Status of CCS Technology in Japan and Brazil: A Comparative Analysis

George Camara
Câmara Consultoria

José Célio Silveira Andrade
Universidade Federal da Bahia

Paulo Sérgio Rocha
Universidade Salvador

Journal of Environmental Science and Engineering B2 (2013) 155-176
Formerly part of Journal of Environmental Science and Engineering, ISSN 1934-8932

Status of CCS Technology in Japan and Brazil: A Comparative Analysis

George Augusto Batista Câmara[1], José Célio Andrade[1], José Puppim de Oliveira[2] and Paulo Sérgio Rocha[3]
1.Federal University of Bahia, Salvador CEP 40.210-630, Brazil
2.UNU-IAS (United Nations University-Institute of Advanced Studies), Yokohama 220-8502, Japan
3. UNIFACS (University Salvador), Laureate International Universities, Salvador CEP 41.950-275, Brazil

Received: August 27, 2012 / Accepted: October 9, 2012 / Published: March 20, 2013.

Abstract: This article presents a comparative analysis of the technology status of CCS (carbon capture and storage) in Japan and Brazil. Japan's GHG (greenhouse Gas) emissions are declining while Brazil's are increasing. Among ESTs (environmentally sound technologies) the potential of GHG mitigation of CCS has gained prominence. The research identifies the main activities and positions of the actors involved in CCS technology implementation in Japan and Brazil, and contrasts and compares reasons for the large-scale use of the CCS technologies in the two countries. This analysis is based on a literature review and a field survey done to collect primary data via visits to organizations and experts. This data was enhanced by an analysis of patent deposits in the area of CCS in the two countries in last 20 years. As regards the legal framework for climate change, and for CCS in particular, while responses to the main international decisions can be found in Japan, in Brazil this is not the case. In Japan the public sector has an effective participation together with private sector and civil society. In Brazil CCS activities are conducted by the private sector which is in turn putting pressure on civil society in particular academia. Currently, Japan is focusing on CCS capture technologies, while Brazil is focusing on CCS storage technologies. In summary, the CCS framework is being more efficiently carried out in Japan than in Brazil.

Key words: CCS technology, environmentally sound technologies, climate change, Japan and Brazil.

1. Introduction

Over the last two decades considerable effort in S&T (Science & Technology), R&D (Research & Development) and E&I (Engineering & Innovation) has been directed to issues regarding CO_2 (carbon dioxide) emissions and their consequences on the climate of the planet. With the advance of monitoring technologies and simulators of climate change both the public sector as well as the private sector or non-profit organizations tend to agree about the impacts of anthropogenic activities on the climate of the planet.

Associated with and supporting the efforts in S&T, R&D and E&I, there is governance, which is understood in this work as the sum of individuals and institutions, public and private, common affairs, in particular GEG (global environmental governance) which constitute the intersection of global governance with environmental affairs [1]. Within this context, there are increasing worries about sustainable development that according to the WCED (world commission on environment and development) is the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [2].

A milestone in sustainable development and environmental impacts on the planet was the UNCED (United Nations conference on environment and development) held in Rio de Janeiro, Brazil in 1992. At this conference the global environmental system

Corresponding author: George Augusto Batista Câmara, Ph.D., research fields: captureand storage of CO_2 (carbon dioxide) in geological reservoirs and oil & gas regulation. E-mail:george@camaraconsultoria.com.br.

and sustainable development [3] were discussed. Twenty years later, another conference is held, Rio+20. At this conference, the UN (United Nations) focused on renewing commitment to sustainable development and expressing the determination to pursue green economy in the context of sustainable development and poverty eradication. The UN further affirms the resolve to strengthen the institutional framework for sustainable development. Together, the proposed actions should fill the implementation gaps and achieve greater integration among the three pillars of sustainable development—the economic, the social and the environmental [4]. In its new perspective, the UN have introduced the term green economy. According to the UNEP (United Nations Environment Programme), a green economy can be defined as one that results in improved human wellbeing and social equity, while significantly reducing environmental risks and ecological scarcities [5].

According to the UN in its document Rio + 20 "The Future We Want" many issues are highlighted as important for a sustainable future but they about advances and gaps in the current global structure. Fig. 1 shows the main areas that the UN highlight about Science & Technology and Climate Change; Governs and States; Private Sector and Framework.

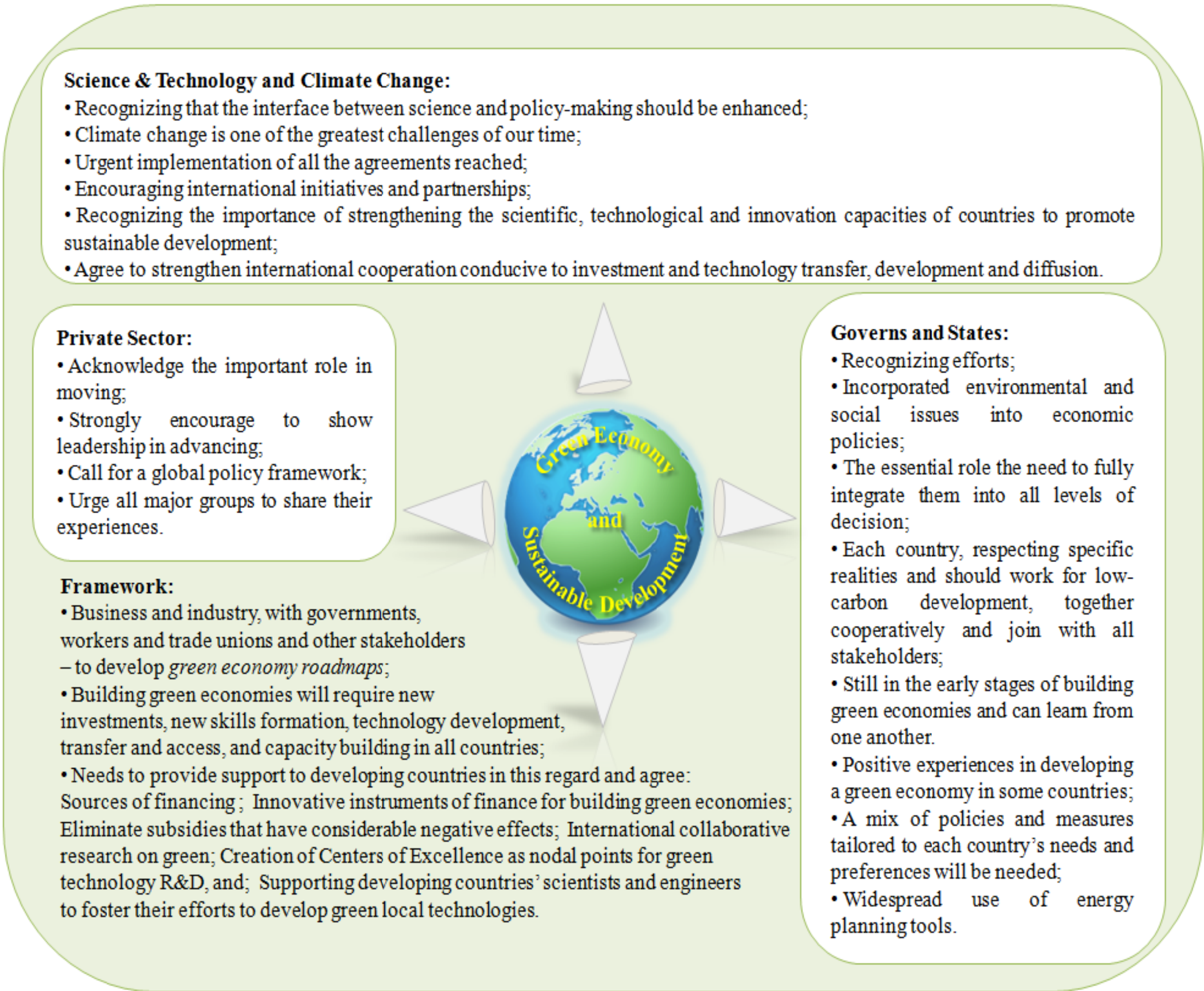


Fig. 1 Main UN highlights in Rio+20 for Science & Technology and Climate Change; Governs and States; Private Sector; and Framework.

Source: Own elaboration based on a reference index [4].

The UN recognizes that a considerable effort has been made by countries, private sectors and civil society to achieve sustainability, but the transition from a model of the high-carbon intensive to green economy will require more synergy between all actors. The transition will probably require extensive use of all the solution technologies available as well as effort in the other areas with education and political solutions.

More specifically, climate change and the currently available technologies recognized for combating CO_2 emissions such as renewables, nuclear energy, power generation efficiency & fuel switching, end-use fuel switching, end-use electricity efficiency and end-use fuel efficiency, the potential of CO_2 mitigation of CCS (carbon capture and storage) have gained prominence.

CCS technologies are defined as a process that consists of separating, collecting and concentrating the CO_2 emitted by stationary sources, transporting it to a suitable storage site, and storing it at the site for a long period, thus isolating it from the atmosphere [6]. Specifically for storage of CO_2 the potential storage methods include geological storage, ocean storage (direct release into the ocean water column or onto the deep seafloor), and industrial fixation of CO_2 in inorganic carbonates [6].

Bachu and McEwen [7] noted that various terms are used to describe CO_2 storage: CO_2 sequestration is used in USA, CO_2 storage is used by UN agencies and in Europe, and terms such as CO_2 removal and CO_2 disposal are also used. Among the CO_2 storage options, one that is in demonstration stage is geological storage. The IPCC [6] defines geological reservoirs as a subsurface body of rock with sufficient porosity and permeability to store and transmit fluids.

Although it is a technology which is very energy intensive and resource inefficient [8], CCS is important due to the fact that it can be implemented at existing and future sites. Furthermore, according to the IEA (International Energy Agency), CCS can control emissions in the short to medium term using technologies that are currently available or likely to become commercially available. Adequate CO_2 capture and storage can contribute to a 19% worldwide reduction in the total CO_2 emissions by 2050 (in blue map scenario), this would represents 11.78 Gt (gigatonnes) in 2050 in relation the baseline emissions 62 Gt [9]. In a specific CCS study carried out by IEA in 2009 [10], it was said that in 2020 in non-OECD countries there would be 50 out of the 100 CCS projects worldwide and in 2050 the forecast is 2,210 out of 3,400 projects worldwide.

