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Global Technology Roadmap for CCS in Industry

Policy Workshop – Report Annexes – Part III

7th and 8th April 2011
Rio de Janeiro, Brazil
Petrobras Research Centre, CENPES
(Centro de Pesquisa e Desenvolvimento Leopoldo A Miguez de Mello)

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Annexes

Annex 3: Presentations 9 to 12

9) Ms Claudia Machado - An overview of the Brazilian centre for excellence in the R&D of CO2 geological storage technologies (CEPAC's) activities
10) Jose Domingos Miguez - Brazil's government position on CCS
11) Mr Paulo Negrais - Practical examples of CCS on industrial sources in Petrobras
12) Mr Jose Roberto Moreira - Renewable CCS from Sugar Fermentation project

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PETROBRAS

PUCRS

Overview of CCS in Brazil

CLAUDIA XAVIER MACHADO
Geographer

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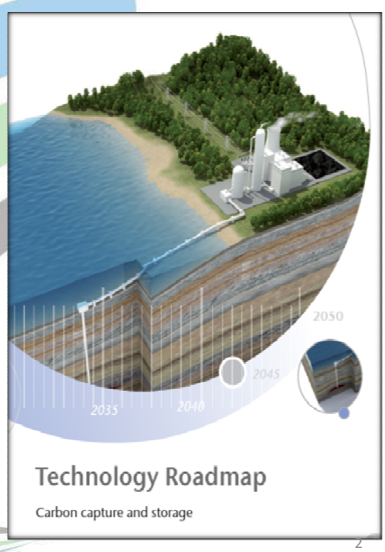
IEA CCS Roadmap

PUCRS

CCS

"important tool to achieving an atmospheric CO_2 stabilization on **450ppm**"

"responsible for **20%** of the total CO_2 emissions reductions out to **2050**"



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IEA's scenario will demand...

Ambitious CCS growth path with 100 projects needed **globally** by 2020 and over 3000 by 2050.

Major **developing countries will need to contribute** to this deployment.

MARCELO KETZER
Head

CEPAC
Centro de Excelência em Pesquisa sobre Armazenamento de Carbono

Description

PUCRS

- Joint initiative of PUCRS and PETROBRAS
- Center for RD&I on CCS with focus on storage.
- Operation and support for CCS pilot projects.
- Site selection and screening criteria.
- International collaboration (e.g., NETL, CEA, UU)
- Capacity building (e.g., 2nd CSLF in Porto Alegre, 2007)
- Node of IPAC-CO2 in South America
- Diversified team (40 people) including associate professors and researchers, undergraduate and graduate (M.Sc and Ph.D) students.

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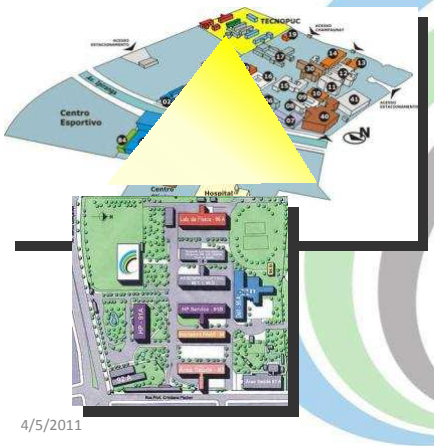
Infra-structure

PUCRS

Main building with 1100 m² located in the most advanced technological park in Brazil (TECNOPUC/PUCRS)



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Human resources

PUCRS

- 24 associate professors (part-time)
- 10 associate researchers (full-time)
- 18 graduate students
- 11 undergraduate students
- 2 lab technicians




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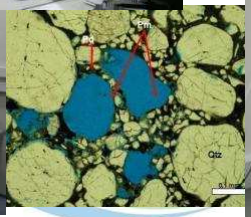
Laboratories

PETROBRAS
PUCRS

- Supercritical CO_2 lab
- Coal characterization lab
- Reservoir characterization lab
- Well bore integrity lab
- Numerical modeling lab





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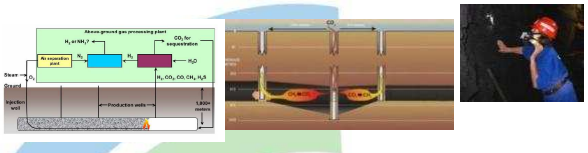
R&D Programs

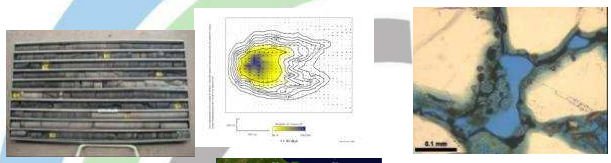
PETROBRAS

PUCRS

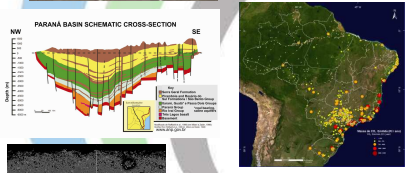
PROCARBO
CCS and unconventional energy resources (CBM, UCG)



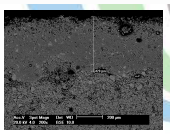
PRORESERVA
Reservoir characterization and geochemistry



