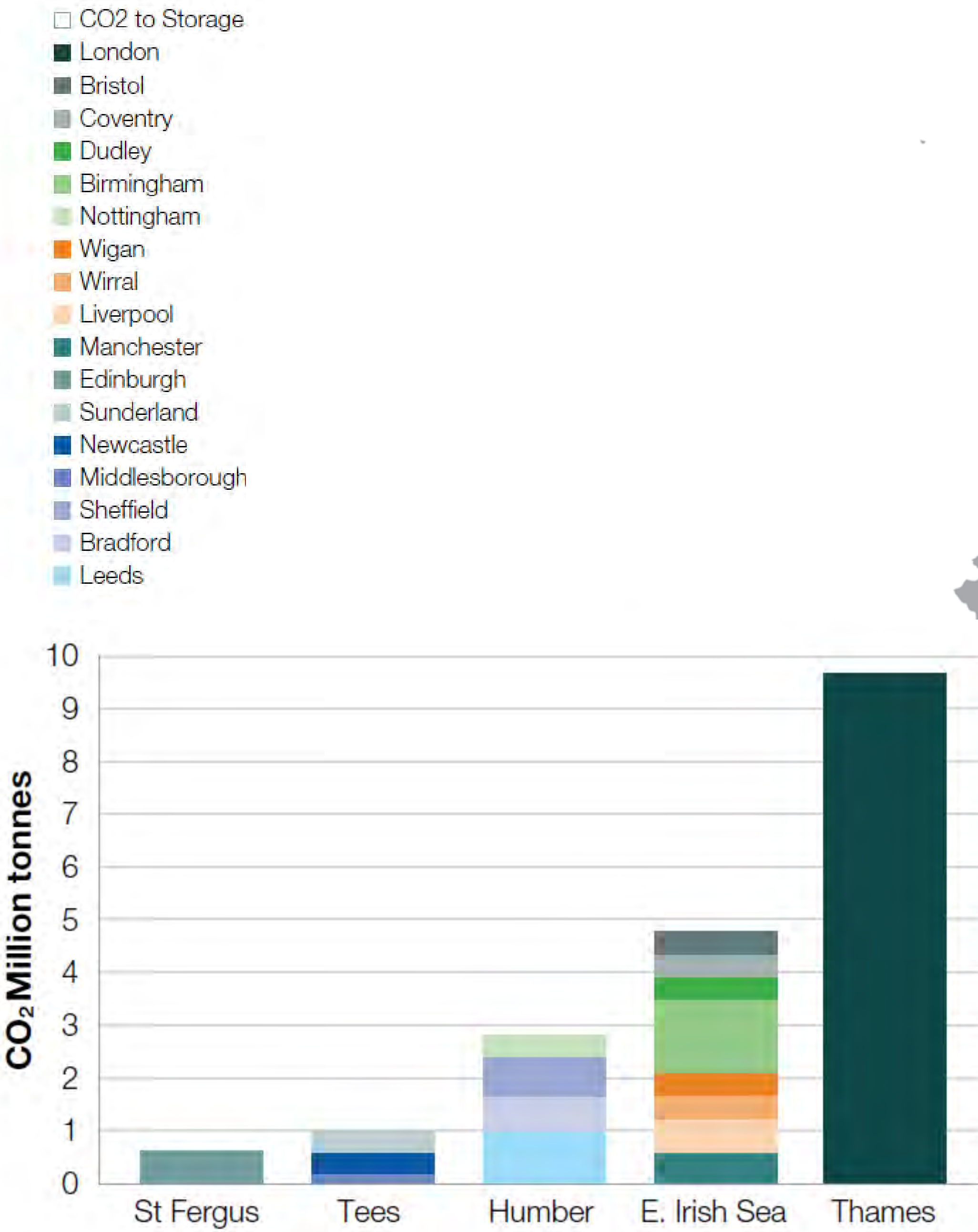
· Improve understanding of the emissions-abatement potential of individual industrial sectors, the relative costs of alternative abatement options and the related business environment including investment decisions, barriers and issues of competitiveness;

