

ELEGANCy

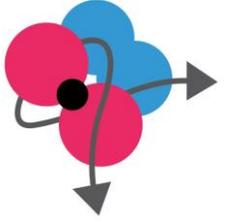
Enabling a Low-Carbon Economy via Hydrogen and CCS

Svend Tollak Munkejord, SINTEF Energy Research, project coordinator

<http://www.elegancy.no/>

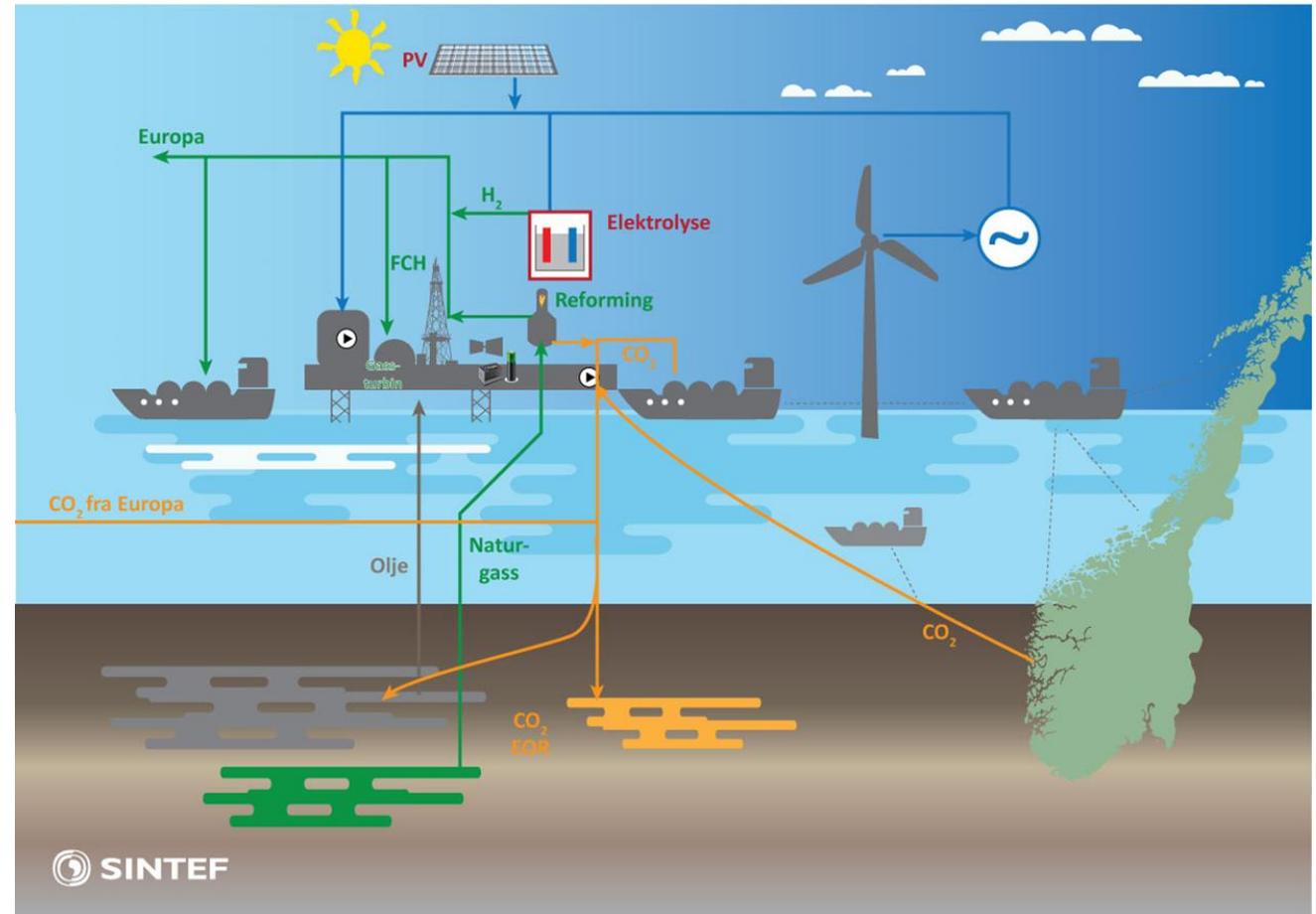
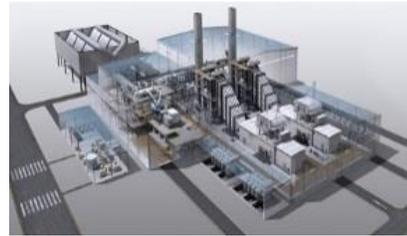
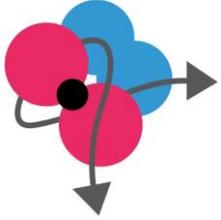
ACT knowledge-sharing workshop, Athens, 2019-11-06

Outline of presentation

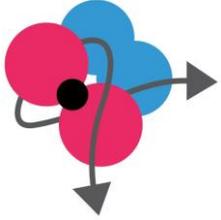


- ELEGANCY
 - Aim & approach
 - Some highlights
 - Communication
 - (Expected) impact

