

Reflections on CCS Demonstration: Demonstrating what, when, where and why?

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A Potted History of the Rise of CCS (Policy)

- *Targets v Technology*
 - 1997 Kyoto Protocol focus on legally-binding QELROs
 - CCS included in KP Art 2.1 & IPCC GHG Guidelines 2006 but repeated failures to get CCS into CDM before Decision 10/CMP.7 at Durban in 2011.
 - Election of George W Bush see US withdrawal from KP replaced by technology focus and creation of CSLF. In 2003, Bush 43 announces \$1B for Futuregen 1.0
- *What does it mean to pick winners?*
 - Proposed 475MW CCS demonstration proposed by BP at Peterhead with HMG support for 'low-carbon' technologies requested by end 2005 to make FID in mid-2007 (instead Blair Govt calls for open competition in late 2006)

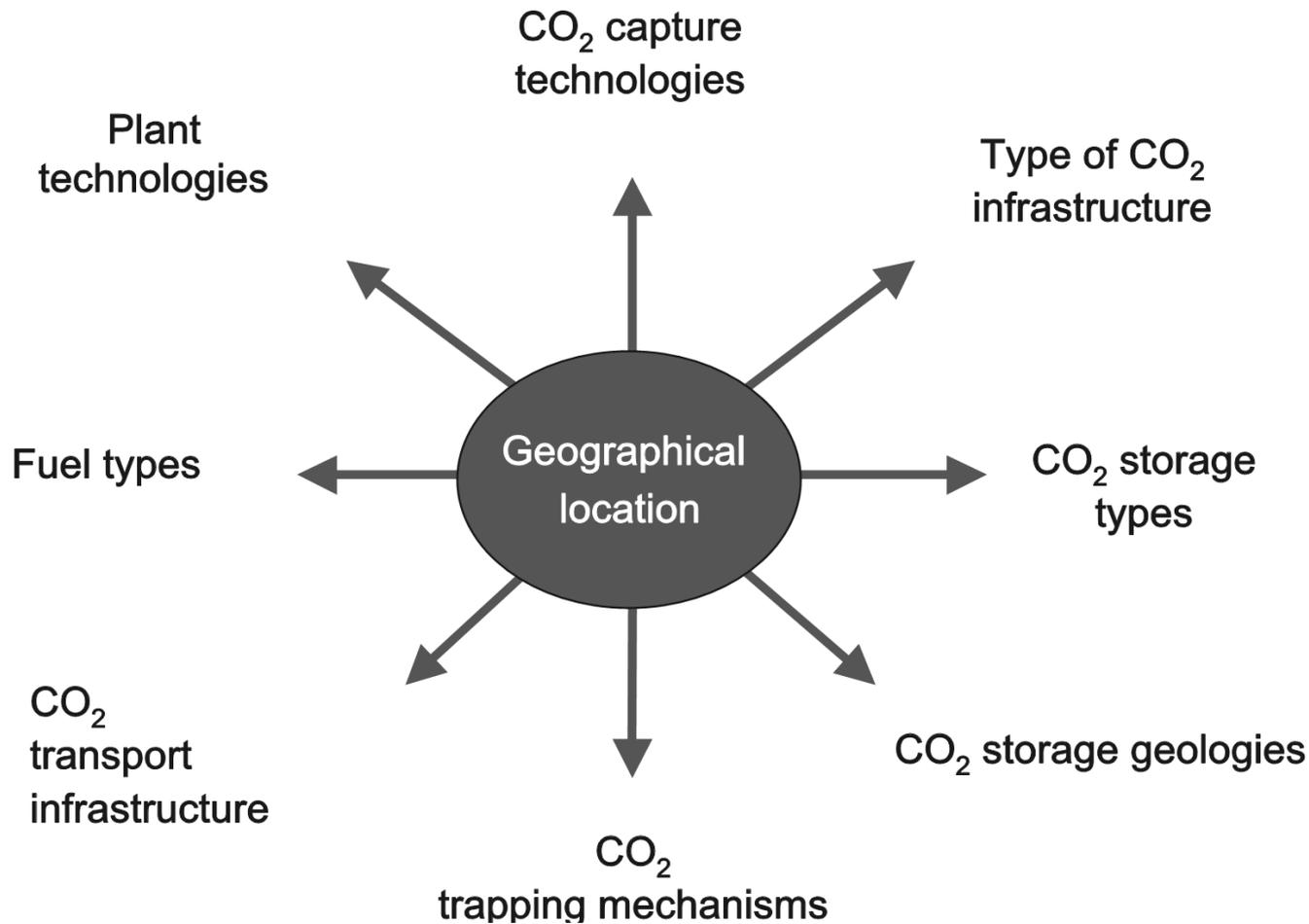


Great Expectations

- In March 2007 European leaders issued a declaration calling for ‘up to 12’ CCS demonstration projects to be in operation by 2015 (by time of ZEP launch’10-12’ ‘by 2020’)
- At 2008 Hokkaido Toyako G8 Summit, leaders:
 - Announced 20 large-scale CCS demonstration projects globally by 2010, taking into account various national circumstances, with a view to beginning broad deployment of CCS by 2020.
 - Established an international initiative with the support of the IEA to develop CCS technology roadmaps and enhance global co-operation through existing and new partnerships.
 - Committed to various policy and regulatory measures to provide incentives for commercialising CCS technologies.
- Norway PM Stoltenberg describes CCS as their ‘moon landing’
- ZEP Demonstration Programme envisions 80-120 commercial CCS projects by 2030

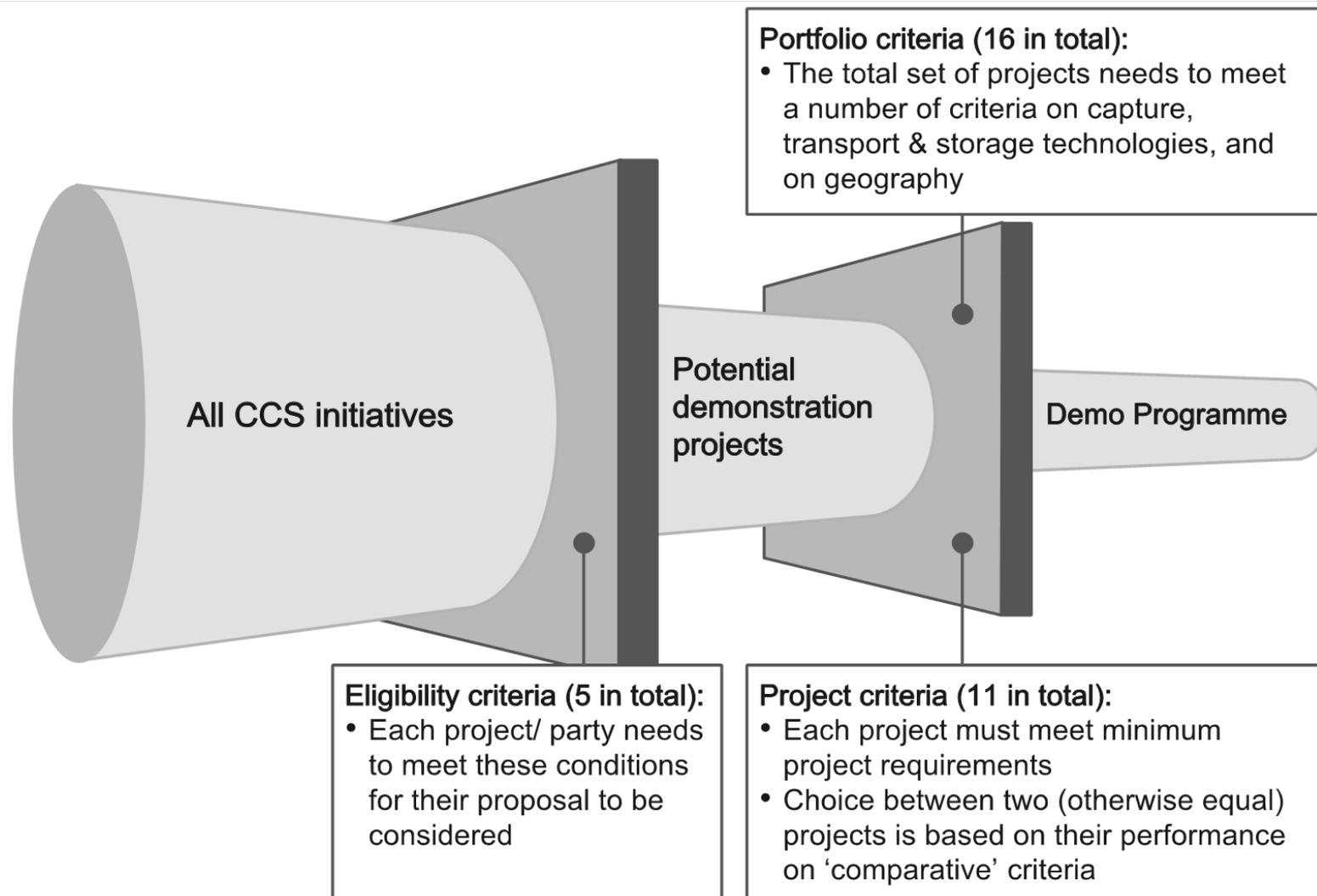


ZEP on demonstrating along multiple dimensions



Source: ZEP, EU Demonstration Programme for CCS

Narrowing down the demo programme



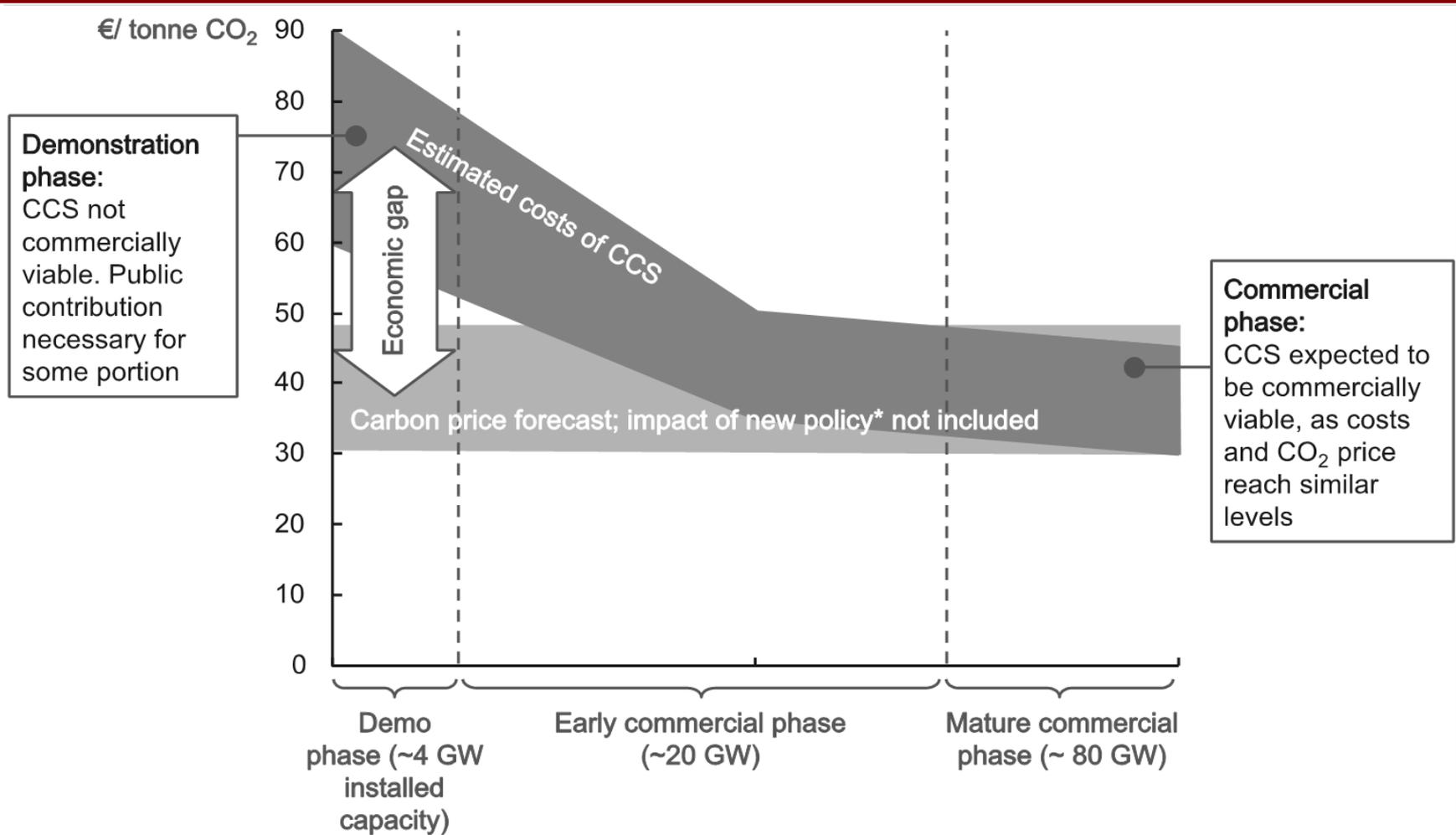


ZEP's 7 archetypal projects to span the space

Archetype 1	<ul style="list-style-type: none"> • Lignite/co-firing with Biomass 	<ul style="list-style-type: none"> • Pre-combustion, variant A 	<ul style="list-style-type: none"> • Cross-border pipeline 	<ul style="list-style-type: none"> • Offshore depleted oil & gas field 	<ul style="list-style-type: none"> • International cooperation
Archetype 2	<ul style="list-style-type: none"> • Gas 	<ul style="list-style-type: none"> • Post-combustion, variant A 	<ul style="list-style-type: none"> • Pipeline 	<ul style="list-style-type: none"> • Onshore structural deep saline aquifer 	<ul style="list-style-type: none"> • Retrofit
Archetype 3	<ul style="list-style-type: none"> • Hard Coal 	<ul style="list-style-type: none"> • Oxy-fuel, variant A 	<ul style="list-style-type: none"> • Ship 	<ul style="list-style-type: none"> • Offshore open deep saline aquifer 	
Archetype 4	<ul style="list-style-type: none"> • Hard Coal 	<ul style="list-style-type: none"> • Post-combustion, variant A 	<ul style="list-style-type: none"> • Pipeline 	<ul style="list-style-type: none"> • Onshore depleted oil & gas field 	<ul style="list-style-type: none"> • Improved efficiency
Archetype 5	<ul style="list-style-type: none"> • Lignite 	<ul style="list-style-type: none"> • Oxy-fuel, variant B 	<ul style="list-style-type: none"> • Pipeline 	<ul style="list-style-type: none"> • Onshore structural deep saline aquifer 	
Archetype 6	<ul style="list-style-type: none"> • Hard Coal 	<ul style="list-style-type: none"> • Pre-combustion, variant B 	<ul style="list-style-type: none"> • Pipeline 	<ul style="list-style-type: none"> • Offshore depleted oil & gas field 	
Archetype 7	<ul style="list-style-type: none"> • Hard Coal 	<ul style="list-style-type: none"> • Post-combustion, variant B 	<ul style="list-style-type: none"> • Pipeline 	<ul style="list-style-type: none"> • Onshore open deep saline aquifer 	

