Risk Governance and Policy Strategies Proposals for Carbon Capture and Geological Storage in Brazil

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Abstract

This article focuses on risk management and the technologies involved in carbon capture and geological storage (CCGS). The main objective is to propose policies and help in the formulation of regulations for CCGS in Brazil.
The main risks were analyzed, along with the risk perception and public acceptance. The work also shows the attempts at regulating CCGS in the world and the environmental legislation that will guide the proposals for regulation of this activity in Brazil. Finally, scenarios were created for forecasting emissions and proposals were made for actions in the short and medium terms to boost CCGS in Brazil.

Keywords
Carbon capture, geological storage, policy, risk governance.

1. Introduction
The greenhouse effect (GHE) that allowed the emergence and expansion of life on earth has been growing due to made-man greenhouse gases (GHG) emissions. The increasing use of fossil fuels since the beginning of the industrial revolution has been increasing the GHE and consequently gradually raising the earth's temperature, affecting the conditions for species survival (Esteves and Morgado in press).
The main GHG are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), whose concentrations in the atmosphere have been rising as a consequence of intensification of human activity. Each of these gases has a different potential to absorb infrared radiation. The Intergovernmental Panel on Climate Change (IPCC) of the United Nations created the global warming potential (GWP) index that normalized the GHE of each gas in relation to CO2, which has a GWP of one. So methane and nitrous oxide have a GWP of 21 and 310 respectively, meaning their warming effect is 21 and 310 times that of CO2.
Table 1 shows the anthropic emissions of GHGs of the United States (USEPA 2011) in 2008, the 27 countries of the European Union (EEA 2010) in 2008 and of Brazil (MCT BRAZIL 2010) in 2005. The emissions of all the gases except for CO_2 are expressed by their GWP rather than in absolute mass values. By determination of the United Nations Convention on Climate Change, CFCs and HCFCs are not included in these inventories because they are controlled by the Montreal Protocol, which regulates emissions of gases that destroy the ozone layer. In the case of the United States and European Union (columns 2 to 5 in Table 1), the total emissions are expressed net of the emissions related to changing land use and forestry, which generate negative emissions in these countries. Therefore, changing land use and forestry in these countries cause an increase in the biological capture of CO_2, thus acting as carbon sinks. Just to have an idea of the order of magnitude, changing land use and forestry in the United States in 2008 accounted for negative emission of 1,140.5 $MtCO_2$, representing 16% of the total of 6,961.9 $MtCO_2$.
The second emissions inventory carried out in Brazil (MCT BRAZIL 2010) presents the emissions for 1990, 1994, 2000 and 2005. Columns 6 and 7 of Table 1 show the GHG emissions of Brazil in 2005. Unlike columns 2 to 5, the figures in columns 6 and 7 include emissions because of changing land use and forestry. The variation in the percentage shares of CO_2 and methane in comparison with those in the United States and European Union is the result of the less intensive industrial activity in Brazil. Besides this, the GWP methodology overstates methane emissions, which have a relatively high value in Brazil due to the importance of farming and stock breeding in

comparison with industrial activity.

Table 1: GHG Emissions – USA and EU – Year: 2008 and Brazil – Year: 2005 (using GWP)
Sources: USEPA (2011), EEA (2010) and MCT BRAZIL (2010).

	USA 2008		**EU 2008**		**Brazil 2005**	
	Mt CO_2 eq.		Mt CO_2 eq.		Mt CO_2 eq.	
CO_2	5.921,400	83,9%	3.062,000	82,3%	1.637,905	74,70%
CH_4	676,700	9,6%	302,000	8,1%	380,241	17,34%
N_2O	310,800	4,4%	282,000	7,6%	169,259	7,72%
FCs e HFCs	136,000	1,9%	66,000	1,8%	4,593	0,21%
SF_6	16,100	0,2%	9,000	0,2%	0,602	0,03%
Total	7.061,000	100%	3.721,000	100%	2.192,600	100%

2. Carbon Capture and Geological Storage

Carbon capture and storage (CCS), also known as carbon capture and geological storage (CCGS), is a process to mitigate climate change by which the CO_2 generated by concentrated industrial activities, such as thermoelectric plants, fossil fuel extraction and refining facilities and other industrial processes that rely on combustion, is captured and stored in geological formations. The study by the IEA (International Energy Agency) (2010) shows that the reduction of GHG emissions can only be attained by adopting a series of technological measures. As seen in Figure 1, with an intense effort to reduce emissions, through a mixture of CCGS, carbon sequestration by biomass, increased use of renewable energies such as nuclear and enhanced energy efficiency, the world can reduce its emissions from a baseline of 57 $GtCO_2$ a year to 14 $GtCO_2$ a year.

