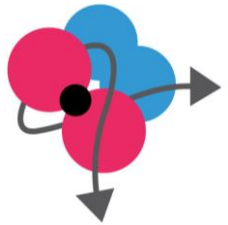


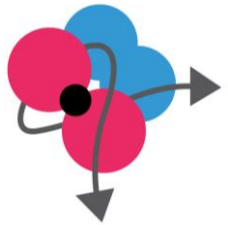
Enabling a Low-Carbon Economy via Hydrogen and CCS

Svend Tollak Munkejord, SINTEF Energy Research, project coordinator

http://www.elegancy.no/

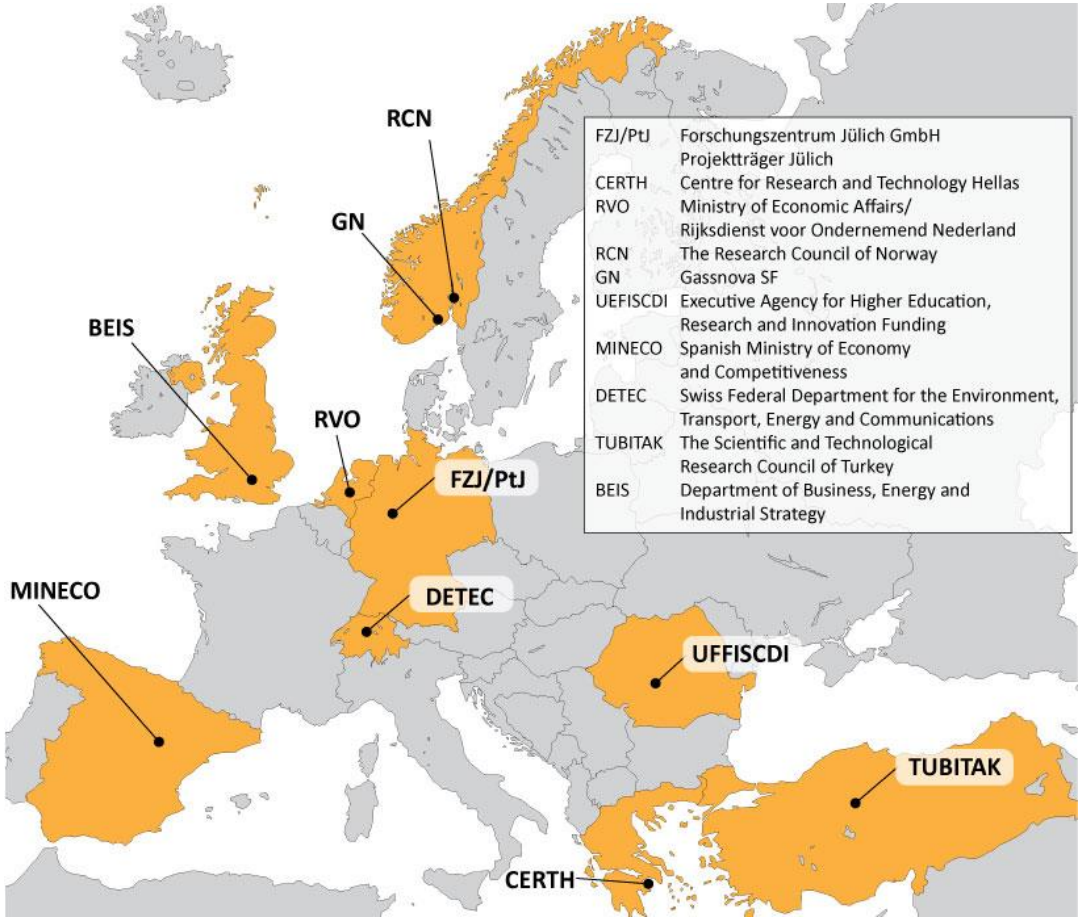
2018-05-08

Outline of presentation



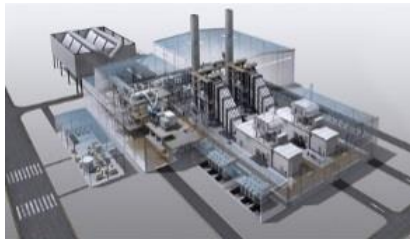
- ELEGANCY
  - Aim
  - Approach
  - Some details
  - Status

