

The European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP)

Strategic Deployment Document

Key recommendations

Experts agree that CO₂ capture and storage technology (CCS), together with improved energy conversion efficiency, is a near-term solution to reducing CO₂ emissions from fossil fuel power generation on a *massive* scale. Its *immediate* deployment is therefore vital if we are to avoid the catastrophic consequences of climate change we are facing today.

Yet despite most of the technology elements being available, CCS is still not deployed for two key reasons:

1. The costs and risks still outweigh the commercial benefits
2. The regulatory framework for CO₂ storage is not sufficiently defined.

The Strategic Research Agenda therefore describes a collaborative programme of technology development for reducing the costs and risks of deployment; while the Strategic Deployment Document outlines how we can accelerate the market to achieve **zero emission power production by 2020**. To this end, the Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP) recommends:

1. *Kick-starting the CO₂ value chain with urgent short- and long-term commercial incentives:*

- By 2007, clarify the conditions under which the geological storage of CO₂ qualifies for the EU Emissions Trading Scheme and other incentive mechanisms
- By 2007, clarify CCS status under European Union guidelines for State Aid
- By 2007, create early mover funding mechanisms to support the development of 10-12 large-scale CCS projects which demonstrate a diverse range of infrastructure, technologies, fuels and storage locations.
- Establish long-term, sustainable mechanisms to supplement EU ETS, informed by experience gained in demonstration projects.

2. *Establishing a regulatory framework for the geological storage of CO₂:*

- By 2007, amend existing EU legislation (concerning waste and water) in order to clarify the conditions under which CO₂ is stored underground
- By 2008, implement new EU guidelines for Member States permitting geological storage projects (including risk management, site selection, operation, monitoring, reporting, verification, closure and post-closure).

3. *Gaining public support via a comprehensive public information campaign:*

- Generic EU-wide outreach via multi-media (TV, internet, print)
- Local, focused outreach in support of early mover CCS projects.

4. *Establishing robust RD&D funding under the FP7 and national programmes (see Strategic Research Agenda):*

- Improve energy conversion efficiency, reduce cost and reduce scale-up risk of CO₂ capture technology
- Undertake EU-wide mapping of large CO₂ sources and geological storage
- By 2008, establish a Joint Technology Initiative as part of a portfolio of mechanisms for maximising European co-operation.

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Foreword

Following developments in clean power generation and the priority given to ‘zero emission power generation’ in the Sixth Framework Programme (FP6), industrial stakeholders and the research community had several meetings in 2004 which resulted in the creation of a Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP).

Its brief? To identify and remove the barriers to creating highly efficient power plants with zero emissions, which would drastically reduce the environmental impact of fossil fuel use, particularly coal.

In the autumn of 2005, the Advisory Council and Coordination Group - along with the Working Groups and Mirror Group - were also established. The Technology Platform was officially launched in December and a Vision Paper was published the following May.

The Coordination Group is responsible for the Strategic Research Agenda (SRA) and the Strategic Deployment Document (SDD), and overseeing the five Working Groups. These comprise experts from industry, research and NGO¹ communities and are divided into the following areas:

- i) Power Plant and CO₂ Capture Technologies
- ii) CO₂ Storage and Use
- iii) Infrastructure and Environment
- iv) Market, Regulations and Policy
- v) Communications and Public Acceptance.

Each Working Group has contributed to the SRA and SDD with a view to realising our Vision:

To enable European fossil fuel power plants to have zero CO₂ emissions by 2020.

N.B. As the Strategic Research Agenda and Strategic Deployment Document are aimed at different audiences, some of the text is duplicated in order to maintain consistency.

¹ Non-governmental organisation

1. CO₂ capture and storage (CCS) : its time has come

Let no one be in any doubt – climate change is happening and it is happening at an alarming rate: sea levels are rising, oceans are acidifying and temperatures continue to rise. Indeed, if we do not succeed in keeping the average global temperature increase below 2°C (relative to pre-industrial level), the consequences – even as early as 2050 - could be grave. Every region in the world will be affected, including Europe.

The solution is, of course, unanimous: reduce greenhouse gas (GHG) emissions - especially CO₂ - and by 50%-80% by 2050, according to the IPCC². This is confirmed by the EU Green Paper on energy³. Yet with world energy demand predicted to increase by 60% between 2002 and 2030⁴, and renewable energies to make up only a third⁵ of the energy mix by 2050, the immensity of the challenge becomes clear. Clearly, fossil fuels - coal, oil, gas - must remain the primary energy resource for a long time to come.

CCS could reduce CO₂ emissions in the EU by 56% by 2050

A portfolio of solutions is therefore essential, including renewable energies, improved energy efficiency and nuclear power. But that still leaves an enormous gap between global energy demand and their potential to reduce CO₂ emissions on the massive scale required. To these, we must therefore add CO₂ capture and storage (CCS) technology.

As a safe and efficient method of capturing and storing millions of tonnes of CO₂ emissions underground for thousands of years, CCS represents the bridge to a sustainable energy system. Indeed, if deployed to its full potential, it could reduce CO₂ emissions in the EU by 56% by 2050, compared to today⁶.

That's because power plants equipped with this technology will emit less than 10% of their produced CO₂. As such, they can not only act as base load (i.e. providing a steady flow of power, regardless of grid demand), but as back-up for intermittent renewable energy. When used with pre-combustion CO₂ capture technology, they can even produce clean hydrogen as a by-product, which can then be used for either electricity or as a fuel.

Zero emissions from European fossil fuel power plants by 2020

To this end, The European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP) was established in 2005. Its goal: to enable zero CO₂ emissions from European fossil fuel power plants by 2020. This will involve implementing a complete CO₂ value chain - from the capture of CO₂ at large emission sources, to its transportation to storage sites, to its storage in underground geological formations.

² Intergovernmental Panel on Climate Change, "Third Assessment Report - Climate Change 2001", Cambridge University Press, 2001

³ Commission of the European Communities, *Green Paper: A European Strategy for Sustainable, Competitive and Secure Energy*, 8 March 2006, Brussels {SEC(2006)317}

⁴ The IEA World Energy Outlook 2005

⁵ Shell's Long-Term Energy Scenarios

⁶ Bellona Paper, August 2006, http://bellona.no/artikler/notater_stangeland_solomon

It is an ambitious goal, but an entirely feasible one. After all, the technology has been practised over decades – CO₂ has been separated from gaseous streams for several years in many industries. It has also been used and stored extensively in Enhanced Oil Recovery (EOR). This is borne out by the number of CO₂ capture and storage projects already planned or taking place throughout the world today, with Europe a leader in CCS technology.

However, it is a precarious lead and current projects do not demonstrate its full potential. Indeed, substantial R&D is required,⁷ not only to reduce the cost and increase the efficiency of CO₂ capture technologies, but demonstrate the safety and feasibility of large-scale CO₂ geological storage. There is certainly no shortage of suitable storage sites – on land or offshore – and we should exploit as broad a range of configurations as possible.

We therefore need to initiate the immediate large-scale deployment of CCS, starting with 10-12⁸ industrial-scale demonstration projects, Europe-wide.

These should be ready for commissioning by 2015 *at the latest* – but many will be ready before this date. At this stage, it is imperative that we ‘learn by doing’ - in parallel with R&D projects into more advanced, innovative concepts – in order to accelerate technology development.

A co-ordinated effort is essential

This will require substantial investment, a burden which industry cannot take on alone, with each full-scale project costing as much as €500 - €1,000 million apiece and all the risks such a commitment involves. Indeed, it is why such a step change has not already happened.

It means taking an integrated approach, with the cooperation of both industry and government – at national and EU levels - and a combination of funding sources. It also means kick-starting the CO₂ value chain with a range of fiscal incentives and a clear regulatory framework that goes beyond 2012. Only then will investors have the long-term certainty they require to commit their funds and resources.

European early mover funding mechanisms will be key to achieving this objective.

CCS complements, not replaces, renewable energy

Yet all will be to no avail without the approval and consent of regulators and the public. We therefore also need to initiate an ongoing dialogue which cultivates the understanding that CCS is not only safe and reliable, but a vital and complementary solution to our longer-term goal for renewable energy. As such, ZEP is a process that must work in concert with the other EU efforts, such as the Hydrogen and Fuel Cell Technology Platform and ECCP⁹ initiatives.

This is a challenge we can most certainly meet - but only if we begin that process *now*. Europe can afford to wait no longer.

⁷ See Strategic Research Agenda (SRA)

⁸ These should demonstrate a diverse range of infrastructure, technologies, fuels and storage locations

⁹ European Climate Change Programme

The cost of *not* reducing CO₂ emissions...

While we can broadly estimate the investment required to implement CCS - currently €500 - €1,000m per project - this is expected to fall, as we gain experience and advance technological development. Any estimation of costs, however, must also include that of *not* implementing it, i.e. dealing with the tangible effects of climate change from unchecked CO₂ emissions.

According to the latest Synthesis Report published by the Intergovernmental Panel on Climate Change - "Climate Change 2001" - GHG emissions have already made the world 0.6°C warmer and, if no action is taken, there will be an increase of between 1.4 and 5.8° by 2100. Climate change models established by the IPCC indicate that *if we fail to keep below 2°*, dramatic climate effects will occur, including:

- Increased flood, landslide, avalanche and mudslide damage
- Increased risks of infectious diseases epidemics
- Increased property and infrastructure losses
- Increased damage to coastal ecosystems
- Decreased water resource quantity and quality
- Increased risk of forest fire

The IPCC has confirmed that CCS is one of the key technologies required to reduce CO₂ emissions.

2. Proven technology...on a small-scale

What is CO₂ capture?

The purpose of CO₂ capture (when efficiently integrated into a steam or gas & steam power plant) is to produce a concentrated stream that can be easily transported to a CO₂ storage site – a deep underground geological formation.

CO₂ capture applies mainly to large power plants fired with hard coal, lignite, natural gas¹⁰. It also applies to large, single point emission processes such as refineries, cement plants, chemical plants and steel mills that can use the same or similar technology - as well as transport infrastructure – thus increasing the efficiency of the entire CCS system. It can even apply to biomass, paving the way for net *negative* emissions, because biomass also draws CO₂ down from the atmosphere whilst it is growing.

There are three main technology options under development:

- **Post-combustion** systems separate CO₂ from the flue gases produced by combustion of a primary fuel (coal, natural gas, oil or biomass) in air. Can be retrofitted to existing power plants, as well as new builds.
- **Pre-combustion** systems process the primary fuel (natural gas or synthetic gas from coal) in a shift reaction to produce streams of CO₂ and hydrogen which can be separated. *The hydrogen can then be used for either electricity or as a fuel - accelerating the transition to a hydrogen economy.*
- **Oxy-fuel combustion** systems use oxygen instead of air for combustion, producing a flue gas that is mainly H₂O and CO₂, which can be easily captured after the water vapour is condensed.

