Technical support for an enabling policy framework for carbon dioxide capture and geological storage

Task 3: Incentivising CO_2 capture and storage in the European Union

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Summary

To date CO_2 capture and storage (CCS) is not deployed at a commercial scale, and a range of policy instruments could be used to provide adequate incentives for large scale deployment of CCS in the European Union. Five groups of incentives are discussed: (1) the EU Emissions Trading Scheme (weak and strong version); (2) Member-State-based public financial support through investment support, feed-in subsidies or a CO_2 price guarantee; (3) an EU-level low-carbon portfolio standard with tradable certificates; (4) an EU-wide CCS obligation for all new fossil-fuel-based power capacity, and (5) public-private partnerships for realizing a CO_2 pipeline infrastructure. The nature of the policy, mainly whether the scale of the instrument matters, and whether much public financial is involved, determines whether it will be implemented by the EU or at the Member-State level. Support for CCS projects at the Member-State level, however, will require amendment of the Community Guidelines for State Aid for Environmental Protection.

The EU Emissions Trading Scheme

The EU ETS is the most cost-effective instrument to reduce greenhouse gas emissions, and its implementation so far has resulted in a substantial forward EUA-price for the 2nd Phase (2008-2012). At this point, it is difficult to predict, however, what level of incentives the ETS will provide for future CCS activities. If the allocation method will remain based on National Allocation Plans, grandfathering, and limited harmonisation by the European Commission, incentives may remain weak. This scenario has resulted in substantial doubt as to whether the ETS will lead to sufficient deployment of CCS in the short term, or even the longer term. The EU ETS has short-term horizons, and without a perspective of long-term deep emission reductions, operators will initially prefer the technological options that are more competitive and cost-effective in the short term. Thus, the incentive it provides for technological innovation is low and may remain low in the future. A number of complementary policies can therefore be considered, both at the Member State and the EU level, to correct this so-called innovation market failure (section 2).

Public financial support

Subsidies to CCS operations may take various forms. We discuss three potential subsidy structures for CCS:

- *Investment support* for CCS, because of the high cost, is often proposed to fund early but full-scale demonstration before there is a price signal from the ETS to further CCS deployment. Once the option is more developed, investment subsidies could also take the form of a transport network that the government can rent out for use by CCS operators against a low, subsidised, price. Cost burden for the government in investment support schemes are relatively high, but the instrument is quite effective and gives the government influence on the investment decisions (section 4.1).
- *Feed-in subsidies* have become widely used to stimulate the introduction of electricity from renewable sources, and could also be applied to CCS. In a feed-in scheme, a fixed fee would be guaranteed per unit of CCS-based electricity produced, to compensate for the higher costs of the project vis-à-vis conventional generation. Feed-in systems have proven very effective in stimulating new investments in renewable generation technologies, but, because of its attractiveness for investors, are likely to discourage further technological innovation and may result in overshooting the target (section 4.2).
- *A guaranteed CO_2 price* for CCS would fund the gap between the costs of CO_2 reduction and the CO_2 market price. Governments could warrant buying back EUAs generated by CCS against a fixed price. Thus, uncertainty as to how much of the operator's investment in CCS an industry would be able to recover would be taken away. In theory, the scheme would be the most cost-effective of the Member State policies introduced here (section 4.3).

A low-carbon portfolio standard with tradable certificates

A low-carbon portfolio standard with tradable certificates is a requirement for consumers or their retail suppliers (or, alternatively, electricity generators) to source a minimum percentage of their electricity from a specific kind of energy or fuel. It has been successfully applied in the field of renewable electricity in various European countries and US States. A low-carbon portfolio standard could also be an effective instrument to stimulate the introduction of CCS in the EU. In competitive markets strong incentives are passed on to producers and their equipment suppliers to cut costs and seek cost-reducing innovation. In addition, the system guarantees that environmental targets will be achieved if regulations are designed well, and enforced. A trading component could be introduced to add flexibility and lower overall system costs, e.g. for Member States with limited CO_2 storage capacity. In addition, a portfolio standard for CCS could be coupled with a portfolio standard for renewables in case guarantees are needed that CCS implementation does not go at the expense of renewable energy. Disadvantages of a portfolio standard are the complexity of the standard and the trading regime. It also poses all the risks of failing technology or higher costs on the operators (section 5).

CCS obligation from 2020 onwards

A CCS obligation could stipulate that all new coal- or fossil-fuel-fired power capacity would capture and store its CO_2. An obligation could be expanded to other large CO_2 point sources. Operators will most likely transfer the costs of the obligation to the consumer, although under current conditions the sale of EUAs would cover part of the cost. An obligation is environmentally effective, very easy to monitor, and compliance can be determined in a straightforward manner. It will also strengthen the willingness of financiers to invest in CCS technology and take away much of the regulatory uncertainty. However, an obligation for a certain technology poses to the operators a risk of a failing technology, lack of sufficient storage potential in areas with a high electricity demand and the risk of high costs (section 6).

Public-private partnerships

Although public-private partnerships are not a genuine policy instrument that will in itself enable CCS, they may prove valuable for realizing enabling large pipeline infrastructure for the transportation of CO_2. Contrary to individual pipelines, the realisation of entire networks may well go beyond the interests and budgets of individual industries although they are likely to generate efficiency benefits on the system level. Partnerships for CO_2 piping could be modelled on Trans-European Energy Networks. Public financing of required investments is probably most valuable if done early in the deployment period of CCS. However, more detailed economic research is needed before such support can be justified (section 8).

Interactions and impacts of policies

A number of interactions and impacts triggered by the introduction of additional incentives for CCS can be identified.

- *Interaction with the EU-ETS* - The impact of any policy instrument that stimulates the capture and storage of CO_2 either at the EU or the Member State level would lower the demand for EUAs at the EU trading market, which would in turn reduce CO_2 market prices. There is a variety of ways to address this market impact. The impact on the carbon price can be countered by lowering the overall amount of EUAs allocated or auctioned. Alternatively, rules for new entrants may be adjusted so as to limit the volume of EUAs available in the market. The interaction of MS policies with the ETS is likely to be less important, since the geographical scope is smaller, as not all Member States will apply them (section 7.1).
- *Interaction with policies for renewable energy* - An often-raised concern is that support for CCS may divert resources away from renewable energy, and might even lower EU and MS appetite for renewable energy targets. Diversion of funds can happen on the level of R&D, but also in terms of policymakers', media, industry and public attention. It might even be possible that a renewable energy portfolio standard is replaced by a low-carbon portfolio standard, or that commercialisation subsidy for renewables will include CCS. In those cases,

the resources will clearly be divided over renewable energy and CCS. Such a negative impact on renewable energy implementation may be prevented by making the share of renewables in research and development funding, as well as in a portfolio standard, dependent on the amount of CCS implemented (section 7.2).

- *Impact on the security of energy supply* - It has been argued that CCS improves the security of energy supply, because it will allow for a more clean and climate-friendly use of coal. However, CCS *as such* will not diversify energy sources away from turbulent areas. Only if the CO_2 market price is sufficiently high to render CCS operations profitable, and if the gas price is high enough to trigger a switch to coal-based electricity, would CCS be beneficial for security of supply (section 7.3).
- *Impact on the electricity market* – An obligation or portfolio standard will lead to a rise of the cost of producing fossil-based electricity. This may make the use of coal or gas capacity with CCS as a base load option relatively costly, and lead to its deployment during peak load periods only (section 7.4).
- *Impact on innovation* – The impact that each of the incentivising policies has on innovation will differ. In general, further technological development and cost reduction may be discouraged if the additional CCS costs are fully covered by public funds. This is true for investment support, a feed-in system, and a CO_2 price guarantee alike, unless the level of support would be continually lowered to force companies into improvements. A low-carbon portfolio standard or CCS obligation would be more effective in stimulating ongoing cost reductions (sections 4, 5 and 6).

A low-carbon portfolio standard and an obligation will provide incentives for CCS without spending a significant share of the government budget on subsidies. These instruments will pose the costs and risks related to CCS on the CCS operator, which is likely to advance innovation in particularly CO_2 capture technology. If on the contrary the government would pay a fixed subsidy for CCS, the incentive to further develop CCS technology will be weaker. It therefore seems more attractive to place the cost and risk burden on the CCS operator, as this is also the stakeholder that can influence the level of innovation in CCS (section 10).

Technological maturity and policy choice

The policy instrument applied should be consistent with the innovation phase of the CCS technologies. In the demonstration phase, policy incentives should stimulate in particular cost reductions through learning-by-doing and economies-of-scale. In the up-scaling phase, incentives should lead to greater diffusion and to reduction of the financial risks involved. In the commercialisation phase, CCS technologies would be sufficiently mature to compete with other CO_2 reduction options, and may be subject to economy-wide price instruments only. Table S1 presents possible matches between policies and the innovation phases (section 10.1).

Table S1 Possible timing of incentivising policies for CCS technologies in three innovation phases. Some instruments may be complementary, but most are not.

Projected time horizon	Demonstration *2010-2020*	Up-scaling *2015-2030*	Commercialisation *2025-2040 →*
CCS in ETS (weak incentive)	Yes	Yes	Yes
CCS in ETS (strong incentive)	Yes	Yes	Yes
Investment subsidy	Yes	No	No
Feed-in subsidy	Yes	Yes	No
CO_2 price guarantee	Yes	Yes	No
Portfolio standard + certificates	No	Yes	Yes
CCS obligation	No	Yes	Yes

The maturity of CCS technology differs per component. Therefore, a mixture of the policy instruments is not unthinkable, for instance when in a single CCS project, the capture technology is in the demonstration phase but the storage component is fully mature. Care should be taken, however, to avoid double-counting and unnecessary subsidy-stacking.

Criteria assessment

The policy instruments for incentivising CCS have been assessed against a number of criteria. The results are briefly discussed below, and are summarised in a qualitative way in Table S2 (section 10.2).

- *Effectiveness* evaluates the extent to which options can be expected to achieve the objectives of the flanking policy. The ETS will unlikely prove to be sufficiently effective to realise large-scale deployment of CCS in the coming decade or so, unless a "strong" ETS can be realised. The dynamic efficiency of the scheme - i.e. the extent to which innovation and technological change are stimulated - is not guaranteed. The other policy instruments are all designed to increase that effectiveness for the case of CCS, and have in other contexts demonstrated to do so.
- *Risk and cost burden* evaluates the extent to which financial risk of CCS projects is born by those who are informed best on the costs: the CCS operators. Member State policies that provide funding to CCS operations tend to transfer much of the financial risk related to CCS projects with national governments, who do not have direct access to information on costs and risks related to these operations.
- *Consistency* is the extent to which policy instruments are likely to limit trade-offs across the economic, social, and environmental domain. This includes the consistency with the ETS for the other options. Since policies at the EU level will have a greater geographical scope than Member State policies, and will hence cover more emissions, the market impact will be greater and interaction with the EU ETS is also likely to be larger.
- *Feasibility* assesses whether a policy option can count on support from stakeholder groups (such as NGOs, business practices, etc). The assessment of this criterion focuses on concerns of the NGO community. Obligation and portfolio instruments may be more acceptable to the NGO community and hence easier to implement than policy instruments that divert part of the limited funds available for greenhouse gas abatement to CCS.