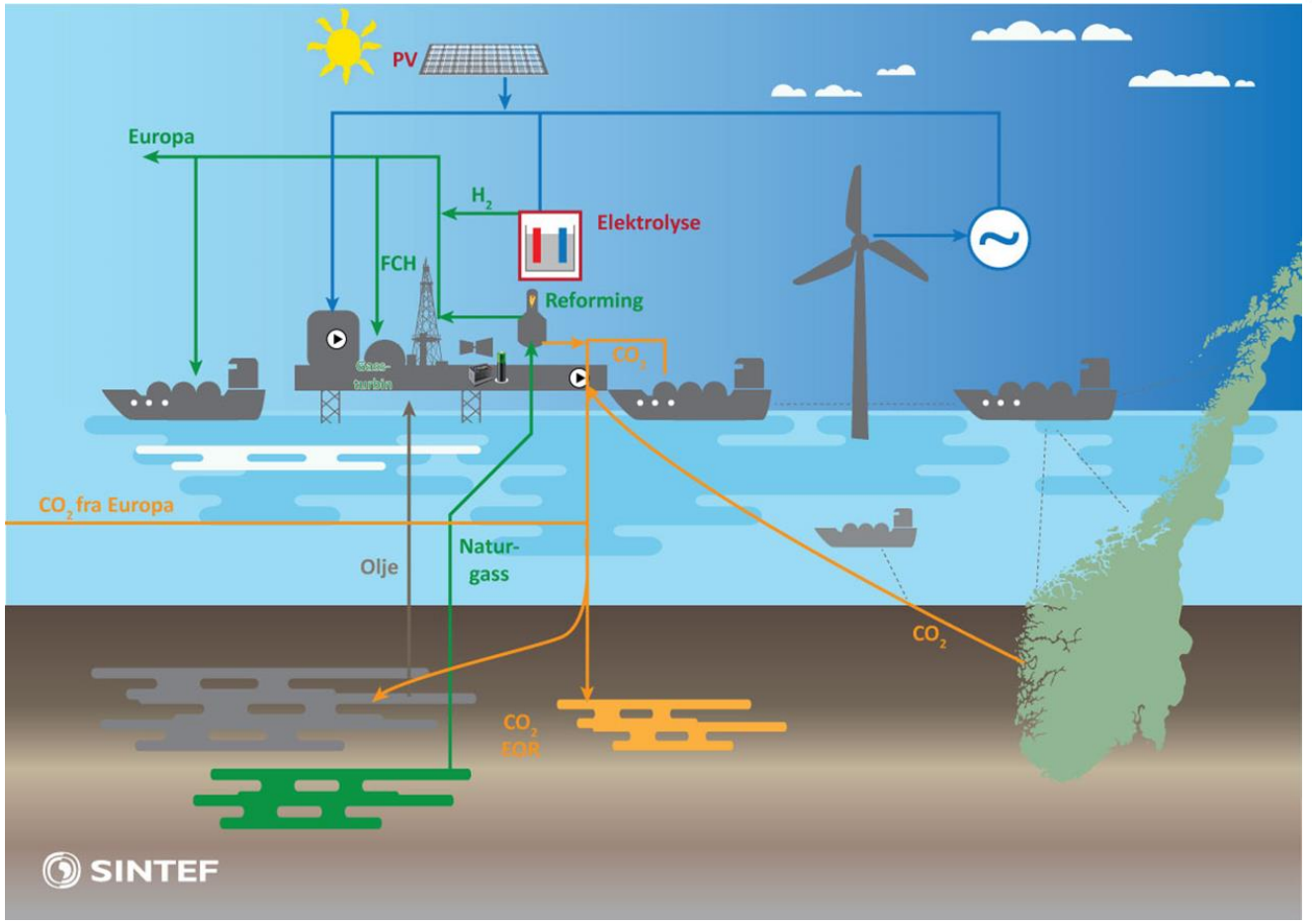
ERA-NET ACT



- Accelerating CCS Technologies
- H2020
- Ten partners from nine countries
- Led by The Research Council of Norway
- First call budget: 41 MEUR

ELEGANCY – context





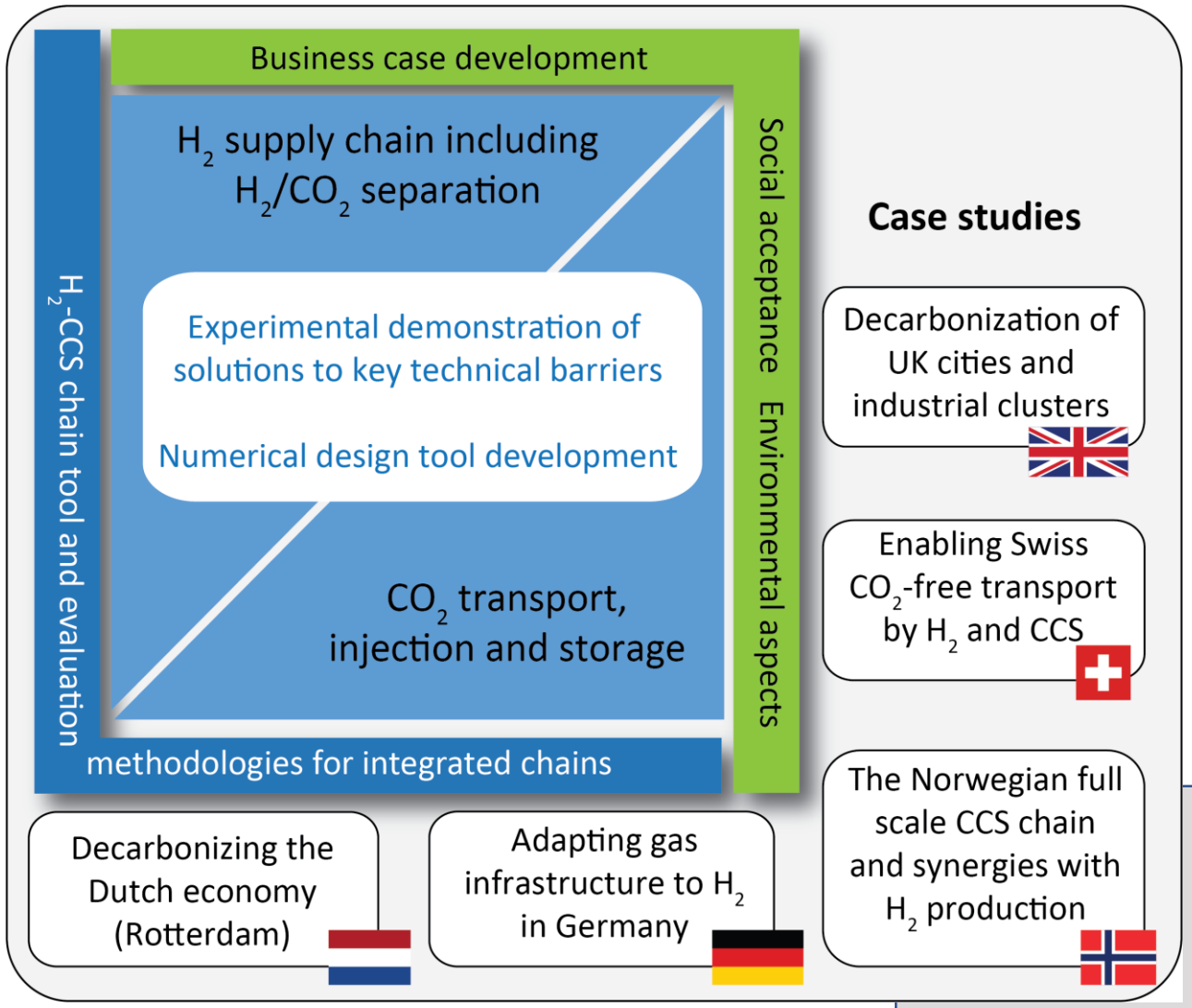
- The low-carbon economy needs H_2
- The low carbon economy needs CCS
- Combining hydrogen with CCS offers an exciting opportunity for synergies and value creation
- ELEGANCY aims at contributing to fast-track the decarbonization of the European energy system

