CLEAN COAL TECHNOLOGIES
PROJECTS IN CEPAC/PUCRS

Marcelo Ketzer
Roberto Heemann

Brazilian Carbon Storage Research Center
Pontifical Catholic University of Rio Grande do Sul

3rd Symposium on Gondwana Coals
Porto Alegre, September 17, 2009
AGENDA

The history of CEPAC and CCS in Brazil

CEPAC infra structure

R&D Programs

Carbometano Brasil CBM/ECBM Pilot Project (site Porto Batista)
The history of CEPAC and CCS in Brazil

2003
IFP/PETROBRAS Meeting in Ruel-Malmaison
NGCAS (IFP/BP) Project

2004
I Brazilian CCS Technology Roadmap
(Rio de Janeiro)

2005
CENPES / Carbon Sequestration and
Climate Change Network

2006
I PETROBRAS Climate Change and
Carbon Sequestration International
Seminar (Rio de Janeiro)

2006
1st Project of CCS is approved
with CENPES Network and
Academia (CEPAC)

2007
II Brazilian CCS Technology and
Sustainability Roadmaps
(Porto Alegre and Rio de Janeiro)

2008
Inauguration of the
Brazilian Carbon Storage
Research Center and
1st CSLF Capacity Building Workshop in
Brazil (Porto Alegre)

2008
Miranga CCS Pilot Project
(PETROBRAS) and
2nd Capacity Building Workshop in
Brazil (Salvador)

2009
Drilling of two wells for
preparation of the Porto Batista
CCS Pilot Project (CEPAC)
Joint initiative of PUCRS (Pontifical Catholic University of Rio Grande do Sul) and CENPES` Carbon Sequestration and Climate Change Network (PETROBRAS)
Infra-structure:
• Main building with 1100 m² located in the most advanced technological park in Brazil (TECNOPUC/PUCRS)

Human Resources (68 persons):
• 18 undergraduate students
• 16 graduate students
• 16 associate researchers
• 18 associate professors

4 research programs
12 R&D projects
PROCARBO – Research program on clean coal technologies and unconventional and energetic use of coal CBM, ECBM, UCG
PRORESERVA – Research program on reservoir characterization and quality prediction for CO₂ storage and hydrocarbon exploration
CARBMAP – Research program on source and reservoir matching for CO$_2$ storage
Brazilian capture, transport and storage atlas
PROINPO – Research program on wellbore integrity
Geographical distribution of sedimentary basins with R&D participation of CEPAC

- Paraná Basin
- Recôncavo Basin
- Campos Basin
- Santos Basin

WI Project (Wyoming e Colorado, USA)
Proposition of new projects:

- Complete Carbometano Brasil Pilot Project (Porto Batista site)
- Replicate Carbometano Brasil to other coal deposits
- Testing UCG+CCS technologies to coal deposits in Brazil
Partnerships

<table>
<thead>
<tr>
<th>Agência Nacional do Petróleo, Gás Natural e Biocombustíveis</th>
<th>![anp]</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Energy Technology Laboratory (NETL) / Department of Energy (DOE) - E.U.A</td>
<td>![NETL]</td>
</tr>
<tr>
<td>Lawrence Livermore National Laboratory - E.U.A.</td>
<td>![LLNL]</td>
</tr>
<tr>
<td>Carbon Sequestration Leadership Forum (CSLF) - E.U.A.</td>
<td>![CSLF]</td>
</tr>
<tr>
<td>Commissariat à l’Énergie Atomique (CEA) - França</td>
<td>![CEA]</td>
</tr>
<tr>
<td>Universidade de Aveiro - Portugal</td>
<td>![Univ_Aveiro]</td>
</tr>
<tr>
<td>Universidade Fernando Pessoa - Portugal</td>
<td>![Univ_Fernando_Pessoa]</td>
</tr>
<tr>
<td>UCG Partnership</td>
<td>![UCG]</td>
</tr>
<tr>
<td>COPELMI Mineração Ltda.</td>
<td>![COPELMI]</td>
</tr>
<tr>
<td>Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq)</td>
<td>![CNPq]</td>
</tr>
</tbody>
</table>
## Partnerships

