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Combustion in a CO_2/O_2 mixture for a CO_2 emission free process.

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Introduction

The energy sector within the European Union emits around 3400 million tons of CO_2 per year, of which the energy supply side produces around one third. The rest comes from traffic, industry and the domestic sectors. Work has begun to develop different processes to produce energy from fossil fuels with no CO_2 emissions. Several techniques are being studied, including underground storage of captured CO_2. There is already a great deal of experience on the storage of CO_2, mainly from the oil and gas industry. Transport of CO_2 is also a well known and well established technology. The major costs stem from the capture of the CO_2 and transforming it to a liquid form.

Vattenfall has, as part of a larger project, started to examine the different options available for reducing the CO_2 emissions from the energy supply system. Their potential, costs, and the consequences of different options are being addressed. The working name of the project is “the CO_2 demo project”, and its ultimate aim is to establish the possibilities to build a full size lignite-fired true zero emission power plant demonstration unit in future. It must however be emphasized that although the technology is promising it cannot have any impact on the emission pattern in many years. It is developing but full scale realization takes considerable time for any new technology, at least 15 – 20 years

Options for achieving CO_2 emission reductions

Renewable energy sources and means of reducing greenhouse gases are developing rapidly. Nevertheless, Europe will remain dependent on fossil fuels for a long time, whether we like it or not. The focus of our work is therefore on the use of fossil fuels.

In the short term (within the Kyoto agreement time frame) the least costly measures for reducing CO_2 emission are obtained by replacing old plants with low efficiency to new ones, and by changing from solid fuels to gas. This may provide a 15% reduction. The replacement of old technology with new is generally desirable, since energy is used more efficiently. This has also been expressed in the efforts for combined heat and power generation, which is more energy efficient than power-only generation. Unfortunately a CHP plant is expensive, and the potential is very limited. Locally, however, for example in the Nordic countries, CHP can theoretically provide 20 – 30% of the power needed.

Changing from coal to gas is also a relatively low cost measure for the early plants, but the problem lies in that gas is also a fossil fuel and thus its potential is limited. This option is discussed thoroughly in the EU Green paper on “security of supply”(European Commission, 2000). Considerable concern is expressed there about dependence on a limited and politically not very favorable energy source like gas. If many actors changed from coal to gas, this would rapidly have major consequences. If a CO_2 emission reduction of 20% were to be achieved this way, 55% of all coal-fired plants in Europe had to be shut down, and gas use in the energy sector would double. In Germany it would triple, in which case this option would not be as economical than if only a small change were made. The realistic potential is thus limited to approximately a 5% CO_2 reduction, when some 20% of the coal generating capacity is switched to new gas-fired plants, and gas consumption will increase by about 30%.

It is of course also desirable to use truly sustainable forms of energy such as windpower, solar power, biofuels and hydropower. These renewable energy sources can be introduced, generally at a high cost, largely dependent on volume. The potential is, however, limited to a 10 - 15% reduction. The goal set in the EU white paper on renewable energy is 16%. Locally however, wind and water can play a larger role, as in the German state of Brandenburg, where a target of 20% from windpower has been set.

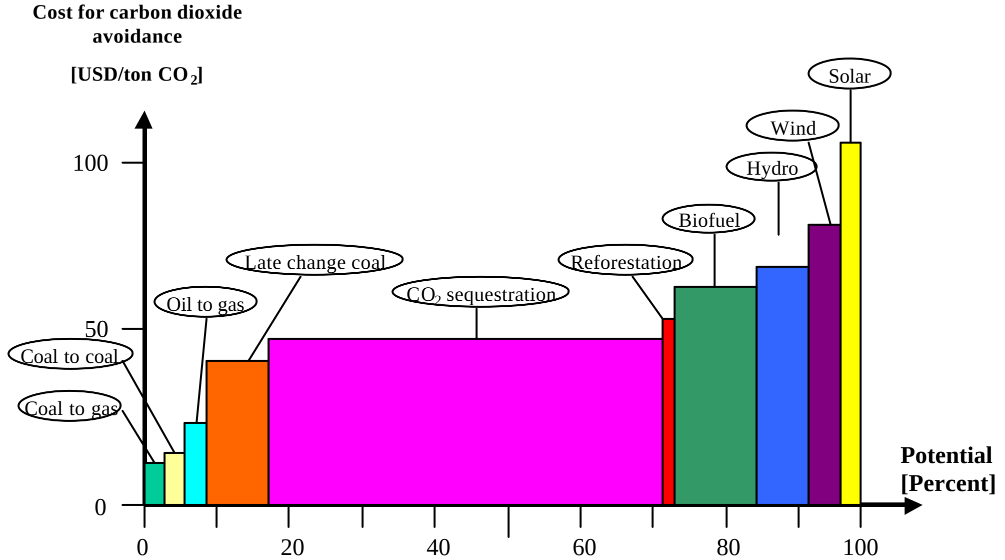
The recently completed work of the ECCP (European Climate Change Program) stated that CO_2 emissions can be reduced by about 30% within the Kyoto protocol time frame, but with the marginal costs rising to over 200 €/ton of CO_2. The 8% required in the protocol will cost something like 20 €/ton CO_2. This corresponds to about a 25% increase in electricity prices, on a European base.

