PROJECT 34 – CCS IN OFFSHORE SALT CAVERNS

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Research Centre for Gas Innovation
cleaner energy for a sustainable future

Workshop – RCGI - CO2 Abatement Program
University of São Paulo, Brazil
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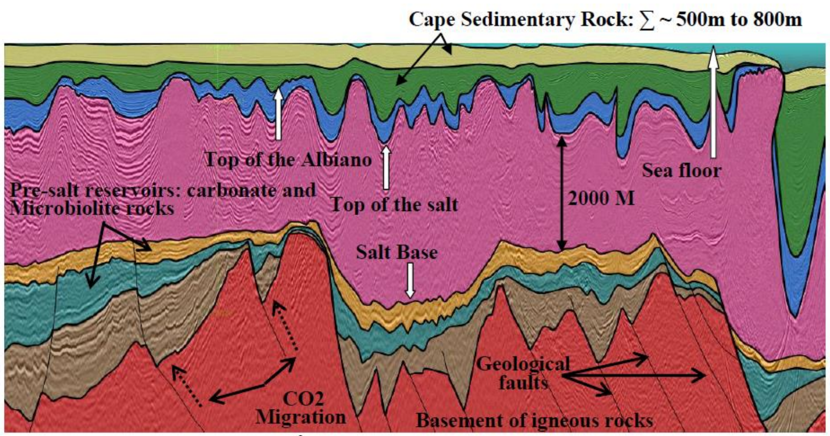
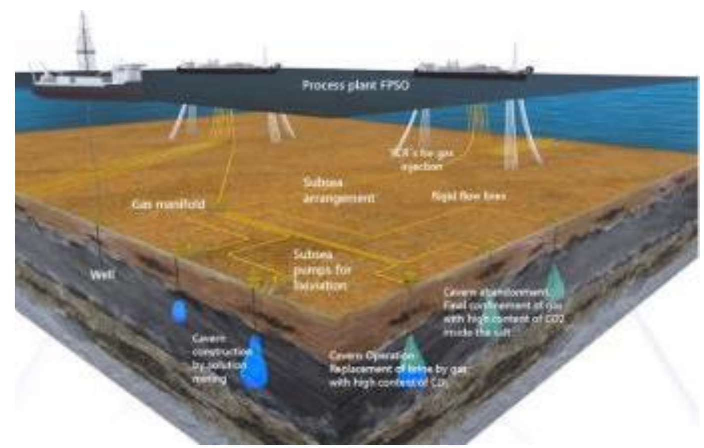
Introduction

- CO_2 found pre-salt reservoirs - **Earth´s mantle origin**, migrating to pre-salt reservoirs through geological faults;
- **Today** ⇒ **Disposal of gas** with high content of CO2 in the reservoirs (EOR);
  - Continuous increase of CO2 content levels and RGO inside the reservoir ⇒ Potential closure of production wells over time;

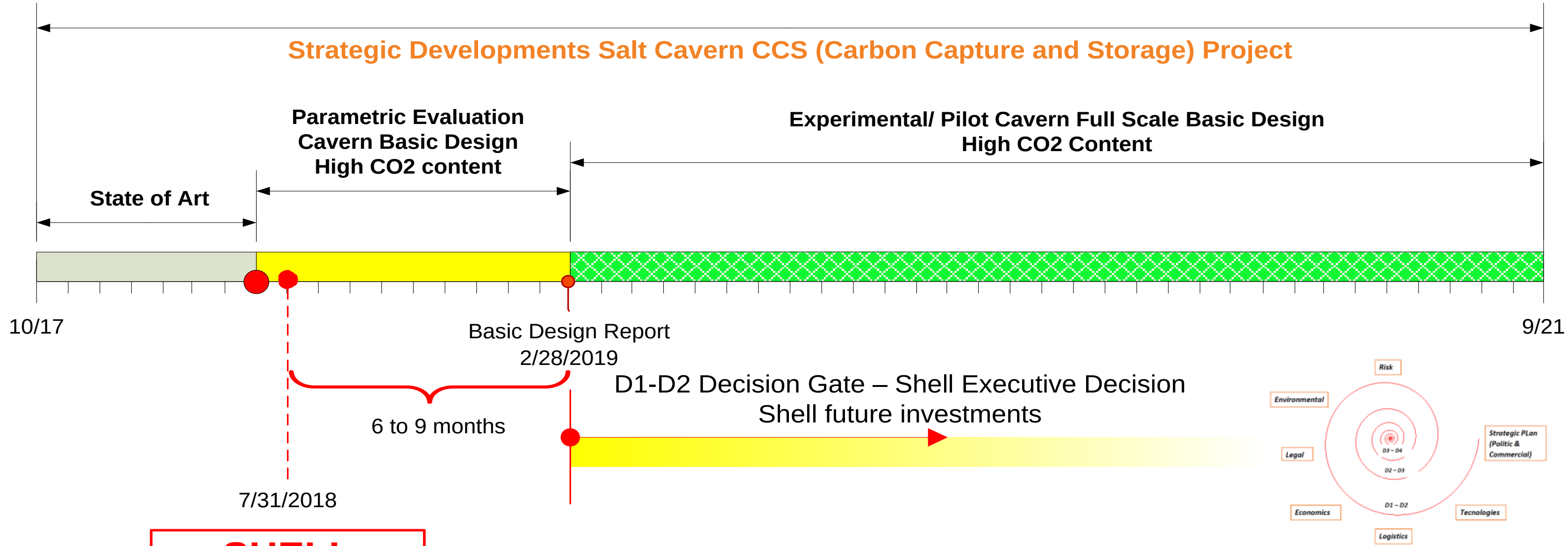


Limiting boundary conditions **Pre-salt reservoirs** ⇒ **Large salt domes** above Pre-salt reservoirs