<table>
<thead>
<tr>
<th>Associação Brasileira de Carvão Mineral (ABCM)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Associação Beneficente da Indústria Carbonífera de Santa Catarina (SATC)</td>
<td></td>
</tr>
<tr>
<td>Rede Carvão - Rede de Pesquisa, Desenvolvimento e Inclusão do Carvão Mineral</td>
<td></td>
</tr>
<tr>
<td>Instituto ECOAR</td>
<td></td>
</tr>
<tr>
<td>Instituto Ecoclima</td>
<td></td>
</tr>
<tr>
<td>Instituto Ecológica</td>
<td></td>
</tr>
<tr>
<td>Ecology Brasil</td>
<td></td>
</tr>
</tbody>
</table>
Paraná Basin CBM/ECBM Project

Porto Batista Pilot Site

Charqueadas Coalfield – RS
PROCARBO – Clean Coal Technologies Program

Why CBM / ECBM projects in Brazil (RS State)?

Porto Batista screening criteria's (CBM x ECBM x CCGS)

Steps to building Porto Batista Pilot Site

Field operations - methodology (analysis and assays) and sampling

Next steps
PROCARBO – Clean Coal Technologies Program

• Petrography and geochemistry characterization of selected coal fields and coal seams

• CBM/ECBM – Determination and estimation of coalbed methane content in coal samples (Q1 lost gas-Q2 desorbed gas and Q3 residual gas)

• CARBOGIS – Coal Gasification in situ and syngas generation associated to the carbon CO$_2$ capture and geological storage;

• PRORESERVA – Simulation of CO$_2$ plume and interactions between CO$_2$-fluid-rock;

• CARBOMETANO – Technical and economic viability of CBM/ECBM and UCG projects;
Mining operations – open cast in Charqueadas coalfield-RS-Brazil (COPELMI Mining)

UCG

CBM e ECBMR
CBM/ECBM Projects
Enhanced Coalbed Methane Recovery

Coal Seam
Motivation to CBM / ECBM and CCGS projects in brazilian coal production states (RS – SC – PR)

Take into account the brazilian southernmost coal resources (RS – SC – PR and off-shore undiscovered potential coal reserves), geological, structural, cap rocks characterization and the increasing natural gas demand the CBM/ECBM projects are strategic (back-up for the regional energy matrix)
Coal resources in Brazil are located in the Parana Basin

Paleozoic-Mesozoic sedimentary rocks

<table>
<thead>
<tr>
<th>Stage</th>
<th>Lithostratigraphy</th>
<th>Irati Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>KUNGURIAN</td>
<td>Passa Dois Group</td>
<td>Palermo Formation</td>
</tr>
<tr>
<td></td>
<td>Guatá Group</td>
<td></td>
</tr>
<tr>
<td>ARTINSKIAN</td>
<td></td>
<td>Rio Bonito Formation</td>
</tr>
<tr>
<td></td>
<td>Itararé Group</td>
<td></td>
</tr>
<tr>
<td>SAKMARIAN</td>
<td></td>
<td>Rio do Sul Formation</td>
</tr>
</tbody>
</table>

lithostratigraphy after Schneider et al. (1974)
Nowadays there are know how enough to CCT projects implementation in brazilian Coal Industry. The challenge is to guaranty financial support to CBM/ECBM and UCG pilot and demonstration projects. The environmental, legal and regulatory framework will be supported by the first pilot projects experimental results and feasibility analysis.
Porto Batista Pilot Project (CBM / ECBM)

Key to CBM / ECBM exploitation success
Best matched capacity (CO$_2$ stationary sources and coalfields)

The stationary CO$_2$ emissions can be capture from coal power plants and petrochemical centers close to Porto Batista Pilot Site (Charqueadas Coalfield) to be used in ECBM projects. The excess of CO$_2$ can be storage in Paraná Basin saline aquifers.
Paraná Basin
(coal seams and saline aquifers)