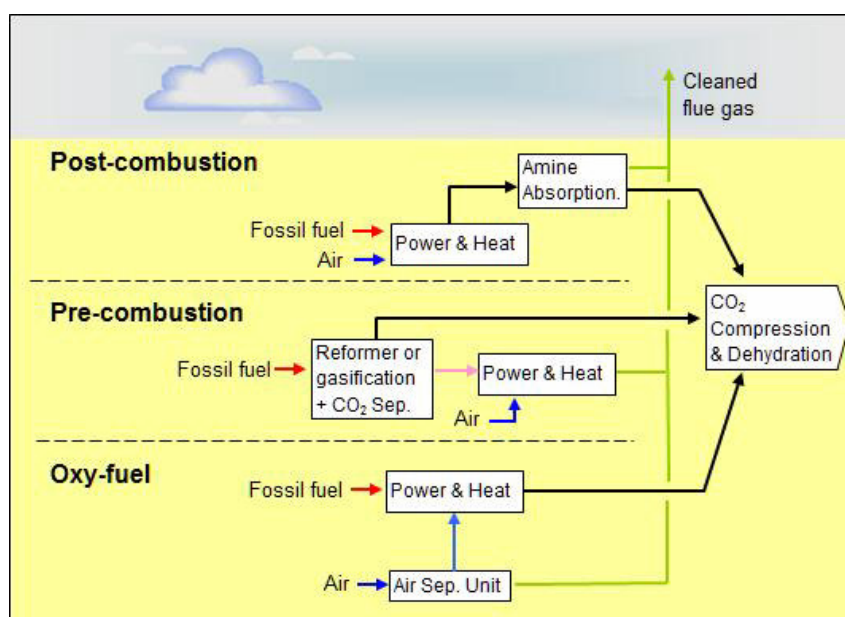


Fig. 1 - Main technology options for CO₂ capture from power plants

¹⁰ Although several CO₂ capture technology developments for coal also apply to oil, it is not considered an economically preferred fuel for future power generation (except for niche applications).

In principle, all can be applied using commercially available equipment, with varying degrees of system modification. However, a significant scale-up will be required - 20-50 times - no power plant in the world today being equipped with capture technology on such a scale.

Minimising the energy requirements for capture and improving the efficiency of energy conversion processes will also continue to be high priorities in order to reduce costs and the consumption of primary energy sources (which CO₂ capture increases).

This must be urgently addressed through the implementation of industrial-scale demonstration projects and associated research projects, with all technologies given equal weighting (until clear conclusions have been established).

The early standardisation of 'capture-ready' power plants is also essential if we are to meet escalating demand for generating and manufacturing capacity in Europe as quickly and efficiently as possible.

CO₂ - a commodity or by-product, but *not* a waste

The monitoring, risk and legal aspects associated with CO₂ capture also appear to present no significant new challenges, as they can easily be added to well-established health, safety and environmental control regulations within related hydrocarbon industries.

Indeed, CO₂ should be considered as a commodity or by-product, but not as a waste, as this would entail a whole range of legal ramifications. CO₂ has been handled successfully for decades and any risks implied with its use can be – and have been - effectively managed or mitigated. In fact, many existing post-combustion capture plants already produce high purity CO₂ for use in the food industry. It also has the potential to be used in a host of industrial applications as well, e.g. in chemistry, materials etc.

No shortage of CO₂ storage options anticipated

The existence of suitable, quality, geological storage capacity is clearly a prerequisite for the application of CCS in the million to billion tonnes range and there is no shortage of suitable storage options available. How much of that potential can actually be utilised will be closely linked to the research and demonstration activities carried out over the next few years.

CO₂ can be stored using a variety of different mechanisms (single free phase, dissolved in water, absorbed on surfaces, trapped by relative permeability and fixed in minerals), with several options for underground storage. (Storage in the deep oceans is not considered an option for Europe.)

The relative order-of-magnitude potential of the various storage methods may be expressed, very simply, as follows:

- 1000 Deep saline aquifer storage (porous rocks)
- 100 Oil/gas field use and storage
- 10 Deep unmineable coal bed use and storage
- 1 Mineral sequestration

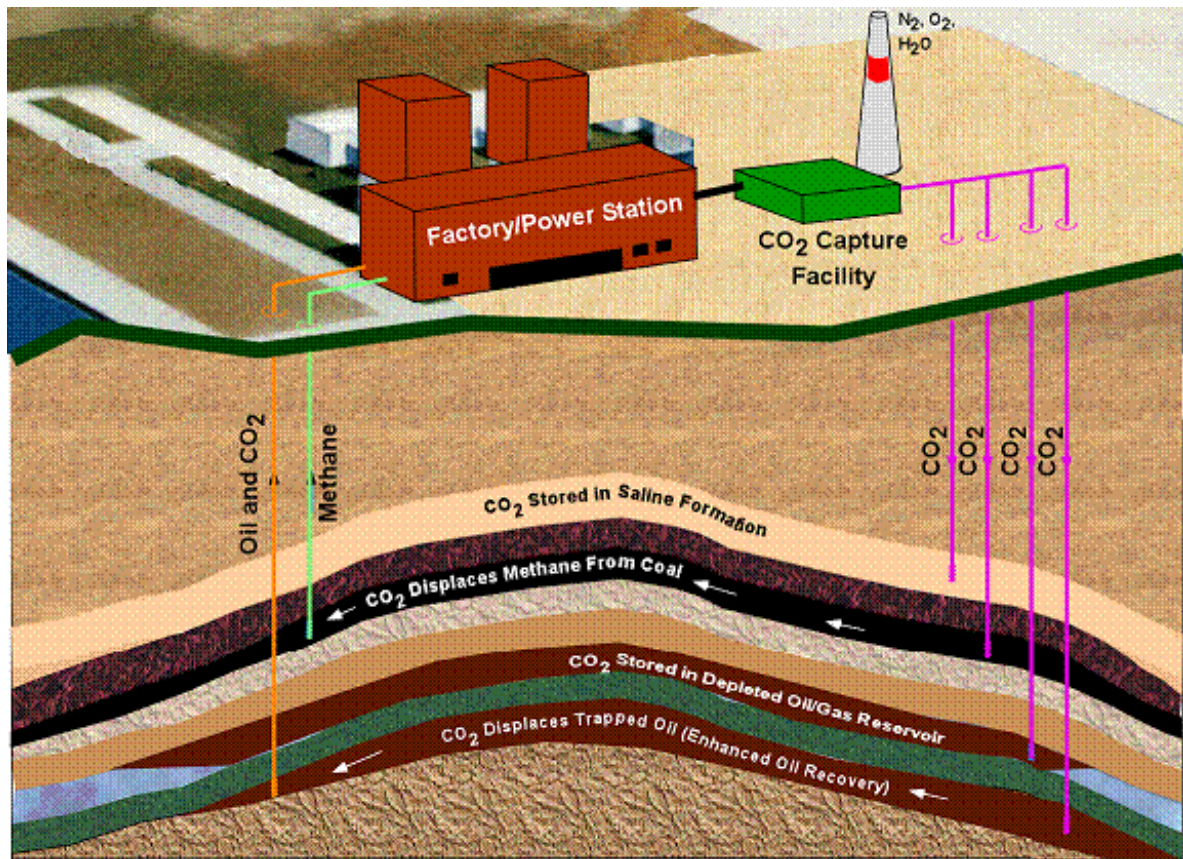


Fig. 2 shows the wide variety of options for CO₂ underground storage available

Deep saline aquifers (or formations) have the largest storage potential globally, but are the least well explored and researched as, up till now, they have not had any economic potential. We therefore need to build a more comprehensive dataset of their geological characteristics through considerable research and larger-scale injection projects.

For example, the Utsira is a large, regional deep saline aquifer which has been used by Statoil since 1996 to store CO₂ removed from gas production. At over 400 km by 50-100 km, it is over 26,000 km² and capable of storing up to 600 billion tonnes of CO₂¹¹. To put this into perspective, this is equivalent to all the CO₂ emissions from all the power stations in Europe for the next 600 years!

The GESTCO and GeoCapacity¹² projects (under FP5 and FP6) have already begun the task of identifying deep saline aquifers that are accessible to large CO₂ emissions sources, both on land and close to the shore.

Although we believe these formations hold the most promise, we need to demonstrate storage in a variety of types and settings in order to realise the full potential of this medium. It means exploring as many countries as possible, especially those with few hydrocarbon deposits and less knowledge of deep geology, in order to include them in our evaluations.

¹¹ See IEA Greenhouse gas website: <http://www.ieagreen.org.uk> and Sleipner CO₂ project reports

¹² Both GESTCO and GeoCapacity are assessing the capacity for CO₂ geological storage in Europe

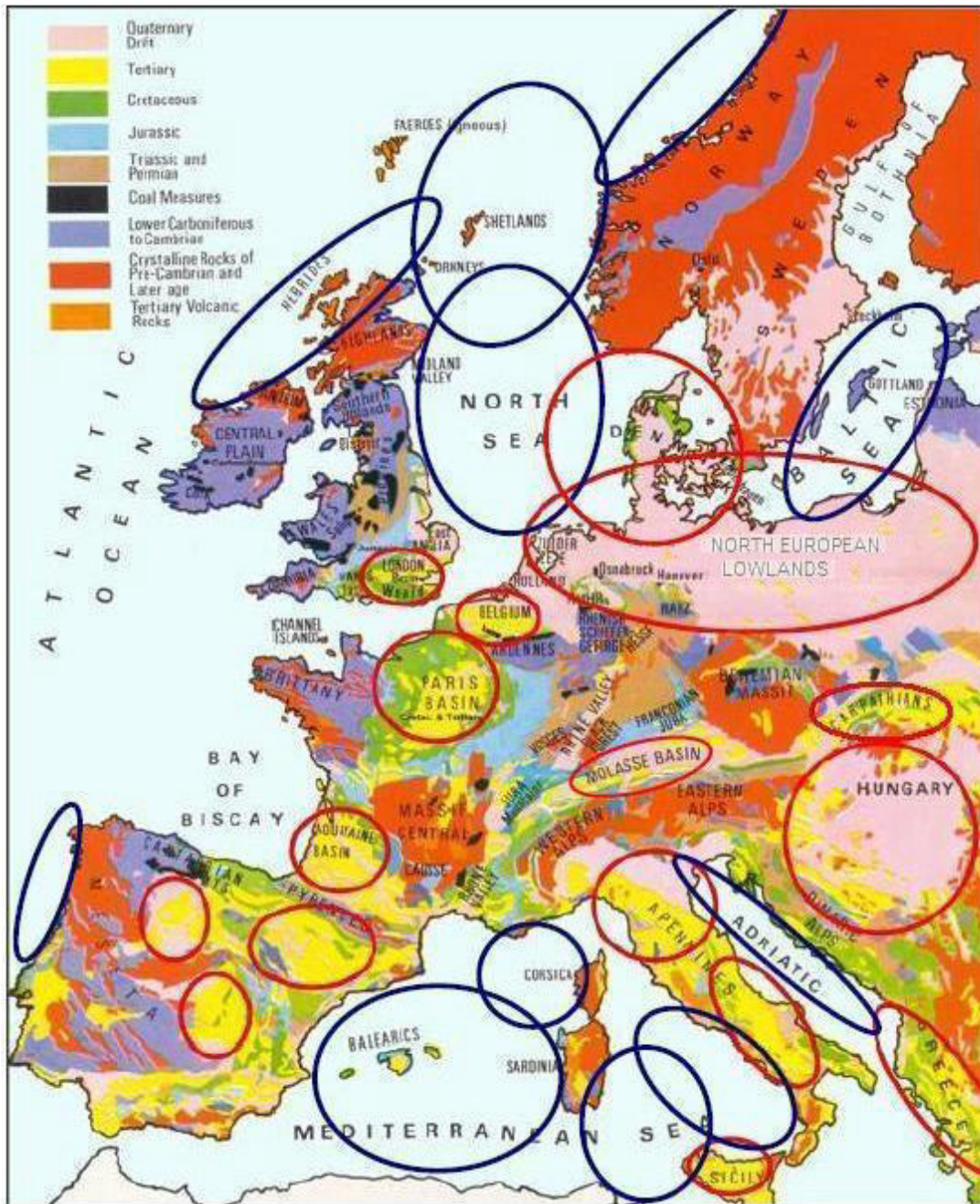


Fig. 3 shows major on- and offshore sedimentary basins in Europe which are possible storage sites. Cost analyses must be performed to identify the most cost-effective. Modified after Kirkaldy, 1967

