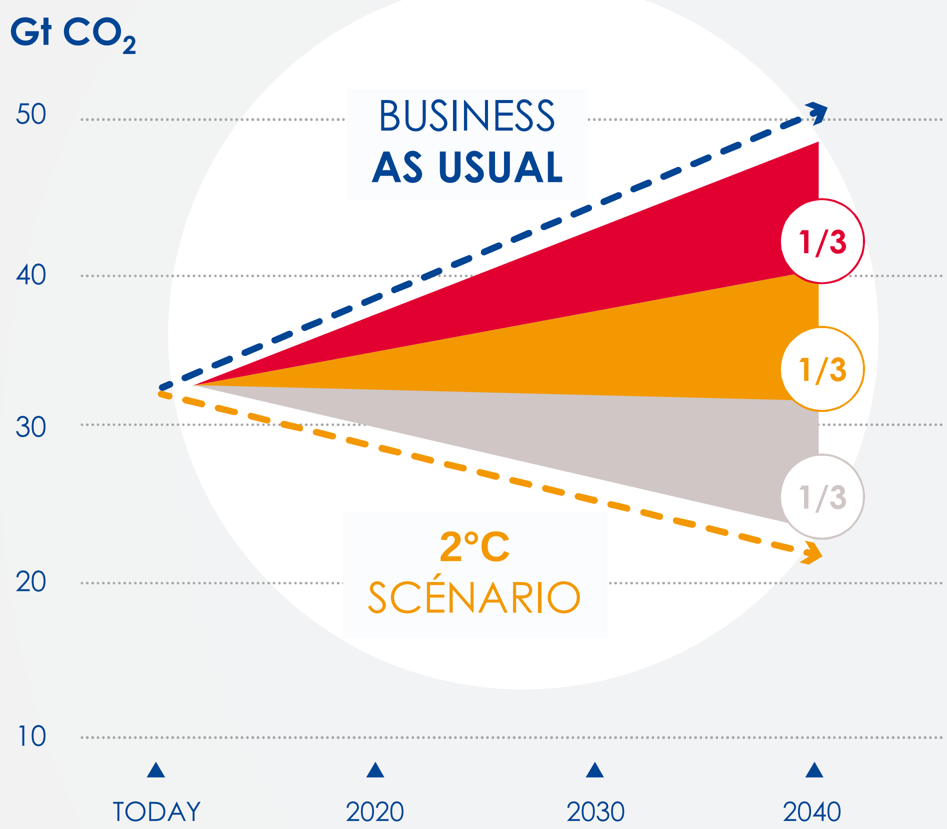
TOTAL

CCUS R&D Roadmap within our CLIMATE STRATEGY

3 AREAS OF FOCUS TO MEET **THE 2°C TARGET**



- More **renewable** energies
- More **energy** efficiency
- **Optimized** energy mix

14%

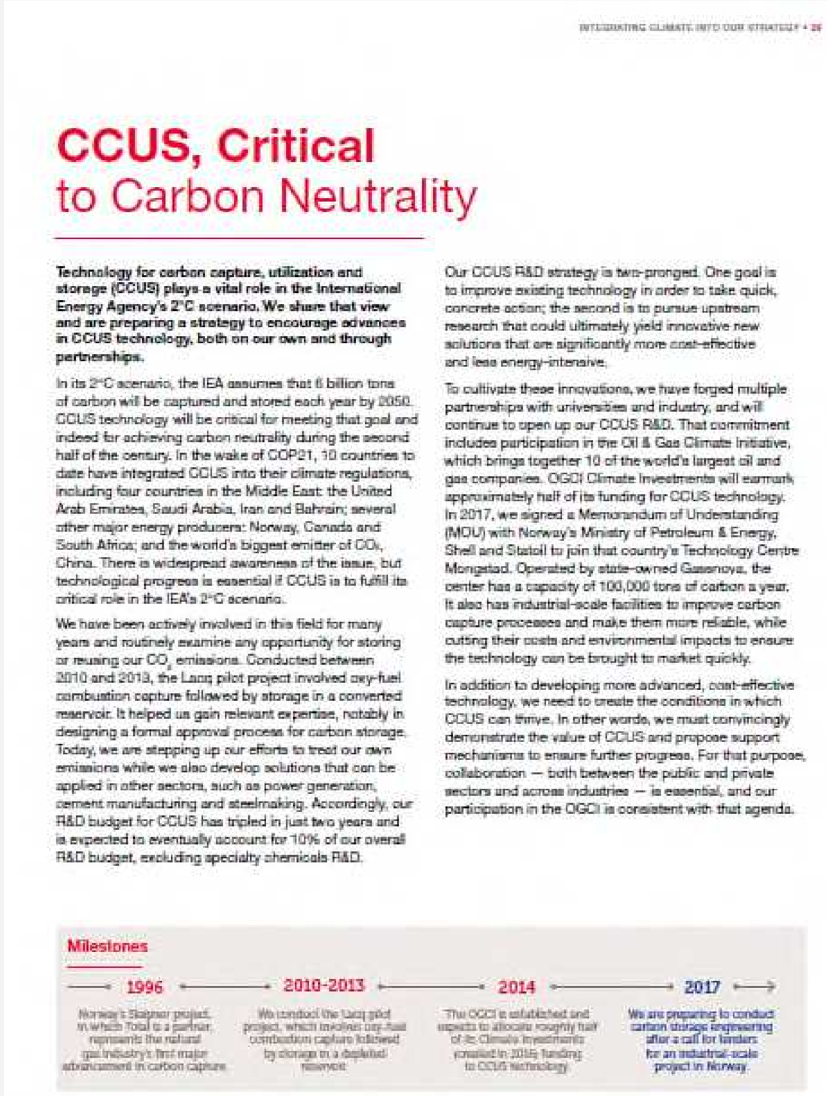
CCUS Contribution
to 2°C reduction

= 6 Gt of CO_2/year by 2050

CCUS Critical to Carbon neutrality

CCUS TOTAL'S STRATEGY

http://www.total.com/sites/default/files/atoms/files/integrating_climate_into_our_strategy_va.pdf



INTEGRATING CLIMATE INTO OUR STRATEGY • 25

CCUS, Critical to Carbon Neutrality

Technology for carbon capture, utilization and storage (CCUS) plays a vital role in the International Energy Agency's 2°C scenario. We share that view and are preparing a strategy to encourage advances in CCUS technology, both on our own and through partnerships.

