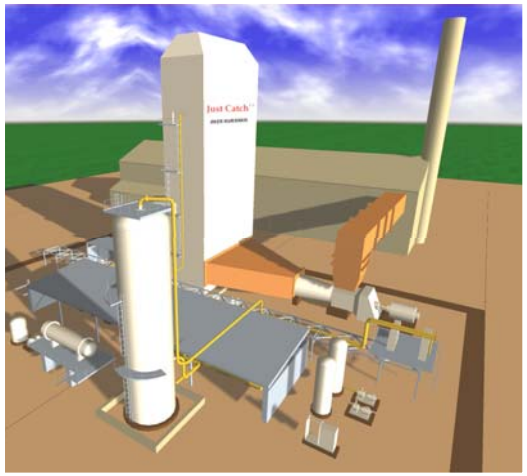
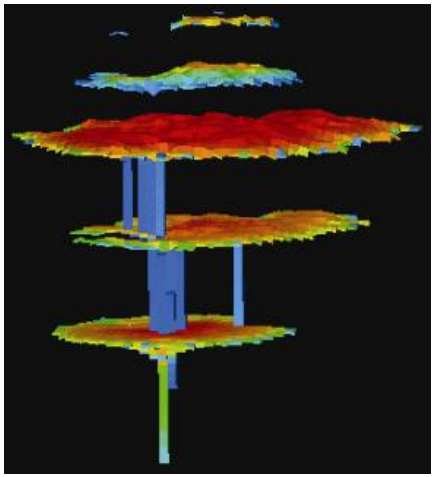
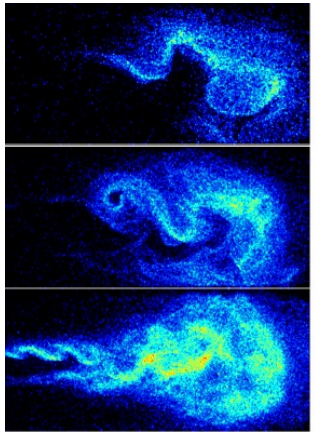
International actions on carbon capture and storage in SINTEF - approach and challenges







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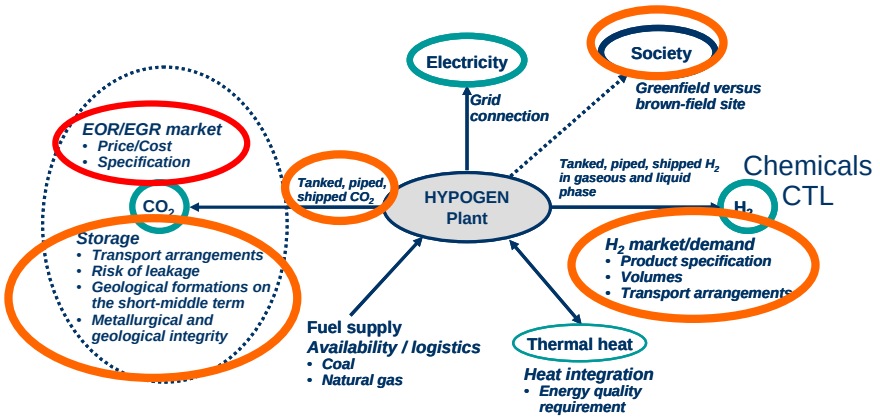
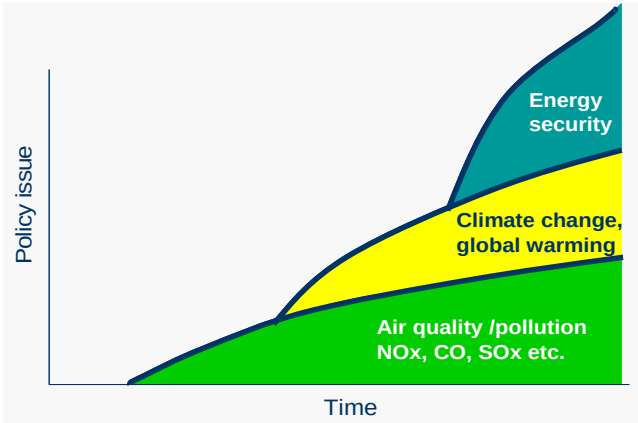
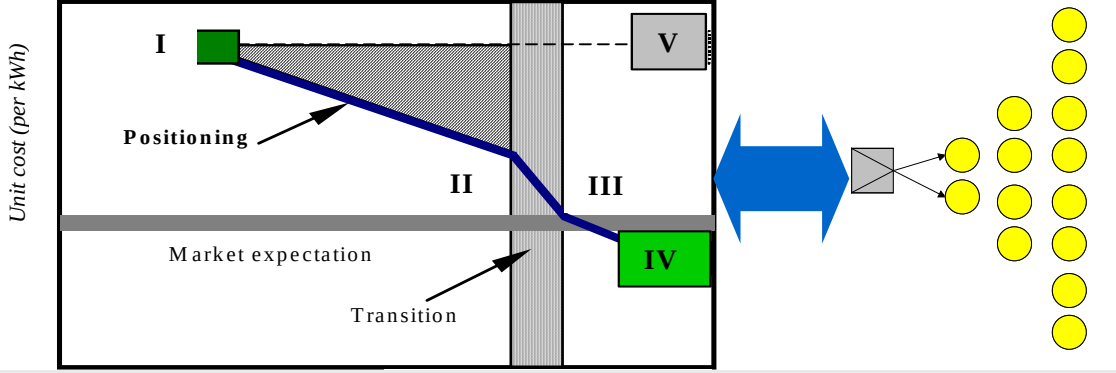
E-mail: Jens.Hetland@SINTEF.no
www.SINTEF.no

Topics:

1. SINTEF/NTNU – in the CCS play
2. The BIG picture
3. The BIC CCS Centre
4. SOLVit Programme
5. ECCSEL – The European CCS Lab Infrastructure