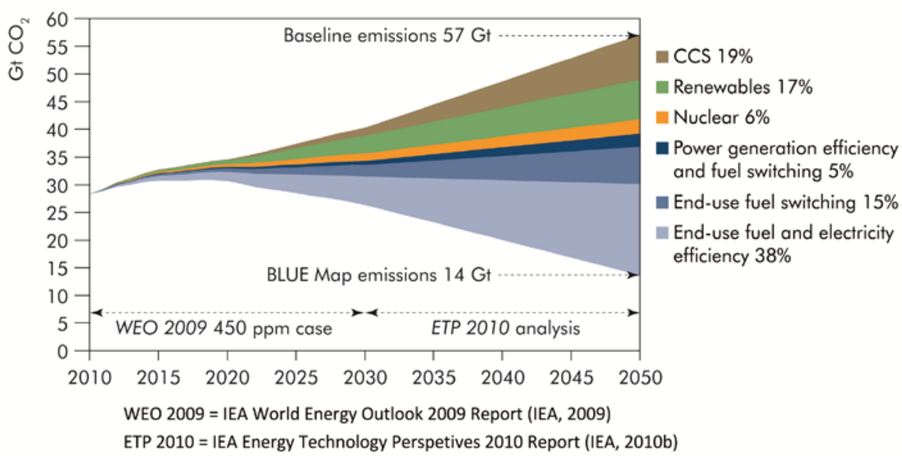


Figure 1: Scenarios for reducing CO2 emissions. Source: IEA (2010).

3. CCS Steps – Involved Technologies

The CCS process can be divided into six basic steps: Separation, Dehydration, Compression, Transport, Injection and Storage and monitoring.

3.1 Separation

At present there are basically four cases where the concentration of CO_2 emissions makes its separation for geological sequestration technically and commercially viable. The first is related to the processes of extraction of natural gas, which depending on where and how it is extracted brings with it a varying percentage of CO_2 along with a series of other gases and impurities. The second case the process of gasification of coal, which generates large amounts of CO_2. The third is the generation of hydrogen, in which CO_2 is generated as a byproduct. And the fourth situation, which contributes most to emissions, is the generation of CO_2 from industrial processes involving combustion. Figure 2 presents, as an example of this fourth case, a coal-fired power plant. The coal is burned to heat a boiler to generate steam, which drives the turbines coupled to the generators. The exhaust gases, composed of roughly 15% CO_2, 85% N_2 and under 1% of other compounds such as sulfur oxides (SO_x) and nitrogen oxides (NO_x), pass through a desulfurization system for removal of most of the sulfur-based compounds. The exhaust gases then go to the capture unit, where the CO_2 is separated from the other constituents, which are discharged into the atmosphere. The part discharged is mainly composed of nitrogen (N_2).

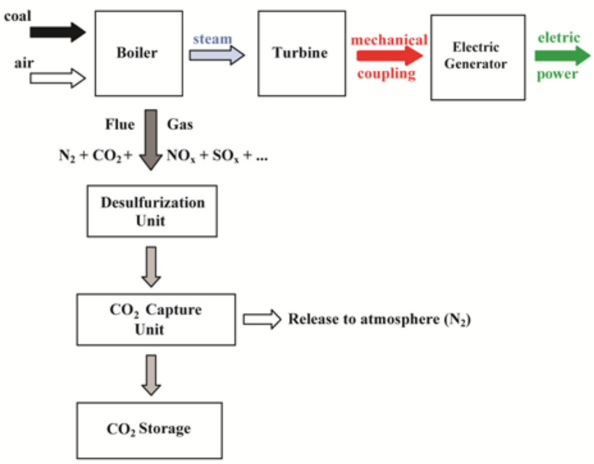


Figure 2: Coal thermoelectric plant with carbon capture.

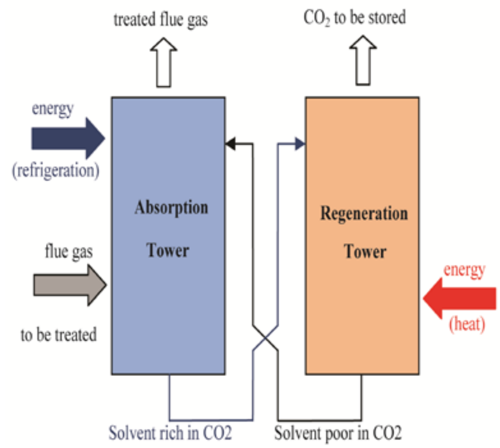


Figure 3: Absorption and regeneration processes

Today there are a series of CO_2 separation methods already developed or under development, among them the more used are: Chemical absorption; Physical adsorption and Oxy-combustion. Various factors influence the choice among these separation methods: available space for allocation and consumption of energy by the separation plant, concentration of CO_2 in the gases to be processed, pressure of these gases, level of purity and percentage of CO_2 separation.