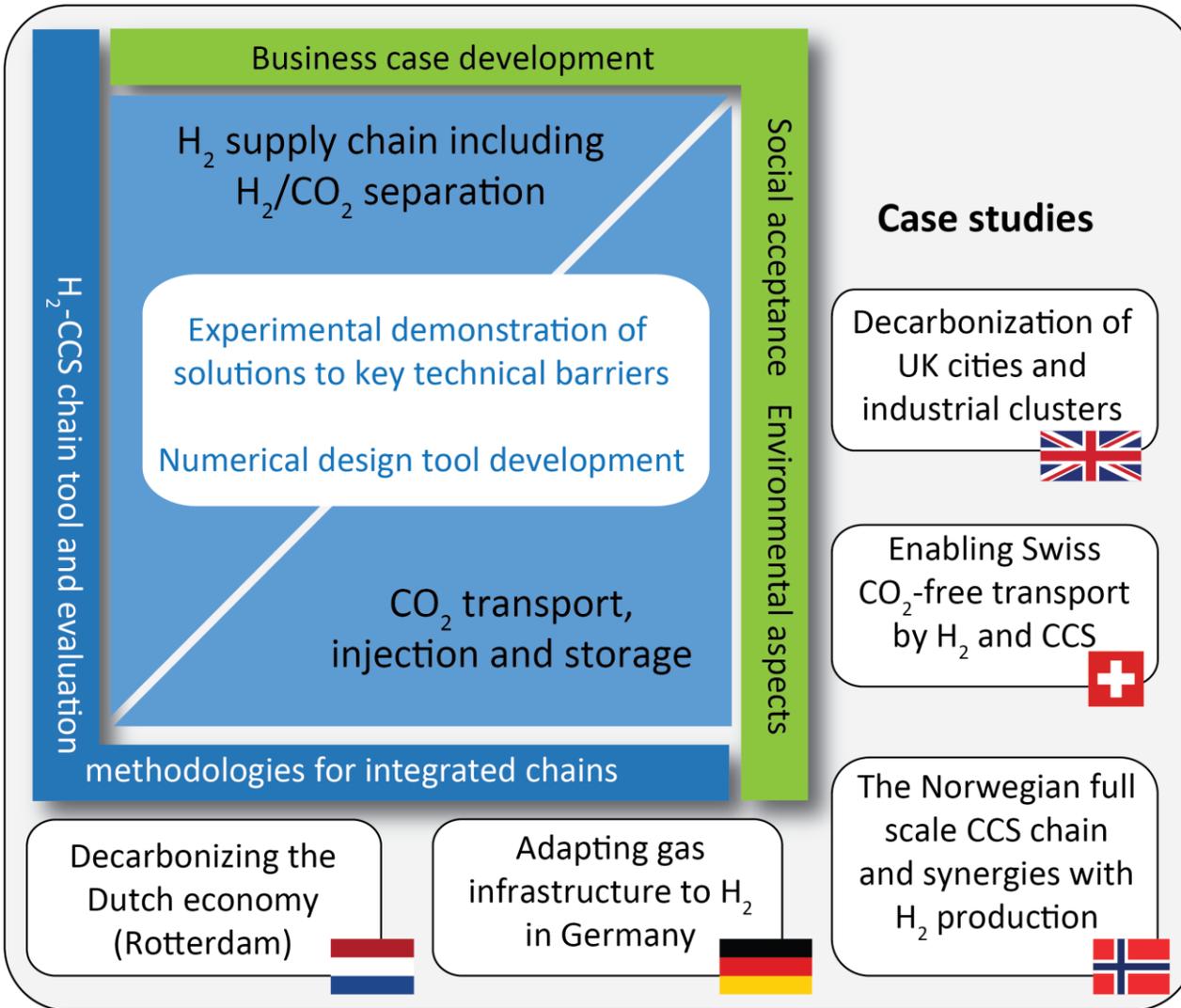
ELEGANCY – context



- The low-carbon economy needs H₂
- 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 – key information



Case studies

Decarbonization of UK cities and industrial clusters



Enabling Swiss CO₂-free transport by H₂ and CCS

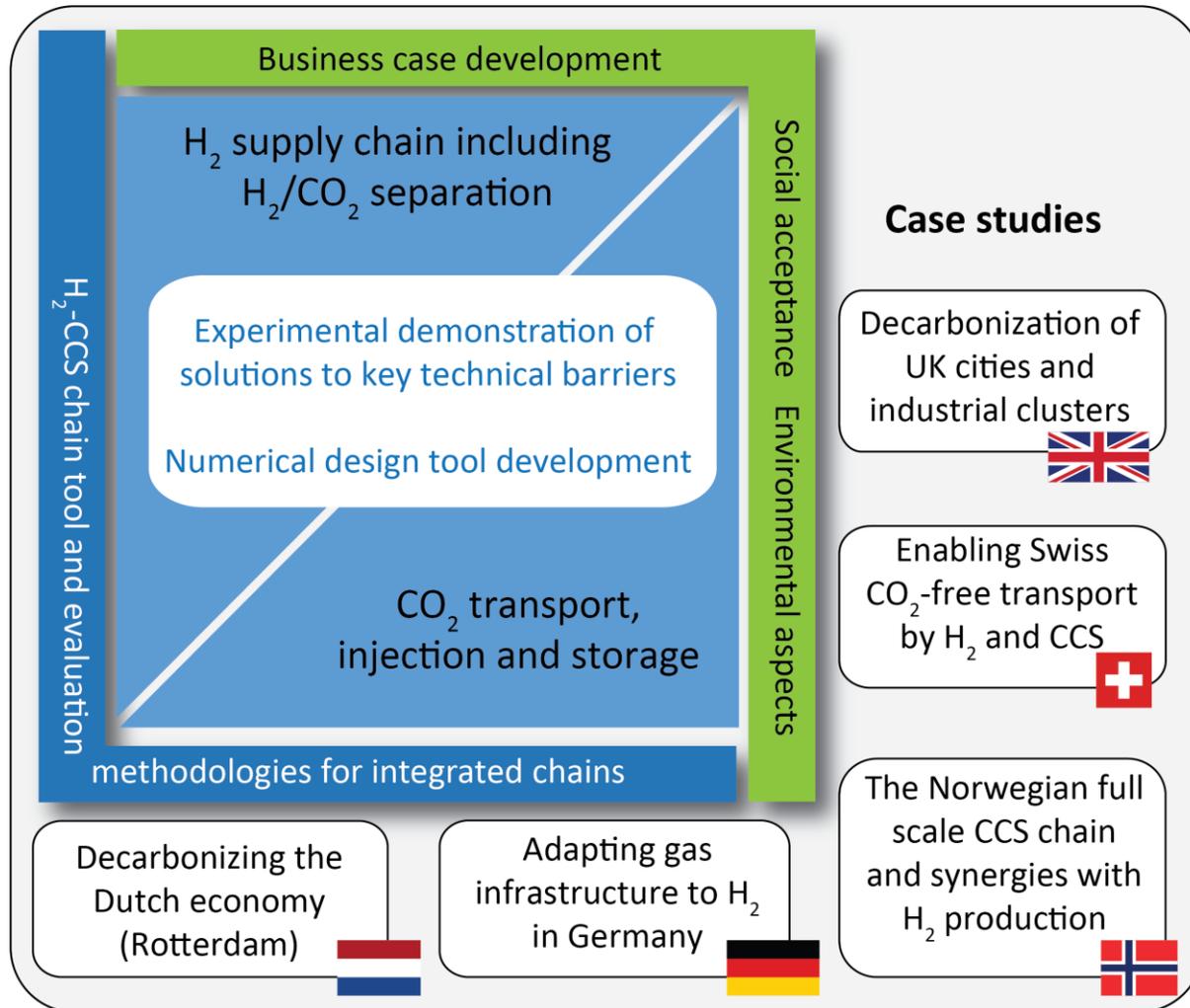
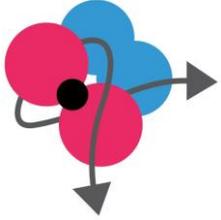


The Norwegian full scale CCS chain and synergies with H₂ production



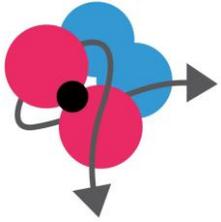
- Duration: 2017-08-31 to 2020-08-31.
- Budget: 15 599 kEUR

ELEGANCY – Enabling a low-carbon economy via H₂ and CCS by...