However, among the solution technologies available perhaps the wide use of CCS technologies is the most complex as it does not depend on the efforts of one actor alone, but on united efforts. The success of the implementation of CCS technologies involves the public sector, private sector and civil society. When one of these actorsis not involved due to principles or other priorities, it is certain that CCS projects will be unsuccessful.

Understanding the public sector as governments and its regulatory agencies, and the private sector as companies, and finally, civil society as academy, NGOs (Non Governmental Organizations), and society, Fig. 2 shows the main issues identified for CCS synergy among these actors.

In many cases the synergy for large-scale use of CCS varies according to each country. Principally, when a comparative analysis of the CCS technologies status for implementation on a large scale between developed countries (Annex 1 of Kyoto Protocol) and developing countries (non-Annex of Kyoto Protocol) is made, according to Román, CCS becomes a political and strategic issue, rather than simply a technological solution to a problem [11]. It is therefore important to analyze the evolution and success or failure for CCS large-scale use in Annex 1 and non-Annex countries.

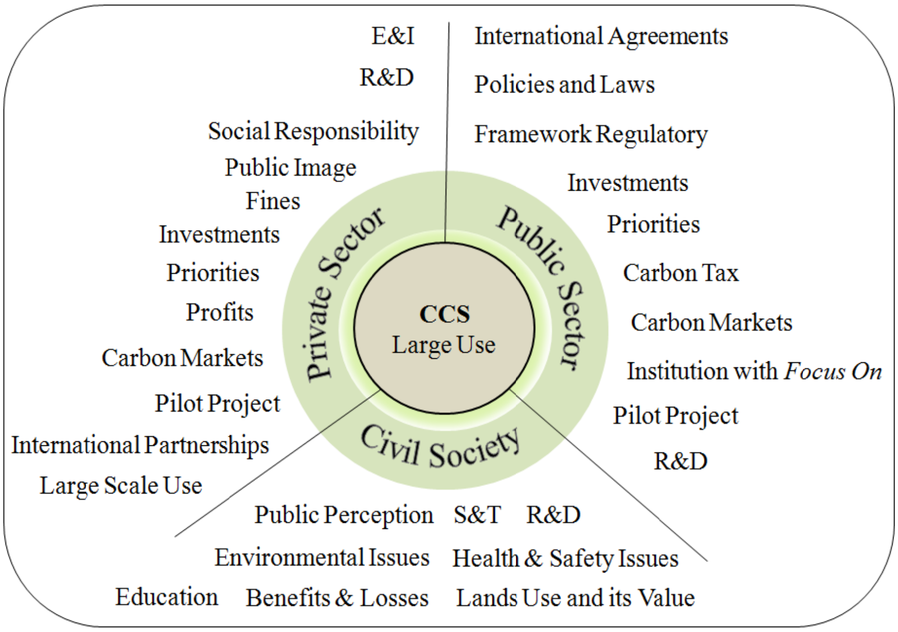


Fig. 2 The main issues for finding the CCS synergy between the actors.

Source: Author's own.

1.1 Justifications and Methods

This article supports the thesis that the large-scale use of CCS technologies will only be successful if there is synergy between actors principally in developing countries. Furthermore, the research group's understanding is that the large-scale use of CCS technologies is critical for changing the current model of high-carbon intensive activity to green economy. Batista [12] suggests that before new and better environmental technologies become the norm, the market has to go through a transition period between the old modes of production using end-of-pipe technologies, and new, cleaner technologies, while seeking environmental practices that promote cleaner development. Thus, in any analysis of the diffusion of CCS technologies in developing countries it is vital to identify the gap and propose the solution for problems such as regulatory framework and synergy between the actors with reference to developed countries.

This article shows a comparative analysis between the current situations of CCS technology implementation in Japan and in Brazil. Japan was chosen because among the developed countries it does not have a demonstrative or commercial large-scale CCS project, which makes it a special referential comparative for developing countries that are at the same stage, unlike other developed countries such as the USA, Canada or Norway which are more advanced in CCS technology implementation on a large-scale. The choice of Brazil is associated with the current economic status of the country; the forecast is for increased energy requirements in association with population increase, the recent discovery of the large pre-salt cluster oil & gas field, and the Brazilian capacity for CO_2 storage.

The research was carried out in two countries using exploratory, descriptive and analytical research methods that focus on qualitative and quantitative data. Primary data were collected through visits to companies/institutions, and consultations with specialists such as researchers and stakeholders. Indirect observations came from participating in discussions and lectures on the subject of study and in forums with domain experts. Furthermore, participating in official meetings, with the approval of the relevant authorities, and recording the results was very useful. Secondary data such as institutional documents, reports, studies and projects were collected from various resources and analyzed, this datawas supplemented by a patent deposit analysis on CCS technologies in the two countries over the last twenty years.

This paper provides an introduction that addresses the most recent concepts and issues about climate change and global environmental governance. After the introduction, the current situation related to CO_2 emissions in the two countries in question are described. The results and discussions are shown through the comparative analysis of the CCS technologies in Japan and Brazil from the perspectives of the public sector, private sector and civil society. Finally, the paper concludes with an overview of the outcome and main gaps found.

2. Current Situation Related with GHG Emissions in Japan and Brazil

The countries researched are currently among the 10 biggest economies in the world[1]. Fig. 3 shows the GDP (Gross Domestic Product) of Japan and Brazil in comparison with the other main economies in the world. Japan is the second economy among developed countries and Brazil is the fourth among developing countries. Another important aspect is population growth. While Japan's population is stable and decreasing, Brazil's population is increasing. This is illustrated in Fig. 4[2].

As regards GHG (greenhouse gas) emissions, both countries have published their GHG national inventory, however, Japan due to being an Annex 01

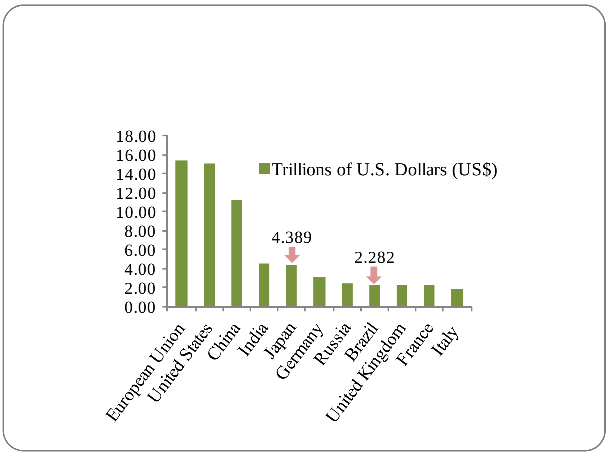


Fig. 3 Gross domestic product (purchasing power parity) per Country plus European Union in 2011 by CIA.

Source: Author's own based on data from CIA.

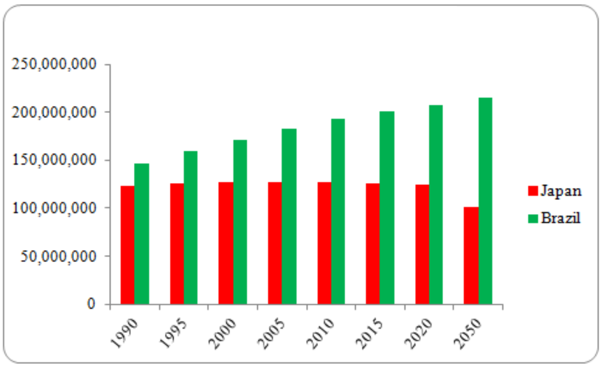


Fig. 4 Population forecast in 2050.

Source: Author's own based on data from by National Institute of Population and Social Security Research and Instituto Brasileiro de Geografia e Estatística—IBGE.

annually elaborate its GHG national inventory [13] and Brazil elaborated in 2009 a more complete GHG national inventory [14]. Furthermore, both countries reported their GHG emissions for UNFCCC (United Nations framework convention on climate change) according to Kyoto Protocol. Because Japan is in Annex 01 of Kyoto Protocol it has a GHG emissions target with year reference in 1990. The target given to Japan for the first commitment period (five years from 2008 to 2012) is to reduce average emissions of greenhouse gases by 6% from the base year (1990 for carbon dioxide, methane and nitrous oxide, and 1995 for HFCs, PFCs and sulfur hexafluoride).

Brazil does not have a target because it is not in Annex of Kyoto Protocol, but in 2010 the Brazilian

[1] Information collected from US Central Intelligence Agency (CIA), site accessed in May/2012 of "The World Factbook"(ISSN 1553-8133) in: https://www.cia.gov/library/publications/the-world-factbook/rankorder/2001rank.html.

[2] Information collected from National Institute of Population andSocial Security Research, site accessed in May/2012: http://www.ipss.go.jp/index-e.asp, and from Instituto Brasileiro de Geografia e Estatística, site accessed in May/2012: http://www.ibge.gov.br.

government sent its NAMAs (Nationally Appropriate Mitigation Actions) to the UNFCCC. In this document the Brazilian Government established its GHG emissions target for reducing between 36.1% and 38.9% projected GHG emission for 2020. Fig. 5 shows the GHG emissions situation in Japan and Brazil according to national inventories and the UNFCCC documents [3] elaborated with the GWP (global warming potential)values.

It can be seen in Fig. 5 that there are differences between Japan's GHG emissions and Brazil's GHG emissions. The line for Japan indicates that the effort to reduce GHG emissions has had results and it can fulfill the established targets. While for Brazil, the line indicates that there is an increase in GHG emissions and it will require great effort to fulfill the established targets.

It is also interesting to examine CO_2 emissions *per capita*. CO_2 emissions *per capita* in Japan in 2009 were 8.98 tonnes [13] while in Brazil CO_2 emissions *per capita* in 2005 were 9.10 tonnes [14]. It is important to emphasize that the population in Brazil will continue to increase until 2020 (Fig. 4) and the Japanese population will remain stable. This means that Brazil will have to work harder to reduce GHG emissions. Another aspect that needs to be analyzed in Brazil's current GHG emission situation is the growing need for energy. According to the National Energy Plan-2030 [15], in 2030Brazil will need 557 MTOE (Mega tonnes of oil equivalent) which would be an increase of 237% in 23 years (in 2007, 239 MTOE was supplied). In this plan the proportion of renewable power generation will increase from 46% in 2007 (110 MTOE) to 46.5% in 2030 (259 MTOE). The highest growing energy source is natural gas which will rise from 9.29% in 2007 to 15.5% in 2030. This is related to the recent discovery of oil & gas fields offshore called the pre-salt cluster with reserves currently estimated at 14 billion barrels [16]. This discovery will put Brazil among the biggest hydrocarbon producers in the world. However, the initial test in pre-salt reservoirs, specifically at Tupy, show that the presence of CO_2 in natural gas is between 8%-12% [17]. This percentage is considered significant in comparison with the composition of other hydrocarbons.