CARBMAP
Source-sink matching



PROINPO
Well-bore integrity



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CARBMAP Research Program

CARBMAP

BRAZILIAN MAP OF CO_2 CARBON CAPTURE AND STORAGE

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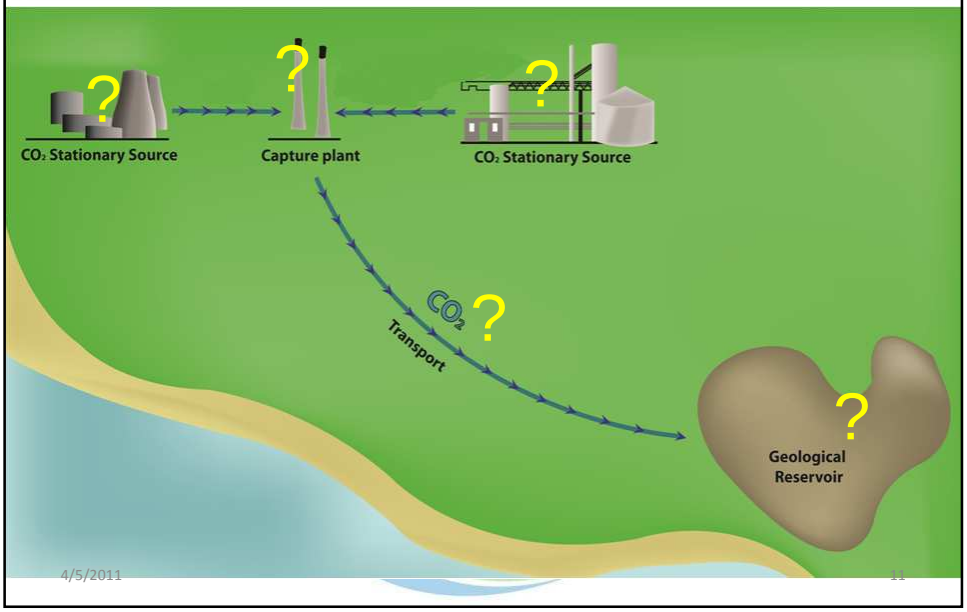
WHY MAPPING BRAZIL??

PUCRS



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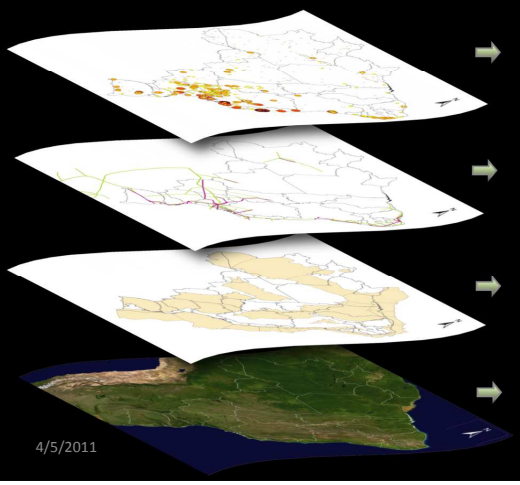
CARBMAP's Goals

PUCRS

- Develop and manage a Geographic Information System – **GIS** (database)
- Create products that allows direct and detailed analysis of CO_2 stationary sources, capture technologies, pipeline infrastructure and geological reservoirs with potential for CO_2 storage.

How does CARBMAP work?



Geographic Analysis:
Integration of all factors involved in CO_2 capture, transport and geological storage (CARBMAP).

Stationary Sources and Capture:
Location of stationary sources, quantity of CO_2 emitted, industry sector and capture technologies suggested (ANEEL, IGA).

Transport:
Oil and gas pipelines and terminals, constructed and planned (PETROBRAS 2003, ANP 2001-2008, ANEEL 2005, Ministério dos Transportes 2007, TRANSPETRO 2008).

Storage Potential Reservoirs:
Map of Brazilian sedimentary basins with potential for geological storage (Milani et al., 2007).

Base Image:
Mosaic of South America satellite images (Source ANNEL 2008).

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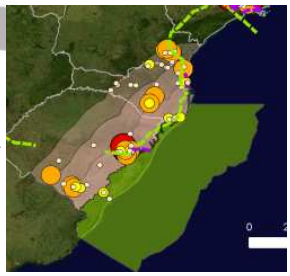
Geographic Analysis

CO_2 emission sources

Existing pipelines routes

Geological reservoirs



Overlay

Buffer: 300km radius

Data matching allows direct and detailed analysis including its prospects and potential.

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CO_2 Stationary Sources

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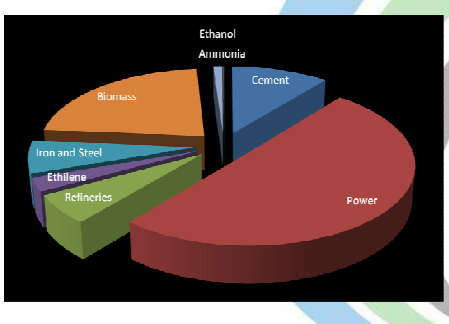
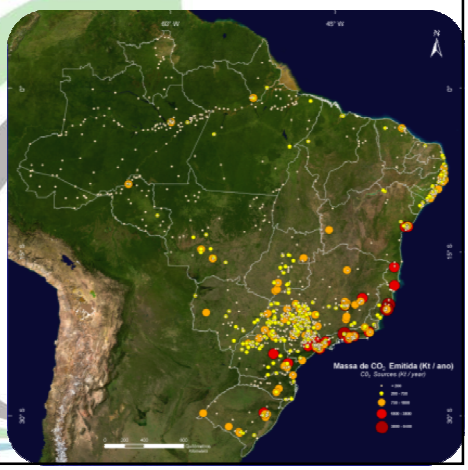
Location
CO_2 emissions
Plant industry sector





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CO_2 emission calculations

PUCRS

Physical power of the CO_2 source ✖ plant work hours ✖ emission factor = CO_2 emission

The emission factors adopted are:

Fuel Class	Emission Factor (gr CO_2/kWh)
Oil	500
Gas	400
Coal	1000

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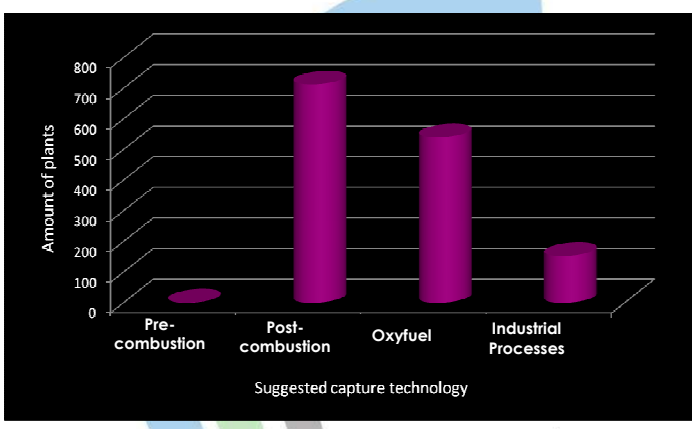
Suggested capture technologies

PUCRS



Classification criteria:
source sector and type of fuel

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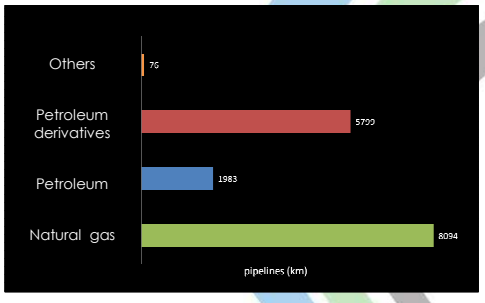
CO_2 Transport

PUCRS

- **Map existing and planned pipelines and terminals**
- **Identification of transported product**



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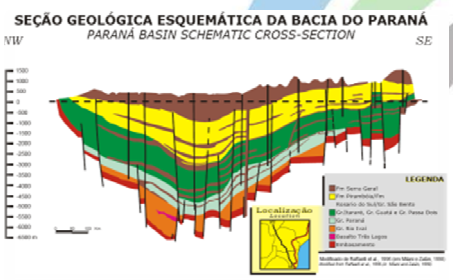
CO_2 Geological Storage

PUCRS

- Allocation of Brazilian sedimentary basins
- Geological reservoirs identification and characterization.



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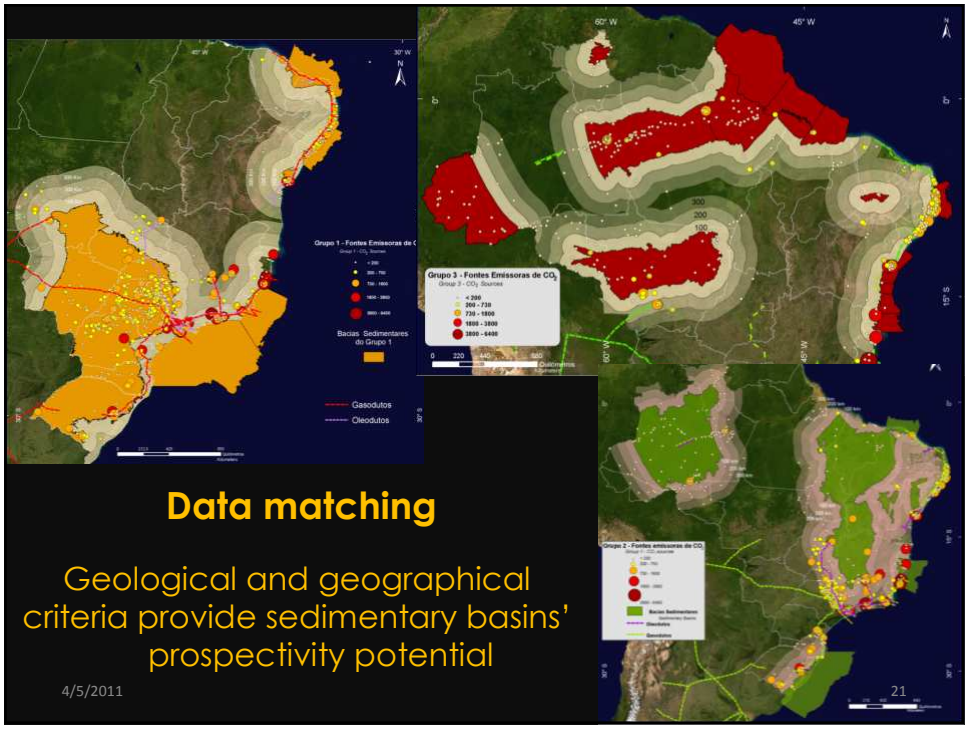
RESULTS



Data matching

Geological and geographical criteria provide sedimentary basins' prospectivity potential

- tool for countries who intend to develop CCS with the best cost-benefit relation and safety of the processes.
- disseminates information on CCS beyond scientific circles which helps to create a positive public perception
- encourage the development of research, especially on areas which data is still are insufficient.

Claudia Xavier Machado
Geographer
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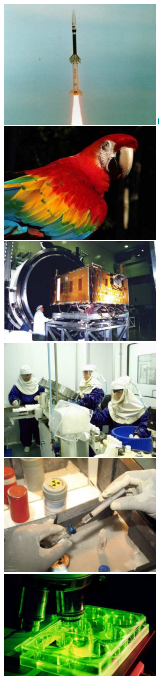
www.pucrs.br/cepac



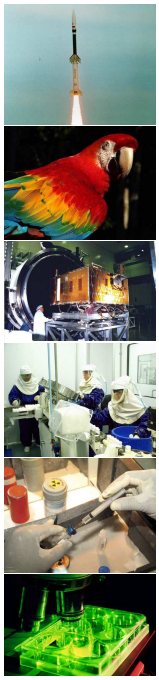
Ministério da
Ciência e Tecnologia

Brazil's Position on CCS

Global Technology Roadmap for CCS in Industry
Rio de Janeiro, April 8th, 2011

José Domingos Gonzalez Miguez

Ministry of Science and Technology
Executive Secretary of the
Interministerial Commission on Global Climate Change



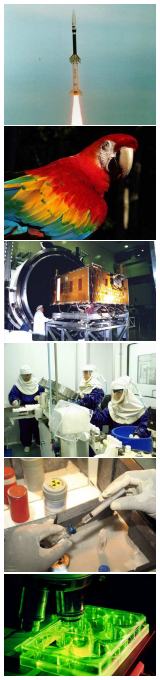
GENERAL REMARKS

Climate Change Mitigation: CCS is an option for the portfolio of technologies.