Table S2: Multi-criteria analysis of policy options. For a legend, see below the table.

	Criteria			
Options	Effectiveness	Risk and cost burden	Consistency	Feasibility
CCS in ETS (weak incentive)	-	0	+	+
CCS in ETS (strong incentive)	+	+	+	+/-
Investment support	+	-	0	-
Feed-in subsidies	+	-	0	-
CO_2 price guarantee	+	-	0	-
Low-carbon portfolio standard	+	+	0/-	+/-
CCS obligation	+	+	0/-	+

+ Positive result on criterion
- Negative result on criterion
0 Positive nor negative result on criterion (indifferent)
+/0/- Result on criterion depends on details of implementation (e.g. on allocation in ETS)

Conclusion

Although the EU ETS is the most cost-effective instrument to reduce greenhouse gas emissions, there are substantial questions as to whether its weak scenario will lead to sufficient deployment of CCS in the short term because of low incentive levels and the "innovation market failure". If the "strong" ETS scenario would be politically unfeasible, additional instruments on the EU and the Member State level can be effective in correcting this failure. These instruments have been reviewed, discussed and weighed in this document.

While Member State policies are likely to have less interaction with the ETS, and will be more consistent with other policies, they are less attractive from the perspective of environmental organisations as they are more likely to displace resources for other mitigation options. In addition, those policies tend to pose an important part of the financial risk of CCS projects with national governments, which have the lowest insight in the actual costs and risks of CCS. Overall, it seems that EU wide structural policies score higher on the identified criteria.

The use of public-private partnerships may be attractive in the case that a CO_2 transport infrastructure would need to be set up, and where central coordination leads to system efficiency gains. Public support to required investments is probably most valuable if done early in the deployment period of CCS. However, more detailed economic research is needed before such support can be justified.

It seems likely that the target of 10-12 demonstrations by 2015 is within reach, given the number of proposals in the EU and the willingness of Member States to dedicate funds to their implementation. However, rules on State Aid need to be revised, and the desirability of more structural incentives at the MS level, possibly in addition even to EU level measures, should be closely examined for undesired interactions.

1. Introduction

CO_2 capture and storage (CCS) currently is not deployed at a commercial scale. The various components of CCS are still in different categories of technological maturity (IPCC, 2005). Coal-bed methane recovery, for instance, is thought to be in the demonstration phase, whereas Enhanced Oil Recovery (EOR) is characterised as a mature market technology. Oxyfuel combustion is in the research phase, and pre- and post-combustion capture of CO_2 are "economically feasible under specific conditions". The latter means that the technology is well understood and is applied in selected commercial applications, but only if the market conditions are conducive to the technology, such as in a favourable tax regime or a niche market.

The IPCC characterisation of technological maturity of CCS components pinpoints the fact that it is not obvious that a market signal will be sufficient to pull CCS technologies into the market. For a complex technology, with many different aspects, simple policies often do not work.

A range of policy instruments could be used to provide adequate incentives for CCS. Broadly, five, possibly complementary, policies can be distinguished. Firstly, the EU emissions trading scheme is in theory a powerful instrument to stimulate CCS operations. A number of limitations and design issues, however, remain unresolved and have a bearing on CCS, especially if prices remain low. Other policies may therefore be considered. Secondly, market-based instruments may be used to complement the ETS, such as a CO_2 price guarantee or a low-carbon portfolio standard with tradable certificates. Thirdly, regulation at the EU level may be put into place to compel industry to capture and store its CO_2, and to have EU wide CCS deployment and retrofitting by a fixed point in time (2020 or perhaps later). Fourthly, additional public resources may be committed towards CCS operations, either as investment support or through a system of feed-in subsidies, although the EC legislative framework on State Aid would need adjustment to allow Member States to financially support CCS operations. Fifthly, public-private partnerships may be established to realize a series of demonstration projects across the EU, as well as a CO_2 pipeline infrastructure. Industry, financial institutions, national governments and possibly the European Commission could cooperate to realize CCS. Exactly where or by whom CCS demonstrations will be realized remains to be resolved.

While the policy categories mentioned cannot be compared on a single policy-making level and some of them function outside of the realm of the EU, they may co-exist and are therefore all outlined to provide the full policy picture.

This report aims to outline possible incentivation to further the deployment of CCS in the EU. The analysis is designed to be part of an impact assessment the European Commission is undertaking on CCS. The objectives of this report are the following:

- Explore whether the EU Emissions Trading Scheme will lead to significant deployment of CCS;
- Detail the policy options for giving incentives to CCS through market-based or regulatory instruments, at the Member State and at the EU level;
- Explore the interaction between the ETS and various identified options for CCS regulation;
- Present a number of questions that need to be addressed if public-private partnerships are to be established for the realization of CCS projects in the EU;
- Provide a multi-criteria analysis for the various policy options in accordance with the European Commission Guidelines for Impact Assessments.

Section 2 starts out with a discussion on the adequacy of the EU ETS. Next, it goes into some design issues related to the inclusion of CCS in the ETS. Section 3 elaborates the various innovation phases CCS technologies will need to go through, and indicates briefly what type of incentivising policies may be required in each of these. Sections 4 to 6 elaborate a number of additional incentivising policies. For each policy option, a number of important aspects are highlighted. Section 4 introduces public financial support instruments: investment subsidies, feed-in subsidies and a CO_2 price guarantee. Section 5 goes into a possible low-carbon portfolio standard with a system of tradable certificates on the EU level. Next, section 6 discusses the implications of introducing a CCS obligation. Section 7 goes into interactions between policy instruments. Section 8 provides a provisional overview of questions related to possible public-private partnerships that may be instrumental in realizing CCS projects. Section 9 addresses the questions how the proposals for large-scale CCS operations advanced to date far would need to be complemented to obtain a varied portfolio of CCS demonstrations. Section 10 provides the multi-criteria analysis of policy instruments to stimulate CCS, and section 11 concludes.

2. Business-as-usual: CCS in the EU ETS

2.1 Introduction

The EU Emissions Trading Scheme is a powerful instrument to assist in mitigating climate change, and to meet the EU objective to reduce greenhouse gas emissions by 20% in 2020[1]. Nevertheless, the EU ETS has limitations: it is a regional instrument which is in the process of development, and it is less suitable for stimulating long-term innovation. Hence, to effectively realize large scale deployment of CCS across Europe, it may be necessary to consider the introduction of additional incentives. In section 2.2 this will be examined.

To make the most of the capacity of the ETS to further CCS, design and implementation characteristics need to be considered systematically, notably accounting and allocation issues, since these are likely to affect the incentive imparted by the trading scheme substantially. Section 2.3 therefore deals with some principal design characteristics.

2.2 Would CCS deployment be achieved through the ETS?

The EU ETS was introduced as a market-based approach to reduce CO_2 emissions in a cost-effective manner. Such a market-based approach to environmental problems should ideally solve two common market failures: the externality of environmental impacts, and the lack of incentive for technological change (Jaffe *et al.*, 2005). The ETS is a market-based instrument that gives a price to the environmental externality of CO_2 emissions. This price depends on the supply and demand for CO_2 emission allowances, and therefore on the allowances initially allocated at the start of a trading period in the scheme. In this way, the common market failure of not internalizing environmental damage in production costs is addressed to a certain degree by a cap-and-trade regime.

However, cap-and-trade approaches do not provide the incentives needed to compensate innovators for inducing technological change. In addition to not addressing this technology market failure, the ETS specifically has design features that make it worse. The short-term horizon of the trading periods, without perspective of long-term deep emission reductions, will make operators of installations prefer the technological options that are more competitive and cost-effective in the short term rather than highly innovative, step-change technologies, such as CCS. This is likely to deter the development of technologies that involve particularly high demonstration costs (such as CCS), as the return on investment in innovation is unlikely to be sufficient. For the ETS to work more effectively to promote such technologies there would need to be a clear long-term perspective of deep emission reduction requirements, preferably operating at a global level. In the absence of these, and while there is no prospect of deep cost

[1] Environment Council February 20 2007.

reductions for CCS, it is unlikely that CCS will be significantly incentivised in the short term, especially in the, in terms of ETS market share important, electricity sector. Current CO_2 market prices as well as future projections for the 2008 – 2012 period of the ETS show price levels around 21 €/tCO_2 (PointCarbon, 2007). Such prices are insufficient for inducing structural deployment of CCS, although it will be high enough for some options (see IPCC, 2005). If the ETS were to create more stringent caps, and therefore higher prices, CCS would probably be deployed. This would also need to be coupled with long-term signals and policy commitments on emission reduction targets, to say 2050. However, we need to take into account the possibility that due to various mechanisms, this might not be the case.

Even if it would help if the ETS would have a longer time horizon, it will not fully address the technology market failure. In order to effectively advance technological innovation, a number of complementary policies can be considered. It is likely that both at the EU and at the Member State level, action will be undertaken. Member State policies could include investment support for demonstration, guaranteed CO_2 prices to enable domestic implementation, or feed-in subsidies for CCS-based electricity supply. For the Member State to be able to deploy such policies, they would need to be accepted as permissible under EU State Aid regulations, as highlighted in the Task 1 report (NortonRose *et al*., 2007). EU level policies complementing the ETS may comprise a portfolio standard (a requirement to source a minimum percentage of electricity from a specific kind of energy or fuel), or an obligation to capture and store CO_2 in the power (or other large point sources) sector.

2.3 Design issues related to CCS in the ETS

2.3.1 Allocation mechanism

Opting in CCS operations during the ETS second period (2008-2012) - and any subsequent period in which EUAs would be allocated primarily free of charge (i.e. not auctioned) - would imply a continuation of current practices. As is custom now, existing installations would have their emission allowances allocated based on historical emissions prior to investment in CCS. New entrants would have their emission allowances allocated based on a benchmark that would not take into account CO_2 capture, in order for them to reap the benefits of installing CO_2 capture.

