THE POTENTIAL OF CARBON SEQUESTRATION TECHNOLOGIES[1]

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Minister, Ladies and Gentlemen, Good afternoon!

Thank you for the invitation, and thank you for your kind introduction, Mr. Chairman. It is a great pleasure and honour for me to be here tonight.

Addressing our global energy and climate realities is a complex and sobering task. I'll consider one aspect, or question, rather; How to cover the expected increase in energy demand, particularly in developing countries, without Greenhouse Gas (GHG) emissions running wild. What is the potential of Carbon Capture and Storage (CCS) technologies in this regard? Do they represent a sustainable solution – or may we see the sunset of fossil fuels?

But first, to appreciate the unusual dimensions of these issues, I'd like to take a step back and recall a few facts of the global energy-climate situation.

As is well known, global energy use has increased almost exponentially over the past century. It was more than doubled in just two decades from 1950 to 1970, and again from 1970 to 1990. According to the International Energy Agency's (IEA) Business as usual (BAU)-scenario, it seems likely to double again over the next 30-40 years (from 1990), as may be seen from these colored curves in figure 1.

It is not easy to capture the reality behind these figures, but if all current annual energy use of about 10 billion tons of oil equivalents, actually were oil, it would fill some 50 000 super tankers of 200 000 tons, each. Placed one after the other, with a reasonable distance, they would span the earth at equator. This is what we consume every single year, and every year we add some 1 200 new ones.

But, most important, oil, coal and natural gas; fossil fuels, today cover more than 85% of global energy supply, and this share is *increasing*, towards 90%, as most of the growth (90%+) still must be covered by fossil sources. Consequently, global energy related CO_2-emissions are expected to soar by 50%, in just 20 years, according to IEA (grey columns, in figure 1), in sharp contrast to the aims and ambitions of the Kyoto protocol of a swift decrease.

Predicting the future is a difficult business, so may not the IEA predictions be all wrong, too? Excepting global economic or other disasters, they, unfortunately, are not, for two main reasons:

[1] Carbon Abatement Technology Seminar, The Foundation for Science and Technology, Royal Society, London, October 25, 2005.

1. As shown in figure 2, according to the IEA, more than 95% of energy growth in the next 20 years will be in developing countries, not in the OECD area, as in the previous period. China and India have more than 1/3 of world population, but a current share of global annual energy consumption of less than 1/7. This situation is rapidly changing. The actual growth may be 50% lower or 20% higher than predicted; it does not really make a big difference regarding consequences. Energy demand will soar; China alone increased their oil imports by some 40% last year, destabilizing the oil market, and sending oil prices well above 50$ a barrel.

2. This growth will be increasingly based on fossil fuels (90%+), for several decades. New renewables will remain insignificant for a long time. Even in the most optimistic scenarios, with a large increase in nuclear power, renewables and energy efficiency measures, a predominant part of this energy supply will be based on coal, in fact, in China by more than 60%, if nothing drastic is done.

The question is just, what *can* be done? We are faced with a number of contradictory challenges, not properly addressed by the Kyoto protocol or any other international agreement (figure 3).

First, how do we cover this enormous short term energy demand growth in developing countries? These countries are not obliged by the Kyoto protocol. If their growth has to be covered by yesterdays' – or even today's state of the art technology based on coal, CO_2-emissions in these countries will explode; double or treble, over the next couple of decades.

Second, if the Inter Governmental Panel on Climate Change (IPCC) is anywhere near reality in their long-term scenarios, it will be necessary to stabilize atmospheric CO_2-concentrations at some acceptable level.

And, finally, as a consequence of this, it may be necessary to drastically reduce GHG emissions within a few decades.

The only viable response, then, apart from reducing demand, which may be very difficult, is changing to new low CO_2-emission (LE) energy technologies.

Our options are renewables, nuclear and CCS technologies, or reducing demand (figure 4). Renewables, that is on a large scale hydro, solar and bio-fuels, undoubtedly represent a long term, clean energy solution. Solar energy, in particular, has an almost unlimited potential, everywhere – even in cold, snowy Norway, where we, believe it or not, have some 100,000 small PV-units installed (figure 4, top left). There are two serious problems with solar power, however, one is to go from typically Watt to MW size units, and the other is costs; cost efficient solar PV-technologies are unfortunately decades away.

So, is it thinkable that we may see a renaissance of nuclear power? I definitely share the views of an increasing number of concerned scientists, as expressed by Professor James Lovelock, in Independent, May 24, last year, that in this situation, nuclear power should be de-demonized and definitely not ruled out.

