Clean Coal with CO_2 Capture and Storage

Juan Carlos Abanades

Coal consumption is growing worldwide (4.5 per cent in 2006), reserves are abundant, and they are very broadly distributed throughout the world, thus giving them very high strategic value. Emerging economies like China are mainly responsible for this increase in demand, but there are also several developed countries like the United Kingdom and Denmark that have registered pronounced growths in the consumption of coal. It is possible that 3,000 new coal-based power plants may be built worldwide during the next 25 years (many more than natural gas plants). Consideration is also being given to the possibility of coal competing with oil in the production of automobile fuels, on the basis of growing interest in coal-to-liquid (CTL) transformation technologies, particularly in countries with large reserves like the United States and China. In this context it is necessary to ask a very simple question: has anybody heard about the climate change problem? For even with the most modern and efficient technologies, coal emits twice as much CO_2 as any other fossil fuel by unit of final energy produced (kWhe – of a litre of diesel or of any other energy product). Consequently, the growing use of coal, as we know it today, is radically incompatible with any objective for the reduction of greenhouse gas emissions.

In its Fourth Assessment Report, 2007, the United Nations Intergovernmental Panel on Climate Change (IPCC) has estimated that it is necessary to reduce greenhouse gas emissions by between 50 and 80 per cent by 2050 (using the year 2000 as the base year) in order to attempt to stabilise the increase in the average world temperature to around 2°C. Evidently, time plays against us, and the objectives are more and more ambitious as action is delayed and emissions continue to increase with respect to the same reference year (in 2005 they were already almost 15 per cent more than in 2000). Numerous political leaders across the planet are assuming ambitious objectives for the reduction of emissions in the long term.

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Information regarding climate change floods the media, and is already beginning to raise public awareness regarding its impacts and the challenges that we face in our attempts to mitigate and adapt to its effects. The powerful economic and geopolitical reasons that explain the recent upturn in the consumption of coal throughout the world can only be compatible with the fight against climate change through the development and rapid implementation of clean coal technologies.

To talk about clean coal technologies a few years ago was synonymous with technologies producing very low emissions of minor contaminants (SO_2, NO_x and others), and with high energy output in the transformation of coal to the final energy product. Today the concept of clean coal must also be linked to the need to capture and permanently store within the subsoil the CO_2 produced in the process that transforms coal into final clean energies (electricity, hydrogen, automobile fuels with low carbon content, etc).

There are many reasons to be optimistic regarding the future of CO_2 capture and permanent geological storage technologies (CCS) as a powerful tool to mitigate climate change. The technology necessary for implementation is in many cases already available in the chemical, gas and oil industries, where it is common practice to tackle large scale gas separation operations (capture), transport fluids long distances and store them in sealed geological formations.

The scale economies of these processes makes then relatively competitive when there exists a stable price to penalise the carbon emitted into the atmosphere. The IPCC published in 2005 a review of the existing and emerging CO_2 capture and storage technologies, and concluded that in most of the stabilisation scenarios at between 450 and 750 parts per million by volume (ppmv), CCS will contribute between 15 per cent and 55 per cent to the world's accumulative mitigation effort to 2100. Currently there are four large fully operational CO_2 capture and storage projects in the world (Sleipner, In Salah, Weyburn, Snovit), which jointly store four million tonnes of CO_2 a year (tCO_2/year) in depleted oil and gas deposits, or in geological formations close to these deposits. Extensive experience has also been acquired in assisted recovery of oil operations (where CO_2 is used to move and extract oil retained in deposits that are near depletion).

The electricity sector has announced the first large-scale demonstration projects (MWe in their hundreds) in the European Union and the US. During 2007 and 2008 the European Commission published various documents that acknowledge a vital role for CCS in Europe, a role that is as important as the development of renewable energies or energy efficiency in the fight to reduce CO_2 emissions from now up to 2050. In fact, the scenarios considered by the EU predict an almost complete implementation of CCS within the European electricity sector by 2030, beginning with the construction of a dozen demonstration plants with different technologies and locations between 2015 and 2020.