For the short term these options are the only ones available. For the slightly longer term, the option of capturing and permanently storing CO_2 from fossil fuels is very promising. The potential is great, and there is considerable industrial experience. The present cost is high, estimated at 50 €/ton of CO_2 a few years ago, but this is still lower than for most renewables. Research and development of CO_2 capture and storage might bring down costs considerably. At present the total cost is estimated at 30 – 35 €/ton of CO_2.

In the very long term other new sustainable energy sources will have to be developed, but the technology for emission free fossil fuel utilization might buy some time for the development of as yet unknown energy sources, which are necessary. Storage capacity exists for more CO_2 emissions in Europe than the amount of fossil fuels available could generate. Yet coal will last at least a couple of hundred years, while oil and gas are more limited at present, 30 and 70 years respectively.

As a mental model a diagram has been developed, where the costs for different options for reducing CO_2 emissions in Europe are shown as a function of their reduction potential in a schematic, but as correct as possible way.

Cost and Potential of options to reduce CO_2 emissions
Principal example



The picture will look different when different time perspectives are adopted

The figure shows the potential and the cost of CO_2 avoidance for different options. It is only schematic, as pointed out above. It also reflects a future where CO_2 capture and storage has been developed according to the current cost estimates. The figure illustrates what options are available, their estimated potential as a percentage of all CO_2 emitted within the EU from the energy supply sector, and a cost estimate.

Development of a technology for emission free use of fossil fuels.

Initiatives to develop processes to produce energy with little or no emissions of CO_2 have been frequent in the last few years. Among these initiatives are a number of processes based on combustion of fossil fuels with capture and permanent storage of the carbon dioxide. To date, there are some conventional methods based on absorption of CO_2 in an amine, but no new processes have been fully developed and tested.

At several recent conferences and seminars and also in the "SACS project", a consensus regarding cost levels for storage and capture of CO_2 seems to have been established. The total cost for transport and underground storage including pumping and drilling has been established at 3 – 8 €/ton of CO_2, based on 25 years of experience from the oil and gas industry. The major cost, however, is related to capture and conversion of CO_2 into a transportable and storable form, which includes compression of the CO_2. This has provided incentives for development of other less expensive ways of capturing the CO_2.

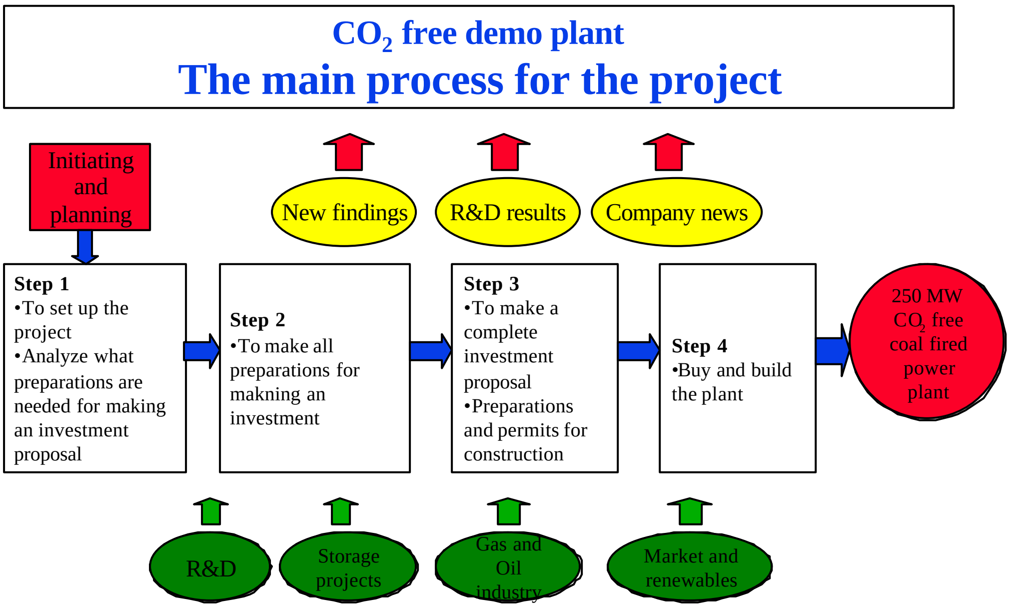
The available storage capacity is also reasonably well known. It is a familiar fact that there are large rock formations like those that contain gas and oil, but without any gas or oil. Under the North Sea in layers below the formations containing oil, huge storage potential exists. At present large scale experiments are being performed to learn about how the liquid CO_2 behaves at these depths. Extensive drilling in the Baltic during the seventies in an attempt to find oil there failed, but it gave knowledge of rock formations suitable for CO_2 storage. If they can hold gas for millions of years, they can also store CO_2. On shore the same formations exist. Almost all of northern Germany and southern Scandinavia are situated on a formation some 1000 to 2000 meter down. Thus the German Geological Institute in Hannover states that there is abundant storage capacity in Europe.