Transfer of CCS technologies: Acceleration of research on CCS technologies and development, deployment and diffusion.

Application of CCS in developing countries: It depends on the technical maturity, costs, diffusion and transfer of technology and assessment of environmental issues.

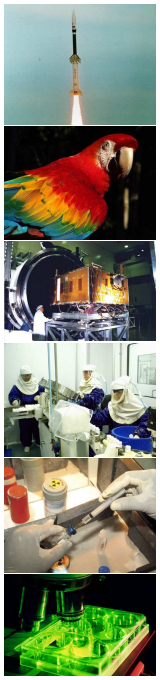
Process intensive in both capital and technology.



CCS as CDM Project Activity

Decision 7/CMP.6 (Cancun): CCS is eligible under the CDM, provided that the following issues are **addressed and resolved** in a **satisfactory manner**:

(a) Non-permanence, including long-term permanence;
(b) Measuring, reporting and verification;
(c) Environmental impacts;
(d) Project activity boundaries;
(e) International law;
(f) Liability;
(g) The potential for perverse outcomes;
(h) Safety;
(i) Insurance coverage and compensation for damages caused due to seepage or leakage.



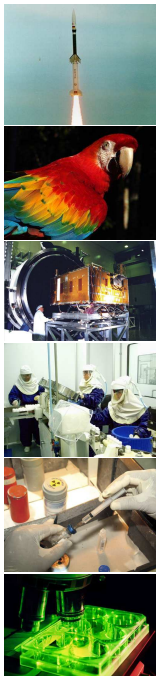
CCS as CDM Project Activity

Decision 7/CMP.6 (Cancun):

- Elaboration of M & P at SBSTA 35 (Durban – December 2011)

- M & P shall address:

  - selection of the storage site based on stringent and robust criteria, ensuring the long-term permanence;
  - stringent monitoring plans;
  - suitability of the use of modelling;
  - criteria for site selection and monitoring plans may draw upon relevant guidelines by international bodies;
  - stringent boundaries identification;
  - any release of CO2 measured and accounted; reservoir pressure continuously measured and data independently verifiable

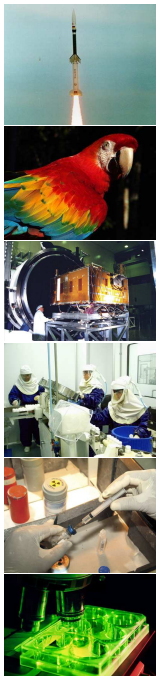


CCS as CDM Project Activity

Decision 7/CMP.6 (Cancun):

- M & P shall address:

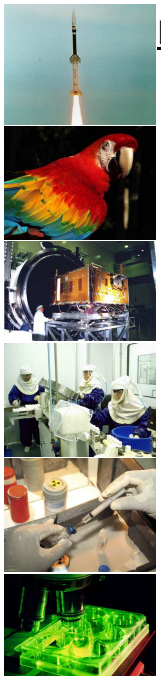
  - appropriateness of the development of transboundary;
  - any project emissions associated with the deployment of CCS accounted for as project or leakage emissions;
  - a thorough risk and safety assessment (independent entities);
  - comprehensive socio-environmental impacts assessment (independent entities);
  - Short-, medium- and long-term liability for leakage; seepage; seismicity or geological instability; damage to the environment, property or public health;
  - adequate provision for restoration of damaged ecosystems and full compensation for affected communities in the event of a release of CO2 established prior to any deployment of related activities.



CCS as CDM Project Activity

Decision 7/CMP.6 (Cancun):

-Technical Workshop between SBSTA 34 and SBSTA 35 (between June – December 2011)



Final remarks on CCS in Brazil

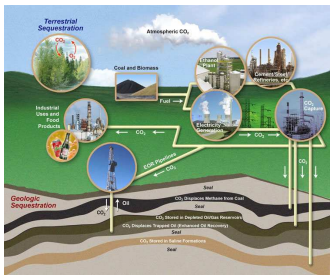
Specificities

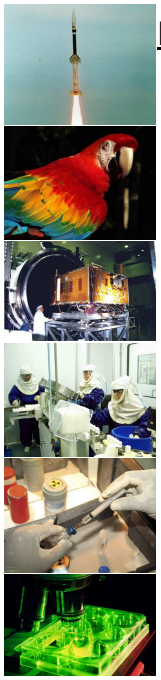
- CCS in connection to the development of Pre-Salt;

- Experience on CO2 injection in aquifers as well as EOR;

- Capture, high CO2 content and CO2 removal from Natural Gas among main challenges;

- Potential on RCCS (Renewable CCS).





Final remarks on CCS in Brazil

Actions for consideration

- Starting and enhancing networks;

- Capacity development actions (industry. academia and technical schools);

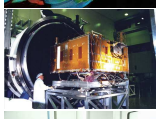
- Best practices development and dissemination;

- Diffusion and transfer of technology;

- Assessment of environmental issues;

- Development of industry standards.