CO_2 capture technologies

Until now large thermal power plants, cement plants, refineries, steel mills, etc., have been based on processes designed to obtain one or various forms of energy (electricity, heat) or chemical products on a large scale, emitting CO_2 into the atmosphere as a sub product. The challenge for any capture technology is to transform these existing processes (reference systems) into systems that generate the same product but with a CO_2 stream that is separated and compressed so it can be confined (system with capture). Consequently, a CO_2 capture system is the complete process that is necessary for producing the same product as the current system, while generating a concentrated stream of CO_2 that can be compressed, transported and placed in permanent geological storage. Capture technologies are essentially intended for processes that use fossil fuels on a large scale, although it is necessary to stress that they can also be applied in the future to large power plants and industries that use biomass, converting these plants into net sinks of CO_2 from the atmosphere by eliminating permanently from the atmosphere the CO_2 absorbed by the biomass during their growth.

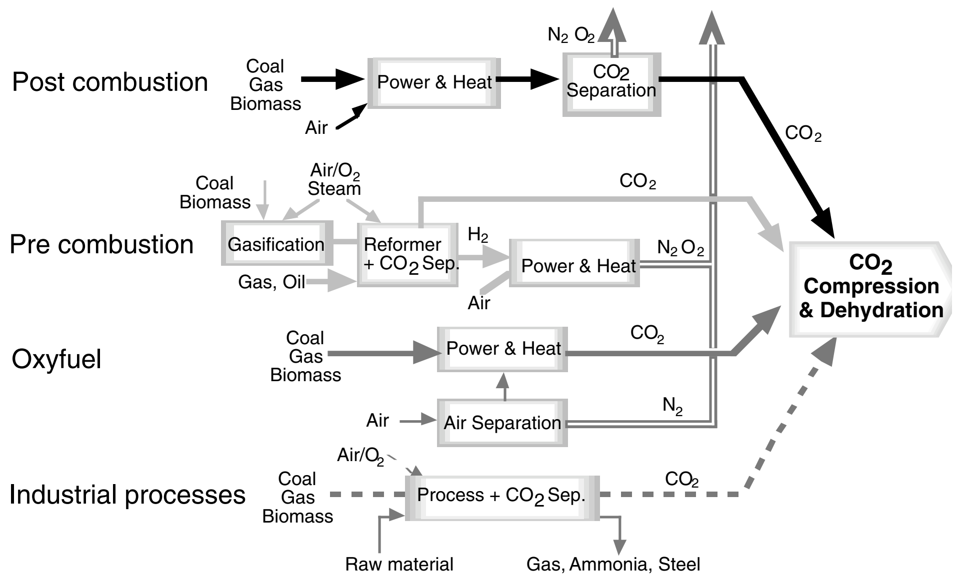

Figure 1: CO_2 capture systems (IPCC, SRCCS, 2005).

By definition all CO_2 capture systems always include a process of separating gases on a large scale, but this separation of gases is not necessarily a separation of CO_2. In fact, systems that capture CO_2 are usually classified depending on the phase of the process in which the separation of gases takes place, and the type of gas that is separated in this phase. Figure 1 outlines capture systems according to this criterion for a large thermal power plant. Alternative capture systems for processes other than the generation of electricity can usually be adapted to this classification (post-combustion, pre-combustion, oxyfuel combustion), although in this table for simplicity they have been included within the category "industrial processes".

– *Post-combustion.* The objective is to separate the CO_2 that is diluted within the remaining components of gas combustion when burning a fossil fuel or biomass with air. Spain's and the world's current energy infrastructure is mainly based on air combustion processes, thus these capture technologies are the only viable alternatives for recently constructed existing plants.