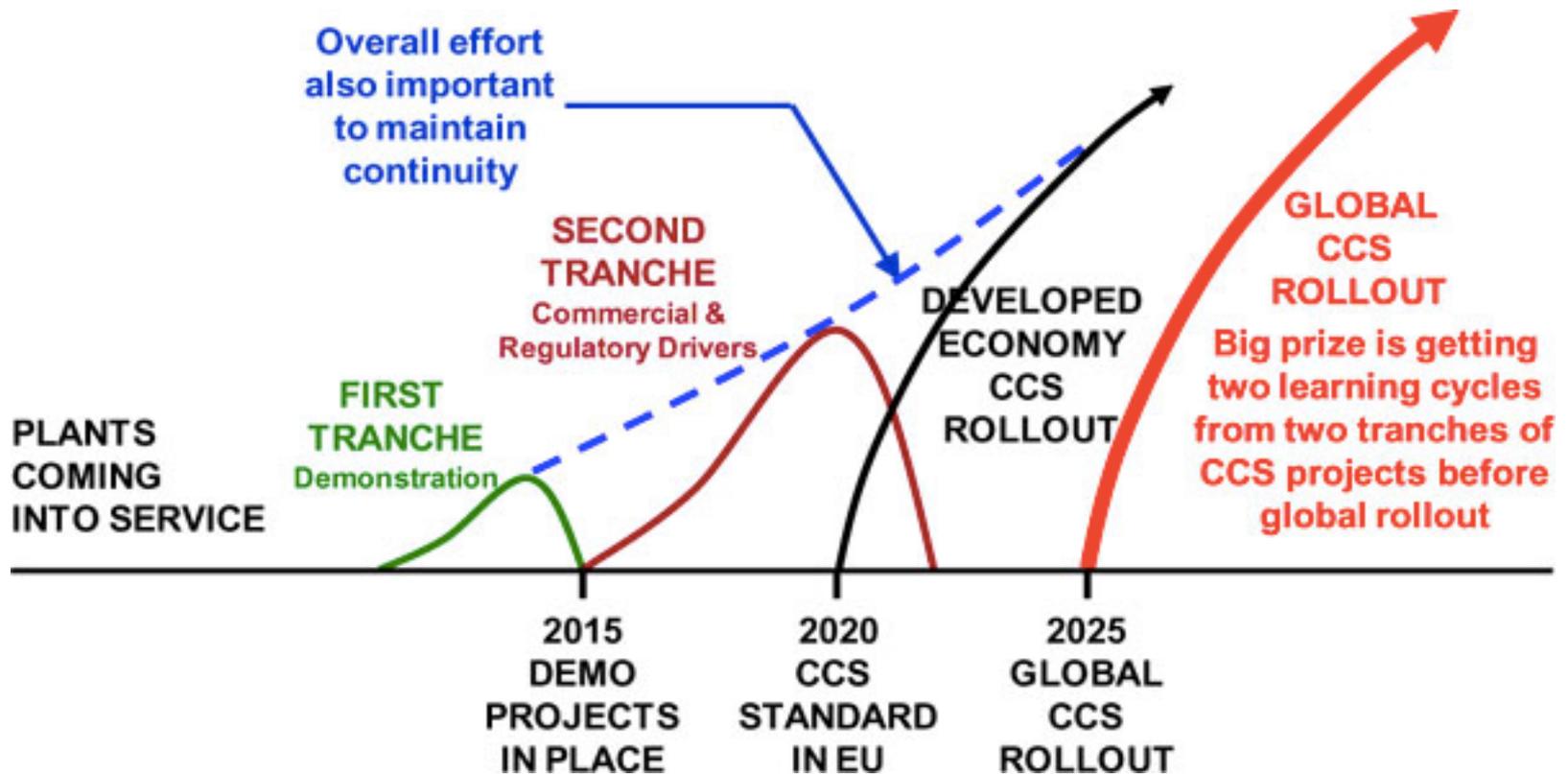


A 2008 view of convergence?



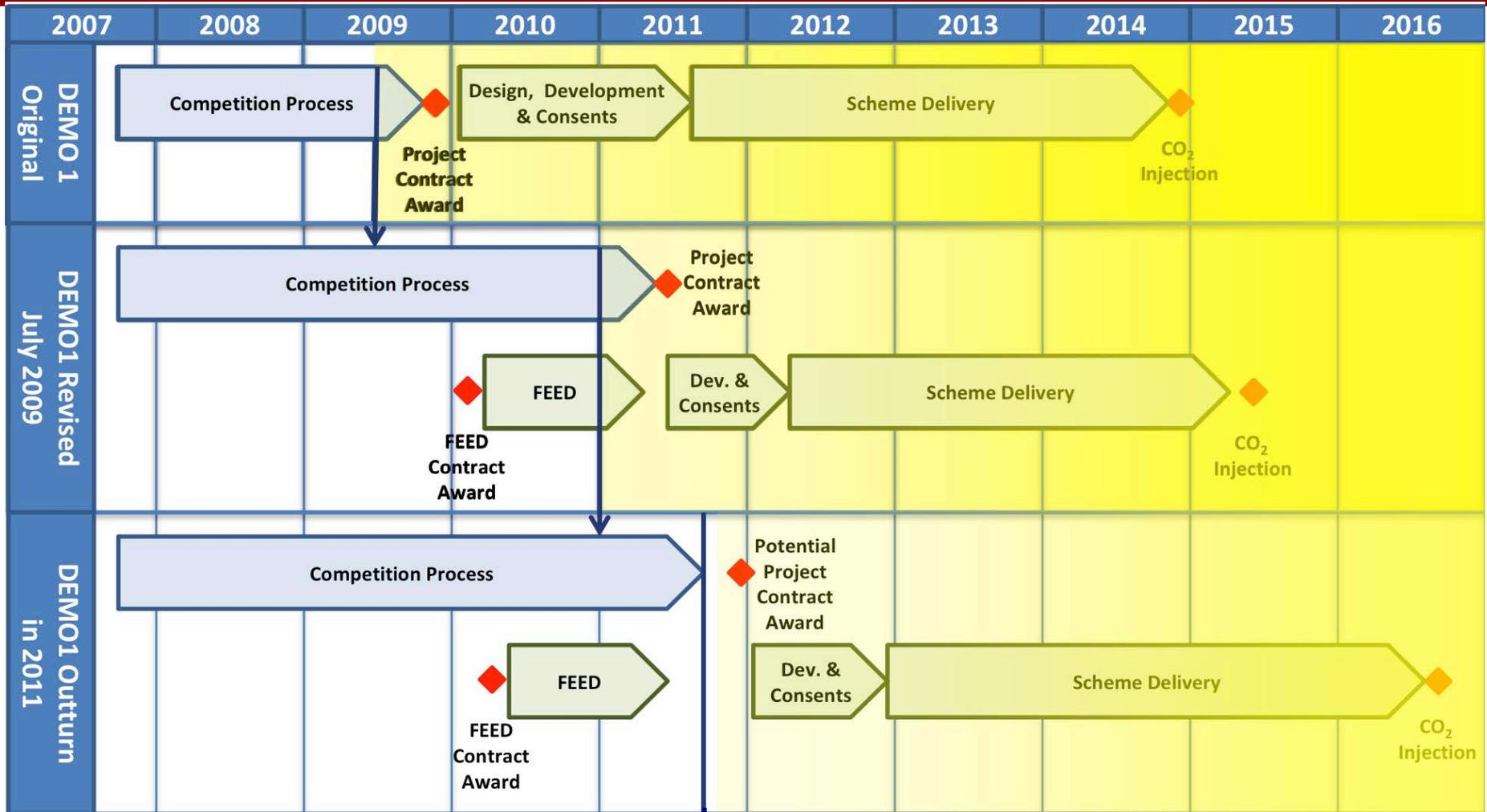
* Carbon price band for 2015 from 2008-15 estimates from Deutsche Bank, New Carbon Finance, Soc Gen, UBS, Point Carbo. Impact of the (possible) new ETS directive and the Copenhagen conference are not included in the analysis
Source: McKinsey & Company "CCS – Assessing the Economics" for the cost numbers; policy implications drawn by ZEP

Visions of sugar-plum fairies danced in their heads



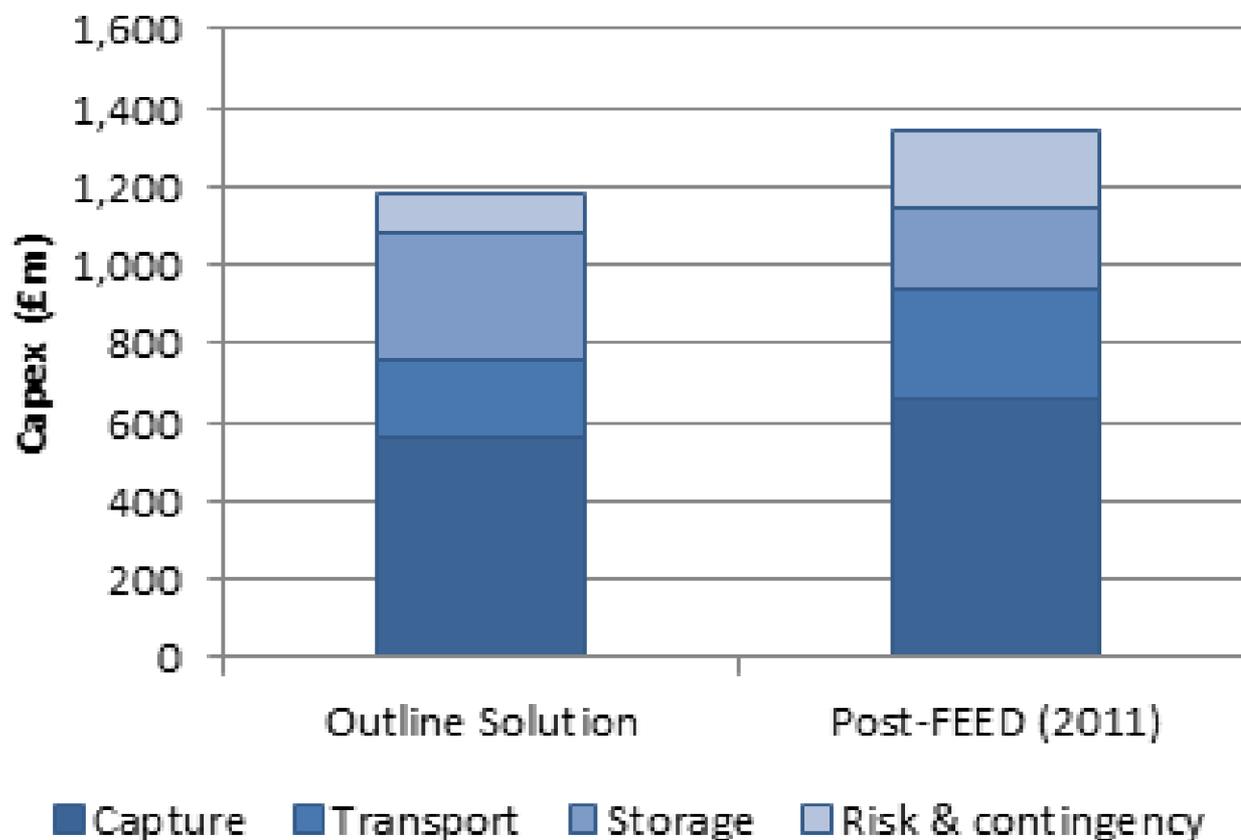
Gibbins and Chalmers (2008)

Reality Bites



Project Cancellation

Longannet project costs: pre- and post-FEED study



F. Jones, CCS Case Study
UKERC/WP/TPA/2013/004

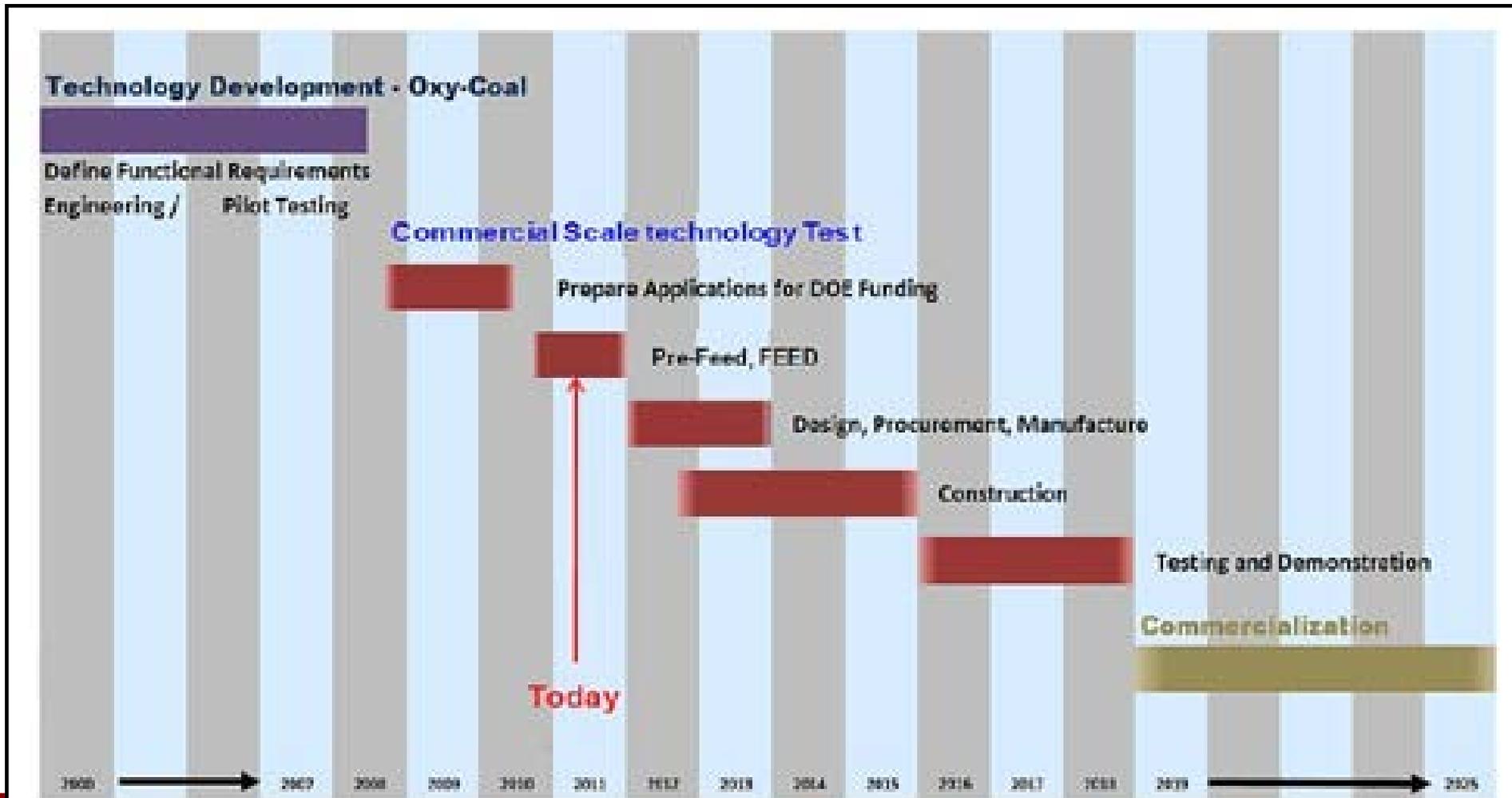


NAO Report on First UK Competition

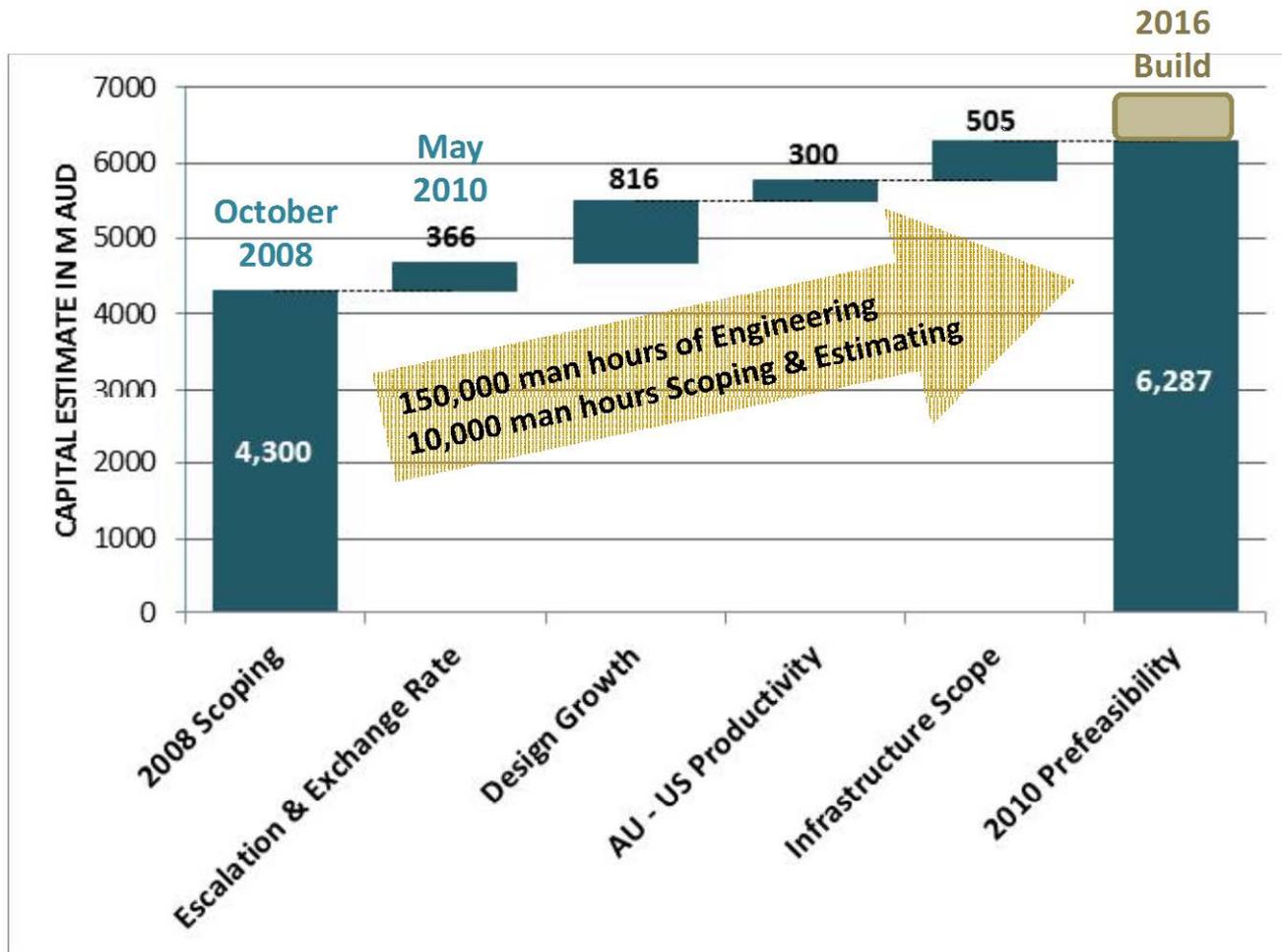
- "In the context of value for money, developing new technologies is an inherently risky undertaking. Taking calculated risks is perfectly acceptable if those risks are managed effectively; but in this case DECC, and its predecessor, took too long to get to grips with the significant technical, commercial and regulatory risks involved.
- "Four years down the road, commercial scale carbon capture and storage technology has still to be developed. The Department must learn the lessons of the failure of this project if further time is not to be lost, and *value for money achieved on future projects.*" (italics mine)
 - Amyas Morse, head of the National Audit Office, 16 March 2012