In its 2°C scenario, the IEA assumes that 6 billion tons of carbon will be captured and stored each year by 2050. CCUS technology will be critical for meeting that goal and indeed for achieving carbon neutrality during the second half of the century. In the wake of COP21, 10 countries to date have integrated CCUS into their climate regulations, including four countries in the Middle East: the United Arab Emirates, Saudi Arabia, Iran and Bahrain; several other major energy producers: Norway, Canada and South Africa; and the world's biggest emitter of CO_2, China. There is widespread awareness of the issue, but technological progress is essential if CCUS is to fulfill its critical role in the IEA's 2°C scenario.

We have been actively involved in this field for many years and routinely examine any opportunity for storing or reusing our CO_2 emissions. Conducted between 2010 and 2013, the Lacq pilot project involved oxy-fuel combustion capture followed by storage in a converted reservoir. It helped us gain relevant expertise, notably in designing a formal approval process for carbon storage. Today, we are stepping up our efforts to treat our own emissions while we also develop solutions that can be applied in other sectors, such as power generation, cement manufacturing and steelmaking. Accordingly, our R&D budget for CCUS has tripled in just two years and is expected to eventually account for 10% of our overall R&D budget, excluding specialty chemicals R&D.

Our CCUS R&D strategy is two-pronged. One goal is to improve existing technology in order to take quick, concrete action; the second is to pursue upstream research that could ultimately yield innovative new solutions that are significantly more cost-effective and less energy-intensive.

To cultivate these innovations, we have forged multiple partnerships with universities and industry, and will continue to open up our CCUS R&D. That commitment includes participation in the Oil & Gas Climate Initiative, which brings together 10 of the world's largest oil and gas companies. OGCI Climate Investments will earmark approximately half of its funding for CCUS technology. In 2017, we signed a Memorandum of Understanding (MOU) with Norway's Ministry of Petroleum & Energy, Shell and Statoil to join that country's Technology Centre Mongstad. Operated by state-owned Gassnova, the center has a capacity of 100,000 tons of carbon a year. It also has industrial-scale facilities to improve carbon capture processes and make them more reliable, while cutting their costs and environmental impacts to ensure the technology can be brought to market quickly.

In addition to developing more advanced, cost-effective technology, we need to create the conditions in which CCUS can thrive. In other words, we must convincingly demonstrate the value of CCUS and propose support mechanisms to ensure further progress. For that purpose, collaboration — both between the public and private sectors and across industries — is essential, and our participation in the OGCI is consistent with that agenda.

Milestones

- **1996** — Norway's Sleipner project, in which Total is a partner, represents the natural gas industry's first major advancement in carbon capture.
- **2010-2013** — We conduct the Lacq pilot project, which involves oxy-fuel combustion capture followed by storage in a depleted reservoir.
- **2014** — The OGCI is established and expects to allocate roughly half of its Climate Investments (created in 2016) funding to CCUS technology.
- **2017** — We are preparing to conduct carbon storage engineering after a call for tenders for an industrial-scale project in Norway.

TOTAL **LEADER IN CCUS TECHNOLOGY** BY 2035

1

CCUS is an **emerging Industry** representing a **business opportunity** on par with Exploration & Production

2

TOTAL is working for **environment more favorable** to the development of CCUS solutions

3

Large scale CCUS deployment may only be achieved via collaborative work and shared investment costs (Public/Private)

4

TOTAL will be positioned along the **full CCUS value chain** and will offer a suite of **highly competitive solutions**

5

To contribute to developing CCUS as an efficient business, TOTAL will first focus on **commercial projects which could be scaled up**

HOW **TO BE A LEADER** ALONG THE WHOLE VALUE CHAIN?

"Be a major CCUS technology integrator along the value chain **to participate to climate change mitigation** and **prepare for new business opportunities**"

DEVELOP INTERNAL KNOW-HOW	PROMOTE COLLABORATIVE WORK & PARTNERSHIPS	BOOST INNOVATIVE TECHNOLOGIES

CAPTURE

Capture CO_2 from all sources by concentrating efforts first on easy to capture sources (native CO_2 and low-hanging fruits in the industry)

Develop disruptive technologies to decrease capture costs

TRANSPORT

Develop knowledge and operational expertise in CO_2 transport (pipelines and ships) to secure the necessary link between capture and storage

UTILIZATION

Develop a portfolio of CO_2-based products through chemical or biological conversion with the objective of targeting mass markets in the long term