- Technological solution under study – **Offshore Salt Cavern** Carbon Capture and Storage (CCS) solution
  - Other technological solutions – Not for large volumes of produced gas;
  - Saline aquifers characteristics in pre-salt region – Suggest unfeasibility;
- **Mature technology** – Salt underground caverns;
- **Premises**
  - Salt caverns for storage of gas with high content of CO2;
  - Gas stream from existing FPSO;
  - Maximize existing FPSO infrastructure (plant, lines, pumps, compressors, umbilical, power);
  - Maximize disposal volume, keeping high safety standards;



Project planning – Activities



SHELL
FPSO SCENARIO

- Field profile;
- Cavern construction;
- Well design;
- Subsea design;
- Topside profile;
- Cavern operation;
- Subsea operation;
- HSSE;
- Legislation;

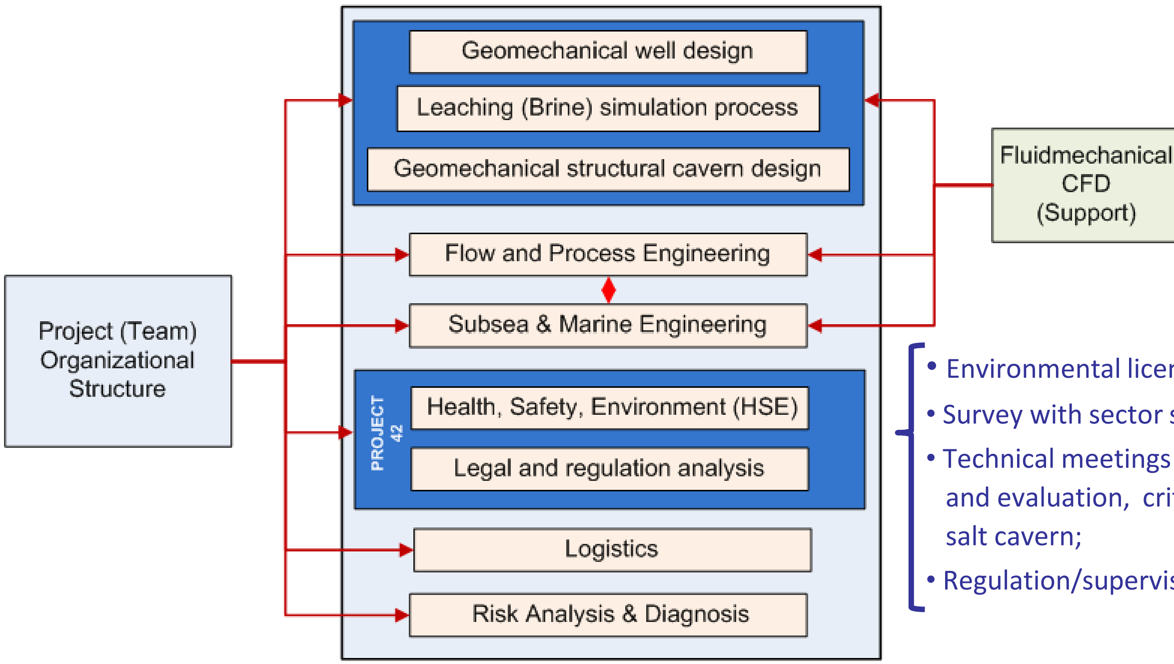
Field profile

FPSO capacity	150Kbb/d
Average RGO (Gas to oil ratio)	220
Average % CO2	20
Water Depth	2140
Injection gas composition (%CO2)	90%
Gas discharge flow rate (FPSO's plant)	1,5 MM/d
Gas discharge temperature(FPSO's plant)	40°C
Gas discharge pressure (FPSO's plant)	250 bar
Pressão de injeção água (FPSO's plant)	
Temperatura Injeção de água (FPSO's plant)	
Water injection pressure (FPSO's plant)	
Reservoir pressure	550 bar
Reservoir temperature	61°C
Reservoir fluid composition	
Power FPSO plant	100 MW (25 spare)

Subsea design

Water depth	2140
FPSO distance	7 km
Umbilical (catenary)	Presalt pattern
Xtree	Presalt pattern
BOP	No
Wellhead	Presalt pattern
Riser (4" e 6") (LW)	Presalt pattern
Flowline rigid / flexible (4" e 6")	Presalt pattern
Pump injection flowrate	300 a 400 m3/h
Injection pump ΔP	78 a 110 bar