To achieve the national GHG emissions reduce targets, Brazil has elaborated a legal framework for climate change. In this legal framework, Brazil launched the National Plan on climate change that resulted in national policy on climate change that established the GHGs emissions reduction targets, two climate change funds and the Brazilian Panel on climate change. This framework is shown in Fig. 6, and it is possible to observe that the Brazilian legal framework for climate change is recent, e.g., the national plan was launched in 2007 and the national policy in 2009 after COP15 in Copenhagen.

In addition to the framework for legal climate change, there are other initiatives in Brazil in the energy sector operated by the Brazilian Government. Although these initiatives are older than the national plan on climate change, they are very important. Among these initiatives, a few can be highlighted, such as CT-Petro (R&D in oil and gas sector) created in 1999, PROINFA-Alternative Energy Source Incentive Program, created in 2002, PROCEL (National Energy Conservation Program), created in 1985 and Federal Oil & Gas and Biofuels Agency (ANP)-Ordinance number 10 from 1999.

The Japanese legal framework for climate change issues began in 1990 with the action plan to arrest

[3]The country targets adopted in this work were obtained from official documents issued bythe Embassy of Japan in Germany (Note Verbale) to UNFCCC in January 26, 2010, and from the Embassy of the Federative Republic of Brazil to UNFCCC in January 29, 2010. The Japanese document establishes a 25% emission reduction in 2020 (base year-1990), which is premised on the establishment of a fair and effective international framework in which all major economies participate and in agreement with those economies on ambitious targets. After the Great East Japan Earthquake in 2011 and the nuclear power plant accident in Fukushima the Japanese Government submitted the document Clarification of Quantified Economy-Wide Emission Reduction Targets to UNFCCC.

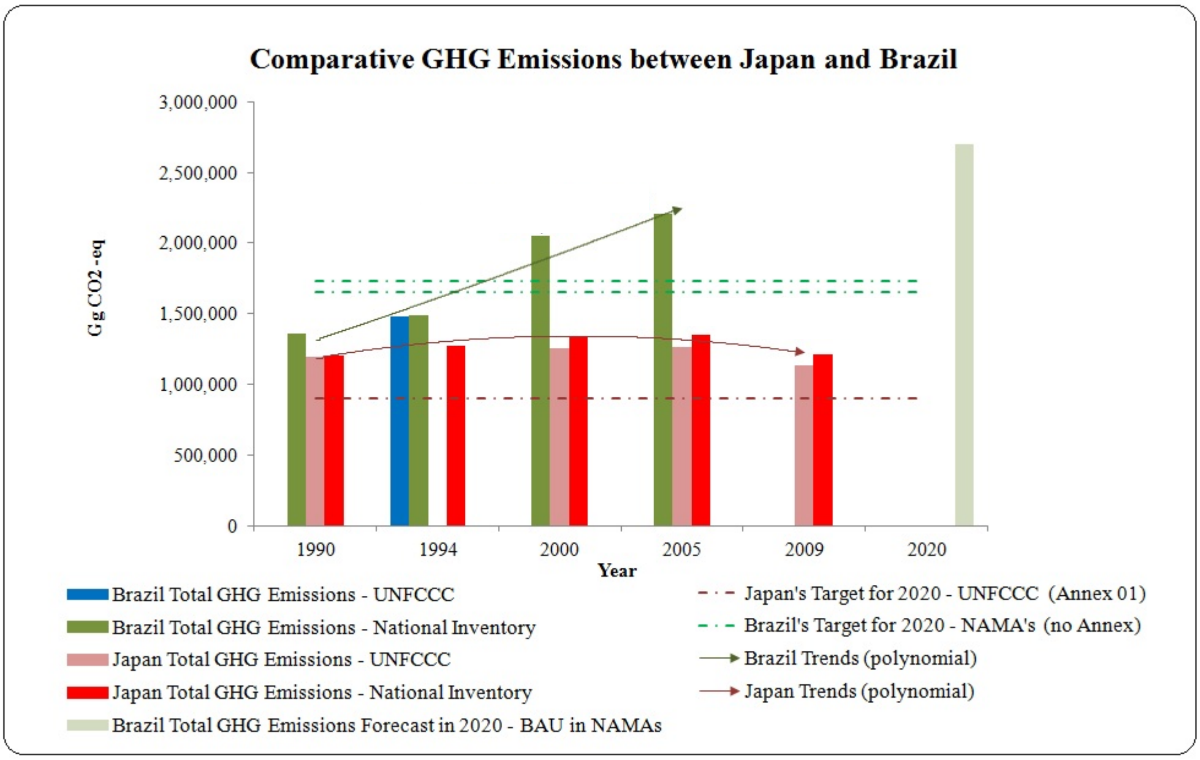


Fig. 5 Comparative GHG emissions between Japan and Brazil.

Source: Author's own.

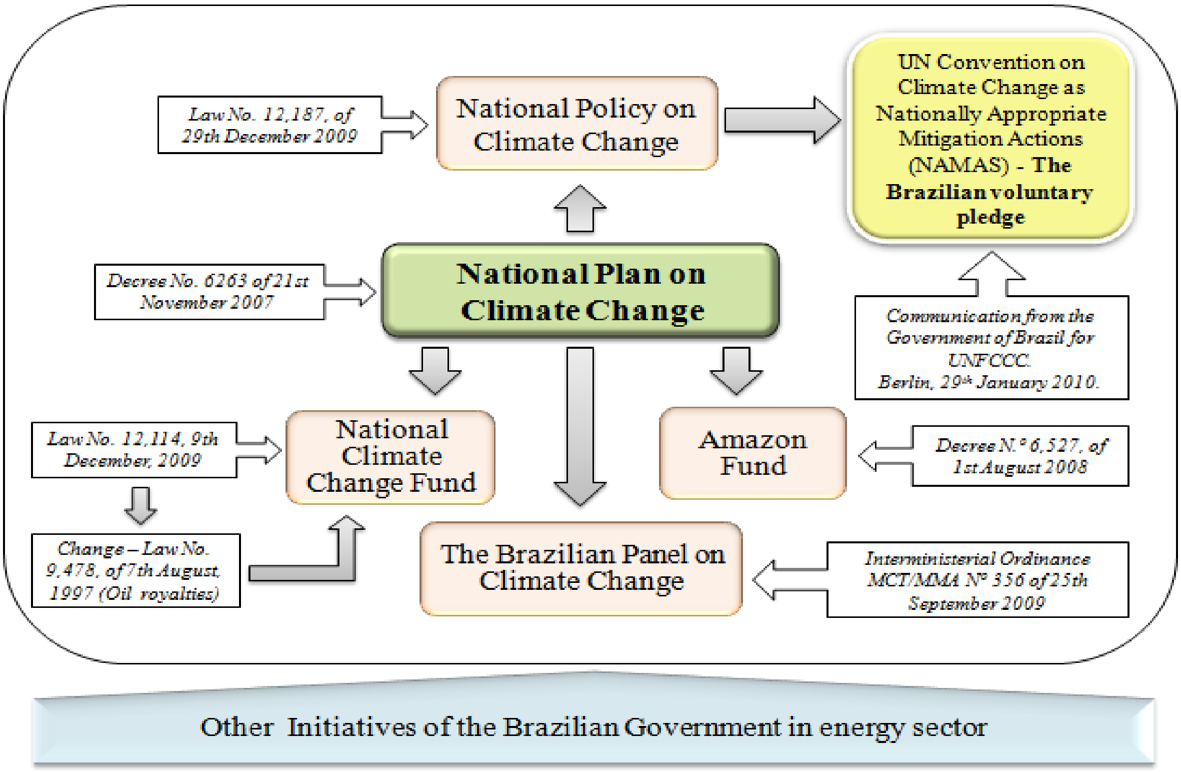


Fig. 6 Policies and Strategies on climate change in Brazil.

Source: Author's own.

global warming. In 1993 the Guideline for Measures to Prevent Global Warming (National Guideline 93) was established. After the adoption of the Kyoto Protocol by the Japanese government the Law Concerning the Promotion of Measures to Cope with Global Warming was formulated in 1998. In this year, the review in Energy Conservation Law was made and the Act on Promotion of Global Warming Countermeasures was approved. In 2002, the Act on Promotion of Global Warming Countermeasures and Energy Conservation Law were amended after the ratification of the Kyoto Protocol by the Japanese Government.

After entering the Kyoto Protocol, the Japanese government launched the Kyoto Protocol Target Achievement Plan in 2005 and another amendment in Energy Conservation Law was made. The plan was partially revised in 2006 and totally revised in 2008. In July 2008, the Japanese government launched the Action Plan for Achieving a Low-carbon Society.

It is important to emphasize the other Japanese governmental initiatives for the main sectors responsible for GHG emissions, these include the Basic Act on Energy Policy, Biomass Nippon Strategy, Strategic Technology Roadmap (Energy Sector), Law Concerning the Rational Use of Energy, Top Runner Programme and Cool Earth Innovative Energy Technology Programme. In Japan there are obligations stipulating target reductions on local governments and co-operation with developing countries.

It can be seen that the Japanese legal framework for climate change basically follows the main international climate change events. Fig. 7 shows in chronological order the relationship between international climate change events and the evolution of the Japanese legal framework for climate change. The development of Japan's overall policy framework to tackle climate change has been a slow, gradual process [18], unlike what has happened in Brazil.