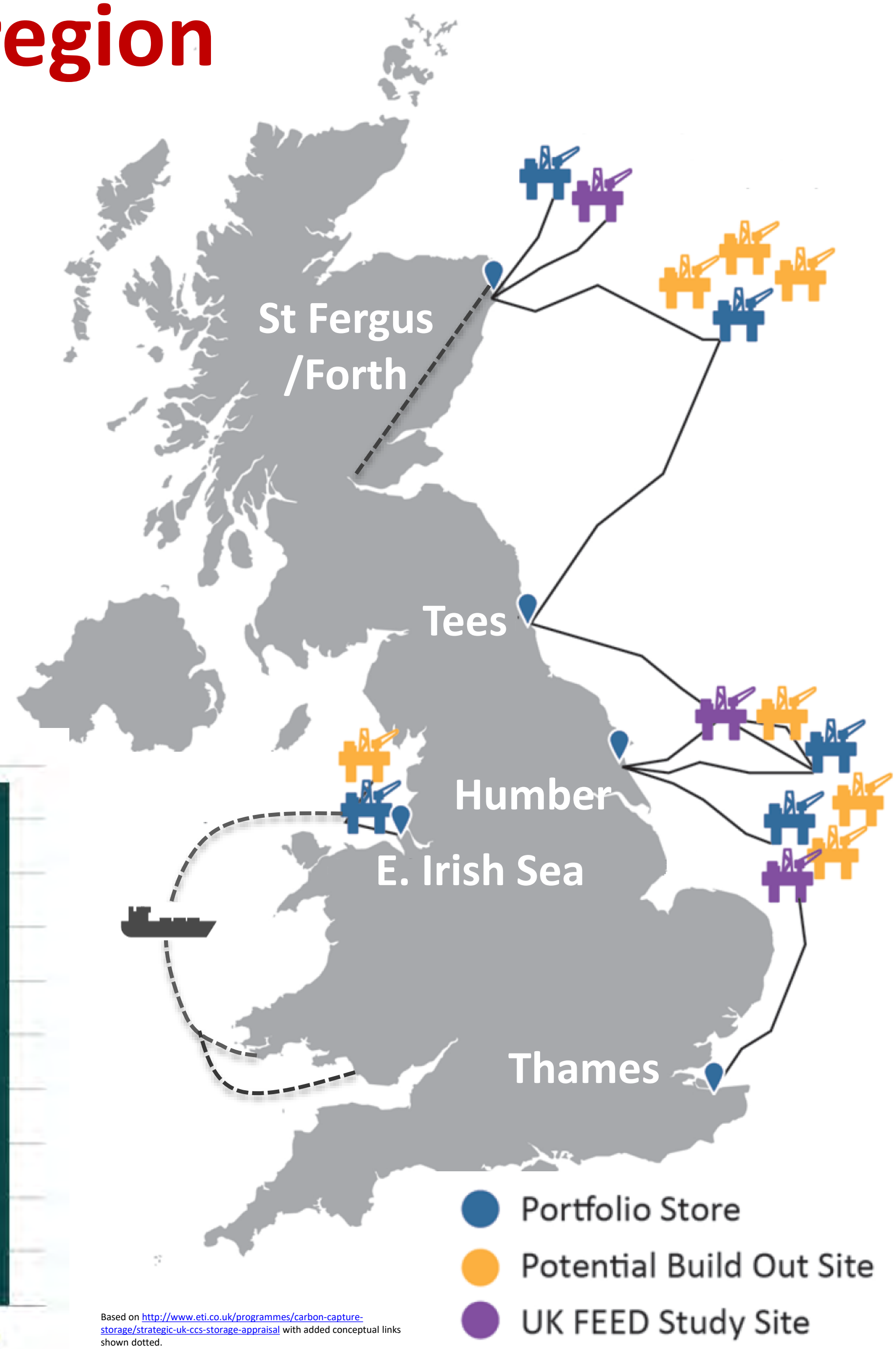
· Establish a shared evidence base to inform future policy, and identify strategic conclusions and potential next steps to help deliver cost-effective decarbonisation in the medium to long term (over the period from 2020 to 2050).

Significant direct CCS in four sectors by 2050 less than 20 $MtCO_2$/yr:
Chemicals (6), Iron & Steel (10 – but predates Redcar closure), Cement (2.5), Oil Refining (2.5).

Indirect CCS through decarbonised electricity and hydrogen in all sectors.

CO_2 from hydrogen by region





H21 Leeds City Gate System

http://www.northerngasnetworks.co.uk/document/h21-leeds-city-gate/

Potential hydrogen storage sites in salt formations (yellow) are another geological asset for the UK.