Project planning – Activities



- Well design, leaching procedure and cavern design – **Well advanced**;
- Plant processing systems, equipments, risers, flowlines, umbilicals – **Under development**
  Participation manufacturers;
  Definition subsea production layout & FPSO

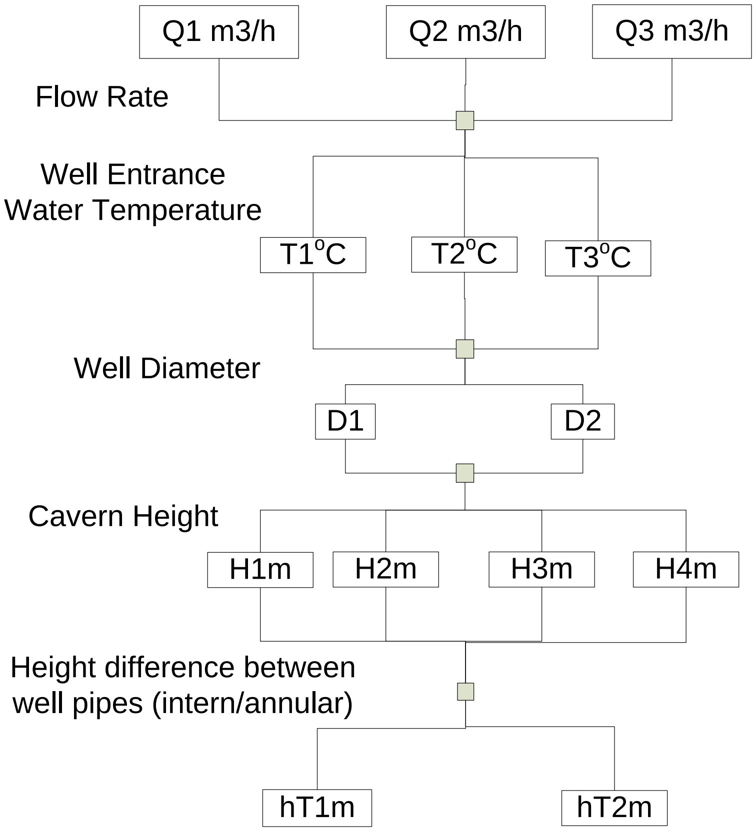
- Environmental license issues and aspects;
- Survey with sector stakeholders & Competent authority of licensing;
- Technical meetings - IBAMA, RCGI and SHELL – Joint identification and evaluation, criteria for environmental licensing experimental salt cavern;
- Regulation/supervision for licensing (assisted operation alternative);

Project planning – Activities

Assumptions

- Cavern Construction
  - Pure halite;
  - Discarding brine at sea;
  - No geological faults;
  - Olefins injected by the FPSO via ring line (diesel flush)
- Subsea
  - Same Xtree for both construction and operation;
  - Installations/facilities, vessels and standard pre-salt procedures;
  - Presumed space riser balcony for installation lines;
  - Power available FPSO for submerged pump/equipments;
- Topsides
  - Olefins injected using the chemical injection system (diesel flush system);
- Cavern Operation
  - Natural gas at 90% CO_2;
  - PDG installed in downhole water injection pipe (P and T);
- HSE / Risks / Legislation
  - No restrictions on the disposal of brine subsea;
  - Qualitative risk matrix used by Shell EIA RIMA of the field of Lula as reference;
- Logistics
  - Drilling ship at disposal for construction of caverns;