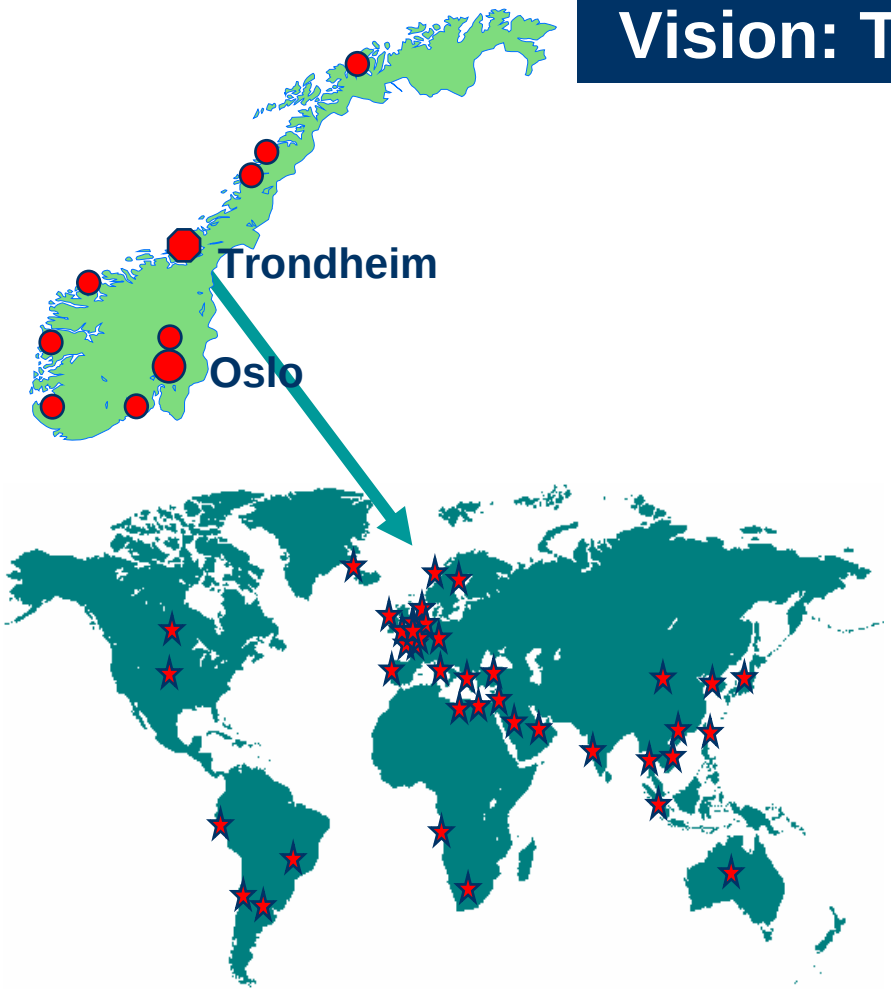


SINTEF/NTNU – in the CCS play

- SINTEF was the first to suggest capture and geological storage of CO_2 as a climate mitigation option (1986)
- Regarded a major provider of R&D with profound expertise along the entire CO_2 chain
- SINTEF's roles and actions pertaining to CCS:
  - References to light-house projects like Sleipner, Snøhvit, Tjeldbergodden, HYPOGEN, ...
  - Coordination of some large European IPs on CCS (FP6/FP7)
  - Responsible for the European CCS Laboratory programme (ECCSEL)
  - R&D performer in the SOLVit programme
  - Coordinator of the BIGCO2 strategic umbrella
  - Operating the BIG CCS Centre (Centre of Excellence)
  - Organiser of leading CCS conferences – GHGT8 (2006) and the biannual TCCS
  - Enjoying an extensive CCS network on the global basis
  - Targeting to strengthen its position within CCS globally

SINTEF – one of the largest independent Research Institutes in Europe

Trondheim, Oslo, Bergen, Stavanger, Tromsø, Raufoss, Ålesund, Mo i Rana, Glomfjord, Porsgrunn, USA, Brasil, Danmark, Chile



Vision: Technology for a Better Society

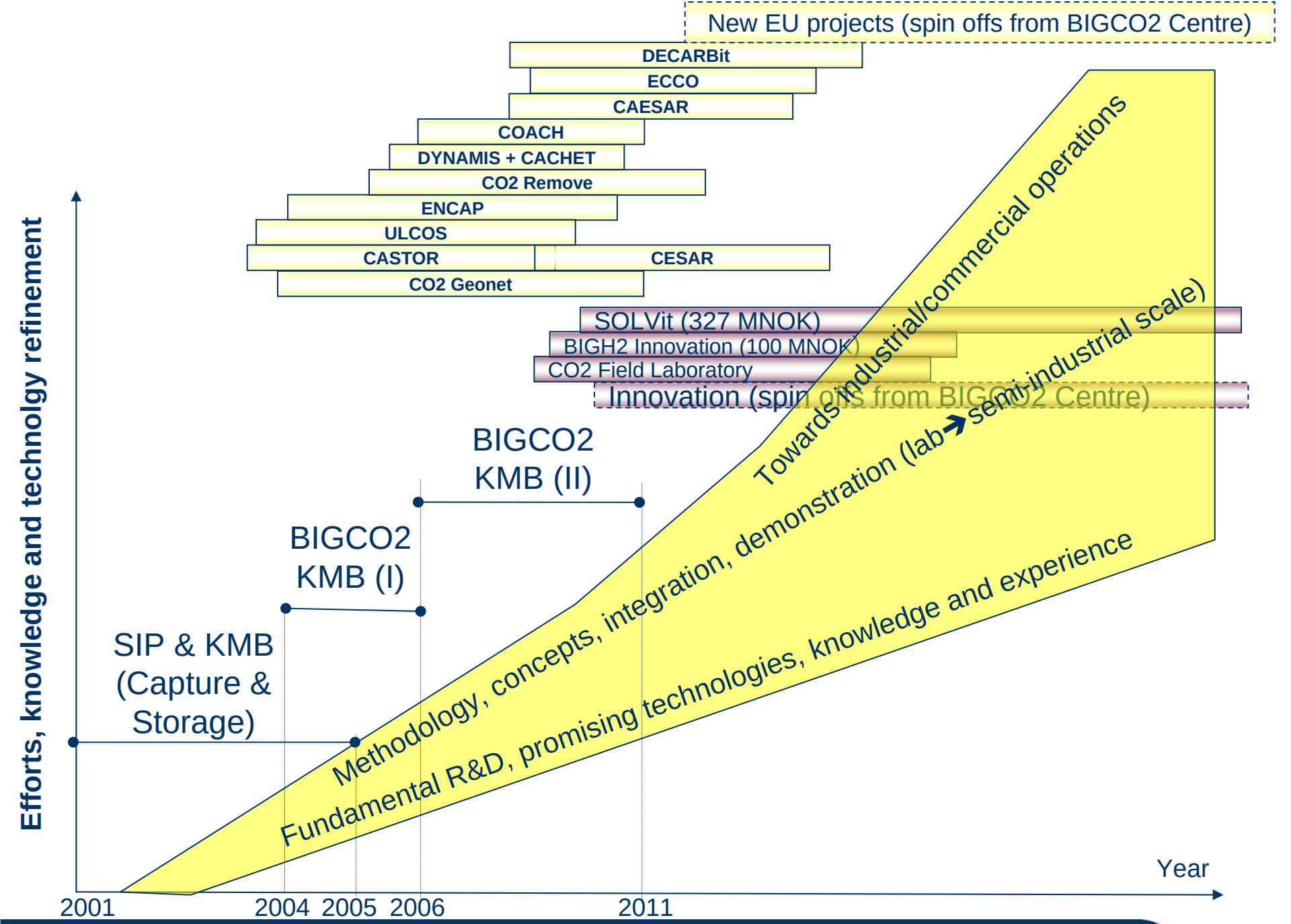
Providing knowledge and services based on scientific research to Norwegian and international clients

Contributing to adding values to customers, creating new businesses and enabling societal sustainability

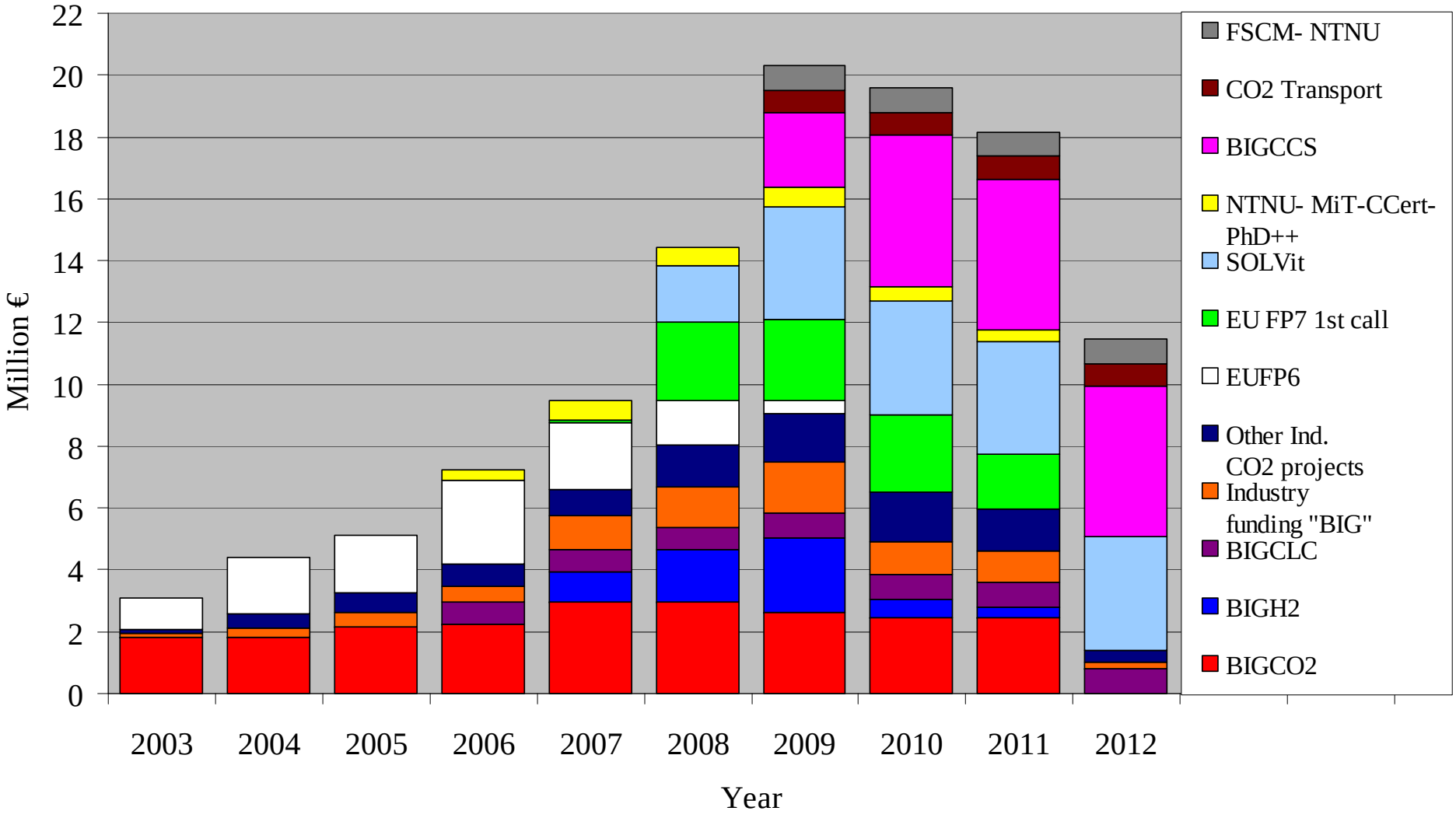
Turnover: 305 M€ (2008)

