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

Strategic Overview

"I applaud the efforts of the ZEP Technology Platform in moving CCS forward as a key solution for dramatically reducing CO_2 emissions in Europe"

Andris Piebalgs, *Energy Commissioner, the European Commission*

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Strategic Overview

covering
Strategic Deployment Document and Strategic Research Agenda

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Foreword

Experts agree that CO_2 capture and storage technology (CCS), together with improved energy conversion efficiency, is a near-term solution to reducing carbon dioxide 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 CO_2 storage is not sufficiently defined.

Following the priority given to "zero emission power generation" in the Sixth Framework Programme (FP6), industrial stakeholders and the research community therefore united to form the European 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 established. The Technology Platform was officially launched in December and a Vision Paper was published the following May.

In August 2006, the Technology Platform then published two key documents – the ***Strategic Deployment Document (SDD)*** and the ***Strategic Research Agenda (SRA)***. While the SDD outlines how we can accelerate the market for deployment, the SRA describes a collaborative programme of technology development for reducing the costs and risks. This Strategic Overview is a summary of both documents, providing key highlights and recommendations on concrete actions required to realise our Vision:

To enable European fossil fuel power plants to have zero CO_2 emissions by 2020.

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Key recommendations

The European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP) recommends (under the Seventh Framework Programme, FP7):

ZEP Deployment Strategy

1. **Kick-starting the CO_2 value chain with urgent short- and long-term commercial incentives:**
   - By 2007, clarify the conditions under which the geological storage of CO_2 qualifies for the EU Emissions Trading Scheme (EU ETS) and other incentive mechanisms
   - By 2007, clarify CCS status under European Union (EU) 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 CO_2:**
   - By 2007, amend existing EU legislation (concerning waste and water) in order to clarify the conditions under which CO_2 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.

"The immediate and wide implementation of CCS is vital if we are to avoid the devastating – and irreversible – consequences of climate change"

Frederic Hauge, *President, the Bellona Foundation*

ZEP Research Agenda

1. **Urgently implementing 10-12 integrated, large-scale CCS demonstration projects Europe-wide:**
   - Improve the cost-effectiveness and availability of current CO_2 capture technologies; optimise energy conversion efficiency when integrated into a power plant; and bring to commercial readiness by 2020
   - Assess the full potential for CO_2 geological storage, demonstrate its safety to the public and understand/respond to their concerns
   - Resolve all technological uncertainties and establish a critical mass of data for exploitation in parallel R&D projects.
2. **Developing new concepts already identified, but not validated, for demonstration by 2010-2015 and implementation beyond 2020, e.g.**
   - Advanced new materials and combustion systems
   - Storage in onshore, deep saline aquifers and CO_2 for Enhanced Oil Recovery in the North Sea.
3. **Supporting long-term exploratory R&D into advanced, innovative concepts for implementation of next-generation technology, e.g.**
   - Innovative CO_2 capture technologies (membranes, adsorption etc.)
   - Innovative concepts for CO_2 storage
   - Simple, reliable tools for long-term modelling and monitoring of CO_2 storage.
4. **Maximising cooperation at national, European and international level:**
   - Mobilise national and European funding and explore new options for launching large integrated projects, such as Joint Technology Initiatives
   - Further promote international cooperation, especially with emerging countries such as China and India.

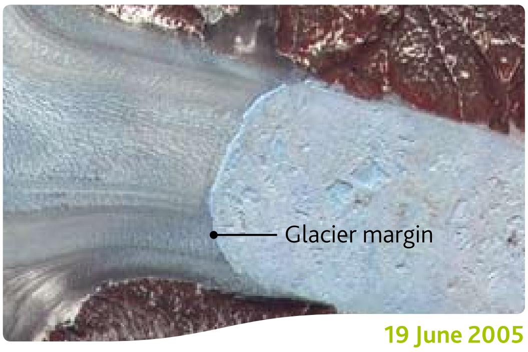
1 CO_2 capture and storage: its time has come

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 CO_2 – and by 50%-80% by 2050, according to the IPCC[1]. This is confirmed by the EU Green Paper on energy[2]. Yet with world energy demand predicted to increase by 60% between 2002 and 2030[3], and renewable energies to make up only a third[4] 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.

12 May 2001

7 July 2003



19 June 2005

Source: NASA

Helheim is one of many glaciers in rapid retreat. If Greenland or West Antarctic Ice Sheets began to melt irreversibly, the rate of sea level rise could more than double[5]

CCS could reduce CO_2 emissions in the EU by over 50% 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 CO_2 emissions on the massive scale required. To these, we must therefore add CO_2 capture and storage (CCS) technology.

1 Intergovernmental Panel on Climate Change, "Third Assessment Report – Climate Change 2001", Cambridge University Press, 2001

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

3 The IEA World Energy Outlook, 2005

4 Shell's Long-Term Energy Scenarios

5 The Stern Review, October 2006

"WWF believes that CCS has the potential to be an important part of the solution to stay below 2°C global warming and cut CO_2 emissions by more than 50% globally"

James Leape, *Director General, WWF International*

As a safe and efficient method of capturing and storing billions of tonnes of CO_2 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 CO_2 emissions in the EU by 56% by 2050, compared to today[6].

That's because power plants equipped with this technology will emit less than 10% of their produced CO_2. 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 CO_2 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 CO_2 emissions from European fossil fuel power plants by 2020. The task? To implement a complete CO_2 value chain – from the capture of CO_2 at large emission sources, to its transportation to storage sites, to its storage in underground geological formations.

It is an ambitious goal, but an entirely feasible one. After all, the technology has been practised within the oil and gas industries for decades. This is borne out by the number of CO_2 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, not only to reduce the cost and increase the efficiency of CO_2 capture technologies, but demonstrate the safety and feasibility of large-scale CO_2 geological storage. There is certainly no shortage of suitable storage sites – on land or offshore.

