regulatory, fiscal framework to encourage investment: it is not there at the present, there is no incentive for the generators to go down this route at all. We have got the Emissions Trading Scheme and a value for CO_2, but we really need better visibility of the value of CO_2 in the future.

In conclusion, there is urgent need for continuing action – if we are going to meet these emission reduction targets we have to do something now, and we have to maintain the impetus. A key issue is the need for greater clarity post-2012 so that investments can be made with some confidence. Remember, the life of a power plant is some 40 or 50 years and we are going to have to make decisions in the next few years, here in the UK and worldwide, that we are going to have to live with for that time. If we get it wrong, we will have to live with the resulting carbon emissions, so we really have to set the agenda now for the future. ❐

1. **www.dti.gov.uk/energy/coal/cfft/cct/pub/catreportlinked.pdf**
2. **http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/ccsspm.pdf**

Making carbon capture and storage a reality?

Kjell Bendiksen

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Addressing our global energy and climate realities is a complex and sobering task. I am going to consider one aspect: 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?

Fossil fuels today encompass more than 85 per cent of global energy supply, and this share is *increasing*, nearing 90 per cent, as most of the growth must be met from fossil sources. Global energy-related CO_2 emissions are expected to soar by 50 per cent in just 20 years, according to the International Energy Agency (IEA), in sharp contrast to the aims and ambitions of the Kyoto Protocol for a swift decrease.

Predicting the future is a difficult business, so why could the IEA predictions not turn out wrong, too? Excepting global economic or other disasters, there are two main reasons why this will not be the case:

1. According to the IEA, more than 95 per cent of energy growth in the next 20 years will be in developing countries, not in the OECD area. China and India have more than one-third of the world's population, but a current share of global energy consumption of less than one-seventh. This situation is rapidly changing. Actual growth may be 50 per cent lower or 20 per cent higher than predicted; it does not really make much difference to the result.

2. Growth will be based on fossil fuels (in excess of 90 per cent) 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, the predominant share of this energy supply will be based on coal, if nothing drastic is done.

The question is: what *can* be done? How do we meet this enormous short term growth in energy demand in developing countries? The only viable response, apart from reducing demand (which may be very difficult), is changing to new low emissions (LE) energy technologies.

Renewable energy sources represent a 'natural' sustainable energy solution. But they have long time horizons and are not expected to get a significant share of global energy supply for several decades.

In the short term, there seems to be a growing consensus that 'clean coal' is the key to large reductions in GHG

discussion

The international dimension. Several speakers pointed out that carbon reduction had to take place in an international context. First, carbon reduction by the UK and Norway, or even by the EU as a whole, was only 'nibbling at the edge' of the problem, given the much greater emissions from other countries. Second, individual countries would have to be mindful of their competitiveness; they could not allow their energy costs to become significantly greater than their rivals. Third, no real progress on energy efficiency or carbon reduction techniques could be made without a full exchange of knowledge and best practice.

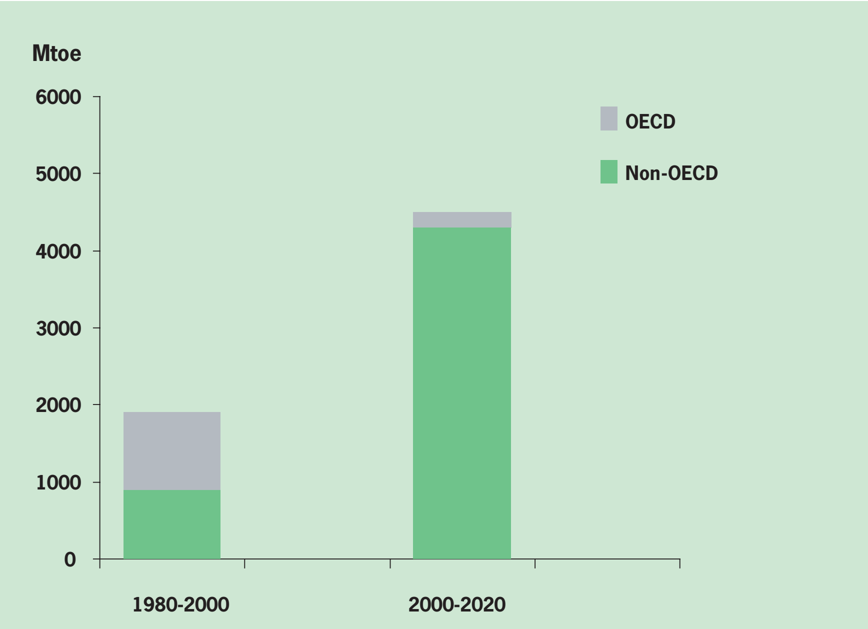

Figure 1. Global energy demand growth. (Source: IEA WEO 2002).