Using CO₂ for **Enhanced Oil Recovery (EOR)** is the most attractive option for early ZEP deployment: not only is the geology well understood and existing infrastructure potentially recyclable, there is even the opportunity to increase revenue from the additional oil production. Indeed, when used in this way, CCS could contribute to improved energy security for Europe by increasing oil production rates, as well as the overall recovery of reserves.

EOR may also be combined with the storage of even more CO₂ after the commercial life of the fields ends. The best opportunities for EOR in Europe are in the North Sea and the use of anthropogenic CO₂ for this purpose would constitute a normal hydrocarbon operation.

Although at the experimental stages, *Enhanced Gas Recovery* (EGR) is also a promising technology for CCS that would further increase European fossil fuel resources. *Depleted oil and gas fields*, too, are attractive because the geology is well understood and the existing infrastructure recyclable.

Enhanced Coalbed Methane (ECBM) has similar potential and the geological aspects of the main European coal basins are, in most cases, quite well-known. While such storage options are seen as small-scale compared to deep saline aquifers, many Member States have coal basins on which operations could be carried out, potentially enhancing the production of methane gas.

Other options, although limited, include *deep unmineable coal beds*, which may become quite important in some coal provinces. *Mineral sequestration*, which consists of trapping CO₂ by reacting with basic rock material, is still at an exploratory stage.

What is clear, however, is that CO₂ storage needs to be demonstrated in a variety of large-scale settings in order to convince operators, academia, regulators and - most critically - the public that it is both safe and desirable.

The first time this will be tested will be when energy companies apply for national permits to build CCS, estimated to be 2010-15.

CCS technology - proven over decades

The good news is that technologies required for CO₂ capture and storage are already well proven - especially in EOR where it is currently in operation in the US, Canada, Brazil, Turkey, Hungary, Croatia and elsewhere. There are over 70 projects in the US alone and it is estimated that over 500 million tonnes of CO₂ has already been stored in US oil fields in the Permian basin.

Most of the tools and methods which will be employed for CCS have therefore been used in the oil and gas industries for decades. This includes monitoring tools for verifying the behaviour of fluid underground and established public standards and regulations for operation procedures. However, some elements such as storage site monitoring, CO₂ migrations, long-term safety and integrity of wells need to be tested more in this context.

It must be remembered that CO₂ is found regularly in hydrocarbon reservoirs worldwide - some gas fields have almost 100% CO₂. Its behaviour underground can therefore be studied in fields where CO₂ has been in place for millions of years. Naturally occurring CO₂ in volcanic areas also offers opportunities to study how leaking CO₂ could eventually affect animals and plants on the surface. Our experience is, of course, primarily with hydrocarbons that are recovered using CO₂, which in some ways behaves differently.

Different capture technologies also have different CO₂ compositions, which must be considered when developing transportation and choosing storage sites. However, these differences can be verified by R&D programmes to improve modelling tools and experience gained from large-scale demonstration projects.

A great deal of research has already been carried out in FP5 and FP6 integrated and Specific Targeted Research Projects (STREP) on various sites throughout Europe. Involving a Europe-wide group of geo-scientific institutes, experienced oil and gas companies - with additional funding from several national authorities – they have included site characterisations and capacity assessments etc, without actually injecting CO₂. One important outcome has been the first draft of a Best Practice Manual for CO₂ storage.

CO₂ storage is already a fact

It is now essential that we apply that research in the marketplace, in parallel with associated R&D projects. Indeed, a number of larger-scale demonstrations of CO₂ geological storage are already underway:

- Permian Basin, US - 35 mega tonnes (Mt)/year, starting 1972; over 70 projects with a total of 500 Mt/stored
- Sleipner, Norway- 1 Mt/year in the North Sea since 1996
- Weyburn, Saskatchewan, Canada - CO₂-EOR, 2 Mt/y since 2000
- K12B, Netherlands - CO₂-EGR, some hundred kilo tonnes (Kt)/year, in the North Sea since 2004
- In Salah, Algeria - 1.2 Mt/y, since 2004
- Frio Brine, Texas USA – 3.0 Kt over a short period in 2005 and 2006
- Nagaoka, Japan - 10.4 Kt, over 1.5 years, 2004-5
- Ketzin, near Berlin, Germany - some 60Kt over a few years (starting 2006)
- Snøhvit, Norwegian Sea - 0.75 Mt/y, starting 2007
- Gorgon, Australia, 129Mt over the life of the project, starting 2008-2010

Some of these are “field laboratories”, with the rest built on an industrial-scale, operated by oil and gas companies as commercial enterprises. As demonstrations or commercial projects using a variety of geology we will be able to learn a great deal from them, but research on a far larger scale is now required.

CCS projects are also happening

The number of combined CO₂ capture and storage projects in Europe which have been announced, or are underway, also demonstrates the confidence industry has in this technology, including:

- Shell and Statoil are planning a new 860MW natural gas fired power plant at Tjeldbergodden, Norway with CO₂ capture. CO₂ will be transported to the Draugen and Heidrun oil field and used for EOR, starting 2011.
- CO₂ capture is planned at a new natural gas fired power plant at Kårstø, Norway for use in EOR, starting 2009.

- CASTOR project under FP6: a pilot plant for CO₂ capture at the coal-fired power plant in Esbjerg, Denmark has been built by international partners – about 8 Kt/year. This is an experimental operation for post-combustion amine capture.
- BP, Southern & Scottish Energy and General Electric are engineering an industrial-scale (350MW) ZEP at Peterhead, with the CO₂ used for EOR in the Miller oil field, Scotland – storing 1.8 Mt/year CO₂, starting 2010.
- Vattenfall is building a 30MW_{th} coal-fired pilot boiler with CO₂ capture at Schwarze Pumpe in Germany, which is due to start operating mid-2008.
- RWE is to build a large-scale, 450MW, integrated coal gasification combined cycle (IGCC) power plant where CO₂ will be captured and stored onshore, starting 2014. It is also proposing a major CCS retrofit to a coal-fed power station at Tilbury in the UK (capture technology yet to be selected), starting 2016.
- E.ON UK are developing an IGCC power plant project with CO₂ captured and stored in the southern North Sea, off the east coast of the UK, starting 2011.
- Nuon is to demonstrate CO₂ capture at its coal gasifier plant near Limburg. It is also planning to build a new multi-fuel IGCC 1200MW power plant in Eemshaven, the Netherlands.
- Powerfuel plan to build a 900MW coal gasifier power plant with CO₂ capture (pre-combustion technology) at Hatfield colliery, UK, starting 2010.
- Progressive Energy plan to build a 800MW IGCC plant using pre-combustion technology at Teeside, UK, starting 2009.
- Total is to retrofit a 30MW boiler with CO₂ capture (oxy-fuel technology), transport and storage in Lacq plant France, starting 2008.
- SEQ International and ONS Energy are planning to build a 50MW power plant with CO₂ capture (oxy-fuel technology) for use in EOR (0.2 Mt/y), near Drachten, the Netherlands.
- In Spain, there is a co-ordinated initiative to build pilot plants in the scale of 5-10MW to explore CCS in post-combustion, pre-combustion and oxyfuel technologies.

All large-scale projects, however, will require Government incentives if they are to progress.

3. Why CCS technology has not yet fulfilled its potential

The true potential of CCS has therefore still not been realised, despite the overwhelming case for its deployment: reducing CO₂ emissions is not only desirable, it is essential if we are to halt the effects of global warming, now alarmingly evident.

The reason is very simple – its real or implied commercial value has been insufficient to compensate for the substantial costs and risks involved. When applied within a holistic value chain approach, it explains why CO₂ projects have been so rare - and will continue to be – until long-term fiscal incentives and a regulatory framework are established.

Those projects that have developed have therefore either been linked to EOR, or where governments have mandated the storage of CO₂ via operating permits or emission penalties; in which case, these costs are taken into account (e.g. the carbon tax on the Norwegian continental shelf).

- ***Power industry***

The power industry will be most affected by a carbon constrained world, accounting for 54%¹³ of all identified stationary CO₂ emission sources in Europe. If we are to reduce CO₂ emissions significantly, it is therefore imperative that the power sector deploys CCS technology on an industrial scale.

Several power companies around the world are now investing in pilot-scale facilities for all three of the main CO₂ capture technologies. However, to date, there are no full-scale demonstrations of CO₂ capture, although it is technologically possible. Indeed, since their cost is higher than that of the current benefits - for either the emitter or user - projects will not proceed unless there is a) sufficient technological advancement, e.g. reducing the cost of CO₂ capture b) fiscal incentives and a long-term regulatory framework or c) broad-based penalties. The latter, however, would simply result in higher power prices.

- ***Oil and gas industry***

The oil and gas industry already runs many large chemical plants which are very similar to some types of CO₂ capture facilities. They also operate large numbers of EOR projects worldwide - currently storing around 35 million tonnes of CO₂/year - as well as the infrastructure that would be upgraded to provide hydrogen as a transport fuel.

Major projects require major funding

Neither industry, however, is willing to commit the significant upfront investment required until they have confidence in the long-term future and commercial value of CCS. Even for EOR projects, incentives are needed to ensure rates of return are competitive enough to attract capital. Mechanisms for funding the transport infrastructure are also essential for kick-starting the CCS industry.