3.1.1 Chemical absorption

Chemical absorption is a widely used process with a series of pilot plants distributed around the world. The oldest commercial CCGS plant is located in Sleipner, Norway and has used this process since 1996 (Solomon 2007).
The process entails using a solvent, normally an amine, which chemically reacts with CO_2, forming a compound. As shown in Figure 3, this reaction occurs in an absorption tower, whose size basically depends on the flow of the flue gas from the industrial process. The compound thus formed is transferred to the regeneration unit where its temperature is raised to release the CO_2. The solvent free of CO_2 then returns to the absorption tower to repeat the cycle. One example of commercial chemical absorption processes is the chilled ammonia process (CAP), which was developed by Alstom Power and is utilized in pilot plants to capture carbon developed by that company in partnership with American electric utilities. The first pilot plant, with generating capacity of 1.7 Mwatts, was the Pleasant Prairie thermoelectric plant of WE Energies in Wisconsin. The second was the Mountaineer thermoelectric plant, with capacity of 20 Mwatts, owned by American Electric Power in West Virginia (Sherrick et al 2009). This plant operated from October 2009 to May 2011, for a total of over 6,500 hours, and reached the goal of validating the technology, capturing over 50 $KtCO_2$ in this period and permanently storing over 37 $KtCO_2$ in a saline aquifer located at a depth of 2,400 meters.

3.1.2 Physical adsorption

Physical adsorption consists of capturing CO_2 by the surface of a solid material, such as activated charcoal or a zeolite, placed in the path of the flow of the gas targeted for removal of CO_2. The CO_2 adsorbs to the surface of the solid particles by surface forces (non-chemical forces). The adsorption process is facilitated by keeping the process at low temperature or high pressure. Once the adsorbent material reaches a determined CO_2 saturation level, the exhaust gas flow is diverted to another path and the chamber containing the adsorbent material is heated or its pressure is reduced to release the CO_2, in a process called desorption. An example of the physical adsorption is a project for hydrogen production units in Port Arthur, Texas run by the company Air Products (2011). This was one of the three projects chosen in Phase II of the Industrial Carbon Capture and Sequestration Program (ICCS) of the US Department of Energy (USDOE). The Port Arthur Units 1 and 2 work based on the traditional process of reform of natural gas by the action of steam. Equations 1 and 2 show the chemical reactions that produce hydrogen from methane. Equation 1 is highly endothermic, consuming a high amount of heat, while equation 2 is slightly endothermic, producing only a small amount of heat. After the reformation process, which is carried out in the steam methane reformer (SMR) unit, the synthetic gas (syngas) generated is composed basically of hydrogen and carbon dioxide associated with some impurities, depending on the composition of the natural gas reformed. The syngas is then sent to the adsorption unit, which works by the principle of pressure swing adsorption (PSA) to separate the hydrogen to be exported.

$$CH_4 + H_2O \Rightarrow CO + 3H_2 \quad (1)$$

$$CO + H_2O \Rightarrow CO_2 + H_2 \quad (2)$$

The project, which received funding of U$ 284 million from the USDOE, will include a CO_2 separation unit and a drying and compression unit in the process, besides interconnection with an existing pipeline to send the CO_2 to the site for geological sequestration. The units are slated to start operating at the end of 2012 and start of 2013 and will capture 1 $MtCO_2$ per year. The vacuum swing adsorption (VSA) process is a variation of the PSA process, whereby the adsorption is carried out at a pressure near atmospheric pressure and the desorption occurs by producing a vacuum in the chambers.

3.1.3 Oxy-combustion

In theory the oxy-combustion process involves burning a fuel using O_2 instead of air as the oxidant. In this process, the N_2 is separated in advance, eliminating the presence of nitrous oxide (N_2O) in the exhaust gas. Since the sulfur removal units are already obligatorily included in industrial processes that burn fossil fuels, except for particulates and other impurities the exhaust gas contains a high concentration of CO_2. However, all oxy-combustion systems in practice work with a mixture of O_2 with recirculated exhaust gas. Therefore, the oxy-combustion only increases the CO_2 concentration in the exhaust gas, making its separation more feasible. As a result, the oxy-combustion process must be associated with at least one of the other separation processes.

3.2 Dehydration

The objective of dehydration is to reduce the level of moisture of the CO_2 as much as possible so that it will be less prone to cause erosion in the mechanical elements involved in the injection process.

3.3 Compression

To be transported, CO_2 needs to be compressed. The compression range depends on how it will be transported. For pipeline transport, the CO_2 needs to be compressed in the range between 1100 and 3100 psi to assure single phase flow, because above 1100 psi, CO_2 remains in single phase within a broad range of temperatures. Since pipelines are subject to great temperature variations, it is important to avoid the formation of two phases, which can cause pressure spikes that can in turn rupture pipes (Barrie et al 2004). The pressure required is much lower for transport in tank trucks, railcars or ships, because the temperature can be kept low through thermal insulation, something that is uneconomic in the case of pipelines. Therefore, pressures of 250 to 400 psi are sufficient to keep the CO_2 in the liquid phase.