14 % of the revenues coming from international clients in 53 countries

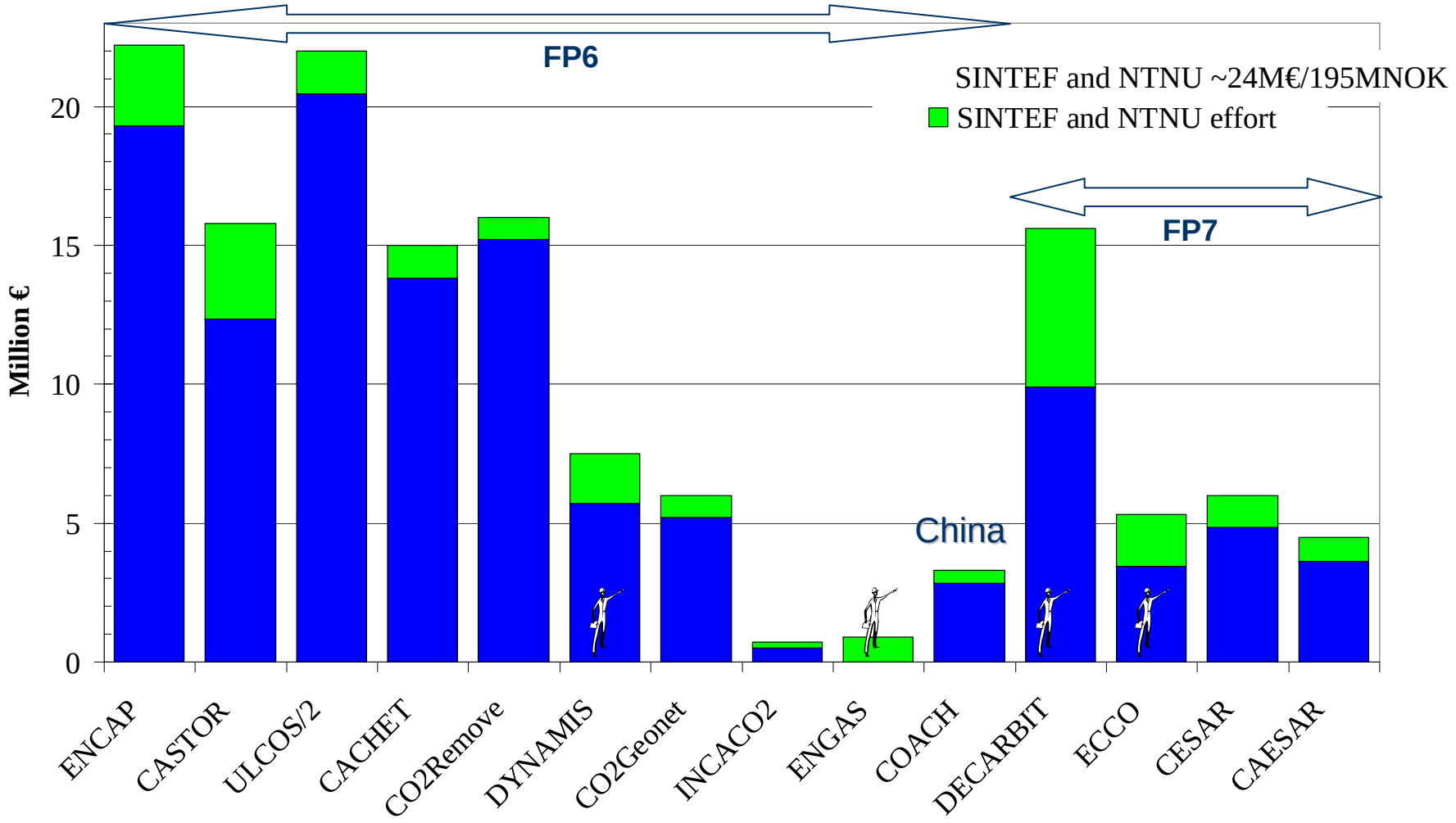
Employing 2145 individual with 64 nationalities
43 % of the researchers having a PhD


New EU projects (spin offs from BIGCO2 Centre)
DECARBit
ECCO
CAESAR
COACH
DYNAMIS + CACHET
CO2 Remove
ENCAP
ULCOS
CASTOR
CESAR
CO2 Geonet
SOLVit (327 MNOK)
BIGH2 Innovation (100 MNOK)
CO2 Field Laboratory
Innovation (spin offs from BIGCO2 Centre)
BIGCO2 KMB (II)
BIGCO2 KMB (I)
SIP & KMB (Capture & Storage)
Towards industrial/commercial operations
Methodology, concepts, integration, demonstration (lab → semi-industrial scale)
Fundamental R&D, promising technologies, knowledge and experience
Efforts, knowledge and technolgy refinement
Year
2001
2004
2005
2006
2011

SINTEF/NTNU CCS Contracts



EU FP6 and FP7 R&D – Our Involvement in CO_2 Capture and Storage



Partners: Vattenfall, RWE, StatoilHydro, BP, Rohoel, Siemens, Alstom, Lurgi. Air liquide, Linde, Progressive Energy, Mitsui-Babcock, DLR, DONG Energy, Elsam, PPC, E.ON, SNSK, ENEL, ENDESA, E.ON, Schlumberger, IFP, TNO, RF, NIVA, OGS, ISFTA, Fraunhofer, IEA-GHG, GEUS, ARCELOR, Corus, BGS, BGR, BRGM, ECOFYS, JRC, Societe Generale, Universities of Twente-Ulster-Chalmers-Stuttgart-Delft-Tsinghua-Zhejiang, KTH, TU- Sofia, KTH, Corning, EDP, ECN, TIPS, TPRI, IET-CAS…

The many steps

The BIG picture

BIGCO2, BIGCLC and BIGH2 – In brief

- Co-ordinator SINTEF Energy Research
- R&D providers
  - SINTEF, NTNU
  - CICERO
  - University of Oslo
  - Deutsche Luft und Raumfahrt – DLR (Germany)
  - Technische Universität Munchen – TUM (Germany)
  - Co-operation with Sandia Nat. Labs Livermore (USA)

- Funding (including storage and EOR):
  - Approx 65/35 % funded by Research Council of Norway/Industry
  - 2001- 2006: Total of 13 M€
  - 2007 – 2011: 12M€ (BIGCO2)
  - 2007 – 2011: 13M€ (BIGH2)
  - 2006 – 2012: 5M€ (BIGCLC)
  - 2009 – 2016: 47M€ (BIGCCS)

