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Carbon sequestration from fossil fuels and biomass – long-term potentials

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Abstract
Carbon sequestration and disposal from fossil fuels combustion is gaining attraction as a means to deal with climate change. However, CO_2 emissions from biomass combustion can also be sequestered. If that is done, biomass energy with carbon sequestration (BECS) would become a net negative carbon sink that would at the same time deliver carbon free energy (heat, electricity or hydrogen) to society. Here we estimate some global techno-economical potentials for BECS, and we also present some rough economics of electricity generation with carbon sequestration.

1. Introduction

Climate change is often considered as one of the most serious environmental problems. This concern triggered the international negotiations that led to the UN Framework Convention on Climate Change (UNFCCC, UN 1992). The convention calls for a "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system".

But it should be kept in mind that the UNFCCC does not attempt to define the concept of dangerous interference with the climate system. Precise calculations of what is "dangerous" is not possible, since (a) the degree of harm any level of climate change would bring is itself subject to a variety of uncertainties, and (b) because whether any level of risk is "acceptable" or "dangerous" is a value judgment (Azar & Rodhe 1997; Azar & Schneider 2001). Science can provide estimates about expected climatic changes and associated ecological and societal impacts, but ultimately the question of what constitutes dangerous anthropogenic interference has to be settled in the political arena—given of course the best scientific assessments available about the likelihood of various potential outcomes.

Azar & Schneider (2001) emphasize that approaches that frame climate policy as the world trying to cost optimise emission trajectories towards a single stabilisation target is a highly incomplete analysis owing to the large uncertainties that attend almost every aspect of the climate problem. In fact, because of these uncertainties, analysis must be offered across a wide range of possible outcomes. Azar & Schneider stress that it is wise to keep many doors—analytically and from the policy perspective—open. This includes keeping the possibility of meeting low stabilization targets open. As more is learned of costs and benefits in various numeraires (e.g., US dollars, number of deaths, etc) and political preferences become better developed and expressed, interim targets and policies can always be revisited (e.g., Lempert and Schlesinger, 2000).

There is a widespread impression that such revisions can only be made upwards, but here we present a technological option that

* will make it possible to meet more stringent CO_2 concentrations than what many people today think is possible,

* and allow for some "climate risk management" that would make it possible to reduce atmospheric concentrations of greenhouse gases in response to negative impacts, if that will turn out to be necessary.

Biomass energy can be carbon neutral, positive or negative, depending on how land use is affected by the biomass source. If the biomass is replanted, the carbon releases from the combustion is recaptured and the biomass energy system is generally CO_2 neutral (see Schlamadinger *et al* 2001 for more detailed descriptions of different biomass energy systems).

However, in a recent short piece in *Science* (Obersteiner *et al* 2001), it was argued that the carbon releases from biomass conversion can also be sequestered and stored in geological deposits, very much in the same as carbon sequestration and storage is being discussed for fossil fuels (see e.g., Parson & Keith, 1998, World Energy Assessment, 2001, Williams, 2001). If so, the biomass energy system will be converted into a negative carbon sink as long as there is enough carbon storage possibilities. We refer to this as Biomass Energy Carbon Sequestration (BECS).

Thus, if widely applied this technology will make it possible to both displace fossil fuels (and thereby reduce CO2 emissions) and remove CO2 from the atmosphere on a continuous basis. This does not mean that we can emit a lot now, and then reverse the concentrations rapidly if that would turn out to be necessary, because the removal rate is not fast enough to be of any significance on time scales less than 50 years (a potential max removal rate might be say 4 Gton C/yr, although it would take at least 100 years before historical emissions from fossil fuels and deforestation, 1850 until now, are reversed - assuming that no other emissions take place over this period and that the max rate of sequestration is achieved instantaneously.

2. Some economics of carbon sequestration

Carbon sequestration from fossil fuels are generally estimated to cost roughly 100-200 USD/ton C (Parson & Keith, 1998). The World Energy Assessment (2000) estimates that the additional cost of electricity from coal or natural gas would be around 2 USc/kWh.

In figure 1, we show the cost of electricity from various technologies as a function of the carbon tax/permit price. We have used technology cost estimates from the World Energy Assessment (2000). We have also included the cost of sequestration from biomass. We assumed that electricity from biomass without sequestration cost 5.1 USc/kWh (a capital cost of 1200 USD/kW, conversion efficiency of 45% and a fuel cost equal to 3 USD/GJ). The cost of biomass electricity with carbon sequestration is estimated at 68 USc/kWh (a higher capital cost of 1700 USD/kW, and a lower conversion efficiency of 36%).