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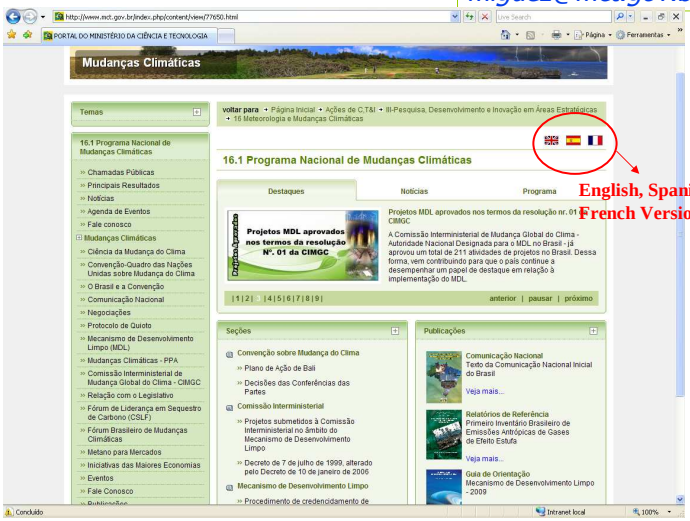
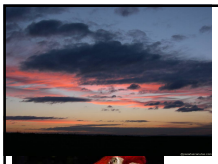
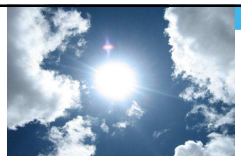
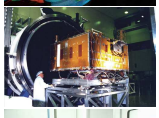
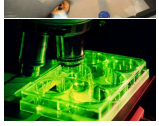


English, Spanish and French Version





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General Coordination on Global Climate Change
Ministry of Science and Technology

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Practical Examples of CCS on Industrial Sources in Petrobras

Paulo Negrais Seabra, D.Sc.
Petrobras' Research and Development Center - CENPES

PETROBRAS

Agenda

GHG inventory

Oxy-combustion FCC Pilot Tests

CCP Initiatives

PETROBRAS

CO_2 Emission Sources at a Typical Refinery Complex

Table 7: An overview of major CO_2 emission sources at a typical refinery complex. Source: van Straelen et al., 2009.

CO_2 emitter	Description	% of total refinery emissions	Concentration of CO_2 stream
Process Heaters	Heat required for the separation of liquid feed and to provide heat of reaction to refinery processes such as reforming and cracking	30-60 %	8-10%
Utilities	CO_2 from the production of electricity and steam at a refinery.	20-50%	4% (CHP Gas turbine)
Fluid catalytic cracker	Process used to upgrade a low hydrogen feed to more valuable products	20-50%	10-20%
Hydrogen manufacturing	For numerous processes, refineries require hydrogen. Most refineries produce this hydrogen on site. The requirements for Hydrogen increase with demands of stricter fuel quality regulation.	5-20%	99%

PETROBRAS

Oxy-combustion FCC Pilot Tests

PETROBRAS

Oxy-combustion FCC Pilot Tests

Objective

• To **demonstrate the technical viability** of running an FCC unit in the **oxy-combustion** mode considering its application for CO_2 capture.

Main Goals

• Test start-up and shut-down procedures
• Maintain stable operation of FCC unit in oxy-combustion mode
• Test different operational conditions and process configurations
• Obtain reliable data for scale-up

PETROBRAS

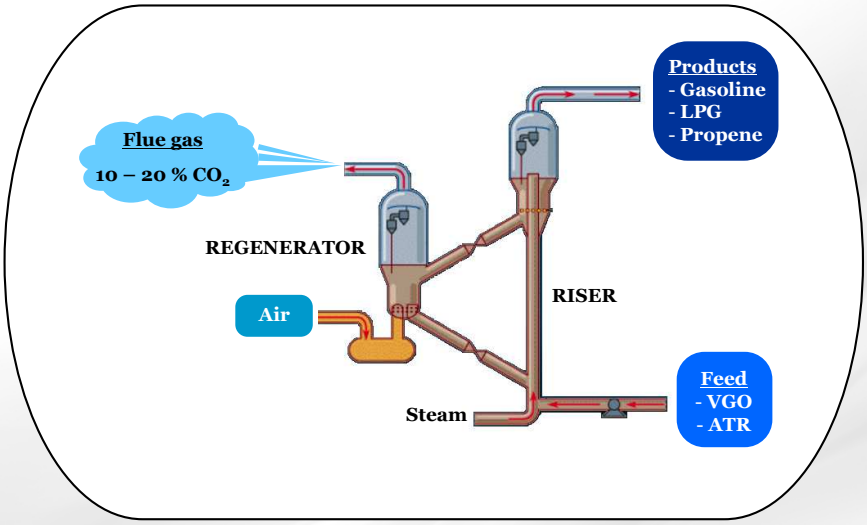
Drivers

Environmental: reduction of CO_2 emissions at the sources

Economics: potential use of CO_2 for EOR

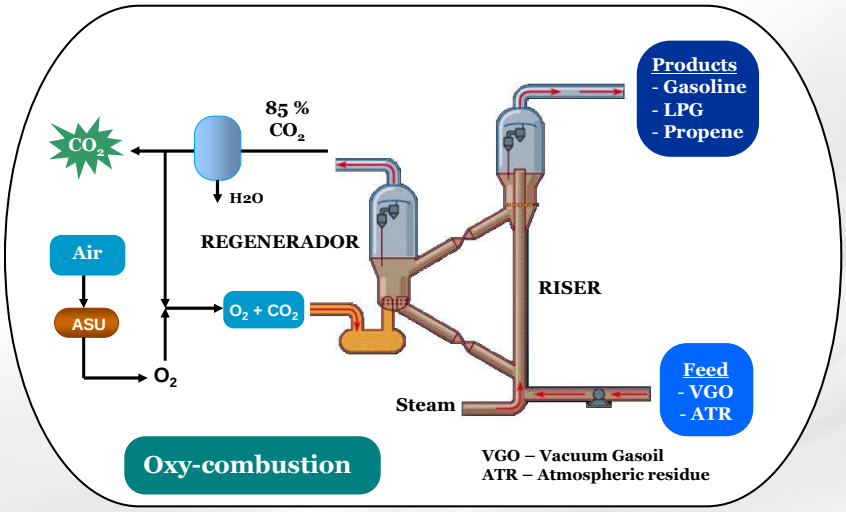
PETROBRAS

Overview of FCC converter



PETROBRAS

Oxy-combustion



PETROBRAS

Background

2005 | Lab scale tests of regeneration of catalyst in presence of CO_2

2006 | Pilot scale experiments indicate good catalyst regeneration and no impact on product slate

Petrobras joins CCP2 → economic evaluation of CO_2 capture for FCC

2007 | CCP2 results → oxy-combustion FCC shown as a cost-effective alternative for CO_2 capture

2008 | Petrobras decides to test oxy-combustion technology in its FCC large scale pilot unit and suggests this next step to CCP3;

Petrobras begins to develop conceptual project to adapt the large scale pilot unit for oxy-combustion operation → definition of study basis;

Preparation of the documentation for bid-out processes.