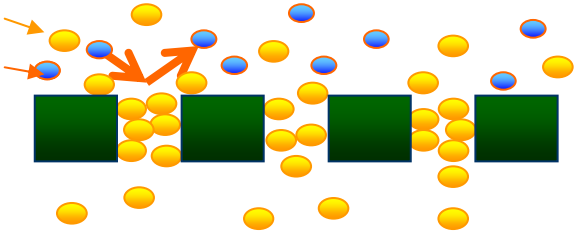
90 M€

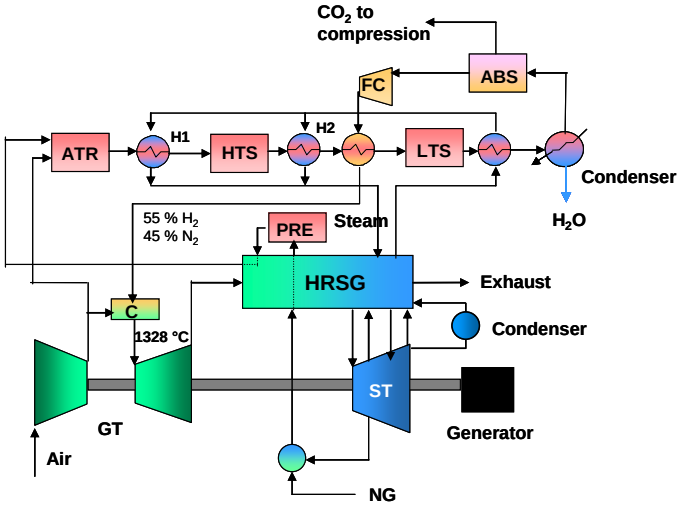
- Industrial consortium
  - Aker Clean Carbon (Norway)
  - GE Global Research (Munich - Germany)
  - Statkraft (Norway)
  - StatoilHydro (Norway)
  - ALSTOM (Zürich, Switzerland)
  - SHELL
  - ConocoPhillips

$BIGCO_2$ National CCS R&D Platform

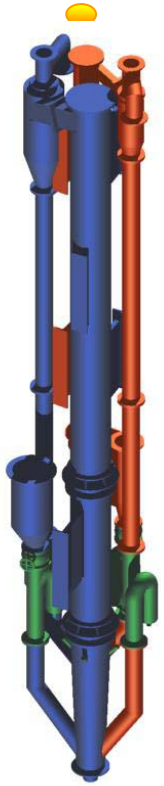
Absorption and desorption studies

Membranes

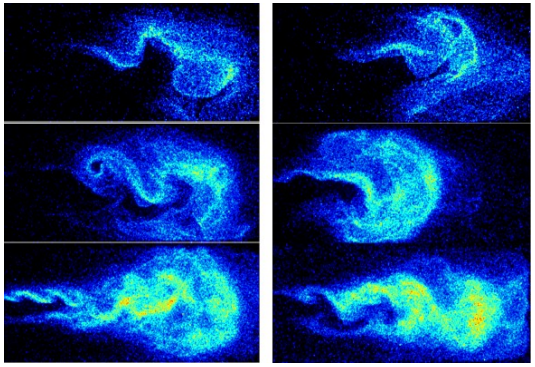




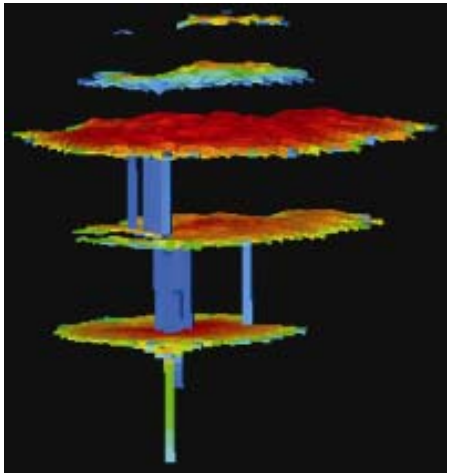
Power cycle studies



Chemical Looping Combustion



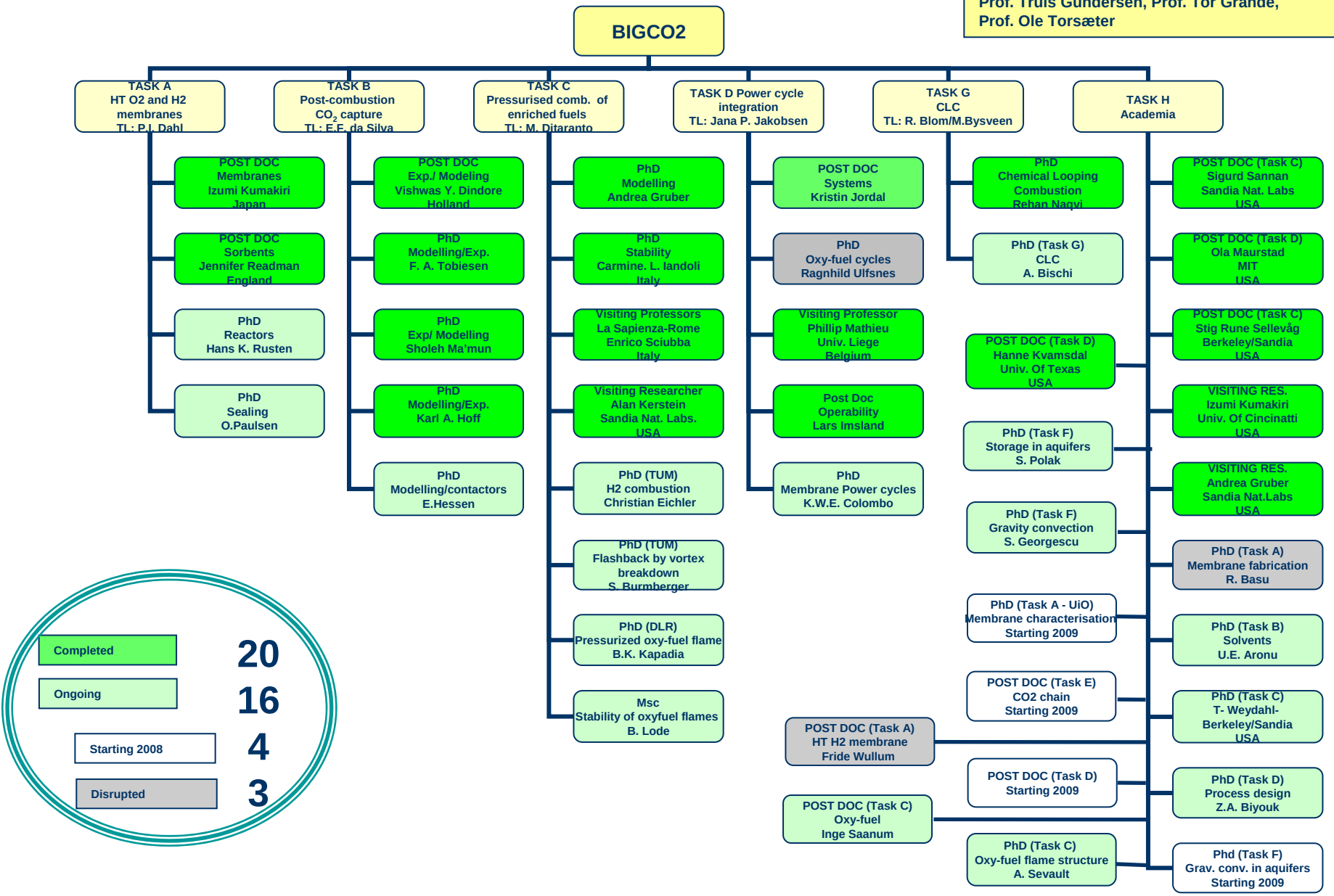
H_2 and De-N_2 combustion



Geological storage

BIGCCS: Educational Program

Scientific advisors for PhD's and Post Doc's:
Prof. Hallvard Svendsen, Prof. Hugo Jakobsen, Prof. Inge Gran, Prof. Olav Bolland, Prof. Bjarne Foss, Prof. Truls Gundersen, Prof. Tor Grande, Prof. Ole Torsæter



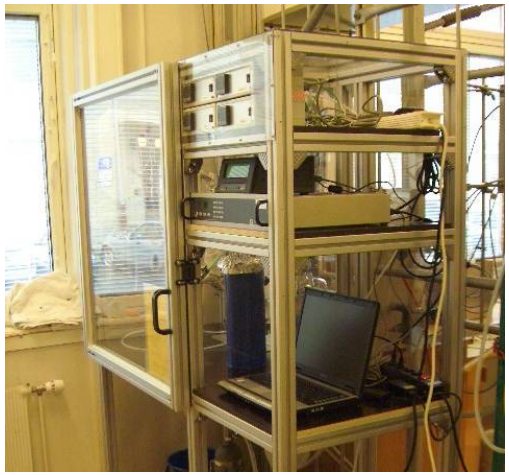
Completed	20
Ongoing	16
Starting 2008	4
Disrupted	3