Back to the Future (gen)

Futuregen 2.0



Escalation of Zerogen Costs



Source: Chris Greig. 2012 EPRI CCS Cost Workshop



2012 DECC Roadmap on Demonstration

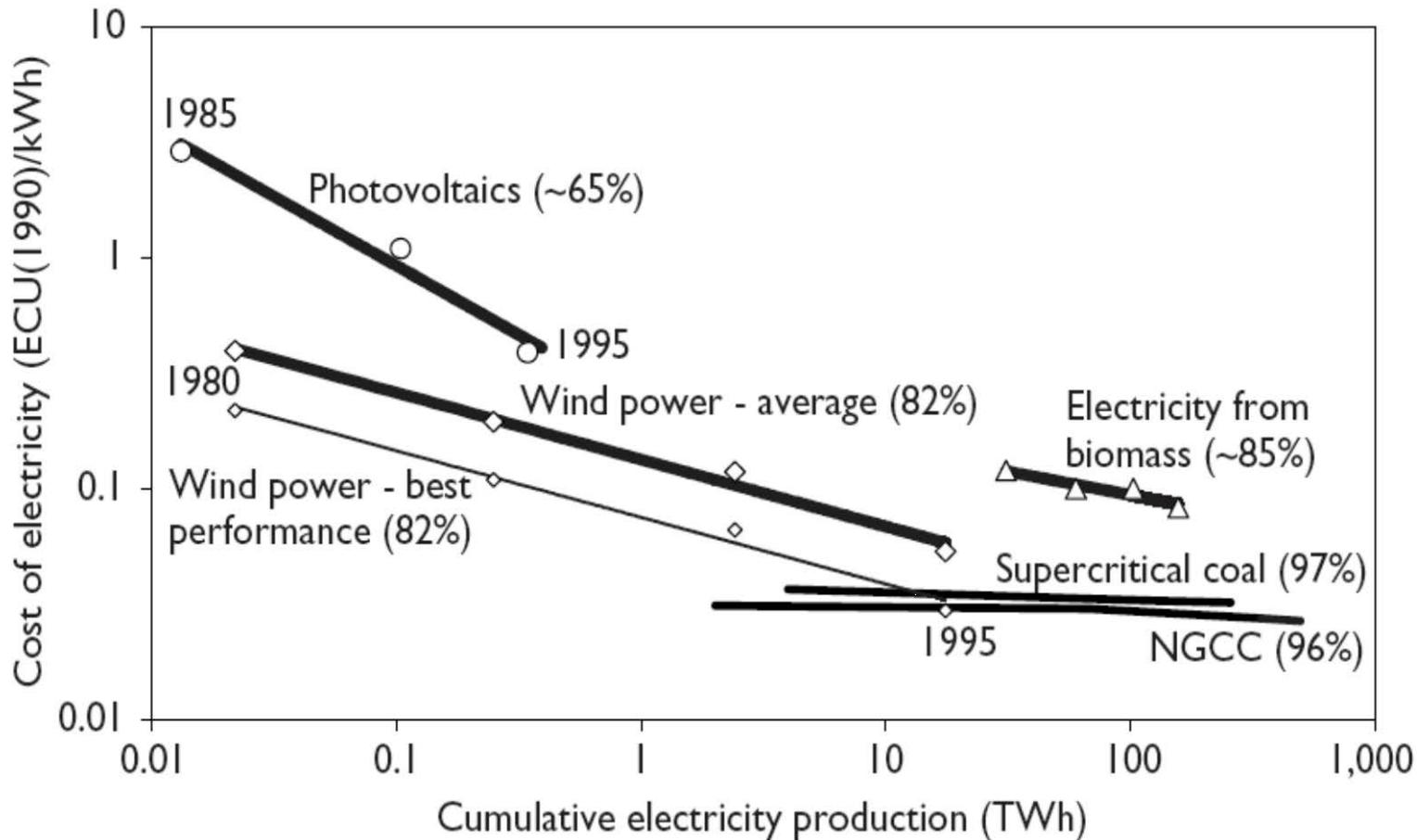
- CCS Commercialisation Programme with £1 billion capital support focused on learning by doing and sharing knowledge to reduce cost of CCS so that it can be deployed in early 2020s
- Roadmap should enable [20-30 GW by 2030], *subject to CCS demonstrating its effectiveness as a cost-competitive low carbon source of electricity generation* in time to meet projected demand
- Our aim is to create for the first time a market in which there is a clear commercial model for CCS in the UK, *provided it can demonstrate the ability to compete with other low carbon technologies*
- International engagement focused on sharing the knowledge we have generated through our programme and learning from other projects around the world to help accelerate cost reduction



2014 DECC Policy Scoping Doc on Demonstration

- In addition to working intensively to help support these first projects, the Government is also thinking ahead. *If the market can demonstrate that costs are falling in line with expectations*, the Government will assess how it can support industry
- We believe that *the immediate priority is to demonstrate the commercial and economic viability of CCS* at commercial scale in the power generation sector
- ***Most new technologies reduce in cost as they develop and mature. Examples of this cost reduction theory include mobile phones, electric vehicles and photo-voltaic solar panels.***
- For CCS, like other low carbon energy technologies such as offshore wind, this cost reduction is crucial for it to play a part in the UK's electricity system to 2030.
- In order to receive CfDs, these projects will need to *demonstrate value for money*

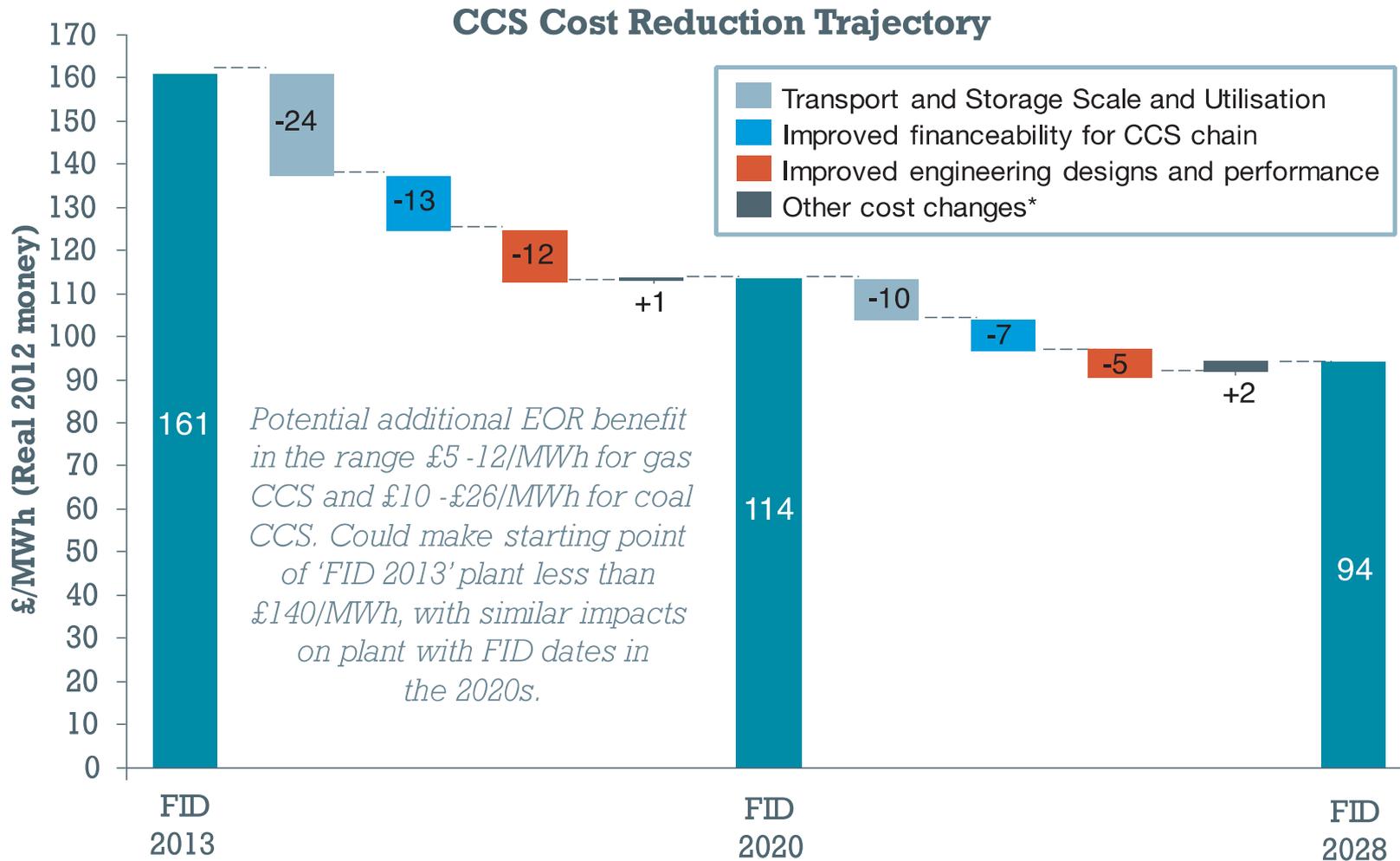
Standard Image of Learning in Energy Technology



Source: IEA (2000)



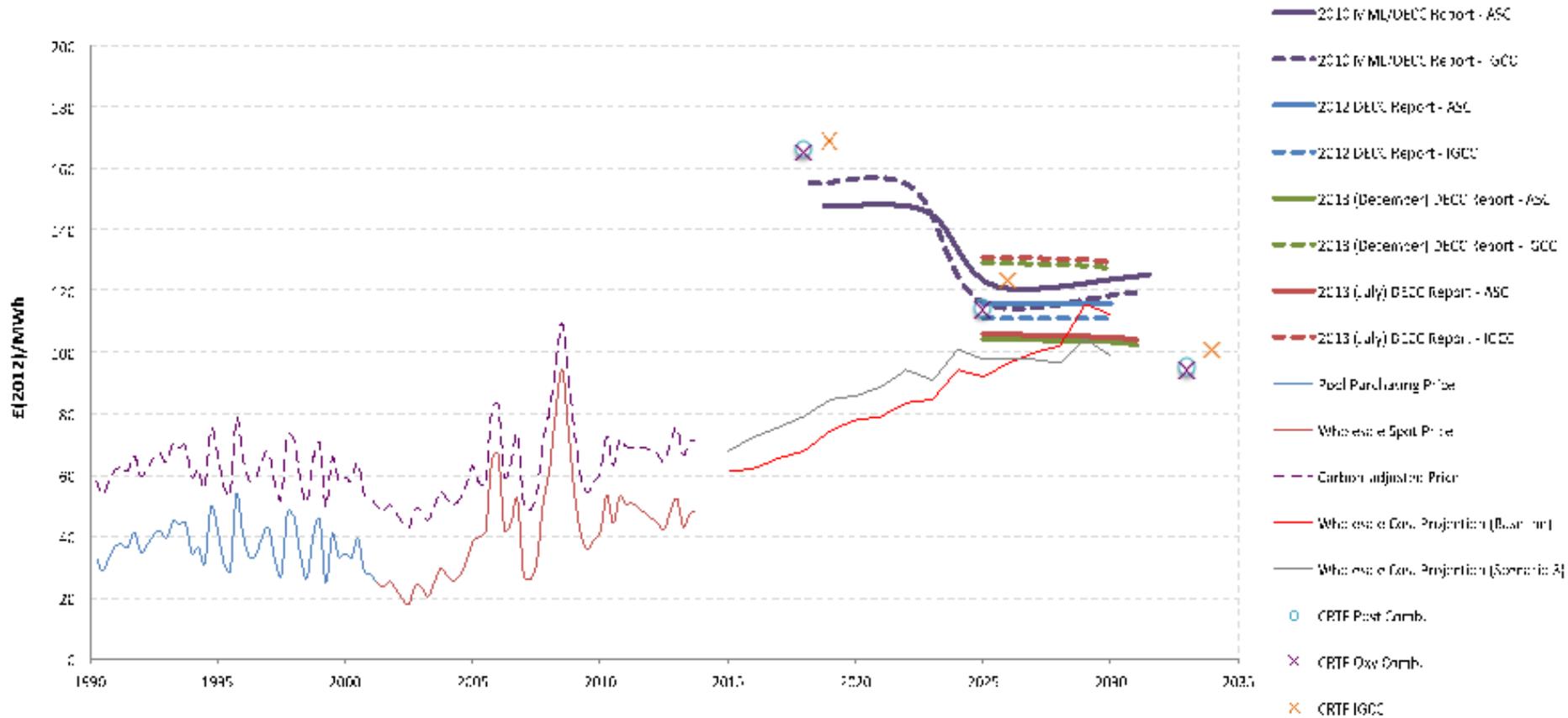
CRTF view of cost reduction



Note: Shows average costs across technologies. *E.G. Increasing CO₂ price, falling storage abandonment costs