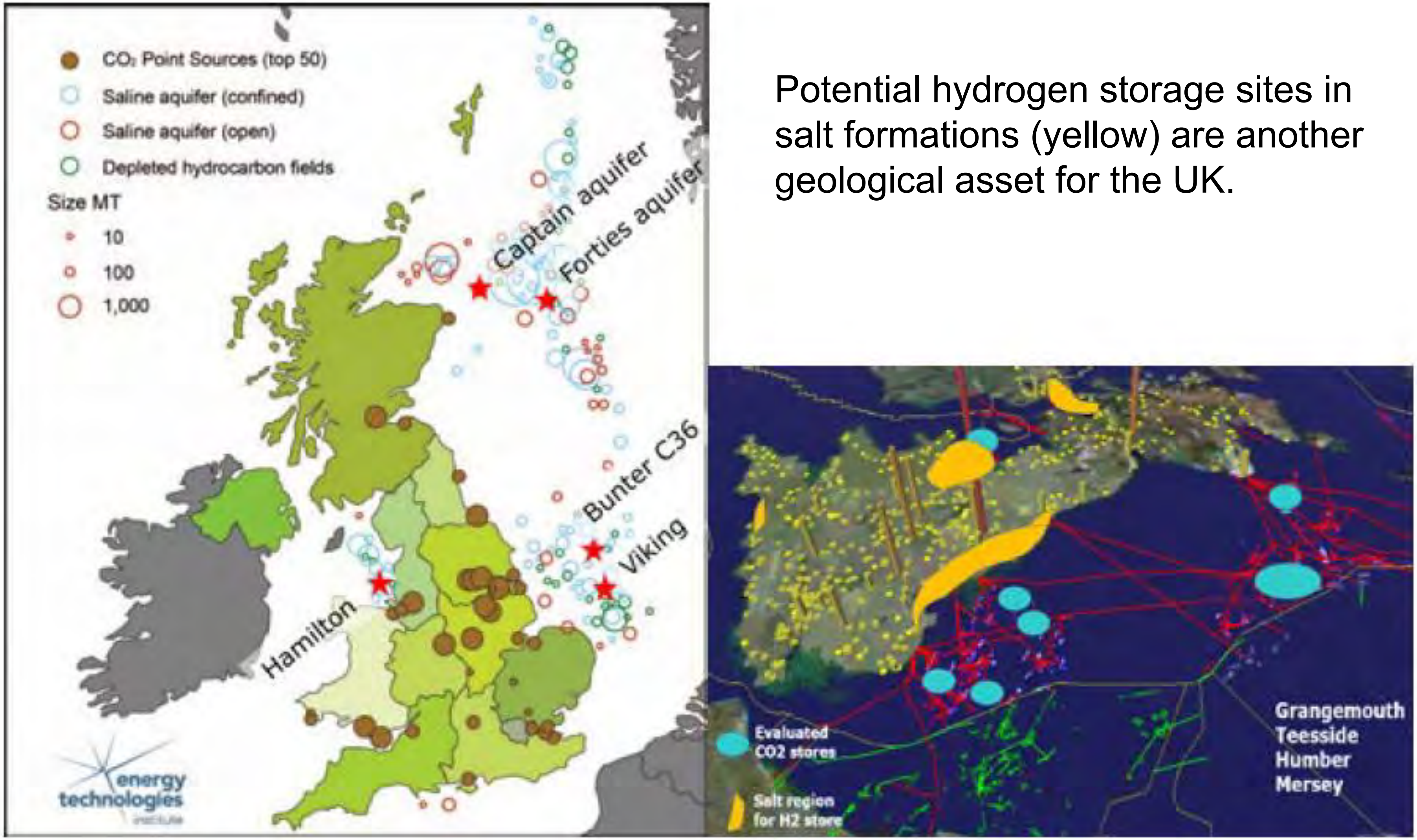


Image 7.3. *UK CCS availability*

UK CCS RESEARCH CENTRE

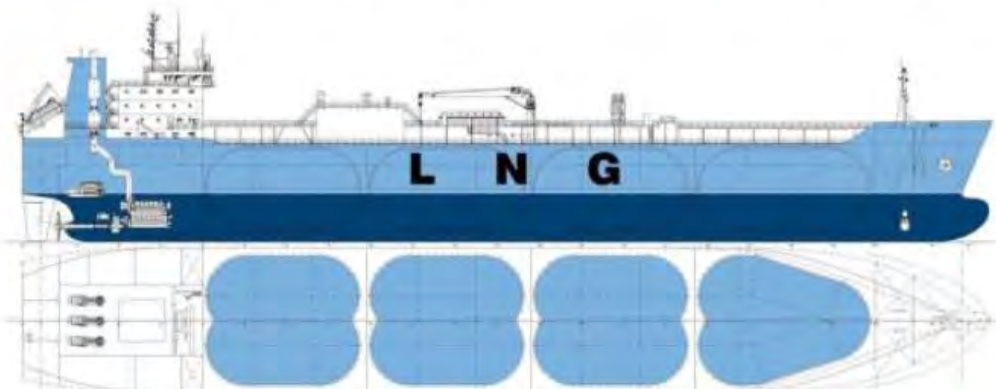
Type C Concepts: World's Largest Bilobe-Liquid Gas Storage Tanks

From: Gas Carriers: Arrangements & Characteristics, Rich Delpizzo, Manager, Global Gas Solutions, Presentation to Marine Chemists, Las Vegas, NV, July 2014.

9,686 m^3 bilobe Type C LNG tanks building at Sinopacific for Denmark's Evergas

Independent Tanks: Type C – Bilobe

- Bilobe tanks being considered for 20-30,000 m^3 size ships



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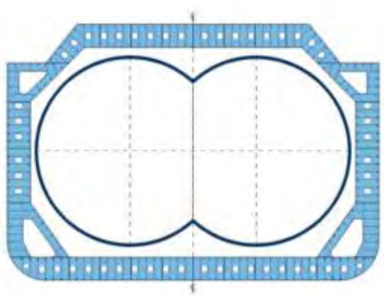


