

Viewpoint

Preparing for global rollout: A ‘developed country first’ demonstration programme for rapid CCS deployment

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Abstract

Carbon dioxide (CO₂) and other greenhouse gases from fossil fuel use in many developed and developing countries are expected to be the major source of anthropogenic emissions for the foreseeable future. As a result, the potential to use CO₂ capture and storage (CCS) for significant reductions in CO₂ emissions from the use of coal (and other fossil fuels) at large point sources could become very important in determining the feasibility of climate change mitigation. Large-scale deployment of CCS in the EU from 2020 has been suggested, but this paper illustrates how time is very short if two complete learning cycles are to be achieved before a possible rollout in the early/mid 2020s. It also highlights some key differences between CO₂ capture technologies that suggest that learning can be achieved more quickly with post-combustion capture than with other options. This might allow rollout to be accelerated by perhaps 5 years for post-combustion capture.

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1. Introduction

The importance of coal for power generation and other applications has been recognised in a range of studies analysing expected developments in the international energy mix, such as the IEA World Energy Outlook (Fig. 1). Since unabated use of fossil fuels, particularly coal, leads to relatively high carbon dioxide (CO₂) emissions, this implies that proven, commercial-scale carbon capture and storage (CCS) technologies are required if countries that rely on fossil fuels are to agree to significant emission reductions as part of a robust global strategy to mitigate the risk of dangerous climate change. For example, the Stern review on the economics of climate change commissioned by the UK Government concluded that

Even with very strong expansion of the use of renewable energy and other low carbon energy sources, hydrocarbons may still make over half of global energy supply in 2050. Extensive carbon capture and storage would

allow this continued use of fossil fuels without damage to the atmosphere... (Stern, 2006).

The three different approaches for CO₂ capture at power plants (and other large point sources of CO₂) that are being considered for near-term commercial-scale deployment are illustrated in Fig. 2. A detailed review of each of these technologies can be found in an IPCC special report on CCS (IPCC, 2005). One important difference between these approaches is that post-combustion capture could be applied to industry-standard pulverised coal combustion plants¹ with minimal modifications to the base power plant, either for newly built or for retrofit applications, whereas changes to base combustion power plant designs are required for oxyfiring and a complete change in base plant technology is required for pre-combustion capture in integrated gasification combined cycle (IGCC) plants.

Since commercial-scale CCS power plant projects are large and capital intensive, it is important to consider how

¹Post-combustion capture technologies, possibly with some modifications, could also be applied to most other power plant types, including industry-standard natural gas combined cycle units, and to industrial processes such as cement and steel manufacture.

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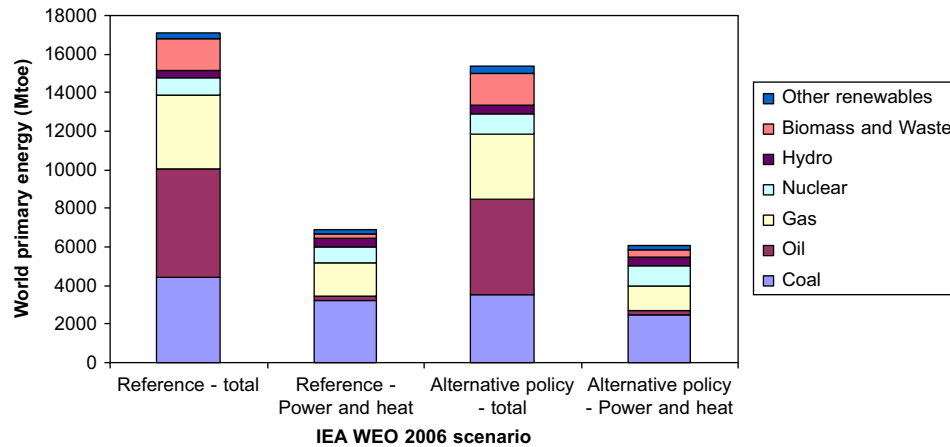


Fig. 1. Global primary energy demand (total and power generation and heat) for reference and alternative policy scenarios in IEA World Energy Outlook 2006 (IEA, 2006).