Acquire operational expertise on CO_2-EOR

STORAGE

Operate and manage a CO2 storage project at an industrial scale

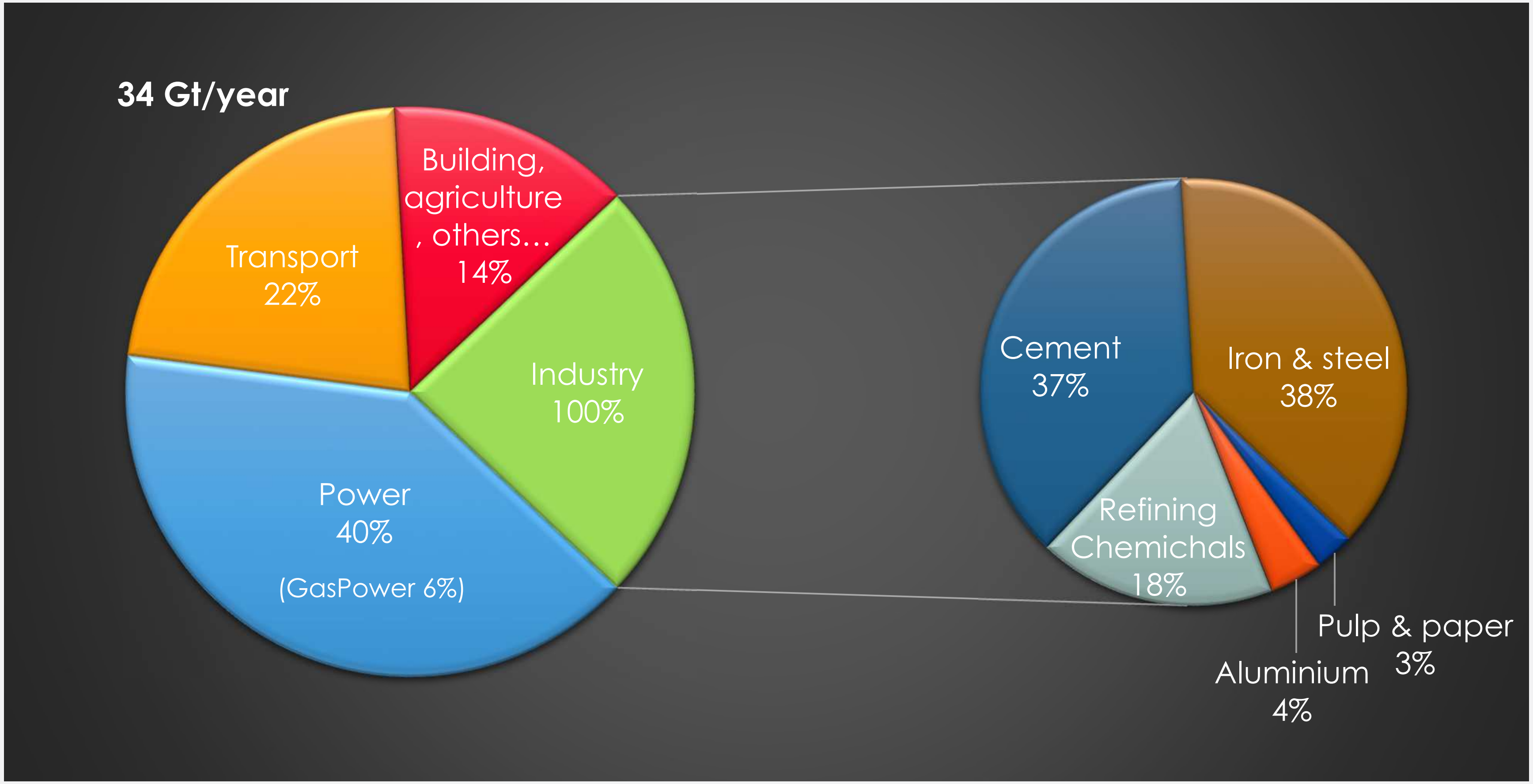
Leverage on TOTAL's existing expertise to solve key storage issues

SUSTAINABLE CCUS VALUE CHAIN

Techno-economic & Environmental Performance Management	Integrated Risk Management	Social responsibility

WORLD DIRECT CO2 EMISSIONS…OUR FOCUS

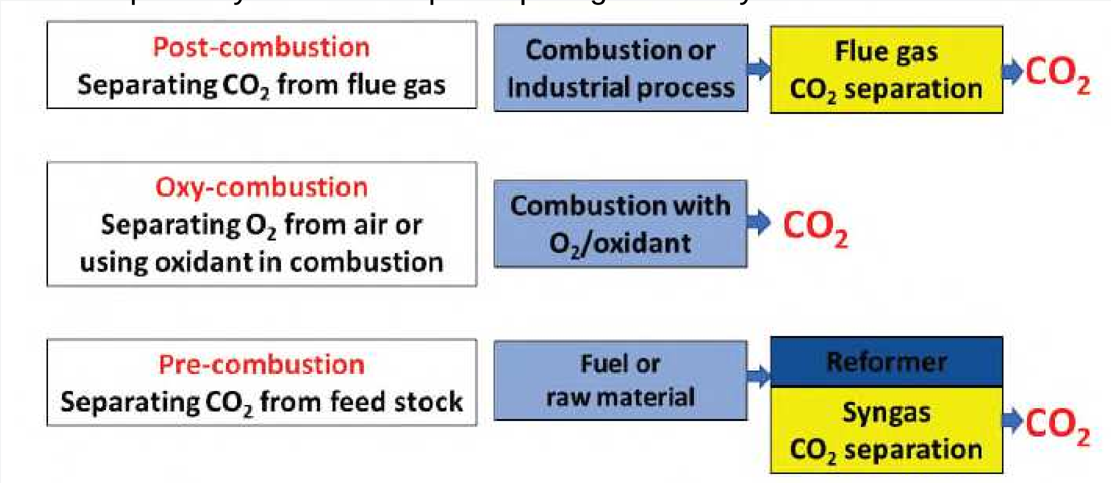
- Gas Power
- Industry in general with a special emphasis on Cement / Steel / Refining



Source: International Energy Agency, Energy Technology Perspectives 2017 - www.iea.org/etp2017

CO2 CAPTURE : COST REDUCTION AND ENERGY PENALTY

Three pathways for CO2 capture. | Image courtesy of Gassnova SF



SOLVENTS

- Control or eliminate toxic degradation product emissions
- Reduce corrosiveness to allow use of cheaper materials

MEMBRANES

- Improve selectivity / permeability and robustness

OXY-COMBUSTION for gas power

- Develop high efficiency supercritical CO2 turbomachines

ADSORBENTS

- Improve material tolerance to water and contaminant
- Increase selectivity and working capacity ($CO2_{ads}$ - $CO2_{desorb}$)

CO2 CAPTURE : SPEEDING UP THE DEVELOPMENT OF BREAKTHROUGH TECHNOLOGIES.