We therefore need to initiate the immediate large-scale deployment of CCS, starting with 10-12 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 advanced concepts – in order to accelerate technology development.

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

What are the main drivers for research?

a) Reduce CO_2 capture and power plant costs

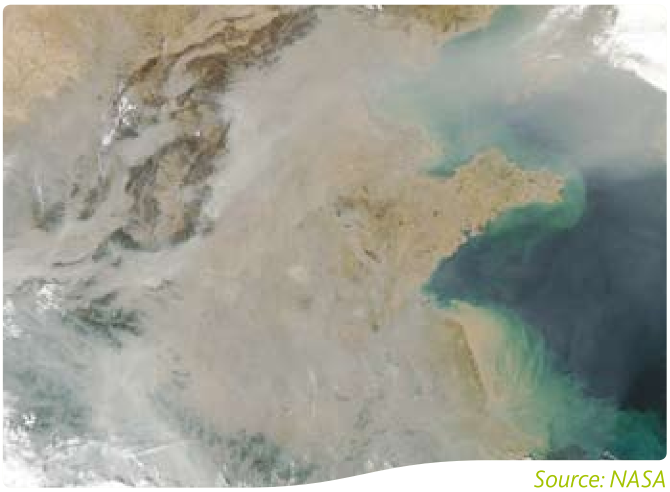
If all R&D gaps are addressed, the three main CO_2 capture technologies are certainly considered capable of achieving commercial readiness by 2020. In fact, they have the potential to satisfy market demand not only in Europe, but worldwide, if global CO_2 challenges are to be met.

Their demonstration in full-scale plants is therefore of critical importance, supported by parallel R&D on key technical issues. These plants should use hard coal, lignite, gas and biomass, and cover the full range of CO_2 capture systems.

b) Demonstrate the safety of CO_2 geological storage

Experts already agree that CO_2 geological storage is both practical and safe. But if we are to gain public support, it must be proved beyond doubt through large-scale demonstration projects, in parallel with an R&D programme for assessing storage capacity and the behaviour of CO_2 underground.

It means building about 10-12 full-scale storage sites, in a variety of geological and geographical settings, Europe-wide. With a lead time of 5-10 years, this will almost certainly be during the seven-year running period of FP7. Such projects would provide a critical mass of scientific data for proving that operations, monitoring, verification, risk and mitigation can indeed be carried out in a manner acceptable to both regulators and the public.



Source: NASA

CCS represents a global business opportunity to reduce CO_2 emissions, especially in countries such as China.

A coordinated 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 CO_2 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.

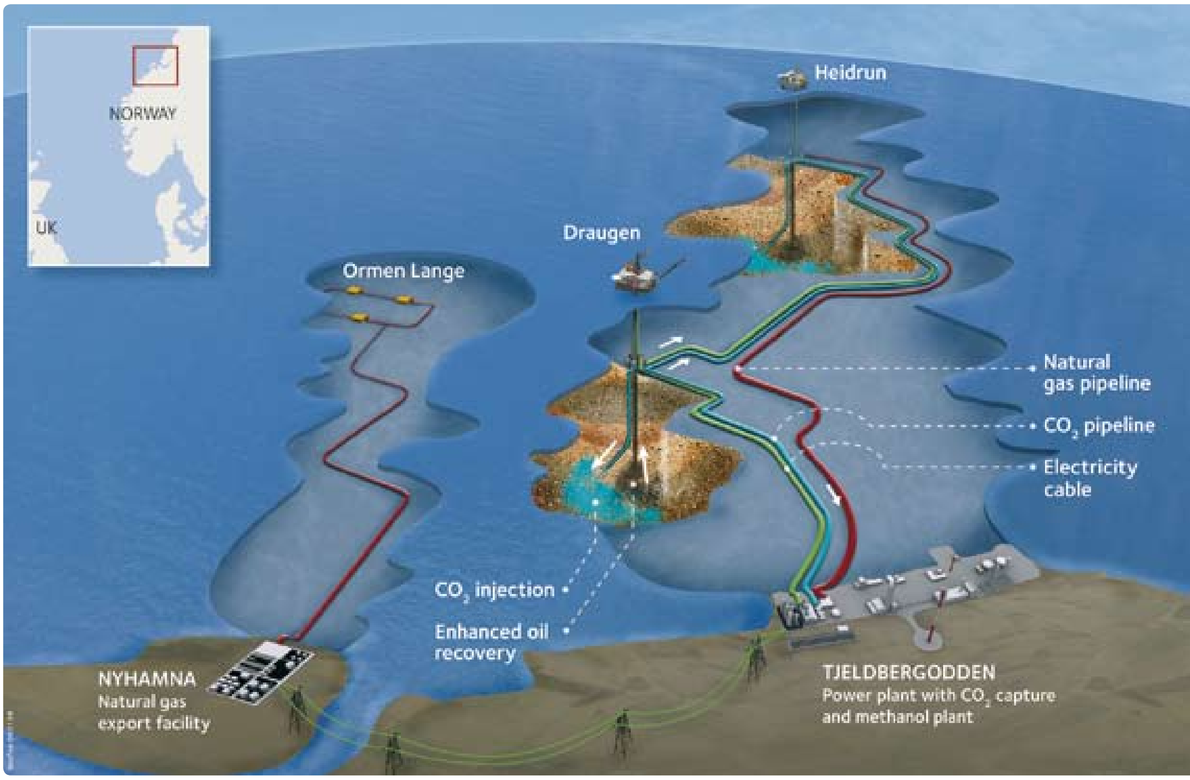
European early mover funding mechanisms will be key to achieving this objective.

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 European Climate Change Programme (ECCP) 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.

Shell and Statoil are developing the world's largest integrated CO_2 project for gas power and Enhanced Oil Recovery at Halten, which could potentially utilise, and permanently store, more than 2 million tonnes of CO_2 a year



The cost of *not* reducing CO_2 emissions…

While we can broadly estimate the investment required to implement CCS, 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 CO_2 emissions.