– *Pre-combustion.* In these systems, the fuel must firstly be transformed into a low or no carbon content fuel (hydrogen). This is achieved through reactions in different phases with water vapour and oxygen, whose end result is a gas that is rich in H_2 and CO_2. Given that these reactions take place at high pressure, any gas separation process is facilitated (capture phase). These capture systems are usually given very significant strategic importance, since they could supply the so-called hydrogen economy, or the production of automobile fuels with low carbon content, provided that the CO_2 resulting from the production of these clean fuels is captured and stored.

– *Oxyfuel combustion.* This consists of combustion with pure oxygen (diluted in CO_2) instead of air, which gives rise to a gas that is very rich in CO_2, enabling its final purification before storage. Consequently, in this CO_2 capture system the critical phase in the separation of gases is the attainment of high purity O_2 from the air.

The costs of capturing CO_2 are estimated at 30-50 euros per tonne of avoided CO_2 (t CO_2) emissions. For the electricity sector this would amount to an increase in the costs of generating electricity of around 0.02-0.03 Euros per kW/h. These costs refer to the use of existing technologies and assume as a reference new high-output thermal power plants, which makes it possible to better absorb the important output losses associated with the CO_2 capture phase. This is one of the weaknesses of the CCS technologies applied to combustion systems: capture by proven methods results in a 10-15 point loss in net output. This means that the application of CCS technologies to most of the current plants is not viable (or economically not desirable). Even for state-of-the-art new combustion plants, current capture technologies (absorption of CO_2 with amino acids, oxyfuel combustion with O_2 obtained through the cryogenic separation of air) lead to increases of 20-35 per cent in the consumption of fuel in order to generate the same electric power. The results are more favourable for pre-combustion technologies, although the reference plants here – integrated coal gasifiers, like the one belonging to Elcogas in Puertollano – are more costly, and reliability problems have not yet allowed them to penetrate the electricity sector. Notwithstanding, solid fuel gasification technologies, like coal and petroleum coke, are extensively implemented within the petrochemical and fertiliser industries.

Currently research is being carried out throughout the world on how to reduce costs (below 15 Euros per t CO_2) and output penalties (around 10 per cent including the compression phase) in all the capture paths, both for coal as well as for natural gas. An example of this research into emerging CO_2 capture technologies are the carbonation-calcination processes that the Consejo Superior de Investigaciones Científicas (CSIC, Spanish National Research Council) has been developing since 2000 for different combustion systems. It is too soon to know which technology will prevail, given that this will depend on the context (type of fuel, regulatory framework of the purity of the CO_2, etc.) and the final cost of many key components in the capture system, currently the object of intense global development.

There are many reasons to be optimistic regarding the future of CO_2 capture

Spain suffers from serious backwardness in the technological development of CO_2 capture with regards to the EU and the rest of the world. This contrasts with the very intense activity during the 1990s in the most developed countries. There is a special programme of the International Energy Agency concerning this issue that dates back to 1991, and there are also significant international and European initiatives and projects within the Fifth, Sixth and Seventh Framework Programs. Within an environment marked by its lagging technological progress and intense foreign competition, it is very important that Spain avoid hasty moves towards technologies without first establishing their added value for our country. In particular, it may be counterproductive to allocate a large amount of public resources to prove technologies on a commercial level when the country does not have the human resources and the business capacity capable of subsequently exploiting these costly investments. In relation to CO_2 capture, Spain should focus on a learning phase and adapt its research teams, which are currently top of the range and competitive in related fields (combustion, materials, catalysis, process modelling, etc.), so as to redirect them towards this field and create the necessary critical mass to be able to successfully execute large R&D&I projects. The objective would be to prepare for the development of specific components in a second generation of "almost commercial" CO_2 capture processes, or in the development of the next generation of capture processes (emerging processes), allowing the private sector to choose and demonstrate within singular scales the specific technology, particularly if the technology has already been developed and protected abroad.