If EUAs were to be auctioned, the opt-in of CCS operations would not affect auctioning practices, unless an obligation or other regulatory measure for capturing CO_2 would be introduced. The allocation mechanism only matters in the case that additional instruments are applied to stimulate the deployment of CCS. This is reviewed in section 7.

2.3.2 Qualification of activities

The European Commission will need to formally approve inclusion of CCS operations from 2008 as an opt-in installation under Article 24 of the ETS Directive[2,3]. Such an approval should include due safety checks to ensure that all components in the CCS chain appropriately avoid emission of CO_2. For the second phase of the ETS, combustion, capture, transport, and storage installations would be opted in as a single installation. Up to 2012, the separate elements of any CCS chain are most likely to be located within a single Member State. EUAs for these chains

2 An alternative approach might be not to define CCS operations as a distinct activity. Instead, CO_2 capture would be considered as an investment in CO_2 abatement technology, undertaken by installations incumbent in the ETS. While in principle this route could result in the same environmental and economic outcome, it lacks an important legal indemnity. Article 24(1) specifies that new activities may participate in the EU-ETS '*taking into account all relevant criteria, in particular effects on the internal market, potential distortions of competition, the environmental integrity of the scheme and reliability of the planned monitoring and reporting system*'. This provision should provide additional assurance that the uncertainties related to the risks of CCS and its inclusion in the ETS are addressed properly.

3 Another example of an opt-in activity under Article 24 is the inclusion of N_2O from the production of nitric acid, as foreseen in the French and Dutch NAPs for the second budget period.

would have been allocated to the combustion installation in the National Allocation Plans (NAPs) for the second budget period

This approach has certain limitations. It may complicate transboundary CCS operations, and could in the future give rise to the question by which NAP such operations would need to be covered. It may also provide organisational barriers to CCS implementation, as power-sector and storage sector companies would have to cooperate in such a joint venture. This problem was also highlighted in the Task 1 report (NortonRose *et al.*, 2007).

From 2013 onwards, therefore, a number of modifications to the treatment of CCS under the ETS is considered. Among these is the possibility to opt-in capture, transport and storage operations as distinct installations under the ETS, thus being able to immediately take account of leakage in the ETS, should this be advantageous (section 2.3.3). Another possibility is to list CCS or its capture, transport and storage components explicitly in Annex I of the Directive. In addition, the current practice, whereby no allowance is given for transport and storage, could be continued, in which case commercial arrangements may need to be made between combustion and capture installations, on the one hand, and transport and storage installations, on the other, so as to compensate the latter adequately for their efforts. Monitoring and reporting guidelines for transport and storage would be implemented in the normal way. However, any other options advanced will also be considered. A more detailed description of this is in the Task 2 report (Zakkour *et al.*, 2007).

2.3.3 Accounting issues

Difficulties in accounting for CO_2 in the CCS value chain could relate to the involvement of various Member States jurisdictions in the CCS chain; the potential seepage of fugitive emissions from capture installations and during transport, and potential long-term seepage from geological reservoirs.

As for the transboundary transfer of CO_2, this issue may be solved by making capture, transport and storage installations eligible as separate ETS activities, as suggested in the previous section. The capture installation would be allocated emission allowances and would need to surrender sufficient EUAs to cover its annual emissions. In the case of a CO_2 pipeline that crosses Member State borders, the pipeline may need to be divided into more than one installation, i.e. one for every segment of CO_2 pipeline that is located in a single country, and leakage from the pipeline would be accounted for as the pipeline installation would have to buy EUAs to comply with the Directive. If a storage reservoir would extend over more than one country, and CO_2 is projected to migrate from the one country's underground into the other country's, the reservoir may need to be divided up in country-specific parts as well, although that may be challenging in terms of allocation of potential leakage. Alternatively, all cross-border migration and seepage would be accounted for by the injection operation.

Seepage during operation would need to be accounted for by the installation to which EUAs were allocated. Long-term seepage, taking place after site closure and abandonment and therefore after the project has stopped generating allowances, arguably poses the largest challenge to accounting CO_2 in such a way that the environmental effectiveness of the ETS is not compromised. Although the storage operation may be included as an installation under the ETS and required it to surrender allowances for emissions, this would not provide any assurance for long-term seepage from the reservoir, given that the storage reservoir would probably not remain an installation under the ETS in perpetuity. There are several ways of dealing with the issue of long-term credit liability:

a) CO_2 credits generated through CCS activities could be discounted according to projections of seepage out of the reservoir in accordance with detected seepage from storage locations. This would affect the value of CCS-EUAs in the market negatively, and a separate commodity or type of credits would have to be created alongside common EUAs. To be absolutely fair to good sites as compared to suboptimal sites, the credits would even have to be site-specific. Another intricacy would be the practical uncertainty in determining exactly how much CO_2 will escape, and thus the degree by which EUAs should be discounted. There is a compelling case (Zakkour *et al.*, 2005) therefore not to reduce the value of EUAs, but leave them unaffected as CO_2 seeps from the storage site (see b).

b) Once the storage operation had met the conditions for liability transfer agreed in agreement with relevant technical standards, the Member State could take over post-closure liability. In this case, seepage would be accounted for in the National Greenhouse Gas Inventories of the countries where the storage operation is located. In order to comply with its greenhouse gas emission reduction target, the country would have to plug the leak in order to reduce emissions, or to reduce emissions in another location if the leak is not posing safety or environmental risks and other options are more economically attractive[4]. It must be noted that this system would place the liability for long-term seepage with the country where the CO_2 is stored, while the country where capture takes place would not be affected by such seepage. If the operator is required to make some financial provision for potential liabilities, this issue would be covered by commercial arrangements.

c) Risk analysis could indicate that, for some types of reservoirs, regulations to ensure safety are sufficiently strict to guarantee satisfactory greenhouse gas permanence for CCS to make a contribution to climate change mitigation. In these cases, safety legislation (which is partly laid down in EU and partly in Member State legislation; see Task 1 report) might make Member State or EU regulation of “global risks” of long-term, small-quantity seepage superfluous.

Obviously, the difficulties related to transboundary transport or sub-soil migration of CO_2 may be circumvented if EUAs were allocated or auctioned under an EU wide ETS emissions cap.

3. Timing of additional incentivising policies

In section 2.2, it has been argued that additional policies on top of the ETS will be needed to advance the introduction of CCS technologies. Exactly which policy instruments are most appropriate for stimulating a certain technology at a specific point in time will depend on a variety of factors, including, importantly, the maturity of the technology. Sandén and Azar (2005) have provided a useful framework to match technical maturity with policy instruments. They distinguish three phases of maturity[5], each of which requires it particular incentivising policies.

In the *demonstration phase*, incentives are needed to bring down production costs while increasing adoption (Table 3.1). Of course, costs related to plant design, steel, chemicals/O_2, and financing will remain. Bringing down costs of immature technologies will often involve the provision of the capital required to realise demonstrations. For CCS, this phase will comprise the construction of up to 12 demonstration plants.

[4] Note that if a Member State fails to achieve its emissions reduction target under the EU burden sharing agreement (Decision 2002/358/EC) then the Commission could bring infringement proceedings under Article 226 of the EU Treaty and this could ultimately result in the European Court of Justice levying a fine on the offending Member State. If a country fails to achieve its emissions reduction target under the Kyoto Protocol in its capacity as an individual signatory it would be subject to the Kyoto compliance regime i.e. it must make up the difference in the second commitment period (if there is one) with an additional 30% penalty; it must develop a compliance action plan setting out the actions that it will take to meet the target and the timetable for doing so, and its eligibility to "sell" under the Kyoto Protocol's international emissions trading system will be suspended.

[5] Note that the IPCC uses a different qualification of maturity.

Table 3.1 Mechanisms leading to lower production costs with increased adoption (based on Sandén and Azar 2005)

Economies of scale in production	Production costs per unit of output decrease when fixed costs are spread over an increasing production volume. Increased production volumes also enable increased division of labour.
Learning by doing	Production processes and organisation are refined and the skill of workers increases with cumulative production.
Incremental product development	Learning by doing and learning by using can feed back into incremental product development. The product is refined to increase the performance-to-cost ratio and better meet the needs of users and producers.
Economies of scope – complementary resources and production processes	The growth of one technology may induce a use of by-products. The value of the by-product can lower the net cost to produce the initial main product. The multiple outputs of oil refineries may serve as example.

In the *up-scaling phase*, the technology will have gained a certain momentum, and other incentives will be needed to induce more users and investors to take on the technology. At this stage, the costs of the technology are sufficiently low, but incentives are needed to advance the diffusion of the technology. Such incentives should help triggering mechanisms that will increase attractiveness of a technology (Table 3.2). In this phase, policies must advance widespread awareness of the option and reduce the financial risks associated with the deployment of a technology. An obligation of the technology may accelerate the rate of up-scaling. This phase will entail the construction of a 'second generation' of CCS plants over a 10-15 year period.

Table 3.2 Mechanisms making a technology more attractive for users and investors with increased adoption, regardless of price (based on Sandén and Azar, 2005)

Decreasing uncertainty	The adoption of a technology will decrease the uncertainty of its merits. Risk adverse producers, users and investors prefer a better-known technology. This is probably of extra importance when it comes to consumer goods, such as private cars and domestic heating systems.
Learning by using	The performance of a technology increases and service costs decrease when users gain experience, in particular valid for complex capital goods such as aircraft and power plants, but also maintenance of consumer capital goods such as cars and houses.
Economies of scale in consumption – user networks	The benefit that a consumer derives from using a good sometimes depends on the number of other consumer purchasing compatible items. For example, if many use the same standard, the cost of complementary goods will decrease and their availability will increase. The availability of machine service and spare parts will also increase.

In the *commercial phase*, the technology can be considered mature. It will be one of a range of cost-competitive options to abate emissions. In this phase, economy-wide price instruments should provide sufficient incentive to induce deployment of the technology. An obligation of the technology may be also considered. In this phase, CCS should be one of the lowest cost options for carbon dioxide reduction, and should be able to exist unsupported by additional policies. This phase may start at any moment between 2025 and 2040, depending on the rate of diffusion of the technology.

In our discussion of policy instruments in sections 4 to 6, we will refer to the distinction in innovation phases introduced here. This will help to settle on the question exactly when the instrument might be of most use at what point in time.

4. Public financial support

Market-based instruments introduce an incentive in a market to perform an action, in this case, to implement CCS. They are often contrasted against command and control instruments, which put a restriction on a certain action (e.g. forbid the build of new fossil-fuel power plants if CCS is not applied to them).