Source: CCS Cost Reduction Task Force, May 2013

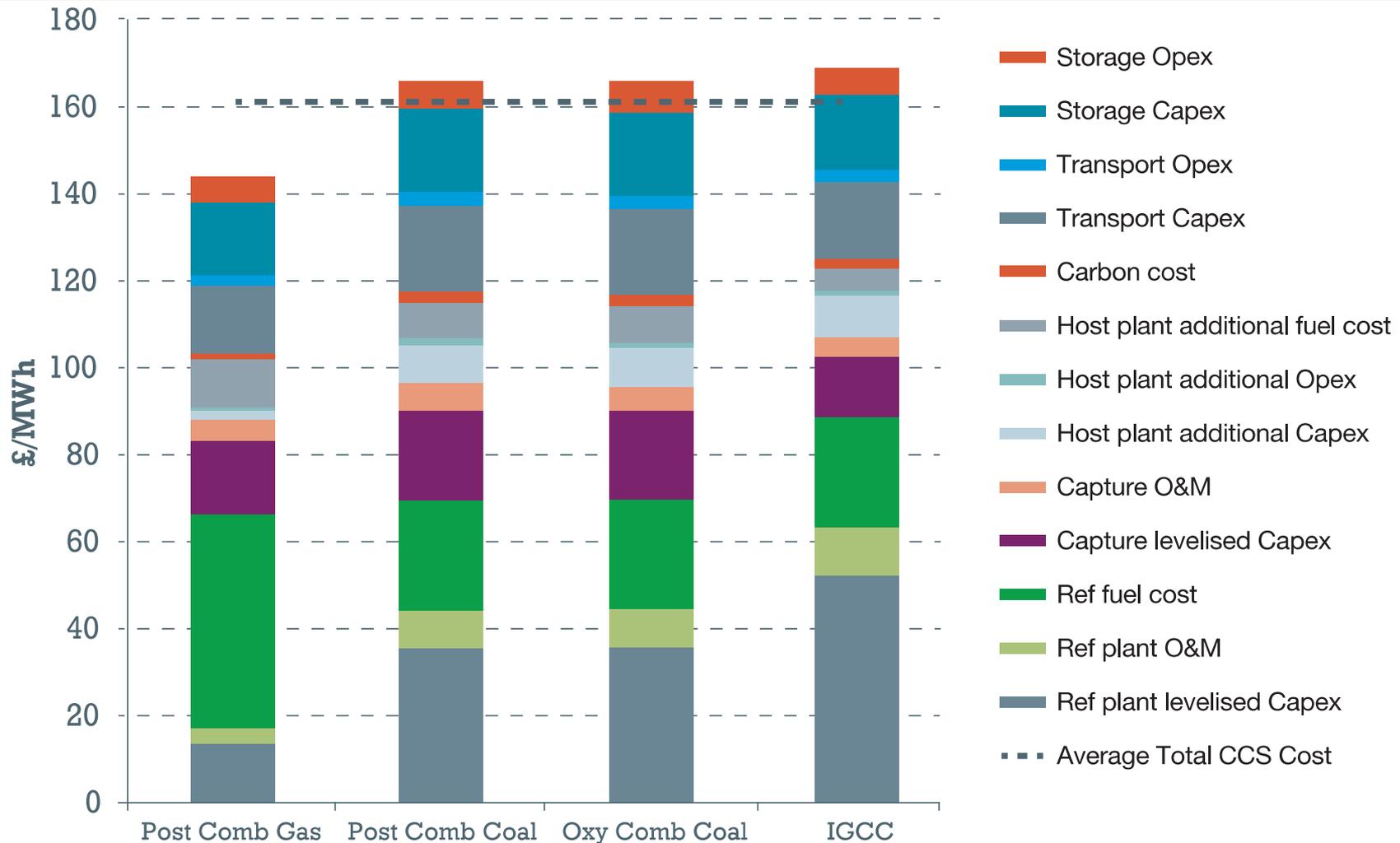
Cost uncertainty over time for Coal CCS



Levi and Pollitt (2015)

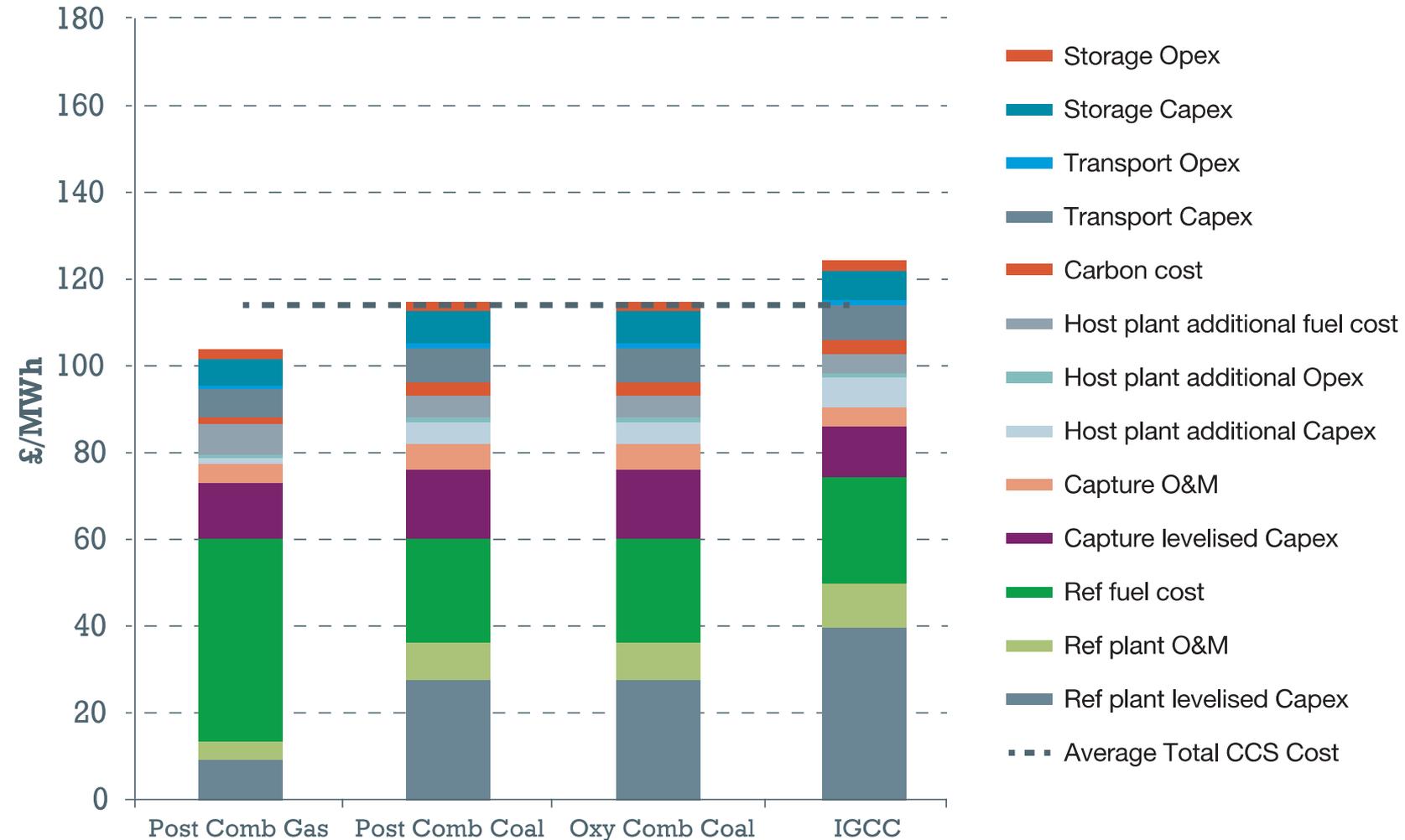


LCOE of 2013 CCS Technologies (2012 GBP)



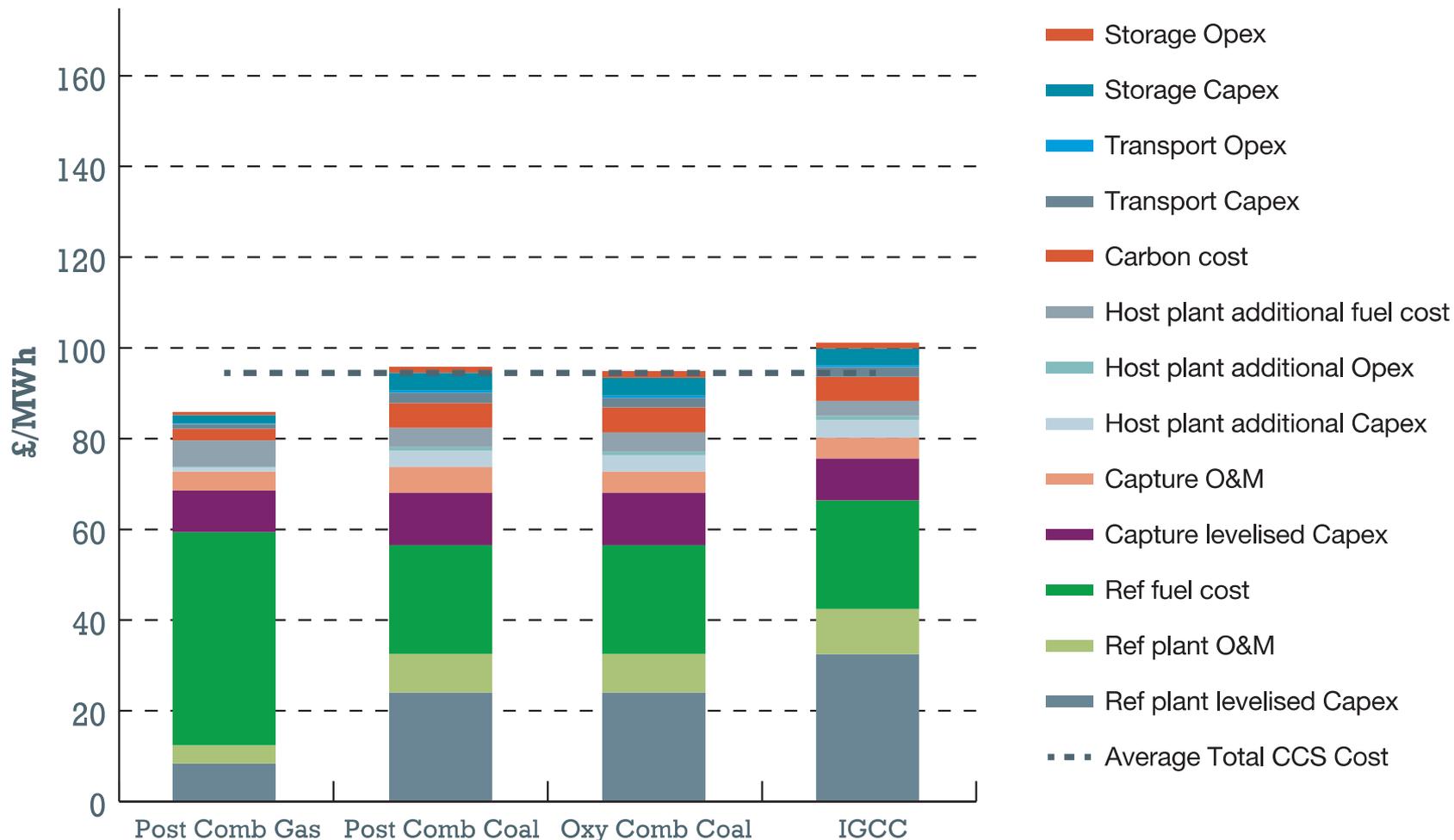
Source: CCS Cost Reduction Task Force, May 2013

LCOE of 2020 CCS Technologies (2012 GBP)



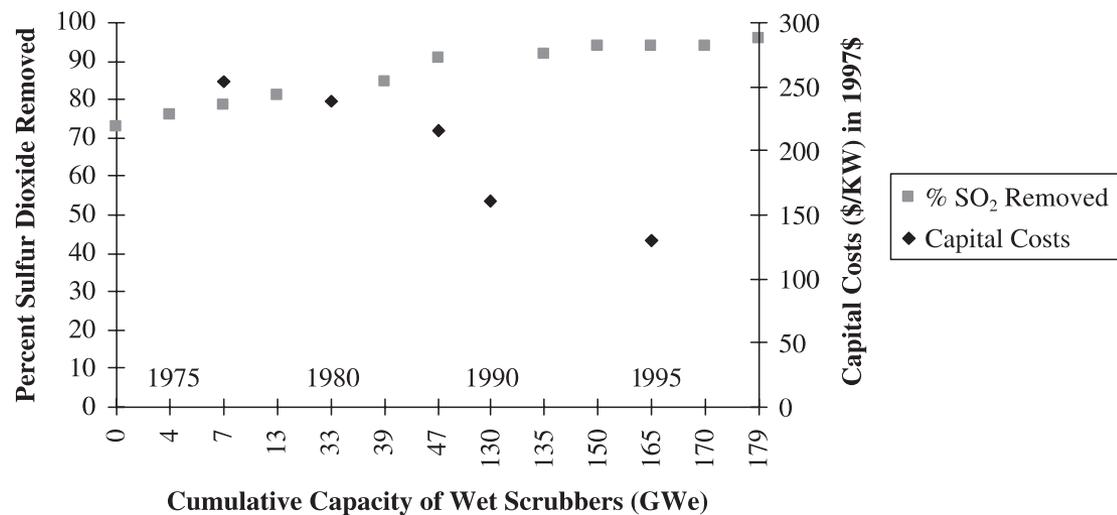
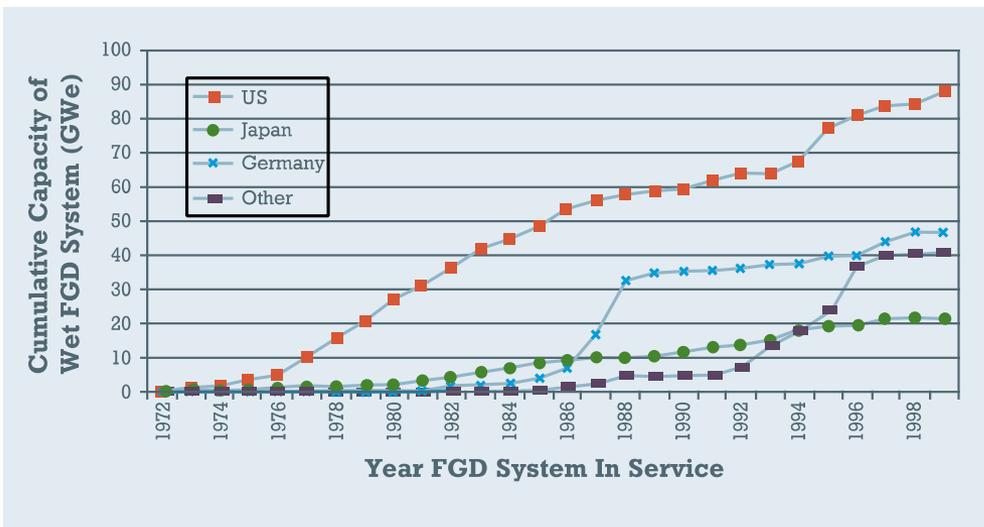
Source: CCS Cost Reduction Task Force, May 2013

LCOE of 2028 CCS Technologies (2012 GBP)

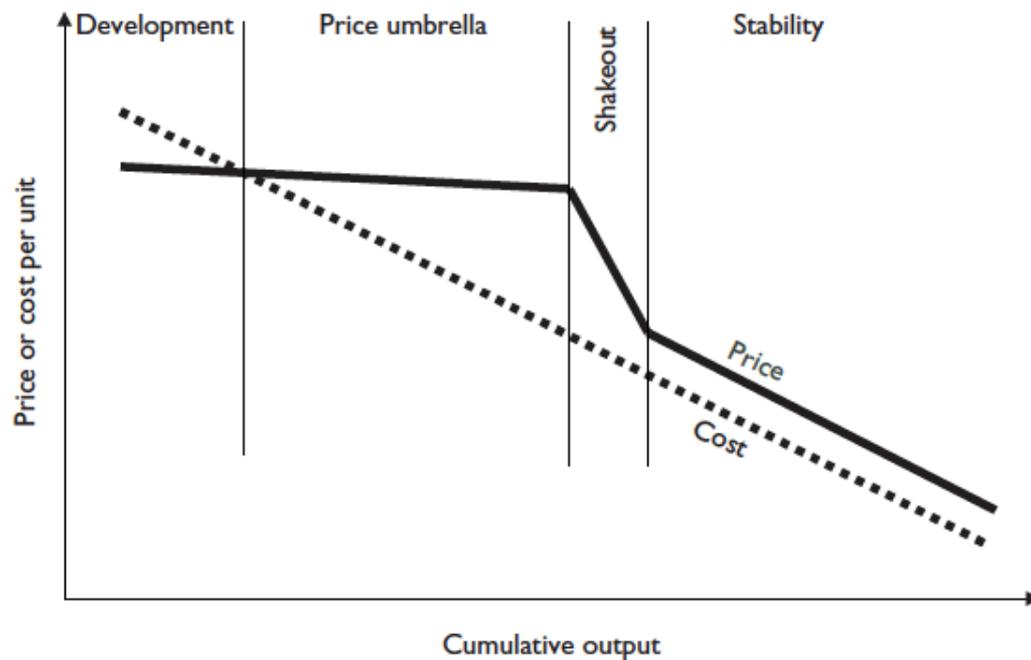


Source: CCS Cost Reduction Task Force, May 2013

CRTF view of learning and FGD systems



The earlier part of the story



Source: Boston Consulting Group (1968)

Source: Azevedo et al (2014), IAEE Presentation



Wide range in learning rates across many techs

Technology	Number of studies reviewed	Number of studies with one factor	Number of studies with two factors	Range of learning rates for “learning by doing” (LBD)	Range of rates for “learning by researching” (LBR)	Years covered across all studies
Coal*						
<i>PC</i>	2	2	0	6% to 12%		1902-2006
<i>IGCC</i>	1	1	0	2% to 8%		Projections
Natural Gas*	8	6	2	-11% to 34%	2% to 18%	1980-1998
Nuclear	4	4	0	<0 to 6%		1975-1993
Wind (on-shore)	35	29	6	-3% to 32%	10% to 27%	1980-2010
Solar PV	24	22	2	10% to 53%	10%	1959-2001
BioPower						
<i>Biomass production</i>	4	4	0	12% to 45%		1971-2006
<i>Power generation*</i>	7	7	0	0% to 24%		1976-2005
Geothermal power	3	0	0			1980-2005
Hydropower	3	0	2	<1% to 11%	3% to 21%	1980-2001

Two-factor learning:

$$C_i = a_i (x_i^{-b_{LBD}})(RD_i^{-b_{LBR}})$$

Source: Azevedo et al (2014), IAEE Presentation

Spread in learning rates for onshore wind

an = 12%
Std Dev = 14%



Source: Azevedo et al (2014), IAEE Presentation



Why has EU underdelivered on CCS?