According to the latest report published by the Intergovernmental Panel on Climate Change (IPCC) – "Climate Change 2007" – GHG emissions have already made the world 0.76° C warmer and, if no action is taken, there is likely to be an increase of between 2.4° and 6.4° 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 CO_2 emissions.

2 Lowering the cost of CO_2 capture

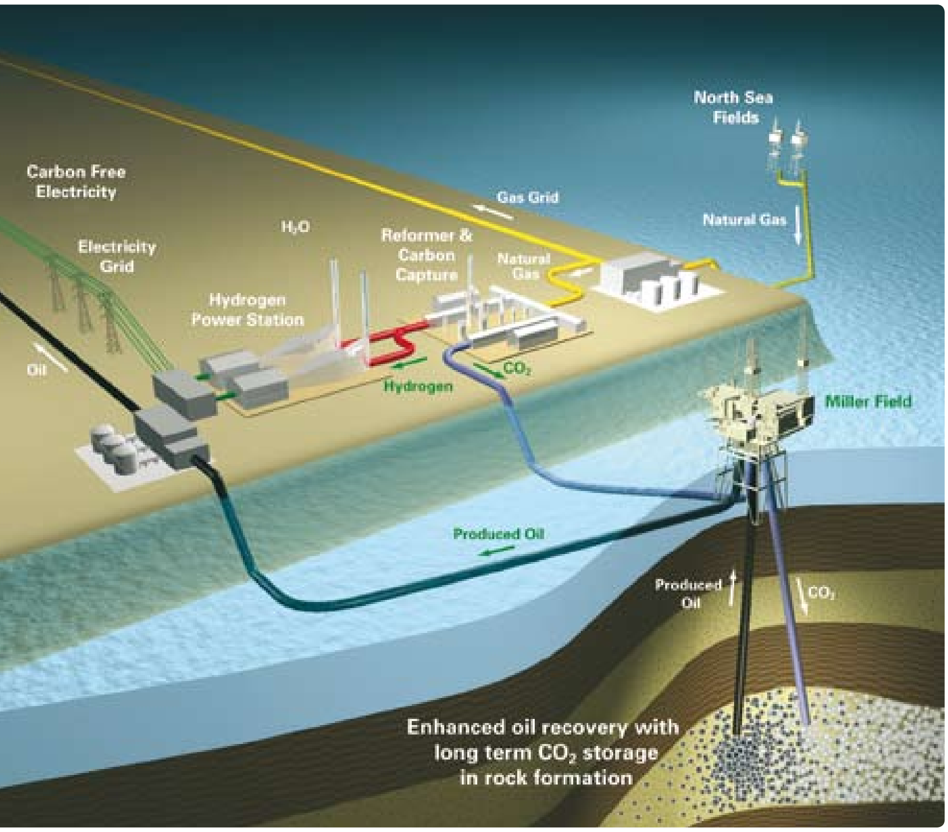
The purpose of CO_2 capture is to produce a concentrated stream that can be easily transported to a CO_2 storage site – a deep underground geological formation.

CO_2 capture applies mainly to large power plants fired with hard coal, lignite or natural gas[7]. It also applies to large, single-point emission processes such as refineries, cement plants, chemical plants and steel mills. It can even apply to biomass, paving the way for net *negative* emissions, because biomass also draws CO_2 down from the atmosphere while it is growing.

Proven technology…on a small scale

There are three main technology options under development:

- **Post-combustion** systems separate CO_2 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.



BP's Peterhead project in North East Scotland will not only utilise CO_2 to increase oil production, but produce hydrogen to generate 475MW of clean electricity

- **Pre-combustion** systems process the primary fuel (natural gas or synthetic gas from coal) in a shift reaction to produce streams of CO_2 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 H_2O and CO_2, which can be easily captured after the water vapour is condensed.

The monitoring, risk and legal aspects associated with CO_2 capture present no significant new challenges, as they can easily be added to well-established health, safety and environmental control regulations within related hydrocarbon industries.

7 Although several CO_2 capture technologies for coal also apply to oil, it is not considered an economically preferred fuel for future power generation (except for niche applications)

"Future commercial use of hydrogen requires CO_2-free or CO_2-lean production technologies. In this context, CCS can contribute to a hydrogen economy"

Prof. Dr Herbert Kohler, *Chairman, European Hydrogen and Fuel Cell Technology Platform*

Why research is needed…

In principle, all three technologies can be applied using commercially available equipment, with varying degrees of system modification. However, a significant scale-up will be required – 20-50 times – including full process integration and optimisation. Minimising the energy requirements for CO_2 capture and improving the efficiency of energy conversion processes are also essential for reducing costs and the consumption of primary energy sources (which CO_2 capture increases).

Making ZEP cost-competitive with other forms of power generation

Our primary goal is therefore to make power generation with CCS competitive with low or zero CO_2 power generation technologies, by:

a) Increasing the efficiency of energy conversion processes

As more efficient ZEPs replace the older, less efficient ones, and improved technology reduces construction costs, it is estimated that net impacts will be compatible with clean air emission goals for fossil fuel use by at least 2020[8].

b) Taking the CO_2 trading system into account

Prices are also affected by the CO_2 trading system – if the price of CO_2 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, CO_2 avoidance costs of €15-€25/t CO_2 should therefore be assumed as ambitious goals.

c) Improving CO_2 capture technologies and power systems

New or improved methods of CO_2 capture, combined with advanced power systems and industrial process designs, can significantly reduce CO_2 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.