This section discusses a number of market-based instruments that provide an incentive through rewarding the application of CCS, through an investment subsidy (section 4.1), feed-in subsidies (section 4.2) and a subsidy on top of the CO_2 price (section 4.3). As all these instruments put a substantial burden on the government budget, it is likely that they would be implemented at the Member State rather than at the EU level.

4.1 Targeted investment support

4.1.1 Characterisation

A range of pilot and demonstration projects have been proposed so far in a number of EU Member States. Yet capital requirements for capturing CO_2 in a power plant are substantial, and seemingly few investors are willing to provide the required capital as long as it is uncertain what the returns on such investments would be. As capital costs of capture operations are high, investment subsidies in absolute terms for those operations may well be more significant than financial support for other elements in the CCS chain.

Apart from required capital for capture equipment, the realization of large scale CCS deployment in Europe will necessitate investments in a CO_2 infrastructure. Governments may subsidise such an infrastructure in two ways: by taking ownership of a CO_2 infrastructure and make companies that wish to use it pay endowment, or by subsidising one or several pipelines. Governments may have two arguments to do the former. Firstly, there may be an efficiency gain if a country-wide CO_2 pipeline network is set up rather than an uncoordinated number of separate capture-to-storage pipelines, especially in countries that are dense in suitable point sources; and secondly, the presence of such a network may lower the barriers for new entrants in CCS technology, as it would lower project risks and lower per-unit transport costs through economies of scale if a functioning large-scale infrastructure is already in place. This option is discussed in section 8.

It is also conceivable that in some cases governments would want to partly fund investments for the storage operation, by subsidising directly or indirectly via research programmes in the field of monitoring techniques (see e.g. the SACS project, which was subsidised by the host country as well as on the EU level).

4.1.2 Timing

Investment subsidies could be used to incentivise CCS in various stages of technological maturity, but is most likely to be for large-scale demonstration of the technology.

4.1.3 Cost considerations

Depending on its scale, capital support to CCS projects could in the time span up to 2015 contribute to the realization of the 10-12 CCS demonstration projects aspired by the Commission. Potentially there will be a continued demand for investment support after 2015 to further industrial-scale deployment of CCS.

To illustrate the magnitude of possibly required investments in CO_2 projects, Table 4.1 provides estimates of capital required for realizing new electricity generation capacity with current capture technologies. It also presents the required investment for CO_2 capture in existing pulverized-coal power plants, and for oxy-fuel combustion.

Table 4.1 *Incremental capital requirements [€$_{2005}$/kW][1] for capture capacity on top of capital required for construction of the combustion plant (based on Thambimuthu* et al*, 2005)*

	Low	Representative	High
Current technologies			
Pulverized coal, new	1160	1290	1490
Natural gas combined cycle, new	515	570	725
Integrated gasification combined cycle, new	1170	1330	1570
Pulverized coal, existing	650	NA	1950
Advanced technologies			
Oxy-fuel combustion	- [3]	800 [2,3]	1870 [3]

[1] 1 US$$_{2002}$ = 1.06 €$_{2002}$; Harmonised Index Consumer Prices €$_{2005}$ / €$_{2002}$ = 100 / 93.9

[2] Since estimates for capital required for oxy-fuel combustion are highly variable, no representative value was given by Thambimuthu *et al* (2005). Instead, the value used by SEQ Nederland B.V. (2004) is shown.

[3] Total capital requirements in a oxy-fuel combustion plant are 910, 1800 and 2870 €$_{2005}$/kW (low, representative, high). In order to estimate incremental capital requirements, a representative NGCC plant without capture was taken as a reference. Total capital requirements for such a plant are in the order of 1000 €$_{2005}$/kW.

Capital required for new CO_2 pipelines is determined by length and diameter of the pipeline, terrain characteristics and the need for booster stations. Obviously construction costs of a pipeline with a smaller diameter are lower, but the pipeline will cause higher loss in pressure, which may necessitate additional booster stations along a pipeline trajectory. For normal onshore conditions total investment for pipeline construction can be expressed as the product of length, diameter, and a correction factor for the terrain. Extra costs for large crossings may amount to 0.5 to 3 M€ each (Hendriks et al., 2003).

Obviously, the investment subsidy instrument may put a relatively high cost burden on governments. This might put pressure on government budgets for other energy and climate operations, such as renewable energy, and may in turn lead to resistance from environmental organisations, which might mobilise the public.

4.2 Feed-in subsidies

4.2.1 Characterisation

Feed-in schemes have become widely used to stimulate the introduction of electricity from renewable sources. In a feed-in scheme, a fixed fee is guaranteed per unit of renewable electricity produced, to compensate for the higher costs of the project vis-à-vis conventional, fossil fuel alternatives. The fee is usually dependent on the technology, the fuel used (in the case of CHP subsidies, for instance) and the development stage a particular technology is in.

Two main approaches to feed-in subsidies are feed-in tariffs (FIT) and feed-in premiums (FIP). In a FIT scheme, a fixed amount of money (tariff) is paid for the electricity produced. A producer who receives a feed-in tariff effectively sells his electricity to the payer of the fee (usually the national government). In a FIP scheme on the other hand, a fixed fee (premium) is paid only to compensate for the financial gap of renewable electricity. With this approach the electricity is sold separately on the regular market. Under both FIP and FIT schemes, fees are usually fixed for a long time, ranging from a few years to indefinitely (i.e. the technical lifetime of the project) to create long term certainty for investors. A variety of approaches to financing these schemes exists. Costs may be collected through connection-charges, as a mark up in the electricity price like in Germany (FIT) or the scheme may be financed from the national budget like in the Netherlands (FIP).

So far, feed in fees have been granted to domestic generators of electricity from renewable sources in various Member States, including Germany, France, Spain, the Netherlands, Greece, Portugal, Denmark and Luxembourg. Feed-in systems have proven very effective in stimulating new investments in renewable generation technologies, as evinced by the fast expansion of wind-power generation in Denmark, Germany, and Spain. Feed-in schemes are simple and transparent. Since investors are guaranteed long-term income security, banks are willing to provide loans and allow project-finance constructions. Its proven effective in stimulating near market technologies makes this policy option worth considering for the promotion of large scale CCS in Europe. In the Netherlands, a FIP scheme has been proposed for the Netherlands for low-carbon electricity (Coninck *et al.*, 2005), but no eventual decision has been made on this.

Despite its wide-spread application and effectiveness, the instrument has a number of weaknesses. For instance, it is likely to result in overshooting or undershooting any target that may have been set for low carbon electricity. This is because normally no maximum or minimum level is set for the amount of low carbon electricity compensated, and the output of such electricity is merely driven by the total amount the electricity producers wish to supply. It seems unlikely however that this would be a problem for the target of 10 to 12 CCS demonstrations in the EU. Lastly, a feed-in subsidy does not lead to incentives for reducing consumption of electricity because the consumer price of electricity does not rise.

4.2.2 Timing

In renewable energy, feed-in subsidies are particularly used to provide a structural incentive for commercialisation. Given the technological uncertainties that still surround an option in the demonstration phase, feed-in subsidies are unlikely to be used for CCS while it is still in that phase. The system is suitable to reduce the financial risks from CCS operations technologies, and may thus be deployed in the up-scaling and the commercialisation phase. There is an important risk, however, that further innovation in CCS technologies, and further cost reduction, would be halted by a feed-in subsidy, which may be particularly problematic in the up-scaling phase.

4.2.3 Cost considerations

Costs for a feed-in system are borne by the government, and may be very high if the system is successful and leads to much deployment of CCS. Ultimately, therefore, the taxpayer would cover the full extra costs of low-carbon electricity, and not the electricity user. Downward adjustment of the tariffs or premiums, because learning brings down the costs and the compensation of the financial gap can be reduced, may meet resistance among producers. In addition, as mentioned in 4.2.2, producers with long-term guarantees and limited risk on new technologies tend to be less active in seeking efficiency improvements and tend to be more reluctant in searching for further opportunities to innovate.

4.3 Guaranteed CO_2 price for CCS

4.3.1 Characterisation

While prices for CO_2 on the emissions trading market are too low to stimulate construction of new CCS capacity, policymakers may consider funding the gap between the costs of CO_2 reduction and the CO_2 market price. Such an instrument could be introduced for CCS only or for other abatement technologies as well. Governments could warrant buying back EUAs generated by CCS against a fixed price. Thus, uncertainty as to how much of its investment in CCS an industry would be able to recover would be taken away.

A CO_2 price guarantee could be applied to the power sector alone, but it could also be extended to include other sectors that are included in the ETS. This adds extra flexibility to increase scope to the instrument. A number of low-cost capture opportunities and a number of more expensive options in industrial, non-electricity sectors might benefit from such a price guarantee (see section 7 below).

4.3.2 Timing

A CO_2 price guarantee is not particularly suitable to provide the substantial capital needed for realizing large scale demonstrations. It may, however, be a useful instrument for stimulating CCS in the up-scaling phase, whilst CCS does not provide a cost-competitive opportunity to reduce CO_2. Under these circumstances, it will help to reduce the financial risk for investors in CCS technologies. If the instrument would apply to CCS only, it would help to enlarge the share of CCS-based emissions reductions in the mitigation portfolio. However, a CO_2 price guarantee would involve the risk of disincentivising ongoing innovation of CCS technologies. Once CCS technologies have matured, maintaining a subsidy in the form of a CO_2 price guarantee no longer seems justified.

4.3.3 Cost considerations

Key to the total cost of a CO_2 price gap policy will be the market price for CO_2, which is uncertain. For the 2008-12 period projections are between 10 and 25 €/tCO_2 (Sijm *et al.*, 2005)[6], depending on the National Allocation Plans, but also on external conditions such as weather and economic growth. Energy prices have a major influence as well. Higher oil and gas prices have resulted in a higher gas-to-coal price ratio, and as a consequence have favoured coal-based electricity, which is more carbon-intensive and generates demand for CO_2 credits. If this trend continues, it would exert an upward pressure on the CO_2 market price. Alternatively, an eventual drop in oil and gas prices would lead to a lower CO_2 market price. Trading of possibly cheap credits from JI and CDM projects on the European carbon market will also bring down the price of CO_2 credits.