3.4 Transport

There are four ways of transporting CO_2 between the emission source and the underground injection site: tank trucks, trains made up of tank cars, tanker ships and pipelines, which in the case of CO_2 are called carbon pipelines. Of these four transport means, only pipelines are viable for EOR projects, where the distances can run into the hundreds of kilometers and the volumes of CO_2 are in the millions of tonnes per year. This high carrying capacity compensates for the high costs of building, maintaining and operating a carbon pipeline. Because of the high initial investments and operating expenses of a carbon pipeline and the large damages that could be caused by a rupture, as well as the fact it may cross land held by many owners, special attention must be given to the commercial, legal and insurance aspects to minimize the economic risks. Suppliers and consumers of the CO_2 carried by pipeline along with the line operator must participate in detailed multilateral agreements with well-defined rights and obligations.

3.5 Injection

In this step, the CO_2 is injected through injection wells, basically into three types of geological formations: exhausted or declining oil reservoirs, saline aquifers and coal beds.

3.5.1 Injection in exhausted or declining oil reservoirs

The option for injection in oilfields where production is waning serves another function besides carbon sequestration: it maximizes oil recovery. This process is called enhanced oil recovery (EOR). The standard production process always involves injection of water to maintain the producing pressure. The EOR process, shown in Figure 4, involves injection of water and CO_2 in alternation. The CO_2 injection increases the oil's fluidity, releasing the oil stuck in the rock pores, while the water, which is by nature not compressible, pushes the oil toward the producing well.

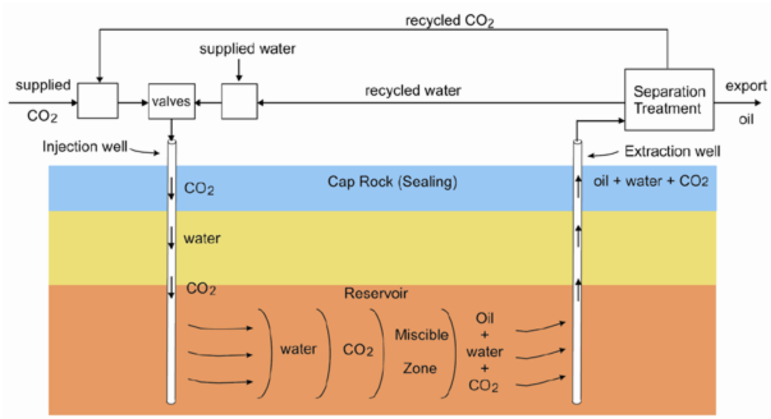


Figure 4: Enhanced Oil Recovery (EOR) Process

An example of the injection of CO_2 in EOR projects is the Weyburn project, located on the border between Canada and the United States. It has been in operation since 2000. The CO_2, with 95% purity, captured in a coal gasification plant in Beaulah, North Dakota, is carried by a pipeline to an oil production field in Weyburn, Saskatchewan, where it is injected (Zhou et al 2004). Figure 5 presents a graph of oil production in Weyburn since the start of the operation in December 1955 until December 2010. The brown area represents the increase in output because of the EOR process. If the process had not begun in 2000, production in December 2010 would have been approximately 10 thousand barrels per day (10 kbopd). The EOR boosted this output in December 2010 to roughly 28 kbopd (Cenovus Energy 2011).

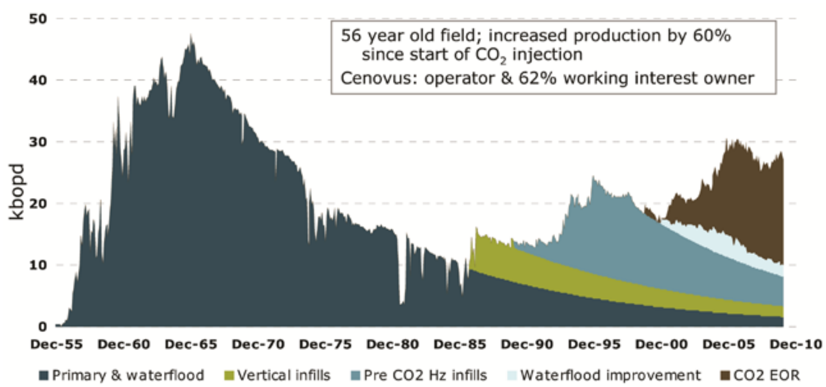


Figure 5: Weyburn Historical Oil Production - Source: Cenovus Energy (2011)