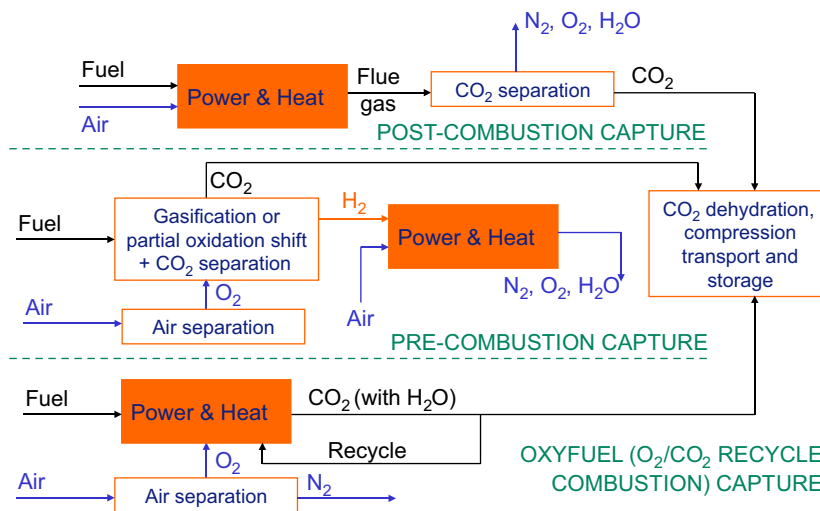


Fig. 2. Schematic outline of leading options for CO₂ capture at power plants (after Jordal et al., 2004).

Government (and other investor) money can most effectively be used to demonstrate CCS technologies to establish an option for actual rollout (i.e. with the main intention then being CO₂ reduction, rather than technology development) at the earliest possible date. In this paper, we outline our view that global rollout of CCS would have to be preceded by two tranches of initial demonstration projects for technology discovery and learning and a ‘developed country first’ rollout. We also outline timescales for the earliest possible global rollout of CCS if relevant stakeholders (including policy-makers and/or industry) decide that it should be used as part of an international effort to tackle climate change.

Finally, we discuss how the relatively minor impact that post-combustion capture has on base power plant design means that smaller initial projects are feasible, with associated reductions in capital required, and in all cases shorter construction periods. This fundamental difference could allow fully proven post-combustion capture equip-

ment to be available more quickly and also should permit more rapid learning through shorter build-and-test cycles.

2. Motivation for fast-track CCS technology discovery and learning

In recent years, policies for reducing CO₂ emissions in many countries have focussed on increasing the use of renewable energy and reducing demand. Current EU policy still follows this approach (Euractiv, 2007) and CCS would probably not be required to meet the 20% reduction target for 2020 if current binding commitments on increasing renewable energy use to 20% of the total energy consumption and stabilising energy demand at roughly current levels are realised. The EU has, however, also offered to raise its 2020 CO₂ reduction target to 30% if other industrialised nations, including the USA, take similar steps. It is likely that CCS would play an important role in allowing Europe to meet a 30% target, as well as in

encouraging the global consensus required for a 30% target to be introduced.

Large amounts of anecdotal evidence also suggest that developing countries will not use CCS before developed countries (except possibly to obtain CO₂ for enhanced oil recovery).² Fast-track demonstration for technology discovery and learning in developed countries is therefore critical if CCS is to be viewed as a viable CO₂ mitigation option. In fact, it could be argued that confidence in CCS will be a pre-requisite for a global agreement involving large CO₂ emissions reductions.³

Cost reduction is another key driver for early demonstration of CCS technologies in commercial-scale, integrated projects because of the time taken to design, construct and then learn from operating these plants. It is generally expected that technology costs reduce with time as a result of ‘learning-by-doing’, particularly with new technologies. A recent study on learning curves for CCS (IEA GHG, 2006a), however, highlighted that an initial period of technology discovery where real costs and performance can be determined is generally seen before cost reductions are observed:

Historical experience for other large-scale technologies indicates that cost estimates made prior to full-scale demonstration tend to underestimate the true costs of the first (and often several subsequent) generation of plants built at full scale. Only after several generations of new plants have been built and operated do costs eventually fall.