Source: TGE Marine Gas Engineering

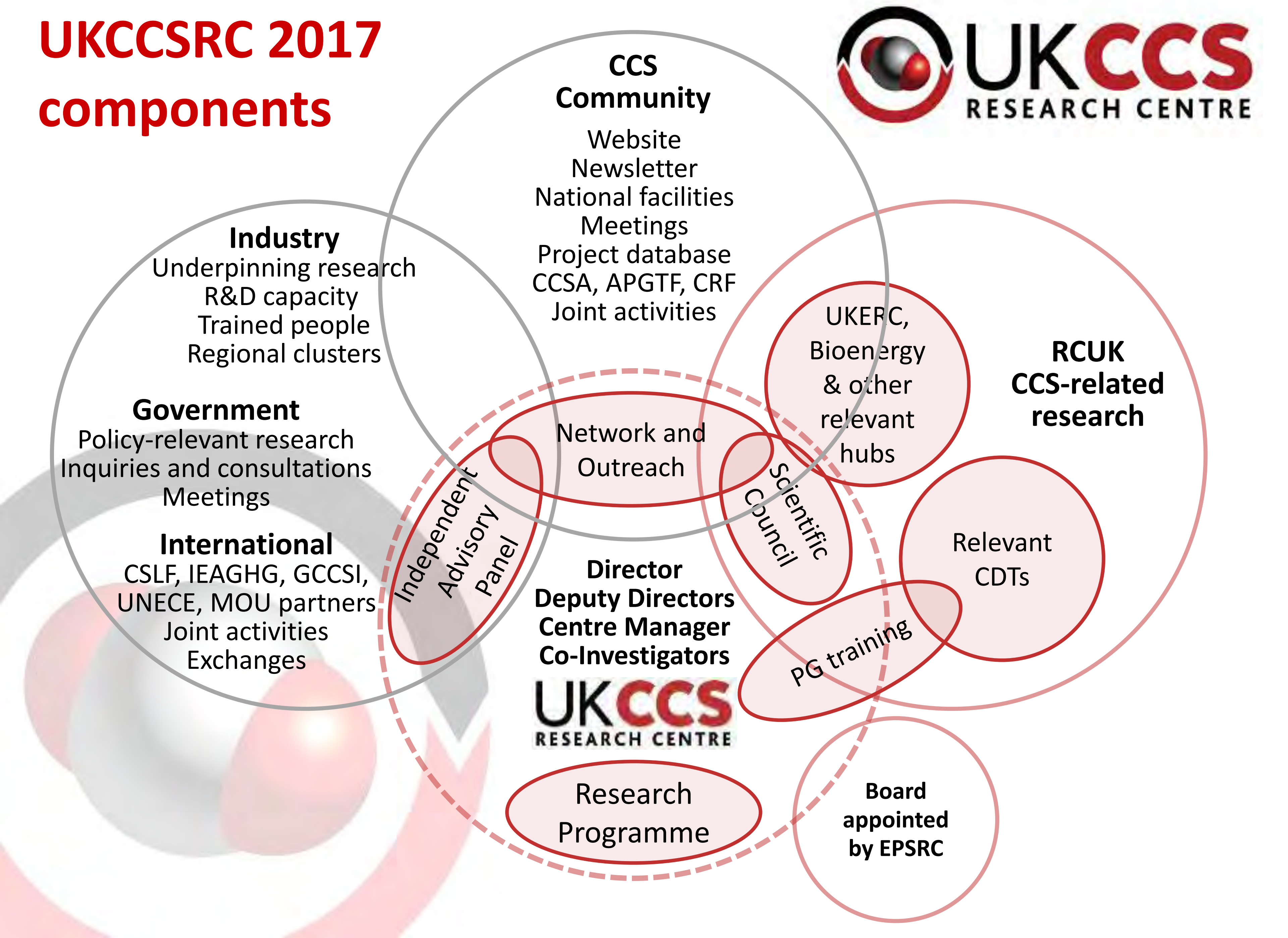
UKCCSRC 2017-2022

UKCCSRC 2017 Strategic Mission

Help ensure that CCS will play an effective role in reducing net CO_2 emissions while securing affordable and controllable electricity supplies, low carbon heat and competitive industries for the UK.

- **Lower costs and integration:** cost reductions for energy systems, industry and the wider economy.
- **Benefits of CCS in energy and economic systems:** inform policy and planning by government and by research funders, industry and other stakeholders.
- **Capacity to support delivery:** maintain an effective UK CCS community to deliver societal benefits to 2050 and beyond.
- **Cohesion, strategy, coordination, collaboration:** be a focal point for setting strategies, coordinating research and collaboration, nationally and globally.
- **Be an indispensable knowledge partner** in the UK and globally.

UKCCSRC 2017 components



Research challenges in CCS

Part 1 - Have built up and be able to maintain the necessary research capacity

- Responsive and sustained strategy from funders
- Broad and deep research community
- Advanced facilities
- Established cooperation with UK industry and other stakeholders
- Links to key international partners for collaboration and delivery