Transport and storage of CO_2

A country can abandon its ideas of developing various or all the CO_2 capture technologies and accept that it will need to acquire these technologies from abroad, but it will always be compelled to find, shape and operate its own locations to safely store the CO_2. The transport of CO_2 long distances (more than 500 kilometres) is viable, but requires major economies of scale (more than 10 Mt CO_2/year) to maintain costs below a few euros per tCO_2. Transport on a worldwide scale is only feasible within a long-term scenario marked by broad global development of CCS technologies. Consequently, all the large projects for capturing CO_2 during the next two decades need to identify a storage area close to the source where the CO_2 is captured.

There have been many exotic proposals for the storage of CO_2. In fact, the first publication on CCS in 1978 proposed the injection of a large part of the CO_2 captured in Europe into a gigantic current of high density water that is submerged from the Mediterranean to the Atlantic at the Straits of Gibraltar. Another frequent proposal is that of reusing CO_2 in certain industrial processes (for fertilizers, foods, etc.). However, these uses are not genuine sinks for CO_2 unless the energy source of the process is not a fossil fuel, and the resulting product has a long life (ensuring that the CO_2 is not re-emitted within a short period of time).

The only realistic option for a massive storage of CO_2 that will mitigate climate change is to confine it in deep natural geological deposits (at a depth of more than 800 metres). The gas and oil industries have significant experience in the identification and use of large storage areas for gas. In fact, large depleted gas and oil fields are the most attractive options for massive storage of CO_2, given that they are sedimentary formations in which fluids have been stored at high pressure during millions of years (Figure 2). In Spain, because there are no large gas and oil fields, the most attractive options are deep saline formations. These usually appear in all sedimentary basins throughout the world. They consist of layers of porous sediments (similar to those containing oil or gas) that accommodate within their pores a great amount of salty water or brine. These layers are capable of

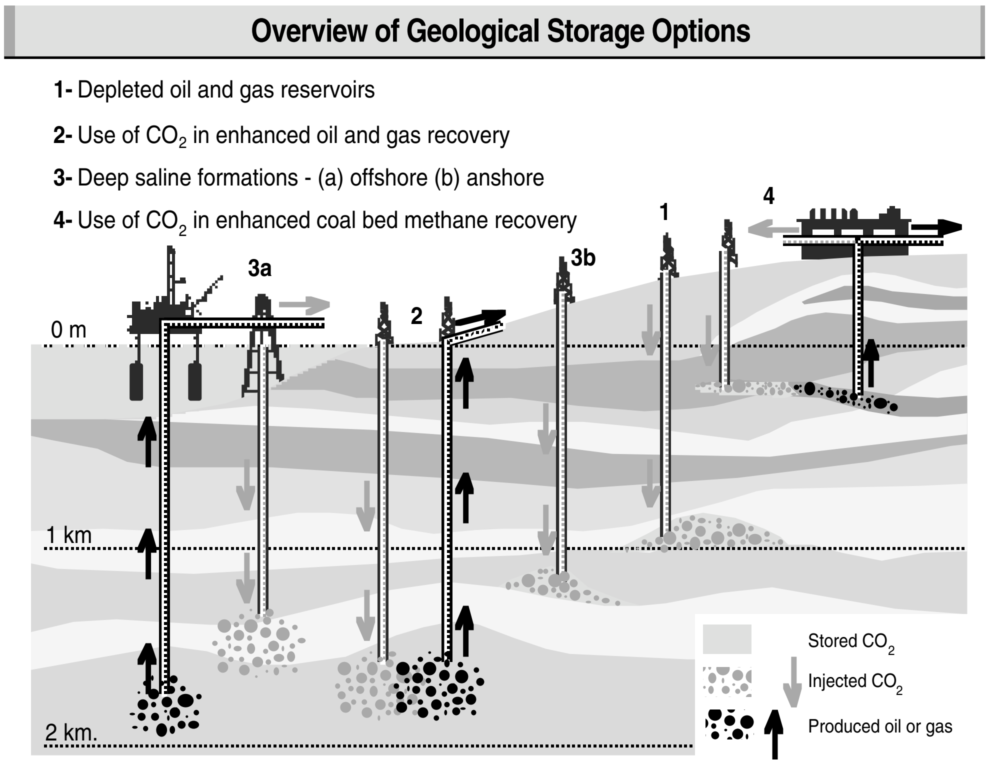

Figure 2. Methods for the storage of CO_2 in deep geological formations (IPCC, SRCCS, 2005).