Nuclear power contributes already one fourth of current electricity supply in OECD-countries, almost 80% in France, over 50% in Sweden and ca. 17% globally. A new

European Pressurized Water Reactor is now being introduced in the market, e.g. the new 1 600 MWe Finnish nuclear power plant in Olkiluoto, now under construction (figure 4, bottom left).

According to a recent OECD/NEA-study, nuclear power, from an economic point of view, is already competitive to conventional gas power, and could provide a very cost-competitive alternative if CO_2-penalties are imposed on fossil fuels. In a longer time perspective fusion may also be an option.

In the short-term, however, there seems to be a growing consensus that “clean coal” is the key to large reductions in GHG emissions.

The new Norwegian government has just announced a very ambitious commitment to implement full scale CCS solutions at all new natural gas power plants, except the first one at Kårstø, based on enhanced oil recovery (EOR), by injection of CO_2, if at all feasible. And the Kårstø plant, under construction, will be prepared for retrofitting CO_2-separation systems (figure 5).

In general, CCS solutions are still far from proven or commercial technology. There is a growing R&D effort on most aspects of CCS technologies in many countries, including Norway. But there are still no full scale or large demo plants in operation anywhere in the world.

This is to me the most important short-term issue; to develop and *build* large demo plants of, say, 100 MW, with necessary CO_2-infrastructures. This was a main recommendation of the Norwegian Gas Technology Commission. As chair of that commission, I was heavily criticized for being too pessimistic, stating that this should be achieved within 2-3 years. Today, almost 4 years later, we still have no sizable pilot or demo plants in operation, not even committed.

International cooperation is very important in this regard, and there are several recent initiatives to promote this, such as The Carbon Leadership Forum, the IEA Greenhouse Gas Program, and the European Union CCS Platform, as well as bilateral R&D cooperation between UK and Norway.

Technological innovation is crucial to reduce the CCS cost gap and minimize energy efficiency losses. As an example of new CCS concepts, the Institute for Energy Technology (IFE), in cooperation with CMR and Prototech AS is developing a Zero Emission Gas Energy Station (ZEG, figure 6).

Its main feature is to produce electricity from natural gas in a High Temperature Fuel Cell, simultaneously producing Hydrogen in an adjacent reactor, using the FC waste heat. Our objective is to achieve very high electricity efficiencies, of 70-80%, a simplified and energy efficient Hydrogen production, and to get pure CO_2 separated out, as part of the process, at no additional expense.

This is, however, a research project, so far largely funded by the Norwegian Research Council, with many uncertainties, and a time horizon of some 5-10 years. Similar systems may also be developed based on gasified coal, and there are, in fact, such initiatives in the US.

How can we get rid of the CO_2, once it has been captured? The obvious, “Standard” solution is to deposit it in deep geological formations. I’ll return to that in a minute, but it is important to be aware that alternative methods may be developed, where CO_2 is considered a *resource* rather than a waste product, that could provide added value and reduce total net costs.

The most discussed option in Norway right now is to use CO_2 from gas power plants for increased oil recovery from fields (e.g. Gullfaks) in the North Sea. A number of recent studies by the Norwegian Oil Directorate, Statoil, NVE, NGOs and others, on the use of CO_2 for enhanced oil recovery have reached very different conclusions, however, with respect to costs, process efficiency, capacities, safety, reservoir properties over field life, and so on. It is still not straightforward.

Other innovative solutions are based on the binding of CO_2 in stable carbonates from silicate minerals, such as olivine, also providing valuable commercial by-products (figure 7). The most promising from a Norwegian perspective is to use olivine minerals, with a potential capacity of some 10-20 Mt CO_2 annually over a very long period, just in Norway.

These concepts are, however, at an early stage. But preliminary studies at IFE are promising, and have indicated that large scale binding of CO_2 in this manner is feasible, and may be achieved at a cost of about 20 € per ton CO_2.

As you may know, there are recent initiatives in the North Sea region, involving several countries, to enable large-scale disposal of CO_2 in deep subsea saline aquifers, or enhanced oil recovery based on CO_2.

At the Sleipner natural gas field (figure 8), some 250 km offshore Norway, the oil company Statoil developed and operates a platform based CO_2-removal plant and injection system. Since 1996, about 1 million tons of CO_2 has been injected annually into the nearby Utsira aquifer, some 1 000 m below the seabed.

The operational experience so far is very good. The movement of CO_2 in the aquifer has been carefully monitored, and the results are promising, with no release of CO_2. The 3D buildup of CO_2 in the aquifer is clearly seen from seismic data, from 1996, 1999, and 2001, in figure 8.