PETROBRAS

Background

2009 | Bid-out processes are successful:

- Linde gas wins bid-out for O_2 supply system
- TecnoProject wins bid-out for CO_2 recycle system
- Petrobras responsible for interconnection of systems

2010 | Basic and detailed projects;

Control strategy defined;

HAZOP of entire project (FCC + O_2 and CO_2 systems + interconnection);

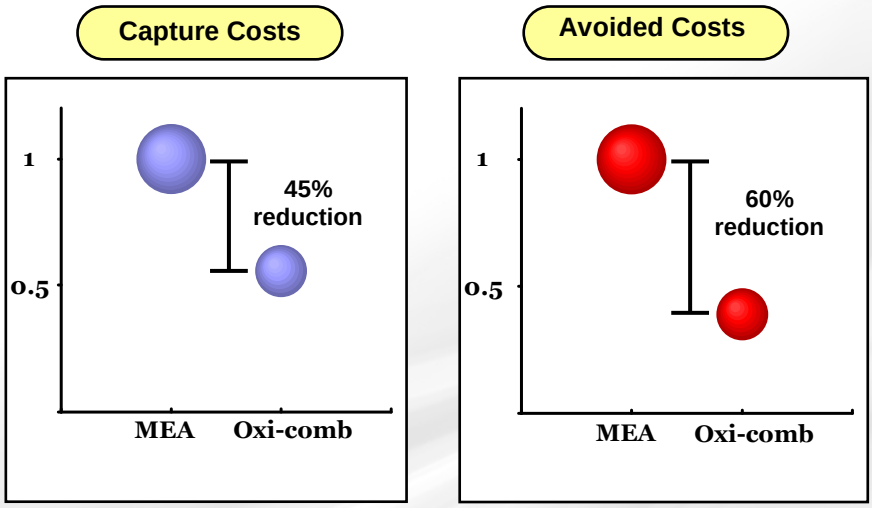
Acquisition of main equipments, instrumentation and other material;

Mounting of skids.

2011 | Pre-startup and commissioning - oxy-combustion operation and tests

PETROBRAS

Costs Analysis



CO_2 Production ~ 2500 t/d

PETROBRAS

Petrobras FCC pilot unit

FCC Pilot Unit – U-144

- **Scale**: it is a large scale pilot unit

Catalyst inventory x 150 → x 280 to 2000

Conventional pilot plant — **U-144** — Industrial unit

Feed flowrate x 200 → x 580 to 2000

- **Capacity**: cat. Inventory = 300 kg; feed = 200 kg/h (30 bpd) VGO; 1t/d CO_2 emission
- **Importance**: previously used to scale-up other technological developments

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Petrobras FCC pilot unit

CO_2 Recycle System

- **Includes**: catalyst fines and SOx removal unit, compressor, chiller, CO_2 storage tank and piping;
- **Supplier**: TecnoProject Industriale

Oxygen Supply System

- **Includes**: liquid O_2 tank, vaporizer, flow and pressure control skid, O_2 injector and piping;
- **Supplier**: Linde Gas

Interconnection of Systems

- **Includes**: piping, instrumentation and gas analyzers;
- **Supplier**: Petrobras/SIX

PETROBRAS

Petrobras FCC pilot unit

- PETROBRAS patent requested in 2006
- Pilot plant scale study concluded in 2007
- Demonstration project – 2011 - CO2 Capture Project (CCP)

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TEAM - Petrobras FCC pilot unit

CENPES:
Leonardo Fialho de Mello (coordinator)
Gustavo Torres Moure
Oscar Rene Chamberlain Pravia
Raul Rawet
William Richard Gilbert
Hugo Borges Pereira

SIX:
Rodrigo Gobbo
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Odnei Cesar Macalossi
Patricia Elaine Bridi,
Murilo Honório da Silva
Helio Toshio Sakurai

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CO_2 Capture Project - CCP

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CO_2 Capture Project - CCP

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CCP3 Project Portfolio

- **Oxy-combustion**
  - FCC (Pilot test UO-SIX) – 2011 - **Petrobras**
  - OTSG (Once-Through Steam Generator) - vapor production for bitumen extraction – 2011-2012 – (Pilot test with potential use in E&P activities)
  - Refinery heaters (Pilot test) – 2012
  - Chemical Looping Combustion -2011-2012 – development of oxygen carrying species with less environmental impact (without Ni) in pilot scale and design of a demo plant (3 MW) –
- **Pre-combustion**
  - MWGS (Membrane Water Gas Shift) (Pilot test) for H_2 production via steam reforming in refineries – 2012-2013
- **Post-combustion – project portfolio in revision**
  - Chemical absorption with solvents based on ionic liquids– 2011-2012 (pilot scale)
  - TSA (Thermal Swing Adsorption) with rotating reactor–2011-2012 (lab scale).

PETROBRAS


PETROBRAS
Thank you!