3.5.2 Saline aquifers

Saline aquifers exist in the great majority of the world's regions. Since this water cannot be used for drinking or farming, the option to store CO_2 in these aquifers appears very promising. The first project to capture carbon of this type was developed by Norway's Statoil in its Sleipner natural gas field in the North Sea. According to Statoil, the percentage of CO_2 in the natural gas of its Sleipner field is approximately 9% (BGS 2011), which is above the level tolerated by its consumers. In 1991, the Norwegian government introduced a tax of US$ 50 dollars per tonne of CO_2 emitted. These two aspects combined (standards required by consumers and government taxation) prompted Statoil to develop the geological capture project. Physically the project is composed of two platforms. On the first one the natural gas rich in CO_2 is extracted. This gas is sent to the second platform where the CO_2 is separated by chemical absorption, then compressed and injected into a saline aquifer located 1000 meters beneath the seabed. According to the projections of a special report of the IPCC (2005), the total storage capacity of the Sleipner project is 20 $MtCO_2$, of which nearly 11 $MtCO_2$ had already been stored by the end of 2008 according to Statoil.

3.5.3 Coal beds

For the storage of CO_2 in coal beds to be feasible, this process must be associated with the production of methane from the bed. The injection of CO_2 enhances the production of methane, hence the name enhanced coal bed methane recovery (ECBM). The process is being studied by, among others, the Swiss Federal Institute of Technology (ETH) and other research organizations funded by European Commission and US Department of Energy (USDOE). These studies aim to obtain the necessary knowledge to apply the technology in large scale.

3.6 Storage and monitoring

Storage and monitoring are considered to be single step, because monitoring is required to assure that the CO_2 stored will not leak out to the atmosphere. According to the report of the Special Intergovernmental Panel on Climate Change (IPCC 2005), this monitoring aims to verify possible leaks or other aspects indicating deterioration of the storage over the long term, to assure there are no risks to the environment. Various technologies can be used to perform different types of monitoring: Monitoring of the injection flow and pressure; Monitoring of the underground CO_2 distribution; Monitoring of the integrity of the injection wells; Monitoring of the local environmental effects and Monitoring by a network of sensors placed at points distant from the injection sites. All the data gathered by these monitoring efforts are fed into computer systems equipped with "intelligent" software as part of a risk management system, which besides indicating tendencies that can foretell risky situations and determine operational changes, also indicates mitigation routes in case of leaks or malfunctions of the system.

4. Risk Governance of CCGS Projects

Normally in industrial undertakings, the causes of events with large adverse effects are treated by managing the technology, that is, by specifying the equipment and materials, preparing rules and procedures, training programs, etc. The effort to reduce risk is concentrated in diminishing the probability of the occurrence of the causes that can trigger a series of events that lead to catastrophe and to assess the consequences. These consequences are analyzed by using the data on the area surrounding the project, its population and natural resources. Therefore, contingency plans are drawn up for mitigation of the catastrophic events if they occur. However, the focus is on the causes.

4.1 Risk during transportation

According to a study by the Pipeline & Hazardous Materials Safety Administration (PHMSA) of the U.S. Department of Transportation (USDOT), in that country in 2008 there were 5,580 Km of carbon pipelines in operation, mainly involving enhanced oil recovery (EOR) projects. Most of these lines cross sparsely populated regions, a characteristic that reduces the severity factor of the risk associated with transporting the CO_2. This is clearly intended, since the severity reflects the direct effects of possible accidents on people. Nevertheless, while effects on natural biomass may not directly affect local populations, they can cause secondary effects on more distant population centers. If these effects are neglected for not being direct, the losses can be greater and broader in scope, ceasing to be local and becoming regional. In densely populated and highly industrialized regions such as Central and Northern Europe, carbon pipelines linking CO_2 sources with storage sites will have to traverse populated areas, potentially prompting public opposition. The current risk perception places the risks of onshore storage above those of onshore transportation. This is understandable because people have lived for decades with oil and gas pipelines but are not accustomed to the idea of having geological formations beneath their feet containing millions of tonnes of CO_2 "ready to escape". But while onshore storage projects may face low acceptance, offshore projects require a much greater investment in constructing the necessary pipelines.

4.2 Risk of Leakage to the Atmosphere

When injected, the CO_2 is less dense than the saline fluids of the reservoirs, so it can migrate to other geological formations or to the surface. The escape to the atmosphere, besides causing risks to human health and the environment in nearby areas, also obviously reduces the effectiveness of the effort to control GHG emissions intended by the CCS project in the first place. The leakage of high concentrations to the atmosphere can have catastrophic effects on the local biota. CO_2 leakage to the surface can occur because of pre-existing geological fractures or faults, new geological fractures caused by seismic movements, abandoned production or injection wells or long-term changes in the properties of the reservoir's rock formations. The most important aspect to be analyzed is the impact of CO_2 leaks on human health. In this respect, the concentration and exposure time are the two factors that must be assessed. A CO_2 concentration of 150,000 parts per million (ppm), or 15% by volume, can cause a person to lose consciousness in less than one minute. Exposure for one hour to concentrations between 100,000 and 150,000 ppm (parts per million) can cause mortality ranging from 20% to 90% (Koornneef et al 2010).