3. Comparative Analysis of the CCS Technologies in Japan and Brazil

There are currently 5 CCS project in operation around the world (in Salah/Algeria, Sleipner and Snøhvit/Norway, Rangely/United States, and Weyburn-Midale/Canada and United States) [19]. Inthese projects all CCS parts, namely capture,

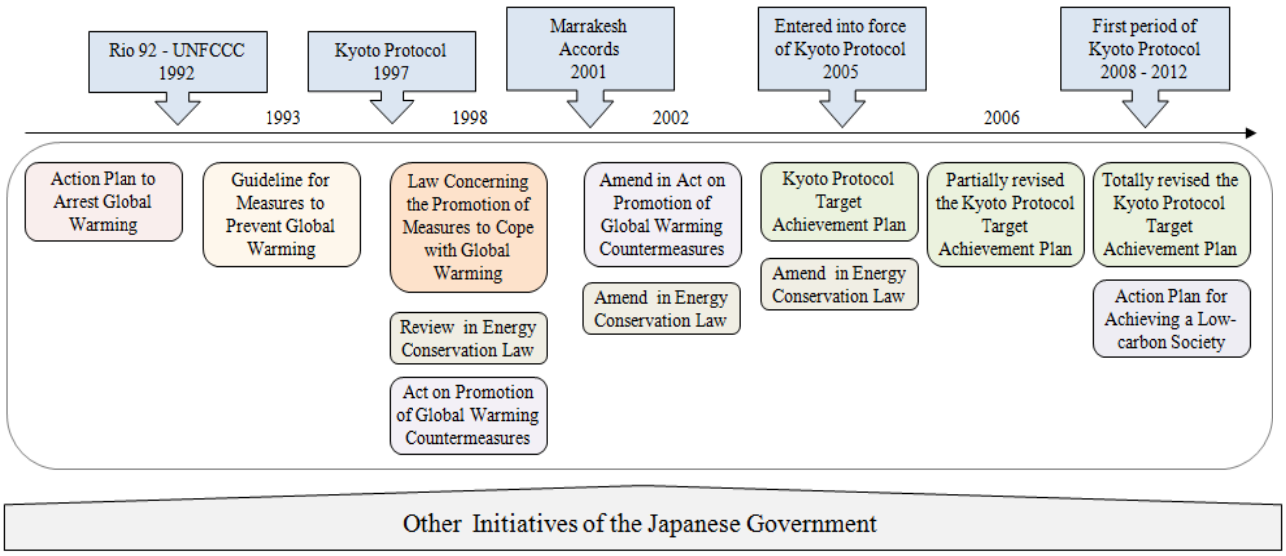


Fig. 7 Policies and strategies on climate change in Japan.

Source: Author's own based on Fig. 2 form.

separation, transport and storage are contemplated. According to the IEA (International Energy Agency) 19-43 projects will be in operation by 2020. Among these projects the Japanese government have committed themselves to 1-2 projects worth 0.1 billion US$ [19].

The IEA Greenhouse Gas R&D Programme (IEAGHG) in its study "IEAGHG, "Global Storage Resource Gap Analysis for Policy Makers", 2011/10, September, 2011." presented a list of selected CCS projects for 2020 recommendation. The projects were selected from available databases (IEAGHG, Global CCS Institute, MIT, Bellona, Scottish Centre CCS and CO_2CRC) on the basis of their current status in February 2011 for bankability status on the 2015-17 horizon [20]. 124 potential bankability CCS projects were selected, 3 in Brazil and none in Japan.

In the IEA Blue Map scenario, it is expected that CCS technologies will capture over 10 Gt of CO_2 emissions in 2050, with an accumulative storage of around 145 GtCO_2 from 2010 to 2050 [10]. The CO_2 storage capacity of the world, considering all geological storage options, is between 1,678 Gt (lower estimate) and 101,100 Gt (upper estimate), including storage options that are not economical [6]. The geological storage capacity in Japan is 146.1 GtCO_2 [21] and the capacity in Brazil is more than 2,035 GtCO_2 [22]. Table 1 shows the geological storage capacity potential in the IEA Blue Map scenario, with the five projects in operation, Japan and Brazil's potential capacity and the world capacity.

It can be observed in Table 1 that the geological storage capacity potential of Japan and Brazil can to have a important contribution for reducing GHG emissions due to the economic situation and, consequently, the existing anthropogenic stationary GHG emission sources. However, the CCS activities in both countries are recent in comparison with other countries such as the US, Canada or Norway. In Japan, CCS activities began in 1988 with the investigation on "Direct Ocean Disposal of Carbon Dioxide" in several laboratories [21]. While in Brazil, CO_2 injection tests were carried out in 1991 by Petrobras [23].

Currently, both the countries have done several CCS activities such as R&D, roadmaps and pilot projects. The pilot project carried out in Nagaoka, Japan injected CO_2 from 2003 to 2005 into a gas field onshore [24] and another pilot project was carried out near the Yubari city, in the Ishikari Coal Basin in Hokkaido. Both were small-scale projects.

In Brazil there are two pilot projects. The Petrobras Miranga Project contemplates three different storage scenarios: EOR (enhanced oil recovery), depleted gas reservoir and saline aquifer [25]. The CEPAC (Centre of Excellence in Research on Carbon Storage) carried out another Brazilian pilot project with support from Petrobras and Copelmi (a Brazilian coal-producing company). The CEPAC Carbometano Porto Batista Project is being developed to investigate ECBM (enhanced coal bed methane recovery) [25].

While the CCS activities are at similar stages, there are relevant differences in the application of the CCS

Table 1 Geological storage potential capacity.

Geological storage capacity potential	GtCO_2
CCS participation in IEA Blue Map scenario (accumulative from 2010 to 2050)	145.000
CCS participation in IEA Blue Map scenario (2050)	11.780
The five current projects in operation[4] (total estimated CO_2 storage capacity)	0.111
Geological storage potential capacity in Japan	146.100
Geological storage potential capacity in Brazil	2,035.000
World geological storage potential capacity (lower estimate)	1,678.000
World geological storage capacity potential (upper estimate)	101,100.000

Source: Author's own.

[4] Data collected from publication "benchmarking worldwide CO_2 saline aquifer injections" by A.Hosa, M.Esentia, J. Stewart and S. Haszeldine, from Scottish Center for Carbon Capture and Storage. March 2010.

technologies. In Japan the public sector has an effective participation together with private sector and civil society whereas in Brazil CCS activities are carried out by the private sector, which is in turn putting pressure on the civil society in particular academia. Although CCS is not receiving the necessary attention from the Brazilian public sector, the development of CCS technologies is important in order to pursue a low carbon economy in Brazil. CCS technologies are considered one of the most significant measures for emission reduction in the Brazilian industrial sector [26].

3.1 Public Sector

Public sector interest in several issues concerning CCS via policies, strategies and actions to address the issue in question can be found, especially with regard to GHG emission issues. Countries have had to take a position in international forums such as the COP (Conference of Parties). For example, CCS inclusion under CDM (clean development mechanism) and recently at COP sixteen held in Cancun/Mexico CCS technologies were considered eligible under CDM, but before the decision, the UNFCCC had consulted several countries and organizations about this inclusion.

The Japanese government supported the adoption for the inclusion of CCS under CDM. In addition to CCS efforts being led by developed countries, there has also been a rapid spread of CCS technologies among developing countries. The CCS under CDM will enable the effective transfer of the technological, human and financial resources from developed countries to developing countries [27]. The Brazilian government is not against the use of CCS, however, it believes that CCS is not eligible as CDM for several reasons. These include the lack of expertise in the implementation of CCS in developing countries, the high costs of dissemination and technology transfer, the evaluation of environmental impact, as well as the process being capital and technology intensive [28].

According to the Brazilian government, CCS is typically a transitional technology for use in the passage of an economy based on fossil fuels transitioning towards a low-carbon intensity economy. The Brazilian government recognizes that CCS may be useful. Thus, CCS technology could be considered a bridge until countries have full confidence in renewable energy. However, the CCS under CDM would result in perverse incentives for increased production of fossil-fuel energy in developing countries, which would enhance the existing technological gap between the developed and developing world [28].

The Brazilian climate change national plan stipulates that the CCS technologies have to be and will be developed by the Brazilian private sector to continue to be able to sustain its viability. The magnitude of GHG emissions, due to growth in the oil and gas industry in next few years, will require the use of large scale mitigation technologies as CCS technology. However, costs are still very high, requiring more investment in new and cheaper technologies. Besides, it is a technology which is in development and new ways to promote it must be found [29].

This work understands that the government's participation in the promotion of CCS technologies cannot resume with only the private sector responsible for implementation of the technology. For the success of the CCS technologies it is necessary that the government promote a favorable environment. This should be composed of Policies and Laws (GHG emissions reductions targets), regulatory framework, participation in international agreements, investments, CCS technologies priorities in mitigation technologies, support in R&D and pilot projects, and if possible, the development of a carbon trade scheme and taxes. It can be said that government participation is critical for the success of CCS technologies.

According to IEA [30], CCS technologies are critical for achieving the targets of the 2 degrees scenario (energy technology perspectives 2012 2°C Scenario). The current funding and policy environment represents a very serious challenge, as sustained effort by governments around the world is needed to promote CCS. The number of large, integrated operational projects remained constant throughout 2011, which was the result of new projects entering the development pipeline and cancellations of existing projects. Given the high capital cost, risks associated with initial projects and the fact that CCS is motivated primarily by climate policy, the technology needs strong government backing by way of CO_2 emissions-reduction policies and dedicated demonstration funding [30].

Table 2 shows the main work done by the Japanese and Brazilian governments to impulse the implementation of CCS technologies related to the main CCS technology issues. From an overview of the number and importance of the work in Japan it can be seen that the Japanese government is more interested in the implementation and diffusion of CCS technologies.

As major world events related to GHG emissions directly reflect the policies and laws of Japan, the same can be said of CCS technology. The main CCS policy that the Japanese government established in July 2008 (Action plan for achieving a low-carbon society) is connected to the G8 decision in June 2008 in Hokkaido, Japan. In this meeting, the G8 decided to support the recommendations of the IEA and the CSFL (Leadership Forum on Carbon Sequestration) for the execution of 20 projects involving CCS on a large scale, because they believed that CCS would play a critical role in combating climate change and meeting energy security challenges [31]. It is necessary to highlight that this G8 decision did not influence the Brazilian government's position on CCS technologies.