¹³ Distribution of CO₂ Emissions by Industry - IPCC Workshop 2002

To put this into perspective, each storage site alone will cost possibly as much as €40-€100m. This pales in comparison to the capital investment needed for CO₂ capture, each facility for a industrial-scale power plant (350-500MW) costing an additional €200-300m; while transportation will cost €50-100m, depending on size and distance. (N.B. These costs are in addition to the cost of building the power plant itself.)

However, costs are expected to fall as we gain experience from demonstration projects and advance technology development. Transport costs will be avoided altogether where ZEP plants are located above the storage location itself.

In order to realise the numerous opportunities for CCS in Europe, some form of incentive and/or government funding is therefore vital. Indeed, CO₂ capture technology has global market potential, as it applies not only to the retrofit of existing power plants, but demand for new ones.

Making ZEP cost-competitive with other forms of power generation

Our primary goal is therefore to create power generation from CCS which is not only competitive with low or zero CO₂ power generation technologies, but also those emitting CO₂ (taking into account the CO₂ emission cost).

a) Increasing the efficiency of energy conversion processes

As the capture process requires energy, it has a direct cost due to the reduced efficiency of power generation (or other processes), or through increased fuel requirements. Increasing the efficiency of energy conversion processes will therefore play a key role in offsetting this cost. Indeed, as more efficient ZEPs become available and replace the older, less efficient ones, and improved technology reduces construction costs, it is estimated that the net impacts will be compatible with clean air emission goals for fossil fuel use by at least 2020¹⁴.

One quantitative standard is CO₂ avoidance costs. However, as neither CO₂ regulations post 2012 nor the future market prices of fossil fuels can be projected today, it is impossible to use them as a development target. However, anticipating that CO₂ emission reduction will be recognised as a global goal, there will be a significant financial value to CO₂. The second quantitative standard is the cost of the plant's power generation. Once again, however, the absolute price of electricity cannot be predicted with accuracy.

b) Taking the CO₂ trading system into account

Prices are also affected by the CO₂ trading system – if the price of CO₂ rises, so too does that of electricity. What's more, the technologies creating the market price are the conventional ones we use today, i.e. gas-fired, combined cycle plants and coal-fired conventional steam plants. In order for CCS technology to compete effectively on world markets, CO₂ avoidance costs of €15 - 25/t CO₂ should therefore be assumed as ambitious goals. The cost of electricity produced should also be competitive with current technologies without CO₂ capture, taking the price of CO₂ emissions into account.

¹⁴IPCC Special Report on Carbon Capture and Storage, 2005

c) Improving CO₂ capture technologies and power systems

New or improved methods of CO₂ capture, combined with advanced power systems and industrial process designs, can significantly reduce CO₂ capture costs and associated energy requirements. Although there is considerable uncertainty as to the magnitude and timing of future cost reductions, it is estimated that improvements to commercial technologies alone can reduce costs by at least 20% - 30% over approximately the next decade.

Indeed, each technology is considered capable - subject to substantial R&D, optimisation and economies of scale - of delivering zero emissions power at prices of €45 - €55/MWh for coal or around €70/MWh for gas with CO₂ avoidance costs of €15/t CO₂ to €25/t CO₂ for coal and €60/t CO₂ to €80/t CO₂ for natural gas (calculated with current fuel prices).

Bringing down the costs of CO₂ capture

- ***Reduce investment costs by***
 - Having simple, robust equipment
 - Maximising economies of scale
 - Ensuring there is sufficient market potential for the technologies.
- ***Reduce maintenance costs by***
 - Having simple and robust equipment with long component lifetimes
- ***Minimise energy requirements by***
 - Increasing energy efficiency of CO₂ capture and conversion processes and their integration with power generation
 - Reducing the amount of feedstock.
- ***Ensure high operational availability by***
 - Training people
 - Developing improved system and process controls for integrated CO₂ capture and combustion systems, transport and storage systems.

Overcoming the barriers to deployment

Whilst developing clear business models for distributing the costs and risks of CCS is key to its wide implementation, there are also other barriers which must be overcome for it to fulfil its true potential.

First and foremost, of course, we need the ***recognition*** of all international treaties and governments that CCS is both an approved and desirable means of reducing CO₂ emissions. With so many different parties in the value chain, ***co-ordination*** is also essential, not only for establishing legal and regulatory policies, but benefiting from economies of scale.

One major prerequisite for reaching our target is that both the supplier industry for plants and components, and power generators are convinced that they have ***a market*** - especially in Europe, but also worldwide. This means that industrial-scale use of

fossil energies for zero emission power generation will also have to be possible and desirable for a period of 40–50 years after 2020.

The commercial availability of *CO₂ storage facilities* is also essential. Should approval not be given for CCS, only efficiency-enhancement measures would not be lost. Increasing the efficiency of the energy conversion process is therefore always beneficial.

Another precondition is the continued availability of *expert knowledge* in universities and institutes, as well as industry. This requires recognition by the public - and by young people in particular - that CCS technology complements, not replaces, renewable energy, with fossil fuels a necessary part of the energy mix for a long time to come. This is key to attracting R&D funding and expertise.

To this end, there must be dedicated training and education for the next generation of professionals to continue the work (whether it be with industrial companies or regulators). Geo-science and engineering disciplines are currently dominant within CO₂ storage and these will need to be supplemented by a broader range of other professionals within biology, social sciences, communications, legal and financial issues etc.

This means universities, in co-operation with research institutes and industry, offer the necessary range of competencies and ensure that funds are available. Developing existing and new CO₂ networks in Europe is also important (e.g. CO₂ GeoNet, CO₂Net, CO₂Net East).

But all these issues can be resolved. There then remains one essential precondition to the development of CCS – *Government incentives*. Without such incentives, even if ZEPs are built, they will be uneconomic to run.

Technical barriers to capture

The cost of integrating processes, optimising systems, scaling up and improving plant efficiency using current CO₂ capture technologies should not be underestimated. For the emerging technologies, however, the situation may be different. Most of these depend on supporting technologies, such as new gas separation technologies.

There has been a structured analysis of new thermodynamical processes for oxy-fuel or pre-combustion CO₂ capture in which a large number were selected for analysis. In ENCAP¹⁵ (FP6), 17 of these processes were selected, all with promising thermal performance, for further analysis. Of these, all but two contained key components considered to have “red light” properties, meaning “completely new development needed or considered a very high cost component”.

This implies that there are major technical obstacles to finding processes more capable than today’s three well-known technologies. So if these obstacles are to be overcome, research has to be started now, since it may take over 20 years to develop a

¹⁵Enhanced CO₂ Capture in Powerstations

completely new key component. A selection process must also be started to identify those processes which have a reasonable chance of developing.

Infrastructural barriers

Concerning the infrastructure necessary related to plants and capture technology, barriers are related to the new plants' supply and size, but also to a kind of institutional infrastructure.

A future system of power plants and storages must be considered as one where several plants produce CO₂. This is fed to a trunkline pipeline system which distributes the CO₂ to different storages. It must be assumed that there will be industries handling transport and maybe systems of underground storages, where the producers can buy these storage services for their CO₂. Thus the new technologies for CCS need - in addition to traditional plant requirements of fuel, water supply and electricity - connection to a CO₂ transport system and space for the extra equipment.

Another barrier, yet to be clarified, relates to the CO₂'s quality requirements. There is a trade-off between the purity of the CO₂ the process produces and the cost of the technology required. What constitutes reasonable CO₂ quality will probably be agreed between the producers, transporters and storage owners during the technology development period. Finally, the sheer volume of CO₂ being transported each year – and the necessity of building of an ever larger infrastructure - may constitute another barrier. Material, rights of way, operations and management will all play a part.

Organisational barriers

As with all current plants, a structured and systematic process for approval must be developed. This already exists, with standards for other types of emissions, safety, handling of substances etc, which must now be adapted to include several new constituents. The barrier is therefore the awareness of the authorities - from the highest international level, down to local communities - for which training and education is required.

Maximising international collaboration

From the R&D initiatives that have already taken place, it is clear that many technical aspects of large-scale CO₂ storage are suitable for international co-operation. We should therefore include opportunities for international collaborative projects within the Seventh Framework Program (FP7).

This would not only ensure continuity in the collaboration already initiated (e.g. with China), but pave the way for further co-operation with other major industrial countries, as well as emerging economies. The EU is already a member of the global Carbon Sequestration Leadership Forum (CLSF).

4. Moving from small- to industrial-scale CCS projects

The overall deployment strategy will most likely start with single CCS projects that are not connected. Eventually, regulatory aspects will be in place, research gaps filled, and models for optimum CO₂ transport infrastructure in place.

Initially, CCS projects will be linked directly to a single storage site. Then, as new CO₂ capture projects are defined, the infrastructure will grow and connect more CO₂ sources with storage locations. Finally, CO₂ capture technology for building zero emission fossil fuel power plants will be commercially available, and from 2015 all new or replacement power plants should be assessed for near-zero or zero CO₂ emissions capability.

Identifying early CCS opportunities

One way to kick-start the development of CO₂ infrastructure is to identify *niche markets* where the cost and income are at acceptable levels. This will motivate stakeholders to act on a commercial basis, even without proper framework conditions, e.g. where CO₂ is given a commercial value. Sources with high CO₂ concentration may also be attractive because capture can be implemented at low cost.

Using CO₂ in a niche market can provide valuable experience in implementing and running CO₂ infrastructures. It may also spur technological development that can be transferred to other CCS applications. For example, use of CO₂ in Enhanced Oil Recovery (*EOR*), Enhanced Gas Recovery (*EGR*) and coal bed methane (*ECBM*) has great potential for improving the economy of a CO₂ value chain. Although the storage potential is relatively small and it is not the final solution, it is sufficient to kick-start an initial CO₂ infrastructure that will reduce the total infrastructure cost.

CO₂ for EOR is time critical and has probably the greatest potential in the short-term to kick-start a CO₂ value chain. Many of the relevant fields need CO₂ now and many others will be able to use and store large CO₂ volumes within a few years. Indeed, governments could utilise CCS not only to meet emission targets, but offset the costs by using the CO₂ to increase oil production. Their involvement would also reduce risks at all levels of the CO₂ value chain by promoting it in its developmental phases, supporting the implementation of new capture technologies and facilitating contracts between consenting companies.

The use of CO₂ in *industrial processes and products* (e.g. agriculture greenhouses, urea fertilizer production) may also contribute to kick-starting CO₂ infrastructure, even though it is much smaller in scope, is not a permanent storage and cannot be included in the ETS system.

There are also potential opportunities in the *power sector* for developing ‘early-mover’ CCS projects, where location of storage sites and other factors could make them an attractive possibility (especially in the case of pre-combustion with other products, such as hydrogen, biomass, SNG, methanol, diesel and naphtha).

How long will it take to build a power plant with CO₂ capture?

A time schedule for constructing a new zero-emission power plant with pre-combustion or oxy-fuel CO₂ capture technology is illustrated below (Fig. 4). This shows that it could be ready for commissioning in 2015 – as long as project development begins in 2006. A new pulverised coal or combined cycle gas turbine with post-combustion CO₂ capture, on the other hand, would typically take 5 years to build, from start to finish. (This could also include building a CO₂ capture facility in parallel.)