ELEGANCY – objectives

Fast-track the decarbonization of Europe's energy system by exploiting the synergies between two key low-carbon technologies: CCS and H_2. To this end, **ELEGANCY will:**

- Develop and demonstrate effective CCS technologies with high industrial relevance
- Identify and promote business opportunities for industrial CCS enabled by H_2 as a key energy carrier by performing 5 national case studies
- Validate key elements of the CCS chain by frontier pilot- and laboratory-scale experiments using inter alia ECCSEL and EPOS research infrastructure
- Optimize combined systems for H_2 production and H_2-CO_2 separation
- De-risk storage of CO_2 from H_2 production by providing experimental data and validated models
- Develop simulators enabling safe, cost-efficient design and operation of key elements of the CCS chain
- Provide an open source techno-economic design and operation simulation tool for the full CCS chain, including H_2 as energy carrier
- Assess societal support of key elements of CCS

ELEGANCY – key information



British Geological Survey
Expert | Impartial | Innovative
Sustainable Decisions
Imperial College London
INEOS
Scottish Enterprise

ETH zürich
CLIMEWORKS
firstclimate
PAUL SCHERRER INSTITUT PSI

GERG
the european gas research group
INNOVATION FOR EUROPE'S ENERGY FUTURE

Swerea MEFOS

SINTEF
GASSCO
TOTAL
AkerSolutions
UiO : University of Oslo
equinor

ECN
TNO innovation for life

RUHR UNIVERSITÄT BOCHUM RUB
uni per
Open Grid Europe
The Gas Wheel

- Duration: 2017-08-31 to 2020-08-31.
- Budget: 15 599 kEUR

ELEGANCY – work packages

Case studies incl. social acceptance, environmental aspects and CCS-H_2 market considerations: UK (large-scale decarbonization), Netherlands (Rotterdam decarbonization), Norway (full scale CCS chain and H_2 production), Switzerland (decarbonization of transport sector), Germany (adapting gas infrastructure and processes to H_2) **WP5**

H_2-CCS chain tool and evaluation methodologies for integrated chains: (ICL, SINTEF, PSI, RUB, TNO) **WP4**

Business case development: (UiO,FirstClimate,SDL) **WP3**

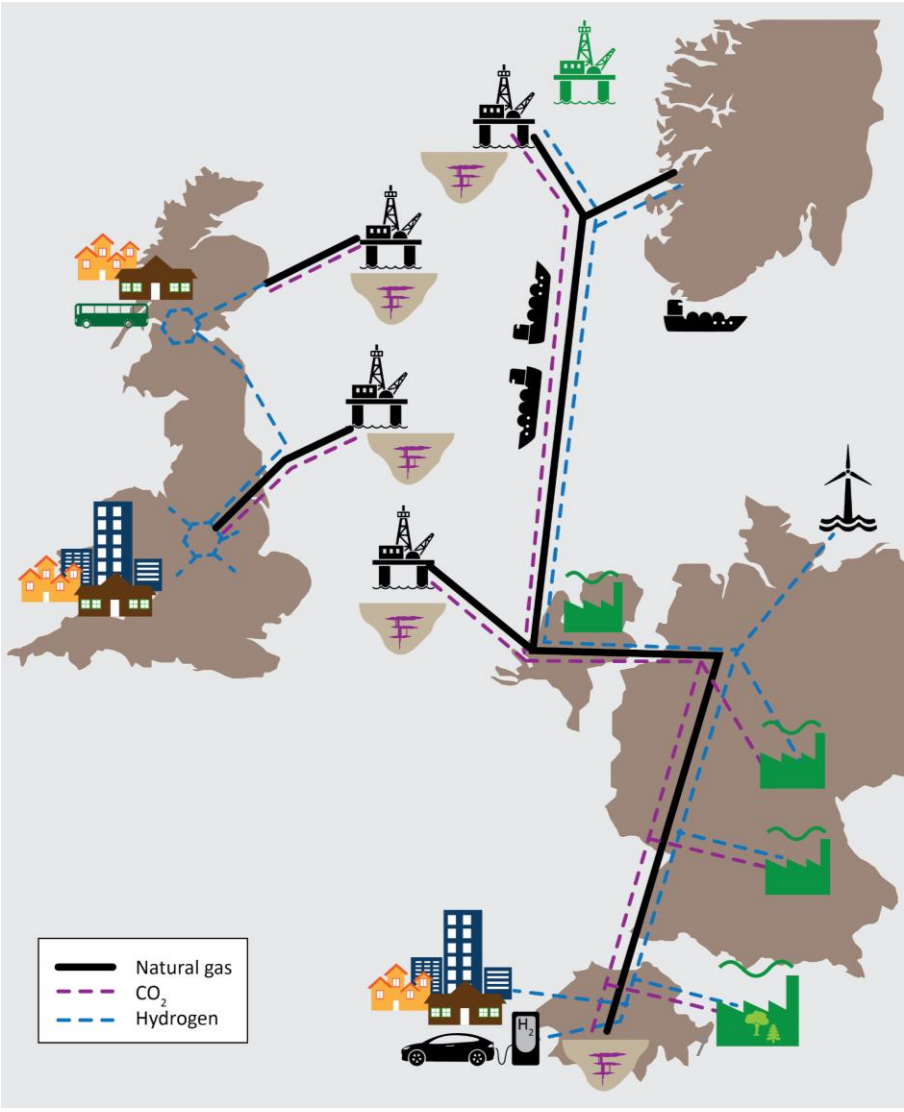
H_2 supply chain including H_2/CO_2 separation **WP1**

- H_2 from natural gas (ETH, PSI)
- H_2 from other sources (ECN)
- Characterization of CO_2-CO-H_2 mixtures (RUB)