Theoretical capacity of saline aquifers:
ca. 462,000 Mt

Theoretical capacity in deep coal seams:
ca. 200 Mt

Better Matched capacity
c. 135 Mt CO$_2$/year
(Large storage capacity!)
CCS targets:

- Devonian saline aquifers
- Permian saline aquifers and coal seams

Geological sinks - onshore

Guarani fresh water aquifer
Paraná Basin - Best matched capacity of all Brazilian basins
Charqueadas-Santa Rita Coalfield
(CO$_2$ stationary sources and coalfields)

Triunfo Petrochemical Center
&
Porto Alegre region
Motivation to CBM / ECBM and CCGS projects in coal production states (RS – SC and PR)

CBM/ECBM projects would be a local gas supply backup alternative - short distances (150km) to consumer regions and industries such as Triunfo Petrochemical Center assuring energy security for Rio Grande do Sul and Santa Catarina states.
Brazilian Natural Gas demand – 55 millions of m$^3$/day (55% import X 45% domestic production)

- Brazil/Bolivia Natural Gas pipeline length 3150 km (2000 miles) - 30 millions of m$^3$/day to Brazil (2.3 million to the southern region)

- Domestic offer of about 25 millions of m$^3$/day
Screening criteria - Porto Batista Pilot Site selection
Charqueadas Coalfield (Triunfo District) / RS - Brazil

The potential Charqueadas-Santa Rita Coalfield target areas between 300 m – 800m overburden

**Coal resources corresponding to 3,000 Mt (1,800 Mt below 300 m depth)**

More then 150m of siltstones and shales potential cap rocks

**Do not observed occurrence of water leakage in old underground coal mines**

**CO₂ matching (emissions and coalfields)**

**Robust regional and local geological characterization**
(COPELMI and CPRM boreholes dataset, maps and well descriptive profile)

**Emissions sources / consumption centers (CH₄ and CO₂ matching)**
Charqueadas coal seams characterization

Organic extract – 5,700 ppm (I1F e I2B coal seams)

Tabela 2. Grupos de macerais e poder refletor médio das camadas MB, I1F e I2B nas sondagens S34 e S41, Bacia de Charqueadas e das camadas SR1, SR2 e SR3 das sondagens P4 e 5CA-02-RS, Jazida de Santa Rita (segundo Correa da Silva, 1984)

<table>
<thead>
<tr>
<th>Camadas</th>
<th>Vitrinita</th>
<th>Liptinita</th>
<th>Inertinita</th>
<th>Minerais</th>
<th>Poder Refletor</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB (S34)</td>
<td>50</td>
<td>6</td>
<td>18</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>MB (S41)</td>
<td>42</td>
<td>7</td>
<td>20</td>
<td>31</td>
<td>0,51%</td>
</tr>
<tr>
<td>SR1 (P4)</td>
<td>50</td>
<td>9</td>
<td>13</td>
<td>28</td>
<td>0,43%</td>
</tr>
<tr>
<td>SR1 (O2)</td>
<td>37</td>
<td>13</td>
<td>19</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>I1F (S34)</td>
<td>29</td>
<td>16</td>
<td>30</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>I1F (S41)</td>
<td>31</td>
<td>13</td>
<td>26</td>
<td>30</td>
<td>0,47%</td>
</tr>
<tr>
<td>SR2 (P4)</td>
<td>30</td>
<td>6</td>
<td>28</td>
<td>36</td>
<td>0,50%</td>
</tr>
<tr>
<td>I2B (S34)</td>
<td>39</td>
<td>8</td>
<td>28</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>I2B (S41)</td>
<td>40</td>
<td>7</td>
<td>29</td>
<td>24</td>
<td>0,46%</td>
</tr>
<tr>
<td>SR3 (P4)</td>
<td>32</td>
<td>5</td>
<td>24</td>
<td>39</td>
<td>0,44%</td>
</tr>
<tr>
<td>SR3 (O2)</td>
<td>35</td>
<td>4</td>
<td>19</td>
<td>42</td>
<td></td>
</tr>
</tbody>
</table>
Charqueadas coal seams characterization