For an existing coal or gas-efficient fossil fuel post-combustion plant, the timeline would, of course, be shorter - no more than 4 years - as it would only entail building the CO₂ capture facility.

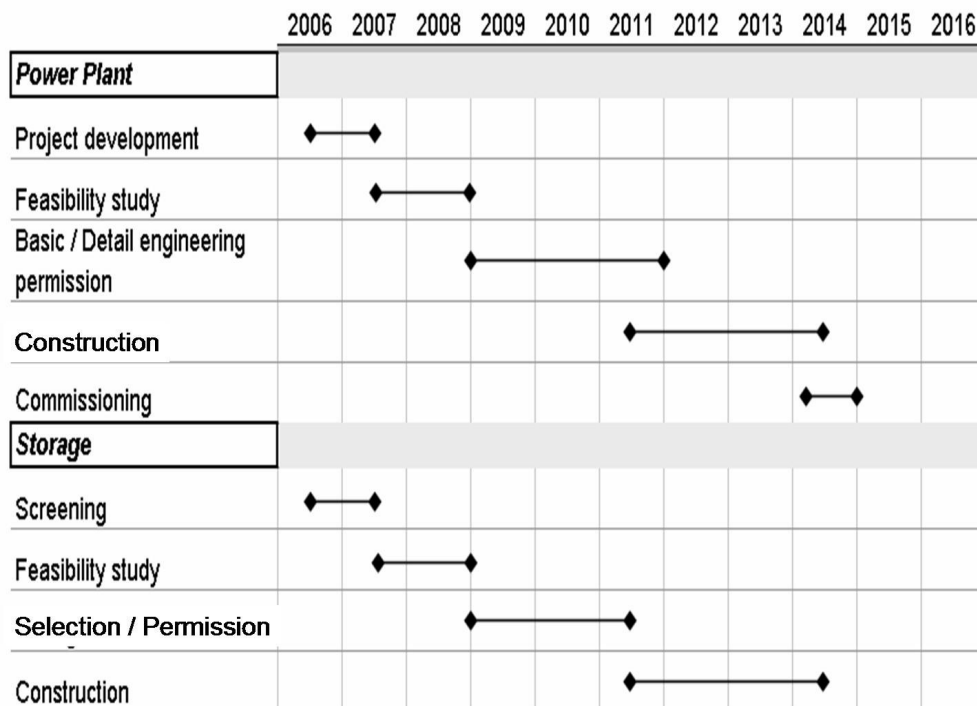


Fig. 4: Timeline for implementing an integrated CCS project, including a new zero emission power plant with pre-combustion or oxy-fuel CO₂ capture technology

How long will it take to construct a CO₂ storage site?

For deep saline aquifers, construction would only involve minor structural works to support injection wells and may take around 3-4 years. With lead time for permitting estimated to take another 2-3 years, risk analysis should be conducted as early as possible to ensure against bottlenecks.

For an EOR project, the field operator must reorganise his field to include tankage, water handling, CO₂ compression and recompression, as well as CO₂ processing. Onshore, this usually takes around 1-2 years and may run concurrently with field or reservoir pattern flooding; offshore, it may take as long as 6 years.

Making the step change to full-scale deployment

Experience gathered from single projects will obviously be extremely valuable for future projects and spur further planning and development. In fact, Europe currently

holds the leading position within CCS. However, it is a precarious lead and if we are to maintain – and increase – it, a step change is vital. Indeed, Canada has already started new CO₂-EOR projects, while Argentina is considering them and Australia advances its plans for the Gorgon gas field. The US, on the other hand, has more experience in EOR than anywhere else. It means that CCS activities are now underway in gas and oil fields on five continents, making this a truly global activity.

We therefore propose that Europe introduces the concept of industrial-scale demonstration projects for zero emission power generation and geological storage in the FP7 as the only means of unlocking the full potential of this technology.

It means building about 10-12 storage sites, with a longer operational lifetime (at least 30 years), in locations the length and breadth of Europe – ready for operation. With a lead-time of 5-10 years, this will almost certainly be during the 7 year running period of FP7 from 2007. Such projects would prove that operations, monitoring, verification, risk and mitigation etc can indeed be carried out in the manner acceptable to both regulators and the public.

The CO₂ will come from selected capture plants and industrial facilities that are identified as the most economical, as the foundation of the CO₂ value chain. Transport systems will also begin to be built at the same time.

What makes a good CO₂ storage demonstration site?

Different audiences will of course, require different demonstrations. All, however, need to be convinced that large volumes of CO₂ can be stored safely - and for a very long time - in a variety of geological and geographical sites:

- Different *geology* because the different behaviour of CO₂ and its storage reservoir will show how generally applicable the concept is. Sites should consider such features as reservoir and cap rock types, deep saline aquifers or combinations with EOR/EGR or ECBM;
- Different *geography* or topology to reassure people in as many different countries as possible on the safety of CO₂ geological storage.

A good storage site (either for underground CO₂ storage or combined with EOR/EGR) also needs to be:

- Large – for large volumes of compressed, clean CO₂
- Long lasting – deliveries need to carry on for some years, preferably 10 or more
- A reservoir with a good seal - preferably a well-defined deep saline aquifer, a field designated for EOR/EGR/ECBM, or an exhausted oil/gas field, or for pure storage
- Preferably on land for access
- Near a CO₂ source that's sufficiently large, utilising state-of-the art capture technology
- Accepted by regulators and neighbours, and site characterised
- Operated by companies with skilled personnel capable of seeing the project through.

Engineering, planning and approval procedures, a construction time of 3-4 years, combined with capture plant building and transport system, all done in parallel – plus some years to gain operational experience - will set the stage for full scale development when ZEP plants are deployed at 2020.

This means that industrial-scale plants must be commissioned by 2015 *at the latest* to ensure commercial-scale applicability from 2020. Our biggest challenge will be the need to develop several projects, in parallel, over just a few years. This will require strong cooperation - not only at national and European levels, but amongst the power, petroleum and supply industries.

It is therefore essential that we do not wait for the CO₂ infrastructure to be fully established before developing initial projects – they can be carried out in parallel with the deployment of an overall infrastructure.

Action plan

CO₂ capture

- **Europe to introduce the concept of large-scale demonstration sites for CO₂ capture in the FP7.**
- **Develop pathways to commercialisation for CO₂ capture technology.**
- **Undertake 10-12 industrial-scale capture demonstrations which demonstrate and give confidence in post-combustion, pre-combustion and oxy-fuel technologies. Encourage partnerships between industry and Government.**
- **Identify possible locations for new power plants and other industrial plants with large CO₂ emissions during 2007.**
- **Increase technology development - particularly for “next generation” technologies that will reduce CCS costs by at least 50% over what is currently possible.**
- **Each power plant has its own plant life cycle. By 2015, all power plants due to be replaced, or have increased capacity, should be assessed for CO₂ capture.**

CO₂ storage

- **Europe to introduce the concept of major demonstration sites for geological storage in the FP7.**
- **Establish potential storage locations during 2007 for 10-12 full-scale projects, with an operational lifetime of 30 years (including 4-6 onshore, with a minimum capacity of 2 million tonnes CO₂).**
- **Establish an EU storage programme to develop the necessary knowledge, skills and capability for large-scale storage in a deep saline aquifer by 2010.**

5. Building a transport infrastructure

Our long-term strategy is to link large-scale plants together, where economically feasible. This obviously requires careful planning, with the responsibility for coordination confined to the transport method operator. They will be responsible for the allocation of all CO₂ volumes received into and out of the system, gains or losses and for validating volumes stored. As the CO₂ infrastructure may involve both state and privately owned companies, coordination schemes under different ownership options should also be established.

However, operation and maintenance of transport and storage facilities may be managed by companies subject to a regulated revenue scheme, similar to those for natural gas and electricity transmission activities. In practice, this will apply to multiple sources CO₂ gas streams transported in a single transport system to a regional, or even single storage site. Transparent and non-discriminatory rules and tariffs for third party access to the CO₂ infrastructure will also need to be established.

It is highly unlikely that within the short- to medium-term (i.e. by 2020), an EU-wide CO₂ infrastructure will develop similar to that for petroleum products and natural gas. It will most likely be single source to storage, or multiple sources to regional storage. If projects become geographically close enough over time to be linked as storage becomes limited, then interconnects will be built where it is economic to do so.

Defining the optimum CO₂ infrastructure

An overall CO₂ infrastructure in Europe should not only minimise economic costs and environmental impacts, but be easy to adapt and implement by all countries – either as one giant infrastructure or separate, regional networks. Modelling tools therefore need to be developed and different scenarios evaluated so that the optimum CO₂ infrastructure is defined. These need to take into consideration:

a) Identify optimal locations for new power plants

The CO₂ infrastructure must allow for the fact that new zero emission fossil fuel power plants will be built in the future. When considering the optimal location for a new power plant, the storage of CO₂ must also therefore be taken into account, along with site size, existing installations, proximity to fuel supply and energy users and grid connections. Studies to determine the optimal location for new power plants should consider:

- What will mainly be transported: CO₂, power, hydrogen or primary fuel
- The security aspects related to safe de-carbonised fuel supply for ZEPs and proximity to urban areas
- The need to minimise economic investments and production cost. The cost of implementing CCS has to be considered, along with the cost of producing power and, if applicable, hydrogen.

b) Use of existing infrastructure

Studies should be carried out to determine whether existing infrastructure originally designed for transporting natural gas or petroleum products - pipelines, ships, trucks and train - can be retrofitted for CO₂ transport. Existing compressors, offshore

platforms, wellheads and control systems will also require modification. Such studies must include evaluations of:

- Material resistance to the corrosive behaviour of CO₂
- The volumes of CO₂ to be transported
- The pressures and temperature applied during transportation

c) Transport systems and optimal transport routes

Once capture location, CO₂ volume and quality and storage sites are determined, we then need to consider what is the best transportation method. Due to its lower cost, pipeline will ultimately dominate, although ship, rail and trucks could be considered in transition.

Studies should therefore be performed to identify optimal pipeline routes with respect to geography and geological activity. Although urban versus rural areas should be evaluated, rural areas will, for safety reasons, be the first priority. Suitable pipe materials should also be considered with respect to corrosion resistance, volume flow rate, pressure, temperature etc.

Infrastructure for CO₂ use should be connected to both intermediate and permanent storage sites. This introduces more flexibility in the system and makes it easier to connect future sources and storage locations.

With regard to offshore projects, economic and engineering models must be constructed for each individual project in order to validate all criteria for building transport infrastructure. Re-use of offshore infrastructure could be an option in the mature regions of the North Sea. However, in many cases new facilities might be required.

d) Volume and composition

Power plants are usually considered to be the main point-sources for CO₂, but steel mills, cement plants, oil refineries and chemicals operations are also significant sources. Volume and composition will vary from source to source and increasing the quantity and purity of CO₂ in the captured stream will spread fixed costs even further, benefiting:

- CO₂ providers through easier access to storage
- Member states through their commitments to the Kyoto Protocol
- Suppliers of relevant capture technologies through increased markets
- EU GHG allowance markets through greater liquidity.