It is shown that with increasing carbon taxes, and under the assumption that the sequestered carbon from the biomass fired plant is sequestered and disposed underground, electricity prices will drop as the plant owner is assumed to get paid for his sequestration of the carbon. At a permit price of 300 USD/ton C, the electricity can be sold at no cost since the revenues from the carbon disposal cover the plant cost, the biomass cost and the O&M costs. It might be noted that the Swedish carbon tax on the transportation sector, and household and district heating, is roughly 200 USD/ton C.

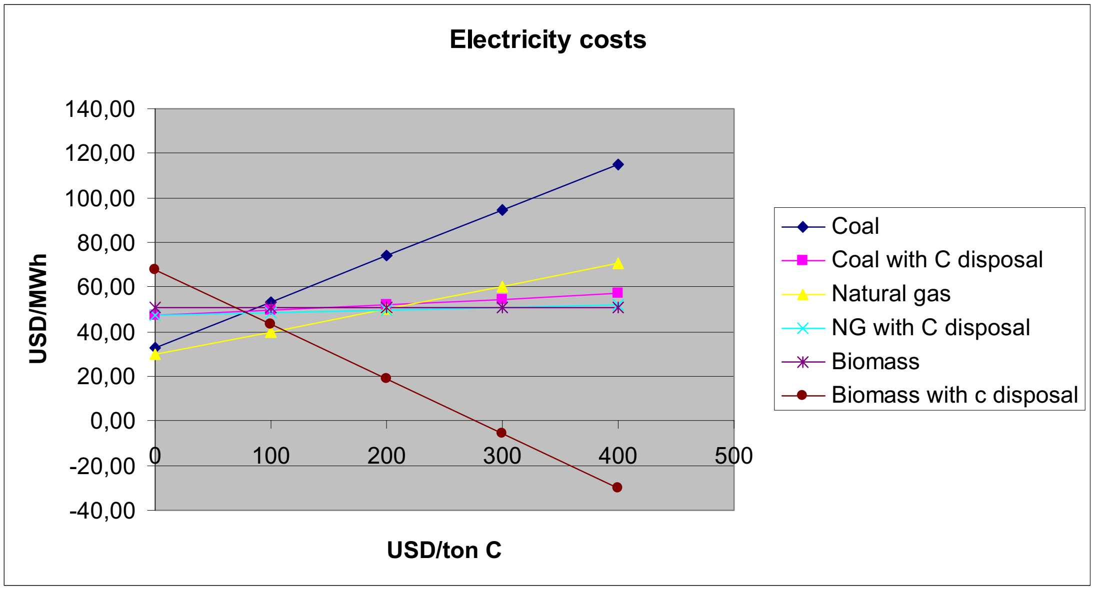

Figure 1. The cost of electricity from fossil fuels and biomass is shown as functions of the carbon tax. Data from WEA (2000) suggest that coal and natural gas based power will cost around 50 USD/MWh with carbon sequestration and disposal costs included (a 90% capture fraction). A carbon tax of 200 USD/ton C is required to make the cost of natural gas based electricity without sequestration as high as that with sequestration. The graph also includes the cost of electricity from biomass with and without sequestration.

3. Carbon prices required to meet the Kyoto protocol and beyond

There is wide uncertainty relating to the costs of meeting the Kyoto protocol, estimates range between marginal abatement costs close to zero and as high as 200 USD/ton C, although modelling studies typically suggest that the cost will end up in the range 25-200 USD/ton C by 2001 (see e.g., IPCC, 2001). In the higher end of the range, carbon sequestration would be economically feasible.

However, following the US declaration that they will leave the Kyoto process, the price of emission permits are expected to drop rapidly. The US was expected to be the largest buyer of emissions permits, and with the large excess of emission permits in Russia and the Ukraine, it is even likely that overall Annex-1 emissions will not exceed the overall Annex-1 target for 2010 even if nothing is done to reduce the emissions. Thus, there is concern that permit prices will collapse to near zero levels.

On the other hand, both the EU and Russia/Ukraine are very interested in preventing the price from collapsing and one may identify several ways to prevent this from happening.