The market price for CO_2 also affects the choice for specific sector(s) to be targeted by a future CO_2 price guarantee policy, because the costs of CO_2 capture differ substantially between industrial installations and zero-emission power plants (ZEPs). In the Netherlands, for instance, costs for capturing and storing CO_2 from industrial point sources are between 6 and 11 €/tCO_2 captured, starting with 4 €/tCO_2 for capture (Hamelinck *et al.*, 2001) and 2 €/tCO_2 for onshore storage (Hendriks *et al.*, 2003). A CO_2 price gap policy would only include industrial point sources if the CO_2 market price stays low. A rising CO_2 market price would automatically cancel the CO_2 price guarantee instrument, as the market price would more than cover the costs of CCS, although it may remain necessary for high-cost CO_2 capture options, such as sources in the steel and cement sectors. For capture and storage of CO_2 from ZEPs, costs start at 20 €/t CO_2-avoided (IPCC, 2005) and the instrument would therefore remain in place longer than for sectors with a smaller price gap, such as refineries or ammonia plants.

Setting a CO_2 price guarantee would require some insight into the costs associated with capturing and storing CO_2. Policymakers would depend on cost information from industry in deciding on the required level of the price guarantee. Cost information would need to be updated frequently to make sure that the level of the price guarantee is not too high.

There would be a risk of collusion of pricing to the extent that operators would work together to provide single estimates of the costs of CCS, needed to decide on the price guarantee level, rather than submitting information on costs in individual operations.

[6] Over the period January-July 2005, the market price for CO_2 was between 6 and 30 €/tCO_2. Prices have increased during 2005, dropped by the end of 2005, rose again up to 30 €/tCO_2 and then plummeted down to 10 €/tCO_2. Prices were stable at around 15 €/tCO_2 from May 2006 onwards, until in January 2007, prices went down again to around 5 €/tCO_2. PointCarbon (2007), in a recent report including the most recently submitted and corrected NAPs, arrive at a carbon price of 21 €/tCO_2 over the 2008 - 2012 period.

5. Low-carbon portfolio standard with tradable certificates

5.1 Characterisation

A portfolio standard is a requirement for consumers or their retail suppliers (or, alternatively, electricity generators) to source a minimum percentage of their electricity from specific energy sources or fuels. It could be set up in a way however to include electricity from installations where CO_2 is captured and stored as well. In order to provide flexibility to participants with a portfolio obligation and to reduce their compliance costs, a parallel system of tradable certificates can be introduced to certify eligible electricity, similar to current proposals of systems of tradable permits for renewable electricity. Any company generating low-carbon electricity by capturing CO_2 would receive CCS certificates. If a company has more permits than it needs, it can sell the surplus to companies that fall short of their target. Such a system can ensure minimum aggregate system compliance costs. Participants in areas with high marginal costs for CCS-based electricity can import their certificates from areas with lower marginal costs.

5.2 Timing

Including CCS in a low carbon portfolio standard may be considered once CCS is beyond the demonstration phase. A portfolio standard will contribute to diffusion of the technology and as such seems an appropriate instrument to use in the up-scaling phase. In the commercial phase, a portfolio standard may be made more stringent to reflect the maturity of CCS technologies.

5.3 Cost considerations

A portfolio standard is potentially an effective instrument to stimulate the introduction of CCS in the EU. In competitive markets strong incentives are passed on to producers and their equipment suppliers to cut costs and seek cost-reducing innovation. Chief strengths of the system are that environmental targets will be achieved, as long as regulations are well-designed and enforced. If the system is complemented by certificate trading, this ensures that targets are achieved at lowest costs, which as such is appreciated by electricity suppliers. Nevertheless, a portfolio system does not provide funds to investors as for instance a system with feed-in tariffs or premiums. Consequently, there is no risk of providing windfall profits to industry. If the portfolio standard implies an ambitious environmental target, high certificate prices may drive up overall costs, which will be passed on to the electricity consumers, thus providing an incentive to reduce electricity consumption.

Portfolio systems for renewable electricity have recently been introduced in, among other areas, Australia, Japan, and at least thirteen states of the US. The following EU countries have adopted a portfolio system: the UK, Belgium, Italy, Sweden, and Norway, although results have varied much and depend on the design of the system. Most countries that have opted for a portfolio standard have chosen a midstream/downstream variant i.e. they assigned the portfolio compliance obligation to electricity consumer or their suppliers (electricity distribution companies). So far, only Italy has opted for an upstream portfolio system, imposing the obligation on power generators or importers (Linden *et al.*, 2005).

6. CCS obligation for new installations after 2020

6.1 Characterisation

The Commission's Communication on Sustainable Fossil Fuels outlined the possibility of a "CO_2-emission phase out", which essentially means the obligation of CCS for all new fossil-fuel-fired power stations from 2020 onwards. This straightforward "command and control" measure contrasts with the market-based approach taken in the ETS. In principle, such an obligation could be expanded to other industries that represent large CO_2 point sources. Early candidates would be refineries, ammonia factories, and hydrogen plants. Once the technology is more developed, cement and steel factories could be included. In the long run, also CO_2 capture from biomass plants can be considered.

An obligation could be accompanied by smart measures that enable earlier phase-out of CO_2 emitting coal-based power plants, primarily related to timing. A measure could be included for instance that over the course of 2020 – 2040, all coal-fired power plants are retrofitted with CCS, which would speed up the phase-out of old-fashioned power plants. This would even be made easier if an obligation that all fossil-fuel-fired power stations should be built "capture-ready" from 2012 onwards would be included, although this can also be left to the operators if the obligation for retrofitting is announced sufficiently ahead of time. In such a way, by 2040, all CO_2-emitting coal-fired power plants could be retrofitted with CCS.

6.2 Timing

CCS technologies will need to have matured to some extent before an obligation can be considered. An obligation can be applied to an option still in the demonstration phase, but would need to take effect at some date in the far future, e.g. 10 years. In that way, companies have time to prepare themselves. A mandate may be considered in the demonstration phase to accelerate diffusion of the option, or in the commercial phase, when the technology will be widely accepted.

6.3 Cost considerations

'Command and control' options will impose a higher cost burden on the stakeholders. There are two possible reasons for this. Firstly, they do not allow operators to select the cheapest low carbon option available. In the case of fossil-fuel fired power production, however, this does not seem to be a problem as CCS is the only option to drastically reduce CO_2 from that type of source, and if the same obligation applies to all. Note that companies are still able to divert to other means of generating electricity. Secondly, if there are other technological options available, an obligation may retard further development of the mandatory technology option into a better and more advanced version of the prescribed technology. However, also here, it can be questioned whether this would constitute a real problem for the development of CCS. The mandate does not discourage investments in more efficient CO_2 capture technologies, and at the time of construction state-of-the-art technologies may be applied. A condition for this would be that the mandate should not be restricted to known CO_2 capture technologies, so as not to exclude any possibilities, but should pose a generic mandate, e.g. to capture and store at least 85% of the greenhouse gases that would be emitted in the case a conventional plant was built.

Apart from these inefficiencies, which appear to apply only partly for CCS, an obligation for a certain technology, especially one which has not yet been demonstrated on a full scale yet, poses to the operators a risk of a failing technology. Although the concept of CCS is certainly proven, the practicalities of scaling-up capture in power sector are by no means all solved. In addition, lack of sufficient storage reservoirs in areas with rising electricity demand may lead to disproportionally high costs for various regions in the EU.

7. Interactions between policy instruments

7.1 Interaction with the EU-ETS

It has been argued that the use of instruments in addition to a carbon trading instrument such as the EU ETS would only be economically acceptable in the case that they contribute to "the static or dynamic efficiency of the trading scheme, or delivering other valued policy objectives" (Sorrell and Sijm, 2003). It was already argued in Section 2.2 that additional incentives for CCS on top of the EU ETS might be legitimate. The reason is what is sometimes called the R&D or innovation market failure, or the limited dynamic efficiency of the market trading scheme. With this in mind, this section will investigate how various policy instruments complementary to the ETS would interact with the ETS, and whether this interaction can be deemed acceptable.

7.1.1 Carbon market impact of additional CCS policies

The impact of any instrument that tilts the mix of mitigation options towards CCS on an emissions trading market will lead to greater deployment of a relatively expensive abatement technology. Policy instruments that would provide funding to CCS projects, such as investment subsidies, feed-in subsidies or a CO_2 price guarantee, would subsidise part of the operator's marginal costs of abating emissions The CCS-obligation or low-carbon portfolio standard place the full cost and risk burden on the CCS operator.

Introducing a technology bias in an emissions trading scheme, through regulation or subsidy, has a depressing effect on the price of EUAs. This is illustrated by Figure 5.1. Figure 5.1a shows the marginal abatement cost curve before an additional policy on CCS is introduced. Suppose the emission reductions enacted by the ETS are 50MtCO_2/yr, this would lead to an equilibrium carbon price of p_e. The 10 MtCO_2/yr of CCS options, with mitigation costs of p_{ccs}, are more expensive than the p_e, so CCS will not be realised.

Figure 5.1b shows what happens when flanking policy is introduced that induces the implementation of the 10 MtCO_2/yr of CCS. In case the allocation of allowances remains unchanged, the abatement apart from CCS will decrease to 40 MtCO_2/yr, thus depressing the carbon price.

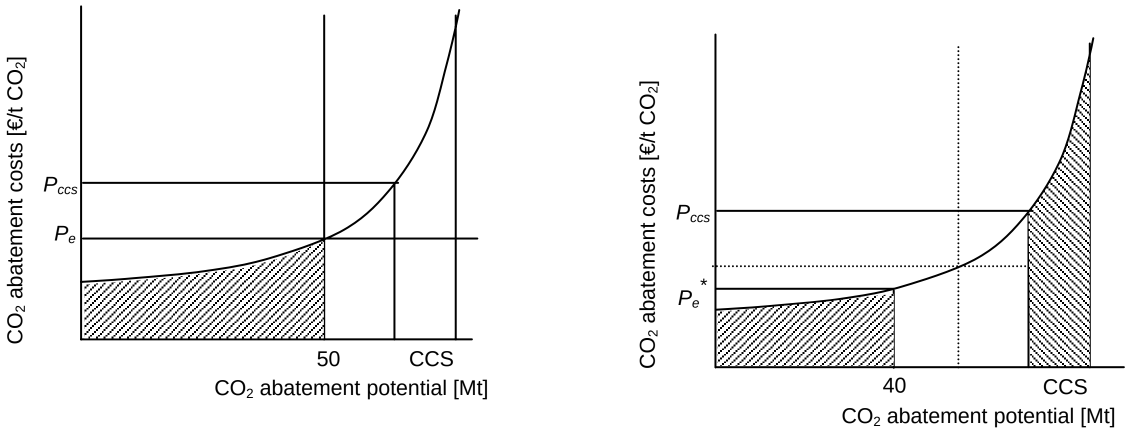

Figure 7.1 Marginal abatement costs curves for a portfolio of CO_2 abatement options (a) excluding and (b) including CCS technologies

Thus, any flanking CCS policy will have a depressing effect on the EUA price. This applies for all additional instruments, be it an investments subsidy, a guaranteed CO_2 price, a portfolio standard or an obligation.