RCCS - Renewable CO_2 Capture and Storage from Sugar Fermentation Industry in Sao Paulo State

Prof. Dr. José Roberto Moreira
Rio de Janeiro, 08 de abril de 2011

❖ **RCCS Project: Promote the carbon dioxide capture and storage in the ethanol production process emitted from sugar fermentation.**

- **Separation of CO_2 from industrial sources**
- **Transport to a storage location and long-term isolation from the atmosphere**

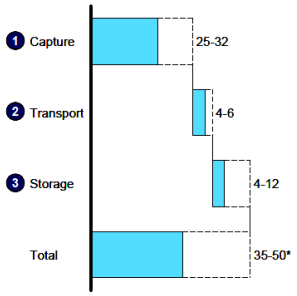
❖ **RCCS = Renewable CCS: presents the additional advantage of converting the overall CO_2 emission balance from the process into a negative one when deployed in an ethanol producing plant.**

- **Not just reducing CO_2 emissions, but removing CO_2 from the atmosphere**

Exhibit 9

Total cost of early commercial projects – reference case

€/tonne CO_2 abated; ranges include on- and offshore



Assumption

- CO_2 capture rate of 90-92%
- CCS efficiency penalty of 7-12% points
- Same utilization as non-CCS plant (86%)
- CO_2 compression at capture site

- Transport through onshore/offshore pipeline network of 200/300 km in supercritical state with no intermediate booster station
- Use of carbon steel (assumed sufficiently dry CO_2)

- Injection depth of 1,500 m in supercritical state
- Use of carbon steel (assumed sufficiently dry CO_2)
- Vertical well for onshore/ directional for offshore

* Ranges are rounded to 5 on totals

Source: Team analysis

Exhibit 11

2 Early commercial reference case – Details of transport cost

Transport cost
€/tonne CO_2 abated

	Onshore	Offshore
Capex	4	6
Opex	0.1	0.1
Total	4	6

Assumptions

- Network of three 900 MW plants connected to shared pipeline
- € 1,3 m per km for 24" onshore pipeline (20% cost increase for offshore pipeline)
- Total length of network: onshore 200 km and offshore 300 km

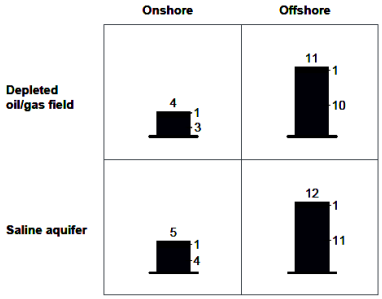
- Inspection and monitoring of pipeline – ~1% of capex

Source: Team analysis

Exhibit 12

3 Early commercial reference case – Details of storage cost

Storage cost, €/tonne CO_2 abated



Assumptions

Opex
- Monitoring (€ 1 m p.a.)
- Operations teams (€ 2 m p.a.)

Capex
- Cost per new well:
  - Onshore € 5 m
  - Offshore € 18 m
- 10% spare well capacity
- Seismic monitoring
  - DOGF* € 14 m
  - Saline aquifer € 28 m

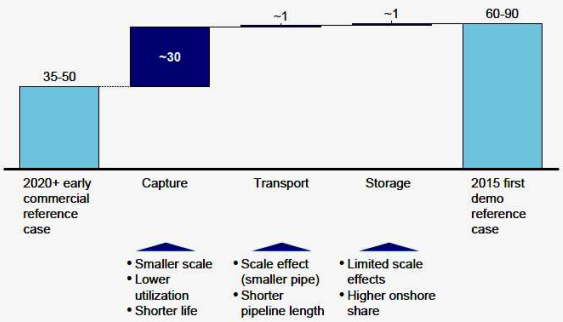
* Depleted oil and gas fields

Source: Team analysis

Exhibit 14

Cost delta between demonstration and early commercial reference case

€/tonne CO_2 abated



Source: Team analysis

Source: Carbon Capture & Storage: Assessing the Economics, McKinsey &Company

Project Components	Expected Outcomes	Indicative SCCF Financing[a]		Indicative Co-Financing[a]		Total ($) c =a + b
		($) a	%	($) b	%	
1. Establishment of enabling environment for RCCS technology transfer	1. Completed technical and financial studies on the construction and installation of RCCS system equipment	**1,040,000**	**28**	**2,700,000**	**72**	**3,740,000**
	2. Streamlined licensing requirements for RCCS projects established					
2. RCCS Technology Demonstration	**3. Completed construction works for pilot RCCS project**	**500,000**	**18**	**2,400,000**	**82**	**2,900,000**
3. Capacity building on RCCS Technology Application	4. Renewable CO_2 capture and sequestration technology demonstrated and documented project results disseminated	**800,000**	**26**	**2,300,000**	**74**	**3,100,000**
	5. Local technical capacities on RCCS are strengthened					
4. Monitoring	6. Proper, effective and successful project implementation	**60,000**	**80**	**15,000**	**20**	**75,000**
5. Project Management		**250,000**	**46**	**300,000**	**54**	**550,000**
Total Project Costs		**2,650,000**		**7,715,000**		**10,365,000**

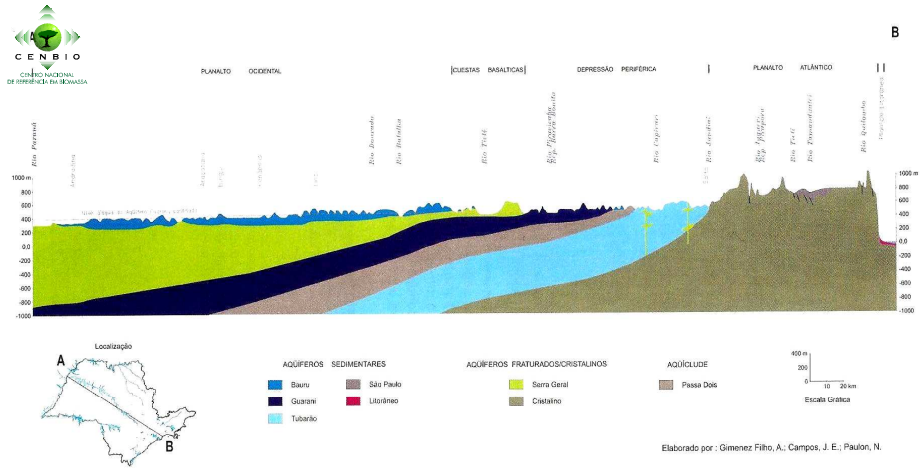
- **The RCCS project was designed based in the huge Brazilian experience in sugar, ethanol and bioeletricity production in the sugarcane mills**