- Russia and the Ukraine can act as oligopolists, so as to maximise their revenues from selling the emissions.
- The incentives for not selling emission permits may increase even further if Russia and Ukraine are given stricter abatement targets for the second commitment period.
- It is not likely to politically acceptable in the EU to meet the Kyoto targets merely by buying emission permits from the east, in particular since these emission permits do not correspond to real reductions. One option here would be to buy permits only under the condition that the revenues are re-invested in the Russian energy sector (e.g., energy efficiency programs, etc). There are at present discussions between EU and Russia along these lines.
- If the remaining Annex 1 countries pursue the Kyoto process, this will likely create an internal pressure on the US to join Kyoto, perhaps even before 2010. A generous distribution of sinks, or a cap on permit prices as has been suggested by RFF (Toman 2000), might be compromises that might make Kyoto more attractive to the US. If the US re-enters, then the risk of a collapse of Kyoto prices is negligible.

In any case, the permit price is not likely to be high enough to initiate any large scale introduction of CO2 sequestration from fossils nor biomass. However, if we are to meet more stringent targets in subsequent commitment periods, sequestration and disposal will likely become economically efficient.

We have developed a linear programming model that can be used to assess Kyoto policies (Persson *et al* 2001). In Figure 2, we present a scenario in which the permit price on carbon is assumed to be 80 US$ tC^{-1} by 2010. The permit price is assumed to increase, by 4% yr^{-1}, ending up in approximately 150 US$ tC^{-1} by 2025. In our model, this tax rate is not high for the EU cannot reach there Kyoto target during the first commitment period (2008-2012) by them self (however, with the inclusion of other measures such as energy efficiency policies, the target might be met). The CO_2 emissions are almost stabilized while they according the Kyoto target shall be reduced by 8% from the 1990 emission level. But overall, the Kyoto commitment is reached due to the carbon surplus existing in Russia and Ukraine, as mentioned above.

It should also be noted that CO_2 sequestration becomes competitive by 2015-2020 and increases in importance in time. By 2025, 75 MtC yr^{-1} is disposed, which roughly is 10% of the present CO_2 emissions in EU.

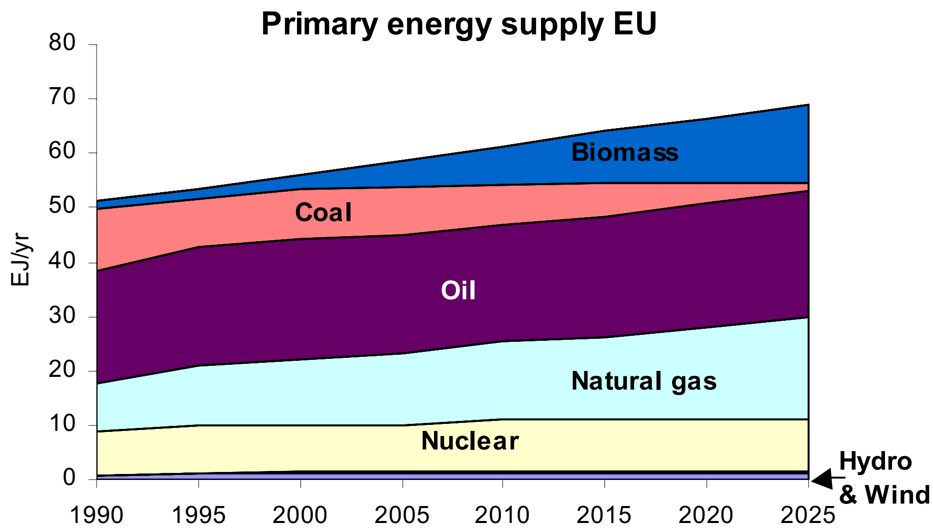

Figure 2. EU Primary energy supply. An increased use of biomass, natural gas and wind is used to reduce CO_2 emissions. Carbon sequestration becomes competitive by 2020 (under the assumption of more stringent post Kyoto abatement targets).

4. Global scenarios

The potential for carbon sequestration from biomass energy can be estimated in a back-of-the-envelop manner in the following way. Assume a potential for biomass energy by the year 2100 equal to 200 EJ/yr. Clearly this is a very large amount of biomass, and it would probably require a land area of plantations corresponding to perhaps as much as 0.5 Gha, or roughly 1/3 of the entire global crop land (this calculation assumes an average yield of 10 ton DM/ha/yr which would lead to 100 EJ from plantations and 100 EJ/yr from by-flows and residues in forestry and agriculture). See Berndes *et al* (2001) for a detailed survey of global biomass energy potentials. Some argue that degraded lands could be targeted with these plantations, others are concerned about social and environmental conflicts that may arise if/when dedicated plantations come to compete with food production for agricultural lands (see Hall et al, 1993, Carrere & Lohman, 1996, Azar & Berndes, 1999, Azar & Larson 2000, for various perspectives).