absorbing huge quantities of CO_2, depending on the size and characteristics of the layer and the mechanism with which the CO_2 is retained (hydrodynamic barrier due to non-porous upper layers, dissolution of brine, solidification due to a reaction with brine components, etc.). As an example, it is estimated that the only currently operating formation of this type (Utsira, in Norway), where one $MtCO_2$/year has been injected since 1996, could store all of Europe's CO_2 emissions for the next 100 years. The world's storage capacity in deep saline formations is between 1,000 and 10,000 gigatonnes of CO_2 (Gt CO_2). Capacity estimates are reduced as the selection criteria for the location of these formations is tightened so as to guarantee that there are no large-scale leakages of CO_2 within reasonable time frames, thus resolving the problem of mitigation over several thousands of years.

Spain has only recently started, over the past three years, CO_2 storage evaluation projects. The necessary technologies for search, design, drilling, injection and control of the CO_2 within the subsoil are already substantially developed within the gas and oil industries, and the cost is known, although it varies substantially (between 0.5 and 10 euros per t CO_2), depending on the characteristics of the geological formation and the size of the project. These costs have been calculated on the basis of a breakdown throughout the life of the project (decades). However, investments are concentrated in the first phase, where the risk of failure is higher and the monitoring required is also greater. Consequently, the search for areas to store CO_2 and their design in accordance with the detailed requirements established by regulatory bodies so as to permit CO_2 storage could end up being a barrier that slows down the development of CCS technologies.

There are two types of risks in the storage of CO_2: local risks (due to sudden leaks), and global risks (where CO_2 storage is deficient). Local risks are minimised through prevention and detection regulations similar to those applied to other more dangerous gases that are more common in our everyday lives, such as natural gas. With an appropriate selection, most of the CO_2 storage areas should operate without important leaks over a timeframe of various hundreds or thousands of years. However, we must accept the risk of a storage area not operating correctly and producing a dispersed leak of CO_2. If the only gas that leaks is CO_2, and the leak disperses, the situation is not different to the initial state of emissions without CO_2 capture (that is, a 100 per cent leak). Consequently, dispersed leakages of a few storage areas that are not operating correctly do not necessarily imply a serious environmental problem, but rather a problem in the allocation of responsibility, given that the detection of a leak can take place much later, following the conclusion of the authorisation period for the injection of CO_2 into a storage area, after which the corresponding CO_2 emissions rights gained through the capture and storage operation have been exercised.