All CO₂ captured will be classified with respect to volume and gas composition, based on storage requirements and pipeline specifications. All parties will work together to determine the most feasible CO₂ gas stream specifications, which will impact all facets of the project, including economics.

Projects must also match the best CO₂ sources with the most logical storage sites, based on these quality and quantity criteria. Finally, impurity analyses will have to be

performed to determine how each impurity might react in transport settings as well as storage locations.

e) Industry capacity to supply material

It should be remembered that the overall timeframe for projects to be completed depends on the total supply and demand of manufacturing infrastructure available on the worldwide market. They will not only use many of the same materials and engineering resources required for CO₂ capture, but put pressure on pipeline and construction resources.

Technology and knowledge transfer

The starting point for the development of a European CO₂ infrastructure is the identification and transfer of technology, know-how and experience from other parts of the world. This includes design, construction, material selection, operation, regulation, incentives, policy measures, safety, monitoring and public risk assessment. For example, a CO₂ infrastructure was developed in the US 30 years ago in order to provide CO₂ for EOR.

Action plan

- **Identify CO₂ point-sources as part of the infrastructure by 2007.**
- **Map storage capacities and locations (continue GESTCO and ongoing GeoCapacity projects).**
- **Undertake a study on the re-use of existing infrastructure in the North Sea versus new build requirements.**
- **Define optimum model for the European CO₂ infrastructure linking capture and storage locations by 2009.**
- **Start building pipelines that will become part of a European CO₂ transport infrastructure in 2010.**
- **An infrastructure for EOR in the North Sea is the first, larger regional infrastructure that can probably be built. It could begin within the next 5-8 years, capturing and storing more than 30 million tonnes of CO₂ a year.**
- **Linking CO₂ sources to storage locations through transport systems to continue through 2020.**

6. Kick-starting the CO₂ value chain

One thing is clear: without major capital investment, new technologies like CCS will never get off the ground. Indeed, the economic aspects of technology development management should not be underestimated: *without clarity on the financial risks and rewards - including a stable regulatory framework - investors will not have the long-term certainty they need to commit their funds.*

a) *Incentivising the early movers*

Certainly, at current trading levels (€10-20/t CO₂), it does not look like emissions trading will provide sufficient financial support even to cover the costs for CCS at this stage. The CCS value chain therefore needs to be kick-started with the implementation of specific short-term incentives, either at Member State or EU level. They must be:

- Clearly articulated in State Aid Guidelines on CCS implementation, whilst being elaborated and deployed at Member State Level. This should include funding by governments of transport infrastructure, i.e. pipelines.
- Compatible with the EU ETS¹⁶ in its current/future forms and not significantly distort the carbon trading market, or its ability to minimise CO₂ reduction costs will be undermined.

b) *Establishing long-term incentives*

However, long-term incentives are also essential in order to create a stable environment for investors who may be deterred by fears that they could be changed, e.g. as a result of political changes. They also need to be of sufficient value to overcome any vagaries in the greenhouse gas (GHG) market.

Making the most of the EU ETS

Emission trading is a powerful tool for reducing GHG emissions at the lowest cost to society and CCS technology is a key element in fulfilling this objective. Indeed, avoidance of emissions to the atmosphere through CO₂ capture and long-term geological storage should be treated as equivalent to emissions reduction at the source. It should therefore receive similar incentive treatment as renewable energy sources and energy efficiency programmes.

It is therefore essential that CO₂ used for CCS projects is fully accredited under EU ETS, as well as the Clean Development Mechanism (CDM).

This can be achieved by adopting a methodical approach to monitoring and reporting which would put CCS projects on a par with EOR and deep underground disposal of acid gas. It also means taking a mass balance approach to calculating fugitive emissions across the CO₂ capture, transport and injection chain. However, longer-term regulations must be in place to govern the EU ETS beyond 2012.

¹⁶ European Union Emissions Trading Scheme

...and other incentive schemes

There must also be consistency with the stimulation of other parallel developments in clean energy/fuels available to Member States. For example, in the UK, there is a mechanism for green certificates, referred to as *Renewable Obligation Certificates* or ROCs.

ROCs are digital certificates which are traded separately to the actual electricity itself and work as a bonus premium on top of the price paid for the power unit. Energy companies are now required to generate a minimum of 10% of their electricity output from sustainable sources. If they do not manage this, they must buy ROCs on the open market to make up the shortfall. If they fail to do this, fines can be imposed. ROCs therefore potentially represent a constructive incentive for consumers to purchase a given amount of electricity from CCS facilities - provided CCS-based electricity is included in the scheme.

Another incentive scheme is *volume allowances*. Here, petroleum companies using CO₂ for EOR/EGR receive tax reduction on the additional oil/gas extracted in order to compensate for the enormous capital expenditure and risks these tertiary projects involve – be they onshore or offshore. It is estimated that a volume allowance of approximately \$5.00 per barrel could entice an oil and gas company to invest in such a proposition.

Implementation of the CO₂ infrastructure can also be facilitated by changing the taxation system. In some cases, there could be publicly owned entities for investing in ZEP, although these might be time limited. ‘Carbon contract’ incentive schemes are another option, being readily compatible with the EU ETS.

We also recommend establishing a *Clean Power Generation Act for Europe* which stipulates that a certain percentage of energy production should be clean energy – either via CCS, nuclear or renewables. This should be in line with the Renewable Energy Sources (RES) Directive, which sets a target for 12% of electricity to be produced from renewable energy by 2010. The Act should be proposed by the EC and included in the second phase of the European Climate Change Programme (ECCP II).

Kyoto and beyond

Projects must also be viewed in the context of obligations to the Kyoto Protocol¹⁷ and any successors, including Joint Implementation (JI)¹⁸ and Clean Development Mechanism (CDM)¹⁹ projects. The CDM, in particular, is an important pathway for incentivising investment in CCS activities.

¹⁷ Projects must also be viewed in the context of obligations to the Kyoto Protocol and any successors, including Joint Implementation (JI) and Clean Development Mechanism (CDM) projects. The CDM, in particular, is an important pathway for incentivising investment in CCS activities

¹⁸ Joint Implementation (JI) is part of the Kyoto Protocol to provide for projects that aim at reducing emissions or removing carbon from the atmosphere.

¹⁹ The Clean Development Mechanism (CDM) is an arrangement under the Kyoto Protocol allowing industrialised countries with a GHG reduction commitment to invest in emission reducing projects in developing countries as an alternative to what is generally considered more costly emission reductions in their own countries.

It means developing an approval mechanism for CCS projects which incorporates necessary assurances over site selection, permanence, monitoring, remediation and allocation of liability for any third party damage, as well as remediation in the event of seepage emissions. Such a process can easily be developed within the context of the current framework for CDM project approvals.

Any potential methodology for CCS project accounting in the CDM also needs to take into account the forthcoming 2006 IPCC Guidelines for National GHG Inventories.

Creating a level playing field

The present legislative system was not written with CCS in mind and is currently being revised, as successful implementation will depend on consistent and long-term laws and treaties. In fact, a positive movement to permit CCS has already begun, initiated by the EC itself (via a Directorate General Environment taskforce): the London Convention²⁰ has already drafted a proposal that sub-sea CO₂ storage should be permitted and the London Protocol²¹, UNFCCC²²/SBSTA²³, IPCC²⁴ and OSPAR²⁵ are in a similar process.

It means creating a level playing field for all industrial actors, with a common legislative framework wherever possible. Indeed, the larger the system, the more stable it will be and we hope it will extend worldwide. The framework must also have a long lifetime - for at least an investment period (around 30 years).

Many international, regional and EU legal frameworks are relevant to ZEP activities, with definitions and prohibitions that are sufficiently broad to encompass and regulate various power generation, CO₂ capture and geological storage activities. However, only a few (UNFCCC, Kyoto Protocol and the EU's Monitoring and Reporting Guidelines) explicitly address ZEP activities and either include or exclude them from their scope.

Clear and appropriate inclusion in, or exclusion from, legal frameworks will increase transparency, provide regulatory certainty and facilitate ZEP activities and methodologies that are agreed to be consistent with international, regional and EU frameworks.

Crossing the borders

Laws and treaties regulating the economics involved when CO₂ crosses country borders must be consistent and compatible within all countries taking part in a CO₂ infrastructure. Each country therefore needs to implement laws and regulations for CO₂ that are acceptable and compatible with other countries involved in the

²⁰ The London Convention sets out rules to prevent marine pollution by the dumping of waste worldwide and has over 77 member countries.

²¹ The London Protocol also governs the prevention of marine pollution by dumping of wastes and other matter (1996)

²² United Nations Framework Convention on Climate Change

²³ Subsidiary Body for Scientific and Technological Advice of UNFCCC

²⁴ The Intergovernmental Panel on Climate Change

²⁵ OSPAR was set up in 1992 to prevent and eliminate pollution in the marine environment of the North-East Atlantic and entered into force in 1998. Its members include Denmark, the EC Commission, France, Germany, the Netherlands, Norway, Spain and the UK.

infrastructure. These laws and regulations have to address all legal issues related to CO₂ capture, transport and storage, including the potential for single or multiple CO₂ sources to be transported through one or more countries to the final storage site.

Contract considerations

Commercial contracts will need to be developed which address the concerns of all stakeholders, as CO₂ source (seller), transporter (potential seller *and* customer) and CO₂ storage location (customer) all have different economic needs. Alignment is key and contracts will give both parties the confidence to build their share of the infrastructure in parallel, so that (for example) when CO₂ needs to be stored, the site will be operational; or the EOR/EGR project will be expecting to receive it.

Who is liable?

Liability is a key issue that must be addressed to clarify the ownership of CO₂ during transport, and liability during storage – who is responsible, industry or government?

It will also have a significant impact on our ability to reassure the public. Due to rigorous risk monitoring systems, CO₂ leakages will be identified and immediately corrected. However, in the unlikely event of damage caused by leakage, clear regulations on liability must be established, based on the principles of the Environmental Liability Directive.

CCS liability issues are actually very similar to those of other industrial activities and gases. Indeed, CO₂ capture plants and transport already have well-established directives and national legal frameworks; whilst storage facilities can adapt current mining and petroleum laws, whereby the state assumes liability after a law-regulated abandonment process.

The use of insurance or related financial mechanisms should also be explored, including the possibility for specific funds - financed by storage site operators - to cover liability of the storage site, during both operation and after its transfer to the state.