1. improving the Life Cycle Analysis performance of hydrogen production with CCS;
2. enhancing our understanding of CO₂ storage, particularly stemming from H₂ production;
3. enabling low carbon H₂ production with fossil-carbon or biomass via new market models;
4. designing cost-optimal and carbon footprint-optimal H₂ and CO₂ networks;
5. assessing country-specific challenges and opportunities, and identifying feasible country-specific pathways towards a H₂ economy coupled with CCS;
6. educating the next generation of European engineers and scientists on H₂ and CCS.

ELEGANCY – work packages



Case studies incl. social acceptance, environmental aspects and CCS-H₂ market considerations:
UK (large-scale decarbonization), Netherlands (Rotterdam decarbonization), Norway (full scale CCS chain and H₂ production), Switzerland (decarbonization of transport sector), Germany (adapting gas infrastructure and processes to H₂)

WP5

H₂-CCS chain tool and evaluation methodologies for integrated chains: (ICL, SINTEF, PSI, RUB, TNO)

WP4

Business case development: (UiO, FirstClimate, SDL)

WP3

H₂ supply chain including H₂/CO₂ separation

WP1

- H₂ from natural gas (ETH, PSI)
- H₂ from other sources (ECN)
- Characterization of CO₂-CO-H₂ mixtures (RUB)

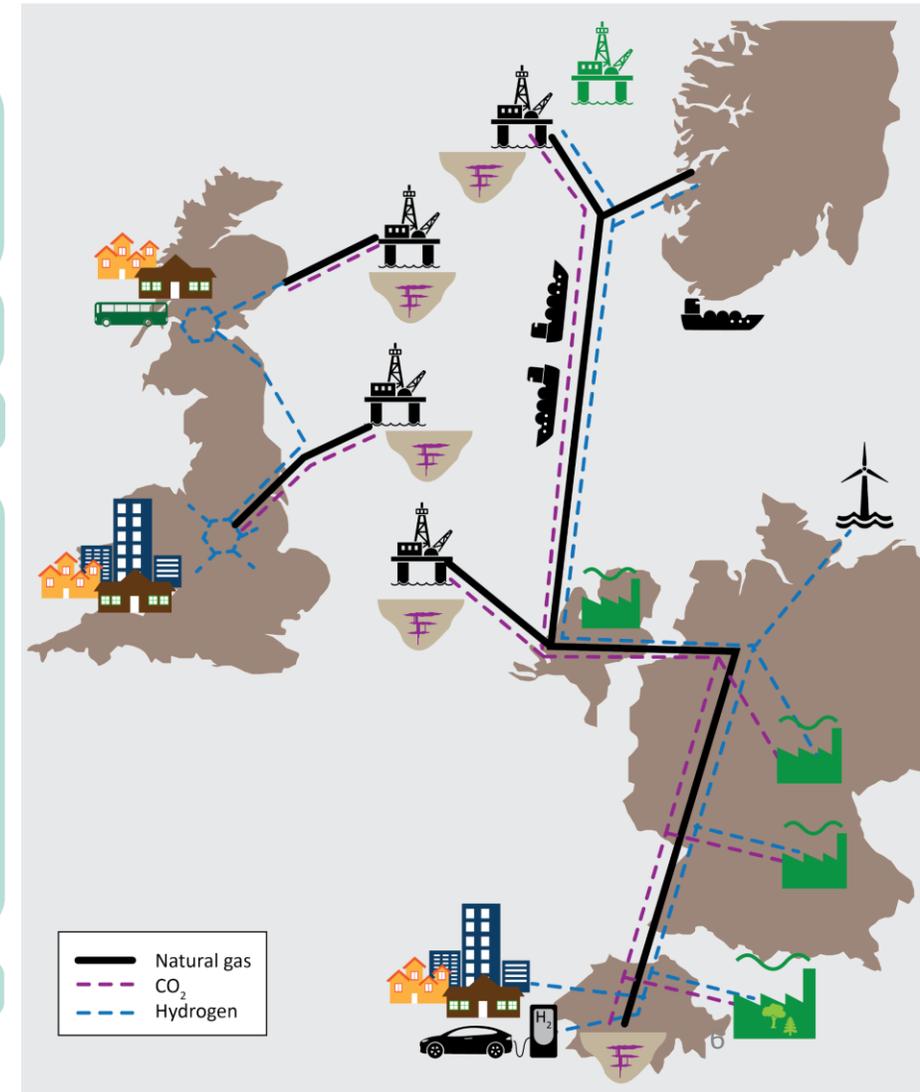
CO₂ transport, injection and storage

WP2

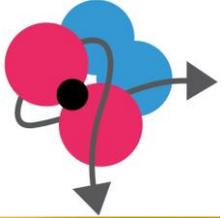
- CO₂-brine model (RUB, ICL)
- CO₂ transport-injection interface (SINTEF)
- Storage-site characterization and selection (ICL)
- Mt. Terri decametre scale experiment (ETH)
- Impact of H₂ in the CO₂ stream on storage (BGS)
- De-risking storage

ELEGANCY project management, network building and dissemination (SINTEF)