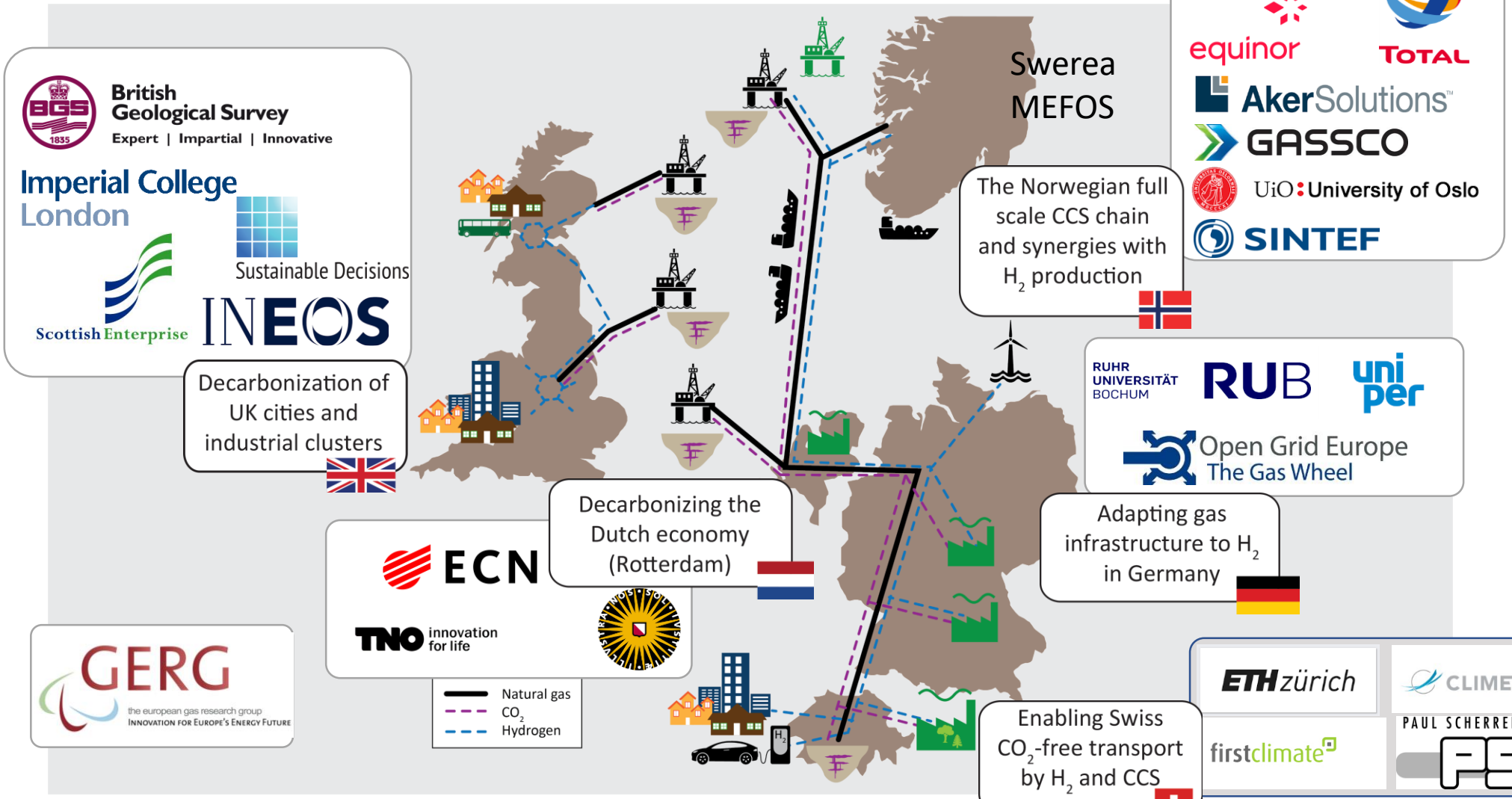
CO_2 transport, injection and storage **WP2**

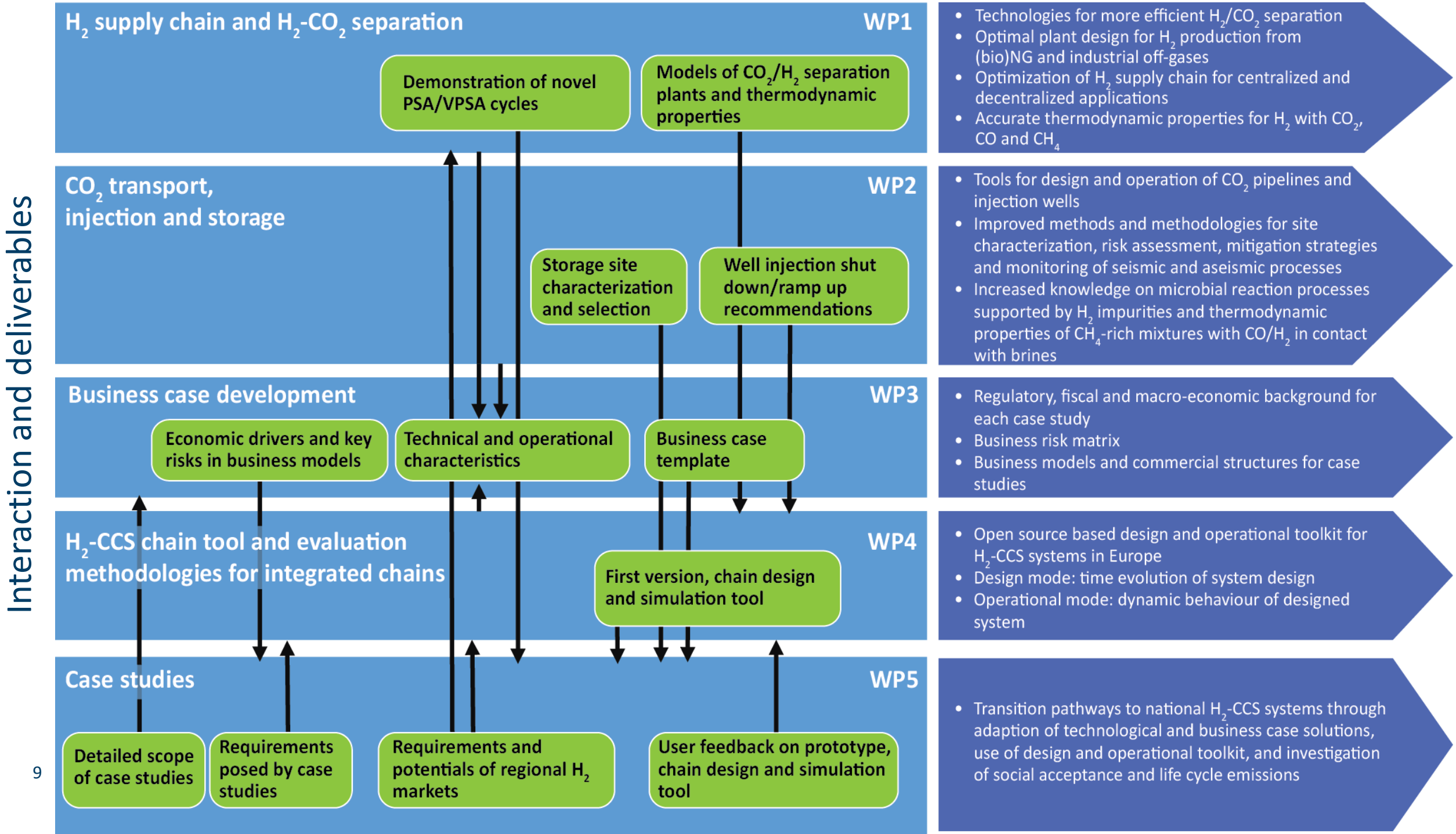
- CO_2-brine model (RUB,ICL)
- CO_2 transport-injection interface (SINTEF)
- Storage-site characterization and selection (ICL)
- Mt. Terri decametre scale experiment (ETH)
- Impact of H_2 in the CO_2 stream on storage (BGS)
- De-risking storage