Action plan

- **Establish appropriate legal and long-term regulatory framework by 2007/8.**
- **Accredit the CCS chain under EU ETS and any subsequent scheme.**
- **Recognise CCS measures as JI/CDM projects so that the CO₂ emission reductions can be applied on a global scale.**
- **Grant EU Allocations to power plants with CO₂ capture in recognition of CO₂ emission reductions.**
- **Harmonise CCS-related legislation in all countries involved in the transport infrastructure.**
- **Establish a comprehensive liability scheme, consistent with the Environmental Liability Directive.**
- **Ensure those involved in legislative activities and approval processes are knowledgeable about CCS technology.**
- **CO₂ used as a gas, liquid or feedstock for the production of chemicals or food products, is not classified in the *European Inventory of Existing Commercial Chemical Substances* and should be addressed in a future review.**
- **Offshore storage: the *London Convention* and the *OSPAR Convention* should ensure that CO₂ is legally recognised.**
- **Onshore storage: the definitions of liquid waste in the *Landfill Directive* need to be tightened up through appropriate site-certification standards.**
- **Propose the establishment of a *Clean Power Generation Act for Europe* in the second phase of the ECCP in line with the RES Directive.**

7. Resolving environmental issues

The CCS process chain has three distinct phases: capture and conditioning, transport and geological storage. Impact on the physical environment is a vital part of the infrastructure's overall design and construction, and deployment of environmental monitoring systems must be integral to any CCS project. Consistent regulation is also needed at both national and international levels to ensure harmonisation of the process chain and compliance with health, environmental, and safety (HSE) requirements.

However, it is worth remembering that there are billions, maybe trillions, of tonnes of CO₂ already present in nature - in volcanic areas, it seeps out daily. Nevertheless, in storage sites that are well-sited, operated and monitored - with proper remedial measures - leakages simply should not happen²⁶.

Zero tolerance for CO₂ leakages

Major acute or chronic leakages are neither acceptable nor expected. Indeed, *in storage sites that are well-sited, operated and monitored, leakages simply should not happen at any significant level.* However, in the unlikely event that they do, sophisticated monitoring and remediation techniques, already well proven in the oil and gas industries, should be able to correct them immediately.

Environmental risks

a) CO₂ capture

The CO₂ flow from CO₂ capture plants normally contains low concentrations of other gas components and impurities may result in environmental impacts at the storage site. Power plants with CO₂ capture would emit a CO₂ depleted flue gas to the atmosphere.

However, the concentrations of most harmful substances in the flue gas would be similar to, or lower than, that from plants *without* CO₂ capture because the CO₂ capture process naturally removes some impurities; while others (e.g. ash, SO_x and NO_x) are removed upstream. Potential leaks therefore cannot reach high levels and, in any case, are easy to control and correct. As such, they do not require special attention beyond present regulations in industrial gases handling.

Some CO₂ capture processes and materials also produce solid and liquid wastes, e.g. solvent scrubbing processes produce degraded solvent wastes which would be incinerated or disposed of by other means.

b) CO₂ transportation

CO₂ leaking from a pipeline forms a potential physiological hazard for humans and animals: it is denser than air and can therefore accumulate in potentially dangerous concentrations in low lying areas. It also transfers CO₂ to the atmosphere, which adds

²⁶ It is very likely that the fraction of CO₂ retained is more than 99% over the first 100 years and likely that the fraction of CO₂ retained is more than 99% over the first 1,000 years (Working Group 2 report on CO₂ Use and Storage)

to overall GHG emissions. If substantial quantities of hazardous impurities, particularly H₂S, are included in the CO₂, pipeline leak or rupture could lead to environmental impacts.

Yet the risks are actually lower than for hydrocarbons. Leaks can therefore be controlled using conventional and regulated processes; while massive releases related to forces of nature, such as hurricanes, seismic events etc can be monitored by alarm and safety systems similar to those already in operation.

The consequences of CO₂ incidents can be modelled and assessed on a site-specific basis using standard industrial methods, taking into account local topography, meteorological conditions, population density and other local conditions.

c) CO₂ storage

Due to the magnitude of the storage and its duration, clear deployment strategies are needed against potential leakage. For onshore storage sites, measures must be taken to prevent CO₂ from reaching the water table and migrating into the overlying vadose zone and, most likely, drinking water aquifers. Depending on the mineral composition of the rock matrix within the groundwater aquifer or vadose zone, the reaction of CO₂ with the rock matrix could release contaminants. The US Environmental Protection Agency (USEPA) has witnessed problems remediating areas that were thought to be contaminated in this way.

Stored CO₂, and any accompanying substances, may affect flora and fauna with which it comes into contact – namely, microbes in the deep subsurface, plants and animals in shallower soils, and on the surface.

Underground injection of CO₂ or other fluids into porous rock, at pressures substantially higher than formation pressures, can induce fracturing. Induced local fracturing and fault activation may present brittle failure and associated micro-seismicity induced by over-pressuring can create or enhance fracture permeability, providing pathways for unwanted CO₂ migration.

Developing a clear risk management strategy

A clear risk management strategy must therefore be developed, including Risk Acceptance Criteria (RAC) in order to drive regulations, ensure compliance by CO₂ producers, transporters and storage site operators – and, crucially, gain public acceptance.

All methodologies should be considered, with *Features-Events-Processes (FEP)* and the *Decision & Risk Analysis (D&RA)* the front runners as they employ a very direct approach (their combined use was proposed in CO₂ Geonet report, 2005). However, our experience of them is still relatively young.

The *Strategic Environmental Assessment (SEA)* and *Life Cycle Analysis (LCA)*, on the other hand, are useful tools for long-term planning and assessments at a conceptual level. The SEA is currently performed on all new power plants as the basis for permitting and covers the entire process chain - from the mine, to emissions, to the deposit of waste materials and water treatment.

The LCA is a systematic and well-established method of analysing environmental impacts, codified in the International Standard ISO 14040. After establishing a system boundary, an LCA will then compare the system with zero emissions with one

without zero emissions (the base case) - the difference will define the environmental impact of CCS.

The concept of the SEA developed from the *Environmental Impact Assessment (EIA)*, when the EIA was applied to larger plans and projects that needed considerations that were not traditionally taken into account in the EIA. The EIA is also important for investigating how carbon balance and other environmental concerns meet key criteria for safe and secure handling – from source to infrastructure to final storage.

Environmental checklist

With the amount of CO₂ planned to be stored every year - several billion tonnes - securing a sustainable environment is key and each new CCS project must take the following deployment strategies into account:

- *Monitoring prior to implementation and during operation*
Standards for leak detection in case of chronic or accidental leakages should be established. Background levels of CO₂ emission, which will vary seasonally, must also be determined prior to implementation. Monitoring should continue in order to establish data over an extended period.
- *Potential flow and escape routes*
Modelling and simulations should be carried out to determine CO₂ route dispersion and the impact of CO₂ gas and impurities on shallow ground and near surface areas.
- *Potential impact of leakages*
Environmental impact assessment should be carried out to determine the possible impact of leakages or ruptures from onshore and offshore infrastructure to human health and safety, terrestrial and marine ecosystems.
- *Footprints*
LCA, SEA or EIA are useful for investigating the carbon balance of the entire CCS chain - from source through infrastructure to final storage, as well as all transport models. Footprints of all infrastructure impact must be assessed and solutions to minimise environmental impact established, including determining the net CO₂ stored and climatic impact.

Action plan

- **Assess risk management strategies for a wide range of cases and geological settings.**
- **By 2007, amend existing EU legislation (concerning waste and water) in order to clarify the conditions under which CO₂ is geologically stored, cf. OSPAR/London Protocol/ UNFCCC/ DOE-NERL (Department of Energy – National Exposure Research Laboratory)**
- **By 2008, implement new EU-level guidelines for Member States permitting geological storage projects (including risk management, site selection, operation, monitoring, reporting, verification, closure and post-closure).**
- **Set measurement, monitoring verification (MMV) standards in collaboration with geo-science expertise in oil and gas companies, as well as universities/institutes, certification companies, regulators and NGOs, based on a decade of monitoring existing CO₂ storage sites, e.g. Sleipner, In Salah, Weyburn etc.**
- **Use the MMV standards as Risk Assessment Criteria for input to new regulations (for site selection, process control and validation).**
- **Include ZEP plants in the Integrated Pollution Prevention and Control (IPPC) guidelines - possibly within point 4.2 of the Annex 1 of the IPPC directive (96/61/EC) - and give these and MMVs to certification companies/institutions as early as possible.**
- **Support eligibility of CCS for ETS-CDM credits when it complies with MMV/RCA standards and is linked to UNFCCC work.**
- **Educate/train communities and regulators right at the start of the process.**

8. Gaining the support of the public

The heated debate over GMOs²⁷ is a stark reminder of what can happen when the public feels its trust has been betrayed. In some countries, a rather secretive approach was used, with much reliance on the opinion of “experts”, resulting in public distrust. It is therefore crucial that we maintain an open dialogue with the public on *all* aspects of CCS technology - CO₂ capture, transportation and storage – and at every stage of its development and implementation.

Indeed, gaining public – and political – support is essential if CCS is to receive the funding, incentives and State Aid guidelines it now urgently requires.

It must therefore be made clear that as fossil fuels will still be required for many years to come and renewable energies cannot reduce GHG emissions significantly in the short-term, CCS will play a vital role in combating climate change, as the bridge to a sustainable energy system. CCS and renewable (as well as fusion) energy are therefore *complementary*, not competing strategies, with the latter still our ultimate, long-term aim.

Public acceptance of CCS is a prerequisite

While *CO₂ capture* itself is not of particular concern or worry for the public, its acceptance of the need to optimise and commercialise CO₂ capture technologies is vital to securing substantial funding and technical resources (without which CCS projects cannot proceed).

Based on the results of transparent and publicly available LCA, SEA or EIA,²⁸ it can be assured that underground *CO₂ storage* is safe. However, we must communicate this fact clearly in order to allay any fears, i.e. sites will not leak or explode. (This applies primarily to storage sites on land, rather than offshore.)

Public acceptance also includes acceptance of *new laws, treaties and regulations* to ensure the successful implementation of CCS projects.

The challenge is to get the key messages out early so that the public are reassured that their lives will not be affected adversely in any way. On the contrary, if we do not develop CCS technology, their lives will almost certainly be affected adversely by climate change.

Ignorance is not bliss

There is a limited, but significant number of publications addressing the issue of public acceptance of CCS from which we can draw the following observations:

- When asked cold, the public do not immediately accept CCS – ***even when they are concerned about climate change***. Those that were mildly positive about CCS in general terms were still neutral to negative about storage in their

²⁷ Genetically modified organisms

²⁸ LCA: Life Cycle Analysis; SEA: Strategic Environmental Assessment; EIA: Environmental Impact Assessment

immediate neighbourhood. They also thought that the risks and drawbacks were somewhat greater than the benefits to society and the environment.

- ***The public favours renewables, in particular solar and wind.*** Studies show an overwhelming support for solar and wind which is important as CCS is perceived by some as delaying the “real final solution”, i.e. renewables.
- ***The public is generally poorly informed about energy and environmental issues.*** In fact, most did not even know where electricity came from and less than 10% of the public had heard of CCS.
- ***After explaining what CCS is about public acceptance becomes more positive.*** One study found that when presented with informed choices, all CCS options were viewed as acceptable and very few thought the technology unacceptable. Another showed that while only 13% of the public views CCS positively before explanations are given, 55% agree with it *after* explanations.