After primary data collection of the organizations, it is possible to say that the Japanese government's main structure for CCS technologies is composed of the METI (Ministry of Economy, Trade and Industry), responsible for policies, guidelines and implementation of the large-scale demonstration projects. Supervised by METI, there is the NEDO(New Energy and Industrial Technology Development Organization) that conducts various activities focusing on research and development related to oil-alternative energy technology, technology for the efficient use of energy, and industrial technology, in particular about CCS technologies conducting the zero-emission coal thermal power technology development project, and the RITE (Research Institute of Innovative Technology for the Earth).

RITE was launched in July 1990 to implement the Japanese government plan "New Earth 21" as a foundation based on the civil code. Currently RITE is considered an institution of public interest. RITE recognizes the global warming problem and considers the key factor as being the economic development of developing countries. However, another important factor is the barrier set to nuclear expansion since the accident of Fukushima Daiichi. RITE focuses on developing technologies for mitigating global warming, particularly those of CCS. Nowadays RITE is carrying out the Nagaoka CCS demonstration project, CO_2 geological storage capacity study, research on separation technologies: membranes and absorbents, ocean sequestration R&D and workshops and symposium[5]. The other public research institution is the National Institute of AIST (Advanced Industrial Science and Technology) which is carrying out research into CO_2 storage and fixation capability evaluation, underground storage and ocean sequestration.

In addition to R&D in Japan, the Japanese government has established international partnerships and bilateral agreements with a focus on CCS technologies: APP (asia-pacific partnership on clean

[5] Data collected from interviews and organizations publication as the institutional journal "RITE Today", 2012, Vol. 7 Annual Report in http://www.rite.or.jp/index_e.html, accessed in May, 2012.

Table 2 Government participation CCS critical issues and intensity.

Japan(evidence)	CCS issues & intensity	Brazil(evidence)
London convention, London protocol, United Nations convention on the Law of the Sea, United Nations framework convention on climate change, Kyoto protocol, APP(Asia-pacific partnership) on clean development and climate, MARPOL (international convention for the prevention of pollution from ships), CSLF (carbon sequestration leadership forum).	International agreements	London convention, United Nations convention on the law of the sea, United Nations framework convention on climate change and Kyoto protocol, MARPOL (international convention for the prevention of pollution from ships), CSLF (carbon sequestration leadership forum).
Law concerning the promotion of measures to cope with global warming, Kyoto protocol target achievement plan, cool earth-innovative energy technology program and action plan for building a low carbon society.	Policies and strategies	National plan on climate change (CCS technologies have to be, and will be, developed for the Brazilian's private sector) National policy on climate change.
Marine pollution act (law relating to the prevention of marine pollution and marine disaster) and desirable safety and environmental standarts for the implementation of CCS.	Framework regulatory	No actions evidenced
The Japanese government has budgeted US$116 million for study on large-scale CCS demonstration since fiscal year 2008 (FY 2008). Government subsidy via the Japan CCS company US$ 208.2 million. Australian callide oxyfuel project US$32 million. Existing tax incentives avaliable from the MOE for the development of technology to combat global warming (inclusive CCS technologies).	Investments	No actions evidenced
Action plan for building a low carbon society, 2008: —CCS technology has the potential for roughly 30 percent of Japan emissions, and in the steelmaking process, which accounts for roughly 10 percent; —Japan will commence verification test on large scale at an early stage from 2009 onward and implementation by 2020; —Japan will work to resolve issues such as enhancing environmental impact assessments and monitoring, putting legislation in place and ensuring public approval. Strategic technology roadmap (Energy Sector)-Energy; technology vision 2100-METI, 2005; Cool earth-innovative energy technology program-METI, 2008; Energy plan-METI, 2010.	Priorities	According to national policy on climate change the Brazil priorities are: Land Use-Amazon deforestation and cerrado deforestation; Agriculture and cattle-raising-pasture recovery, Agriculture-cattle integration, No-till farming, Biological nitrogen fixation; Energy-energy efficiency; biofuel implementation use, Energy supply expansion of hydroelectricity, alternative source; Other-ironworks-replace coal with charcoal
No CO2 tax	Carbon tax	No CO2 tax
MOE ETS (Ministry of environmental) Trial ETS (Japanese government) Tokyo ETS (Tokyo metropolitan area) The keidanren scheme (Japan federation of economic organizations)-no governmental initiative.	Carbon markets	CDM (clean development mechanism)-via designated operational entity-MCT (ministry of the science and technology). BM&F (brazilian mercantile and futures exchange)-no governmental initiative.
Ministry of economy, trade and industry-METI Research Institute of innovative technology for the earth-RITE (METI) CCS research group-ISTPEB (METI) National institute of advanced industrial science and technology-AIST.	Institution with focus on	No actions evidenced
Nagaoka CCS demonstration project (RITE). Yubari pilot project, Hokkaido (JCOAL-METI), CCS large scale use from 2015 onwards.	Pilot project	There are CCS pilot projects in Brazil but these projects has not direct participation of the Govern
R&D on ocean sequestration by "Moving Ship Method" (NEDO-RITE). Workshops and symposiums (RITE). Combined IGCC and CCS feasibility study, Fukushima (Japan CCS Co.-NEDO). Tomakomai project (Japan CCS Co.) Kitakyushu project (Japan CCS Co.) Nakoso-Iwaki Oki project (Japan CCS Co.)	R&D	Indirect incentives for oil & gas private sector companies as Petrobras via ANP Ordinance 10/99-set a tax of 1% on oil & gas production has be invested in R&D. Federal and States R&D Agencies (CNPq, CAPES, FINEP, FAPESP, FAPESB, etc.)

Legend: High compliance; Moderate compliance; Low compliance; No focus on CCS technologies; No actions evidenced

Source: Author's own.

development and climate), The Global CCS institute (the Japan regional office opened in February 2012), Japan-EU cooperation on energy technology, Japan-US CCS cooperation meeting, joint statement on the enhancement of cooperation on climate change and energy security by the Japanese and Australian governments, demonstrative project of oxyfuel CCS in Australia, demonstration study on CCS-EOR for coal fired power plants in China, feasibility study of CCS and EOR in Indonesia by METI.

3.2 Private Sector

The private sector is led by profit. Nowadays with the increase in discussions about environmental issues the private sector is taking this into consideration. This is due to an increased awareness in the private sector about social responsibility and/or public image. According to Porter and Brown [32], the productive sector has historically been seen as an opponent of national environmental policies and global and environmental issues, and as a threat to competitiveness due to the imposition of additional costs. However, most of the R&D in environmental technologies can be found in the private sector.

The participation of the private sector in environmental technologies should be supported by public sector via a well-built structure political and strategies. If the public sector wants to impose taxes, fines, and a legal framework, then it has to clarify priorities, make public investment and create incentives and market instruments such as carbon markets. As well as this, it is important to create an atmosphere of innovation in order to attract the private sector to large-scale use of environmental technologies as this is the main sector responsible for the spread of environmental technologies.

The development of CCS technologies in Japan has occurred with interaction between the public sector and private sector. Government policies and strategies have a direct influence on the private sector. For example, after the launch of the “Cool Earth 50” by the government in May 2007, the steel industry and the public sector co-organized the initiative COURSE 50 (CO_2ultimate reduction in steelmaking process by innovative technology for cool earth 50). COURSE 50 is composed of six steel companies, NEDO and a joint implementation with seven universities, two companies and RITE. The active participation of the government in R&D CCS technology activities has also occurred in other private sectors such as energy, principally in coal powered energy. There are subsidies via METI and NEDO for JCOAL (Japan Coal Energy Center).

Many actions for the development of CCS technologies in Japan traditionally have focused on CO_2 capture and separation from stationary sources. In May 2008, the private sector founded Japan CCS Co. Ltd. (JCCS). JCCS is composed of 36 shareholder companies: 11 electricity companies, 4 petroleum, 5 engineering, 4 petroleum resource developing, 5 trading, 2 iron and steel, 2 gas utilities, 1 chemical, 1 nonferrous metal and cement and 1 steel pipe industry. These companies are responsible for providing investment and personnel. JCCS is contracted by the Japanese government via METI and NEDO for the development of CCS projects. Furthermore, JCCS interacts directly with civil society through their research actions. Fig. 8 shows the framework of the JCCS project. Currently the main projects are the site characterization for CO_2 storage (Tomakomai project, Kitakyushu project, Nakoso-Iwaki Oki project) and the Combined IGCC and CCS Feasibility Study in Fukushima.

Data collected from national laws and a visit to Global CCS Institute.

The interaction between the public sector and the private sector in Japan can be seen here. This interaction is not via fines or taxes but via investment and incentives. The Japanese private sector also participates in multinational CCS projects such as in Salah in Algeria and it has also done international partnerships such as in the Callide Oxy Fuel Project. Table3 shows the main CCS technology work done by the Japanese private sector.

In Brazil CCS technologies have been developed mainly in the oil and gas sector, but the public sector alsohasa direct influenceon actions. In 1999 the