3. Technology types for CO₂ capture

In addition to recognising different approaches to CO₂ capture (e.g. post-combustion, pre-combustion, etc.), it is important to realise that there are two broad types of projects that CCS can be applied to. These are

- (1) those involving CO₂ released during conventional oil or gas extraction and processing and unconventional oil production from tar sands or other heavy feedstocks, or the conversion of fossil fuels to carbon-containing energy vectors such as Fischer Tropsch liquids or synthetic natural gas production and
- (2) projects producing decarbonised energy vectors (electricity or hydrogen).

²In part this is for technical reasons, a desire to have the technology ‘tried and tested’ in the developed world, but also to establish that developed countries are themselves prepared to embrace a technology that unavoidably involves increased costs (leaving aside carbon emission charges) and reduced efficiency for fossil fuel use.

³Experience with the Kyoto process to date suggests that both developed and developing countries that are significant producers and/or users of coal (e.g. USA, China and India) are currently unlikely to commit to serious global action on climate change without a technology to tackle CO₂ emissions from coal that does not prohibit its use. CCS technologies are the only possibilities for fulfilling this role.

All ‘Type 2’ projects (producing electricity or hydrogen) should be capable of ensuring that typically only 5–20% of the carbon content of the original fuel is ultimately emitted to the atmosphere. ‘Type 1’ projects producing carbon-containing energy vectors would still result in significant CO₂ emissions even with CCS, typically around 50% or more. Thus, when global CO₂ emissions mitigation is taken seriously, only Type 2 schemes producing decarbonised energy vectors will be accepted as environmentally sustainable (Gibbins and Chalmers, 2007).

Existing experience of CCS on a relatively large scale has all been associated with applications involving production of carbon-containing energy vectors.⁴ Type 1 projects such as these provide some useful experience that can be applied to Type 2 CCS projects. There is an urgent need, however, to demonstrate specific technologies and integration approaches that can only be implemented in commercial-scale Type 2 CCS projects. Thus, we suggest that the majority of projects included in a supported demonstration programme aiming to develop CCS as a serious CO₂-mitigation option should be Type 2, so currently electricity power plants, though in some cases (pre-combustion capture) with hydrogen as an intermediate.⁵

It should also be noted that many coal-fired power plants are likely to be built before CCS is commercially viable. Given the long operating life of these plants, it is expected that CO₂ capture will make commercial sense before they are decommissioned. As a result, new plants that are not fitted with CO₂ capture when they are initially built should be suitable for later retrofit of CO₂ capture. Such plants are often referred to as ‘capture ready’.⁶

⁴For example, both the Sleipner demonstration in the Norwegian sector of the North Sea and the In-Salah project in Algeria remove CO₂ from produced natural gas. In these niche applications, CO₂ must be separated from the produced gas anyway, so the incremental cost of implementing the scheme is relatively low. Another well-known project uses CO₂ produced at a gasification plant in North Dakota, which is used for enhanced oil recovery and ultimate storage in the Weyburn field in Canada. See IPCC (2005) for further details of these projects and other, smaller demonstrations.

⁵Currently no major use is made of hydrogen as an energy vector, and it is not clear that hydrogen is essential for decarbonisation of energy in transport (King, 2007) and buildings.

⁶A number of studies considering how best to make a plant capture ready have now been undertaken, including a recent engineering study conducted for the IEA Greenhouse Gas R&D Programme (IEA GHG, 2007). Almost all of these plants will use pulverised coal or fluidised bed boiler technology providing steam for conventional turbine generators. Fortunately, these types of plants can be made suitably capture-ready with minimal additional expenditure, and a single capture-ready design philosophy can readily accommodate a wide range of future post-combustion capture technology developments (and also some oxyfuel capture options).