<table>
<thead>
<tr>
<th></th>
<th>MINA*</th>
<th></th>
<th></th>
<th></th>
<th>S_{171}**</th>
<th></th>
<th></th>
<th></th>
<th>S_{41}***</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MB</td>
<td>I_{1}F</td>
<td>I_{2}B</td>
<td>MB</td>
<td>I_{1}F</td>
<td>I_{2}B</td>
<td>MB</td>
<td>I_{1}F</td>
<td>I_{2}B</td>
<td></td>
</tr>
<tr>
<td>Umidade %</td>
<td>6,6</td>
<td>10,2</td>
<td>14,8</td>
<td></td>
<td>2,6</td>
<td>2,6</td>
<td>4,2</td>
<td>1,5</td>
<td>2,4</td>
<td>4,5</td>
<td></td>
</tr>
<tr>
<td>Cinzas (bs)%</td>
<td>14,0</td>
<td>17,5</td>
<td>19,2</td>
<td></td>
<td>40,5</td>
<td>41,6</td>
<td>34,4</td>
<td>67,7</td>
<td>41,7</td>
<td>50,4</td>
<td></td>
</tr>
<tr>
<td>Matéria volátil (bs) %</td>
<td>36,7</td>
<td>36,2</td>
<td>41,9</td>
<td></td>
<td>24,9</td>
<td>25,3</td>
<td>26,5</td>
<td>15,6</td>
<td>22,5</td>
<td>17,5</td>
<td></td>
</tr>
<tr>
<td>Matéria volátil (bsic) %</td>
<td>43,8</td>
<td>45,3</td>
<td>43,1</td>
<td></td>
<td>49,2</td>
<td>39,6</td>
<td>36,9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbono (bs) %</td>
<td>54,4</td>
<td>49,0</td>
<td>46,9</td>
<td></td>
<td>32,0</td>
<td>30,5</td>
<td>34,9</td>
<td>16,2</td>
<td>34,4</td>
<td>29,9</td>
<td></td>
</tr>
<tr>
<td>Carbono (bsic) %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>56,2</td>
<td>54,7</td>
<td>56,8</td>
<td>50,8</td>
<td>60,4</td>
<td>63,1</td>
<td></td>
</tr>
<tr>
<td>Enxofre (bs) %</td>
<td>0,6</td>
<td>0,7</td>
<td>0,7</td>
<td></td>
<td>1,3</td>
<td>0,8</td>
<td>0,9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P. Calorífico (bs) cal/g</td>
<td>4326</td>
<td>4302</td>
<td>4896</td>
<td></td>
<td>6579</td>
<td>6829</td>
<td>5930</td>
<td>7271</td>
<td>7366</td>
<td>7463</td>
<td></td>
</tr>
</tbody>
</table>

* NAHUYS (1967) análises feitas em material flutuado em líquido de densidade 1,50.
** FERREIRA et al. (1978).
*** Sobre carvão bruto (I_{1}F carvão puro; MB e I_{2}B carvão + estéreis).
Assessment of **performance and safety** of Cap Rocks under CCS conditions
- Cap Rock characterization (heterogeneity, continuity, connectivity, stratigraphy, faults X fractures);

- Cap Rock properties (reactivity, permeability, mineralogy and homogeneity)

- CO$_2$/Cap Rock interaction (diffusion, rupture, capillarity, fractures opening/closure, minerals dissolution, supercritical CO$_2$ behavior);

- Geologic context

- Risk analysis

Modified from Credoz, 2008
### Charqueadas Coalfield
**Cap rocks potential lithologies**