4.3 Risk of Underground Movements

One of the most important aspects that must be analyzed regarding injected CO_2 is its capacity to carry metals in the underground that can contaminate groundwater. The presence of saltwater, as in storage in saline aquifers, is important because it promotes the formation of carbonic acid, which reacts with the surrounding minerals and can carry the metals present in them. This transport can contaminate nearby potable water aquifers. In the case of silicate rocks, the carbonic acid reacts very slowly with the rock so there is practically no change in the porosity and permeability. In contrast, carbonate rocks react more quickly with the CO_2, altering the porosity and permeability. This effect, however, is damped by the rapid increase of the pH of salt water, which leads to a decrease of acid action on the rocks (Wilson et al 2007).

An example where the risk of underground movement is present is the project developed by In Salah Gas (ISG), a joint venture among British Petroleum (33%), Statoil (32%) and Sonatrach, the Algerian national oil company (35%). The gas produced by the production wells in the Sahara Desert region has an average CO_2 concentration of 7%, a level that needs to be lowered to under 0.3% for the gas to be exported to Europe. Therefore, a purification plant was built at the Krechba Oasis, 700 Km from Algiers (Iding and Ringrose 2000). The purified methane is sent northward in a pipeline that connects to the Algerian gas exportation network, while the captured CO_2 is pressurized, carried by pipeline and injected in a saline aquifer located below the gas field. The main risk of this undertaking is the possibility of migration of the CO_2 toward a drinking water aquifer that lies above the gas reservoir. Investigations demonstrated that the upper part of the reservoir where the CO_2 is being injected has a thick layer of schist that seals this reservoir. However this risk of groundwater contamination should be given priority attention, in this desert region, where there have historically been violent conflicts involving water rights.

5. Policy and Regulation

Governments play an essential role in CCGS, by setting safety standards and other requirements for operation and obtaining public support. The deployment of CCS projects relies on the approval of civil society, who must believe that the injected CO_2 will stay stored in the reservoir for thousands of years. To this end, the analysis of possible risks associated with the escape of CO_2 is an essential stage in the life cycle of the storage system and aims to promote and ensure the safety of the activity to the environment and to human health, contributing to the technology's acceptance (Esteves and Morgado 2011). One of the main sticking points for the expanded use of carbon sequestration, mainly in densely populated areas, is the acceptance of the people living above or nearby the reservoir that will be used. The same situation exists for the location of sanitary landfills, prisons, power plants or any other large project with potentially negative impacts. While society at large agrees on the need for such undertakings, those most closely affected generally feel otherwise, often because of a lack of knowledge of the real risks involved. This is the well-known "not in my backyard" conundrum. In the case of carbon sequestration, the benefits accrue to the population of the entire planet, not just a region or state, making this contrast between the general welfare and local concerns as stark as it possibly can be. Winning public support thus requires a major effort to educate the public about the real risks of geological storage of carbon. A real example of the public acceptable importance is the project of Shell in Barendrecht, Holland (Kuijper 2010). This project planned to store some 10 $MtCO_2$ over a period of 25 years, captured from Shell's hydrogen gasification plant at the Pernis refinery near Rotterdam. The CO_2 would be transported by a pipeline about 20 km and injected in two depleted natural gas fields over a mile deep under the city of Barendrecht. Despite many public hearings held by the city council and strong support of the central government, through approval of by the Dutch Senate, Ministry of Economic Affairs and Ministry of Housing, Spatial Planning & the Environment, the project faced strong opposition from the citizens of Barendrecht and it finally had to be canceled.

In most countries the regulation of CCS is the responsibility of the central (federal) government. In the United States, Australia and Canada there is shared responsibility among the federal, state (provincial) and local spheres. The specific legislation to regulate the activities involved in CCS should start from existing laws on extraction and processing of fossil fuels. International accords and mechanism such as the United Nations Framework Convention on Climate Change (UNFCCC), which was created in 1992 at the United Nations Conference on the Environment and Development (Rio 92), have an important role in fostering CCS. Among the Kyoto Protocol's features is the Clean Development Mechanism (CDM), which permits developing countries, which are not required to have emission reduction targets, to develop projects to reduce GHG emissions and in return acquire Certified Emission Reduction (CER) certificates. At the Seventeenth Conference of the Parties (COP 17), in Durban, South Africa, in December 2011, it was finally decided that CCS is included as eligible under the CDM. Despite the uncertain future of the Kyoto Protocol itself, the CCS inclusion as CDM reflects international acceptance that CCS is a low carbon technologies like solar and wind.