ELEGANCY project management, network building and dissemination (SINTEF) **WP6**



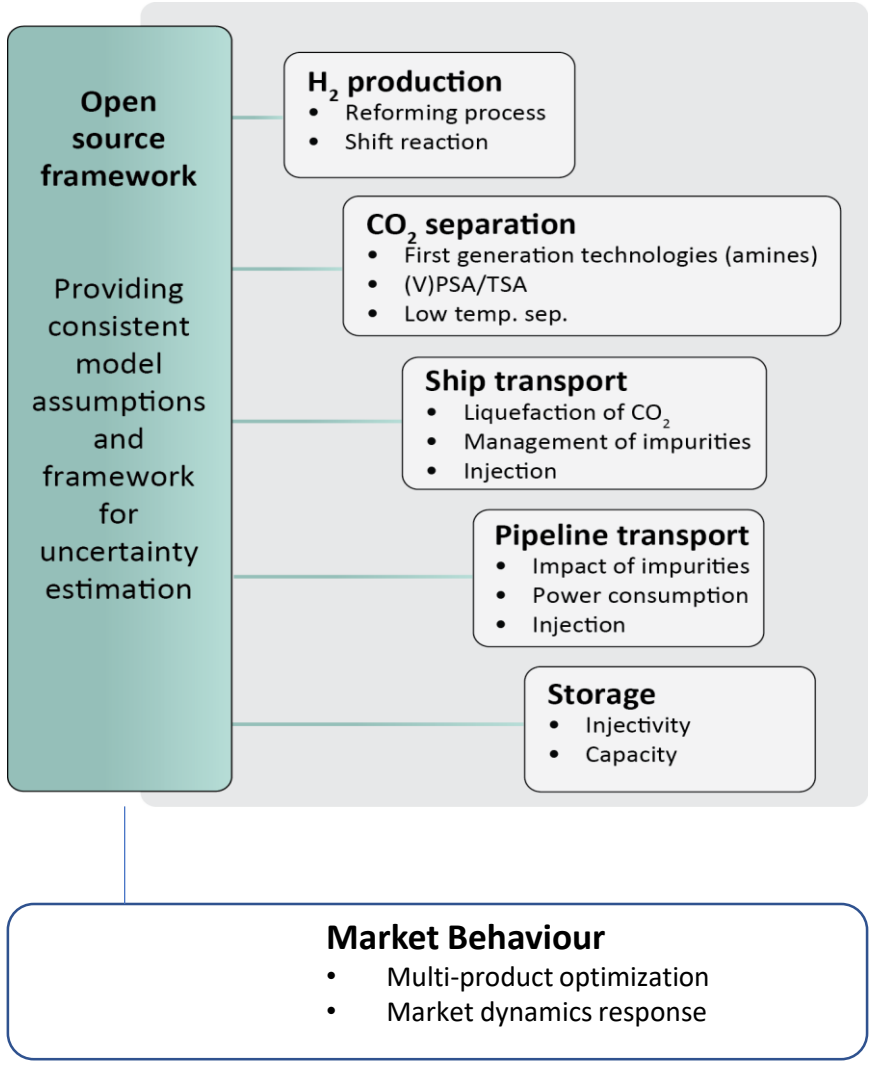
ELEGANCY – Case studies




Interaction and deliverables
H2 supply chain and H2-CO2 separation
WP1
Demonstration of novel PSA/VPSA cycles
Models of CO2/H2 separation plants and thermodynamic properties
CO2 transport, injection and storage
WP2
Storage site characterization and selection
Well injection shut down/ramp up recommendations
Business case development
WP3
Economic drivers and key risks in business models
Technical and operational characteristics
Business case template
H2-CCS chain tool and evaluation methodologies for integrated chains
WP4
First version, chain design and simulation tool
Case studies
WP5
Detailed scope of case studies
Requirements posed by case studies
Requirements and potentials of regional H2 markets
User feedback on prototype, chain design and simulation tool
• Technologies for more efficient H2/CO2 separation
• Optimal plant design for H2 production from (bio)NG and industrial off-gases
• Optimization of H2 supply chain for centralized and decentralized applications
• Accurate thermodynamic properties for H2 with CO2, CO and CH4
• Tools for design and operation of CO2 pipelines and injection wells
• Improved methods and methodologies for site characterization, risk assessment, mitigation strategies and monitoring of seismic and aseismic processes
• Increased knowledge on microbial reaction processes supported by H2 impurities and thermodynamic properties of CH4-rich mixtures with CO/H2 in contact with brines
• Regulatory, fiscal and macro-economic background for each case study
• Business risk matrix
• Business models and commercial structures for case studies
• Open source based design and operational toolkit for H2-CCS systems in Europe
• Design mode: time evolution of system design
• Operational mode: dynamic behaviour of designed system
• Transition pathways to national H2-CCS systems through adaption of technological and business case solutions, use of design and operational toolkit, and investigation of social acceptance and life cycle emissions