- Lack of bankable support (no CO₂ demand for EOR or other revenue streams)
- Poor policy design (link to EUA price, no mechanism to deliver technology in a liberalised market (i.e., no EPS, little dedicated technology support))
- Lack of coordination between Member states and EU
- Tepid government support and local public opposition
- Continued reliance on ‘cheap talk’
- Never has been clarity on what is being demonstrated nor the rationale for commercial-scale operations

Demonstrate What?

- Which technology? at what scale? at what cost? to what end?
- Possible objectives:
 - **speed of deployment**
 - but speed of initial demo deployment does not necessarily imply that this will produce more plants in 2030 and beyond it may produce less
 - **industrial policy**
 - can help stimulate interest in CCS and expand geographic coverage, but in general more applicable to industrial CCS than power CCS
 - **value for money**
 - some element of cost competition will be vital, but it is still impossible to assess value for money without a better understanding of what “value” is and, for demonstration at least, value ultimately lies in learning
 - **learning potential**
 - learning from diversity: validation of the main available technological options
 - learning from replication: learning-by-doing
- Who should bear the costs of demonstration?

So what should we support? Replication v diversity

- Replication:
 - Unlike, say, wind turbines, which has seen significant learning-by-doing benefits, the number of replications involved in CCS is much smaller
 - There is little good evidence of the benefits of replication for CCS. One of the few public data points is SaskPower's claimed 20-30% reduction in capital costs for the next unit after BD3
- Diversity:
 - More attention needs to be paid to the types of diversity that should be encouraged, which requires coordination (or at least greater cognizance) of projects
 - The principle of diversity should extend to the firms involved in CCS demonstration projects, diversity in their industrial background and core competencies, as well as the proposed integrated capture-transport-storage solutions
- The value of learning-by-doing from almost simultaneously implemented projects may be limited.
- Other key factors include R&D and technical change, competition, and time

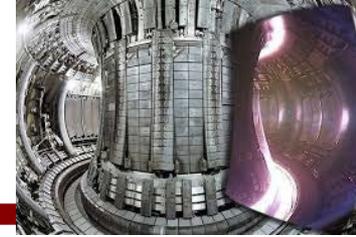


Otherwise, how was the play Mrs Lincoln?

- Not having CCS in the energy mix reflects the absence of a politically, economically and commercially viable path towards a 650 ppm world
- Absent large scale rollout of 'demonstration' of CCS projects, learning is far more challenging so understanding what projects can demonstrate is critical
- Benefits of learning-by-doing from replication are typically better achieved at the commercialization stage of development, but jury is still out as to which CCS technologies will be most successful and how CCS will fare relative to other low-carbon technologies
- Coordination is essential to ensure the needed diversity and avoid early picking of winners and support a varied range of technical solutions.
- Goal of any CCS demonstration 'programme' is not just to learn what designs and configurations are best suited to various environments, but to encourage suppliers to invest in supply chain so scaling up can be managed more quickly and cheaply in the future and ramp up RD&D
- Danger of overemphasising 'value for money' or CO₂ savings at demo stage may lead to missed opportunities such as learning about flexibility
- A CCS project delivers two outcomes – learning about costs and technical improvements, and the know-how needed to operate the plant reliably and the demo phase should attempt to improve along both dimensions

Thanks!

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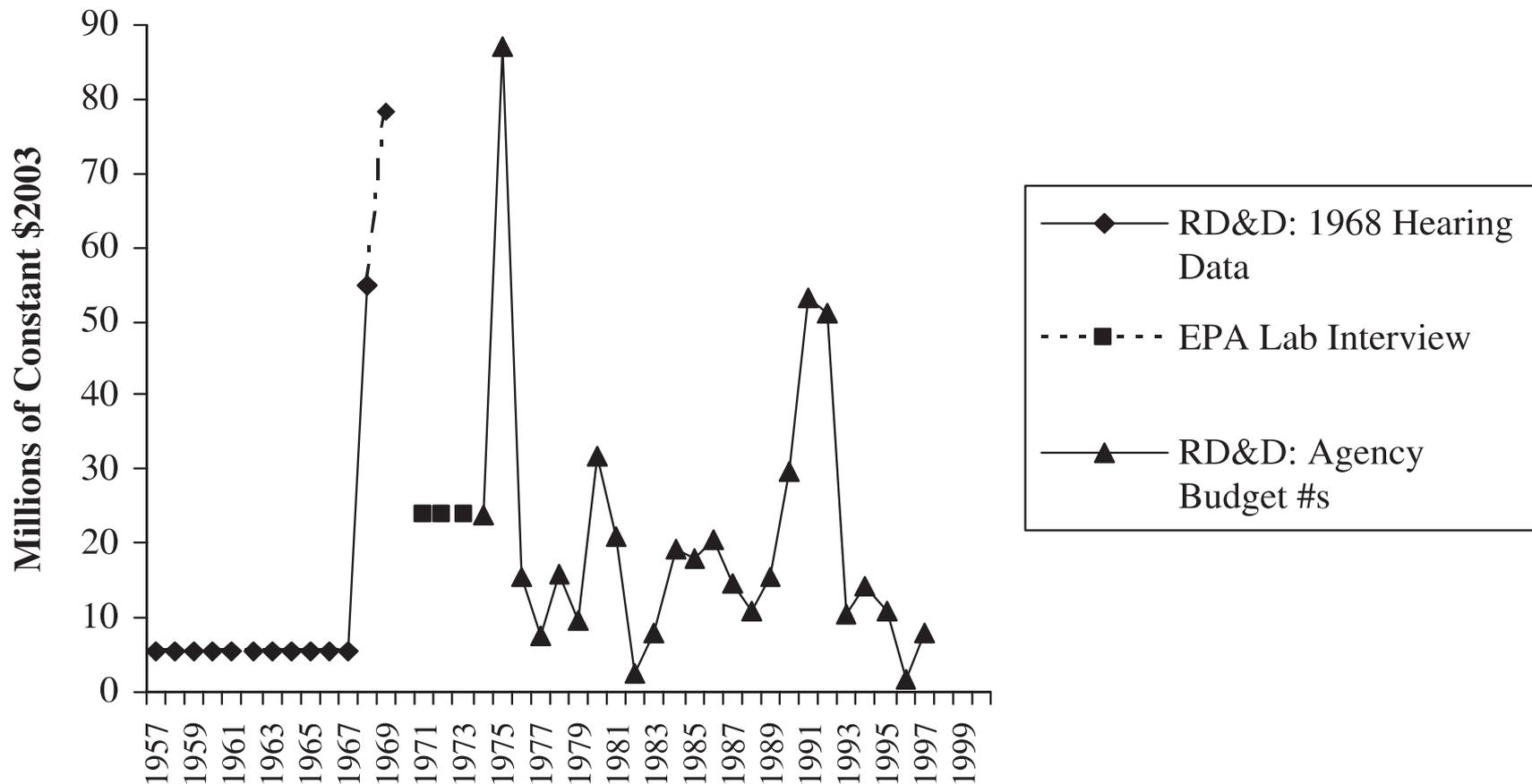


Could be worse...

- ITER designed to produce 500 MW output (50 MW to operate) in order to demonstrate the principle of producing more energy from the fusion process than is used to initiate it
- ITER initiated in 1988 following Reagan-Gorbachev summit and construction began in 2013
- As of June 2015, building costs now >US\$14 billion (3 times the original estimate). The facility is expected to finish its construction phase in 2019 and will start commissioning the reactor that same year and initiate plasma experiments in 2020 with full deuterium-tritium fusion experiments starting in 2027



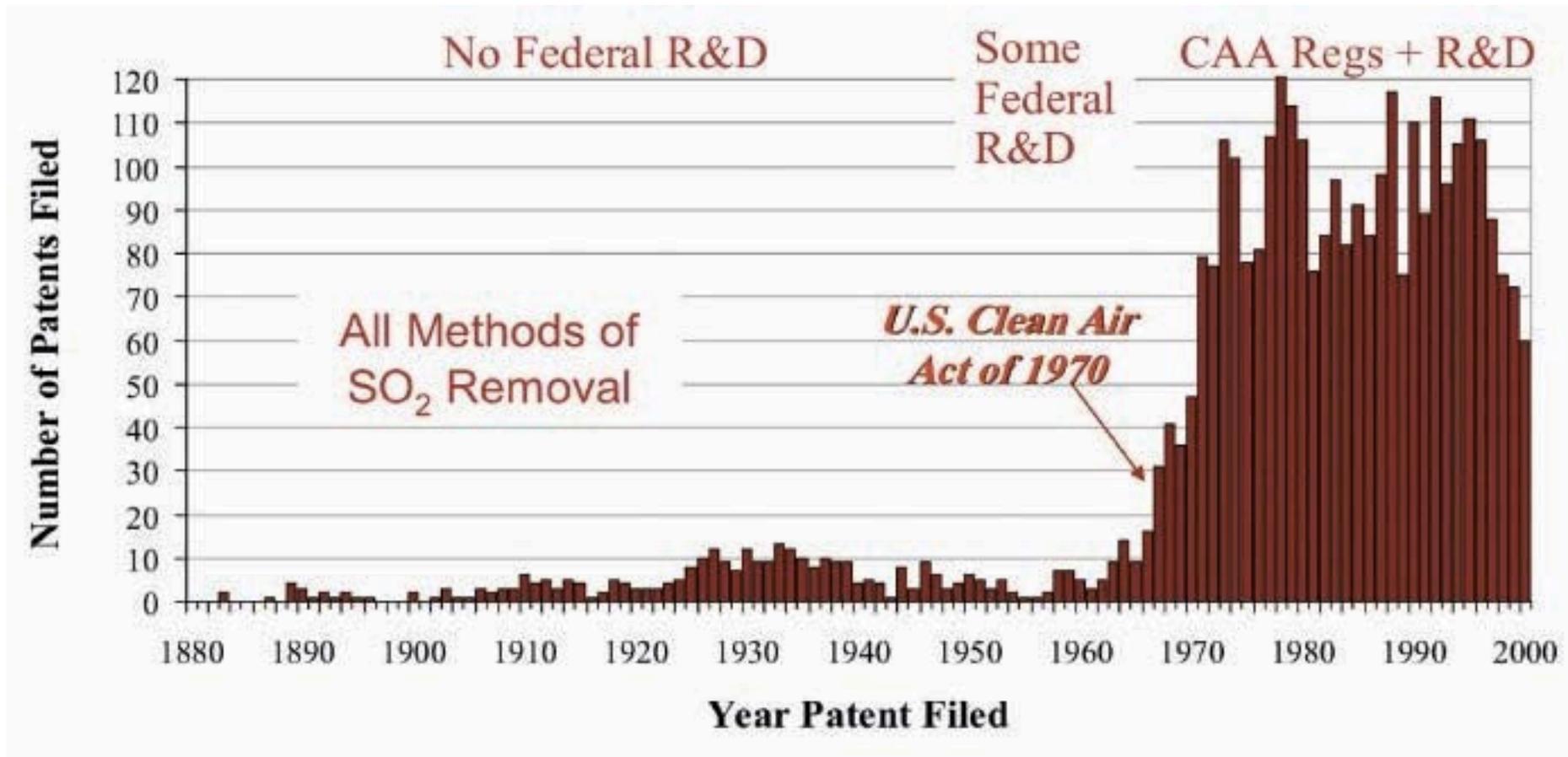
RD&D Expenditures for SO₂ control



Source: Taylor, M.R., Rubin, E.S., and Hounshell, D.A. "Regulation as the Mother of Innovation: The Case of SO₂ Control." *Law & Policy*, **27**: 2, 348-78, April 2005.