Commercialisation

TCM: technology qualification

environment-friendly solvent

demonstration

CHEERS Project
Chemical Looping Combustion

Contaminant resistant adsorbent

The world's largest facility for testing and improving **CO_2 capture technologies**

New materials
QSPR approach

Fundamentals

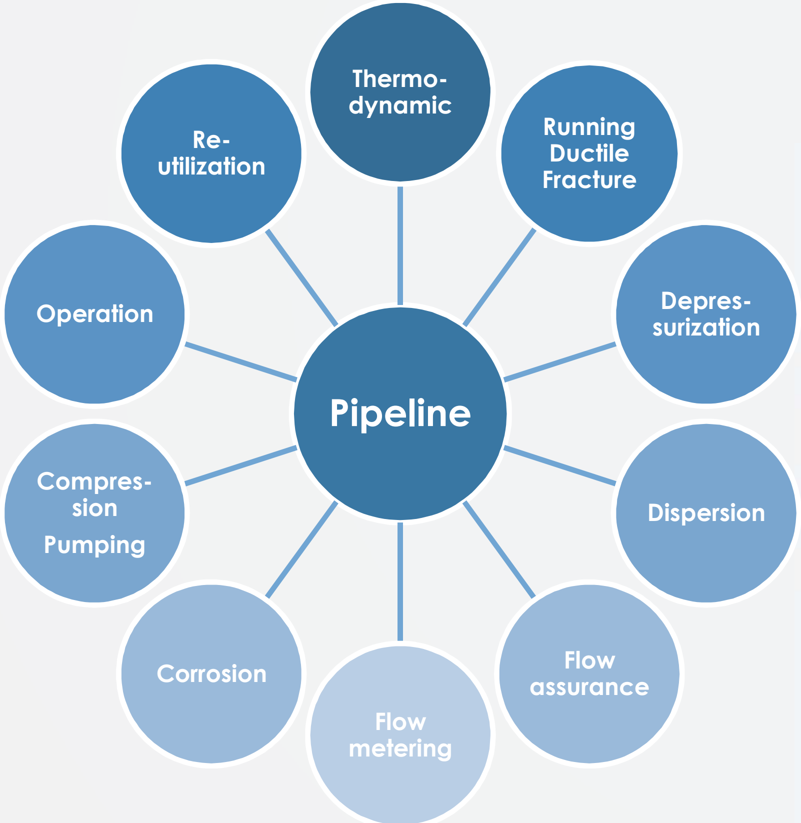
CO2 TRANSPORT

In the years to come (order of magnitude)[1]

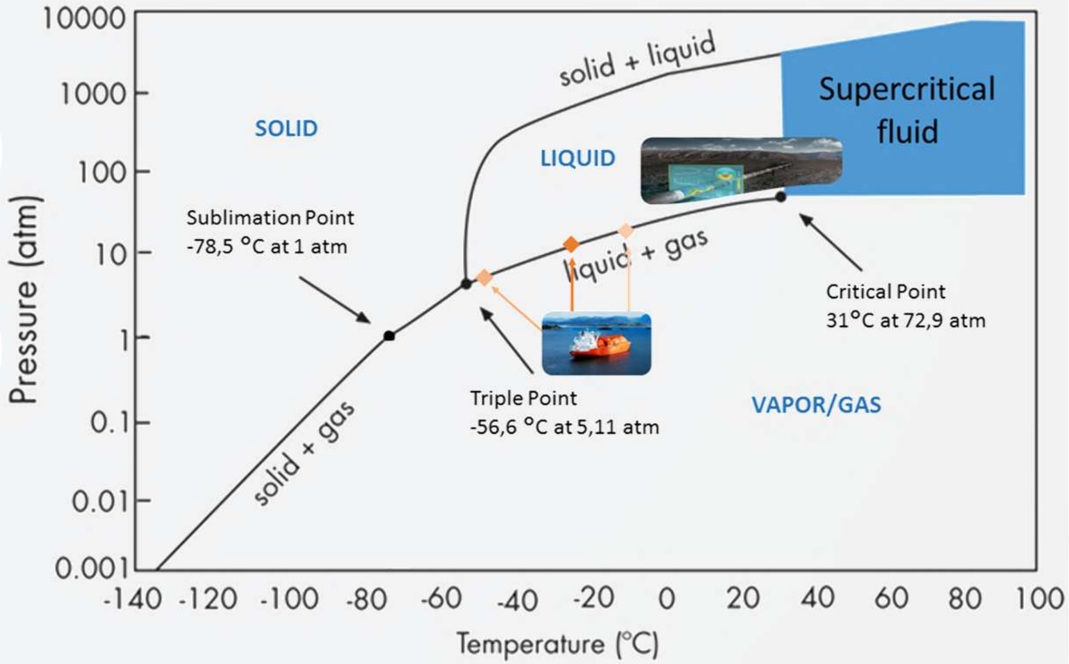
Pipeline : 25 000 km in 2030 and 100 000 km in 2050

Need of ships from 30 000 up to 100 000 m^3 – 10 to 20 new built / year in 2040

[1] https://hub.globalccsinstitute.com/sites/default/files/publications/25906/transport-co2.pdf