UK CCS R&D Programme
£253M, running 2011 onwards

Department for Business, Energy & Industrial Strategy

RESEARCH COUNCILS UK

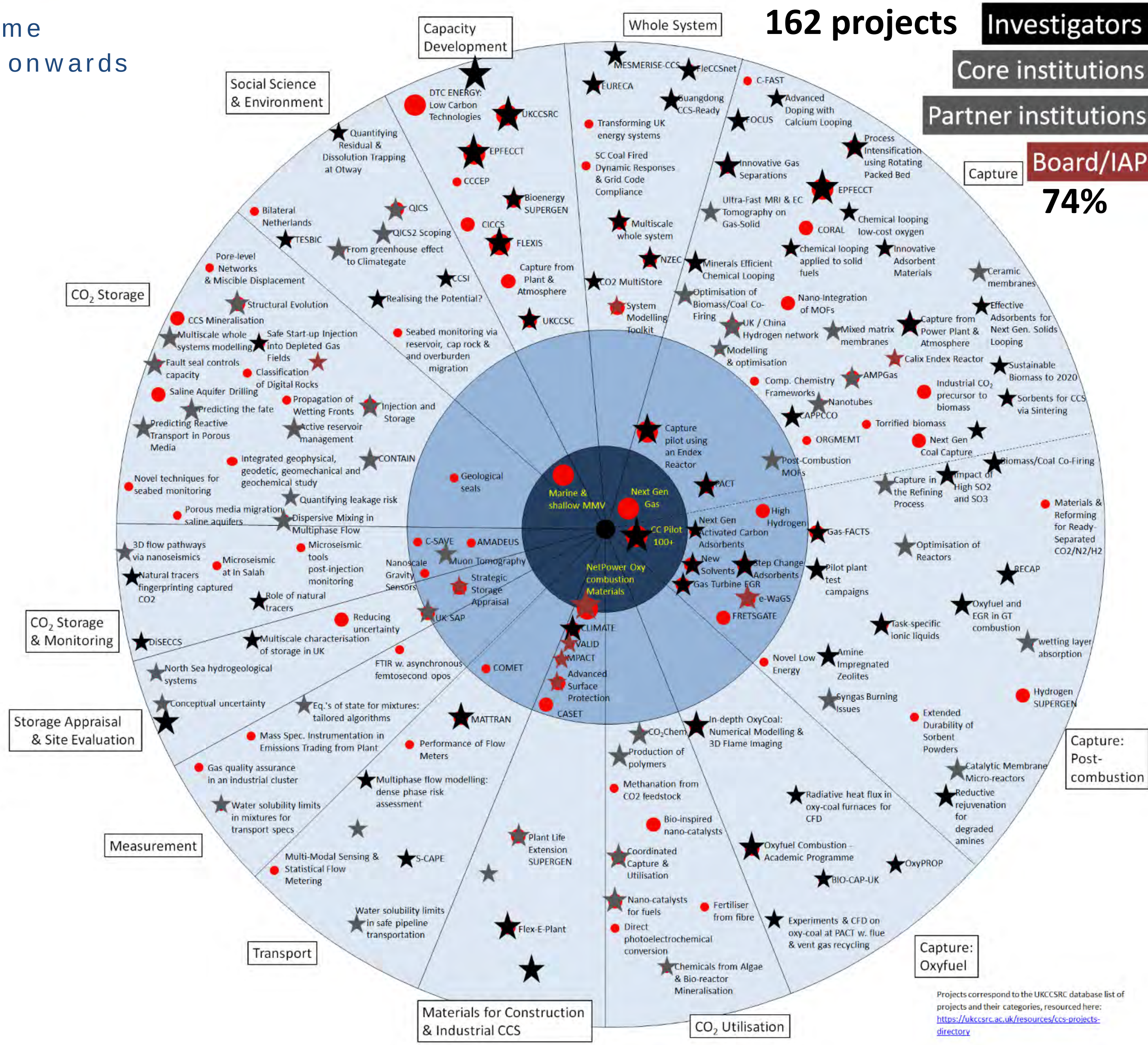
UKCCS RESEARCH CENTRE

UKCCSRC PACT FACILITIES

energy technologies institute

LCICG Low Carbon Innovation Co-ordination Group

Innovate UK Technology Strategy Board



Projects correspond to the UKCCSRC database list of projects and their categories, resourced here: https://ukccsrc.ac.uk/resources/ccs-projects-directory