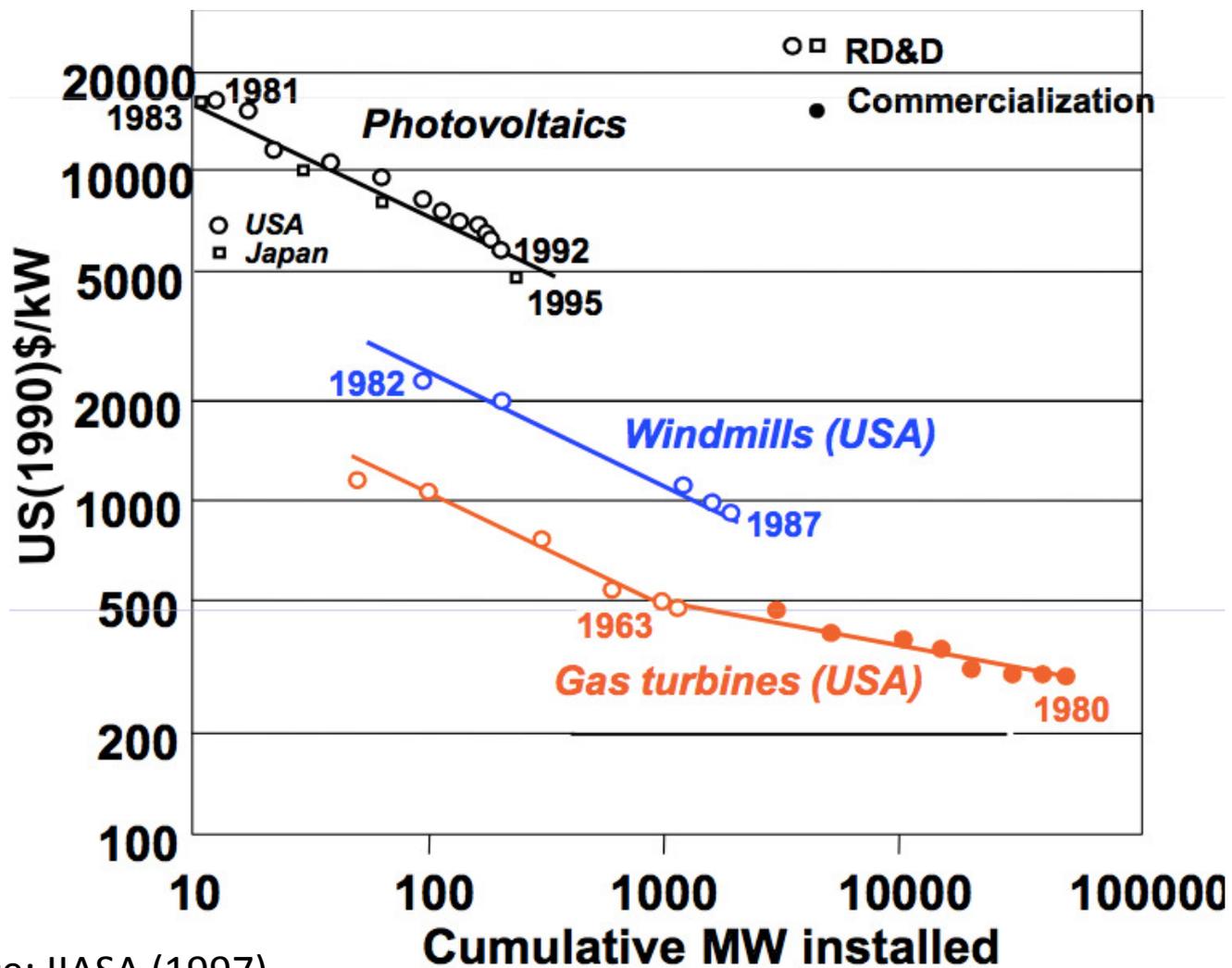


Patents for SO₂ Control



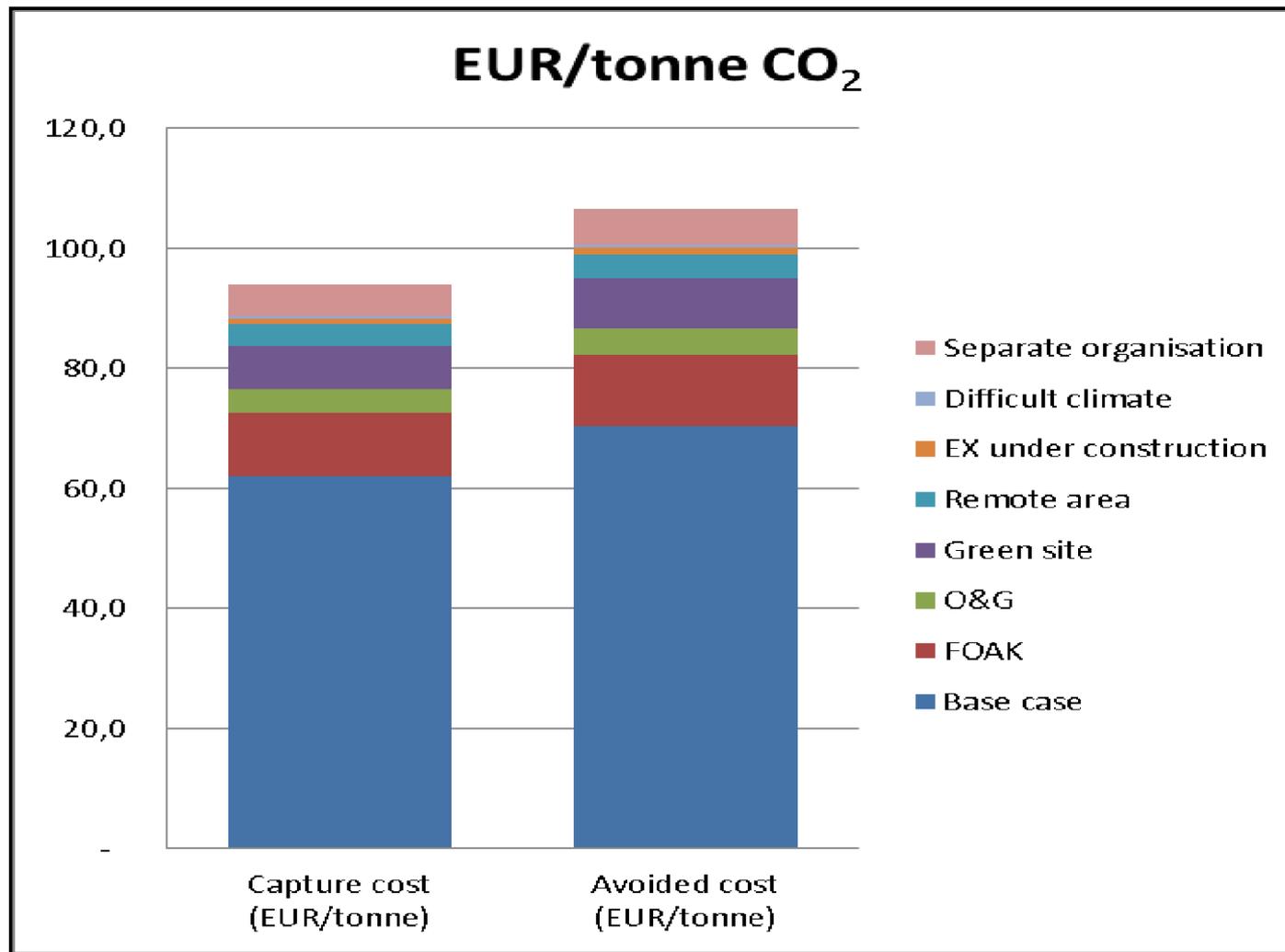
Source: M.R. Taylor, E.S. Rubin, and D.A. Hounshell. 2005. "Control of SO₂ Emissions from Power Plants: A Case of Induced Technological Innovation in the U.S." *Technological Forecasting and Social Change*, 72 (6), 697–718.

Moving from RD&D to Commercial Operations



Source: IIASA (1997)

Impact of location factor on costs



Skagestad, Lach, Røkke, and Eldrup, Critical Factors Influencing CO₂ Capture Cost, a Case Study, GHGT12



More 'real-world' impacts: supply chain bottlenecks

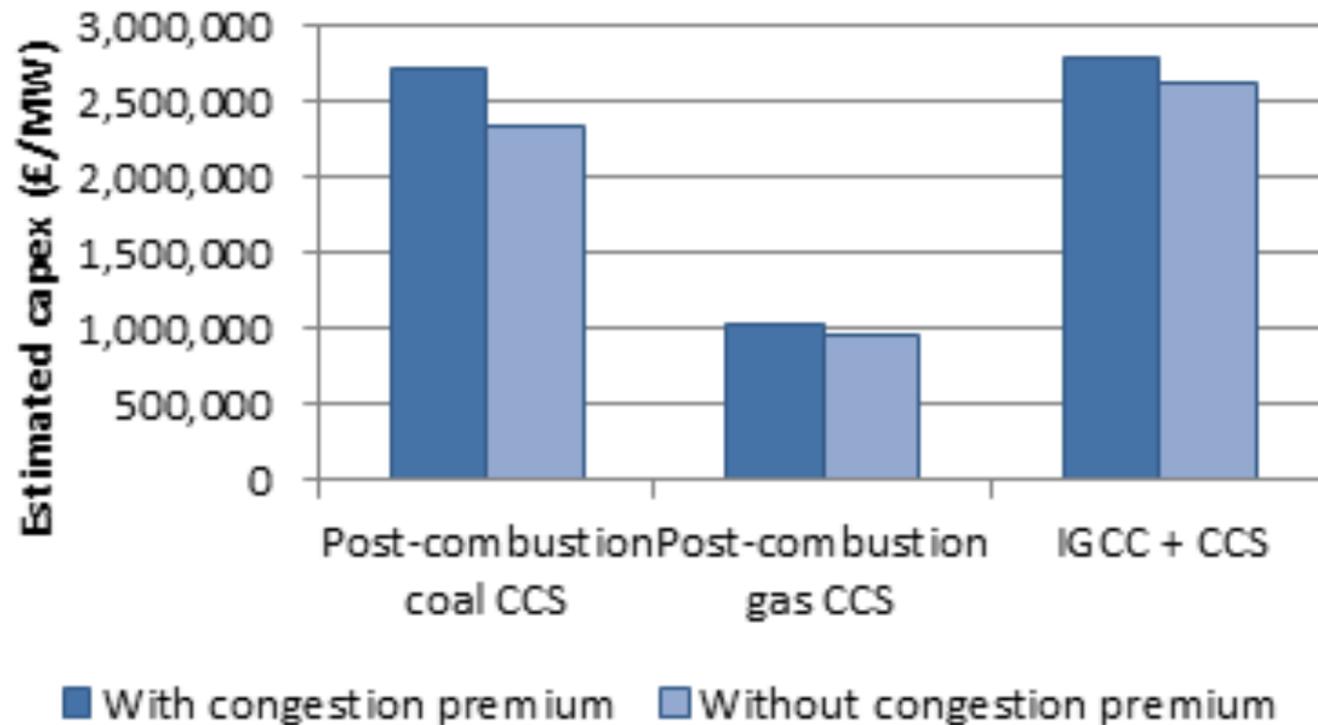


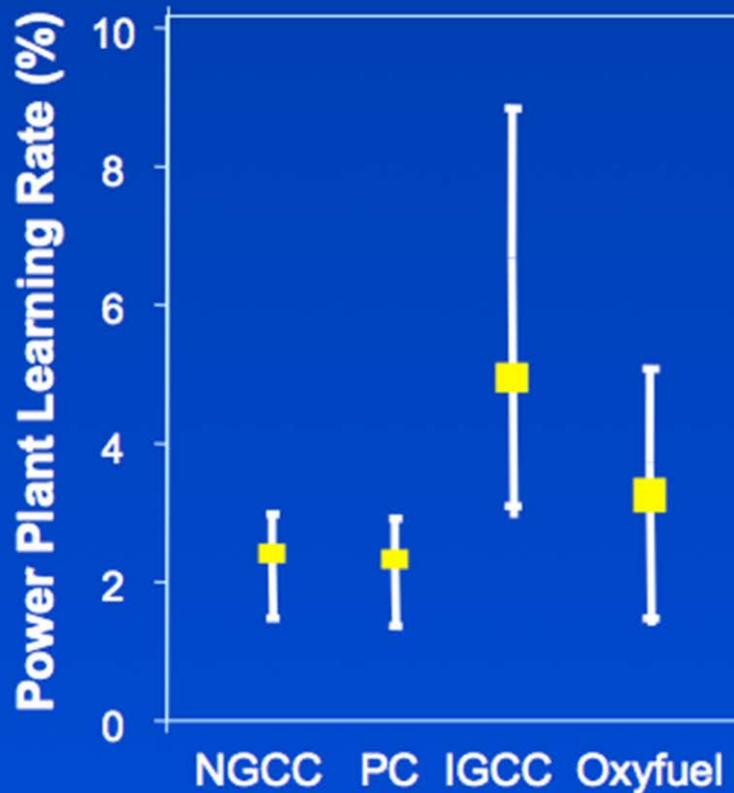
Figure 4: The estimated 'congestion premium' for CCS cost estimates arising from supply chain bottlenecks. Based on estimates by Mott MacDonald (2010).