Statoil has since decided to implement a similar CO_2-solution on another offshore gas field, Snøhvit, in the Barents Sea region, expected to come on-stream next year.

Carbon sequestration can never become cost free. Carbon dioxide must be separated out, pressurized, transported, injected and safely disposed of for a sufficiently long time span; thousands of years. CCS is complicated, requiring additional processes and equipment, costing money, but more important also *energy*, reducing plant efficiencies by 10 to 20%. Separation technologies are not perfect, either, resulting in some leakages of CO_2, at least of the order of 10%.

To summarize; main challenges of CCS technologies include (figure 9):

1. To reduce the CCS cost gap, and increase energy efficiencies. Technology innovation and improvement are more important than the time horizon for market introduction. Demo and pilot plant experience is critical. We don’t need too many expensive full scale technological dinosaurs.

2. To develop and establish necessary CO_2-infrastructures, with pipelines, boosting and final deposition – and quite fast.

3. The feasibility and safety of large scale global CO_2-deposition systems must be verified, and required legal frameworks and regulation regimes established in this regard (OSPAR and London Conventions). This is a top priority.

4. Evidently, CCS solutions will not be of much, in fact less, use until such infrastructures are operational, placing high risks on front-runner companies.

   And we need first suppliers and users, whose decisions have to be made in the various boardrooms, based on economic considerations.

5. Finally, we must ensure efficient introduction of CCS technologies in line with and in co-existence with renewable ones.

Looking ahead, however, the key question is the potential of CCS technologies. May these technologies actually provide a long term solution to the GHG-problem?

According to a recent IEA study from late last year, the answer is a qualified yes. CCS technologies may in theory enable stabilization of CO_2-emissions in 50 years’ time, at a slightly higher level than today. The crucial assumption is that it must cost something – quite a lot, in fact, to continue to emit CO_2 straight to the atmosphere. If not, forget it. According to the IEA, a universal, global ”Carbon penalty” of as much as 50 US$/t CO_2 is required, gradually introduced over the next ten years, and 15 years later for developing countries (figure 10).

To make a significant impact on the global climate situation, however, this requires deployment of thousands of CCS (coal) power plants over the next decades. Then, in theory, they may account for some 20% of the worlds electricity supply in 2030 and almost 60% in 2050. And, as important, the CO_2-penalty also makes renewables more competitive at an early stage.

But, an estimated 18 billion tons of CO_2 must then be separated, transported and deposited annually in 2050! Is this realistic? It is not only a question safe disposal sites and capacities, but is it feasible to establish and operate a global infrastructure for, say, 200 billions of tons CO_2-waste every decade? I’ll let that sink in for a minute.

Conclusions

Modern societies have a ”bulimic” appetite for energy, but we still do not face an immediate energy resource crisis (figure 11). Again, according to the IEA, oil resources are adequate to cover global needs to 2030 and some time beyond; gas and coal for a significantly longer time span. However, there certainly is a growing concern regarding security of supply of oil and gas, as two thirds of current reserves are in a very small region, the Middle-East countries.

Fossil fuels today cover more than 85% of global energy supply, and this share is increasing, towards 90%. New renewables will remain insignificant, and oil and gas will be with us for a long time.

The gap between the factual and the politically desired energy-climate situation and development widens. If the anthropogenic climate issue really becomes serious, and we have to stabilize atmospheric CO_2-levels and thus reduce emissions drastically, we face a serious challenge indeed; to develop and deploy competitive Low Emission technologies on a very large scale, in just a few decades.

In addition to reducing demand, our options are renewables, nuclear and CCS technologies.

CCS solutions are still far from proven commercial technology (figure 12). There are no sizeable demo plants in operation, anywhere. And several such plants need be established right away, if we are to have any hope of developing competitive CCS technologies within a few decades. Cost reduction through innovation and learning by error is critical in this respect. We cannot afford too many expensive full scale technological dinosaurs.

According to a recent IEA study, stabilization of CO_2-emissions by CCS technologies is feasible, not tomorrow, but in a long-term, 50 years perspective. Even with that time horizon, we are forced to ask; is this realistic? There are no full-scale power plants with carbon sequestration in operation anywhere in the world today, not a single one. But this is not the main issue, the real nut is if we can produce hundreds – thousands - of these plants, in time? And will we be able to establish and operate global infrastructures for 15-20 billions of tons of CO_2-waste annually? May CCS technologies provide a sustainable solution, or will they only be a necessary transitional fix, a historical parenthesis?

I don’t know, these are rather my questions for your discussion. But from on our current technological basis, the answer must be no.