BIGCCS: Post Combustion CO_2 Capture

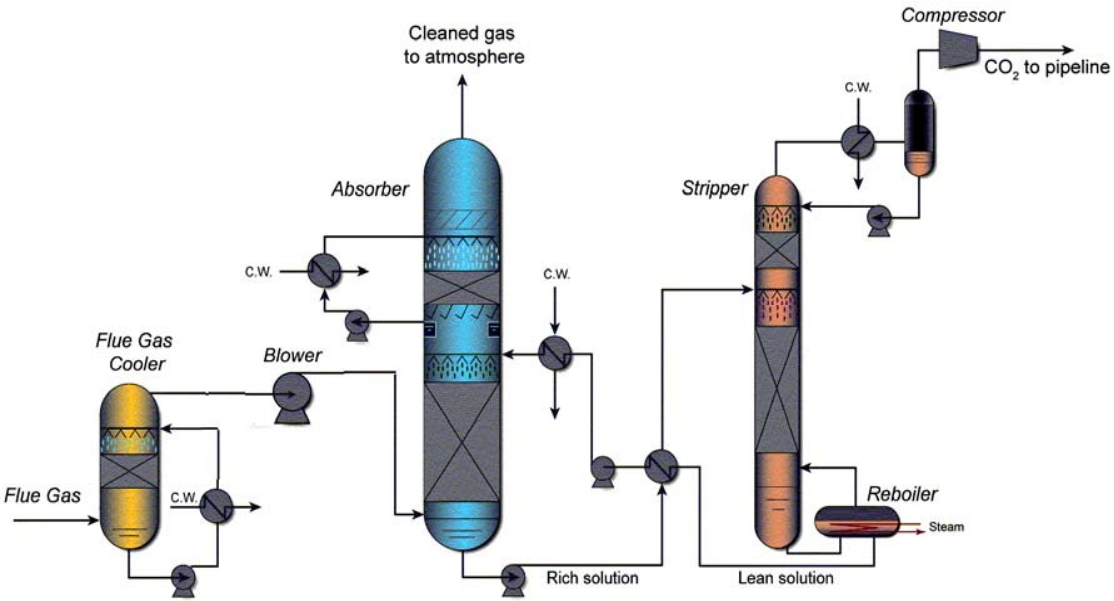
Objectives

- Reduced heating demand for regeneration of solvent targeting **2 GJ/t CO_2** and 5**0% reduction equipment cost**.
- New methodology for screening and early testing of concepts to assess potentiality

Environmental impacts



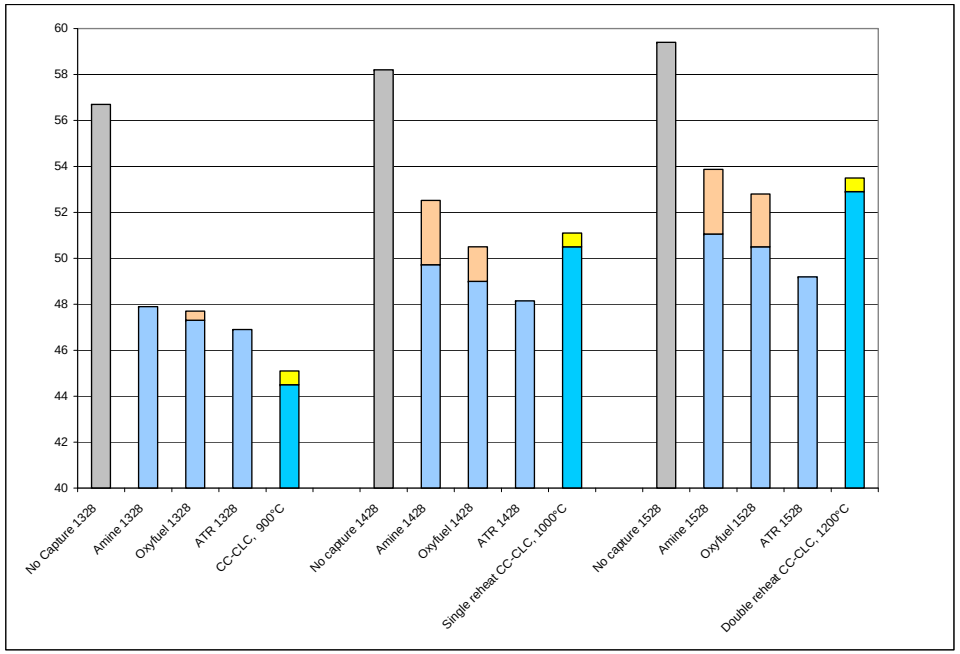
Solvent development



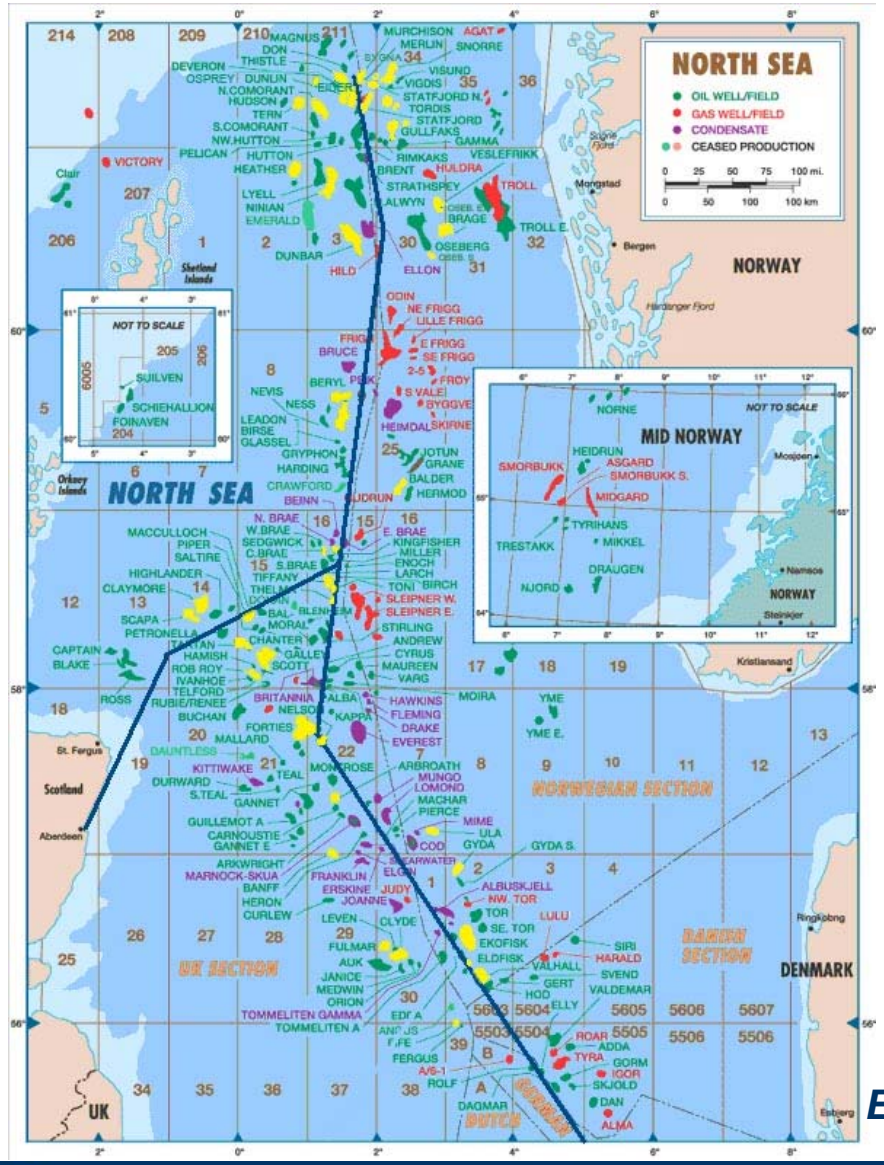
Modelling and simulation

BIGCCS: Power Cycles Integration and Analysis

- Cold flow BIGCLC:
  - Model development
  - Set-up of cold flow CLC rig, functional testing and comparative studies against model work
- Potentiality studies
  - Jordal K., 2008, *Benchmarking of power cycles with CO_2 capture – The impact of the selected framework*, International Journal of Greenhouse Gas Control 2, (2008), pp468-477.
  - PhD thesis (Konrad Eichhorn Colombo): *Detailed transient membrane-based GT power plant models*
- Stabilization of pressure oscillations in oxy-fuel combustion using pre-flame CO_2-injection.