F. Jones, CCS Case Study
UKERC/WP/TPA/2013/004

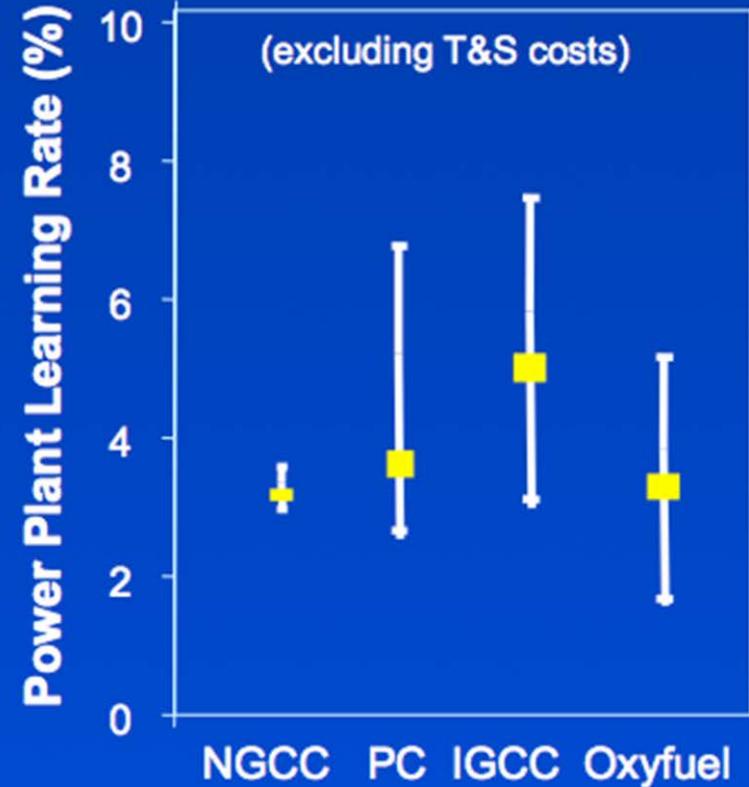


Examining learning rates by CCS technology

TOTAL PLANT CAPITAL COST

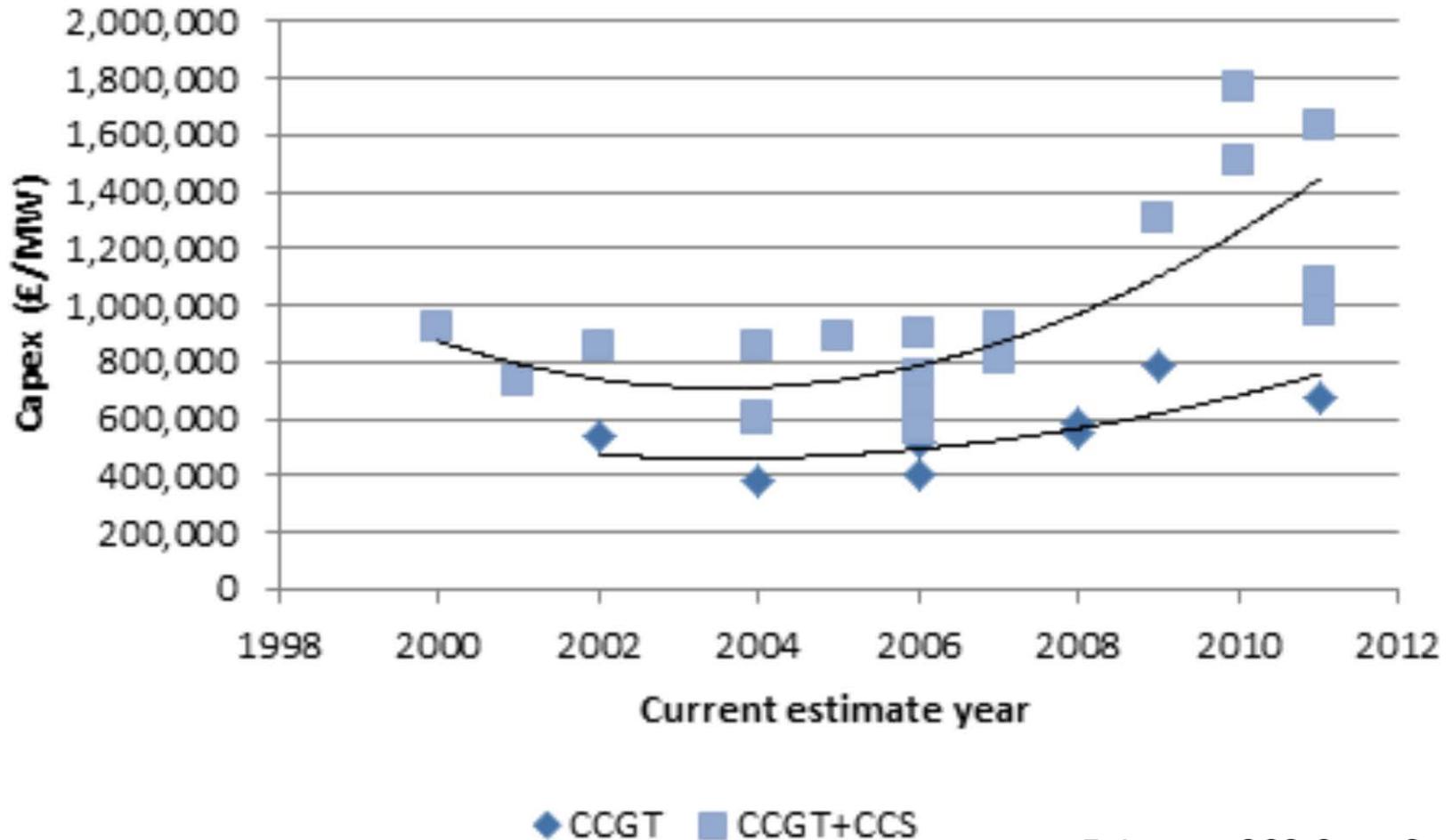


COST OF ELECTRICITY



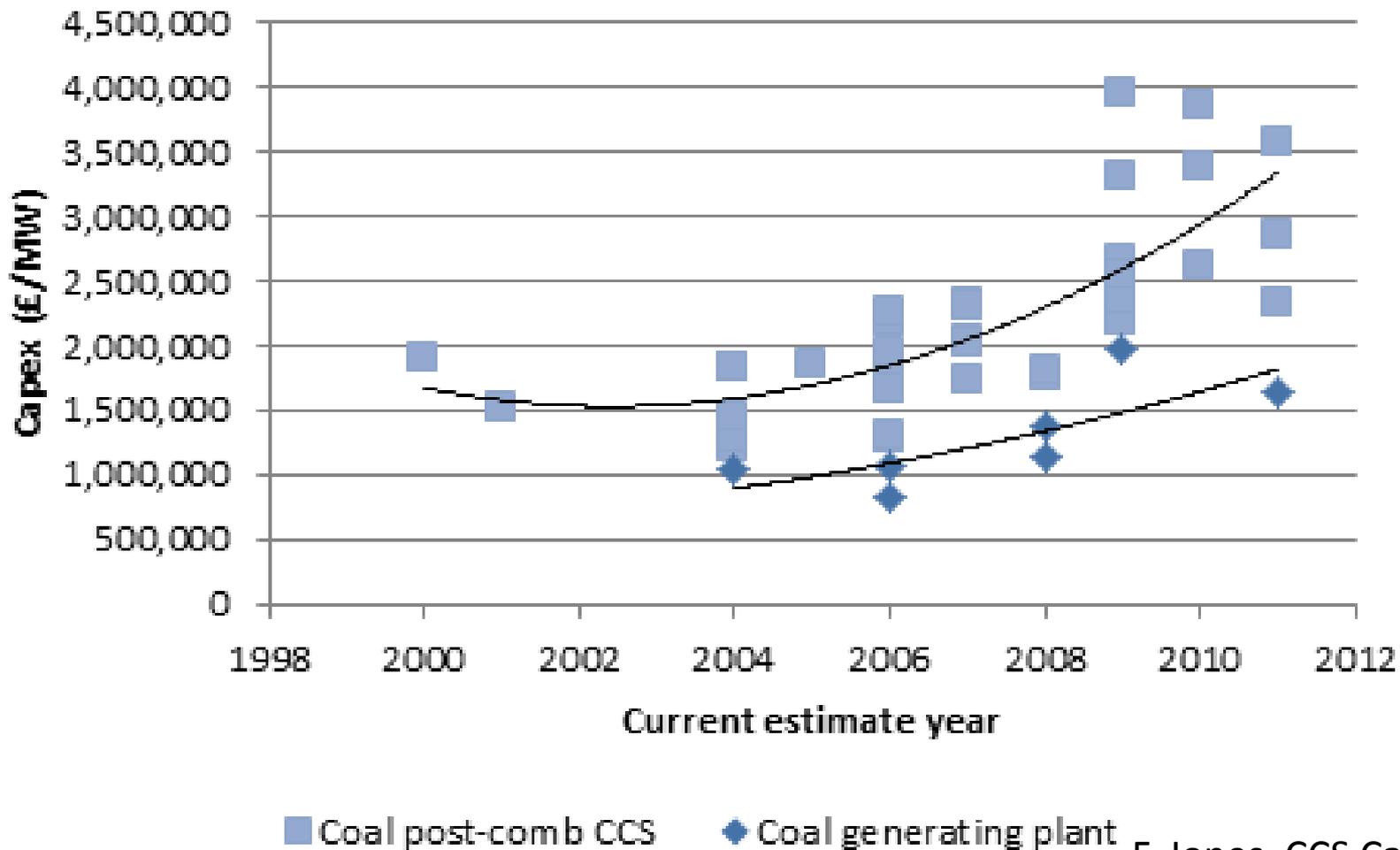
Yeh and Rubin (2013), Learning in Energy Technologies, UC-Davis

Estimated capital costs for CCGT plants



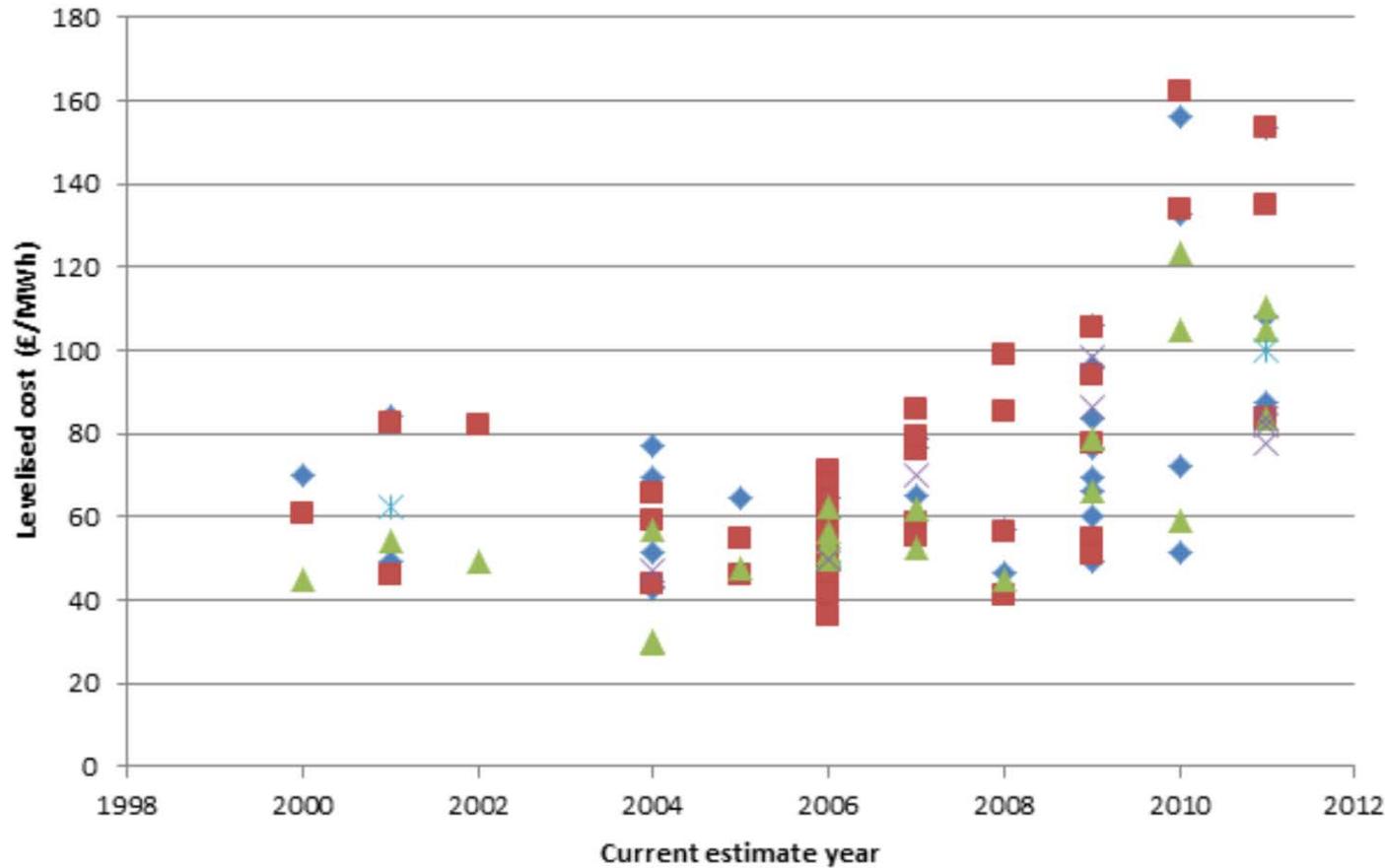
F. Jones, CCS Case Study
UKERC/WP/TPA/2013/004

Estimated capital costs for coal plants



F. Jones, CCS Case Study
UKERC/WP/TPA/2013/004

Levelised cost estimates of CCS technologies

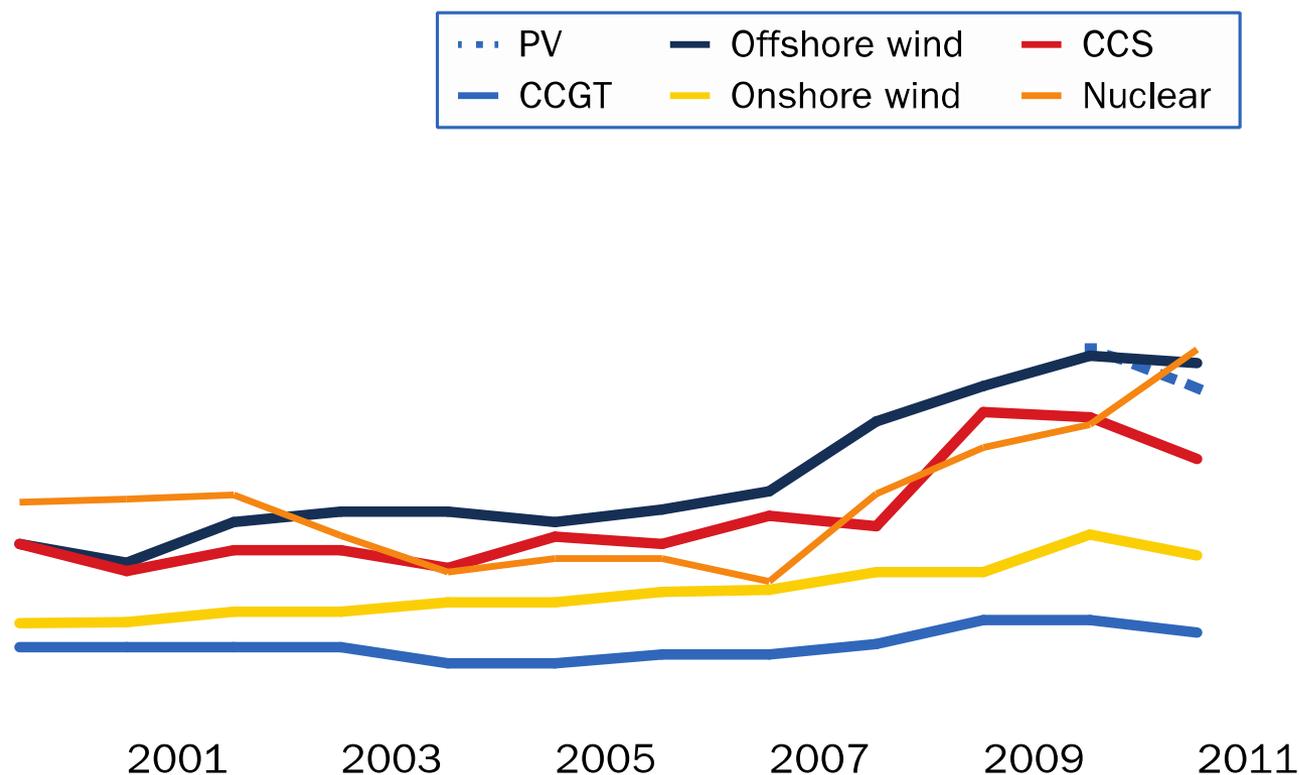


◆ Post-comb coal CCS
 ■ Pre-comb coal CCS (IGCC)
 ▲ Post-comb gas CCS
× Oxyfuel coal CCS
 ✱ Pre-comb gas CCS

F. Jones, CCS Case Study
UKERC/WP/TPA/2013/004

Changing estimates of in-year mean capex values

(2011 million GBP/MW)



Source: UKERC Technology & Policy Assessment Function

Improvement in efficiency of coal-fired plants

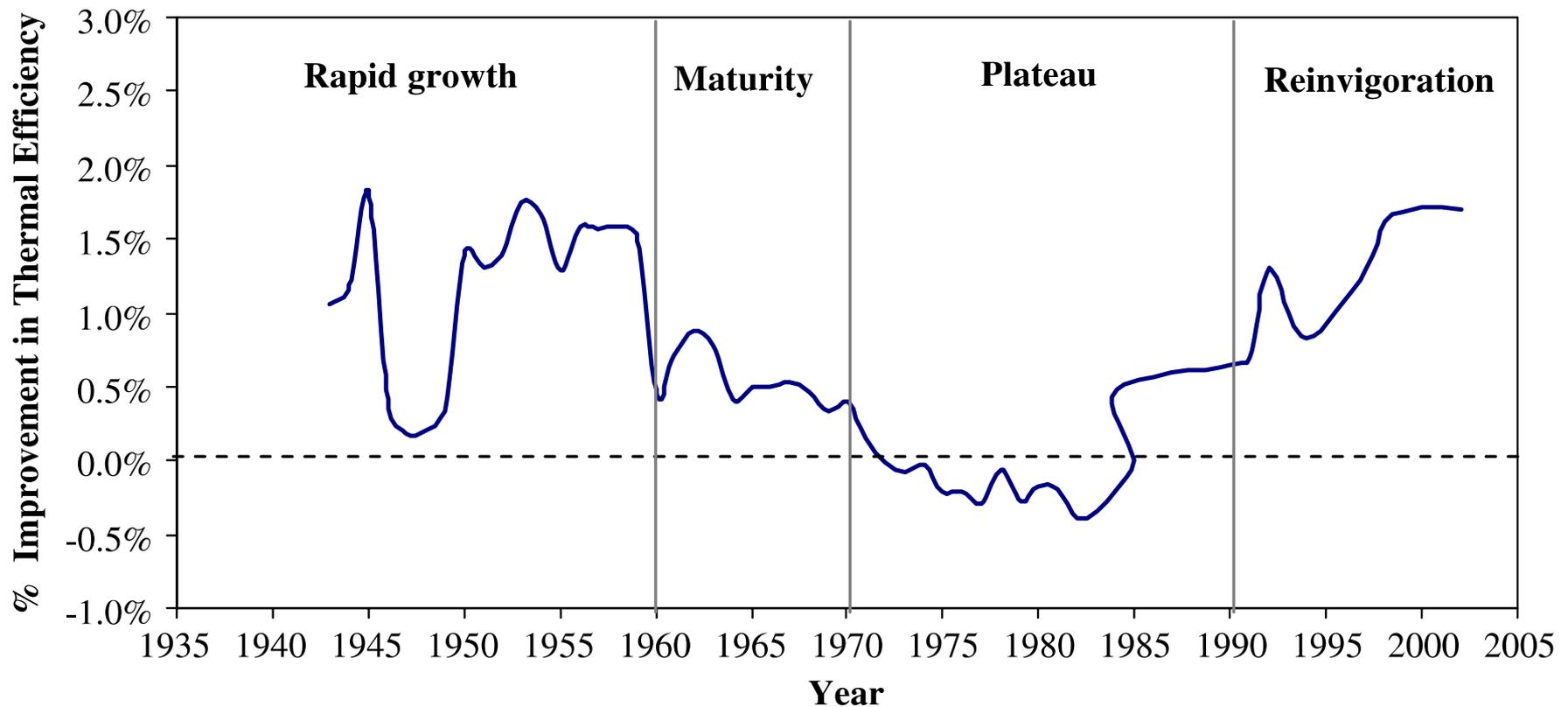
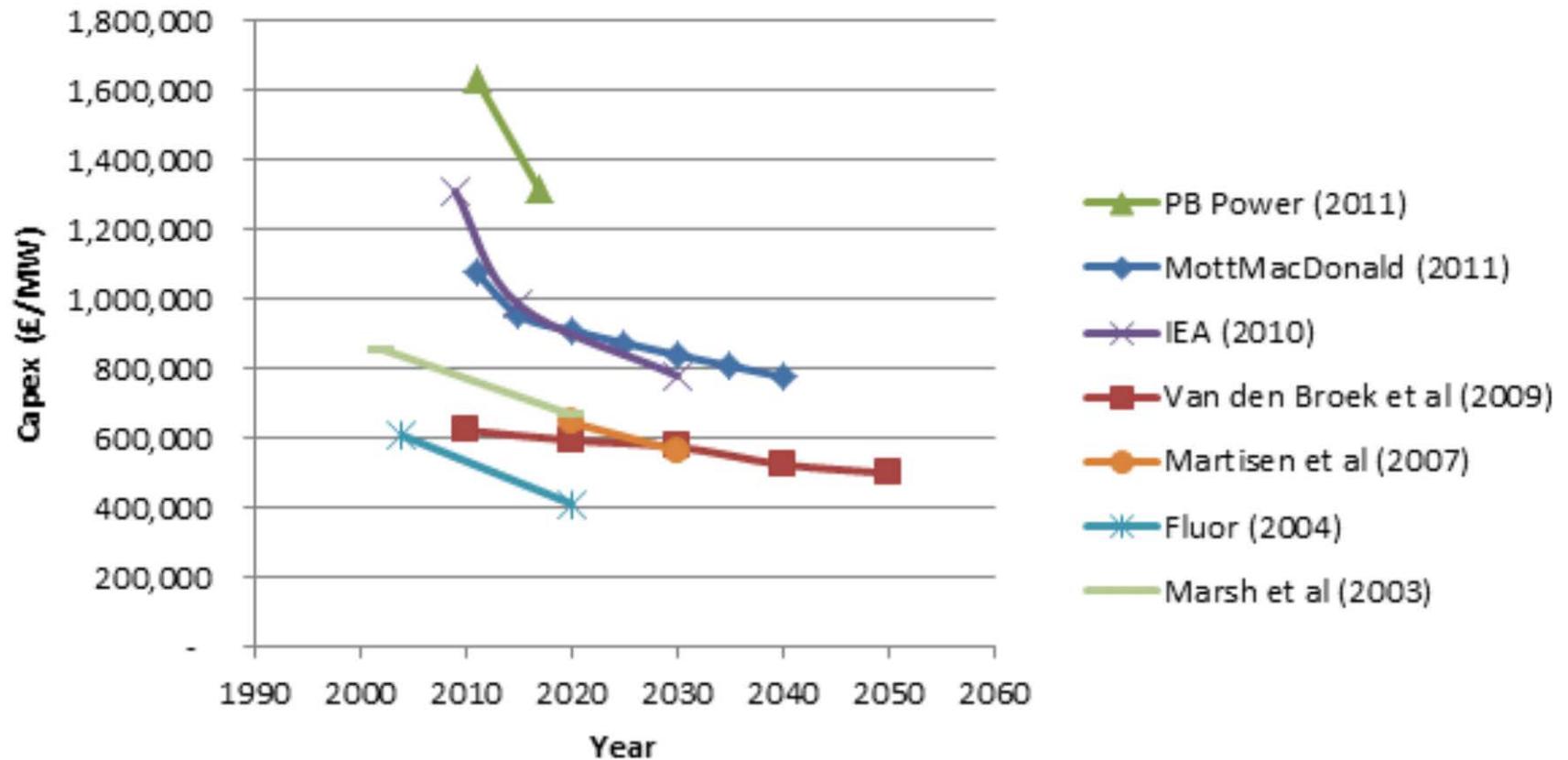


Fig. 6. Improvement (percent change from the previous year, 10-year moving average) in thermal efficiency of coal-fired utility plants over 1935–2002 and corresponding market structural changes.