The level 200 EJ/yr corresponds to roughly 5 Gton C/yr, and it is thus the maximum sequestration potential for this biomass energy supply. In reality, however, the potential is likely to be lower for two reasons.

- First a considerable share of this biomass will most likely be used in applications where CO2 sequestration is not possible, e.g., small-scale facilities.

- Second, the carbon capture at the conversion facility will not be complete (it is generally assumed to be around 90%, although higher numbers are clearly achievable).

Assuming, for the sake of simplicity, that this sequestration potential is nevertheless realised and that it grows linearly from now until 2100, we get a global sequestration potential over the next century equal to 250 Gton C.

In figures 2 and 3, we illustrate a scenario in which an atmospheric CO2 concentration target of 350 ppm is met. (We use a linear programming model of the global energy system developed by Azar & Lindgren, see Azar et al 2000 for details.)

In the scenario, the role of CO2 sequestration is shown to be very important in general, but we also see that negative global CO2 emissions are developed over time. The annual sequestration towards the end of the century becomes very large, since most of the biomass is used in power or hydrogen production facilities (since the possibility to sequester carbon becomes increasingly important and we have not imposed any limits on such options).

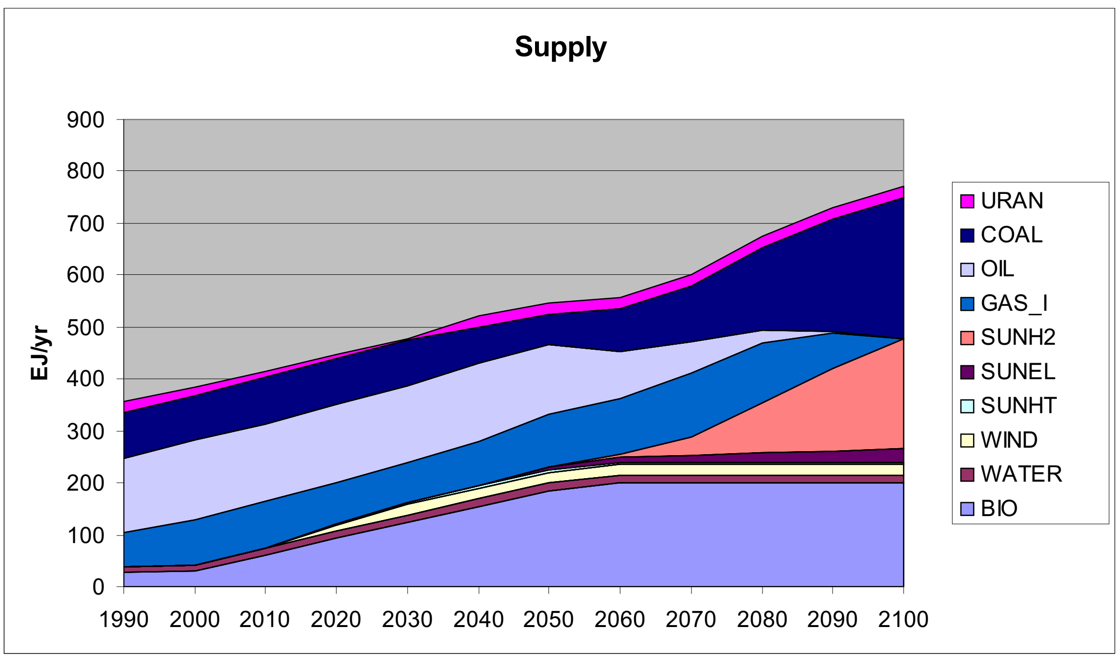

Figure 2: Global energy supply meeting an atmospheric stabilization target of 350 ppm (here modelled by allowing an accumulated emissions of 350 Gton for the period 1990 to 2100). During the final decades of the century, carbon emissions are strongly negative (because of carbon sequestration from biomass energy, and the CO2 concentration continues to drop after the year 2100). The biomass is initially used for heat and process heat production, but with increasing carbon taxes over time, an increasing share of the biomass is used in large scale facilities, for electricity and hydrogen production, where the CO2 may be more easily sequestered.
Source: Azar & Lindgren (2001).