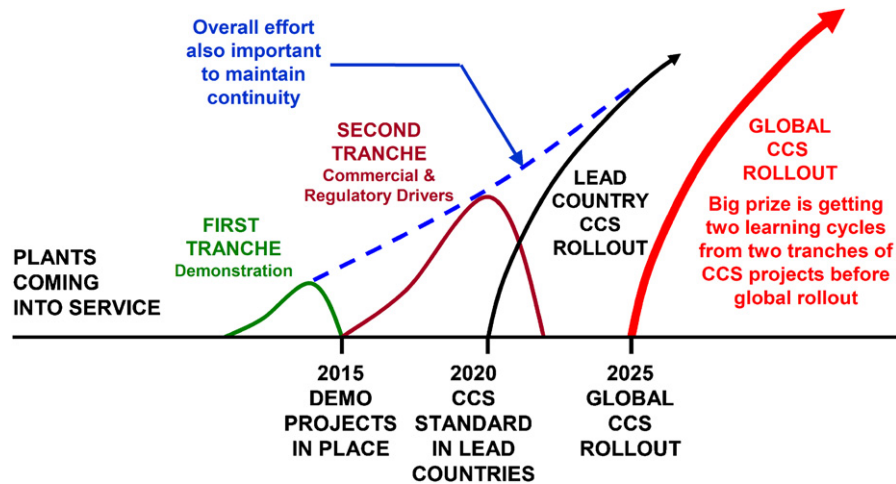


Fig. 3. Schematic view of two-tranche model for demonstration and deployment.

4. Tranches model for IGCC and oxyfuel

4.1. Outline of tranches model for IGCC and oxyfuel technology discovery

When a demonstration and learning programme is designed, it is important that both the number of plants built and the timing between plants (to allow feedback from lessons learned) is considered. As illustrated in Fig. 3, we suggest a two-tranche model for technology discovery, followed by ‘developed country first’ commercial rollout to build developing country confidence in the technology.⁷ It is expected that this approach would have a smaller first tranche followed by a larger second tranche. This should encourage efficient use of capital since it would allow later projects to concentrate on optimisation of plant designs, given experience from Tranche 1 plants to establish design rules that should guarantee plants will work. A two-tranche approach would also allow a gradual build-up of the skilled workforce required to design, construct and operate CCS schemes.

The first, tranche of plants should be treated as demonstration projects where full support is provided for the incremental cost of adding capture (and may also be required for the additional base-plant cost of unproven technologies such as IGCC (EPACT, 2005)). For this first tranche, one key priority is the speed of deployment. It is expected that a relatively small number of plants could be established, demonstrating a range of concepts. The earliest plants would represent a scale-up from pilot tests, but may be smaller than typical sizes for current commercial units, possibly as low as 100 MW. It would, however, be expected that later plants would reach commercial sizes of at least 300–500 MW.

⁷It is, of course, important to remember that CCS will only be commercially viable if it is required by legislators or financially supported by policy mechanisms that provide value to project participants for capturing, transporting and safely storing CO₂.

Once supported demonstration to provide proof of concept at commercial scale for a range of technologies has been achieved in the first tranche of deployment, it is expected that a larger second tranche could consist of semi-commercial projects. In particular, plant technology details in the second tranche might not be specified. Instead, project developers would be allowed to identify schemes that are most suitable to fulfil their commercial and strategic objectives in the context of an incentive and regulatory framework developed by national governments and/or trans-national bodies such as the EU or the UNFCCC to encourage continued development of CCS technologies.

4.2. Timescales for tranches to allow learning

For IGCC and oxyfuel plants, a relatively large amount of obligatory integration between the power plant, capture plant and other ancillary systems is required. Thus, for any commercial-scale demonstration, it is likely to be necessary to build a whole plant (base power plant plus capture plant) each time a new design is tested—or at least to undertake significant modifications if an existing plant is retrofitted or modified. Typical construction times for newly built coal-fired power plants with CCS are likely to be at least 4 years. Although it is possible that some design features could be modified even after the start of construction, other aspects of the design will be frozen relatively early in the plant design process. Thus, it is assumed that a tranche of deployment should be at least 5 years and, in reality, only operating experience over a longer period can give fully reliable feedback for future designs.