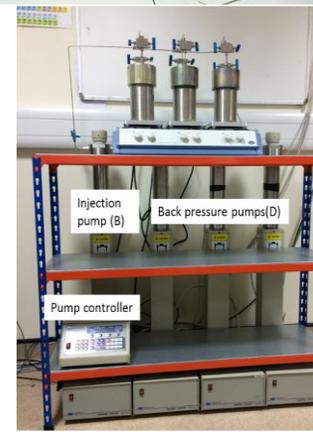
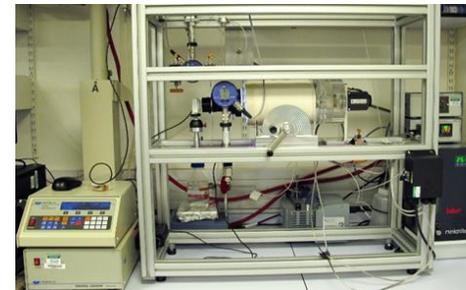
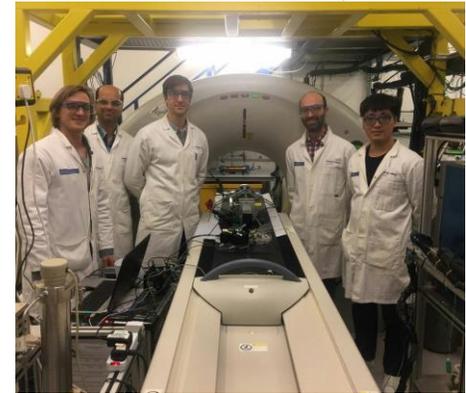
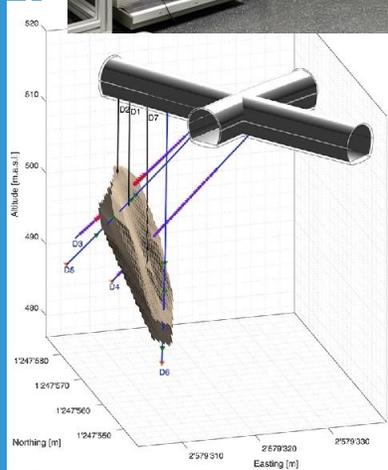
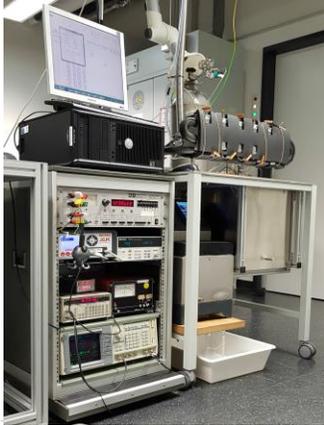
WP6



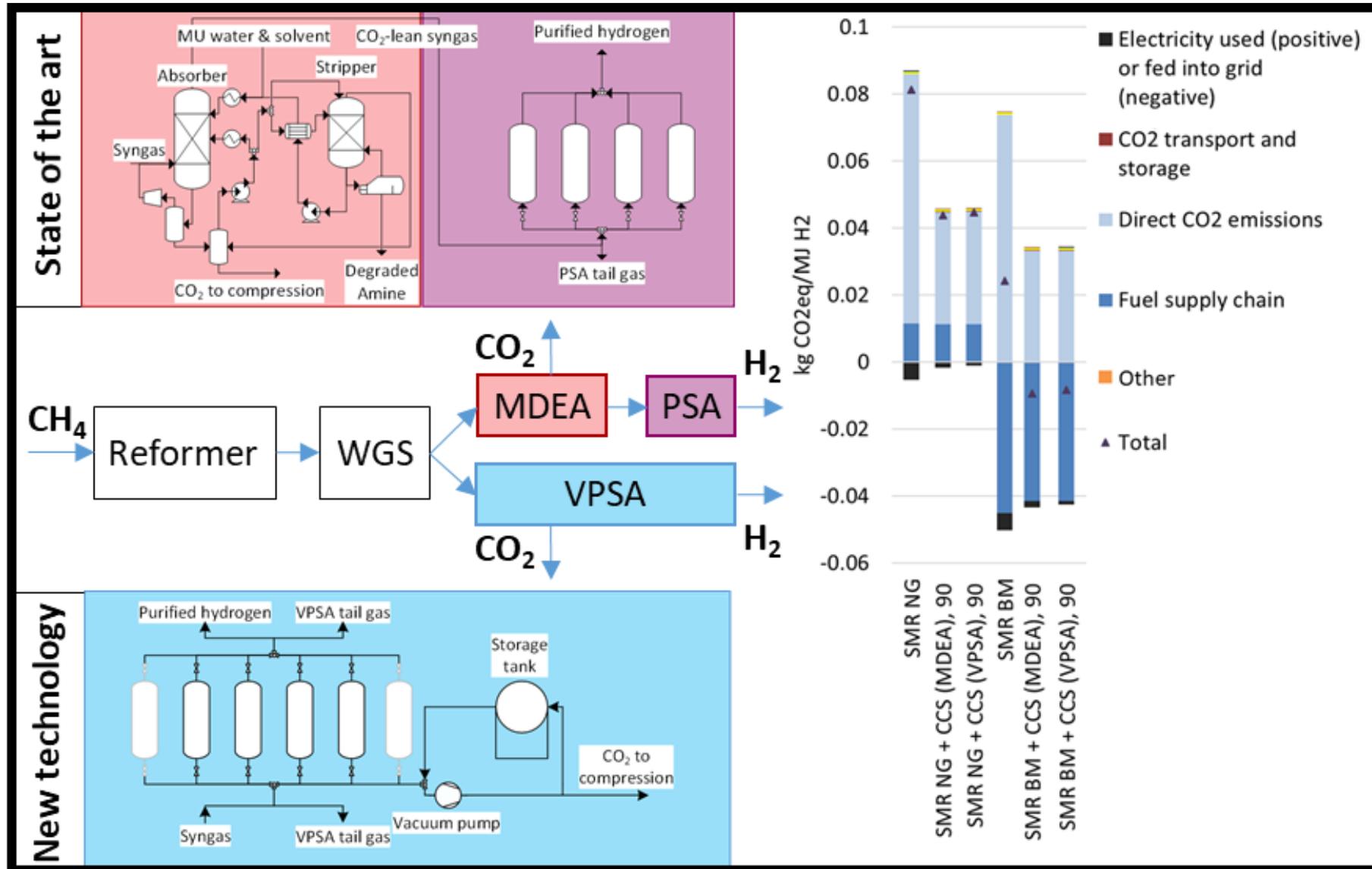
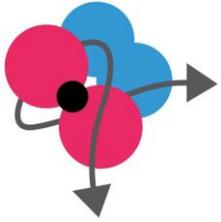
World-class research infrastructure