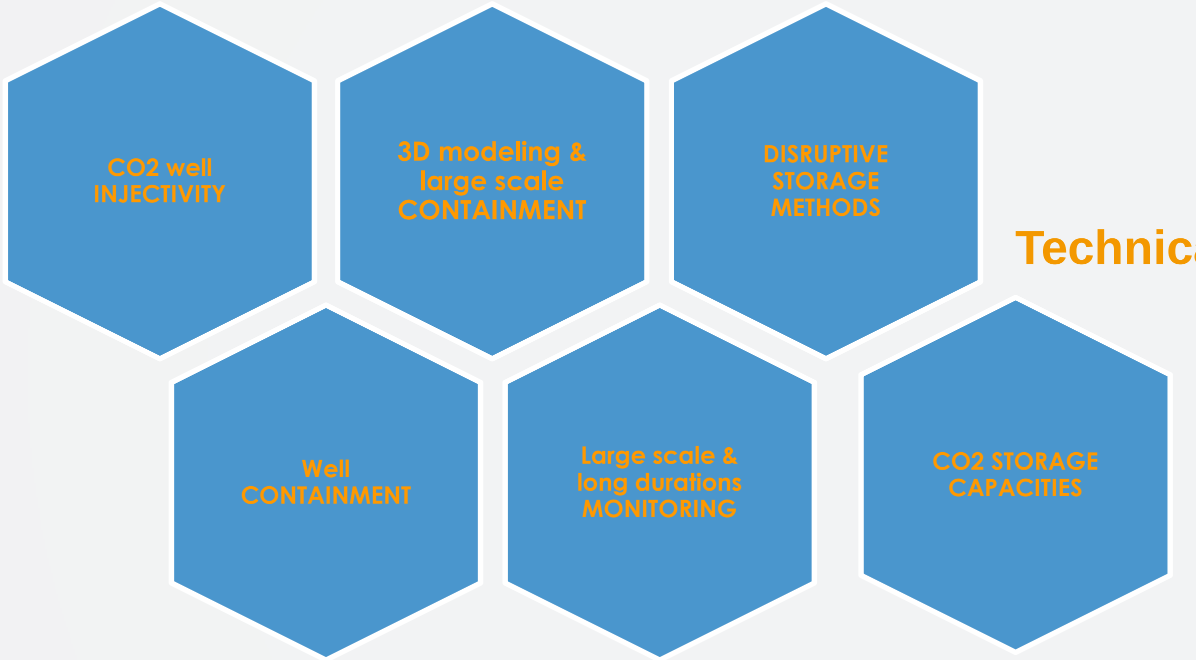


Model physical and chemical behavior of CO2 with its impurities in order to design and operate a safe and cost efficient fluid carrier (pipeline or ship)



CO2 GEOLOGICAL STORAGE

Demonstrate that CO2 storage is an efficient and profitable tool to limit CO2 emissions, while ensuring social acceptability



Technical CHALLENGES

Key collaborations

- UPPA, Pau University - France
- Mont Terri Lab. - Switzeland
- LBNL – USA
- CaMI CO2 pilot – Canada
- Otway CO2 pilot – Australia
- Norvegian CCS consortiums (SINTEF, NGI, etc.)

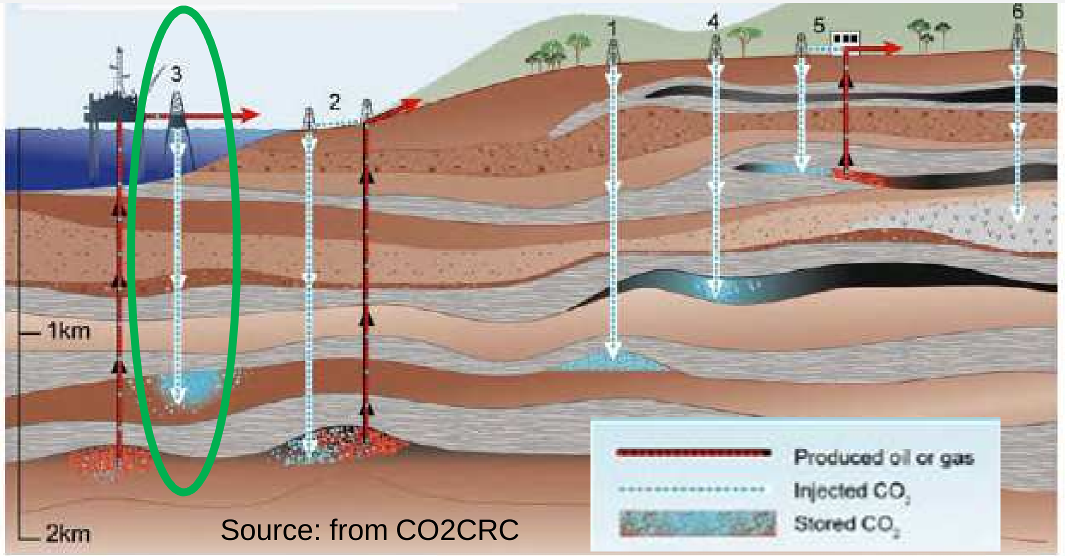
CO2 GEOLOGICAL STORAGE

Injecting CO2 into basin scale deep saline aquifers (salinity greater than that of protected groundwater) is one option for the geological storage of CO2 in order to reduce anthropogenic greenhouse gas emissions into the atmosphere.

Range of geological "storage" options for CO_2

1) Depleted oil and gas reservoirs → Capacity range: 670-900 Gt of CO_2
2) Use of CO_2 in enhanced oil recovery (EOR)
3) **Deep saline water-saturated reservoir rocks** → Capacity range: 1000-10 000 Gt of CO_2
4) Deep coal seams
5) Use of CO_2 in enhanced coal bed methane recovery
6) Other options (basalts, shales, saline cavities, etc.)