There are *no* simple solutions. Changing energy technologies takes a long time and is very costly. Even if Governments put top priority on these issues, we may not be able to stabilize CO_2-emissions and CO_2-levels, in time. In that case we must also be prepared to cope with the consequences of climate change.

So, to conclude, I think the only prudent approach at this point is to follow the recommendation of the World Energy Council’s Congress in Sydney last year: “Keep all options open”.

Thank you for your attention!

Figure 1: Global energy use 1850-2030

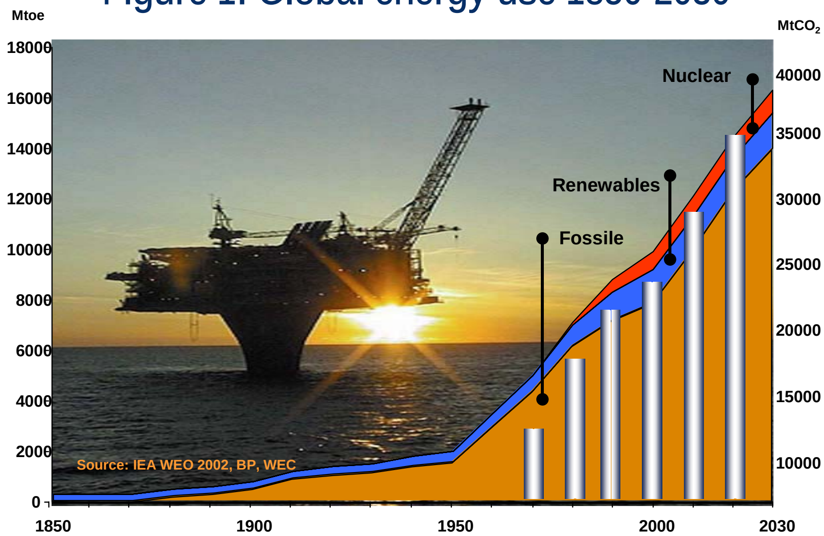

Figure 2: Global energy demand growth

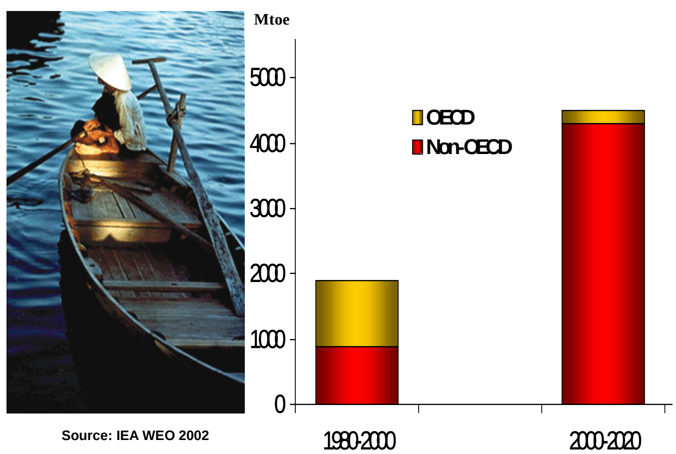

Figure 3: Global energy and climate realities

Three main challenges, not properly addressed in the Kyoto protocol:

1 The enormous short time growth in energy demand in developing countries

2 The necessity to stabilize atmospheric CO_2-*levels*, if the IPCC's 50 years scenarios are realistic

3 As a consequence, to drastically reduce GHG-emissions within a few decades or face climate changes

The response: To develop and *deploy* new Low Emission (LE) technologies on a very large scale

Figure 4: The response: Low Emission Technologies
Renewables, Nuclear and CCS

Figure 5: Norwegian CCS Technology Projects
The Kårstø 420MWe plant: CCS with EOR?

Figure 6: Emerging concepts
The IFE Zero Emission Gas Energy Station (ZEG)

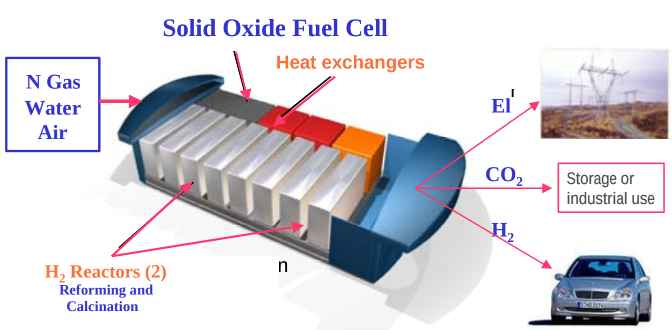

Figure 7: Infrastructures for CO_2

CO_2-deposition, storage or mineral binding

1 “Standard” CO_2-storage solutions
- Deposition in deep geological formations, e.g the Utsira aquifer