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

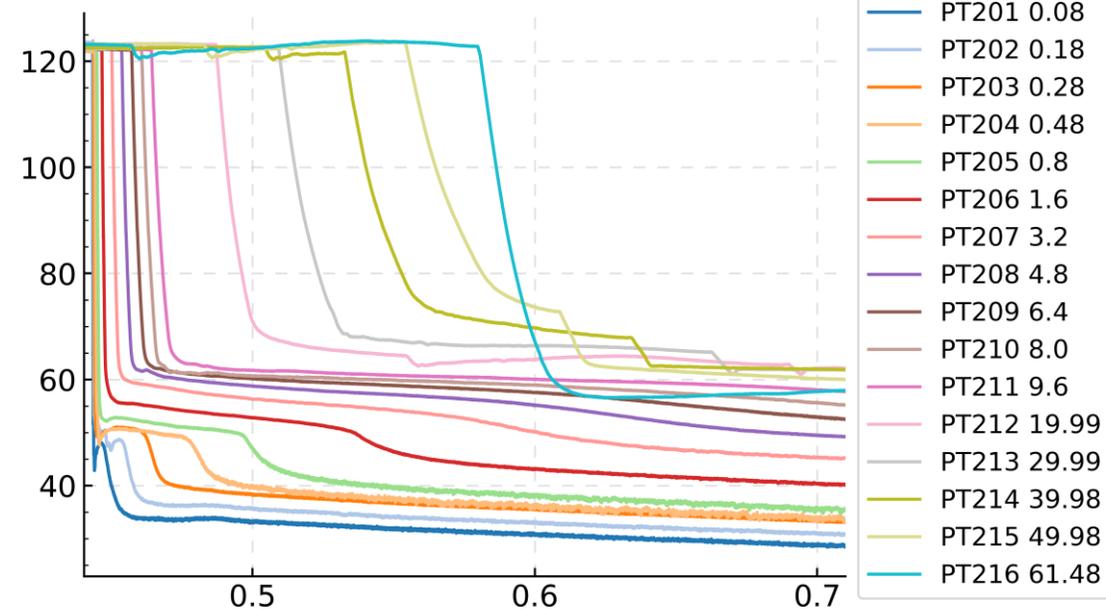
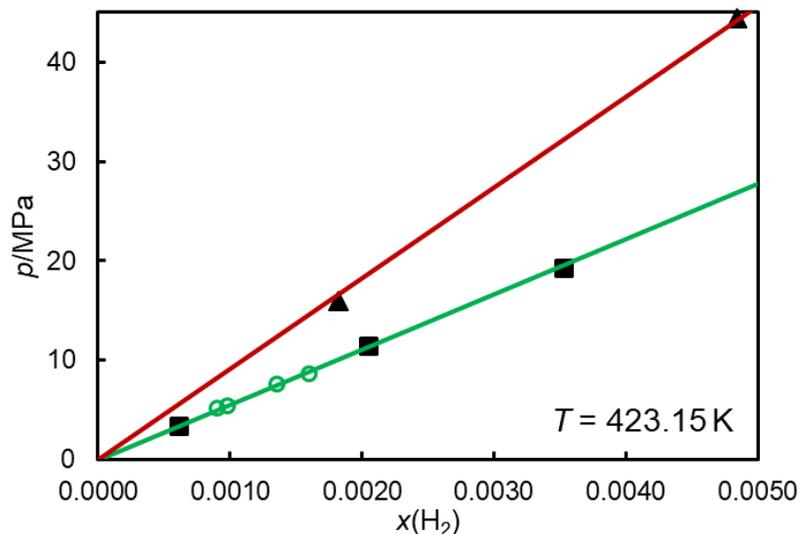


H₂ supply and H₂-CO₂ separation

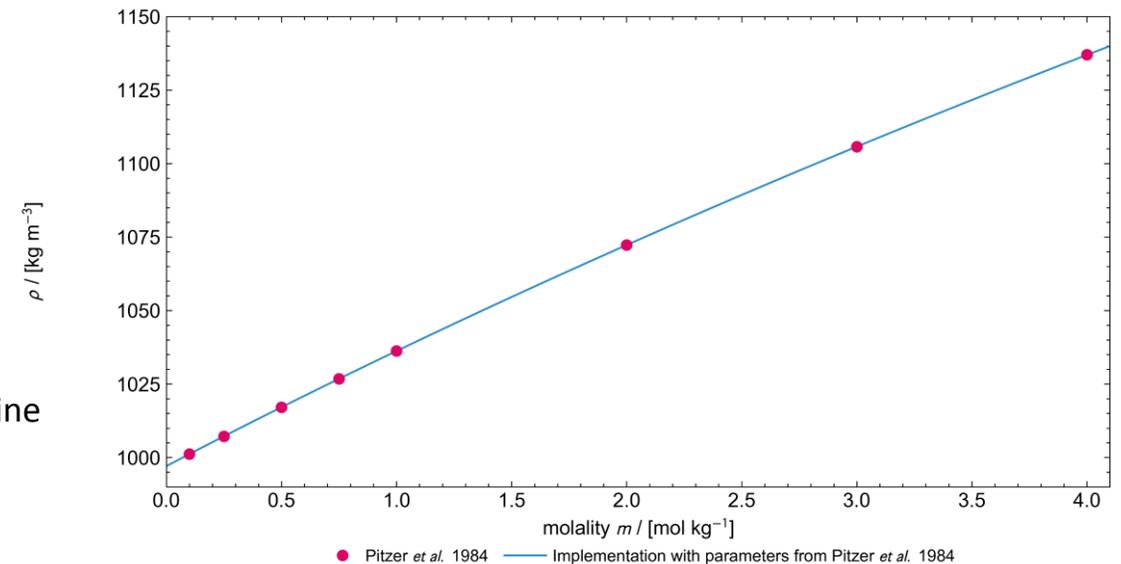


CO₂ transport, injection and storage

- Gas solubility in brines at reservoir conditions: Results show 35 to 40% 'salting-out' effect @ 2.5 mol/kg NaCl (ICL – below).
- Pitzer model implemented in TREND successfully validated for single salts, verification for salt mixtures ongoing (RUB – bottom right).
- Decompression of CO₂-rich mixtures in a tube under way. (SINTEF – top right).