Source: IPCC, 2005



Source: from CO2CRC

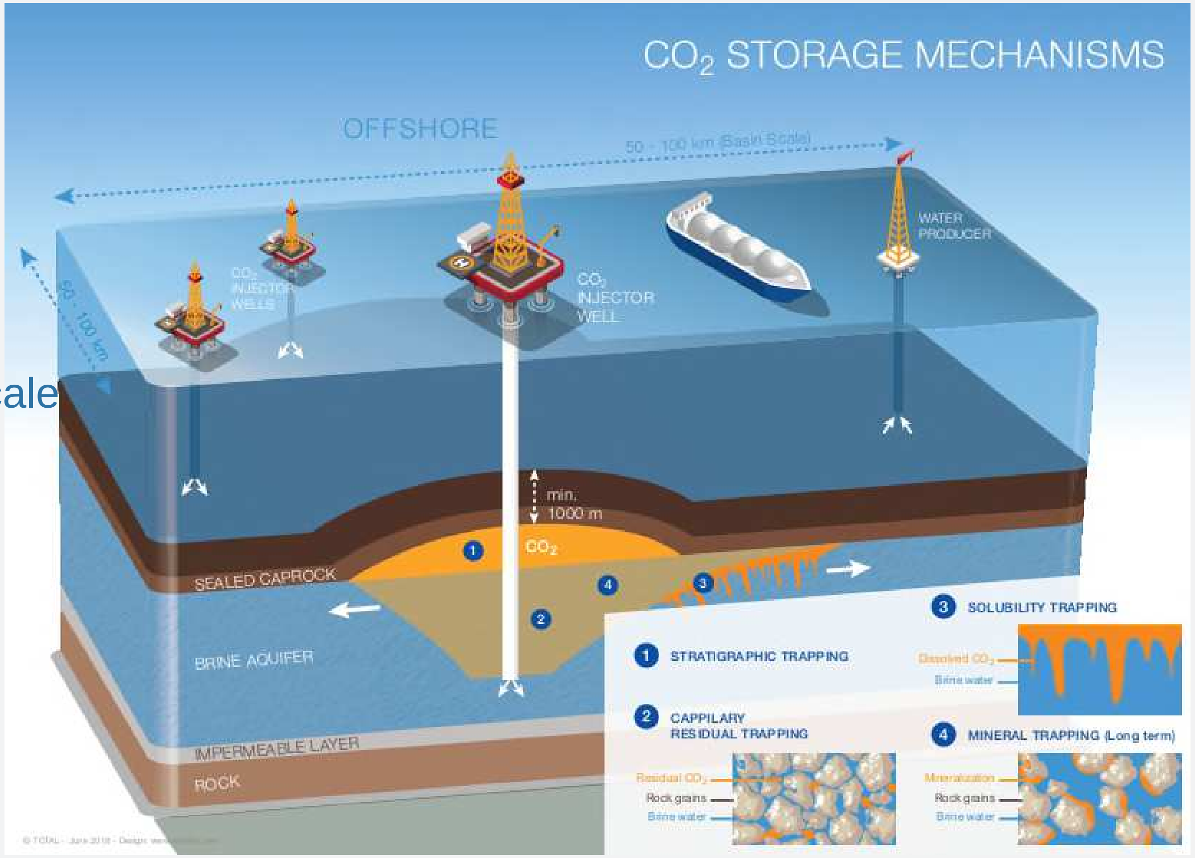
Among worlwide CO2 storage ressources identified, 97% are prospective and need to be matured.

Source: OGCI review 2017

CO2 GEOLOGICAL STORAGE

PRINCIPLES OF CO2 STORAGE IN DEEP BRINE AQUIFER

- ✓ Flow transport:
  - Modeling at basin scale
  - Coupling methods,
  - Computation time reduction
- ✓ Geochemical aspects
  - Modelling long term/large scale trapping mechanisms
  - Kinetics of dissolution
- ✓ Geomechanical aspects:
  - Vicinity of wells modeling
  - Multiscale failure process modeling

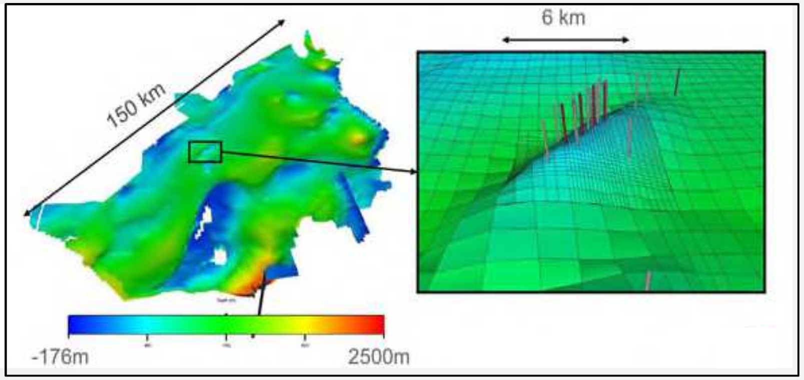


Source: From TOTAL

CO2 GEOLOGICAL STORAGE

BASIN SCALE MODELING (~100X100 km)

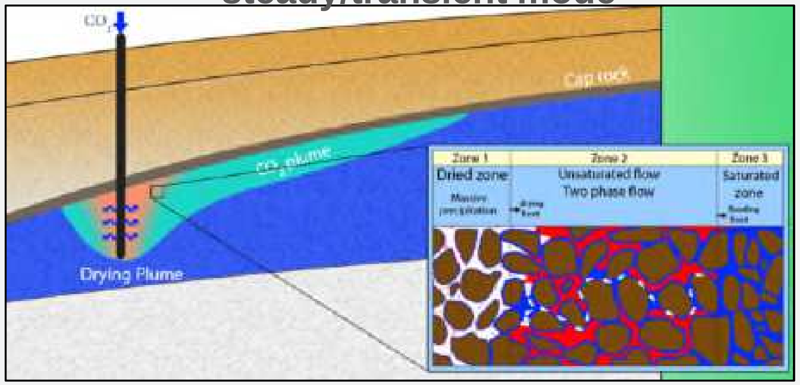
Geology, flows, geomechanics, geochemistry