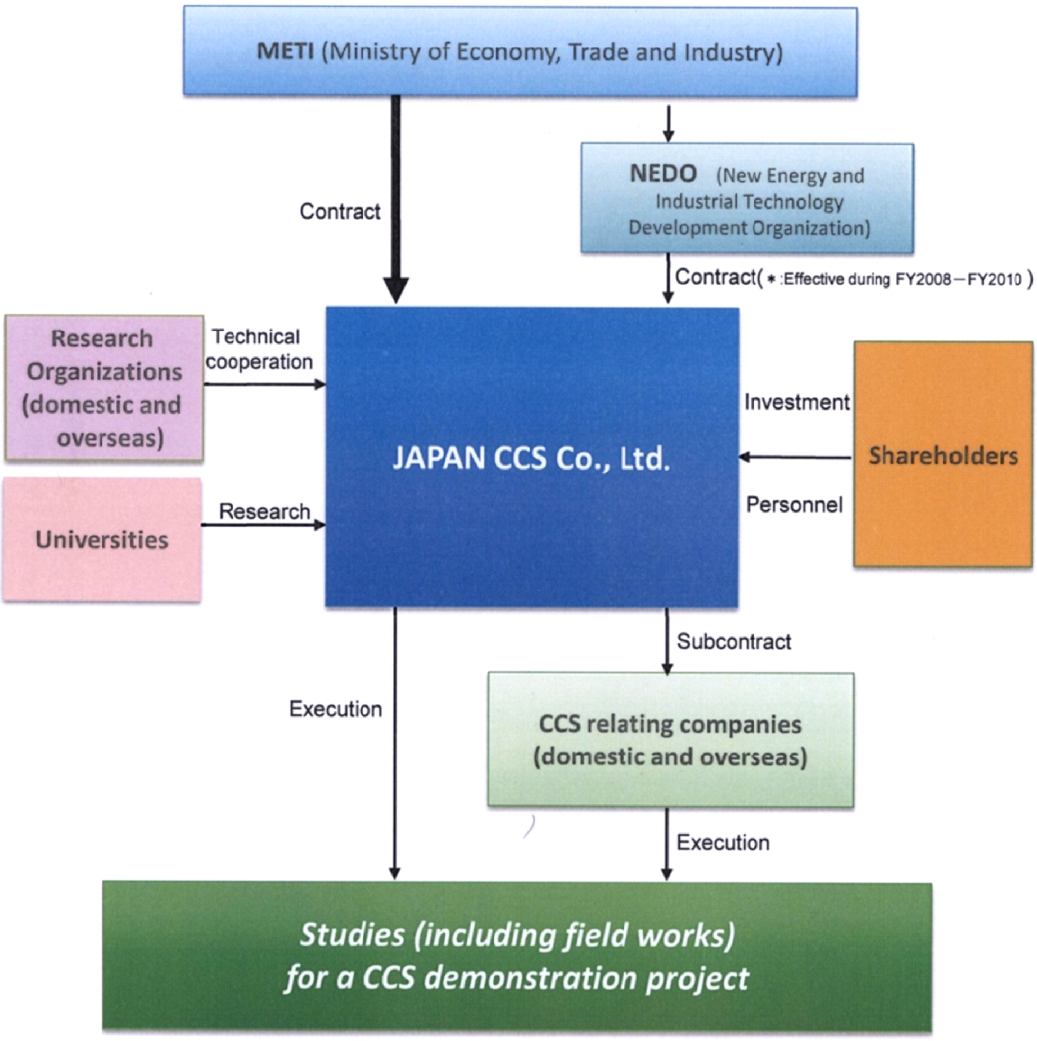


Fig. 8 Project framework.

Source: Image provided by Japan CCS Co during visit at company.

Federal National Agency for Oil, Gas and Biofuel (ANP) established (regulation 10/99) the obligation for oil and gas companies to invest 1% of their oil and gas production in R&D[6]. The main oil and gas company that invests in CCS technologies in Brazil is Petrobras. Between 2006 and 2009 the company invested $30 million in climate change and CCS technologies. Additional investments of $200 million are expected for the 2010-2015 period [33].

The company is currently developing CO_2 capture projects with approximately 10 Brazilian universities focusing on adsorption, modeling and technology capture simulation, inorganic membranes, chemical looping, ionic liquids, metal organic framework, nanostructured solids and CO_2 chemical conversion[7].

The company has a pilot project in Bahia State which is supported by the Brazilian coal industries and National Council for Scientific and Technological Development (CNPq), an agency linked to the MCT (Ministry of Science and Technology). Another pilot

[6] ANP ordinance number 10/99 in http://nxt.anp.gov.br/nxt/gateway.dll/leg/folder_portarias_anp/portarias_anp_tec/2001/abril/panp%2058%20-%202001.xml (accessed in May 2012).

[7] Presentation by Viviana C.B.G. Coelho, Environmental and Social Responsibility. Petrobras employee, on August 29th, 2011 at 9th International Conference-Brazil Energy and Power, 2011-Houston, TX.

Table 3 Status of the Japanese companies in CCS.

Petrobras also contributes to the development and operation of the thematic network on climate change (Rede CLIMA), which focuses on technical cooperation and financial support for science and technology organizations nationwide. Created in 2008 by the National Institute for space research and the ministry of science and technology, the network comprises 12 institutions and aims to develop national capacity in carbon capture, transport and storage areas [33]. Fig.9 presents the R&D Brazilian network for CCS technologies. Project name or action.	Country or region	Company	Description
Eagle IGCC project	Japan	J-Power	Capture test by chemical absorption (2007-2009) and by physical absorption (2010-2013). Funded by NEDO.
Osaki coolgen	Japan	Osaki coolgen corporation	IGCC + carbon capture plant (net electric output: 170MW) to be constructed by 2019.
Callide oxy fuel project	Japan Australia	IHI Co., J-Power, mitsui and JCOAL	Demonstration project in Australia. The callide oxyfuel project is a joint venture between CS energy, the Australian coal association, xstrata coal, schlumberger and Japanese participants, J-Power, Mitsui and IHI corporation. The project has also received financial support from the Australian, Queensland and Japanese governments.
Course 50 (JISF)	Japan	Kobe steel Ltd., JFE steel Co., Nippon steel Co., Nippon steel engineering Co., sumitomo metal Ind. and Nisshin steel Co.	Developing technologies to reduce CO_2 emissions by 30% from steelmaking process. Two technologies: “CO_2 capture from blast furnace gas” & “Hydrogen reduction of iron ore”. NEDO investments.
Participation in the “ln Salah project”	Algeria	JGC Corporation	JGC is a part of the ln Salah project providing project engineering, procurement and construction.
Participation in national and internationals project	Japan, Malaysia, India, Middle East, Europe, North Sea and Korea	MHI (Mitsubishi Heavy Industries Ltd.)	The MHI is the leading Japanese technology provider for post-combustion carbon capture.
Bilateral agreements	Japan US	Mitsubishi	Alliance of Mitsubishi (Japan) and Battelle (US).
New projects	India	NTPC Ltd.—Toshiba corp in India	India’s largest power producer, commenced very preliminary discussions with Toshiba Corp to build a pilot project in India for capturing and storing carbon emissions.
Victoria	Australia	Nippon steel engineering	Under their regional development victoria program, the victorian government has provided $2 million to Nippon steel engineering to investigate the feasibility of coal to synthetic gas technology.
Gorgon joint venture project	Australia	JGC corporation	JGC are one of the project partners who were awarded the “FEED (Front-End Engineering Design) and an option for EPCM (the engineering, procurement and construction management) Contract” by the Gorgon LNG Joint Venture Project in Western Australia.

Table 3 continued

Participation in national and internationals project	Japan, North America and Europe.	Hitachi	Contract to build the steam turbine for Canada's saskpower boundary dam integrated CCS demonstration project. It had carried out pilot scale test of post-combustion technology with Tokyo electric power company in early 1990s. In recent years, it closed contracts in North America and Europe. In the area of Oxy-fuel combustion, it had carried out a FEED study on Coal fired power plant with FORTUM oy. in Finland. It is also the supplier for EAGLE IGCC project.
Feasibility study of CCS-EOR in China	China	Toyota	Toyota studied a feasibility of CCS-EOR in China in cooperation with the research institute of innovative technology for the earth from year 2006 to 2007. Toyota reported the findings and result of the study to METI.
Projects for CO_2 storage	Japan	Japan CCS Co.	Tomakomai project, Kitakyushu project, Nakoso-Iwaki Oki project and combined IGCC and CCS feasibility study, Fukushima.

Source: Author's own. Data collected in visit to Global CCS Institute Japan Regional Office.

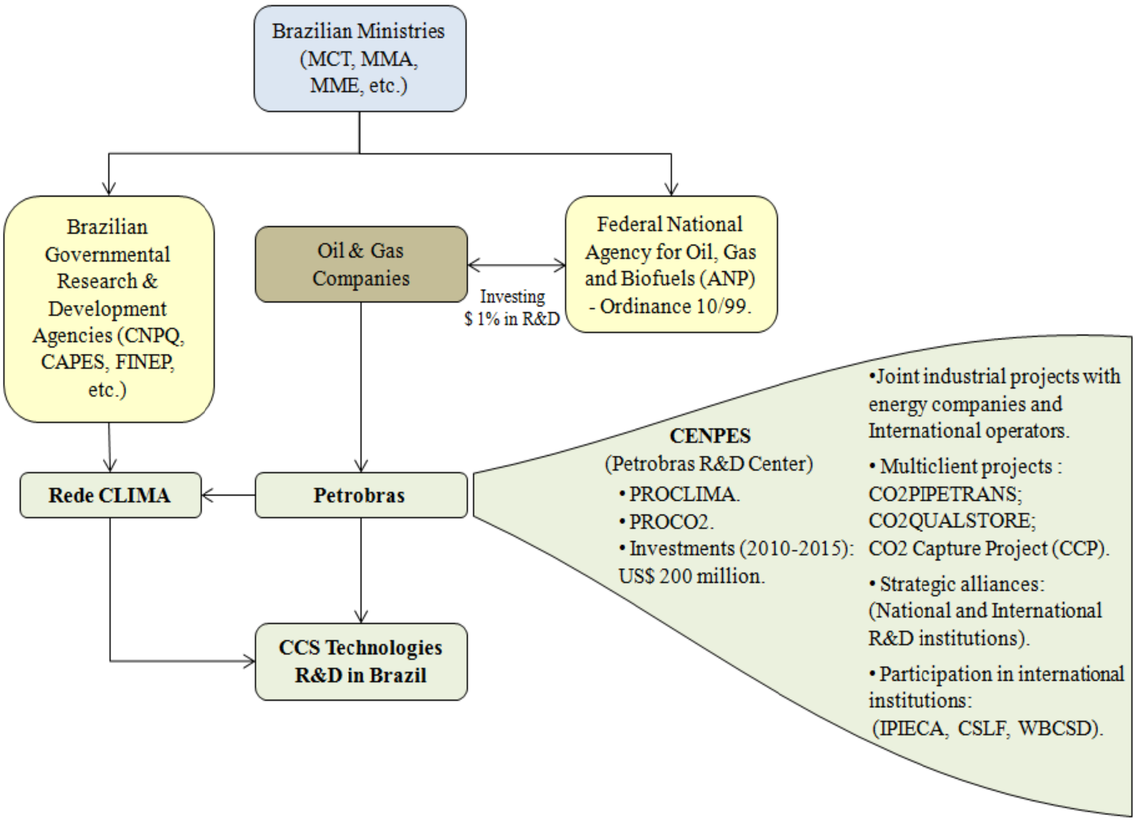


Fig.9 Basic organization for development of the CCS technologies in Brazil.