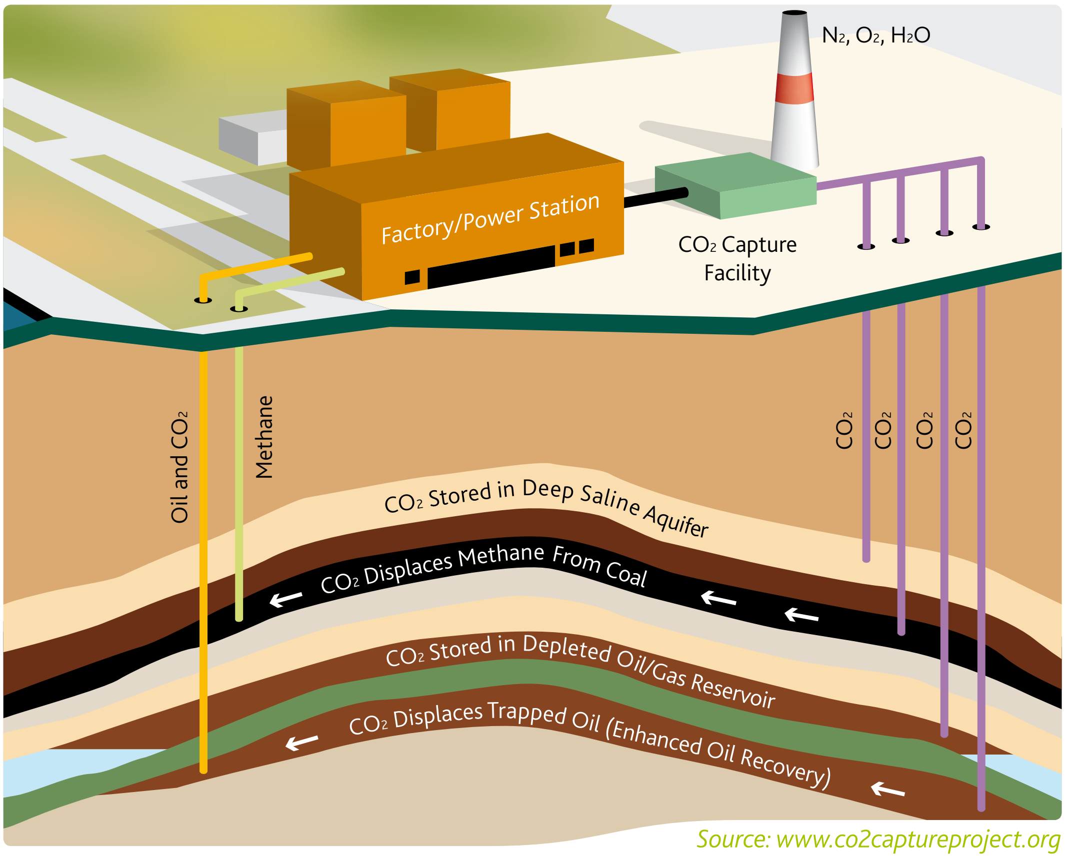
Indeed, each is considered capable – subject to substantial R&D and economies of scale – of delivering future zero emissions power at electricity prices of €45-€55/MWh for coal and around €60/MWh for gas with CO_2 avoidance costs of €15-€25/t CO_2 for coal and €50-€60/t CO_2 for natural gas (calculated with current fuel prices and excluding CO_2 transport and storage costs).

8 IPCC Special Report on Carbon Dioxide Capture and Storage, 2005

3 Demonstrating the safety of CO_2 geological storage

The existence of suitable geological storage capacity is clearly prerequisite and no shortage of storage options is anticipated – on land or offshore. Their relative order-of-magnitude potential may be expressed, very simply, as follows:

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



Source: www.co2captureproject.org

There is a wide variety of options for CO_2 underground storage available

Why research is needed…

For any geological formation, research is needed to improve capacity assessment and ensure that CO_2 can be stored safely for a long period of time. This includes developing proper modelling and monitoring tools, together with knowledge on trapping mechanisms, rock and fluid properties, stability/integrity and CO_2 mobility. It also means establishing a European leakage laboratory site(s) in order to study leaks and their consequences in a controlled environment.

In addition, urgent field studies are required to investigate opportunities for using CO_2 for Enhanced Oil Recovery as the most attractive option for early ZEP deployment.

"The Utsira deep saline aquifer is big enough to store all the CO_2 emissions from all the power stations in Europe for the next 600 years!"

Niels Peter Christensen, *Geological Survey of Denmark and Greenland*

No shortage of storage options is anticipated

Deep saline aquifers (or formations) have the largest storage potential globally, but are the least well explored and researched. We therefore need to build a more comprehensive dataset of their geological characteristics.

Using CO_2 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 offset costs from the additional oil production. Indeed, when used in this way, CCS could contribute to improved energy security for Europe. EOR may also be combined with the storage of even more CO_2 after the commercial life of the fields ends.