There is a variety of ways to address this market impact. The most straightforward way is to adjust the overall allocation based on the expected realisation of CCS as a consequence of the flanking policy. I.e., if an obligation is expected to lead to 2 MtCO_2/yr fewer emissions in Germany, Germany's allocated allowances should be cut by 2 MtCO_2/yr.

In addition, the market effect could be completely removed through the correct establishing of rules for new entrants. If new entrants in a grandfathering system would not be allocated allowances, the supply of EUAs will ultimately be lower, which would correct a price decrease triggered by additional incentives for CCS. In the case of fully auctioned allowances, the number of allowances auctioned should be reduced with the expected implementation of CCS as a consequence of the flanking policies. The impact on the carbon price can thus be countered through the details of the allocation, including the overall level of EUAs grandfathered or auctioned, and the rules for new entrants.

7.1.2 Scope of ETS impact and cost burden distribution

The scope of impact of additional policies for advancing CCS will depend on the coverage of the instrument. The impact of EU-level policies is likely to be largest, as clearly they apply to the entire EU and therefore create a larger market distortion, if the impacts are left uncorrected. An obligation for CCS and a portfolio standard place the largest cost burden on the CCS operators, who could account for those costs by raising consumer prices.

Instruments at the Member State level, such as a guaranteed CO_2 price and a CCS capital subsidy will involve substantial government spending and place much of the cost and risk burden on the Member State that chooses to provide the subsidy. Therefore there will most likely be only a small number of Member States that will apply them, and the market impact is therefore likely to be smaller.

7.2 Interaction with renewable energy policies

Support for CCS might have an effect on Member States' interest in complying with their targets for renewable energy or electricity. The EU aims to have renewable energy sources providing 21% of the electricity by the year 2010, with differentiated targets for each Member State (EC, 2001). In addition, in the March 2007 Spring Council EU leaders adopted the Energy Action Plan (COM(2007)1), which stipulates in a 20% share of renewables in the overall energy mix by 2020. In the primary energy portfolio of electricity producers that wish to reduce their emissions under the ETS, renewable sources of energy will need to compete with fossil fuel based electricity for which CO_2 has been captured and stored. Although in principle the Member States will still comply with their renewable energy targets, it is an often-raised concern that Member States divert resources away from renewable energy, thus lowering the likelihood of the meeting their renewable energy targets. Diversion of funds can happen on the level of R&D, where it would be relatively easy to demonstrate, but also in terms of policymakers', media, industry and public attention. It might even be possible that a renewable energy portfolio standard is replaced by a low-carbon portfolio standard, or that commercialisation subsidy for renewables will include CCS. In those cases, the resources will clearly be divided over renewable energy and CCS, rather than only to renewable energy, and diversion of resources would take place.
It is unsure whether such interactions will raise concerns if they are limited in scope to R&D budgets. However, in the case of clear policy diversion, negative impact of the inclusion of CCS in the mitigation portfolio on renewable energy implementation may be prevented by making the share of renewables in research and development funding, as well as in a portfolio standard, dependent on the amount of CCS implemented. For instance, if 15% of all electricity would have to be low-carbon because of a CCS portfolio standard, one could at the same time adopt a resolution that the share of renewable electricity has to be twice as high.

The issue has also been raised whether CCS, as another mitigation options, should not benefit from the same supportive policies as renewable energy. This issue warrants some contemplation. Some indeed view the justification of flanking renewable energy policies (such as feed-in tariffs) similar to additional policies for CCS. From the viewpoint of correcting an innovation market failure and increasing the dynamic efficiency of the ETS, there is indeed an argument to allow for additional policies for CCS. However, there are differences between CCS and renewable energy, in that renewable energy fulfils additional policy objectives in addition to greenhouse gas reduction, particularly in the field of energy security of supply and air quality. This is further discussed below.

7.3 Co-benefits of CCS

Arguments for costly policies that provide additional incentives to a technology, and distort a technology-level playing field, can be found by looking at co-benefits of CCS. Three characteristics of CCS are commonly mentioned as co-benefits and therefore as arguments for additional public spending on CCS: the enhanced recovery of oil, reduction of air pollution, and security of energy supply. Various views exist on whether these are genuine co-benefits, and the three issues are therefore discussed here.

The enhanced recovery of oil is sometimes called a co-benefit of CCS, as it contributes to security of energy supply by providing a greater use of the worldwide oil resources and reserves. However, EOR is not in need of supportive policies as the economic value of the enhanced oil would be a sufficient incentive for its realisation, especially at current world market oil prices.
Co-capture of CO_2 with other pollutants is sometimes mentioned as a possibility, but an unambiguous conclusion on its feasibility has not yet been reached. Even if the simultaneous capture of air pollutants and CO_2 would be technically and economically attractive, the pollutants would have to be stored simultaneously as well. In Zakkour *et al.* (2007), we already discuss the complexities of injecting a stream underground that contains impurities as a consequence of co-capture of pollutants and CO_2. Co-storage would have to be permitted, leading to legal barriers. In addition, the positive effects of the reduction of air pollutants at the smoke-stack would have to be weighed against the negative effects of additional coal mining as a consequence of the energy penalty. The air-pollution co-benefit at this point is not clear enough to argue for equalising CCS to renewable energy.

Security of energy supply is sometimes mentioned as a co-benefit of CCS. However, although CCS would allow for the continued use of coal in a carbon-constrained world, CCS *as such* does not diversify energy sources away from turbulent areas, and is here therefore not considered to serve that additional policy objective under current gas and CO_2 market conditions. In the case, however, that the market price of EUAs is high enough, the availability of CCS would lead to fewer coal-to-gas fuel switch as an option to reduce carbon emissions, and would therefore be beneficial for security of supply. This is illustrated in figure 7.2, which in a qualitative way outlines the dynamic between the gas and carbon price, and the impact on the security of energy supply argument. The figure shows that only at high gas and carbon prices, the security of energy supply co-benefit of CCS is valid. For conditions of low carbon prices or low gas prices, respectively coal without CCS or fuel switch to gas is preferred, and there is no contribution of CCS to security of energy supply.

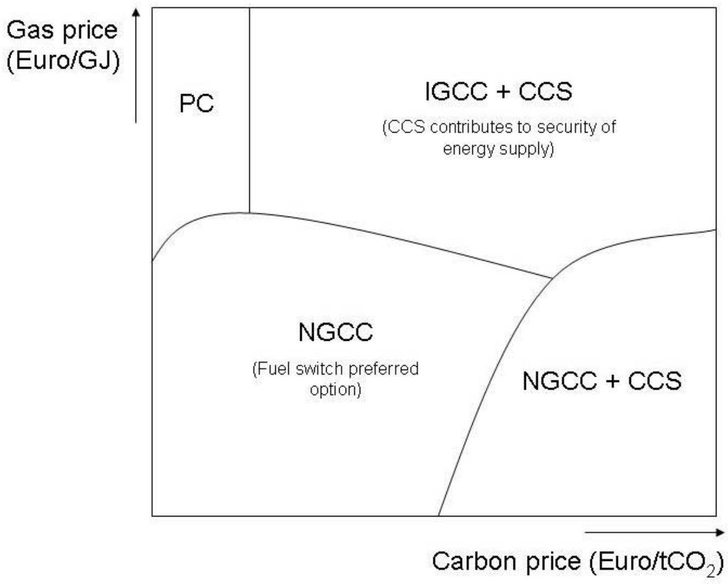

Figure 7.2 Qualitative estimate of contribution of CCS to security of energy supply depending on carbon and gas prices (based on Damen, 2007).

7.4 Impacts on the electricity market and innovation

The impact of the incentivising policies on innovation will differ. In general, further technological development and cost reduction may be discouraged if part of the costs of CCS is covered by public support. Consequently, a low-carbon portfolio standard and an obligation will provide incentives for CCS without spending a significant share of the government budget on subsidies. These instruments will pose the costs and risks related to CCS on the CCS operator, which is likely to advance innovation in particular in CO_2 capture technology. If on the contrary the government would pay a fixed subsidy for CCS, the incentive to further develop CCS technology will be weaker. This is true for investment support, a feed-in system, and a CO_2 price guarantee alike. The remaining incentive for further innovation under such instruments will depend on the level of support provided. It therefore seems more attractive to place the cost and risk burden on the CCS operator, as this is also the stakeholder that can influence the level of innovation in CCS.

However, there are electricity market impacts that need to be taken into account when considering putting the cost and risk burden solely on the CCS operators, particularly for power plants. As an obligation or portfolio standard lead to a rise of the cost of producing coal-based electricity, the CCS options will move down in the merit order of electricity generation options. If only economic reasons and kWh prices would prevail, it is unlikely that a costly option like CCS would be used much for base-load as there are cheaper ways of generating base-load power. However, it is technically challenging to switch a CO_2 capture, transport and storage chain on and off all the time. For peak-load prices, even, profit margins on coal-fired electricity would go down, unless the CCS-capacity is the price-setting option in the merit order and the extra cost can be accounted for by raising electricity prices. The lower economic attractiveness may decrease the use of coal or gas capacity with CCS, particularly if a high energy penalty drives the operating costs upwards. The consequence of an obligation to build CCS may therefore be that the CCS capacity may be built, but not used in the electricity mix, or only used during peak demand.

This may be an economic consideration, but it is often envisaged that CCS is a base-load option for technical reasons – the CO_2 transport network and storage operation are less costly if the

CO_2-stream is not turned on and off all the time, and the capture installation may not be as flexible as the power plant, thus posing technical challenges to operate the plant only at peak load, when electricity prices are high enough and CCS can be the price-setting option. Market conditions, however, may render CCS as a peak-load-only option, as CCS may be too expensive to be a base-load option. It is unclear how this apparent discrepancy between economic and technical reasons to apply CCS would play out under an obligation or a portfolio standard policy regime.

8. Public-private partnerships

8.1 Characterisation

Public-private partnerships (PPPs) are arrangements in which public and private parties cooperate to develop and operate infrastructure or other services with a public interest. Examples include for instance service contracts for road toll services, leasing agreements for public transport infrastructures, or schemes for realizing, financing and operating tunnels or waste water operations (see e.g. Renda and Schrefler, 2005a, b). PPPs present a number of advantages to realize infrastructures, including the possibility to raise financial resources from both the public and the private sector, and to combine public target setting with the operational efficiencies common to the private sector.