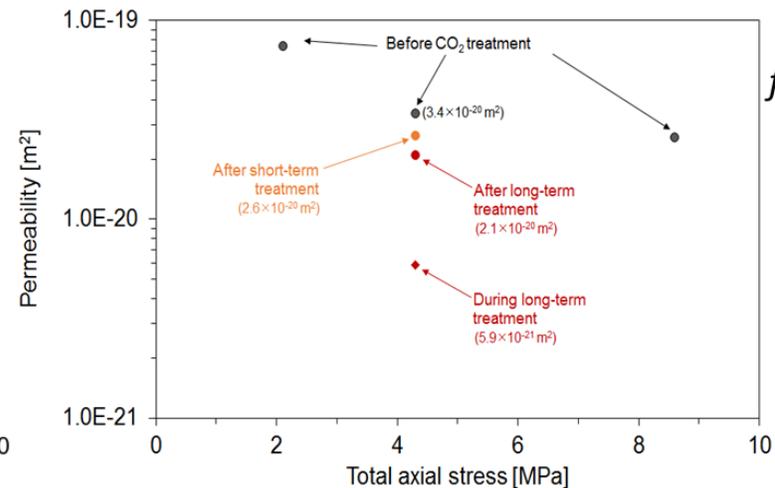
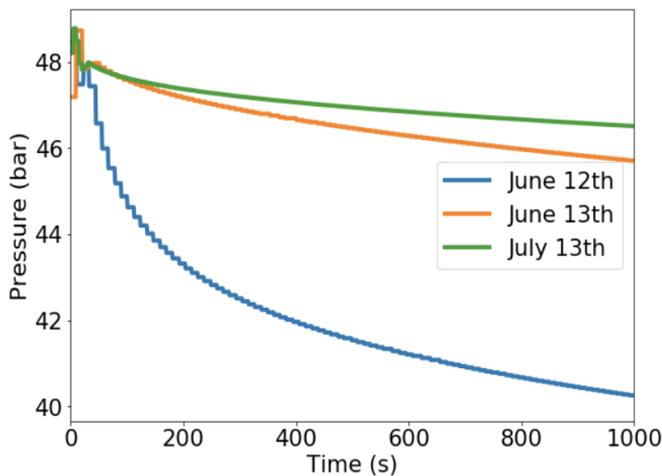
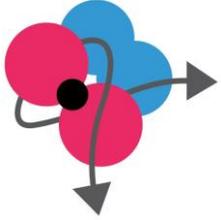
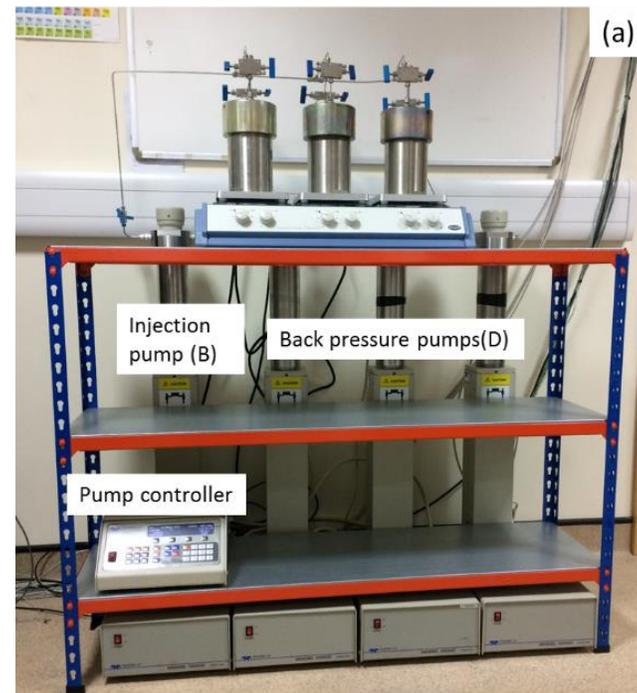


Decompression of CO₂ with 2 mol% N₂ in a tube. Measured pressure (bar) vs time (s) for different positions.



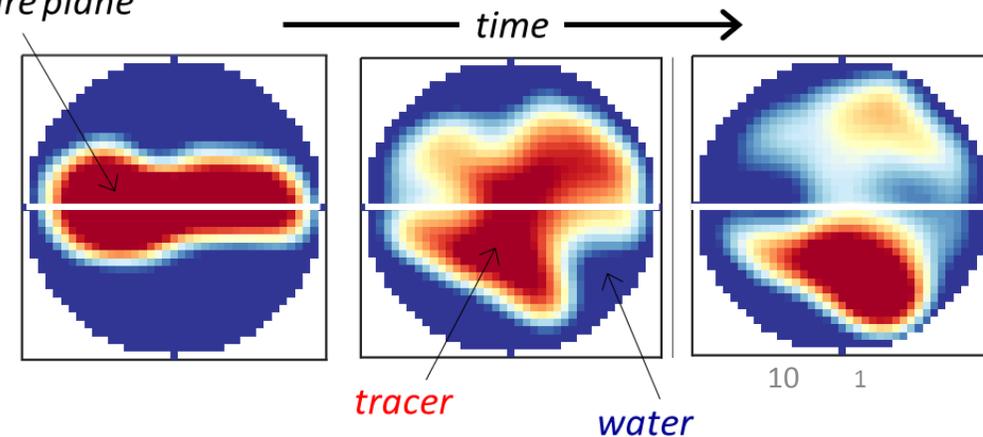
CO₂ transport, injection and storage

- Experimental geomicrobiology set-up will help understanding whether the hydrogen in the CO₂ stream could stimulate microbial activity. The batch tests to investigate the effect of CO₂ and CO₂/5%H₂ have started (BGS, right).
- Experiments and modelling to answer (i) How do caprocks fail? (ii) How do fluids mix in the subsurface? (iii) How does rock heterogeneity influence relative permeability? Characterization of rocks for the CH case study (ICL, below right).
- Mt. Terri CS-D experiment: The transmissivity of the fault seems to decrease with time of exposure to CO₂-rich water. The impact of two month exposure to CO₂-rich water on rock permeability has been shown to be negligible in laboratory experiments at EPFL (SCCER, below).

