The Lacq CO₂ geological storage project
Storage
CO₂ injection into Rousse depleted gas reservoir

- Reservoir: Mano
  - Field: Rousse
  - Jurassic fractured dolomitic reservoir
  - Depth = 4500m
  - Temperature = 150°C
  - Initial Pressure = 485 bar
  - Initial CO₂ = 4.6%, Initial H₂S < 1%
  - No aquifer
  - Av. Porosity: 3%
  - Av. Perm = 5mD
  - Water saturation 30 to 40%
  - One unique well RSE-1 producing the reservoir Mano

Geological cross-section (S – N)
Storage
A known reservoir

- Gas production around 0.9 GSm3, from 1972 to 2008
- P @ end of prod. = 40 bar
- Reservoir surface around 4 km²
- Available: logs, reservoir and cap rock cores, production data (pressure, flow rate, LGR), well tests, regional information (neighbor: Meillon Saint Faust gas field also producing the Mano reservoir)

W – NE seismic cross-section
Storage

Studies for a limited injection

- Injection will be limited to max 100,000 tons of CO₂
- Studies done:
  - Reservoir geological modeling
  - Dynamic modeling
    - History matching BO
    - History matching compositional
    - CO₂ injection for two years
    - Observation period
  - Static modeling of the complex (to look at the leakage pathways)
- Expected P at end of CO₂ injection < 100 bar

Matching with E300

Complex modeling
Objective: to monitor injection parameters
- CO₂ injection flow rate and composition are measured at Lacq before transport.
- At early stage of the project, CO₂ injected composition was considered to be 92% CO₂, 4% O₂, 3.7% Ar, 0.3% N₂
- Current O₂ content is around 6%
- CO₂ transport, well head, well and reservoir in gas phase
- Cumulated CO₂ injected at 22nd June 2011: 18 kton
Objectives
- Site integrity and well integrity
- Check that CO₂ behavior as expected
- Get info to calibrate tools and acquire R&D data

Points 1 to 10

3 periods
- Pre-injection (baseline ante 2010)
- Pilot: Injection + 3 years observation
- Post pilot: to be defined
Well Rousse-1
Specific completion

- Objective: to check well integrity and to have information in the well (injectivity)
- Completion change in February 2009.
- Well Logging to check casing and cement (Sonic Scanner and Isolation Scanner)
- Pressure and temperature gauge at two depths: 3300 and 4400 m (two optical fibers)
- Three seismic sensors at 4180, 4280, 4380 m
- Perforations in Mano reservoir: 4540 – 4566 m
- New completion in March 2011
Objective: to monitor reservoir behavior and update predictive models

- P and T sensor above reservoir at 4400 m
- Stabilized temperature in injection is -4 °C than static temperature (deeper gauge)
- Static reservoir pressure is increasing due to CO₂ injection
- Around 4 bar between flowing and static reservoir pressure
- Good coherence with predictive simulation
Objective: to follow well performance and injectivity
- Calculated VLP (Vertical Lift Pressure) with Prosper
- Thermodynamic is entered with Peng-Robinson EOS with Volume shift
- Injection average condition (sept 10)
  - Flow rate: 52 kSm3/day (95 ton/d)
  - Well head: 27 b – 80°C
  - Deeper gauge: 50 b – 138°C
- Observed information is compared to calculation
- Error is less than 2%
Objective: to be able to detect any changes that could be linked to CO₂ leakage from storage reservoir

- Soil gas, aquifers and rivers water above the reservoir area. Specific surveys twice a year
- Fauna and flora surveys according to seasons
- Alarms thresholds have been defined
CO₂ and CH₄ concentrations in soil: BRGM and fluxes at the soil/atmosphere interface: INERIS 35 points.

- Twice a year during fall and winter (to avoid biologic activity)
- Early base line surveys performed in 2008 and 2009
- No CH₄ concentration and fluxes were recorded
Aquifers: three shallow drinkable aquifers, one deep saline aquifer at 2000 m. Water chemistry and mineral content, every six months (pH, conductivity, carbonates and bicarbonates concentrations)

River water: two standardized bio indicators (IBD and IBGN), water chemistry and mineral content indicators, twice a year at 5 locations

Base line surveys in 2009
Environnemental monitoring
Fauna and Flora

• Fauna and flora: annual inventory of representative ecosystems (33 locations), representative amphibian species and insects species (50 loc.)
• Base line surveys in 2008 and 2009
CO$_2$ Capture, transport
The Lacq pilot plant

IAE GHG– June 23rd, 2011
- Lacq pilot plant project overview
- Lacq pilot plant - Surface technical features
CCS pilot, Lacq, France

Objectives

- To Demonstrate the technical feasibility and reliability of an integrated onshore Carbon Capture and Storage scheme for steam production at a reduced scale (1/10th of future facilities).
- To acquire operational experience and data to up-scale with cost reduction the oxy-combustion technology from pilot (30MWth) to industrial scale (200MWth).
- To develop geological storage qualification methodologies
- To develop monitoring methodologies on site to prepare future larger scale long term onshore storage projects. (Micro seismic monitoring, Environmental monitoring..)