BIGCCS: Enhanced oil and gas recovery with CO_2 and safe underground storage of CO_2



- Envisaging geological storage of CO_2 as a safe, economic and option for large-scale disposal
- Gaining complementary knowledge required for the fundamental understanding relating to:
  - Reservoir geology and chemistry
  - Carbon cycle
  - Emission and storage scenarios
  - Monitoring and verification of safe storage
  - Long-term climate modelling
  - Economic aspects
  - Institutional aspects
  - Political and legal aspects.

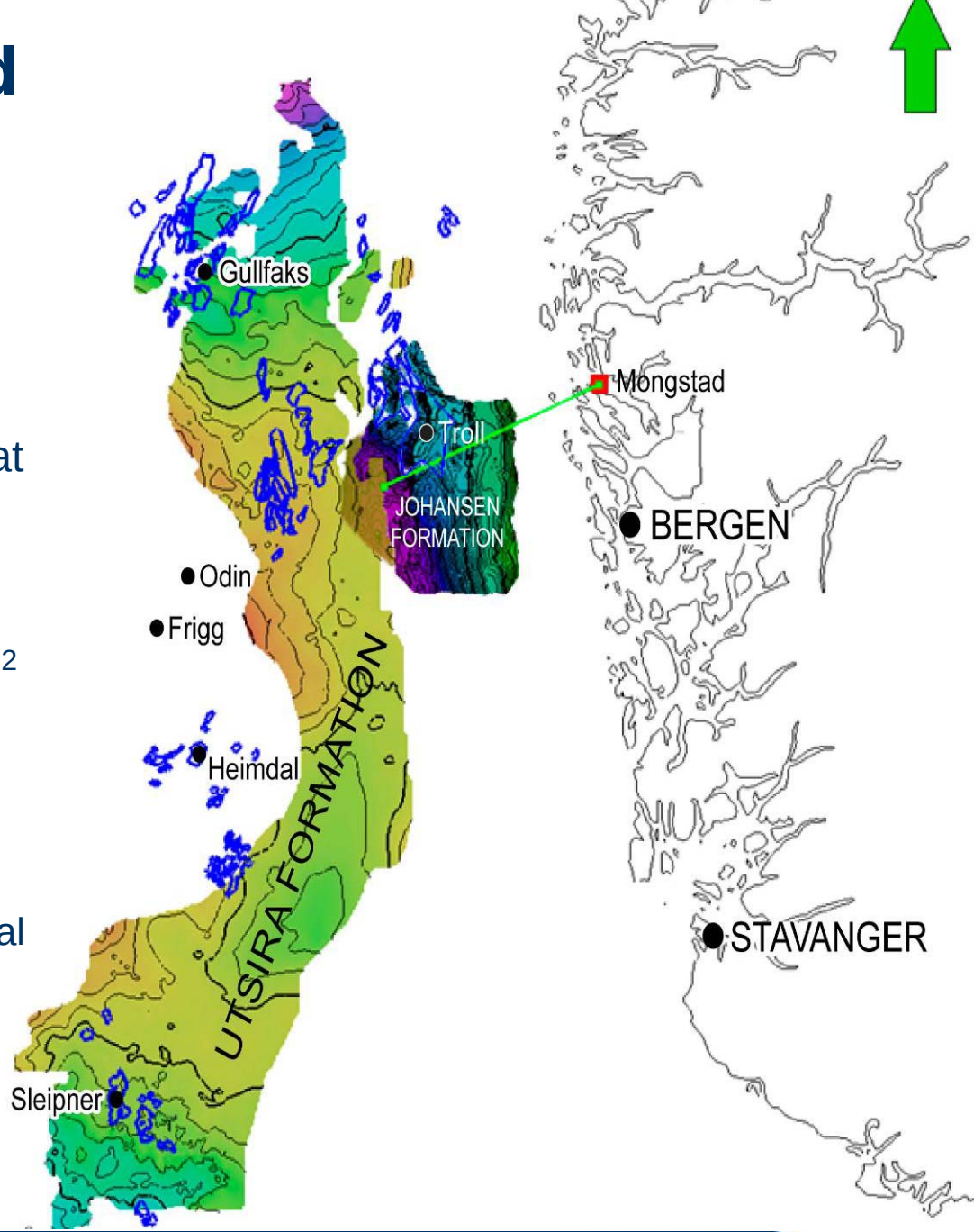
EOR CO_2 value chain

BIGCCS: Utsira and Johansen aquifers

Utsira: 25 000 km^2 sand formation, typical porosity 35%, high permeability (1000 to 2000 mD)

Johansen: very large sand formation at 2200 – 2600 m depth (underneath the Troll gas field)

- A scenario with injection of 40 Gt CO_2 was deemed feasible via detailed reservoir simulations
  - The thickness is 90 m in average varying between 0 and 350 m.
  - The sand is divided by thin shales reducing the effective vertical permeability to 10% of the horizontal permeability
  - Typical top depth is 800 m

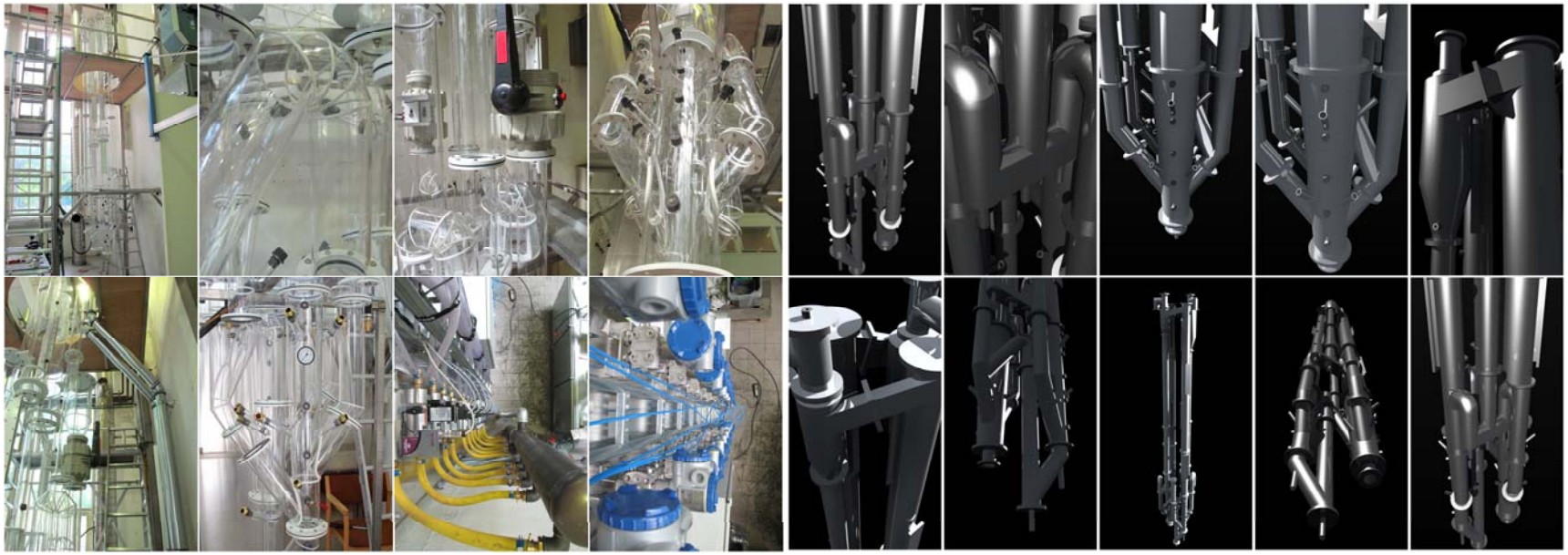


BIGCLC: Chemical Looping Combustion

Phase I: 2007-2009, Phase II: 2009-2013 (5 M€)

Designing, building and testing a new pressurised CLC reactor (@150 kW thermal conversion). Simulation and controls. Working materials characterisation.