<table>
<thead>
<tr>
<th>Associações de fácies</th>
<th>Litologia e raio gama</th>
<th>Superfícies-chaves e Trato de Sistemas</th>
<th>Seqüências de 3º ordem</th>
<th>Litoestratigrafia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marinho restrito</td>
<td>SMST&lt;sub&gt;4&lt;/sub&gt;</td>
<td>HST&lt;sub&gt;3&lt;/sub&gt;</td>
<td>4</td>
<td>Formação Itararé (base)</td>
</tr>
<tr>
<td>Mar epicontinental</td>
<td>HST&lt;sub&gt;3&lt;/sub&gt;</td>
<td>MFS&lt;sub&gt;1&lt;/sub&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supramaré e shoreface</td>
<td>TST&lt;sub&gt;1&lt;/sub&gt;</td>
<td>TS&lt;sub&gt;1&lt;/sub&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mar inferior</td>
<td>TS&lt;sub&gt;1&lt;/sub&gt;</td>
<td>SMST&lt;sub&gt;3&lt;/sub&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoreface / offshore</td>
<td>SMST&lt;sub&gt;4&lt;/sub&gt;</td>
<td>HST&lt;sub&gt;2&lt;/sub&gt;</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Turfeiras em zona costeira</td>
<td>TST&lt;sub&gt;2&lt;/sub&gt;</td>
<td>TS&lt;sub&gt;2&lt;/sub&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluvial-deltaico e estuarino</td>
<td>LST&lt;sub&gt;2&lt;/sub&gt;</td>
<td>LST&lt;sub&gt;2&lt;/sub&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marinho</td>
<td>SB&lt;sub&gt;1&lt;/sub&gt;</td>
<td>TST&lt;sub&gt;1&lt;/sub&gt;, HST&lt;sub&gt;1&lt;/sub&gt;, TS&lt;sub&gt;1&lt;/sub&gt;</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Glacial (títios, turbiditos)</td>
<td>LST&lt;sub&gt;1&lt;/sub&gt;</td>
<td>SB&lt;sub&gt;1&lt;/sub&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Siltstone**

**Massive siltstone**

**Carbonaceous shale**
Porto Alegre – Petrochemical Center 42 km distance

Rio Grande do Sul
Large number of well distributed drillholes data located close to Porto Batista Pilot Area. Robust Geological characteristics: coal seam continuity – coal thickness – overburden – cap rocks – stable structural framework among others.
Correlation Charqueadas-Santa Rita coalfields
(Modified from Piccoli, Marques-Toigo & Correa da Silva, 1985)
Coal seam characterization

Six coal seams occur in the basin, named from top to bottom: SB, MB, I1F, I1Fa, I2B e I3F.

I1F, MB and I2B present regional distribution in the area.
The Charqueadas coal resources reach 2994.4 Mt *in situ*.

Coalfield strike EW 40 km x 4 km reaches 15 km on the east side of the Charqueadas Basin (400 km²), with overburden between 50m and 400m.
Pilot Site Area Selection (CEPAC-01 Well)
02 wells

400 meter depth

Core Diameter – HTW (70,9 mm)

Casing – 4” (101,6 mm)

High sulfate-resistant portland cement – Class G
(Filling the annular space between the bore hole and the casing)

Well Spacing – 20 meters
Gas Sampling

Coalbed methane gas sampling (Q1 – Q2 – Q3)

Sampling protocol adaptations – proactive sampling

Cap rocks characterization (Fm. Rio Bonito – Palermo)

Rock mechanics analysis (Uniaxial Compression Strength)

Rock Fluids (cap rocks – coal – sandstones)

Geophysics Section (density – gamma – resistivity – sonic - down-hole)
Analytical steps

- Gas content determination - chromatography
- 3D Tomography – coal cleat system analysis
- Cap rocks characterization - permeability
- Coal Petrography
- MEV and X-ray analysis (weathering products and mudstones)
- Fluid analysis
- Isotopic geochemistry
- Adsorption isotherms – CH₄ and CO₂ (gravimetric methodology)
Porto Batista Pilot Site Coal Sampling
Field geological description
CEPAC-01 - Porto Batista