From S. Thibeau – Orleans 2009 WS - Aquifer modeling, Izaute et Lussagnet (France)

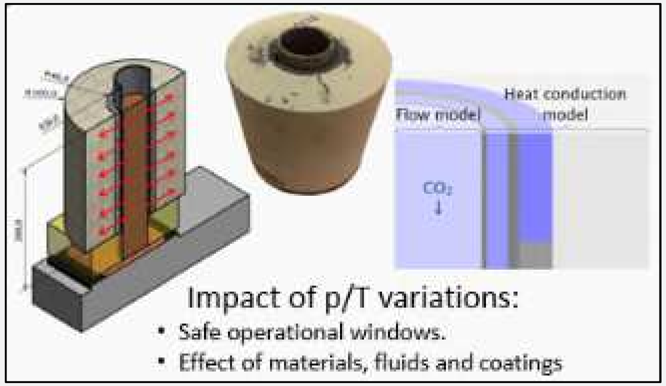
CO2 INJECTION WELLS

Near well bore risks - Modelling CO2 injection in steady/transient mode



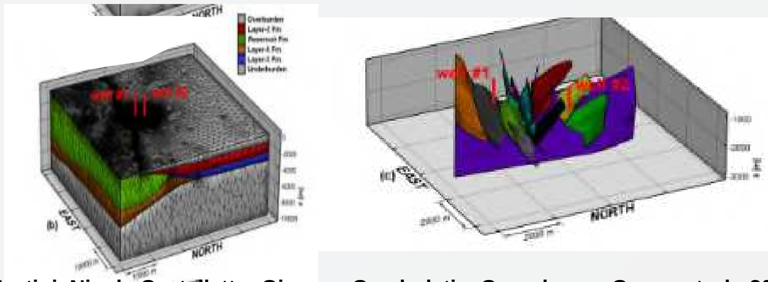
Miri & Hellevang, International Journal of Greenhouse Gas Control 2016