Source: Author's own based on Ref. [33] and presentations by Petrobras employees in technical conferences. A main way to check the status of R&D in a country is to analyze their patent deposits. Here the definition drawn up by the UNFCC with the WIPO (World Intellectual Property Organization) about IPC (International Patent Classification) Green Inventory should be highlighted. The IPC Green Inventory was developed by the IPC Committee of Experts by WIPO to facilitate the search for patent information relating to ESTs (Environmentally Sound Technologies) as listed by the UNFCCC [34].

project in Rio Grande do Sul State is being carried out by the CEPAC (Centre of Excellence in Research on Carbon Storage). In addition, the company participates in international CCS projects and alliances.

In the IPC the green inventory has a specific topic about pollution control which focuses on carbon capture and storage technologies. Altogether there are nine IPC codes related to CCS Technologies. After analysis, the codes can be associated with specific CCS areas (capture or storage). However, it was not possible to associate the codes to the CCS transport area.

With the CCS technologies IPC green inventory codes, a search was made in the European Patent Office[8] for the Japanese and Brazilian patent deposits in the last twenty years. The search was made in several patent offices worldwide and was referenced with the applicant and the publication date. The data were analyzed by amount of the patents deposited by country as the actors contribution. For the actor contributions in the public sector, the patents related to public agents with CCS technologies relations in Japan were RITE, AIST and Agencies, and in Brazil, CNPq, FINEP and CAPES were considered. For the private sector, all patents related to companies, company partnerships or private associations were considered. For Civil Society the patent deposits made by university, research centers, persons or NGOs (nongovernmental organizations) were considered. It is important to highlight that there are patent deposits made by partnerships between actors, in this case, the analysis considered the main applicant. Fig. 10 shows the research results.

The data analyses demonstrate that the private sector is the main actor in R&D and E&I CCS technologies given the number of patent deposits in the last twenty years. While in Japan the actors focus on CCS technology capture and separation, in Brazil the focus is on CCS technology storage. Among the nine codes, Brazil has more patent deposits than Japan in two codes and these two codes are more related with storage activities. It is important to highlight that Petrobras is the main applicant, e.g., in E21B 41/00 code in Brazil, of 19 deposits Petrobras accounted for 16 and in E21B 43/16 code of 18 Brazilian deposits, Petrobras accounted for 15.

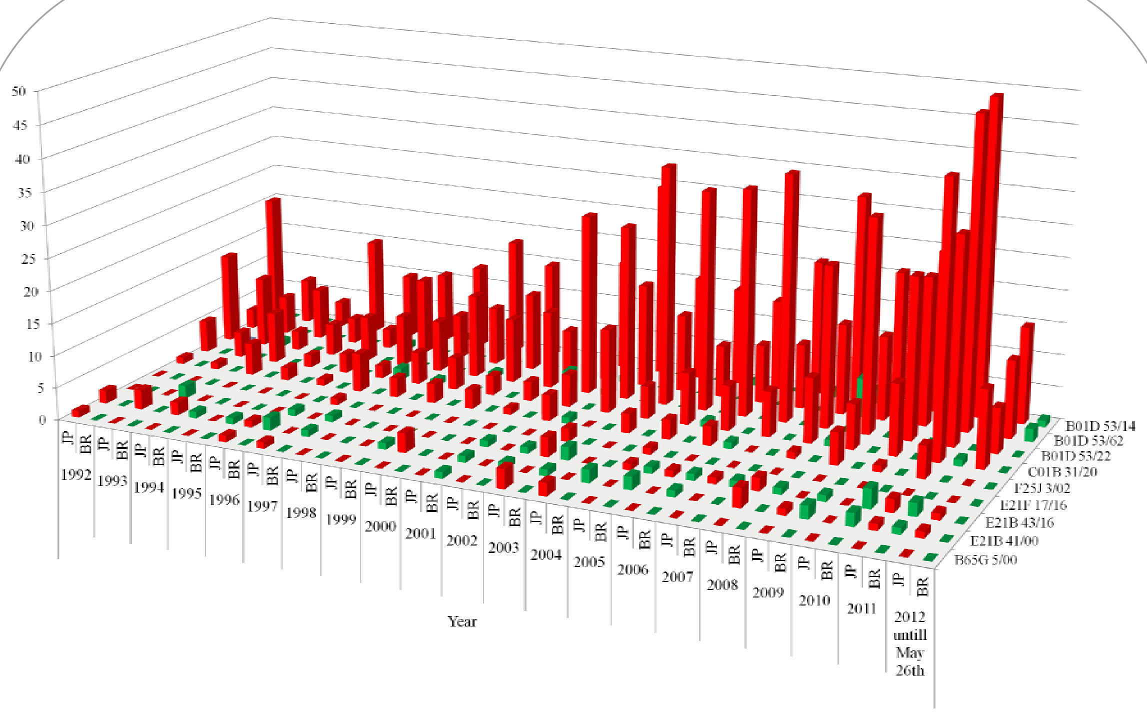
It can also be seen that in Japan the number of the patent deposits increased in the period from 2004 to 2012. This increase indicates the effective participation of the Japanese public sector with specific policies and strategies for climate change and ESTs such as the Law Concerning the Promotion of Measures to Cope with Global Warming, Kyoto Protocol Target Achievement Plan, Cool Earth-Innovative Energy Technology Program and Action Plan for Building a Low Carbon Society. On the other hand, in Brazil an emphasis on the Oil and Gas sector can be noticed due to ANP's ordinance 10/99. One important consideration that is the ANP ordinance 10/99 does not focus on CCS technologies but in general on R&D for the oil and gas sector, the companies are responsible for the allocation of resources.

3.3 Civil Society

The participation of civil society in CCS technologies projects occurs in two ways or via the actors as universities, nonprofit institutions and NGOs or via communities and community associations. However, the focus of the actors concerning CCS technologies is different. Traditionally, the universities focus on S&T, R&D and education while other actors focus on benefits and losses, land use and its value, environmental issues and health and safety issues.

With regard to R&D in academia or nonprofit organizations, it was possible to verify its main field of interested in CCS technologies. The analysis was made by collecting information during the visits to

[8]Search done in "Espacenet—patent search", http://worldwide.espacenet.com/advancedSearch?locale=en_EP (concluded on May 21st).



IPC Green Inventory number	Actors Contribution	From 1992 to May 2012			
		JP	BR	JP	BR
B01D 53/14	Public Sector	10	1	387	10
	Private Sector	372	2		
	Civil Society	5	7		
B01D 53/22	Public Sector	17	0	412	6
	Private Sector	383	5		
	Civil Society	12	1		
B01D 53/62	Public Sector	11	0	244	15
	Private Sector	227	5		
	Civil Society	6	10		
B65G 5/00	Public Sector	0	0	8	1
	Private Sector	8	0		
	Civil Society	0	1		
C01B 31/20	Public Sector	14	0	167	6
	Private Sector	148	5		
	Civil Society	5	1		
E21B 41/00	Public Sector	0	0	17	19
	Private Sector	17	19		
	Civil Society	0	0		
E21B 43/16	Public Sector	0	0	11	18
	Private Sector	11	16		
	Civil Society	1	2		
E21F 17/16	Public Sector	0	0	4	0
	Private Sector	4	0		
	Civil Society	0	0		
F25J 3/02	Public Sector	1	0	51	2
	Private Sector	50	1		
	Civil Society	0	1		

Fig.10 Patent deposits from 1992 to May 2012 of the CCS technologies in IPC green inventory made by Japan and Brazil.

Source: Author's own.

organizations, identifying the organizations involved in CCS projects or via analysis of patent deposits. There are organizations which focus on more than one CCS area and these organizations normally have a specific center for each area, and in this study case, each organization was recognized in analysis in terms of their area of focus. Fig. 11 shows the main academic and non-profit organizations involved in R&D CCS technologies with a focus on policies, capture and storage.

Another important aspect that needs special attention in CCS technologies is education. It is necessary to educate the public as well as the communities about CCS. For the CCS projects to be successful it is necessary to carry out educational activities, discussions at specific forums, workshops, and create a specific educational structure between the actors to establish and to provide a synergy between them. According to the Global CCS Institute 26 CCS projects around the world have been canceled or delayed due to issues such as regulatory, financial, technical and public acceptance issues [36].

For the experts, CCS technology issues can be addressed at congresses or workshops specifically organized to discuss the technologies. This is being done in both countries, in Japan by RITE or academia, e.g., UNU (United Nations University) or non-profit organizations such as IGES (Institute for Global Environmental Strategies). In Brazil the main events have been organized by Petrobras and the Brazilian Petroleum, Gas and Biofuels Institute which is a non-profit private association.

For communities it is necessary to take action with a focus on increasing the peoples' understanding of CCS technologies via the public sector or the private sector. Furthermore, there is a need for local actions involving the community associations and residents. An example of this in Japan is the Tomakomai CCS Project conducted by JCCS and supported by the public sector. In April 2008, Civil Society organized the "Tomakomai CCS Promotion Council", which

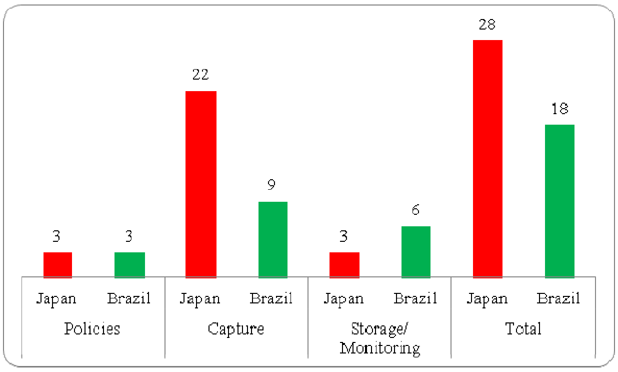


Fig. 11 Academics or non-profit organizations involved in R&D CCS technologies and its "focus on" in Japan and Brazil.

Source: Author's own based in data collected in visits, presentations by Petrobras employees at technical conferences and reference [35].

was established in Tomakomai city. The council is composed of local government authorities, industries, local fishing cooperative and experts and is aimed at the promotion of the CCS project [37]. In this research, no actions promoting CCS technologies involving the communities or communities associations were found in Brazil.

4. Conclusions

This study has attempted to analyze the area of CCS technologies in Japan and Brazil. Current climate change policies of both countries were considered and as Japan and Brazil have responded to the requests of the GEG in the last twenty years in particular about the large scale use of CCS technologies. The main public and private sector action related to CCS technologies was analyzed as well as the response of civil society to public and private sector stimulus.