In the context of CO_2 capture and storage, PPPs might be valuable in particular for realizing enabling infrastructure for the transportation of CO_2, especially when large pipeline networks are involved. Contrary to individual pipelines, the extent of realizing entire networks could go beyond the interests and budgets of individual industries and it may thus represent a classical collective action problem. In addition, PPPs might play a role in realizing a number of demonstrations of CCS technologies, to which the European Commission referred in its Communication on ‘Sustainable Power Generation from Fossil Fuels’. Note that while PPP structures may prove valuable to realise CCS demonstrations and infrastructure, they have not ruled out a number of major problems in other infrastructural and environmental projects in the past. These include an underestimation of construction and equipments costs and construction delays, the overestimation of revenues, and negligence of issues related to social acceptance (Boeuf, 2003).

Public-private partnerships may take many forms. Apart from traditional procurement arrangements, commonly used forms are the so-called Build-Operate-Transfer (BOT) and Design-Build-Finance-Operate (DBFO) structures. In a BOT agreement, the facility is financed and owned by the public sector, while a private party is contracted to design, build and operate the facility for a defined period. Key driver for such a construction is the transfer of risks in design, construction and operation to the private sector. In a DBFO concession, a private party design, builds, finances, and operates a facility for a defined period. The facility is owned by the private sector during the contract period and recovers costs through public support. In a DBFO arrangement, (part of) the financial risk is taken on by the private party as well. The public sector has a modest role only. It will ultimately own the facility and possibly provide part of the funding.

The question as to whether and in which form PPPs might be instrumental in realizing large scale deployment of CCS will be addressed below.

8.2 Appropriate PPP arrangements for CCS

In general, a range of issues needs to be addressed before a proper structure for a public-private partnership can be elaborated, so as to minimize financial and societal risks during design, construction, and operation for the parties involved (EC, 2003). Key questions that need to be answered include: Who would be the appropriate party to settle on the layout of such a pipeline network? How would public and private finance be split? Who would operate the network? Who would own it? In the following these questions are addressed for PPP arrangements for possible CO_2 transport infrastructure.

Design – The design or layout of a CO_2 pipeline network could be done by a public authority or by (cooperating) private parties. Private parties can readily decide on 1:1 connections between capture and storage location that they plan themselves. However, it is uncertain if efficiency gains through large 'backbone' connections would materialize without public intervention. An additional argument for a public role in the layout of a network might be that economically disadvantaged or remote areas could be linked to an EU-wide pipeline network. Considering the Commission's ambition to realize an EU wide deployment of CCS, it has a stake in the design of a pipeline network.

Finance – A major issue structuring possible PPP arrangements for CCS projects will be whether there is a need for public funding. An analogue may be found in the financing of projects for the Trans-European Energy Networks (see Annex I). Community aid to these projects may be granted only to projects of 'common interest'. Such projects aim to promote effective operations, the development of the internal (energy) market, the rational use of energy resources, the development of less-favoured regions, the security of energy supply, and sustainable development in general (art. 2,3,4 and 6 Decision 1364/2006/EC). In deciding on the level of public funding two questions may be raised.

- A first legitimate question would be whether CCS operations in general or only a limited subset should be considered of common interest. A case can be made for qualifying all CCS operations as projects of common interest. Alternatively, one could argue that some operations serve the common interest in additional ways, e.g. by investments in economically weak regions or remote areas.
- A second question to address would be to what extent private parties would be able to finance the envisaged CCS demonstrations projects and the required pipeline infrastructure themselves. While the size of related investments may be substantial, the financial position of utilities and oil and gas industries might need to be considered in some detail before scarce public resources are granted. A generic answer could be provided for by looking into financial results of the relevant industrial sectors over the last five years. Upper limits for public support are suggested by analogues with projects of common interest in the Trans-European Energy Network. Community aid for these projects may not exceed 10% of total investment costs (art 5.3 Regulation 2236/95, amended by 1655/1999, 788/2004, 807/2004). The Community guidelines on State Aid for environmental protection (2001/C37/03) stipulate that for national aid to cogeneration or renewable energy a maximum of 40% of eligible costs applies.

Operation – pipeline infrastructure would be operated by a private entity, either the operator of the capture plant, the storage site, or a third independent party.

Ownership – In most types of PPP arrangements (traditional procurements, BOT agreements) the public sector owns the facility from the very beginning. In other types, such as DBFO concessions, ownership is with the private sector for the contract period, after which it is transferred to the public sector. This begs the question whether public ownership of a CO_2 pipeline network would be imperative. Alternatively, ownership could be with the private sector from the start of construction onward, or public assets could be sold to a private investor at some point during operation of the project.

In brief, private parties participating in a PPP for CCS pipeline infrastructure could take on responsibility for constructing, operating and co-funding the projects. A public party could play a role in laying out a CO_2 pipeline network across multiple borders of Member States in the EU, and provide some funding. Whether a network would need to be owned by the private or the public sector would need to be settled on.

8.3 Instruments for public funding

An important point to consider for any PPP arrangement is which form Community aid should take. Options for Community aid to projects for the Trans-European Energy Networks include the funding of preparatory studies; subsidies of the interest on loans, or of fees for guarantees for loans; direct grants; or participation in risk-capital. Private funding is encouraged in all cases.

Financial institutions as the European Investment Bank (EIB), and the European Bank for Reconstruction and Development (EBRD) for Eastern Europe, could assist in financing (parts of) a network. The EIB already finances, through loans up to 50% of the total cost, many projects in the Trans-European Energy Network (TEN). Furthermore, the EIB and the European Community are major financers of the European Investment Fund (providing 40 and 30% respectively), which provides guarantees for loans for TEN projects. The choice for any particular form of aid may be made on a case-by-case basis, depending on the viability of a particular project and the magnitude of required funding. Regional funds could also be an instrument, as CCS projects might be eligible.

9. Selection of CCS demonstration projects

9.1 The need for a diverse demonstration portfolio

In its Communication on Sustainable Power Generation from Fossil Fuels (EC, 2007), following recommendations of the EU Technology Platform on Zero-Emissions Power Plants, the European Commission indicated that by 2015 10 to 12 large-scale CCS demonstration projects should be realised. Various considerations could be taken into account when determining what kind of CCS projects should be implemented. A number of them are discussed here.

A number of large-scale CCS projects have already been proposed at this point (see Table 9.1), demonstrating considerable private sector interest in CCS. These CCS demonstration projects may go ahead either on a commercial basis in the case of very low or negative costs, given only the incentive provided by the ETS, or (if aid at Member State level is in accordance with Community State Aid rules) on the basis of incentives provided at Member State level. It is in this context that European action to promote demonstration should be considered. The question addressed is whether the park of demonstrations would meet the Community's aims for demonstration.

The Commission has made clear that project characteristics such as the portfolio of capture and storage technologies, geographical distribution, and costs are important in demonstrating CCS in Europe. For instance, it would be useful to have among the demonstrations combinations of various capture and storage activities, in order to gain experience in various types of combustion and capture combinations, as well as in various storage reservoirs. Also, by considering different storage reservoirs, the geographical distribution over the EU Member States might improve.
The starting point for any action would be an assessment of whether the current portfolio of bottom-up proposals of demonstration projects is sufficiently varied, and the extent to which it would be financed without Community intervention.

9.2 Required additions to the portfolio of proposed CCS demonstrations

A range of proposals for CO_2 capture demonstrations have been tabled so far (Table 9.1). The portfolio of projects includes a number of relatively small-scale projects focused on research into particular aspects of CCS that are already funded through research budgets or don't require additional policy, or where perhaps a government takes a commercial stake in the venture. Phase I of the Norwegian Mongstad project is a possible example: the details have yet to be finalised, but the current proposal is that a joint technology company will be set up involving both private parties and the Norwegian state, which will test a number of capture technologies on a pilot scale.

Table 9.1 Proposed large-scale commercial projects of CO_2 capture from power plants and storage (OECD/IEA, 2006)

Country	Power plant	Capacity (MWe)	Storage	Start	Capital	Project	Parties
Germany	IGCC	1000	Aquifer?	2011	€1.7bn	Siemens	Siemens
	PC + oxyfuel	300	Aquifer?	2012-2015	?	Schwarze Pumpe	Vattenfall
	IGCC	450	Aquifer?	2014	< €1bn	RWE	RWE
Netherlands	IGCC multifuel	1200	Gas field/EGR	2011	1 G€	Magnum	Nuon
Norway	NGCC	385	EOR?	2009	?	Kårstø	Naturkraft
	NGCC	860	EOR	2011	?	Tjeldbergodden	Shell, Statoil
Poland	IGCC	1000	Aquifer	2012	?	GE	GE, Polish utility
UK	IGCC	800	EOR?	2009	$1.5bn	Teeside	Progressive Energy
	IGCC	900	EOR?	2010	?	Hatfield	Powerfuel
	NG to H_2	350	EOR	2010	$0.6bn	Peterhead Miller	BP, SSE
	IGCC	450	Aquifer/gas field/EGR	2011	?	Killingholme	E.ON
	SCPC, retrofit	500	EOR/EGR?	2011	?	Ferrybridge	SSE
	SCPC	1000	EOR?	2016	£0.8bn	Tilbury	RWE

Careful observation of the list of proposed CCS demonstrations raises questions in the following fields:

- *Location of the plants* - Proposed capture operations are all in north-western Europe, plus one in Poland. This raises questions of geographical distribution of the benefits of such demonstrations. In order to realize EU-wide deployment of CCS, new proposals should preferably include operations in Southern, Eastern and Central Europe regions.
- *Capture technology* - Six of the proposed projects include capture from IGCC plants (so involving pre-combustion). Furthermore, there are two proposals for post-combustion from NGCC plants, and two for post-combustion from SCPC plants, one of which would be retrofitted. Oxy-fuel combustion is relatively immature, and is foreseen in one project, first as a demonstration at 30 MW, and subsequently by up-scaling. The capture technology portfolio seems sufficiently diverse.

In addition, the proposed demonstrations would need to be evaluated with respect to the storage reservoir. Here, the task is more difficult as in many of the demonstrations no announcement has been made of the storage reservoir. We briefly discuss what is know or suspected of the location and characteristics of the CO_2 storage reservoirs.