Fig. 4 provides a schematic illustration of potential timing and feedback for two tranches of technology discovery and learning using newly built plants before commercial rollout. Initial commercial plants in lead developed countries are rolled out from around 2020 and effectively provide a third tranche of learning before an

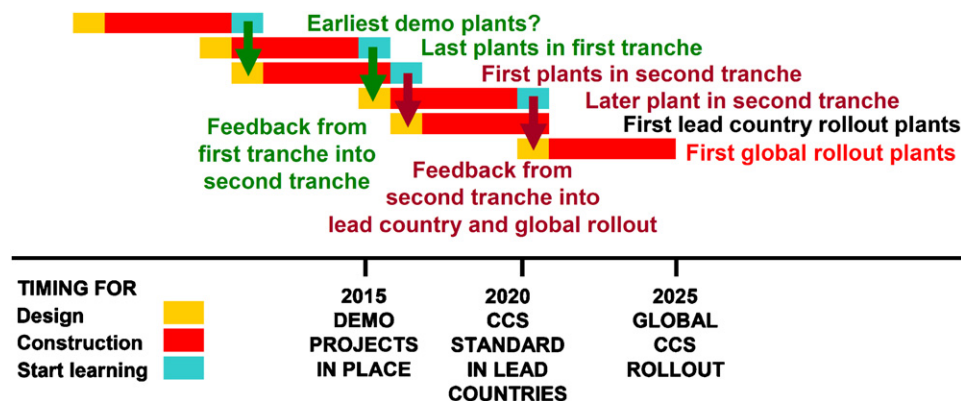


Fig. 4. Schematic timeline for two-tranche model for IGCC and oxyfuel plants.

earliest possible global rollout by around 2025. The short design phase included here represents only a relatively quick 1 year front end engineering design (FEED) study. Pre-feasibility studies and permitting are assumed to happen in years preceding the FEED period, with learning from ongoing projects incorporated at all stages where possible.

One important conclusion from Fig. 4 is that if lead rollout plants are to be operational from 2020, as suggested by some studies and current EU policy proposals (Euractiv, 2007), initial demonstration projects must be operational by around 2011 for there to be time for technology and cost discovery from second tranche plants to inform designs for initial commercial rollout. This is already very challenging and would require that some projects that are already in the later stages of pre-feasibility studies or early FEED work are successfully implemented.

It should also be noted that although we have, for clarity, discussed distinct tranches of deployment for learning, in reality all plant designs will make maximum use of information available from projects that are more developed. A continuous effort may initially seem to be less efficient in terms of unrealised learning that is not available for a newer scheme if the older scheme has not progressed far enough to allow full operation-based learning. It is expected, however, that this continuity could be critical in enabling the rapid development and deployment of CCS since it would allow design teams and manufacturing facilities to evolve, grow and learn more steadily and, hence, sustainably than is possible in an environment with abrupt step changes (up or down) in required activity.

5. Tranches model for fast-track learning with post-combustion capture

Shorter learning cycles are possible for post-combustion capture since the areas requiring development do not involve significant changes to base plant design. While it is advantageous to ensure that the energy requirements of a post-combustion capture plant are integrated effectively with the base power plant, it is not essential for the operation of either. The principles for integrating post-combustion capture are already reasonably well under-

stood (Gibbins, 2004) and do not require as much demonstration as the actual capture processes.