Initially, in the GHG emission context, the trends in GHG emission reduction vary between the countries. If Japan keeps on the current course, it will probably reach the targets set, while Brazil, due to trends in population and economic situation of the country, will possibly need to expand its GHG emission reduction efforts. Brazil's potential to reduce GHG emissions should aim to put the country in a favorable situation on the GEG. To do this, it is important to explore the maximum potential of ESTs.

In Brazil the industrial sector alone is expected to increase its emissions from 180 MtCO2e per year in 2005 to 360 MtCO2e per year in 2030 in the base case scenario [26]. The use of CCS technologies in critical industrial sectors such as steel, chemical, oil &gas and cement. It is important to contribute to Brazil's performance in GHG emission reduction but there is a lack of policies and strategies on the part of the Brazilian government to stimulate the private sector to do this.

In addition, the Brazilian government should carry out other important actions such as offering incentives in R&D for industrial sectors and encouraging promotion and discussion with communities. In addition, the elaboration of a framework specific to CCS technologies among the actors would promote the large-scale use of the CCS and attract foreign investments. The experience in the oil & gas sector could be a reference for the other industrial sectors. Due to the government incentives for R&D in the oil & gas sector, advances in CCS storage technologies have been made and this sector can be considered as a reference compared to other industrial sectors.

The government in Brazil does not support CCS technologies via investments, polices and strategies while in Japan, on the other hand, the government focuses on CCS technologies in an attempt to reach the targets set. However, the Japanese public and private sectors need to pay attention to R&D and E&I in CCS storage technologies. In the current situation for large-scale use of the CCS technologies in Japan, it can be said that Japan is a purchaser of the CCS storage technology while at the same time being a supplier of the CCS capture technologies. As regards the CCS framework between the actors in Japan, it has been carried out well because it has led to intensive interaction among actors.

Due to the importance of CCS technologies in combating GHG emissions, demonstrated by the G08's decision in 2008, it is important to emphasize the need to carry out new research in the short term, e.g., the comparative analysis between CCS projects implementation in Japan and Brazil. This research has attempted to express the current situation of CCS technologies and indicate what areas require greater attention on the part of the actors involved.

Acknowledgments

The CAPES (Brazilian Federal Agency for Support and Evaluation of Graduate Education), UNU-IAS (United Nations University—Institute of Advanced Studies), RITE (Research Institute of Innovative Technology for the Earth) in particular to Dr. Eng. Ziqiu Xue, and the institutions visited in Japan and Brazil.

References

[1] The Commission on Global Governance, Our Global Neighborhood, Oxford University Press (2-3), Oxford, 1995.

[2] World Commission on Environment and Development, Our Common Future, Oxford University Press, New York, 1987.

[3] S. Halpern, United Nations Conference on Environment and Development: Process and Documentation, Providence, RI: ACUNS (Academic Council for the United Nations System) [Online], http://www.ciesin.org/docs/008-585/unced-home.html (accessed May2012).

[4] UN (United Nations) 2012, The Future We Want [Online], http://www.rio20.gov.br/documents/documentos-da-conferencia (accessed May 2012).

[5] UNEP (United Nations Environment Programme), Green Economy Developing Countries Success Stories, UNEP, Geneva, 2010.

[6] IPCC (Intergovernmental Panel on Climate Change), IPCC Special Report on Carbon Dioxide Capture and Storage, Prepared by the IPCC work group III, B. Metz, O. Davidson, H.C. de Coninck, M. Loos and L. A. Meyer (Eds.),Cambridge University Press, Cambridge, 2005.

[7] S. Bachu, T. McEwen, Geological media and factors for the long-term emplacement and isolation of carbon dioxide and radioactive waste, in: Geological Disposal of Carbon Dioxide and Radioactive Waste: A Comparative Assessment, F.L. Toth (Ed.),v. 44, Part 1, Vienna: Springer Verlag, 2011,pp. 23-79.

[8] UNEP(United Nations Environment Programme),

Towards a green economy: Pathways to sustainable development and poverty eradication [Online], www.unep.org/greeneconomy, 2011.

[9] IEA(International Energy Agency), Energy Technology Perspectives 2008, IEA/OECD, Paris, 2008.

[10] IEA(International Energy Agency), Technology roadmap-carbon capture and storage, IEA/OECD, Paris, 2009.

[11] M. Román, Carbon capture and storage in developing countries: A comparison of Brazil, South Africa and India, Global Environmental Change21 (2011) 391-401.

[12] P.N. Batista, O desafio brasileiro: A retomada do desenvolvimento em bases ecologicamente sustentáveis, Política Externa2 (3) (1993) 29-42. (in Portuguese)

[13] Ministry of the Environment, National Greenhouse Gas Inventory Report of Japan, Center for Global Environmental Research, Japan, 2011.

[14] Brazil, Coordenação-Geral de Mudanças Globais do Clima Ministério da Ciência e Tecnologia, Segunda Comunicação Nacional do Brasil à Convenção-Quadro das Nações Unidas sobre Mudança do Clima, Brasília. 2010.(in portuguese)

[15] Brazil, Ministério de Minas e Energia-MME and Empresa de Pesquisa Energética-EPE. Plano Nacional de Energia 2030,Brasília, 2007, p. 324 (in portuguese)

[16] IEA(International Energy Agency), CO_2 Emissions from Fuel Combustion-Highlights, IEA/OECD, Paris, 2011.

[17] A.S. Almeida, , S.T.C Lima, P.S.M.V. Rocha, A.M.T. Andrade, C.C.M. Branco, A.C.C. Pinto, CCGS opportunities in the Santos basin pre-salt development, SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, Rio de Janeiro, April 2010.

[18] K. Tamura, Strengthening legal and policy frameworks for addressing climate change in Asia: Japan [Online], http://www.unep.org/DEC/PDF/Casestudies/CCJapandraft.pdf (accessed May 2012).

[19] IEA (International Energy Agency) 2010,IEA/CSLF report to the Muskoka 2010 G8 summit-carbon capture and storage-progress and next steps[Online],Paris: IEA Publications, http://www.iea.org/book (accessed January 2012).

[20] IEAGHG (IEA Greenhouse Gas) R&D Programme, “Global Storage Resource Gap Analysis for Policy Makers”, September, IEAGHG, Orchard Business Centre, Stoke Orchard, Cheltenham, UK, 2011.

[21] T. Ohsumi, Perspectives on CCS implementation in Japan, RITE Workshop on CCS, Kyoto, 2007.

[22] G.C. Rockett, C.X. Machado, J.M.M. Ketzer, C.I. Centeno, The CARBMAP project: Matching CO_2 sources and geological sinks in Brazil using geographic information system, Energy Procedia 4 (2011) 2764-2771.

[23] U.R.A. Lino, 2005, Case history of breaking a paradigm: Improvement of an immiscible gas-injection project in buracica field by water injection at the Gas/Oil contact, SPE latin american and caribbean petroleum engineering conference, Rio de Janeiro [Online],http://www.spe.org (accessed March 2009).

[24] RITE (Research Institute of Innovative Technology for the Earth)[Online], http://www.rite.or.jp/English/lab/geological/geological.html (accessed May 2012).

[25] B. Beck, P. Cunha, M. Ketzer, H. Machado, P.S. Rocha, F. Zancan, et al., The current status of CCS development in Brazil, Energy Procedia 4 (2011) 6148-6151.

[26] J. Lampreia, M.S.M de Araújo, C.P. de Campos, M.A.V Freitas, L.P. Rosa, R. Solari, et al., Analyses and perspectives for Brazilian low carbon technological development in energy sector, Renewable and Sustainable Energy Reviews 15 (2011) 3432-3444.

[27] UNFCCC (United Nations Framework Convention on Climate Change), Views on carbon dioxide capture and storage in geological formations as clean development mechanism projects activities [Online], http://cdm.unfccc.int/about/ccs/index.html (accessed May 2012).

[28] UNFCCC (United Nations Framework Convention on Climate Change), Views related to carbon dioxide capture and storage in geological formation as a possible mitigation technology-Submission from parties, (Brazilian Submition on the possible inclusion of Carbon Dioxide Capture and Storage in Geological Formation (CCS) in the Clean Development Mechanism)[Online], http://cdm.unfccc.int/about/ccs/index.html (accessed May 2012).

[29] BRAZIL, Law number 12.187, Establishes the Climate Change National Policy, among other decisions, Brasília, 2009.

[30] IEA(International Energy Agency), Tracking clean energy progress-energy technology perspectives 2012 excert as IEA input to the clean energy ministerial, IEA/OECD, Paris, 2012.

[31] G8 2008 Summit Hokkaido Toyako summit outcomes, Environment and climate change section [Online], available: http://www.canadainternational.gc.ca/g8/assets/pdfs/Environment_and_Climate_Change-eng.pdf 2008.

[32] G. Porter, J.W. Brown, Global Environmental Politics, 2nd ed., Westview Press, Colorado, 1996.

[33] Petrobras, Sustainability Report 2010 [Online], http://www.petrobras.com.br/rs2010/en/relatorio-de-sustentabilidade/meio-ambiente/gestao-ambiental/mudanca-do-clima/index. asp (acecessed May 2012).

[34] A. Jolly, J. Philpott, The Handbook of European Intellectual Property Management: Developing, Managing and Protecting your Company's Intellectual Property, 3rd ed., Kogan Page, London, Philadelphia, 2012.

[35] The Global CCS Institute, Strategic Analysis of the Global Status of Carbon Capture and Storage—Report 4: Existing Carbon Capture and Storage Research and Development Networks around the World (Final Report), [Online] http://www.globalccsinstitute.com/publications/strategic-analysis -global-status-carbon-capture-storage (accessed May 2012).

[36] The Global CCS Institute Strategic Analysis of the Global Status of Carbon Capture and Storage—Report 1: Status of Carbon Capture and Storage Projects Globally (Final Report) [Online], http://www.globalccsinstitute.com/publications/strategic-analysis -global-status-carbon-capture-storage (accessed May 2012).

[37] Y. Yamanouchi, M. Higashinaka, T. Yoshii, N. Todaka. Study of geological storage for a candidate CCS demonstration project in Tomakomai, Hokkaido, Japan, Energy Procedia 4 (2011) 5677-5684.