emissions. The new Norwegian government has made a very ambitious commitment to implement full scale CCS solutions at all new natural gas power plants based on enhanced oil recovery (EOR) via CO_2 injection, if at all feasible. The Kårstø plant, under construction, will be conditioned for retrofitting with CO_2 separation systems.

In general, CCS solutions are far from proven or commercially accepted technologies. There are still no full scale or large demonstration plants anywhere in the world. This is to me the most important short-term issue: to develop and *build* large demonstration plants of, say, 100 MW, with the necessary CO_2 infrastructure. This was a main recommendation of the Norwegian Gas Technology Commission. But, almost four years later, we still have no sizable pilot or demonstration plants in operation, or even committed.

Technological innovation is crucial to reduce the CCS cost gap and to minimise energy 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. It will produce electricity from natural gas in a High Temperature Fuel Cell, simultaneously producing hydrogen in an adjacent reactor, using the fuel cell's waste heat. Our objective is to achieve very high electricity efficiencies (70-80 per cent), 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. The most discussed option in Norway is to use CO_2 from gas power plants for increased oil recovery from fields in the North Sea. However, 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 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 binding CO_2 in stable carbonates of silicate minerals, such as olivine, which would also provide valuable commercial by-products. 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.

Recent initiatives in the North Sea region aim at large-scale disposal of CO_2 in deep subsea saline aquifers, or focus on enhanced oil recovery based on CO_2. At the Sleipner natural gas field, Statoil operates a platform-based CO_2 removal plant and injection system. Since 1996, about 1 million tonnes of CO_2 have been injected annually into the nearby Utsira aquifer, some 1,000 metres below the seabed. The movement of CO_2 in the aquifer has been carefully monitored, and the results are promising, with no release of CO_2.

Statoil has since decided to implement a similar solution on another offshore gas field, Snøhvit, in the Barents Sea region; this is expected to come onstream next year.

Carbon sequestration can never become cost free. Carbon dioxide must be separated out, pressurised, transported, injected and safely disposed of for thousands of years. CCS requires additional processes and equipment, costing money, but more important also *energy*, reducing plant efficiencies by 10-20 per cent. Separation technologies are not perfect either, resulting in leakage of CO_2 in the order of 10 percent or more.

Looking ahead, will these technologies provide a long term solution to the problem of greenhouse gases? According to an IEA study from late 2004, the answer is a qualified 'yes'. CCS technologies may in theory enable stabilisation of CO_2 emissions in 50 years' time, at a slightly higher level than today. The crucial assumption is that there must be a cost attached to emitting straight to the atmosphere – quite a high one, in fact. If not, forget it. According to the IEA, a universal 'carbon penalty' of as much as $50 per tonne of CO_2 is required; this would be introduced gradually over the next 10 years (but delayed for 15 years in the case of developing countries).

To make a significant impact on the global climate situation, however, there would need to be thousands of CCS (coal) power plants over the next decades. An estimated 18 billion tonnes of CO_2 must be separated, transported and deposited annually by 2050!

Is this realistic? May CCS technologies provide a sustainable solution, or will they just be a necessary transitional fix, an historical parenthesis? It is not only a question of safe disposal sites and capacities, but will we be able to establish and operate a global infrastructure for, say, 200 billion tonnes of waste CO_2 every decade?

The gap between reality and the politically desirable widens. If the anthropogenic climate issue really becomes serious, and we have to stabilise 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.

Judged from our current technological basis, CCS technologies alone will not provide the answer. There are *no* simple solutions: a sustainable energy system will require new technologies that we hardly can imagine today. The only sensible approach at this point is to keep all options open. ❐