Parametric Design



Project planning – Activities

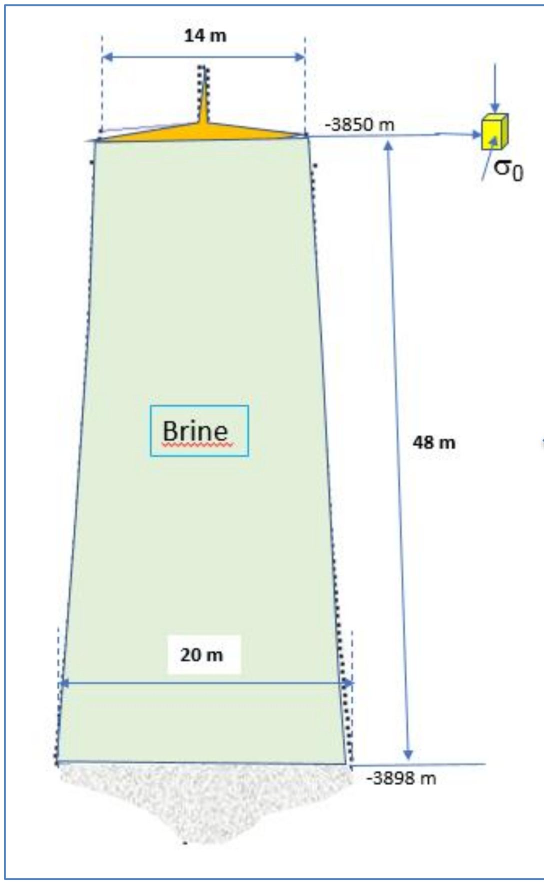
Schedule

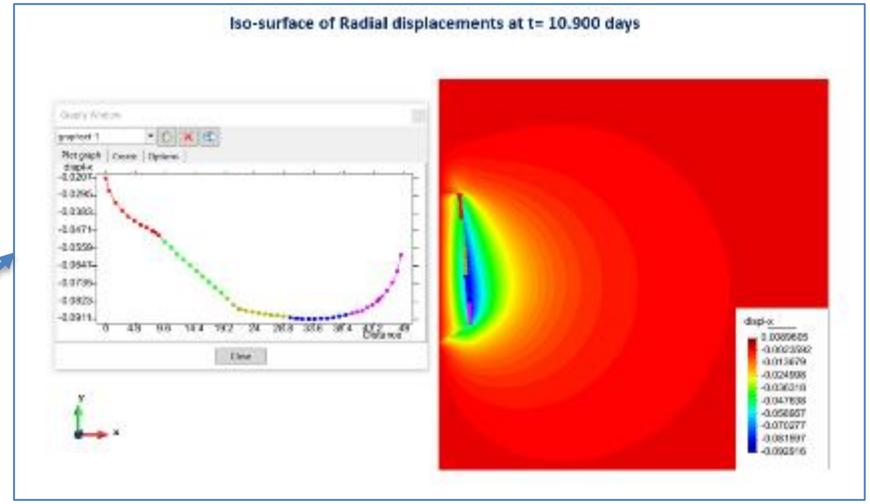
PLANNED ACTIVITIES	Dependency (Y/N)	Activity Number	Type of dependency	Month								
				8	9	10	11	12	13	14	15	16
1. State of the Art Report Elaboration												
2. Solution mining process simulation	N											
2.1 - Disolution factor experimental analysis	N			x	x	x						
2.2 - Parametric analysis for selected cases	N			x	x	x	x	x				
2.3 - Pipe wipe problem	N			x	x	x	x					
3. Fluidmechanical project of pilot cavern - CFD	Y	2	Finish-Finish									
3.1 Physical Modeling - Evaluation olefine pattern interface during Gas / Brine substitution proc	N			X	X							
3.2 Brine substitution												
3.2.1 Geometry, grid modeling/analysis & convergence	N			x	x	x						
3.2.2 Simulations & Analysis	Y	4.1.1	Finish-Start					x	x	x	x	x
3.2.3 Load functions of internal pressures inside the caverns	N										x	x
3.3 Gas filing analysis (High content CO2)	N											
3.3.1 Adaptation numerical grid model, convergence	N						x	x				
3.3.2 Simulations & Analysis	Y	4.1.2	Finish-Start						x	x	x	x
3.3.3 Load functions of internal pressures inside the caverns	N										x	x
4. Flow and Process Engineering	N											
4.1 Flow assessment - Based on models available in publications/references + Experimental tes	N											
4.1.1 Flow assessment - Substitution phase - Gas, CO2 rich stream / Brine	N				x	x						
4.1.2 Flow assessment - Salt cavern final filling process - Gas, CO2 rich stream	N					x	x					
4.2 Assessment of solubility of CO2 rich stream in brine	N						x					
4.3 Conception subsea raw sea water injection system	N							x	x			
5. Subsea & Marine Engineering	N											
5.1 Graphical and electronic model development	N											
5.1.1 3D graphical representation of the salt cavern construction	N			x	x	x	x					
5.1.2 Subsea arrangement for construction and operation of salt caverns	N			x	x	x	x					
5.2 Data collection	N											
5.2.1 Riser	N			x	x	x	x					
5.2.2 Flowline	N			x	x	x	x					
5.2.3 Umbilicals	N			x	x	x	x					
5.2.4 Xtree	N			x	x	x	x					
5.2.5 Mudline water injecttion pump	N			x	x	x	x					
5.3 Monitoring - cavern construction/operational process/abandonment	N							x	x			
6. Logistics	N											
6.1 Salt cavern project scheduling	N											
6.1.1 Problem definition (Well construction, solution mining, subsea arrangement, gas injection and confinement)	N			X								
6.1.2 Process description & mapping, including resources, materials and duration	N				x	x						
6.1.3 Project modelling (precedence diagram, network representation) & Model implementatior	N				x	x	x	x				
6.1.4 Computational experiments	N				x	x	x	x	x	x		
7. Health, Safety, Environment (HSE) and Legislation	N											
7.1 Landscape screening	N											
7.1.1 Team engagement/interviews and learnings	N			x	x							
7.1.2 External stakeholder engagement strategy definition and kick-off	N				x	x						
7.2 Scoping	N											
7.2.1 Environmental study requirements for licensing	N						x	x	x	x	x	
7.2.2 Legal requirements for licensing	N						x	x	x	x	x	
7.3 Stakeholders engagement to conclude licensing strategy	N						x	x	x	x	x	
8. Risk Analysis & Diagnosis	N											
8.1 Cavern Construction APRI	N			x	x	x	x	x	x	x		
8.2 Well design APRI	N			x	x	x	x	x	x	x		
8.3 Subsea Design APRI	N			x	x	x	x	x	x	x		
8.4 Topside APRI	N			x	x	x	x	x	x	x		
8.5 Cavern Operation APRI	N			x	x	x	x	x	x	x		
8.6 Subsea Operation APRI	N			x	x	x	x	x	x	x		
8.7 HSE/Legislation/Assumption APRI	N			x	x	x	x	x	x	x		
8.8 Logistics APRI	N			x	x	x	x	x	x	x		
8.9 Consolidation	N										x	x
9. Phase wrap-up workshop	N											M