Although the transport system constitutes a large cost, transportation of CO_2 in pipelines is conventional technology. The cost and technology vary depending on transport volumes, the kind of sources connected to a storage system and the location of the pumping point, where liquid CO_2 is pumped down to depths of around 1500-1800 meters. CO_2 is a liquid at around 70 bars and room temperature. The transport conditions are considered to be the same as for commercial CO_2 transports today, at some 20 bar and –28 ^{o}C. The cost for transport varies between 3 and 10 €/ton of CO_2.

The CO_2 demo project

Vattenfall has started to examine new ways of creating a zero emission process. We have concentrated these efforts into a project called "the CO_2 demo project". The ultimate goal is to build a 250 MW lignite-fired plant with zero emissions on German ground in future. The work is being performed by our own staff, in collaboration with universities, industrial colleagues and other professional organizations, such as Linde AG and others. It will hopefully show that this is a commercially feasible way of creating an option to use our fossil fuel resources, even with the constraint of threatening global climate change.

Most of our work so far has been devoted to establishing that the concept is viable and to doing some initial work on the technical process side, where some novel thinking has arisen. Considerable progress has been made and the results from the initial stage indicate that the concept is feasible and the costs can be reduced considerably, compared with earlier estimates. The project schedule is described in the figure below.



Carbon dioxide free combustion

There are several possible ways to create a CO_2 free combustion process. They all seem suitable, most of the technology is well known and could be successful, but they are all more or less underdeveloped and have definitely not been optimized for the purpose at hand.

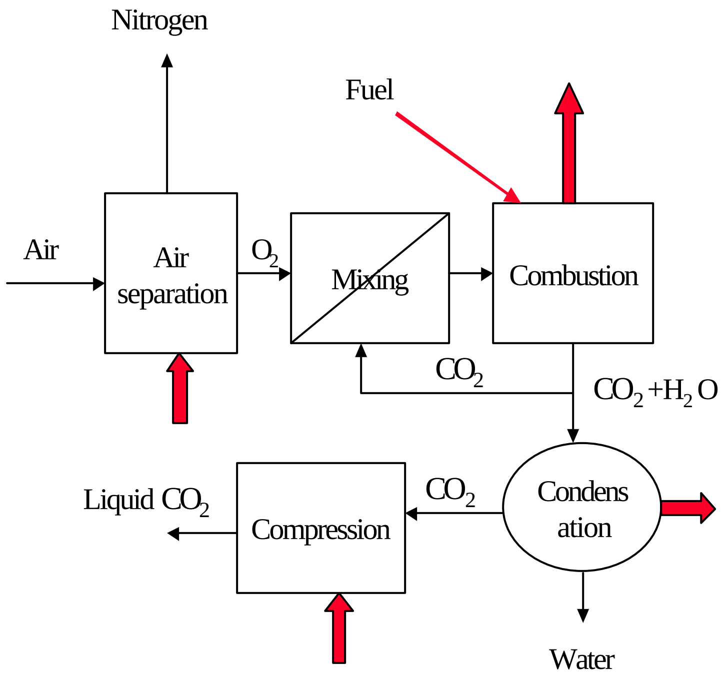
The most common method is to burn the fuel conventionally and then to extract the CO_2 from the flue gas. This can be done with an organic absorber, an amine, which can be regenerated. CO_2 is present in the flue gas at concentrations ranging from 5 to 18% depending on fuel and combustion conditions. The lower concentrations stem from a gas turbine. The rest is, in principle, nitrogen and water vapor. The separated CO_2 is then compressed to a liquid-like form. The separation is high, but not 100%. It is more like 85 to 90% in a real process.