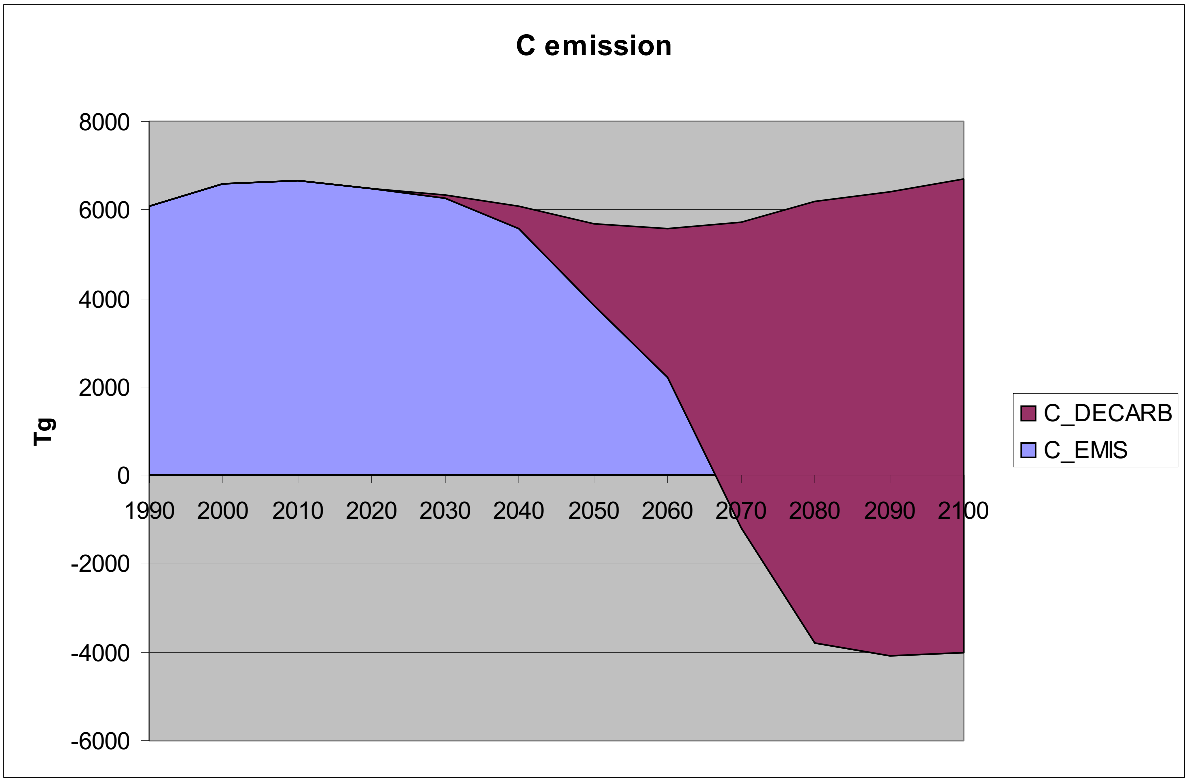

Figure 3: Emissions profile for the 350 ppm scenario. Since decarbonisation from use of bio fuels is allowed negative net C emissions may occur, as the figure illustrates from 2070 and onwards. If the carbon abatement policy continues, atmospheric concentrations of CO_2 will continue to drop beyond the year 2100.
Source: Azar & Lindgren (2001).

6. Conclusions

There is a growing interest in carbon sequestration from fossil fuels. We have shown that the economics of the Kyoto protocol is not likely to favour the introduction of sequestration technologies in the near term, but in the longer term this option is promising. Clearly, sequestration is also possible from biomass, and this has the potential to turn biomass into a negative continuous carbon sink while at the same time offering energy carriers (in particular heat, electricity and hydrogen).

This technological option will

- make it possible to meet more stringent CO_2 concentrations than what many people today consider possible, and
- allow for some "climate risk management" that would make it possible to reduce atmospheric concentrations of greenhouse gases in response to negative impacts, if that will turn out to be necessary,

Finally, it should be kept in mind that the time it takes until the accumulated carbon sequestration from biomass is large enough to play any important climatological role is on the order of several decades. Thus, this option should not be interpreted as an argument in favour of doing nothing in the near term.

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