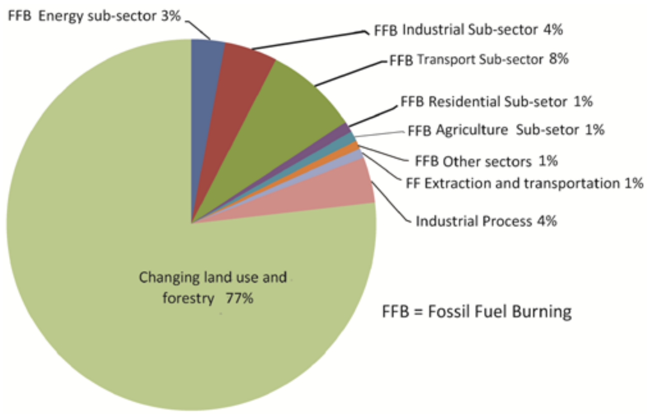
5.1 Brazilian Environmental Legislation

The current Brazilian Constitution, promulgated in 1988, has an entire Article about environment protection. Among other aspects, this article refers to the concept of sustainability, as it was presented by the United Nations in 1987. Law 6,938/81 established the National Environmental Policy and created the National Environmental System (*Sistema Nacional do Meio Ambiente* **-** SISNAMA). Within the SISNAMA structure, the National Environmental Council (*Conselho Nacional do Meio Ambiente* - CONAMA) was created as the consultative and deliberative entity of the SISNAMA. CONAMA issues resolutions that create general guidelines, rules and standards. CONAMA Resolution 01/86 contains the definitions, responsibilities and basic criteria for the use and implementation of environmental impact assessment. To build and operate any project involving an activity considered potentially polluting, it is mandatory to prepare an environmental impact study (*Estudo de Impacto Ambiental* - EIA) and accompanying environmental impact report (*Relatório de Impacto Ambiental* **–** RIMA). The activities listed as potentially polluting that are related to an CCS project are: (a) gas pipelines; (b) extraction of fossil fuel, which would apply in the case of using the CO_2 captured for enhanced oil recovery (EOR); (c) power plants, applicable in case of capture of exhaust gases from these plants; and (d) industrial plants, which would apply to a wide range of industrial activities, both in the petroleum industry (refineries, fertilizer plants, coal gasification plants) and others (steel mills, cement factories, chemical plants, etc.). Presentation of the EIA/RIMA set is a mandatory step of the licensing by the environmental agency (federal, state or municipal) and besides setting out the magnitude of probable impacts (positive and negative), muse define the mitigating measures of the negative ones. Annex I of CONAMA Resolution 237/97 lists which activities need to be licensed at the federal, state or municipal level. Projects whose “environmental impacts exceed the territorial limits of the country or of one or more of its states” fall under the remit of the Brazilian Institute of the Environment and Renewable Natural Resources (*Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis* - IBAMA), the federal environmental agency. Therefore, except for very small CCS projects, federal licensing is required.

6. Scenarios and strategies to reduce emissions using CCGS in Brazil

The construction industry is expanding rapidly due to the infrastructure and public housing works under the government’s Growth Acceleration Program (PAC), as well as the “My House, My Life” housing program, which seeks to build approximately 3 million low and moderate income housing units by 2014 (to significantly reduce the current deficit estimated at 5 million units). In addition to this huge demand for construction projects, many more projects are on tap to get ready to host the Word Cup in 2014 and the Olympics in 2016. Another aspect that can boost industrial production is the policy of requiring increased local content. This policy aims to add technological value to the goods manufactured in the country and reduce the exportation or raw materials without any processing. For example, this will encourage the national steel industry rather than boost export of iron ore. Just as the environmental impact of mineral extraction is a legacy that needs to be managed, the positive effects of generating jobs and foreign exchange from exportation of goods with higher aggregate value will also need to be managed wisely. Figure 6 shows the current shares of the various economic sectors in CO_2 emissions in 2005 (MCT BRAZIL 2010). If by 2020 Brazil manages to expand the supply of agricultural products (including biofuels) without increasing the area used for crops and grazing, the country might reach a balance of zero net emission from this sector. A zero balance does not mean eliminating deforestation. Rather, it means balancing deforestation with replanting and management.

Figure 7 shows an emissions scenario for 2020 considering a zero balance in the category “changing land use and forestry” and forecasts for increased emissions from the industrial and power generation sectors. Figure 8 presents the stationary CO_2 emission sources according to the CARBMAP project (Rockett et al 2010). A total of 361 sources were mapped, adding up to 204 $MtCO_2$ yearly. A concentration can be observed along the coastline of the South, Southeast and Northeast regions and the interior of the Southeast as well, mainly in the state of São Paulo, Brazil’s industrial heartland. Figure 9 shows a map of the country’s sedimentary basins (Ketzer 2011), which occupy 4.8 million square kilometers and have estimated capacity for roughly 2,000 Gt (giga tonnes) of CO_2, distributed among saline aquifers, oil and gas fields and coal beds. The saline aquifers account for the greatest part of this storage capacity. The Paraná (with capacity to store 462 $GtCO_2$), Solimões (252 $GtCO_2$) and Santos (148 $GtCO_2$) basins are the most important for application of CCGS because they are located near concentrations of emission sources and oil and gas fields. The Paraná Basin is near the region with the highest concentration of stationary sources; the Solimões Basin has large gas reserves; and the Santos Basin is the leading area in the country for oil and gas exploration.