In informing the public about CCS, acceptance of the following arguments was therefore essential:

- Anthropogenic global climate change is an extremely serious problem
- Massive reductions in CO₂ emissions are needed to reduce the threat of climate change
- This technology is not only effective but non-harmful.

Who are “the public”?

When communicating with the public, it must be remembered that there are actually many “publics”:

- The *attentive public* consists of those who express a high level of interest in a particular issue; feel very well informed about it; read a newspaper on a daily basis, and regularly read a news magazine or magazine relevant to it;
- The *interested public* consists of those who claim to have a high level of interest in a particular issue, but do not feel very well informed about it;
- The *residual public* consists of those who are neither interested in, nor feel very well informed about, a particular issue.

Since maybe only 10% of the public is concerned with scientific, technological or environmental issues, these are the only ones with whom a real debate can be useful. When communicating with the remaining 90%, one needs to be mindful of the fact that trust in science and technology is low and the belief in “miracle cures” high. Any communication strategy must therefore be conducted by experienced professionals.

Studies also show that, on environmental matters, the public trusts environmental NGOs and scientists but not, generally, governments, media and companies.

Action plan

- *Plan an information campaign - now*

It is very clear that in order to implement CCS on a larger scale, it must be done with full public support – and soon, if it is to have an early impact. This should take into account research into current public perceptions of CCS and climate change (see Strategic Research Agenda).

Groups such as national and European parliamentarians, journalists, environmental pressure groups and representatives of civil society are particularly important targets.

- *Ensure communication is a dialogue, not one way*

Establishing an information campaign about CCS is not without danger, and we must use professional agencies to help define the message, the messenger, the medium used and the target public. We therefore need to start planning for such a campaign in the next few months, with a focus on providing clear scientific information as part of a dialogue that encourages all voices to be heard and involved.

- *Assign a significant budget*

A well-organised outreach campaign is not cheap – around €250k per country – and funds must be set aside. Timing is also critical – in some countries CCS is moving onto the policy agenda relatively quickly; whereas in others, there is still virtually no recognition of CCS, even in policy circles.

- *Regularly monitor the public reaction and respond when necessary*

Both before and after the launch of any campaign, we will need to gauge public opinion, and listen to it regularly (we could use the Eurobarometer, supplemented by focus groups in different countries), in order to watch the evolution and catch objections early. We must then respond to these objections, thoroughly and honestly, using the right messengers.

9. Conclusion

The goal of the Technology Platform for ZEP is clear: to enable zero CO₂ emissions from European fossil fuelled power plants by 2020. It is an ambitious goal, but perfectly feasible – as long as the process starts *now*.

It means CO₂ capture technology must be commercialised, storage locations identified and industrial-scale demonstration projects implemented without delay. It also means establishing a clear, stable fiscal and regulatory framework. Unless investors are convinced that CCS technology has a secure, long-term future, it will simply not get off the ground.

However, rising energy demand and the increasingly visible effects of climate change mean that time is not on our side. We will therefore only achieve our goal by adhering strictly to the following roadmap:

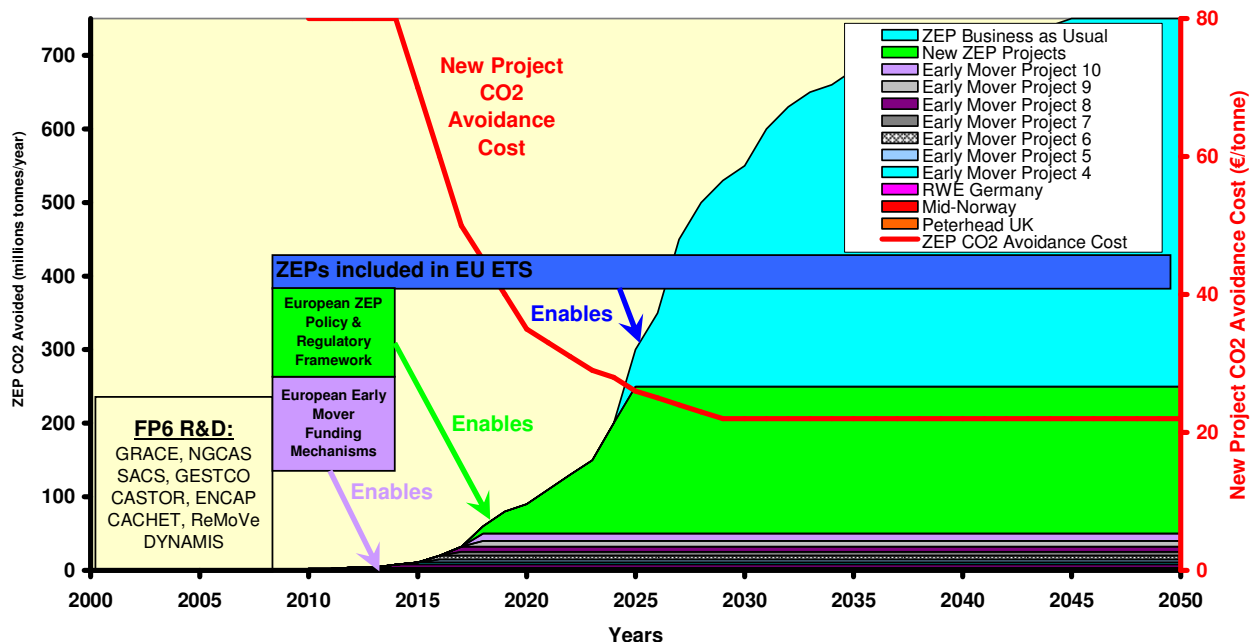
- **Introduce the concept of large-scale sites for CO₂ storage in the FP7.**
- **Engage with regulators and the public in 2007 and carry out an information campaign as soon as possible.**
- **Establish a legal and long-term regulatory framework by 2007/8, including accreditation of CCS under EU ETS, CDM and JI²⁹.**
- **Identify CO₂ point-sources and possible locations for new power plants and other industrial plants with large CO₂ emissions by 2007.**
- **Establish potential storage locations for 10-12 industrial-scale demonstration projects during 2007.**
- **Implement R&D to improve the efficiency of power plants with CCS as soon as possible.**
- **Establish early mover funding mechanisms by 2007.**
- **Undertake a study on the re-use of existing infrastructure in the North Sea versus new build requirements in 2008.**
- **Undertake 10-12 CO₂ capture demonstrations and build 4-6 onshore storage sites by 2015 (with a minimum capacity of 2 million tonnes CO₂).**
- **Define optimum model for the European CO₂ infrastructure linking capture and storage locations by 2009.**
- **Establish an EU storage programme to develop knowledge, skills and capability for large-scale, deep saline aquifer storage by 2010.**

²⁹ Although this is an ambitious target, given the urgency of the situation, it is essential that we push for the earliest possible date.

- Start planning for building pipelines that will become part of a European CO₂ transport infrastructure in 2010.
- Each power plant has its own plant life cycle. By 2015, all power plants due to be replaced, or have increased capacity, should be assessed for CO₂ capture.
- Linking CO₂ sources to storage locations through transport systems to continue through 2020.

The chart below illustrates the expected impact of this roadmap.

Achieving the Vision : zero emission power plants by 2020



The left axis shows the CO₂ that would be avoided by the progressive deployment of ZEPs. The red line shows how costs could be expected to decline as we move from R&D to industrial-scale deployment. Once the expected cost of deployment is less than the expected long-term value of CO₂ traded in the EU ETS, commercial entities will invest in industrial-scale projects.

However, that situation does not exist today and given the 5-year project lead-time, even when it does, it will be 5 years before ETS-enabled projects begin storing CO₂. To enable deployment before it can be financed by the EU ETS, a combination of national and European policies is essential. If this is developed between 2008-2012, it would enable increasing numbers of ZEP projects, with the impact in terms of CO₂ avoided shown by the green area.

To allow the development of those policies and reduce the cost of deployment, the implementation of 10-12 large-scale demonstration projects is therefore vital. The chart illustrates the impact of 10 such projects, enabled by European early mover funding mechanisms.

Glossary

CASTOR	Capture and Geological Storage of CO ₂
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CO ₂	Carbon Dioxide
CO ₂ GeoNet	European Network of Excellence on Geological Storage of CO ₂
CO ₂ Net	Carbon Dioxide Knowledge Transfer Network
CSLF	Carbon Sequestration Leadership Forum
°C	degrees Centigrade
D&RA	Decision & Risk Analysis
DOE-NERL	Department of Energy – National Exposure Research Laboratory
EC	European Commission
ECCP	European Climate Change Programme
ECBM	Enhanced Coalbed Methane
EGR	Enhanced Gas Recovery
EIA	Environmental Impact Assessment
ENCAP	Enhanced CO ₂ Capture in Power stations (FP6)
EOR	Enhanced Oil Recovery
EU	European Union
EU ETS	European Union Emissions Trading Scheme
FEP	Features-Events-Processes
FP5	Fifth Framework Programme
FP6	Sixth Framework Programme
FP7	Seventh Framework Programme
GESTCO	Geological Storage of CO ₂ Project
GHG	Greenhouse Gas
GMO	Genetically Modified Organism
HSE	Health, Safety and Environment
H ₂ O	Water
H ₂ S	Hydrogen Sulphide
IEA	International Energy Agency
IGCC	Integrated Coal Gasification Combined Cycle
IPCC	Intergovernmental Panel on Climate Change
JI	Joint Implementation

k	Thousand
kt	Kilo tonnes
kW	Kilo watt
LCA	Life Cycle Analysis
m	Million
Mt	Mega tonnes
Mt/y	Mega tonnes per year
MW	Mega Watts
MWh	Mega Watt hour
MW _e	Mega Watt electricity
MW _{th}	Mega Watt thermal energy
NGO	Non-Governmental Organisation
NO _x	Nitrous Oxides
N ₂	Nitrogen
OSPAR	OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic
ppm	Parts per million
RAC	Risk Acceptance Criteria
R&D	Research and Development
RD&D	Research, Development and Demonstration
RES Directive	Renewable Energy Sources Directive
ROC	Renewable Obligation Certificates
SBSTA	Subsidiary Body for Scientific and Technological Advice of UNFCCC
SDD	Strategic Deployment Document
SEA	Strategic Environmental Assessment
SO _x	Sulphur Oxides
SNG	Substitute Natural Gas
SRA	Strategic Research Agenda
STREP	Specific Targeted Research Projects
t	Tonne
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency
ZEP	Zero Emission Fossil Fuel Power Plant/European Technology Platform for Zero Emission Fossil Fuel Power Plants

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For more detailed information, please see reports published by the Working Groups of the ZEP Technology Platform on the website of the European Commission (see page 4).

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