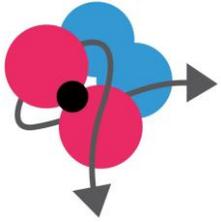


In-situ dynamic imaging of chemical transport

fracture plane



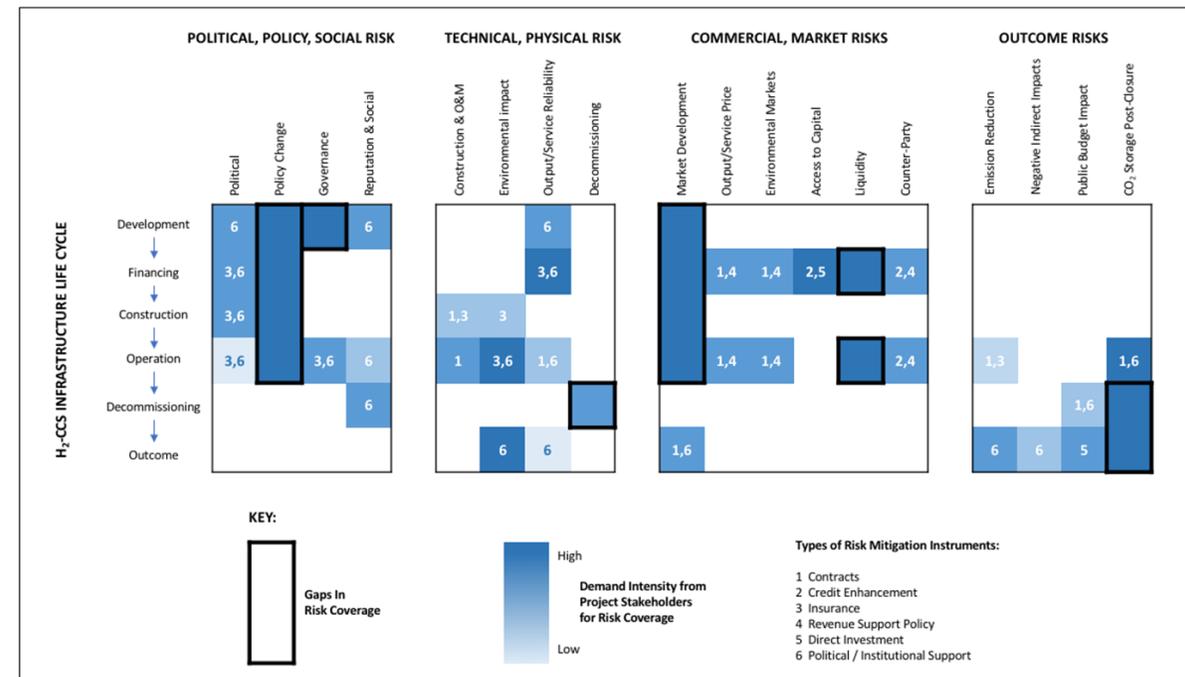
Business case development and legal aspects



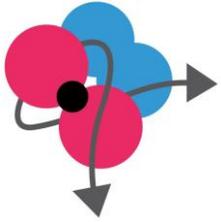
- **Business Model Development Toolbox** available from www.elegancy.no.
- Suite of Excel tools and accompanying guidance applicable to CCS case studies and projects.



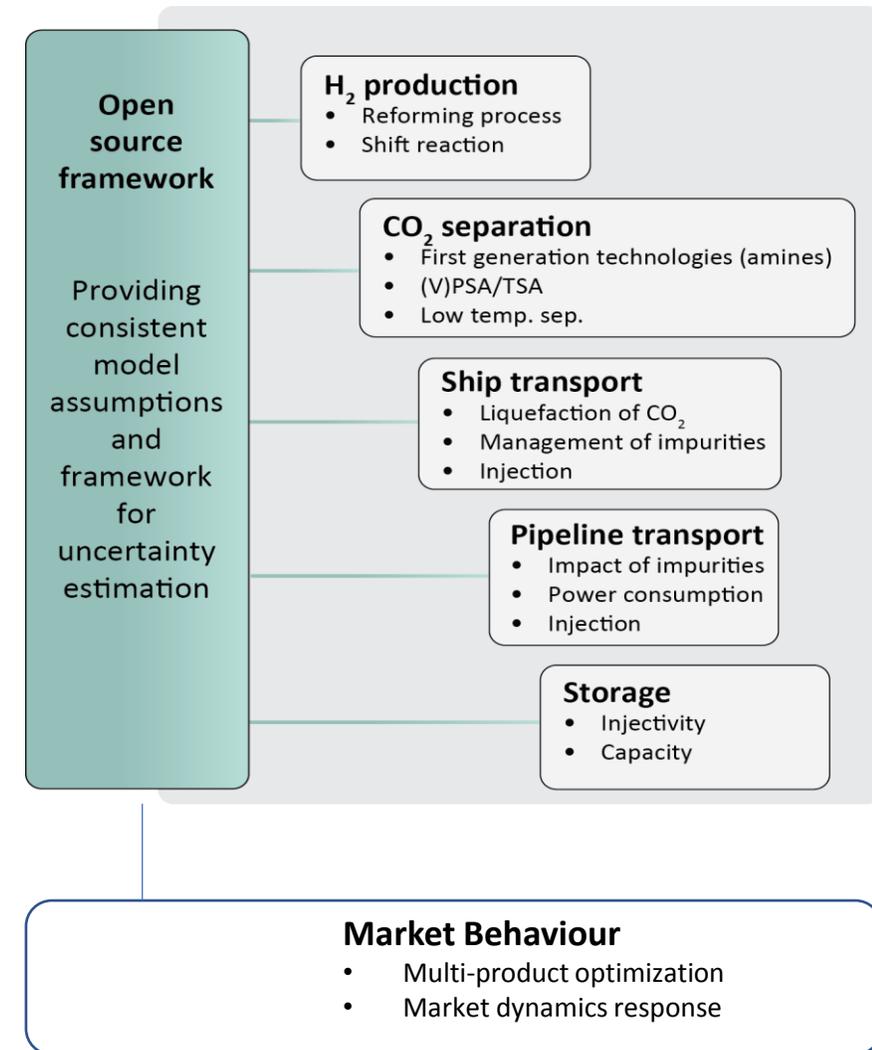
- Purpose of the Toolbox:
 - Assessment of business context, the identification and assessment of business risks, the selection of business models, and the assessment of business cases.
 - Identification and visualization of the key issues for the project early in the development process.
 - Facilitate collaboration and engagement among stakeholders.