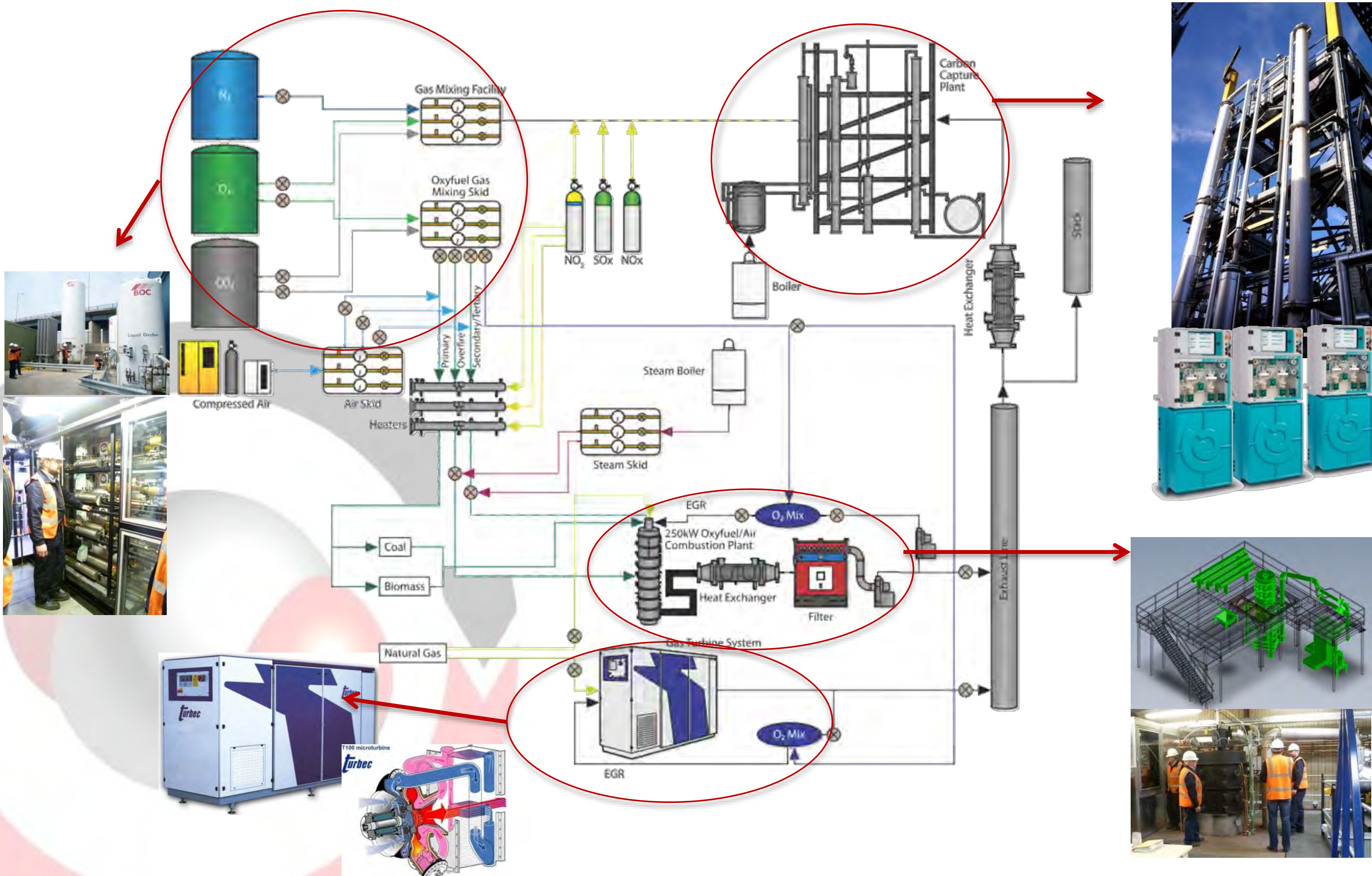
- Project with budget of <£1m
- Project with budget of £1m - £5m
- Project with budget of >£5m

FUNDAMENTAL RESEARCH & UNDERSTANDING

COMPONENT DEVELOPMENT & APPLIED RESEARCH

PILOT SCALE

PACT Core Facility: Integrated Facilities



Research challenges in CCS

UKCCS RESEARCH CENTRE

Part 2 - Identify and help deliver cost-effective pathways to deploy CCS across the whole energy system

- Urgent need to transform CCS system concepts ….
- … and develop the underpinning science to deliver cost-reduction,
- to engage with policy, regional and industry stakeholders
- … and support new commercial, social and technical approaches.

New CCS system concepts and some areas for cost reduction research

Cross-cutting issues

- CCS role in net-zero emission energy systems and pathways
- BECCS interactions with biomass and land use constraints
- Social, policy and commercial viability for CCS delivery models

Combined power, industry and hydrogen clusters

- Novel capture technologies e.g. solids and membranes, for a range of applications
- Gas to power with capture – post-combustion and oxyfuel
- Gas to hydrogen with capture – SMR with CCS and novel routes
- BECCS and other GGR technologies
- Synergies between cluster components (including CCU)

Transport

- Shipping as well as pipeline

Storage

- Using wells and pore space more effectively
- Reliable long-term modelling for liability management
- Offshore EOR
- UK test site

Greenhouse gas removal technologies required before 2050 - and limited biomass available

UK Committee on Climate Change

https://www.theccc.org.uk/wp-content/uploads/2016/10/UK-climate-action-following-the-Paris-Agreement-Committee-on-Climate-Change-October-2016.pdf

- *The UK 2050 target to reduce emissions at least 80% from 1990 levels (i.e. less than around 160MtCO_2e/yr) is challenging and requires significant action across the economy, but can be met in various ways using currently known technologies.*

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NERC GGR programme just started – World First!

http://www.nerc.ac.uk/research/funded/programmes/ggr/

Status of CCS

- CCS has been transformed – its roles in the **net-zero emissions energy system** need to be researched and understood
- Social, policy and commercial viability is essential – Government, including the Treasury, must be on board
- Research communities need to develop and maintain capacity for cost-reduction research
- Plus the linkages to identify the right questions and deliver the answers to the users
- With support, fundamental research can help to deliver options to reduce costs before deployment in the 2020's
- And continue to reduce costs for the rest of the century