Acquire expertise and reduce costs for future industrial deployment
**CCS pilot, Lacq, France**

**Project description**

- **Budget**
  - CAPEX 60 M€
  - OPEX 40 M€

- Up to 100,000 tons of CO2 injected and stored

**Transport**

- 27km long pipe from Lacq to Rousse

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This industrial operation is planned to capture and store ~100,000 tons of CO2 over a 2-year period (eq to the CO2 exhaust emissions of 40,000 cars during a year)
Project phasing

CCS pilot, Lacq, France

<table>
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<tr>
<th>Year</th>
<th>Site screening and conceptual studies</th>
<th>Basic engineering studies</th>
<th>Detailed engineering and procurement</th>
<th>Construction works</th>
<th>Injection well work over</th>
<th>Operational Phase and injection/storage</th>
<th>Base line surveys and monitoring</th>
<th>Information to stakeholders</th>
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Start-up of operational phase: July 3rd, 2009
First CO₂ injection in Rousse reservoir: January 8th, 2010
Permit obtained in May 2009 for capture, transportation and storage based on:
- Specific risk and impact analysis
- Public hearings
- Third party review

Public dialogue – transparency policy:
- Identification of Stakeholders (ONG, mayors…)
- Early public meetings in 2007 (4 public meetings)
- Follow up information committee (7 meetings)
- Information letter every quarter
- Hot line

Scientific Advisory Committee since 2007

Scientific collaboration program with National Institutes and Universities on Rousse storage

Project endorsed by the Carbon Sequestration Leadership Forum (CSLF)

Project information also available on www.total.com/corporate-social-responsibility
Lacq CCS Pilot plant
Surface technical features
CCS pilot, Lacq, France
A complete industrial chain

CO₂ injection

CO₂ transport

CO₂ capture

Natural Gas production

Industrial scale:
30MW th oxycombustion
60 000 t/year CO₂
Integrated within existing facilities
CCS pilot, Lacq, France

Overview

- 30MW\textsubscript{th} Oxy-Boiler
- HP steam to plant network
- Commercial Gas
- Oxygen
- Flue Gas Recycle
- Air
- Stack
- Compressor
- Scrubber
- Cooling tower
- Dryer
- Wellhead
- Compressor
- Depleted Gas reservoir
- 27km long pipe

Lacq Site

Rousse Site
■ Air Separation Unit:
  • Designed to provide oxygen to the boiler for the oxy-combustion process
  • Cryogenic unit, provided by Air Liquide (240 t/d oxygen, purity between 95 and 99.5%).
  • Air Liquide is fully in charge of the ASU (installation, operation and maintenance of the unit on the Lacq site)

■ Air Boiler revamped to Oxy Boiler:
  • Air Liquide has developed and built 4 oxy-burners (8MWth each)
  • Alstom has revamped the boiler – Major modification was the installation of a Flue Gas Recycle
  • Oxy-boiler produces 40 tonnes/hour of steam 60b/450°C (30MWth) which feeds the HP steam network of the Lacq plant

■ Cooling of flue gases:
  • From 250° to 30°C to condense steam and concentrate the CO₂
In oxy-combustion, the high purity oxygen feeding the boiler has to be diluted with a recirculation of flue gases (FGR) from the boiler outlet to the burners.
Technical features
Compression, dehydratation

Compression for CO₂ transport to the injection site
- Alternative compressor 1 MWh
- 3 stages, Flowrate 100 kSm3/D
- Suction P 1barg; discharge P 27 barg

Dehydratation unit
- Molecular sieves device
- 35 ppm of water outlet
- Regeneration by nitrogen
Transport and storage

- Transport pipe
  - Carbon steel pipe / CO₂ stream is deeply dehydrated to avoid pipe corrosion
  - 12” from Lacq to Pont D’As
  - 8” from Pont d’As to Rousse

- Rousse compressor
  - 2nd compression to allow for injection in the geological reservoir
  - 1 stage reciprocating compressor
  - Pinlet 27bar ; Poutlet 51 bar

- Well
  - Standard wellhead
  - 3.5” tubing
  - P&T transducers are mounted on the tubing – Signal is transferred to the surface through optical fibers
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