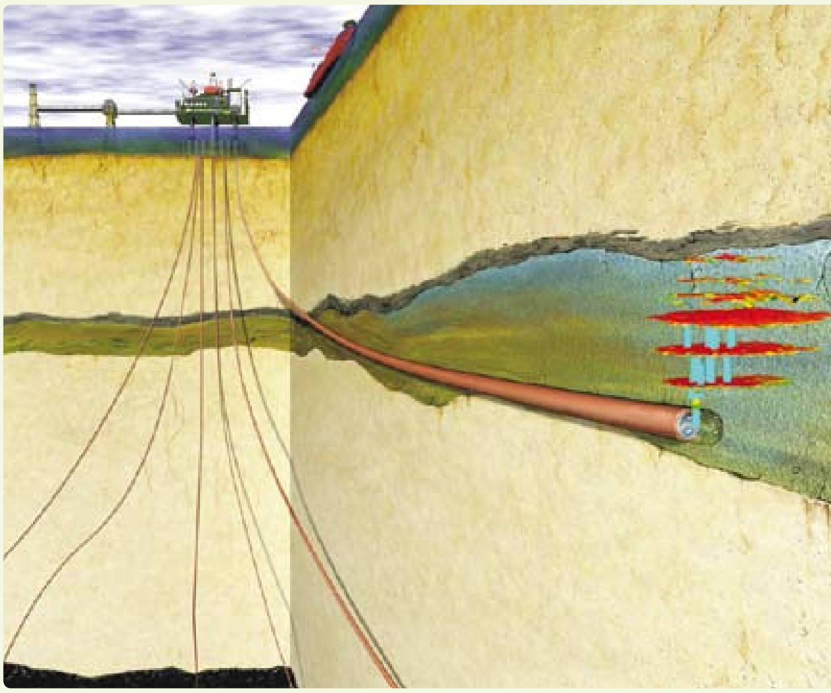
Although at the experimental stages, **Enhanced Gas Recovery** (EGR) is a promising technology for CCS that would further increase fossil fuel resources. **Depleted oil and gas fields** are also attractive because the geology is well understood and existing infrastructure recyclable. **Enhanced Coalbed Methane (ECBM)** has similar potential. Other options, although limited, include **deep unmineable coal beds**, which may become quite important in some coal provinces. **Mineral sequestration**, which consists of trapping CO_2 by reacting with basic rock material, is still at an exploratory stage.

What is clear is that CO_2 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.

Zero leakage from the Utsira storage site

In storage sites that are well-sited, operated and monitored, leakages simply should not happen at any significant level. This is borne out by experience: for example, one million tonnes of CO_2 from Statoil's Sleipner gas field has been stored in the Utsira deep saline aquifer – 1,000 metres beneath the North Sea – every year since 1996. Since then, sophisticated monitoring equipment has not detected any leakage of CO_2.

In fact, experts agree that it is very likely that the fraction of CO_2 retained will be more than 99% over the first 100 years and likely that the fraction of CO_2 retained will be more than 99% over the first 1,000 years (IPCC Special Report on Carbon Dioxide Capture and Storage, 2005)



Since 1996, one million tonnes of CO_2 has been stored successfully every year in the Utsira deep saline aquifer

4 Building a transport infrastructure

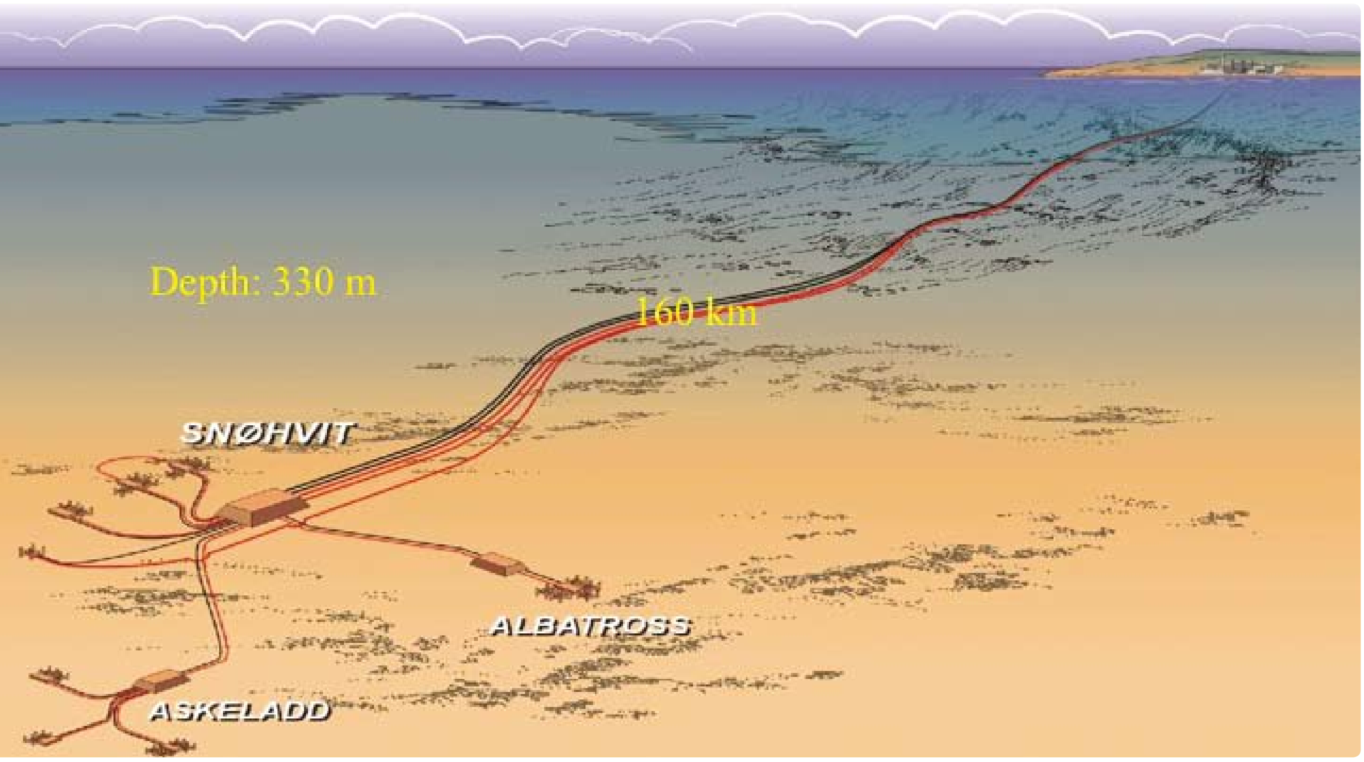
The transportation of CO_2 is already well understood – it has been shipped regionally in small liquid quantities for the last 15 years and a 4,000 km onshore network has been in operation in the US for the past 30 years; while in Europe, at the Snøhvit Liquefied Natural Gas (LNG) processing facility in the Norwegian Sea, a pipeline to an offshore CO_2 storage site is due to start operating in 2007.