H_2-CCS chain tool and evaluation methodologies for integrated chains

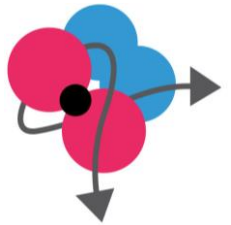
- Open-source framework
  - More widespread use
  - More dynamic
- ‘Open’ or ‘closed’ modules
- Stationary design mode
- Dynamic operation mode
- Multi-scale models for the chain components



World-class research infrastructure

Description	Scale	Partner
Adsorption infrastructure (ECCSEL)	Lab-scale	ETH
Cycling adsorbent analyser	Lab-scale	ECN
Single- and multi-column reactive PSA/TSA equipment	Pre-pilot, TRL 5	ECN
Equipment for measurements of density, speed of sound and dielectric permittivity	Lab-scale	RUB
Vertical flow facility	Pilot-scale	SINTEF
Pipe and vessel depressurization (ECCSEL)	Lab-scale	SINTEF
Core-flooding laboratory	Lab-scale	ICL
Batch-reactor for mineral-dissolution kinetics	Lab-scale	ICL
Equipment for measurements of CO_2-brine-mineral contact angle, interfacial tension and phase behaviour	Lab-scale	ICL
Hydrothermal laboratory (ECCSEL)	Lab-scale	BGS
Geo-microbiology laboratory (ECCSEL)	Lab-scale	BGS
Rock deformation laboratory (ECCSEL)	Lab-scale	SCCER
Micro-seismic monitoring arrays	Lab-scale	SCCER
Mt. Terri research rock laboratory (EPOS)	Pilot-scale	SCCER

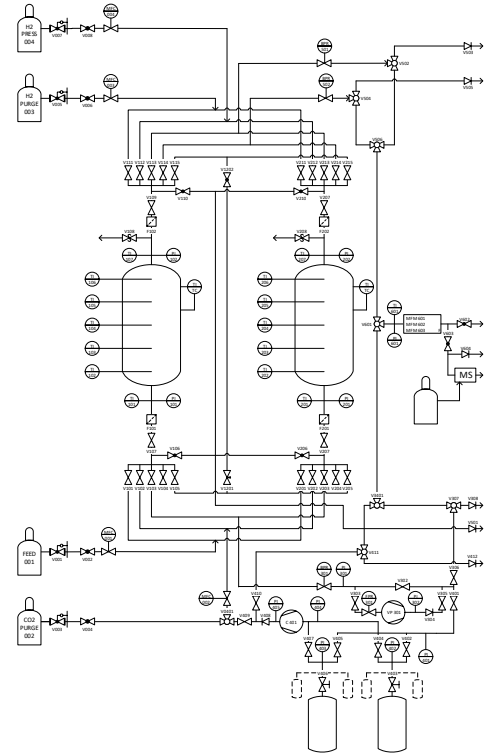
WP1: H_2 supply chain and H_2-CO_2 separation

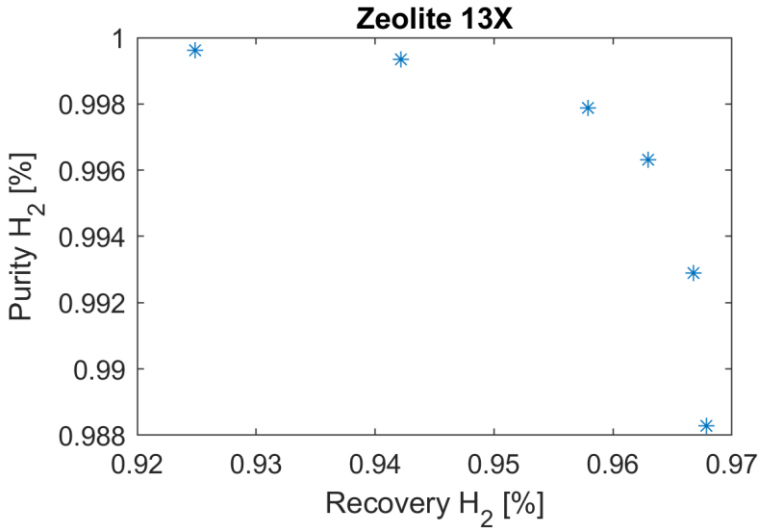


- **ETH**, PSI, ECN, MEFOS, RUB, UU
- Enable efficient H_2 production and CO_2 capture at different plant sizes.
- Find ways to increase the efficiency and productivity of natural gas/biogas reforming and CO_2/H_2 separation independently of the plant size.
- Integrate H_2 production and CO_2 capture with significant industrial processes such as steel production
- Characterize the properties of H_2 mixed with CO_2, CO, and CH_4.
- The research spans the range from the phenomenon level (RUB) via lab-scale experiments (ETH and ECN) to the pre-pilot scale (ECN).

WP1 achievements

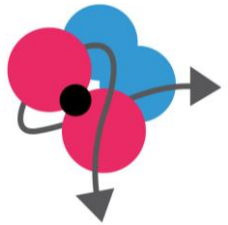
- Major achievements
  - VPSA test plant design finalized (picture right)
  - Optimised VPSA cycles developed for H2/CO2/N2 mixture
  - First results VPSA cycles for SMR syngas (picture below)





max. PUR_{H_2} & REC_{H_2} subject to PUR_{CO_2} > 95 % & REC_{CO_2} > 90 %

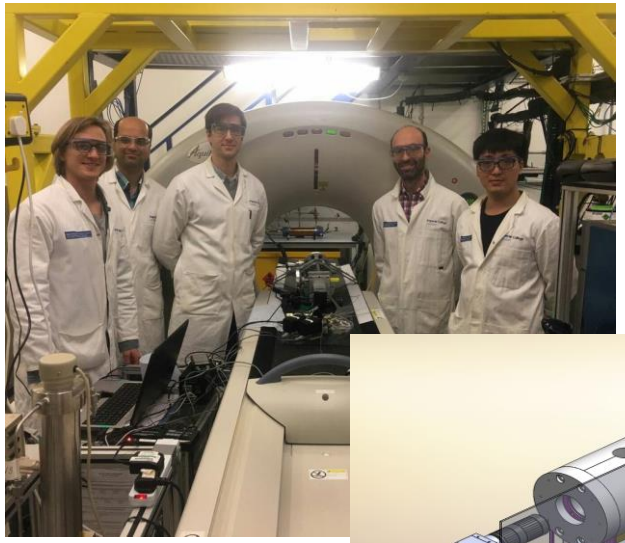
WP2: CO_2 transport, injection and storage