Cavern design

- First project cycle studies
  - Basic geomechanical design of an experimental cavern;
    - Obtain parameters to be used definitive design salt caverns with central CO_2 disposal station;
    - Dissolution / mining process
  - Monitoring plan, to be applied in the construction, operation and abandonment phases of the caverns;
  - Basic geomechanical design of a giant cavern for assessing the technical feasibility of storing large volumes of CO_2 ;
- **Parametric study of caverns with different sizes**;

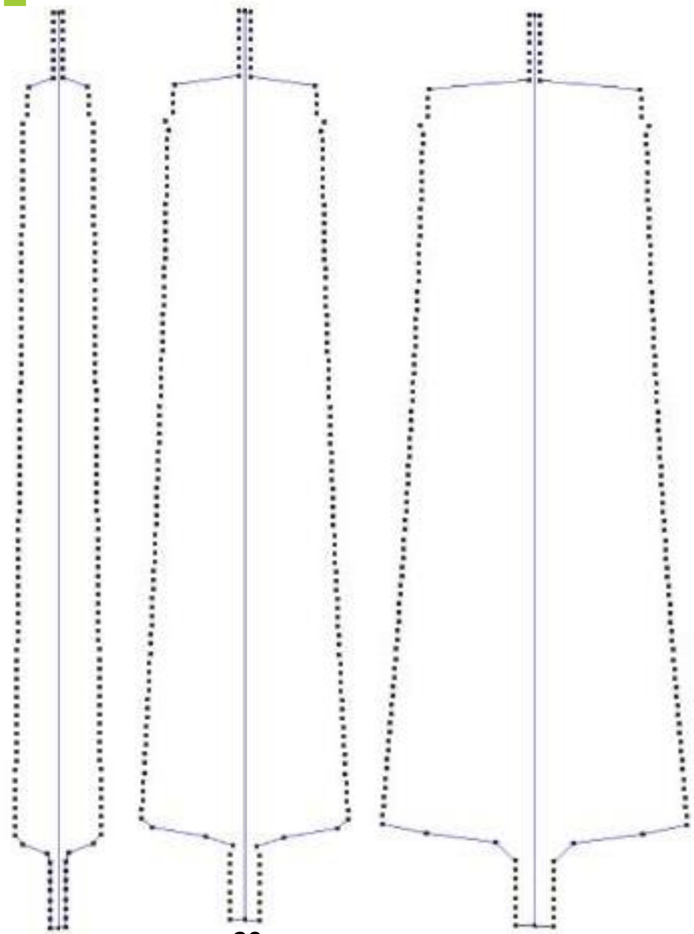
Experimental Salt Cavern





1. Topology data of the experimental cavern certified in the design:
   - Thickness of the safety halite slab protection: 1144 m;
   - Depth of the top of cavern: -3850 m;
   - Depth of the bottom of the cavern: -3898 m;
   - Diameter at the top: 14 m;
   - Diameter at the bottom: 20 m;
   - Height: 48 m;
2. Volume of the experimental cavern obtained by simulation: 11.000 m^3;
3. Volume of gas confined inside the cavern: 4.048.000 m^3;
4. Maximum Gas pressure expected after 2 years of abandonment: 52.460 kPa;
   Observation: The cavern develops very small deformation, so the squeeze of the gas by the closure of the salt rock is negligible;
5. Maximum gas pressure expected after 30 years of abandonment: 52.650 kPa;