A wealth of experience to draw upon

There is also extensive knowledge of the liquid propane gas (LPG) and LNG industries upon which we can draw. Indeed, experience in hydrocarbon pipeline transportation can be transferred directly to CO_2 transport.

Why research is needed…

While there are very few major research gaps regarding CO_2 transportation, all pipeline, ship and equipment materials, metallurgy and seal technologies must be sufficiently advanced to meet safety and environmental requirements for transport systems. Analyses must also be performed to determine how impurities in the CO_2 might react in different transport settings, as well as storage locations.



Snøhvit will be the first LNG processing plant of its kind in Europe, storing 0.75 million tonnes of CO_2 a year from 2007 in the Barents Sea

"Many elements of CO_2 transportation are directly transferable from the oil and gas industries"

Olivier Appert, *Chairman and CEO of Institut Français du Pétrole*

What are the options?

In general, pipelines are used for large volumes over shorter distances, while ships can be used for smaller volumes over long distances; trains and trucks are rarely used. Due to their lower cost, pipelines will ultimately dominate. Nevertheless, the best transport system will vary according to individual CCS infrastructure projects, according to CO_2 volume; distance between source and storage location; geography and geology of the route taken; and costs.

With many potential storage sites both onshore and offshore in Europe, new and ongoing studies are needed to determine the optimal linking of CO_2 sources with storage locations, aimed at minimising costs and the environmental footprint. Transparent rules and tariffs for CO_2 transportation will also need to be established.

Our long-term strategy is to link large-scale plants together, where economically feasible. An infrastructure for EOR in the North Sea is probably the first, larger regional infrastructure that can be built. It could begin within the next 5-8 years, capturing and storing more than 30 million tonnes of CO_2 a year.

It is essential that we do not wait for the CO_2 infrastructure to be fully established before developing initial projects – they can be carried out in parallel with the deployment of an overall infrastructure.

5 Moving from small to industrial-scale CCS projects

The good news is that technologies required for CO_2 capture and storage have been practised for many years – 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 CO_2 have 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. However, some elements such as storage site monitoring and CO_2 migrations need to be tested more in this context.

CO_2 storage is already a fact

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. It is now essential that we apply that research in the marketplace, in parallel with associated R&D projects. A number of demonstrations of CO_2 geological storage are already under way, including:

- Sleipner, Norway – 1 million tonnes (Mt)/year in the North Sea since 1996
- K12B, Netherlands – CO_2-EGR, some hundred kilo tonnes (Kt)/year in the North Sea since 2004
- In Salah, Algeria – 1.2 Mt/year, since 2004
- Ketzin, near Berlin, Germany – some 60Kt over a few years (starting 2007)
- Snøhvit, Norwegian Sea – 0.75 Mt/year, starting 2007

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

Indeed, as many as 13 combined CO_2 capture and storage projects have already been announced – or are under way – in Europe, demonstrating the confidence industry has in this technology[9].

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

RWE's CCS project based on IGCC technology* will produce 350MW net electricity and store 2.3 million tonnes of CO_2 a year in a depleted gas reservoir or deep saline aquifer

** Integrated coal gasification combined cycle*

9 See the Strategic Deployment Document for details: www.zero-emissionplatform.eu/website/library/index.html

6 Kick-starting the CO_2 value chain

The reason why CCS technology has not yet fulfilled its potential is very clear: 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, it explains why CO_2 projects have been so rare – and will continue to be – until long-term fiscal incentives and a regulatory framework are established.

Major projects require major funding

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 CO_2 capture, each facility for a large-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.

Incentivising the early movers

Nevertheless, at current trading levels (€10-20/t CO_2), 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.

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. There must also be consistency with the stimulation of other parallel developments in clean energy/fuels available to Member States.

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 CO_2 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 CO_2 used for CCS projects is fully accredited under EU ETS, as well as the Clean Development Mechanism (CDM). Longer-term regulations must also be in place to govern the EU ETS beyond 2012.

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.

Kyoto and beyond

Projects must also be viewed in the context of obligations to the Kyoto Protocol and any successors, including Joint Implementation (JI)[10] and Clean Development Mechanism (CDM)[11] projects. The CDM, in particular, is an important pathway for incentivising investment in CCS activities.

Creating a level playing field

The present legislative system was not written with CCS in mind and is currently being revised. In fact, a positive movement to permit CCS has already begun, initiated by the European Commission itself (via a Directorate General Environment taskforce): the London Convention[12] has already drafted a proposal that sub-sea CO_2 storage should be permitted and the London Protocol[13], UNFCCC[14]/SBSTA[15], IPCC and OSPAR[16] are in a similar process.

It means creating a level playing field for all industrial actors, with a common legislative framework where 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 – at least 30 years.

Many international, regional and EU legal frameworks are relevant to CCS, with definitions and prohibitions that are sufficiently broad to encompass and regulate various CCS activities. However, only a few explicitly address them. Laws and treaties regulating the economics involved when CO_2 crosses country borders must also be consistent within all countries involved in a CO_2 infrastructure.