Many of the principles associated with post-combustion capture plant can also be demonstrated effectively at less than full scale (e.g. at 10% 'slipstream' scale).⁸ Subsequent demonstration at full scale is still required, but with high confidence of success. This means that effective initial demonstration and development of post-combustion capture technologies can take place on suitable existing power plants, as well as on new plants built with capture in mind. Learning cycles can also take place through modifications to existing capture plants or through the addition of a further slipstream unit to an existing power plant, with associated savings in both construction times and capital expenditure.⁹

Fig. 5 illustrates a revised post-combustion fast-track version of the tranches model. It is assumed that a 'full' tranche for post-combustion capture (i.e. including construction of a new capture plant, not just developing technology within the capture plant) could be around 2 years shorter than for IGCC and oxyfuel. While comparison of Figs. 3 and 5 may appear to represent different timescales for global CCS deployment, they can easily be unified in a scenario in which the existence of post-combustion capture provides the confidence for a 2020 global rollout, with IGCC and oxyfuel subsequently entering the market for newly built CCS plants when they are proven and if they are commercially competitive.

⁸For example, at this scale factors such as solvent life, materials corrosion and energy requirements can be investigated and improved with acceptable accuracy. This situation contrasts with IGCC CCS plants, and to a somewhat lesser extent with oxyfuel plants, where the reliable operation of a full-scale power plant has to be demonstrated. In addition, some developments (e.g. improved solvent formulations) can be implemented very quickly, with little or no equipment modification in some cases.

⁹Of course, this relative ease of retrofit also implies that post-combustion capture technologies, once developed, are likely to provide a good option for mitigating CO₂ emissions from existing power plants, as long as they are suitable for retrofit. Although some integration with the base power plant is required, changes to accommodate post-combustion capture are likely to be relatively minimal if the base power plant is designed (or modified) with the potential for future developments in mind (IEA GHG, 2007).

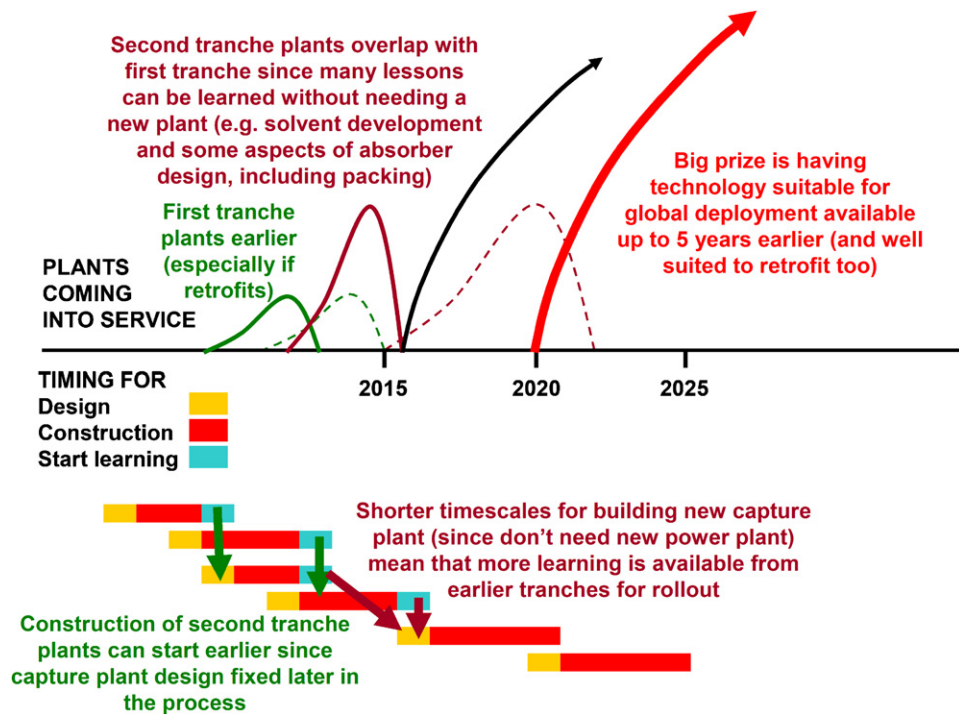


Fig. 5. Schematic view of fast-track development of post-combustion capture.