Cavern design – leaching process



10 dias

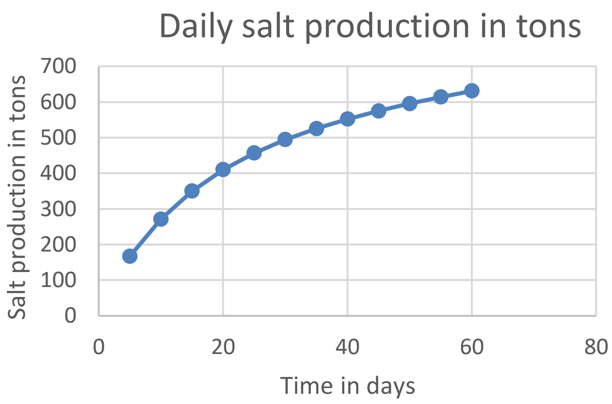
30 dias

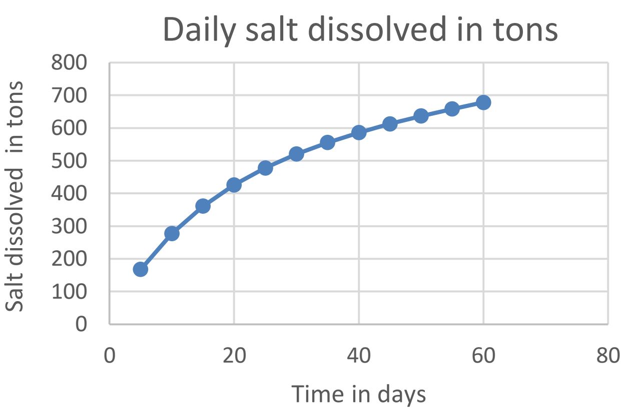
50 dias

Evolution of the solution mining process

20 dias

Schematic ilustration of the brine /seawater flow inside the cavern

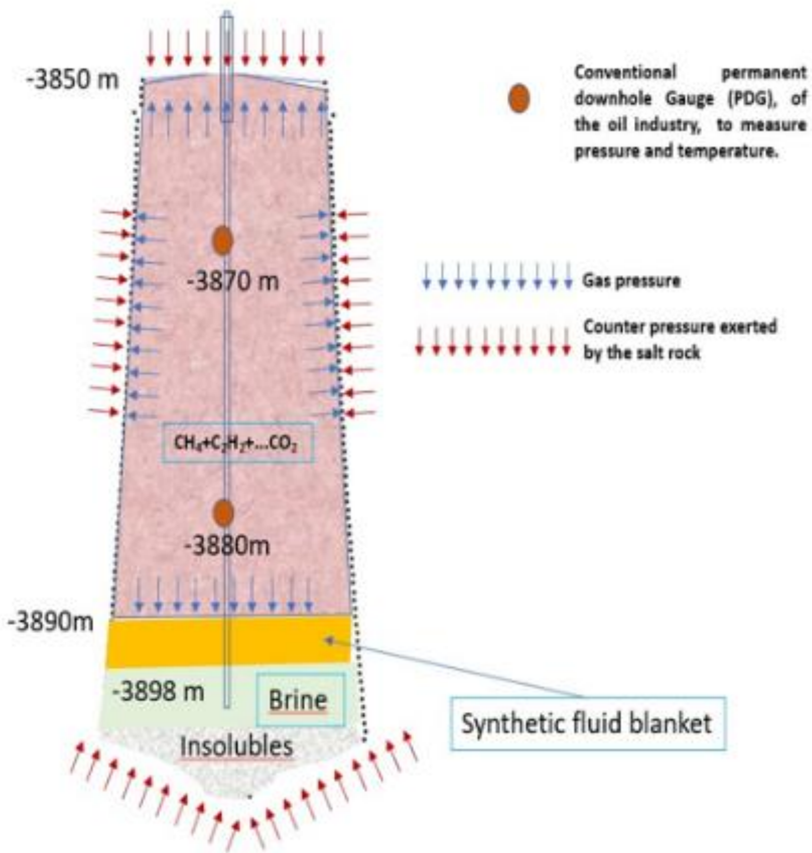


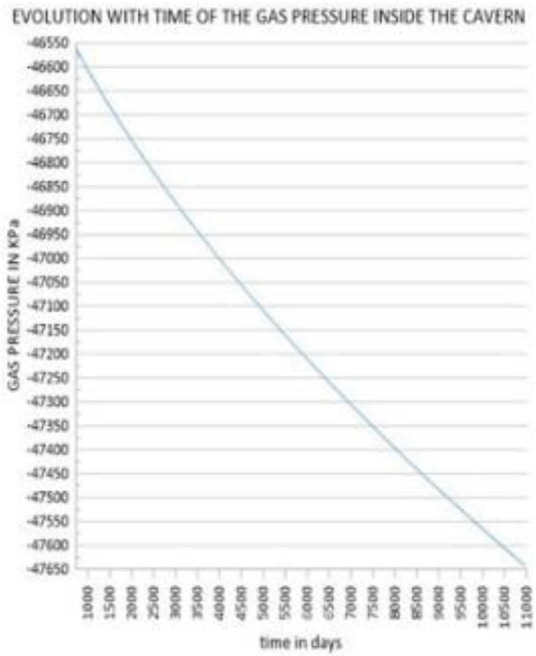


Dissolution profile of the experimental cavern

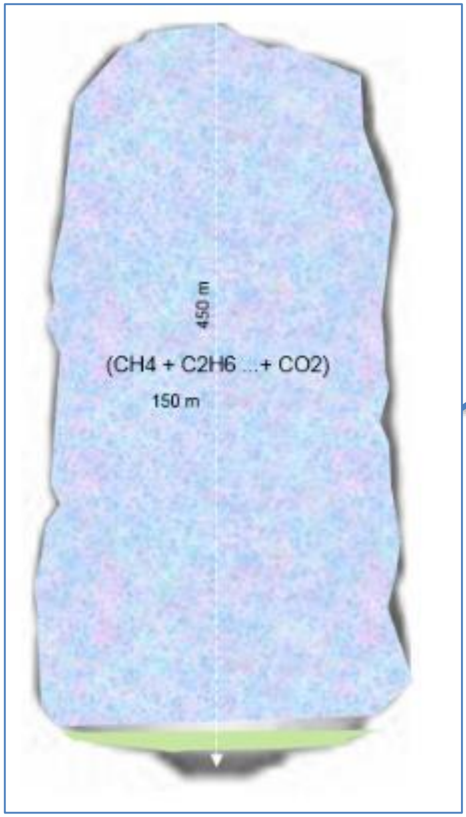
Experimental salt cavern – Monitoring

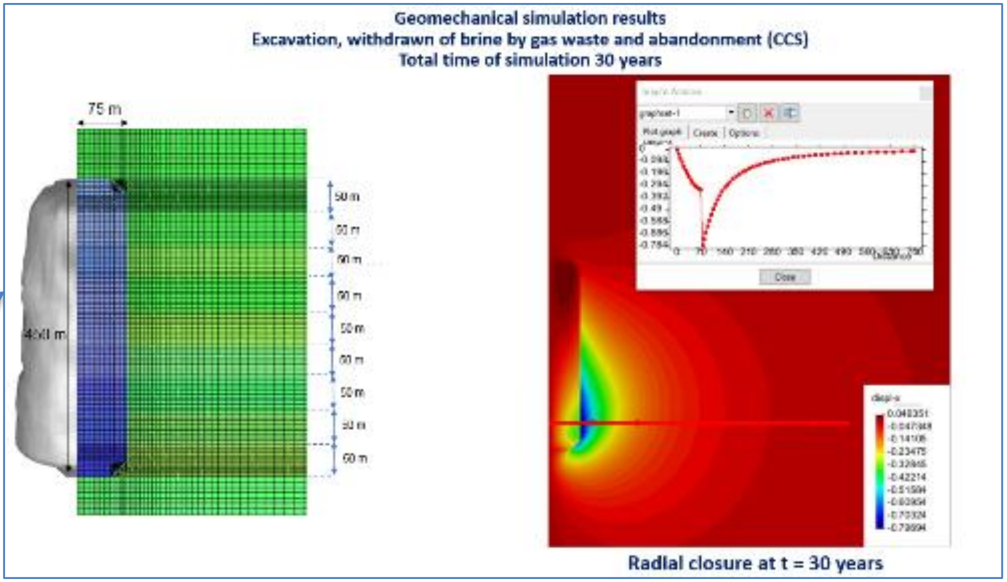
Monitoring of the gas pressure inside the cavern





Giant Salt Cavern

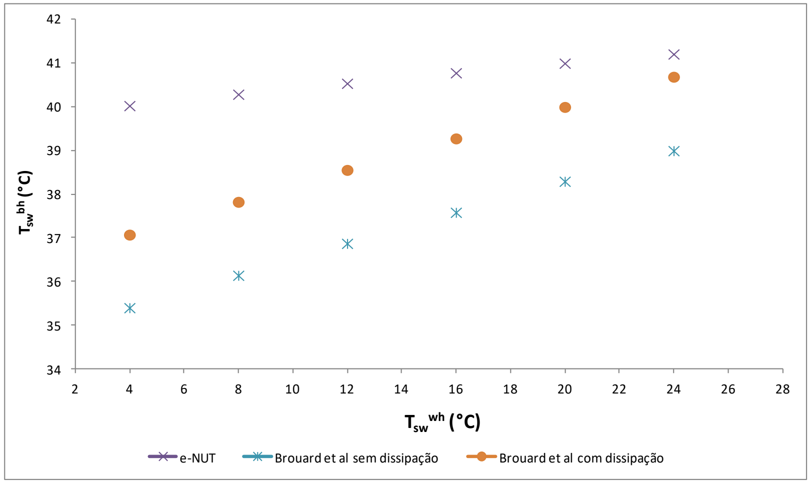




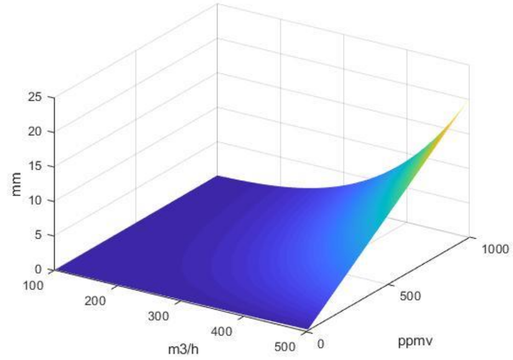
1. Dimensions of the pilot giant cavern certified by the geomechanical project:
   - ✓ **Thickness of the safety halite slab protection between the top of the cavern and the bottom of the sedimentary cap rock: 750 m;**
   - ✓ **Depth of the top of cavern: -3440 m;**
   - ✓ **Depth of the bottom of the cavern: -3890 m;**
   - ✓ **Diameter: 150 m;**
   - ✓ **Height: 450 m;**
   - ✓ **Geometrical Volume of the cavern: 7.4 E+06 m3;**
2. Storage volume of gas stream with high content of CO2 in one cavern: 3,840,000,000 Sm3;
3. Maximum Gas pressure expected after abandonment: 465 bar;
4. Based on the salt dome studied for CCS application, one cavern can store 4 billion Sm3 or 7.2 million tons of CO_2. Considering the pillar size between caverns of 750 m, 5 times the diameter of one cavern, the salt dome can accommodate the construction of 15 caverns, thus providing the confinement of approximately 108 million tons of CO_2.