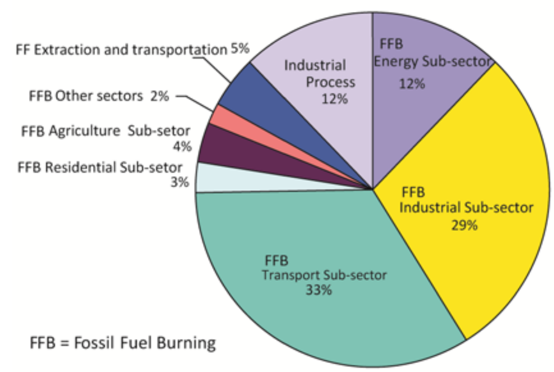


Figure 6: Brazilian CO_2 emissions 2005

Figure 7: Brazilian CO_2 emissions scenario for 2020.

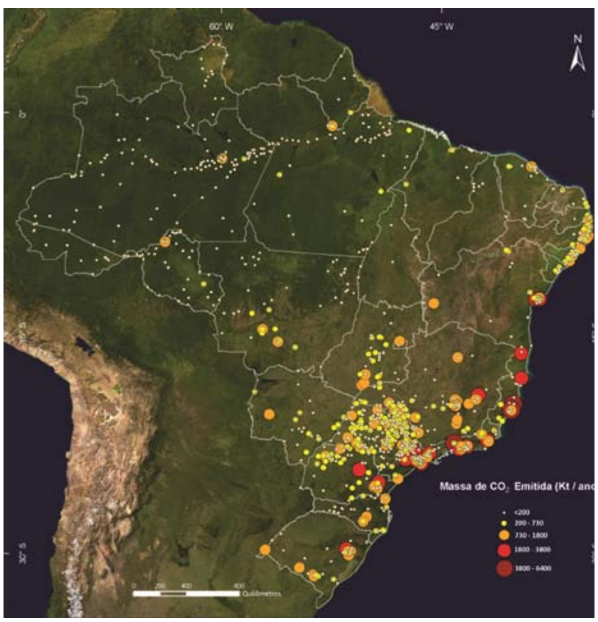


Figure 8: Stationary CO_2 emission sources

Figure 9: Brazilian sedimentary basins

The most recent milestone in the expansion of the Brazilian gas pipeline system, mainly present along the coast, was the interconnection of the Southeast and Northeast networks with the entry into operation of the Gasene pipeline in March 2010. This expansion of the pipeline network allows envisioning implementation of a two-way methane-CO_2 system that would take natural gas with high CO_2 content, produced in the offshore sub-salt fields, to thermoelectric plants in the states of São Paulo and Rio de Janeiro. These plants would be equipped with technology for CO_2 capture. The same pipeline would carry the CO_2 from the power plants for injection in the production basin, in depleted geological formations or for EOR. This two-way system could be most easily implemented as part of expansion along existing rights of way. The sharing of these routes between new carbon pipelines and existing oil & gas lines would reduce the costs of construction, operation, maintenance and monitoring (Esteves and Morgado in press). In the case of platforms far from shore, where the construction of subsea pipelines might not be economically feasible, the gas extracted can be transported to the mainland in tankers, which could also take the CO_2 back to the injection installations. In this case, the CO_2 could be carried from the emission sources to the coast in pipelines and transferred to ships designed to carry both compressed natural gas and carbon dioxide.

7. Conclusions

Brazil and other developing countries like China and India, among others, still has huge pent-up demand for consumer goods from a large segment of the population. It is necessary to increase economic activity to assure all citizens a minimum level of consumption for a dignified life. A growing energy supply is a necessary condition for economic growth and higher living standards, a pattern that is particularly present in emerging countries. However, energy production is responsible for most of the world's output of GHGs. The search for technologies to ameliorate this source of emissions must be seen as a long-term effort. This work shows that in the short and medium terms, due to the intense use of fossil fuels, CCGS is the only feasible technological option for large-scale mitigation of GHG emissions, in a process of gradual transition to a global energy mix dominated by carbon-free sources. Besides the technological challenges of managing the risks of CCGS, its application requires detailed regulations in each country that are clear and in line with international regulations, so as to attract sufficient private investments in the sector and assure the safety, sustainability and public acceptance of this mechanism.

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