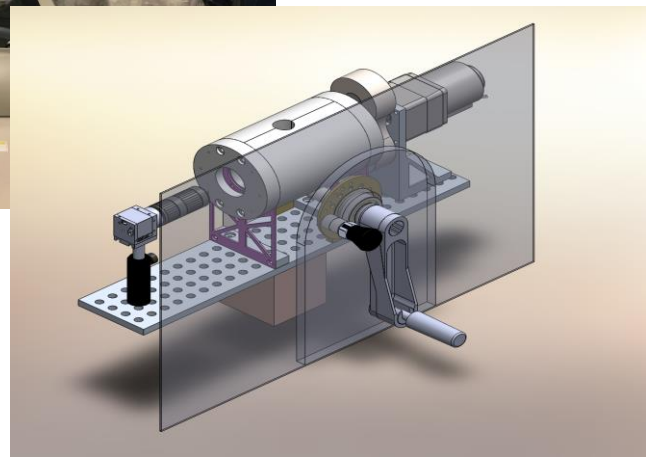
- **SINTEF**, BGS, SCCER, ICL, RUB – *De-risk storage*.
- Develop an accurate property model for CO_2-brine in the presence of impurities.
- Mature and validate tools for the safe, efficient and cost-effective design and operation of CO_2 pipelines and injection wells.
- Perform petrophysical chemical analyses for the characterization and selection of storage sites in Switzerland.
- Design and perform decameter-scale experiments at the Mt Terri research rock laboratory.
- Reduce uncertainties in injection, storage and monitoring of CO_2 produced by
  NG reforming for H_2 production.

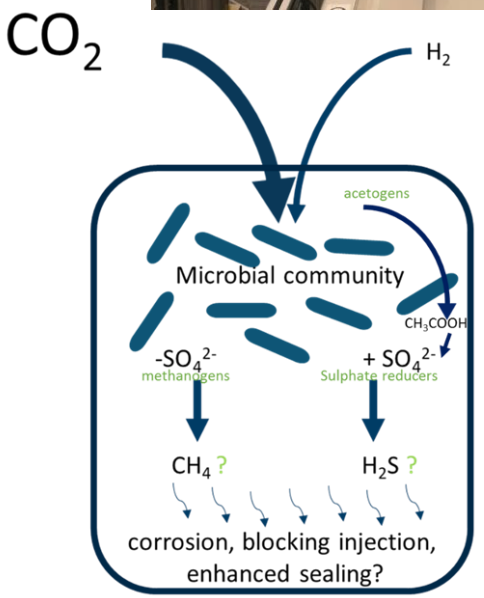
WP2 achievements

- Rock samples from the Mt Terri field site have been selected (D2.3.1)
- Core-holder for reactive transport experiments (ICL) has been commissioned and first experiment have been carried out
- Progress on design and construction of the apparatus for measuring hydrogen solubility in brines (ICL, far right)
- Modelling CO_2-brine properties has started (RUB)
- Literature review on response of microbes to H_2 in subsurface environments soon complete (BGS, right)



First experiment at ICL in collaboration with ETHZ (SCCER)