- **This model is not unique to Brazil, but can be used in ethanol production from any raw material, via biological route, around the world**

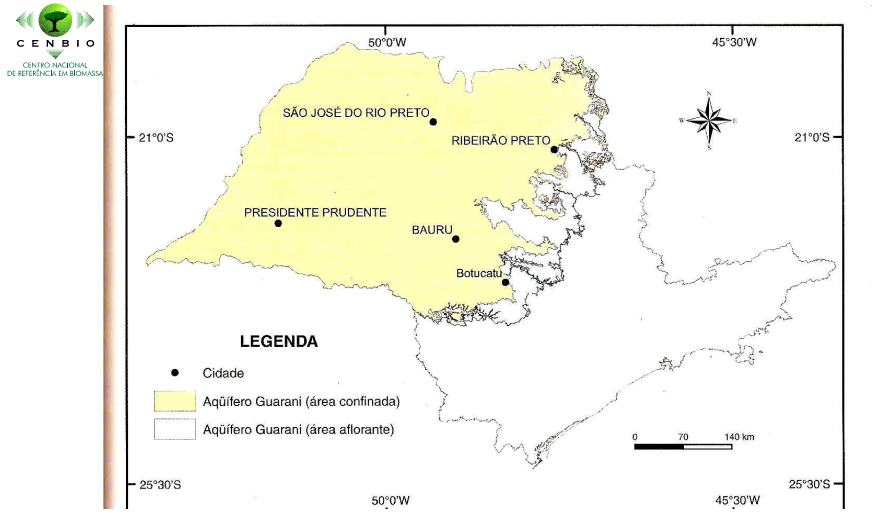
- **Among the agricultural products that could be used to produce ethanol the sugarcane is the preferred option, not only in terms of cost but also because of its positive net energy balance**

- **The proposed project is globally significant because over 80 countries grow sugarcane, and Brazil is viewed internationally as a leader in technological innovation and competitiveness in the sugarcane processing industries**

- **The Brazilian project foreseen the system instalation in the Sao Paulo State**
  - **São Paulo holds 2/3 of all ethanol production in Brazil**
  - **There is plenty of groundwater.**

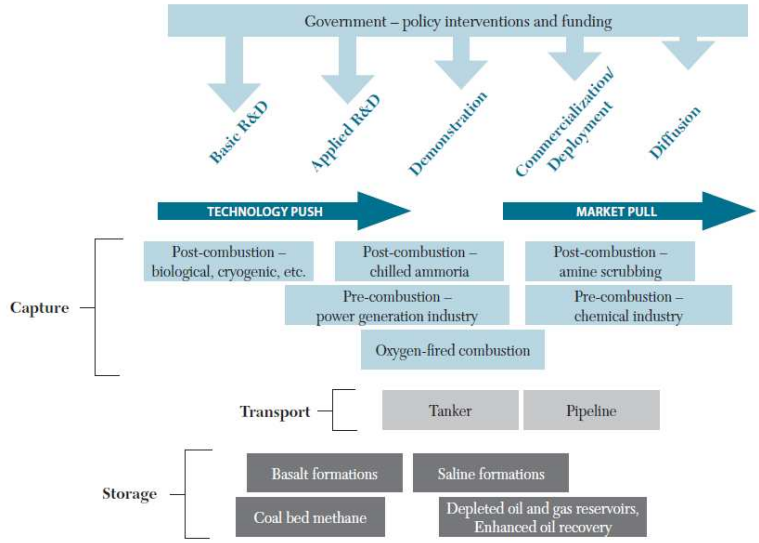


Schematic hydreological section of the Sao Paulo State
Source: Mapa de Águas Subterrâneas do Estado de São Paulo, Governo do Estado de SP, 2005.



Guarani aquifer location
Source: Mapa de Águas Subterrâneas do Estado de São Paulo, Governo do Estado de SP, 2005.

FIGURE 2 Range of CCS Technologies and Their Stage of Advancement as of 2010



Note: Innovation chain arrows adapted from E3G/Chatham House.

BARRIERS

•To establish CCS credibility and acceptability as a safe, reliable, long-term form of storage.
•There is insufficient technical and economic information in CCS available
•There is no technical or environmental regulation, or legislation in this regard
•The financial viability of CO2 capture and storage from sugar fermentation industry has not been tested in commercial sugar mill operations
•There is insufficient understanding in the sugar sector regarding CCS
•There is insufficient knowledge of CCS in the industry, scientific and technical sector

The widespread application of RCCS will depend on:

•Technical viability and costs (this will be tested through the pilot project at a sugar mill in Sao Paulo state);
•Diffusion and technology availability (technology transfer is the aim of the proposal);
•Brazil's capacities to apply the technology (capacity building will be a large component of the proposal and will include technical and scientific institutions);
•A conducive legal and regulatory framework (the project will streamline the legal and regulatory requirements for CCS).

The implementation of the RCCS project will:

- ✓**Promote the utilization of a new production process of renewable fuel;**
- ✓**Contribute to an expansion of another sustainable use of biomass for energy;**
- ✓**Introduce new technology to the sugarcane industry;**
- ✓**Lead to reduced greenhouse gas emissions with the CO2 capture and storage in Brazil;**
- ✓**Enable the transfer of technology and knowledge and the spread of CCS projects;**
- ✓**Bring a significant increase in the environmental status of the ethanol;**
- ✓**Overcome the barriers to commercially-practiced collection and utilization of CO_2 capture and storage.**

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