Provided that the necessary development work on IGCC and oxyfuel technologies is pursued in parallel, so that they are only a few years behind, we expect that no significant societal disadvantages¹⁰ are likely to occur if CCS is adopted with only post-combustion capture available initially. Post-combustion capture is essential as a retrofit technology, and so cannot represent a dead end if CCS is to be employed at all.¹¹ Present studies (e.g. IEA GHG, 2006b) also suggest that the costs of electricity production from coal-fired power plants with each of the technologies illustrated in Fig. 2 are likely to be similar. Current differences in estimated costs are relatively small compared with uncertainties and the scope for improvements by learning-by-doing. It might be argued that if the introduction of CCS is delayed until new technologies are available then costs will be reduced, but this will always be the case!

6. Conclusion

This paper has presented a conceptual model for rapid demonstration and deployment of CCS where an initial cost and technology discovery period (broadly consisting

of two tranches of learning) is followed by a phased rollout, first by developed, and then by developing, countries. Of course, if real events are to approximate to this model, then policy-makers, electricity sector members and other key stakeholders must be convinced that the opportunities offered by this approach outweigh the associated costs and risks. For projects to progress, potential investors must also believe that this approach is more beneficial than spending an equivalent amount of effort and money on other available climate-mitigation (or investment) activities. This is challenging in the current regulatory environment.¹²

For IGCC and oxyfuel, based on a target date for developed countries to rollout commercial (i.e. carbon price exceeds capture cost) CCS plants by 2020, before global rollout in 2025, it is shown that immediate support for early projects is critical to begin the technology discovery and learning process. The importance of continuity in CCS development is also highlighted. Although overlapping of tranches might initially be assumed to be sub-optimal, since insufficient time is available to pass lessons from one plant to the next,

¹⁰Obviously, suppliers of particular technologies may lose out if other technologies make it to market first, but this is not directly a problem for society as a whole. There is a theoretical risk for society of locking in early to a particular technology approach which may turn out to be sub-optimal, but against this must be set the need for urgent action on climate change, with definite risks associated with delay.

¹¹A very large retrofit market for post-combustion capture appears inevitable, given the total dominance of pulverised coal plants in the existing world fleet, so we suggest that the concept of an avoidable 'lock-in' does not arise.

¹²In particular, there is continued uncertainty over future legislation for CO₂ emissions and EU energy policy favouring the use of renewables and reductions in energy use to meet the current binding target of 20% CO₂ emissions reduction in 2020. It is likely, however, that supported initial demonstration of CCS will be crucial in proving it as a viable technology and could play a significant role in bringing forward global agreement to take action on climate change by providing an option for significantly reducing CO₂ emissions from coal (and other fossil fuels) without prohibiting its use.

benefits from sustainable growth of the skilled labour pool and manufacturing capacity can offset this.

For post-combustion capture early action and continuity is also crucial, but it is expected that a more rapid approach could be taken on technology and cost discovery since many of the areas that need significant development do not require a new power plant or capture plant to be built for alternatives to be explored. Where a new capture plant is required, a retrofit at a suitable existing power plant could reduce the length of a tranche of deployment by around 2 years compared with a newly built IGCC or oxyfuel plant. These characteristics mean that post-combustion capture, and hence CCS as a policy option, could be ready for developed country rollout by 2015 and global rollout by 2020. Rapid learning is also likely to continue after these dates, with the ability in many cases to upgrade existing post-combustion capture plants as well as to build improved new units using either post-combustion or other capture technologies.

The importance of making current newly built coal-fired plants capture-ready (i.e. suitable for later retrofit of CO₂ capture, probably with post-combustion capture technology in most cases¹³) is also critical since significant capacity is likely to be constructed before CCS is used as standard. If these plants cannot be retrofitted with CO₂ capture once suitable CCS technologies are commercially viable, then operators will be left with stranded assets or society may be locked-in to CO₂ emissions from these plants for perhaps 40 years or more.

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¹³Oxyfuel may be an inherently attractive retrofit capture option for circulating fluidised bed boilers, since the circulating solids can be used to moderate bed temperatures with little or no need for flue gas recycling, although post-combustion capture technologies could also be retrofitted.