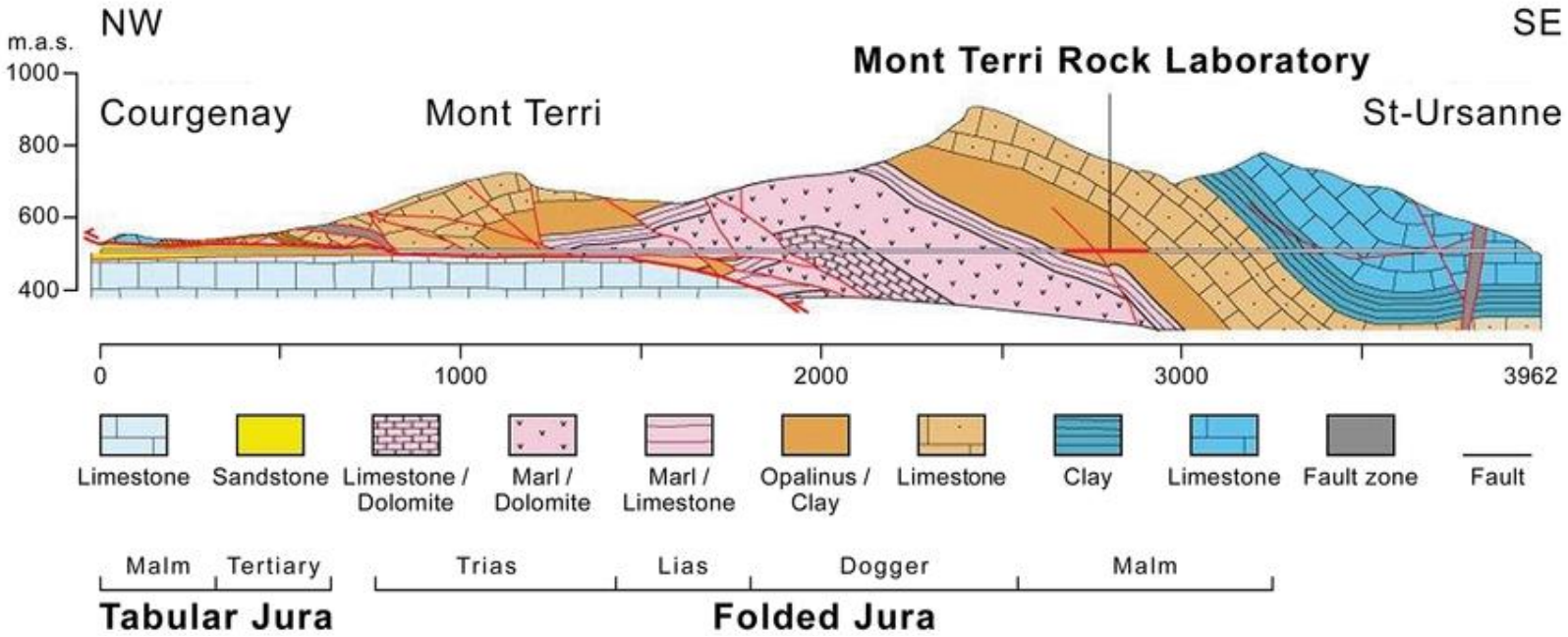


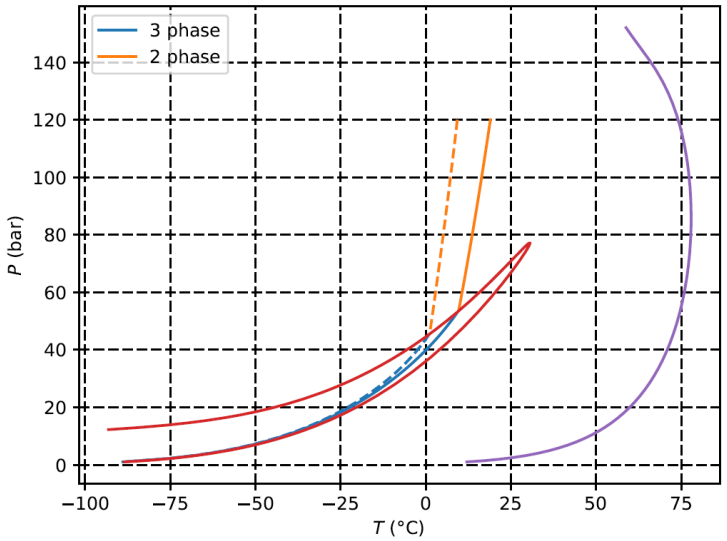


Conceptual diagram of key microbial reactions in CO_2 environment with low levels of hydrogen

WP2 achievements

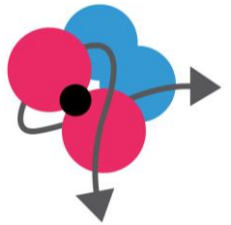
- Progress on multiphase flash calculations (SINTEF, right)
- Planning of boreholes geometry and instrumentation for the Mt Terri experiments is (almost) completed (SCCER, below)





Above: Isentropic decompression of a mixture of 95% CO_2, 2% N_2 and 3% H_2O from 120 bar and 10 and 20 °C. A state with one gas and two liquid phases occurs.

WP3: Business case development for H_2-CCS integrated chains

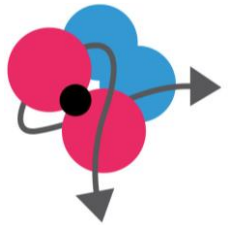


- UiO, SDL, FC
- Assess the regulatory background, identify barriers, mitigation strategies and opportunities for H_2-CCS.
- Assess the macro-economic, market and fiscal background to identify plausible business models.
- Develop business models and business case templates for use in the WP5 case studies.

WP3 achievements

- New partner and WP3 leader approved (UiO);
- Submission of Deliberables and preparation of forthcoming ones;
- Workshop (combined) 9 March 2018.

WP4: H_2-CCS chain tool and evaluation methodologies for integrated chains

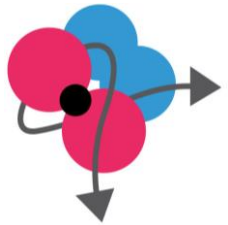


- **ICL**, SINTEF, PSI, RUB, TNO
- Enable the evaluation of integrated H_2-CCS chains with respect to technological and economic efficiency, operability and environmental impact
- Develop an open-source systems modelling framework with a steady-state design mode and a dynamic operational mode.
- Develop multiscale models and an integrated modelling approach for the chain components incorporating results from WP1 and WP2.
- Apply the methodology in conjunction with the case studies in WP5 with respect to (i) the potential time evolution of the system and (ii) integrated assessments of proposed designs.

WP4 achievements

- Major achievements (since last Board meeting)
  - Completion of specification documents
  - Very early protoptype of design tool
  - Key chain components identified
  - Continuing discussions with WP5
  - Good teamwork between members

WP5: Case studies



- **SINTEF**, BGS, TNO, UU, ECN, RUB, PSI, ICL, SDL, ETH, SCCER, CW, FC, INEOS, SE, AKSO, GERG
- Develop a roadmap for decarbonizing the Rotterdam industry
- Decarbonize the Swiss transport sector and prepare the way for a Swiss CO_2 storage site
- Support the UK H21 roadmap
- Decarbonize German natural gas as an energy carrier
- Evaluate the benefit of converting Norway's NG resources to H_2 with CCS

WP5 achievements

- Established an overview of regional requirements and potentials of H_2 markets
- Established the use industrial user group for port Rotterdam (NL)
- Established an overview of regional requirements and potentials of H_2 markets for H21 Leeds City Gate (UK)
- In collaboration with ALIGN-CCUS (ACT project), established a ‘baseline’ of CO2 storage for low-carbon industrial growth in UK
- Scenario definition for H2/CCS in the Swiss case study including in/out exercise to determine system boundaries (CH)
- Framework for comprehensive and consistent environmental evaluation of transport technologies based on LCA developed and implemented for passenger vehicles (CH)
- The first assessment (technical, economic, law, social acceptance) of options for a decarbonized gas infrastructure in Germany is completed, and is used as a basis to develop the German infrastructure scenarios
- Identified scenarios for H2 utilization and CCS synergies with the full scale project in the Norwegian Case Study


ELEGANCY will fast-track
the decarbonization of
Europe's energy system

Acknowledgement

ACT ELEGANCY, Project No 271498, has received funding from DETEC (CH), BMWi (DE), RVO (NL), Gassnova (NO), BEIS (UK), Gassco, Equinor and Total, and is cofunded by the European Commission under the Horizon 2020 programme, ACT Grant Agreement No 691712.