10 Part of the Kyoto Protocol, Joint Implementation (JI) provides for projects aimed at reducing emissions or removing carbon from the atmosphere

11 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 more costly emission reductions within their own countries

12 The London Convention sets out rules to prevent marine pollution by the dumping of waste, with over 77 member countries

13 The London Protocol also governs the prevention of marine pollution by the dumping of wastes etc

14 United Nations Framework Convention on Climate Change

15 Subsidiary Body for Scientific and Technological Advice of UNFCCC

16 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 European Commission, France, Germany, the Netherlands, Norway, Spain and the UK

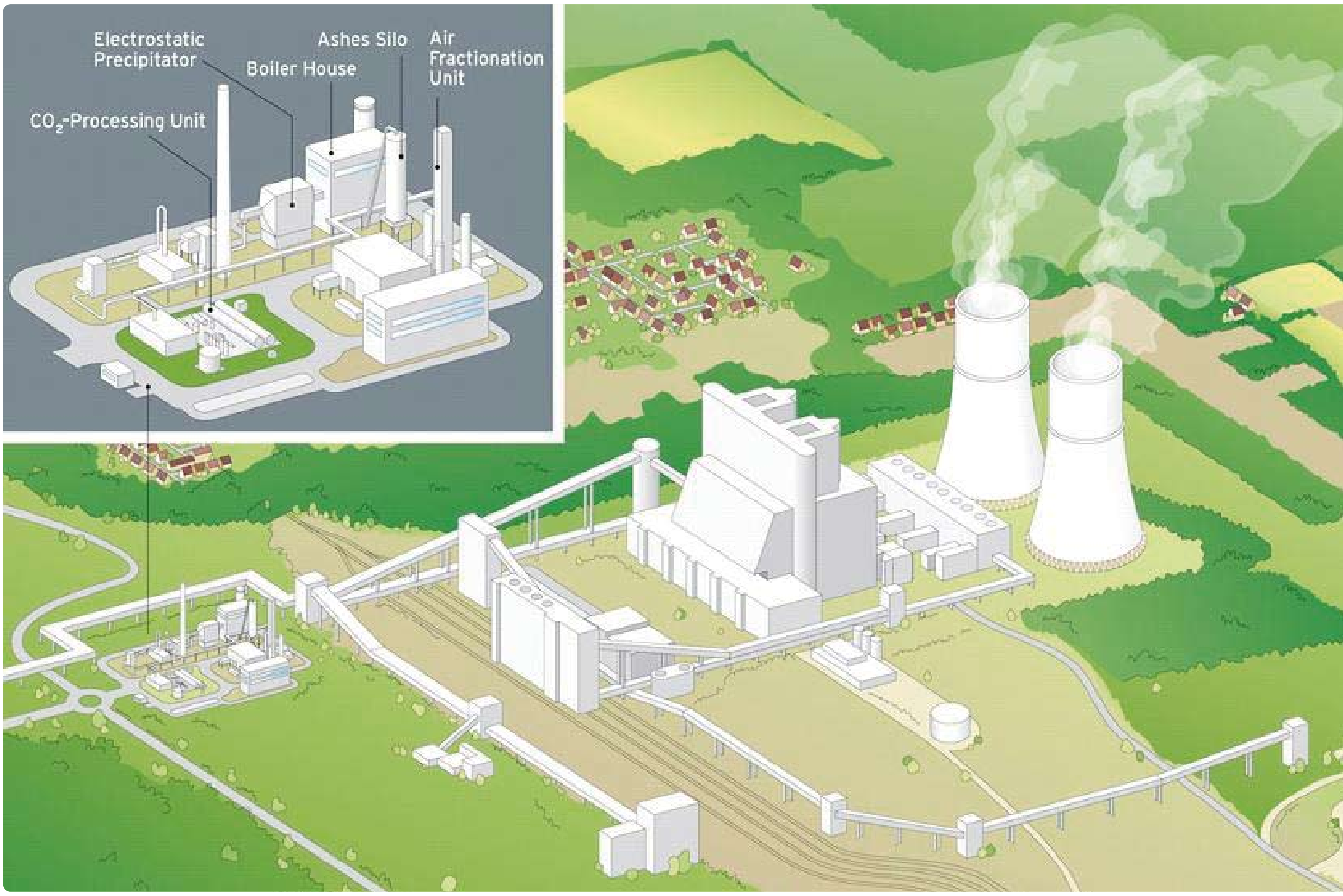
"With the right incentives, the private sector can deliver solutions. Delay would be costly or dangerous"

Sir Nicholas Stern, *The Stern Review, October 2006*

Who is liable?

Although any CO_2 leakages will be identified and immediately corrected due to rigorous risk monitoring systems, clear regulations on liability must be established, based on the principles of the Environmental Liability Directive. This will have a significant impact on our ability to reassure the public.

CCS liability issues are actually very similar to those of other industrial activities and gases. Indeed, CO_2 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.



Vattenfall Europe is building a 30MW$_{th}$ coal-fired pilot boiler with oxy-fuel CO_2 capture technology at Schwarze Pumpe in Germany

7 Resolving environmental issues

Experts already agree that storing CO_2 underground should pose no health, safety or environmental hazard – either over the short or long term. Indeed, CO_2 is comparatively benign – it will neither burn nor explode and even comprises 8% of human breath! It is worth remembering that there are billions, maybe trillions, of tonnes of CO_2 already present in nature – in volcanic areas, it seeps out daily.

CO_2 has been handled successfully for decades

In fact, CO_2 has also been handled successfully for decades and any risks implied with its use have been effectively managed or mitigated: many existing post-combustion capture plants already produce high-purity CO_2 for use in the food industry and other industries.

Zero tolerance for CO_2 leakages

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.

Well-established monitoring and remediation techniques from the oil and gas industries are directly transferable to CCS

"It is far safer to put CO_2 into the ground than into the sky – and we have the knowhow"

Dr John Ludden, *Executive Director, British Geological Survey*

Developing a clear risk management strategy

However, 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. This means developing a clear risk management strategy, including Risk Acceptance Criteria (RAC), in order to drive regulations, ensure compliance by CO_2 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. 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.

Although some CO_2 capture processes and materials produce wastes, both CO_2 capture and transport are already covered by well-established frameworks for permission and organisational processes. With CO_2 storage, the main risk of leakage is due to wells, faults and seals. Although the best corrective actions are still under discussion, experience in the oil and gas industries is directly transferable.

Why research is needed…

Although much environmental research has been done in the area of CO_2 ground contamination, further studies are required. These should cover the entire CO_2 infrastructure chain – including CO_2 capture plants, onshore and offshore pipelines, ships, storage sites and process equipment – to assess any risk of leakage.