Flow Assessment

- Expected seawater temperature at well bottom hole
  - Two models implemented ⇒ Estimate effect seawater temperature at well bottom hole during dissolution:
  - Both indicated that seawater reaches well bottom hole at a temperature close to brine inlet, regardless of seawater temperature at wellhead



- Is erosion an issue?
  - Brine contains insoluables
    - DNVGL-RP-O501 (managing sand production and erosion);
  - **During dissolution**
    - Brine flows through annular space between outer pipe and inner pipe
  - **During brine substitution by gas**
    - Brine flows through inner pipe

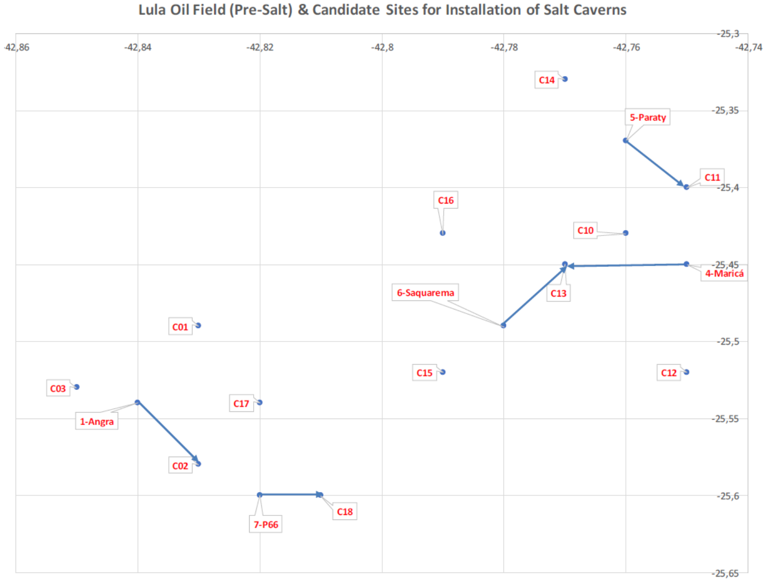


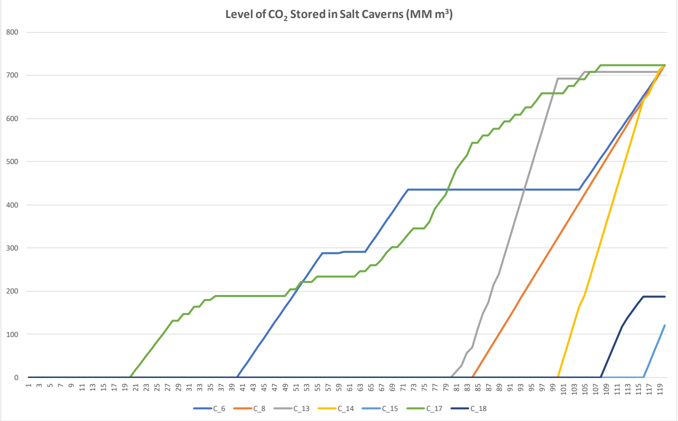
2 years of brine substitution (conservative)

Depending on the flowrate and concentration, erosion could be an issue

Logistics

- **Global Development Strategy**
  - Plan construction several caverns associated to existing oil & gas wells and new projects;
  - Plan = *f* (amount available resources; prioritization issues; location/size; sharing cavern with more than one FPSO);
    - Limited resources and conflicting decisions;
  - Optimization approach = PROPOSED;
  - Main phases:
    - 1) Elaboration different scenarios concerning Santos Basin development;
    - 2) Mathematical modelling;
    - 3) Optimization.
  - Output:
    - 1) Location; 2) Size; 3) When to build; 4) Connections between FPSOs and salt caverns.





Risk Analysis


RISK ASSESSMENT MATRIX

SEVERITY / PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

- **Methodology**
  - Development of Preliminary Risk Analysis (APRI, in Portuguese), identifying hazard events, causes, and consequences;
  - Evaluation of events’ frequency and consequences’ severity;
  - Qualitative Risk assessment according to SHELL standards;
  - Barriers identification;
    - Establishment of mitigation plan

- Scope:
  - **Cavern well construction APRI**
  - Well design APRI
  - Subsea Design APRI
  - Topside APRI
  - Cavern Operation APRI
  - Subsea Operation APRI
  - **HSE / Legislation / Assumptions APRI**
  - Logistic APRI

HSSE & Regulation – Project 42

- **Contribution project 42**
  - **1. Screening**
    - 1.1. Definition of the type of licensing by Project 42 staff (all team);
      - 2 months – August and September;
    - 1.2. Discussion about type licensing with participation of IBAMA and Project 34;
      - 1 month – September;
  - **2. Scoping**
    - 2.1. Scope of the Environmental Study (analysis of alternatives, risk assessment, impact analysis and PBA (mitigating measures):
      Definition scope Environmental Study required for licensing (EIA team)
      - 5 months – November to March;
    - 2.2. Discussion about the scope with participation of IBAMA and Project 34
      - 5 months - November to March.
  - **Deliverables**
    - March
    - Understanding about the screening step of salt cavern project licensing;
    - Draft of the Term of Reference of the Environmental Study.

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