- Taking CLC to a **next stage of maturity level** in order to become competitive in large-scale power generation with CO_2 capture.
- Targeting 15€/ton, >90% capture rate, efficiency penalty < 6 %

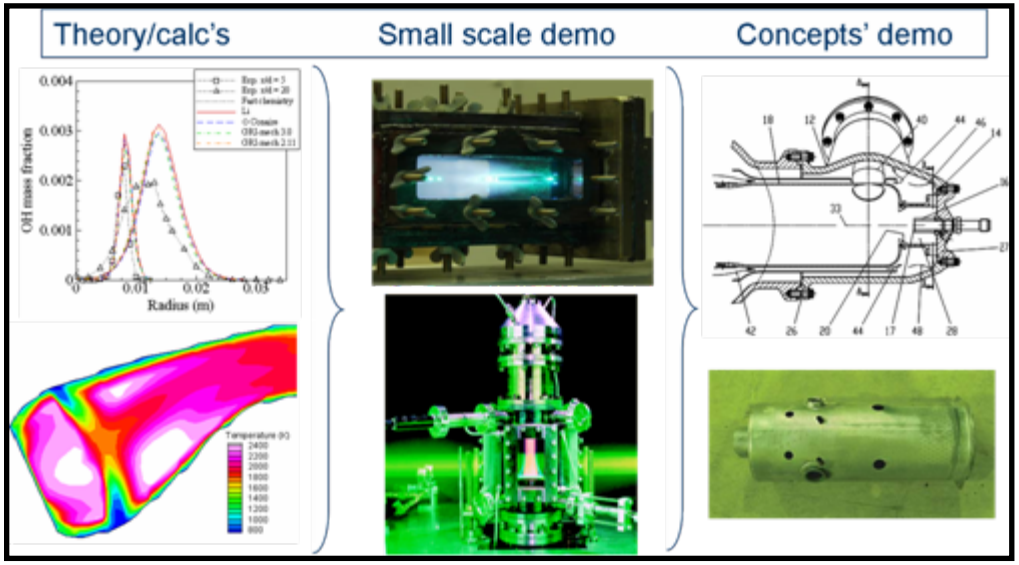


BIGH2 "Innovation" project

Budget of ~13 M€. Starting 2008

Developing a H_2-fuelled gas turbine combustor for LPM Operation Mode

- Targeting pre-combustion capture
- Key for coal based CCS systems
- Eliminating/reducing the dilution requirements
- Improving efficiency
- Approach:
  - Combustion & fluid-dynamics theory, advanced modelling and laser diagnostics
  - Concept ➔ demo



Project's consortium established in early 2008: SINTEF (Project owner and R&D), DLR (R&D partner), ALSTOM Power (Manufacturer). 3 phases. Budget of ~12 M€

BIGCCS Centre

International CCS Research Centre

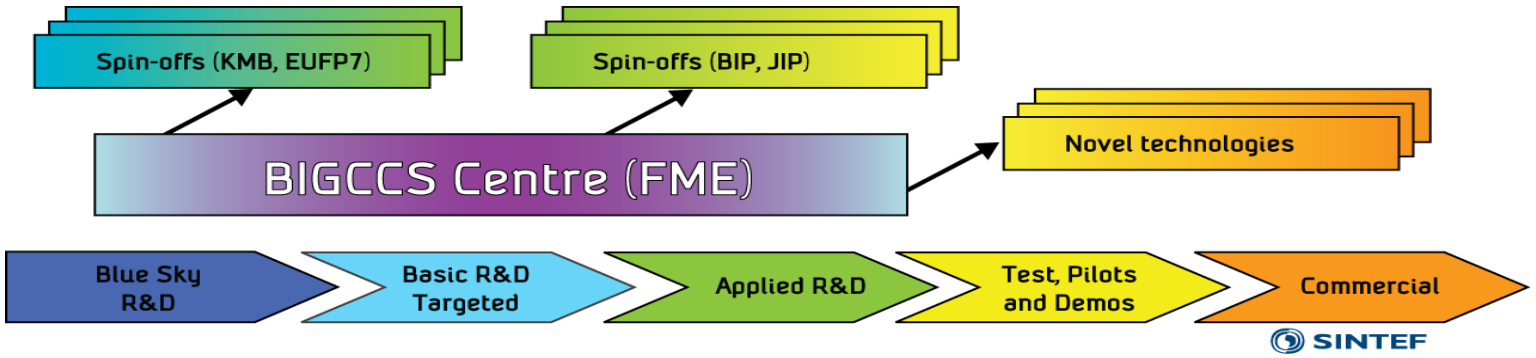
Budget 47 M€ over 8 years

2009-2016

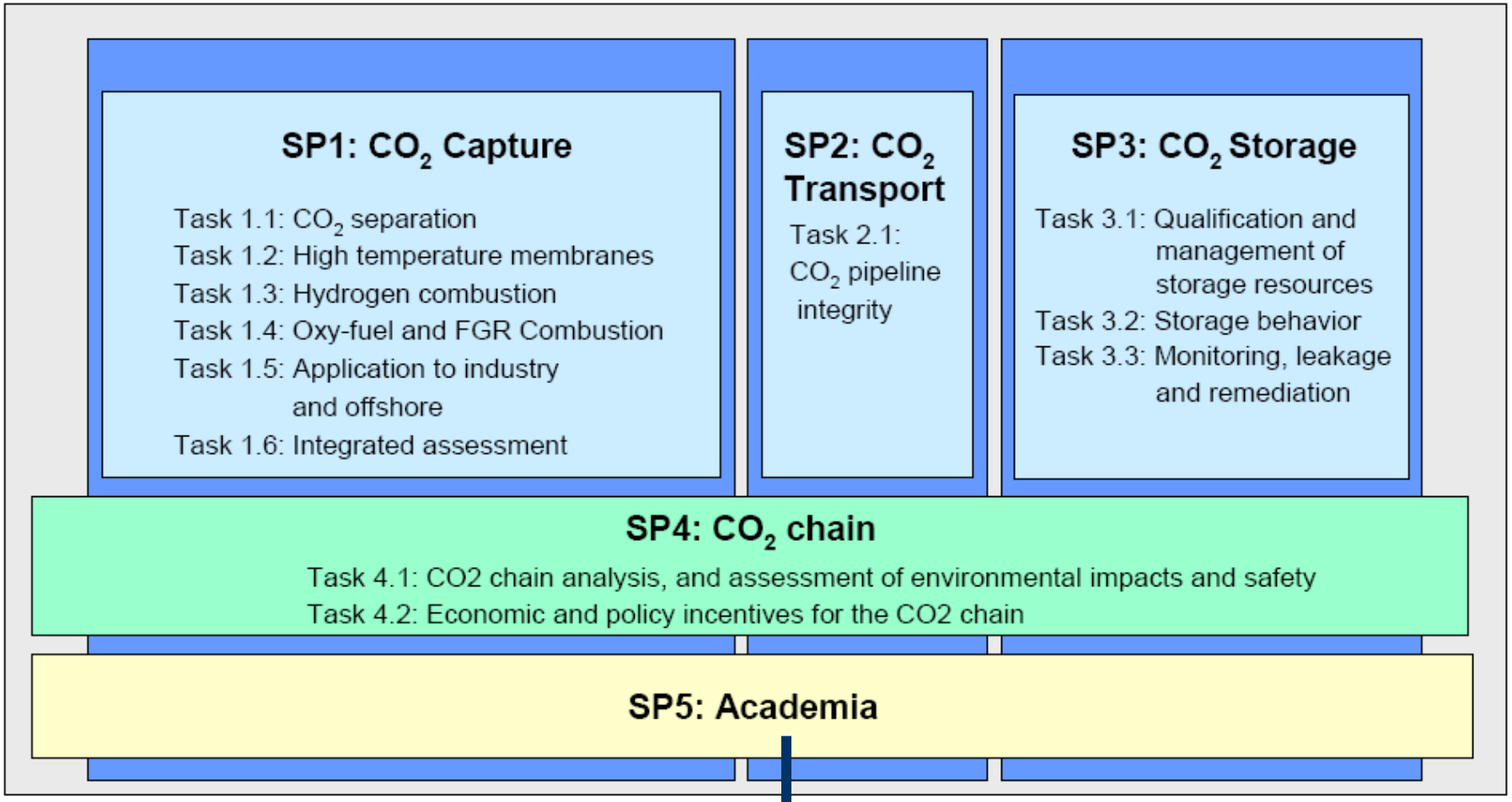
26 partners, 8 nations

Objective:

1. **Contributing to the fulfilment of targets set by Norwegian parliamentarians in the Climate Accord (agreed upon in 2008)**
2. **Enabling sustainable power generation from fossil fuels based on cost-effective CO_2 capture, safe transport and geological storage of CO_2**



BIGCCS Centre structure



- 18 PhD theses
- 8 Post doctors

BIGCCS Centre consortium

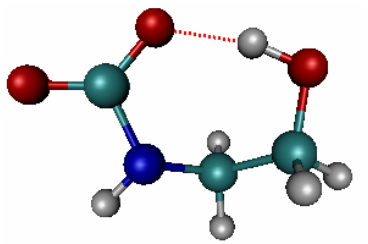
- Storage ➔ Addressing the North Sea, Norwegian Sea, Barents Sea
- CO_2 transport ➔ flow phenomena and material challenges
- Capture ➔emerging processes, membranes and sorbents. Combustion of hydrogen in gas turbines and of fossil fuels with pure oxygen

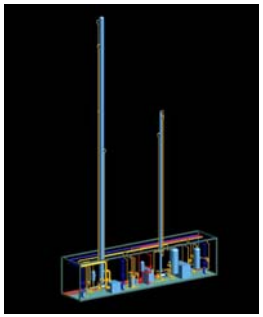
SOLVit Programme

Budget 40 M€, 8 years (starting 2009)

Qualifying commercial absorption solvents (short term) including viable post-combustion systems based on absorption chemistry and adapted process design

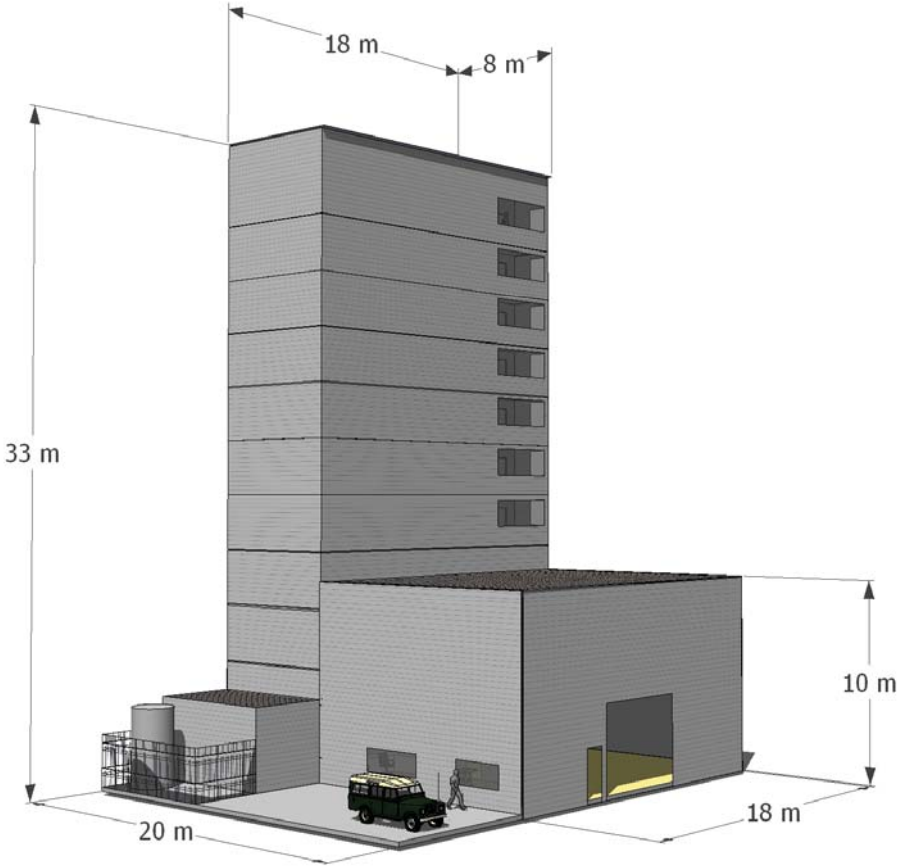
- Taking stock of world-class experience in solvents and absorption technology
  - Fundamental chemistry ➔ bench-scale testing
  - Model development ➔ pilot scale testing
  - Real flue gas/MTU from various sources ➔ full-height rig testing
  - Qualification for large scale demo (100 000t CO_2/yr) ➔ testing at a most appropriate level





MTU: Mobile Test Unit (ACC)

SOLVit: Test facility in Trondheim



- Industrial height absorber (25 m) for 90% capture rate
  - Testing entire loading regime
  - Direct verification of energy requirement
- Long-term tests of solvents
  - Degradability
  - Reclaiming
  - Operability
- Small diameter, 20 cm
  - Wall effects not critical to purpose of tests
  - Small amounts of solvent needed
- Flexibility towards new solvent systems

AKER CLEANCARBON · SINTEF · NTNU · SCOTTISHPOWER · GASSNOVA · Statkraft · e·on

ECCSEL
European CCS Lab Infrastructure

NTNU/SINTEF are jointly responsible for developing the pan-European CCS network of laboratories to one unit

Budget: 81 M€ (whereof 23 M€ Norwegian financing)

Operating from 2011

Officially put on the Roadmap

Pan-European research infrastructure for CCS

(Refer http://www.ntnu.no/eccsel/index.php)

The ECCSEL

Norway

- **NTNU/SINTEF**
- Universitetssenteret på Svalbard (UNIS)
- Universitetet i Bergen (UiB)
- Institutt for Energiteknikk (IFE)
- International Research Institute of Stavanger (IRIS)
- StatoilHydro
- Aker Kværner

Europe

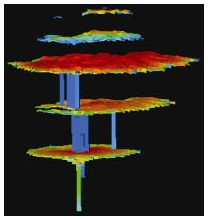
- DLR Stuttgart - Institute of Combustion Technology - Tyskland
- University of Stuttgart - Tyskland
- Technical University of München - Tyskland
- Eotvos Lerand Geophysical Institute of Hungary (ELGI) - Ungarn
- Eidgenossische Technische Hochschule Zürich (ETH) - Sveits
- Polish Academy of Sciences - Polen
- Danmark og Grønlands Geologiske Undersøkelser (GEUS) - Danmark
- University of Zagreb (RGN) - Kroatia
- Netherlands Organisation for Applied Scientific Research (TNO) - Nederland
- Technical University of Delft (TUD) - Nederland
- IFP - Frankrike

World

- USA (MIT)
- Kina (Tsinghua University & Shanghai Jiao Tong University)
- Japan (RITE & KIFEE)

Summarising





SINTEF:
... first to suggest capture and geological storage of CO_2 as a climate mitigation option
... first CCS project in 1986
... instrumental in materialising CCS (e.g. Sleipner, 1996)
... major player in the European CCS R&D community
... profoundly addressing all aspects of the CO_2 chain

International Actions on CCS in SINTEF:

- SINTEF's annual R&D budget dedicated to CCS exceeds 20 M€
- SINTEF is the largest R&D provider on CCS within EU-FP6/FP7, and
  - is the coordinator of some larger European CCS projects
  - operates the World's largest CCS R&D project (BIGCO2)
  - is the organiser of a biannual international CCS conference (TCCS)
- The BIGCCS project and the Pan-European CCS Lab (ECCSEL) enable SINTEF/NTNU and partners to offer facilities and environments for theoretical and experimental research under the hallmark:

International Centre of Excellence on CCS

Acknowledgements

- The European Commission for its support of the following projects:
  - DYNAMIS - “Towards Hydrogen and Electricity Production with Carbon Dioxide Capture and Storage”, under Contract # 019672 (2006-2009).
  - COACH - Cooperation Action within CCS China-EU, under EC/FP6 Contract #038966
  - EMINENT – Early Market Introduction of New Energy Technologies, Contract #Tren/05/FP6EN/S07.56209/019886
  - DECARBit – Decarbonise it, under grant agreement # 211971
  - ECCO, ENCAP, ECCSEL etc.
- The Research Council of Norway for supporting:
  - the strategic BIGCO2 research umbrella and
  - the subordinate projects pertaining to CCS
- Gassnova for supporting the BIGCO2 research umbrella