8 Gaining the support of the public

The heated debate over GMOs[17] 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 – at every stage of its development and implementation.

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

CCS: the bridge to a sustainable energy system

It must 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 energy are therefore *complementary* – not competing – strategies, with the latter still our ultimate, long-term aim.

Industrial-scale demonstration projects provide the ideal opportunity to engage with the public and understand their concerns. This should form part of a comprehensive public information campaign, for which funds must be set aside – around €250k per country. Timing is 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.

17 Genetically modified organisms

"At this early stage in the public awareness of CCS, we need to gain experience with real projects that meet tight regulatory standards and move us up the technology learning curve"

Dr David Reiner, *Course Director of the MPhil in Technology Policy, University of Cambridge*

Why research is needed…

A successful outreach campaign requires in-depth knowledge of the public's perception of both CCS and climate change using sophisticated socio-economic research tools.

While CO_2 capture itself is not of particular concern for the public, its acceptance of the need to commercialise CO_2 capture technologies is vital to securing funding and technical resources. Based on the results of transparent and publicly available risk assessments, it can be assured that underground CO_2 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, as opposed to 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.

9 Looking ahead to 2020

Given the urgency of the situation, deployment of CCS must begin with the implementation of the most promising technologies available today. However, as the application of CCS grows and the industry opens up to more players, many new technologies may become available which have not yet been identified.

If next-generation technology is to be ready for implementation by 2020, longer-term exploratory research into advanced, innovative concepts must begin immediately.

It means providing dedicated training and education to the next generation of professionals. Geo-science and engineering disciplines are currently dominant within CO_2 storage and these will need to be supplemented by a broader range of professionals within biology, social sciences, communications, legal and financial issues etc. Developing existing and new CO_2 networks in Europe is also key.

Maximising EU and international cooperation

Strong cooperation from all stakeholders will therefore be required in order to optimise resources, avoid duplication and maximise synergies. The ZEP Technology Platform will obviously play a key role in promoting coordination at a European level – between power and utilities, oil and gas companies, equipment manufacturers and R&D centres.

Ensuring Europe maintains its competitive edge may also require a dedicated programme, in the form of a public-private-partnership, in order to accelerate the development and demonstration of innovative technologies on a large-scale.

FENCO ERA-NET
Fossil Energy Coalition

This is already happening: the EC is not only coordinating Member State activities through the European Research Area (e.g. FENCO ERA-NET initiative[18]), but playing an active role in many global initiatives, e.g. the Committee of Energy Research and Technology (CERT) and Working Party on Fossil Fuels (WPFF) of the International Energy Agency (IEA) and the Carbon Sequestration Leadership Forum (CSLF), which involves 22 countries worldwide.

The EU also has Science and Technology Cooperation Agreements with many countries, such as Argentina, Australia, Brazil, Canada, China, India, Russia, South Africa and the US. Indeed, the role of emerging countries such as China, India and Brazil will be vital to curbing future CO_2 emissions.

Making the link

It is equally important to link up with other related European Technology Platforms and initiatives in order to maximise opportunities in sustainable energy, i.e. Advanced Engineering Materials and Technologies (EuMaT); Steel (ESTEP); Hydrogen and Fuel Cells; Sustainable Chemistry; Biofuels; and Sustainable Mineral Development.

18 Fossil Energy Coalition

10 Conclusion

The goal of the ZEP Technology Platform is clear: to enable zero CO_2 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 CO_2 capture technology must be commercialised, storage locations identified and full-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.

As importantly, Europe needs to commit to a fully coordinated research agenda in order to:

a) Bring current CO_2 capture technologies (together with improved power plant efficiency) to commercial readiness by 2020

b) Develop new concepts for implementation beyond this date.

Time is not on our side

But none of this will be achievable without full public support. Indeed, implementing a comprehensive outreach campaign is a matter of urgency – not only to reassure the public, but convince them of the necessity of deploying CCS as soon as possible. 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:

Achieving the Vision: zero emission power plants by 2020

DEPLOYMENT

- Introduce the need for 10-12 CO_2 capture and storage demonstration projects 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 JI[19].
- Identify CO_2 point-sources and possible locations for new power plants (and other industrial plants with large CO_2 emission) and storage sites in 2007.
- 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.
- Define optimum model for the European CO_2 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.

19 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 CO_2 transport infrastructure in 2010.
- Each power plant has its own plant life cycle. By 2015, all power plants which are due to be replaced, or have increased capacity, should be assessed for CO_2 capture.
- Build 4-6 onshore storage sites by 2015 (with a minimum capacity of 2 million tonnes CO_2).
- Linking CO_2 sources to storage locations through transport systems to continue through 2020.

RESEARCH

- Promote R&D activities which enhance the technological assets of the European industry in order to improve competitiveness edge.
- Introduce new options for launching integrated projects, such as public-private-partnerships.
- Define specific roadmaps for launching innovative concepts – even if commercial implementation is long-term, planning has to start now.
- Establish development tools for testing innovative processes or storage facilities. These could include specific sites dedicated to the investigation of innovative technologies, e.g. pilot plants for CO_2 capture, leakage laboratories etc.
- Define R&D projects using experimental data from demonstration projects in order to develop and validate new tools (e.g. modelling tools for CO_2 storage).
- Support the establishment of networks in key technology and scientific areas (e.g. combustion science, thermodynamics, materials, fluid mechanics, separations, geoscience). Organise meetings and promote knowledge transfer between European research centres and joint access to common tools.
- Develop an information kit for training scientists and engineers in zero emission power plant technology.

This document has been prepared on behalf of the Advisory Council of the European Technology Platform for Zero Emission Fossil Fuel Power Plants. The information and views contained in this document are the collective view of the Advisory Council and not of individual members, or of the European Commission. Neither the Advisory Council, the European Commission, nor any person acting on their behalf, is responsible for the use that might be made of the information contained in this publication.

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