Potential for CO_2 capture and storage in Spain

The capture and storage of CO_2 may be especially important in countries like Spain, where use of fossil resources is intensive (80 per cent of our primary energy), and whose objectives for the reduction of CO_2 emissions over the upcoming decades are ambitious. Although some important initiatives have already been launched within the Instituto para la Diversificación y Ahorro de Energía (IDEA, Institute for the Diversification and Saving of Energy), there are still no energy forecast models available in Spain that are able to quantify the level of penetration of CCS during the next few years, as is already done globally and in Europe. In the absence of these forecast models, it is possible to use the simple methodology of "wedges" made popular by Pacala and Socolow of the University of Princeton, which allows for an initial impression of the scope that the different mitigation options must possess within the framework of a fixed objective for the reduction of emissions over a sufficiently long period of time. This simple method has been applied here for Spain, estimating how many thermal power plants (or refineries, or other large stable sources of CO_2) need to be installed in our country over the upcoming decades (to 2050) to cover a determined percentage (20 per cent) of the total mitigation effort. To apply this method, and as indicated in Figure 3, the base is the current emissions level (point A, in 2006). A triangle is drawn between the long-term emissions objective (point B, in 2050) and a reasonable level of emissions in the absence of drastic policies to mitigate climate change (point C, also in 2050). Defining realistic short and mid-term emissions reduction objectives for a country like Spain can be risky. However, it is relatively easy to define long term (2050) objectives, if we take into account the fact that Europe's commitments within this timeframe coincide with IPCC commitments. Consequently, in line with the approach outlined in the initial paragraphs of this paper, to define point B it is assumed that Spain will need to reduce its emissions in 2050 by 80 per cent with respect to the levels in 2000. Defining point C is also risky, without economic and energy forecast models, but a very conservative assumption has been adopted (point C = point A). That is, it is assumed that emissions in Spain have peaked and that they will remain at their current levels during the period 2005-2050, compensating the growing consumption trends with relatively simple energy saving and efficiency policies. Even with such an optimistic assumption in the establishment of points C and B, Figure 3 still produces an enormous result (the area of the ABC triangle), which defining the mitigation effort that Spain must carry out during the upcoming decades: it must avoid the emission of at least 8,500 $MtCO_2$ equiv. There are various solutions that should play a part in fulfilling these requirements (each one would be a kind of "wedge" in the triangle, like the one marked for the CCS). The main options (it is not necessary to choose all of them) are greater energy savings and efficiency, the development of renewable energies, nuclear contribution, the promotion of natural CO_2 sinks, and the capture and storage of CO_2.

To cover 20 per cent of the minimum mitigation effort that Spain must comply with by 2050 (8,500

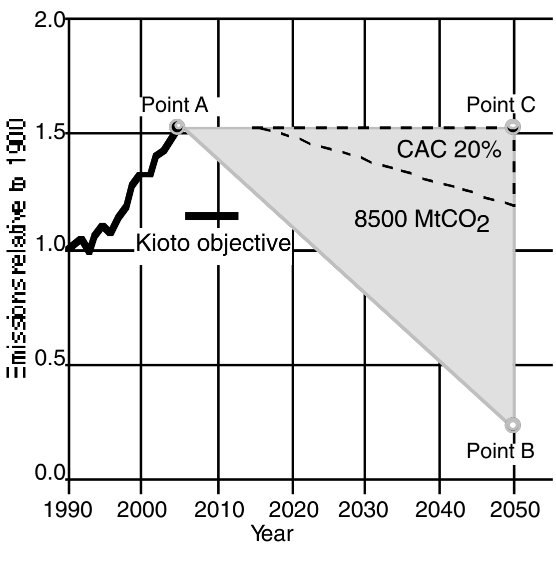

Figure 3. Minimum reduction of greenhouse gas emissions that Spain must face from here until 2050, and a possible "wedge" pertaining to CO_2 capture and storage.

Mt CO_2 equivalent) with CO_2 capture and storage, it would be necessary to install a new 540 MWe thermal power plant with CO_2 capture capabilities each year from 2015 to 2050 (the estimate has been made on the basis of a coal reference plant with a net output of 0.47 and emissions of 0.8 tCO_2/MWhe, and with a capture plant of 0.37 and 0.15, respectively. 0.9 capacity factor in both). This would require for the same period storage capacity for more than 2,000 Mt CO_2.

Despite the magnitude of these figures, it is once again necessary to stress the technical and economical viability of CO_2 capture and storage as the most important option in the mitigation of climate change throughout the world, in particular when applied to coal. Over the next two decades, CO_2 capture and storage technologies could be one of the key tools in Spain for achieving drastic reductions in CO_2 emissions while there is a slow transition within our society towards more sustainable behaviour, and towards an efficient and renewable energy system.