- *Location of the reservoir* - So far, storage operations (as well as estimated storage potential) are concentrated in the countries around the North Sea. If CCS is to be an affordable mitigation option in other parts of Europe as well, it will be essential that suitable storage locations are identified and assessed in those regions. It could be considered to prioritise CCS demonstrations in southern, central and eastern Europe.
- *Nature of the storage reservoir* – Injection of CO_2 is currently done or planned at a large scale in a number of saline reservoirs, as well as in several enhanced hydrocarbon recovery operations, particularly EGR. EOR has been announced in several of the projects in Table 9.1, but to date no experience with it exists in Europe. So far, no projects involving depleted oil and gas fields or ECBM have been announced. A case can be therefore be made to actively pursue the testing of these reservoirs for CCS.
- *On or offshore location of the reservoir* – The risks that storage of CO_2 imposes on humans and the environment will most likely be smaller in offshore than in onshore locations. Primarily including offshore locations may therefore be recommended until greater confidence among the public at large in CCS has been achieved. Focussing storage of CO_2 primarily in offshore locations, however, also has disadvantages. More familiarity with the behaviour of both CO_2 in onshore locations and impacts such operations have on public perception would also provide useful insights. In addition, only allowing offshore locations may give the impression that confidence CCS is low. Keeping a balance between onshore and offshore reservoirs is therefore recommendable.

10. Assessment of CCS policy options

10.1 Timing of policies and technological maturity

A number of incentivising policies may be considered on top of the ETS to stimulate the introduction and diffusion of CCS technologies. We discussed the characteristics of various instruments, including a low-carbon portfolio standard with tradable certificates, regulation of CCS, and other public support instruments that would most likely be applied on the Member-State level. Each of these instruments has its own characteristics and may be deployed in one or various innovation phases (Table 10.1).

The table attempts to structurally evaluate how combinations of policies could provide the most effective incentive to further deployment of CCS technologies. At an early stage, additional policies may be confined to public financial support mechanisms to remove some of the financial risks related to early demonstration, and reduce costs through economies-of-scale and learning-by-doing.

Once the first generation of CCS operations has been realized, diffusion of CCS may be promoted through more structural policies that contribute to greater awareness of CCS as an abatement option. This may be done through a financial support instrument on the one hand, i.e. a feed-in system or a CO_2 price guarantee, but may gradually be replaced by a more restrictive form of policy; a low-carbon portfolio standard or a CCS obligation. As soon as CCS is fully commercial and ETS-prices are high enough, no financial support will be needed. Further diffusion of the option can then be realized by introduction or maintenance of a portfolio standard or an obligation.

Table 10.1 Possible timing of incentivising policies for CCS technologies in three innovation phases. Some instruments may be complementary, but most are not.

Projected time horizon	Demonstration *2010-2020*	Up-scaling *2015-2030*	Commercialisation *2025-2040 →*
CCS in ETS (weak incentive)	Yes	Yes	Yes
CCS in ETS (strong incentive)	Yes	Yes	Yes
Investment subsidy	Yes	No	No
Feed-in subsidy	Yes	Yes	No
CO_2 price guarantee	Yes	Yes	No
Portfolio standard + certificates	No	Yes	Yes
CCS obligation	No	Yes	Yes

10.2 Criteria assessment

A criteria assessment of the policy options discussed in sections 4-6 is based on the following criteria:

1. Effectiveness: The extent to which options can be expected to achieve the objectives of the flanking policy.
2. Risk and cost burden: The extent to which financial risk of CCS projects is born by those who are informed best on the costs: the CCS operators.
3. Consistency: The extent to which options are likely to limit trade-offs across the economic, social, and environmental domain. This includes the consistency with the ETS for the other options.
4. Feasibility: The extent to which the option can count on support from stakeholder groups (such as NGOs, business practices, etc). The assessment of this criterion focuses on concerns of the NGO community.

In further discussions, we can refine the criteria, and expand or decrease the number of policy options. For instance, one might consider categorising policy options into subgroups, as comparing an instrument such as an EU-wide CCS obligation is in many ways different from the case when one or two Member States would implement investment subsidies on CCS.

The results of the multi-criteria analysis are summarised in Table 10.2.

Table 10.2: Multi-criteria analysis of policy options. For a legend, see below the table.

	Criteria			
Options	Effectiveness	Risk and cost burden	Consistency	Feasibility
CCS in ETS (weak incentive)	-	0	+	+
CCS in ETS (strong incentive)	+	+	+	+/-
Investment support	+	-	0	-
Feed-in subsidies	+	-	0	-
CO_2 price guarantee	+	-	0	-
Low-carbon portfolio standard	+	+	0/-	+/-
CCS obligation	+	+	0/-	+

+ Positive result on criterion
- Negative result on criterion
0 Positive nor negative result on criterion (indifferent)
+/0/- Result on criterion depends on details of implementation (e.g. on allocation in ETS)

In terms of effectiveness, the "weak" ETS scenario, with a price signal of around 20-30 €/tCO2 in 2030, would have a negative result for CCS deployment, but the "strong" ETS, which would yield EUA prices of around 90€/tCO_2 would provide sufficient incentive to realize structural deployment of large-scale CCS. The dynamic efficiency of the scheme - i.e. the extent to which innovation and technological change is stimulated - is not guaranteedin both cases. The other instruments are all designed to increase that effectiveness for the case of CCS.

Scores on the "cost and risk burden" criterion vary across the policy options. In general, the policies we identified as Member State policies pose a higher risk and cost burden on government. We have assessed this as negative for two general reasons: information asymmetry, which decreases cost effectiveness of policies, and incentives for cost reduction. If the level of subsidy is determined by a government, which is the case for investment subsidies, CO_2 price guarantees or feed-in subsidies, it is likely that the government will pay more than strictly necessary to cover the incremental CCS costs, because the level of information of governments is lower than the information that the CCS operators have. This information asymmetry may then decrease the cost effectiveness of the policy. In the case of the obligation for CCS or a low-carbon portfolio standard, the cost and risks will be placed on the CCS operators. Not only will this be good for cost-effectiveness as not more funding will be placed on CCS than necessary, also the CCS operators will have an incentive to improve CCS technology in order to keep the costs low.
Consistency relates to the level of interaction with the ETS (see section 7.1). All options will interact with the ETS, and will depress EUA prices. However, this can be corrected if the overall (or MS-specific) number of allocated allowances is corrected for the market distortion. The EU level policies will likely have a greater scope and would therefore have a larger impact on the ETS than the policies of single Member States. In addition, the difficulty in correcting the cap to minimise the ETS efficiency effects will be different at the Member State level than for the EU level.

For the feasibility criterion, the interaction with renewables may play a role, particularly in the perception of NGOs. It can be argued that on the EU level, obligation and portfolio instruments can be linked to renewables implementation levels. On the MS level, where a range of greenhouse gas abatement technologies compete for limited funds, this problem will be more severe. It should be noted that the views of the environmental NGO community are represented here. For the business sector, the feasibility would probably be higher for the MS policies and lower for an EU-wide obligation.

11. Conclusion

Although the EU ETS is the most cost-effective instrument to reduce greenhouse gas emissions, there are substantial questions as to whether its weak scenario will lead to sufficient deployment of CCS in the short term because of low incentive levels and the "innovation market failure". If the "strong" ETS scenario would be politically unfeasible, additional instruments on the EU and the Member State level can be effective in correcting this failure. These instruments have been reviewed, discussed and weighed in this document.

While Member State policies are likely to have less interaction with the ETS, and will be more consistent with other policies, they are less attractive from the perspective of environmental organisations as they are more likely to displace resources for other mitigation options. In addition, those policies tend to pose an important part of the financial risk of CCS projects with national governments, which have the lowest insight in the actual costs and risks of CCS. Overall, it seems that EU wide structural policies score higher on the identified criteria.

The use of public-private partnerships may be attractive in the case that a CO_2 transport infrastructure would need to be set up, and where central coordination leads to system efficiency gains. Public support to required investments is probably most valuable if done early in the deployment period of CCS. However, more detailed economic research is needed before such support can be justified.

It seems likely that the target of 10-12 demonstrations by 2015 is within reach, given the number of proposals in the EU and the willingness of Member States to dedicate funds to their implementation. However, rules on State Aid need to be revised, and the desirability of more structural incentives at the MS level, possibly in addition even to EU level measures, should be closely examined for undesired interactions.

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Appendix A Financing Trans-European Energy Networks

Guidelines for Trans-European energy networks have been laid down in Decision 1364/2006/EC of the European Parliament and the Council. The Guidelines cover objectives, priorities and broad lines of action by the Community in respect of trans-European energy networks. Article 2 regulates that the '*Community will promote 'the interconnection, interoperability and development of trans-European energy networks and access to such networks*.'. Article 5 states that to this end projects will be identified that are of '*common interest'*, as well as '*priority projects, including those of European interest*'. In addition, *'a more favourable context for the development of those networks will be created'*. Article 12 stipulates that '*When projects are considered, their effects on competition and on security of supply shall be taken into account. Private financing or financing by the economic operators concerned shall be the main source of financing and shall be encouraged. Any competitive distortion between market operators shall be avoided, in accordance with the provisions of the Treaty.'*
Council regulation 2236/95, amended by regulations 1655/1999, 788/2004 and 807/2004, defines the conditions and procedures for the granting of Community financial aid in the field of trans-European networks. Article 4(1) requires that *Community aid for projects may take one or several of the following forms:*

a. co-financing of studies related to projects, including preparatory, feasibility and evaluation studies…;
b. subsidies of the interest on loans granted by the European Investment Bank or other public or private financial bodies…;
c. contributions towards fees for guarantees for loans from the European investment Fund or other financial institutions…;
d. direct grants to investments in duly justified cases;
e. risk-capital participation for investment funds or comparable financial undertakings…[which] shall not exceed 1 % of the budgetary resources…

Furthermore, Article 4(4) states that *The Commission shall specifically promote recourse to private sources of financing for projects funded under this Regulation where the multiplier effect of Community financial instruments can be maximised in public-private partnerships…*

An important provision is laid down in Article 5(3), which specifies that *Regardless of the form of intervention chosen, the total amount of Community aid under this Regulation shall not exceed 10% of the total investment cost. However, the total amount of Community aid may exceptionally reach 20%...[including for] projects concerning satellite positioning and navigation systems…, priority projects on the energy networks, [and] sections of the projects of European interest…'*.

Community aid may be granted only to projects of common interest, according to Article 2 of this regulation. Projects of common interest are defined by articles 2, 3, 4 and 6 of Decision 1364/2006/EC. TEN projects of common interest aim to improve essential equipment or installations in electricity and gas networks. They should promote the effective operations and development of the internal (energy) market and the rational use of energy resources; the development of less-favoured regions; the security of energy supply; and a sustainable development in general. More specifically, such projects should solve problems of bottlenecks, congestion and missing links, establish energy networks in isolated regions, facilitate the development of renewable energy production, and/or ensure interoperability of networks. In addition, projects of common interest must display potential economic viability.