Another method is to “decarbonize” the fuel, e.g. to separate as much carbon as possible from the fuel. Using a “water shift” reaction, a hydrogen rich gas with a surprisingly high remainder of energy can be obtained relatively easily. This method can, of course, be applied to natural gas and also to gasified coal. The hydrogen rich gas is then burned using relatively conventional equipment. Work has also been initiated in this area to develop gas turbines for such fuels and to develop the process itself. The gas companies are taking the lead.

A third method is to create an oxidator without nitrogen for the combustion process. Without the nitrogen ballast the flue gases contain only CO_2, water and any impurities that may be present. One such oxidator is a solid oxide. This oxide can be regenerated in a solid recirculation loop, for instance using a circulating fluidized bed system. The process is known as chemical looping combustion and does not seem suitable for solid fuels at present.

The CO_2/O_2 combustion process.

A fourth method is to separate the oxygen from air in a conventional process. The oxygen is then mixed with recirculated flue gases from a combustion chamber. This mixture serves as the oxidator for the fuel in the process. The nitrogen in the air is replaced by CO_2, and the flue gas consists only of carbon dioxide, water, a little oxygen and small quantities of pollutants. This process eliminates the need for an absorber, and for the energy consuming absorption process, but the air separation process does require energy. The principles for a unit with CO_2/O_2 combustion are shown in the figure below.



The part of the process, which is not conventional is the boiler with the combustion chamber. The other parts are readily available industrial equipment. The air separation unit is a type of equipment sold for thousands of applications. The compressor for the CO_2 is not very common in the sizes needed for a power plant, but is well-established machinery. The flue gas condensation unit is also very common in the Nordic countries in many heating and cogeneration plants especially for wet fuels and for biofuels. In this application, one difference might be the quantities of pollutants in the gas.

If recent research results are correct, the flue gas cleaning equipment will also be reduced considerably. An ordinary filter is included before the condensation unit. Most of the remaining particulates will be retained by the condensate. Some of the sulphur dioxide will also be washed out of the gas stream. Water treatment for the condensate will therefore be needed, but this is commonly available technology. After the condensation unit a dryer is introduced in the gas stream. This device known as the “TEG” (Tetra Ethylene Glycol) unit dries out the remaining water vapor, and the gas is ready for compression. The SO_2 behaves similarly to the CO_2 and is also obtained in liquid form when the CO_2 is transformed to liquid in a cooler after the compression. So what is left is liquid CO_2 with liquid SO_2 dissolved in it. The SO_2 is a non-corrosive liquid, since no water is present and it can be disposed of with the CO_2. In this way, an almost emission free process is developed and the desulphurizing equipment in a conventional plant can be omitted.

This process has recently been studied in several smaller projects. Work has also been initiated to develop basic knowledge of this combustion process to be able to create a commercially viable process without major technical risks.

Comparison with the Lippendorf lignite power plant

Some recent work at Chalmers University of Technology in Gothenburg Sweden has been focused on two parts of the process, the possibilities of integrating the energy consuming parts into the power process and the handling of the remaining flue gases. As a basis for the studies, the existing Lippendorf plant in Germany, has been used. The results are very promising and are, in short:

- Cost for the capture and transformation of the CO_2 to liquid can be reduced considerably, amounting to 10-13 €/ton of CO_2.
- The plant can be made a true “zero emission plant”, with virtually no CO_2 emissions, no sulphur emissions, and considerably reduced NO_x emissions.
- The investment cost can be less than for a conventional plant
- The output of the plant will be reduced from 865 MW to around 700 MW, which constitutes the major cause for the extra production cost of about 20%, or 1 pf/kWh

At present this process seems to be the most favourable and cost effective one for coal, and possibly also for gas. In the future, some major technological breakthrough might be achieved, for example if new ceramic membrane technology can be introduced for air separation.

Conclusions

If all the present knowledge remains true in the future, when work has progressed, the avoidance cost for a whole system can be calculated to about 30 €/ton of CO_2.

- This corresponds to 60% of the present Swedish CO_2 tax.
- It would also set a ceiling on the cost for measures to be taken for CO_2 emission reductions, because the potential is so great.
- It would create a possibility of using coal as a fuel and still showing concern for the climate change issue.
- This option is less expensive than almost all other options including windpower, biomass, and small hydropower plants, and it is also cheaper than the present cost estimates for implementing the EEG and KWK laws in Germany.
- It would also create an option for using an energy source which is found all over the world, is relatively cheap, does not have the obvious security problem of oil and gas and, last but not least, is so plentiful that it will last for several hundred years.
- It would not jeopardize the security of the energy supply to the EU member states.

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