OPTIMIZE WELL CONSTRUCTION & OPERATION



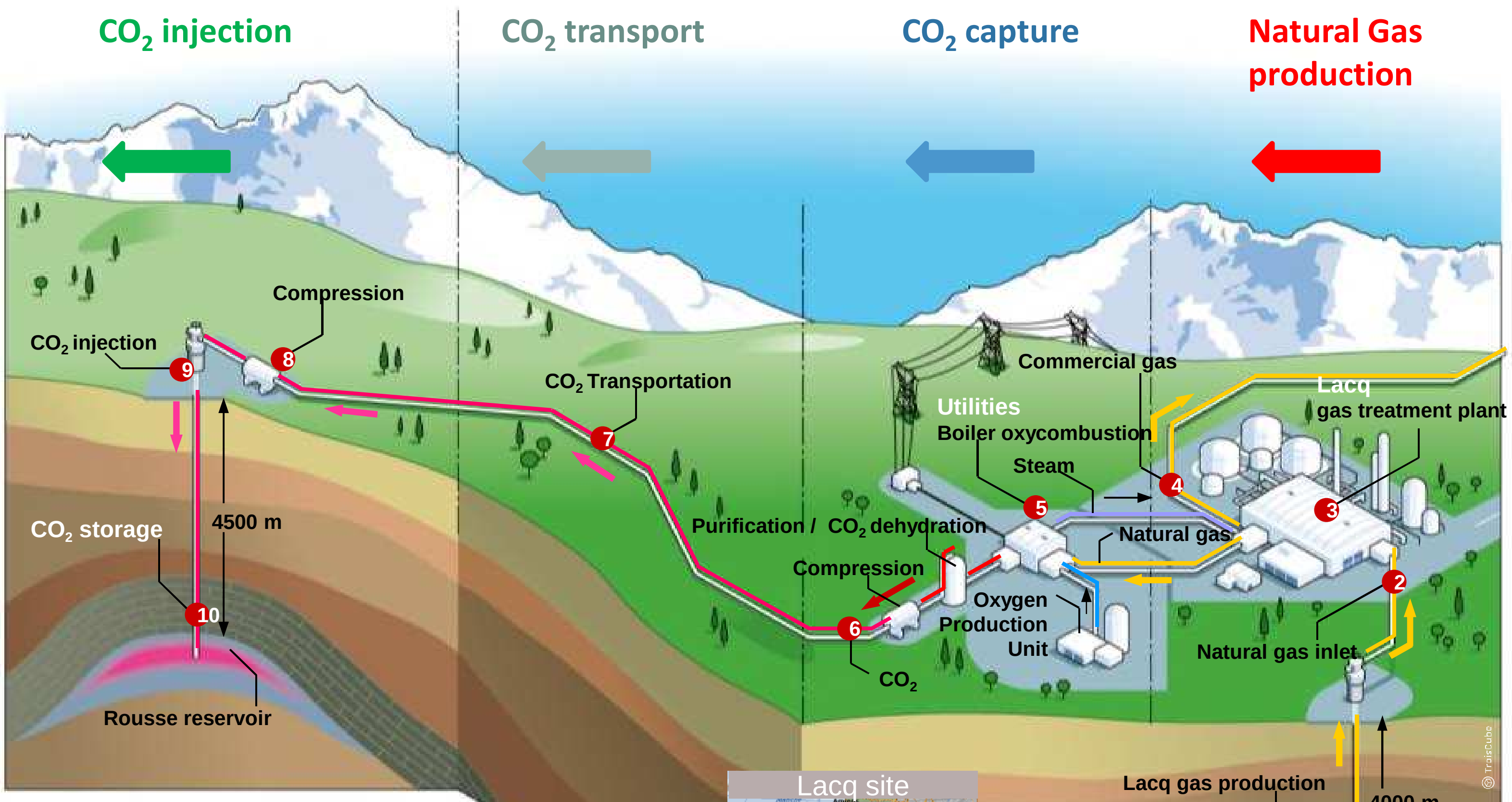
SINTEF – NCCS consortium - 2017

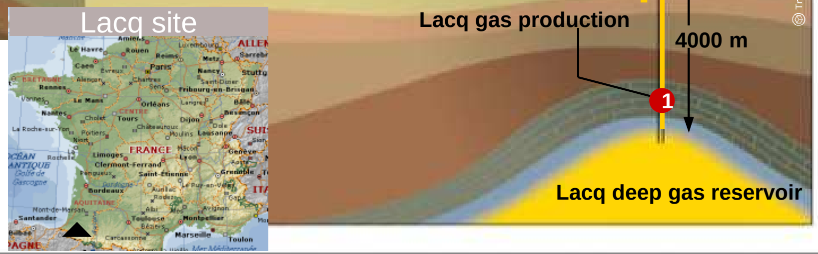
GEOMECANICAL SIMULATIONS & Fault planes modeling
50km X 50 km model: unstructured grid



From Pietro Teatini, Nicola Castelletto, Giuseppe Gambolati – Greenhouse Gas control - 2013

LACQ AND ROUSSE: 1ST EUROPEAN ONSHORE CAPTURE-TRANSPORT-STORAGE





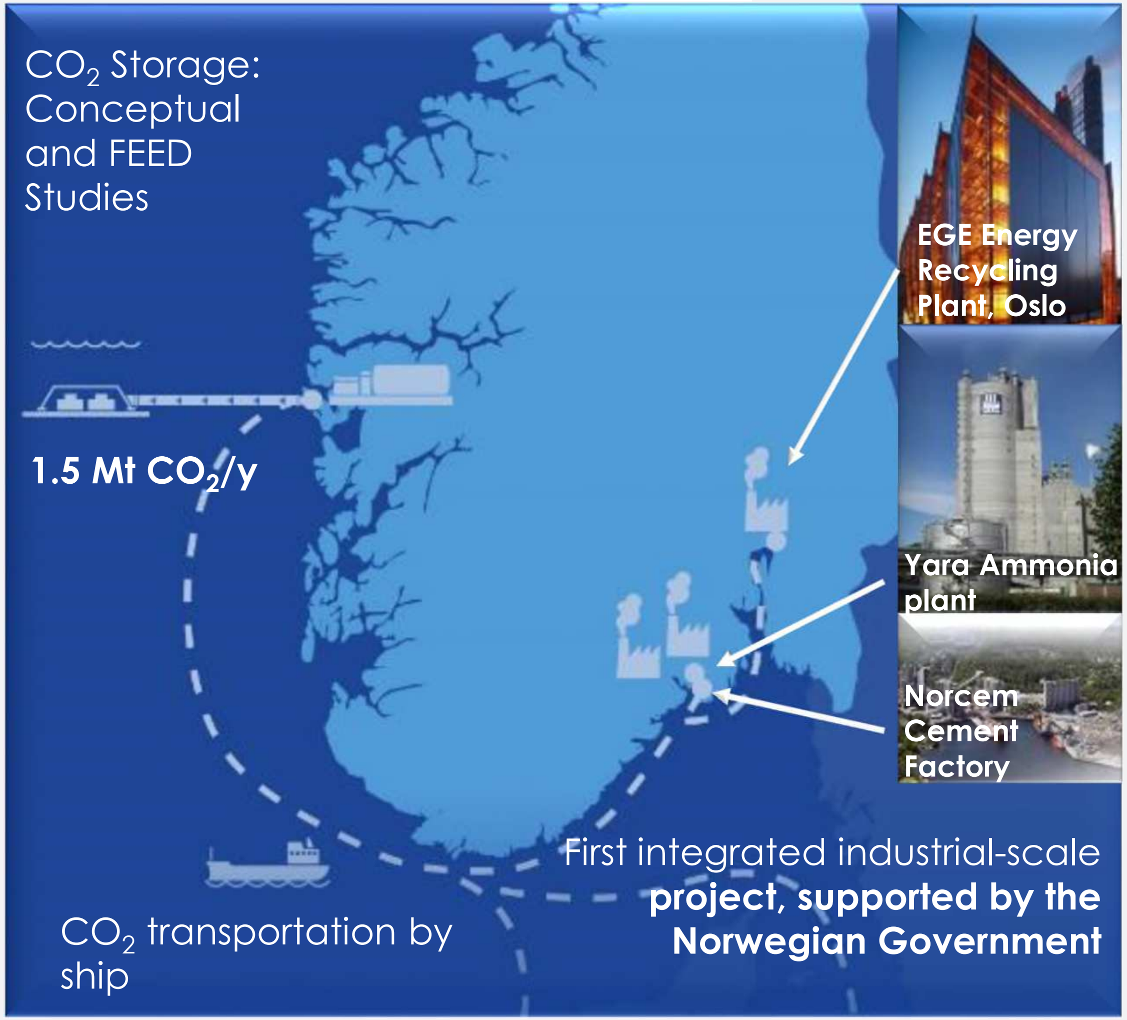
Industrial scale based on gas fired oxycombustion
30MWth
51 ktons stored until march 2013

NORWEGIAN DEMONSTRATION CCS PROJECT

equinor · Shell · TOTAL

to develop viable, reproducible commercial CCS model in view of carrying out other major projects

Start up 2023/24



TOTAL **LEADER IN CCUS TECHNOLOGY** BY 2035

Decrease technologies **C**ost

Improve our **C**arbon footprint

Contrib**U**te to a more favorable development context

To **S**ustain our activities in the future

DECREASE CCUS TECHNOLOGIES COST

DECREASE GLOBAL CARBON FOOTPRINT

INCREASE CCUS SOCIAL ACCEPTABILITY