2 Innovative methods: CO_2 as resource, providing added value
- CO_2 for Enhanced oil recovery from oil reservoirs (e.g. on the Norwegian Continental shelf)
- Binding of CO_2 by production of stable carbonates from silicate minerals (e.g olivine), providing valuable by-products
- Integrated industry projects (commercial products)

Fig. 8: ”Standard” CO_2-storage/deposition methods

CO_2 accumulation and migration: Verification by 4D seismics

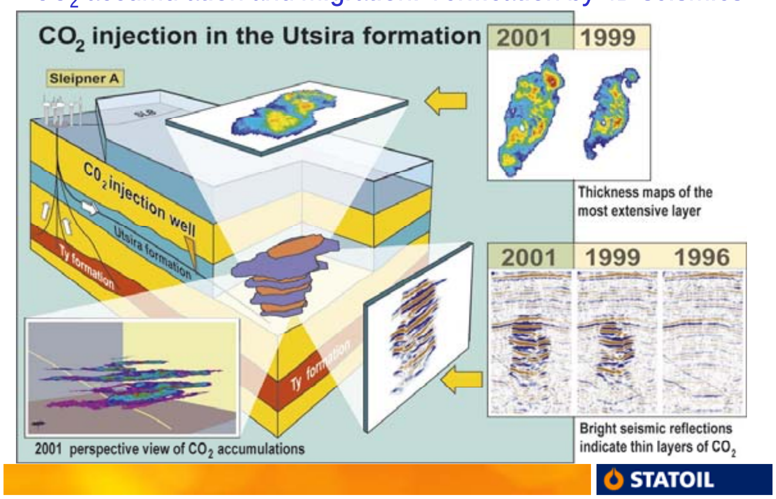

Figure 9: Challenges of CCS Technologies

1 Reduce CCS cost gap through innovation
- More important than the time horizon, and
- A technology shift is required to achieve extra costs down to expected quota prices and improve energy efficiency losses (from 15 to < 10%)

2 Develop necessary infrastructures; assert feasibility of large scale global CO_2-deposition systems

3 Establish required legal framework and regulation regimes (OSPAR and London Conventions)

4 Reduce risk for pioneers; need first suppliers and users

5 Ensure efficient introduction and co-existence with non-fossil LE solutions

Figure 10: The potential of CCS Technologies

The IEA (ETA 2004) 2050 Scenario

- **Stabilization of CO_2-emissions by 2050 is possible, provided**
  - **It must cost something to emit CO_2 freely to the atmosphere: A universal global emission "penalty" of 50$/t CO_2 introduced in 2005-15**
  - **Economic incentives will lead to necessary technologic development and solutions, and to their actual deployment and use**
- **Low emission technologies may contribute significantly**
  - **21% of world el-supply in 2030 & 56% i 2050 (65% in OECD area)**
  - **Corresponds to 4-5000 coal and gas power plants**
  - **The CO_2-penalty also makes renewables competitive at an early stage**
- **But: An estimated 18 billion tons of CO_2 must be separated, transported and deposited annually!**
  - **Is this realistic? Is it even thinkable to establish and operate a global infrastructure for 15-20 billion tons of CO_2 annually?**

Figure 11: Conclusions

1. **Energy-climate realities**
   - **Modern societies have a "bulimic" appetite for energy**
   - **There is no immediate resource crisis (IEA)**
   - **Fossil fuels cover 85%+ of global energy demand, and their share increases towards 90%**
   - **CO_2-emissions expected to increase by 60% towards 2030**
   - **It will be necessary to stabilize atmospheric CO_2-levels (IPCC)**
2. **Low Emission Technologies**
   - **Objective: To develop and deploy competitive LE-technologies in time**
   - **Future alternatives are Renewables, Nuclear and CCS technologies**

Figure 12: Conclusions (2)

3. **CCS Technologies**
   - **Feasible, but still far from commercial technology**
   - **Serious challenges**
   - **CCS technologies may *in theory* stabilize emissions in 2050 (IEA 2004)**
   - **Requires deploying 4-5000 CCS plants with infrastructure in 50 years**
4. **Final Questions**
   - **Is it feasible – *possible* to establish and operate global infrastructures for 15-20 bn. tons of CO_2 annually?**
   - **Is CCS a sustainable solution or a historical parenthesis?**
   - **Will New renewables, nuclear power and CCS technologies be adequate to stabilize CO_2-emissions (and levels) in time**
   - **If not, we must be prepared to cope with consequences of climate change**
   - **There are *no* simple solutions: "Keep all options open" (WEC 2004)**