Camada total de Canão MB

331,40m
334,00m
334,20m
334,40m
335,00m
336,70m
337,20m
337,80m
338,20m
338,45m
342,00m
342,20m
342,40m
344,00m
344,40m
348,00m
348,20m
348,40m

MB

SPC com vários filmes millimétricos de vítrína (<1mm)

EV, Viscoso com NV (<1mm a 2mm) com filmes irregulares de carbonato

SMinza-esouro

SMinza-darro a médio, passagens alteradas, ROD=3%

SMinza-esouro com planos de deslocamentos (Sildonoxides)

SMinza-darro fragmentado

SMinza-esouro AM fino marron e castanho, ROD=42.50

SMinza-médio com raro filmes arenosos e passagens de "SILT ARN"

SMinza-medio completamente fragmentado

SMinza-esouro

SMinza-darro algo arenoso

SMinza-esouro com raro filmes arenosos

Camada total de canão "11F"

SILT arenoso cinza-esuro

Alternância de níveis (<0,5cm) de SILT arenoso cinza-esuro e ARN fino branco

ARN fino branco com TB cinza-esuro, silicificado

SILT cinza-médio com raro filmes arenosos e passagens arenosas

SMinza-médio algo arenoso ROD=0%

Camada Total "12B"

SMinza-esouro com raro filmes arenosos

SPC

SMinza-daro
Cap Rock biogeochemical alterations

SELO

Solution
\(\text{CO}_2^+\)

Micro-organisms

?
Sampling of fluids and rock plugs
“Rock DNA” - “Compared Genomic Stratigraphic”
Well CEPAC-01 – coal sampling orientation
Waiting the coal sampling moment...
Field Coal Sampling
Geophysics Section
(density – gamma – resistivity – sonic -down-hole)
Coal cleat analysis systems
Coal cleat analysis – Charqueadas Coalfield
Coal cleat analysis – 3D tomography
Well complementation
annular space between the bore hole and the casing

High sulfate-resistant portland cement
- Geological and structural 3D modeling
- Coal cleat analysis (CT Scan)
- CO$_2$ injection simulation (swelling and shrinkage)
- Simulators for gas and water production in coal seams and other geological formations;
- Gas diffusion through fractured media;
- Horizontal and vertical wells;
- Data input via sorption isotherms (matrix-cleat interface)
Next step - construction of sites for R&D in MMV technologies:

- Near-Surface investigation:
  - CO₂ properties and behavior;
  - Surface leakage (seepage) detection strategies;
  - MMV integration;
  - State-of-the-art techniques for early near-surface CO₂ detection.
Subsurface investigation (CO₂ injection in coal seam):

- Phenomenology involved in the system CO₂-H₂O-Water;
- Leakage/seepage prediction via computational modeling;
- MMV integration;
- State-of-the-art geophysics for early leakage detection and remediation
CLEAN COAL TECHNOLOGIES - CCT
IMPLEMENTATION STRATEGY

Porto Batista Pilot Site development stages

- International cooperation
- Technology transfer
- Program funding
- Capacity building

PROJECT PARAMETERS

CHARACTERISATION PHASE

VALIDATION PHASE (PILOT PROJECT)

DEPLOYMENT PHASE (DEMONSTRATION PROJECT)

COMERCIAL PROJECT

(MMV) Monitoring Measurement and Verification

Environmental impact assessment

Risk assessment studies
Next steps

Adsorption Isotherms data analysis (CH$_4$ and CO$_2$)

Coal samples petrography analysis
Relationship between coal composition, litotypes and gas content
(for each canister)

Evaluation of Charqueadas coalfield gas in place

High precision permeability tests – cap rocks characterization

Geochemistry and isotopic data analysis

Rock fluid analysis – DNA

Construction of sites for R&D in MMV technologies
Thank you for all your support!!
Dedication, team work and participation

Thank you for all CEPAC staff!!
Thank you
for your attention !!

More information

roberto.heemann@pucrs.br
marcelo.ketzer@pucrs.br

http://www.pucrs.br/cepac