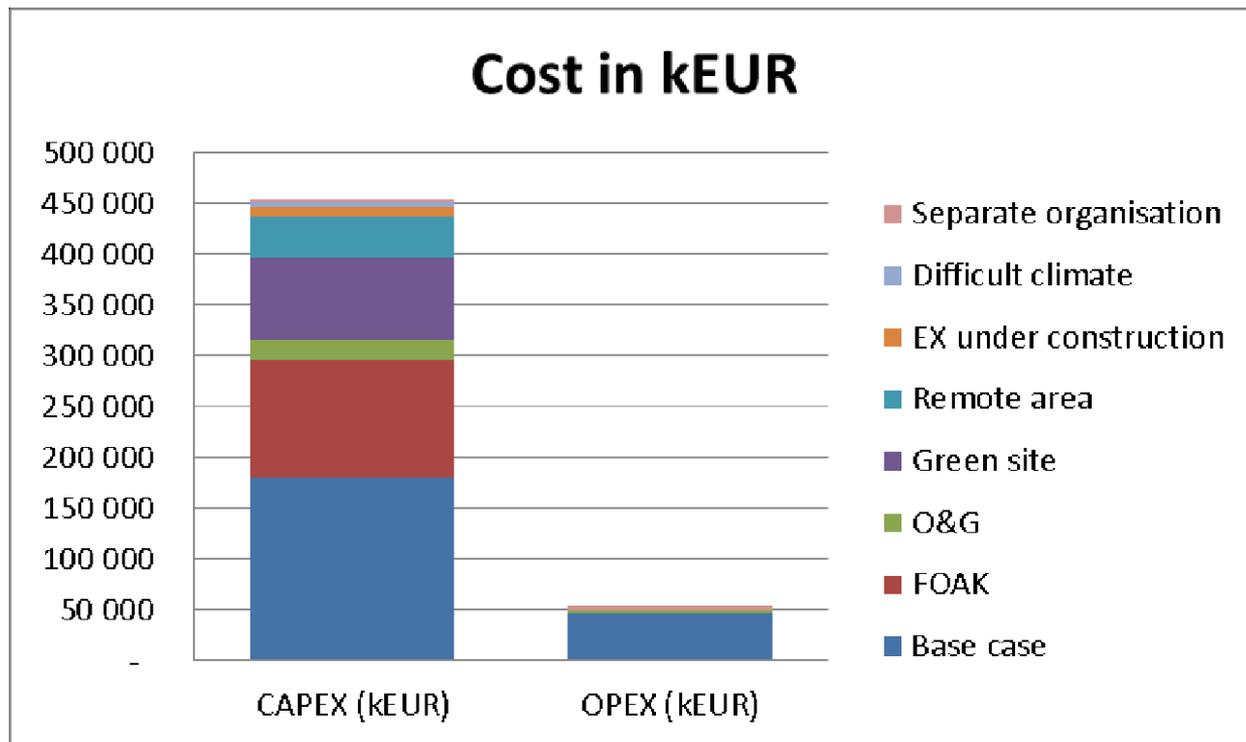
Source: S. Yeh, E.S. Rubin, A centennial history of technological change and learning curves for pulverized coal-fired utility boiler, *Energy* 32 (2007): 1996–2005

Estimates of future capital costs: post-comb gas CCS



F. Jones, CCS Case Study
UKERC/WP/TPA/2013/004

Moving from generic to 'real world' costs



For case of post-combustion MEA capture plant on a 400 MW gas turbine

Skagestad, Lach, Røkke, and Eldrup, Critical Factors Influencing CO2 Capture Cost, a Case Study, GHGT12



Where are we now?

EU Energy Union 'Four Core' Priorities

- world leader in developing the next generation of renewable energy technologies, including environment-friendly production and use of biomass and biofuels, together with energy storage;
- Facilitating the participation of consumers in the energy transition through smart grids, smart home appliances, smart cities, and home automation systems;
- Efficient energy systems, and harnessing technology to make the building stock energy neutral, and
- More sustainable transport systems that develop and deploy at large scale innovative technologies and services to increase energy efficiency and reduce greenhouse gas emissions.



Additional 'research priorities'

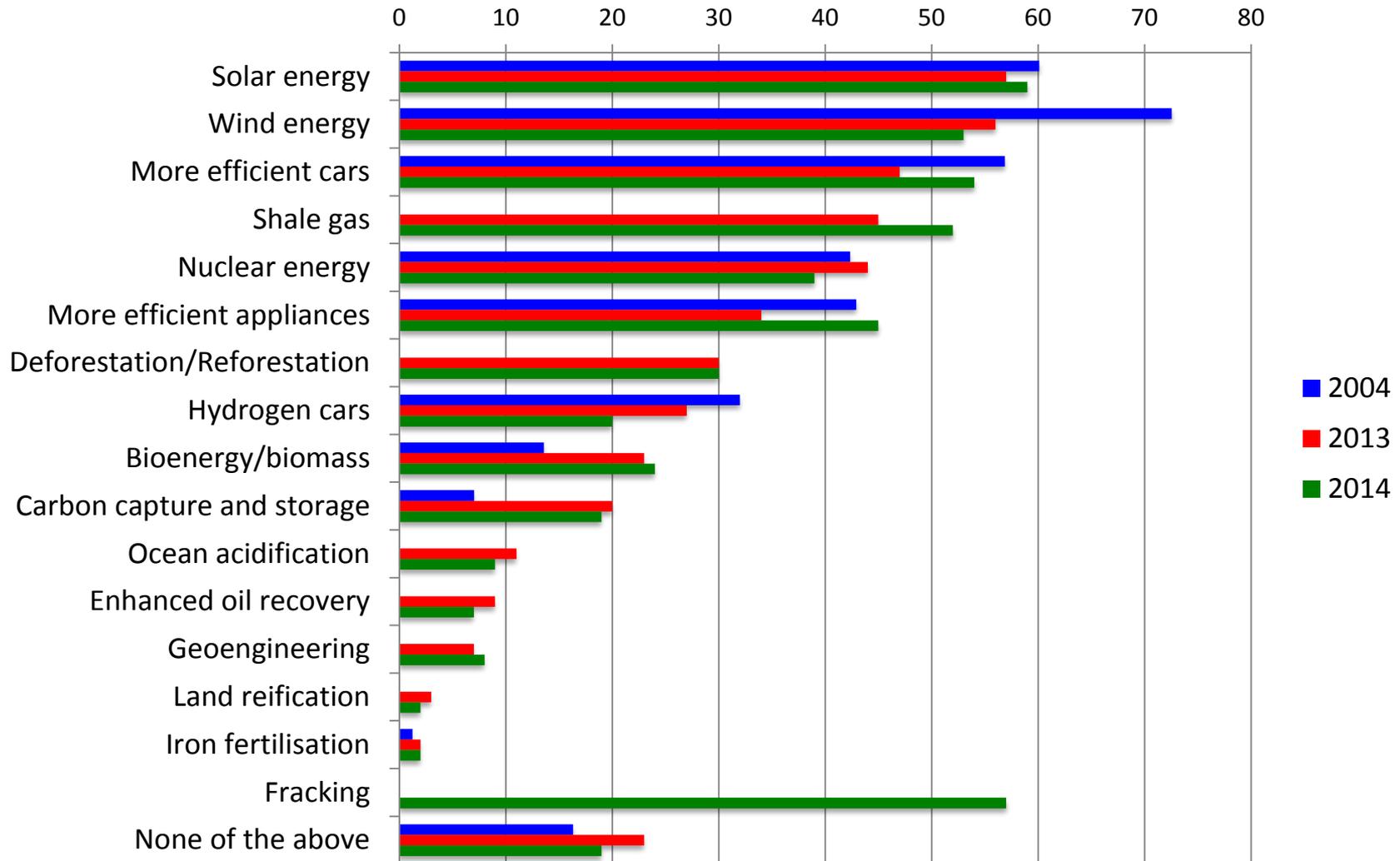
- On top of these four common priorities, there are additional research priorities which merit a much greater level of collaboration between the Commission and those Member States who want to use these technologies:
 - A forward-looking approach to carbon capture and storage (CCS) and carbon capture and use (CCU) for the power and industrial sectors, which will be critical to reaching the 2050 climate objectives in a cost-effective way. This will require an enabling policy framework, including a reform of the Emissions Trading System and the new Innovation Fund, to increase business and investor clarity, which is needed to further develop this technology.
 - Nuclear energy presently produces nearly 30% of the EU's electricity. The EU must ensure that Member States use the highest standards of safety, security, waste management and non-proliferation. The EU should also ensure that it maintains technological leadership in the nuclear domain, including through ITER, so as not to increase energy and technology dependence.



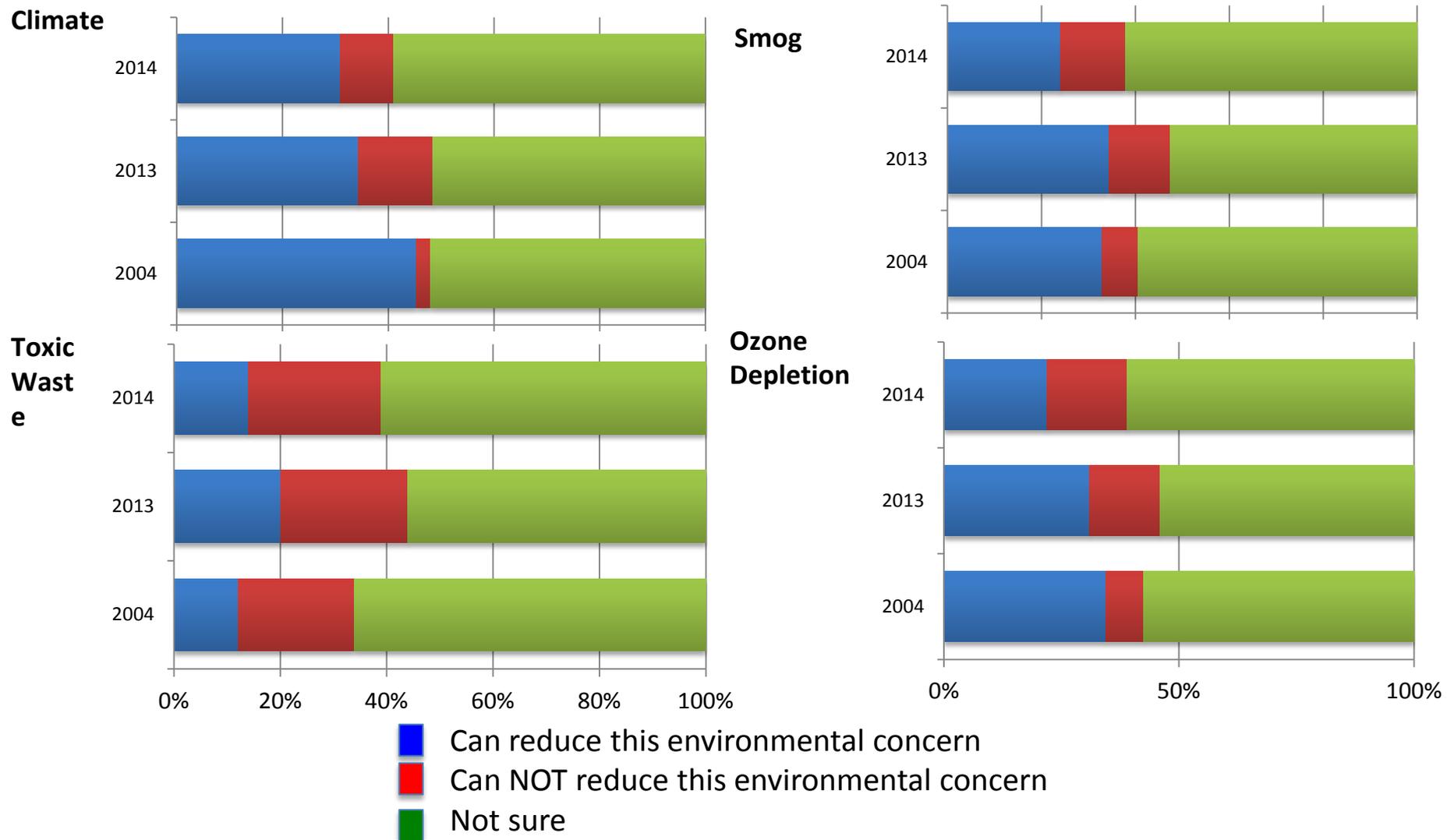
Principles De Coninck, Stephens and Metz (2009)

- Global coordination: the initiative should enable a variety of CCS technologies to be demonstrated in various contexts and countries.
- Transparency: the initiative should ensure open information availability and exchange between countries to promote broad global efficient learning on CCS.
- Cost-sharing: the initiative should set up a cost-sharing structure that pools global demonstration funds and reallocates them efficiently to allow for fast access of emerging economies to CCS technology and demonstrations.
- Communication: the initiative should design mechanisms to support demonstration projects that engage broad and different types of stakeholders and that incorporate education and outreach efforts. Open and effective communication with stakeholders, the media and the general public should be integral, and the cooperation should heed principles of risk communication, and support an open dialogue on CCS with all involved.

Have you read about any of the following in the past year?



Do you think 'Carbon capture and storage' or CCS can or can not reduce each of the following environmental concerns?



Less than 2% can recall any details of CCS demos

The UK has narrowed down funding for these CCS projects to two main proposals. One project is meant to be in Yorkshire and the other in Scotland. Can you name either of these projects or any of the companies involved? IF you cannot name either of these projects or the companies involved, please skip this question, please do not look up the answer, this question will automatically skip forward in 1 minute.

Response	Count
Drax	11
Peterhead	8
Longannet	6
Shell	5
EDF	4
SSE	4
White Rose	4
British Gas	3
Ferrybridge	2
Fracking	2
Humber	2
Quadrilla	2
Kingsnorth	1
Hatfield	1
SCCS	1
Eon	1

Support for £1B capital budget for CCS demos

The UK Government plans to spend £1 billion to support the demonstration of carbon dioxide capture and storage (CCS) technologies, which would capture carbon dioxide from a large power plant and store it under the North Sea. To what extent do you support or oppose this commitment?