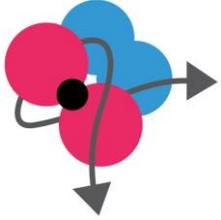


H₂-CCS chain tool and evaluation methodologies for integrated chains



- 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



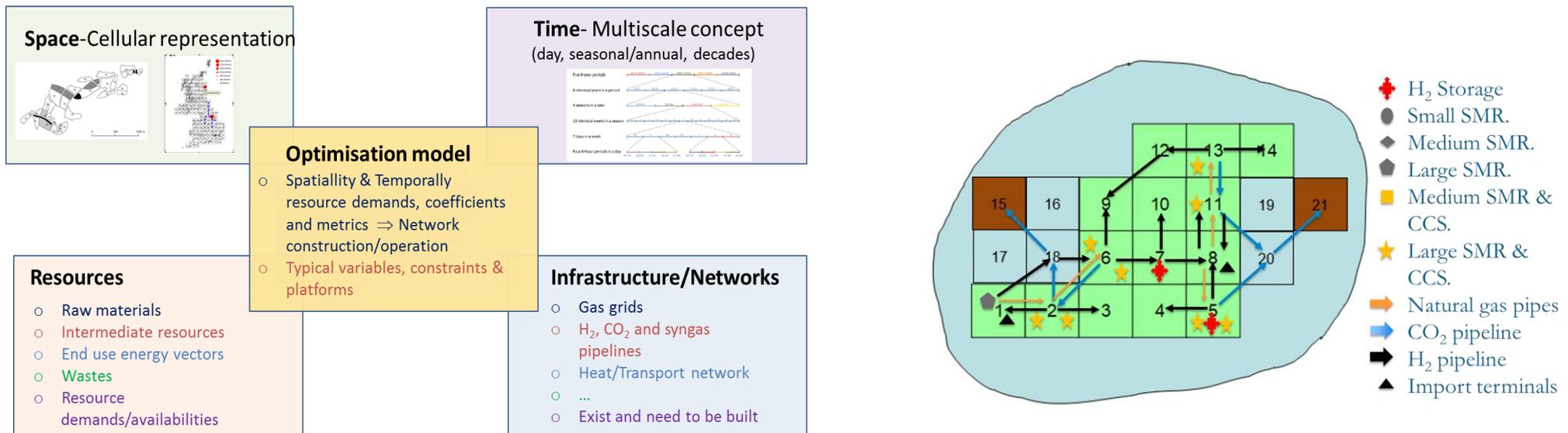


H₂-CCS chain tool

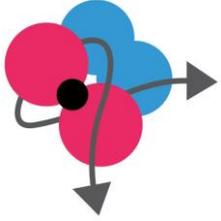
Design mode:

- Able to represent “real world” scenarios using past data.
- Capable of designing infrastructure for all key resources, whilst ensuring that CO₂ emissions are constrained as the total cost of the network is minimized.
- The model incorporates geographical input data relating to H₂ demands, geological storage volumes, natural gas infrastructure, to be used in the optimization.

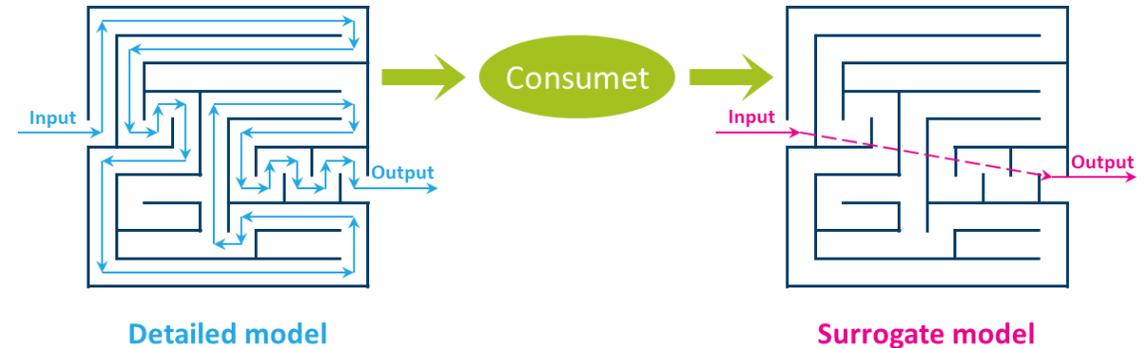
Resource Technology Framework:



Constructor of surrogates and metamodels

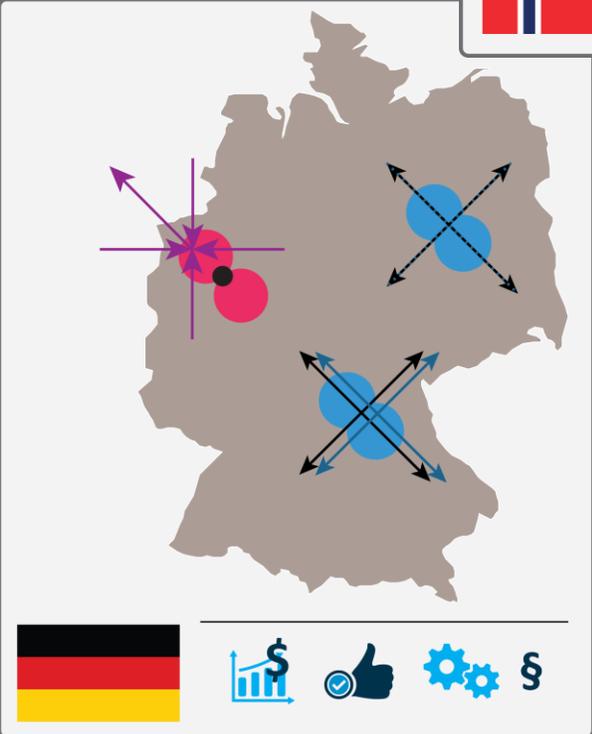
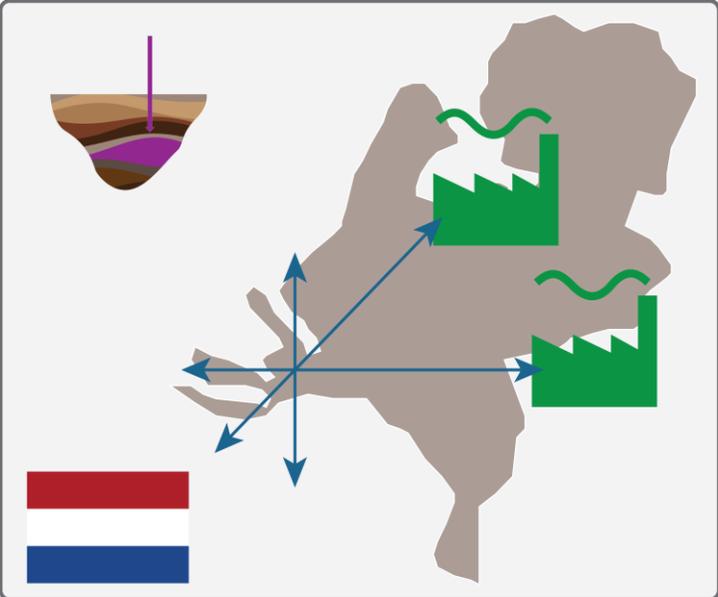


- Free tool based on Python
- Develops surrogates (simplified models) from detailed models
- Surrogates used for inclusion of knowledge of detailed model
- Large variety of basis functions for the surrogates included
- Uses
 - Adaptive sampling for a reduction in sampling points
 - Lasso regression for simpler models



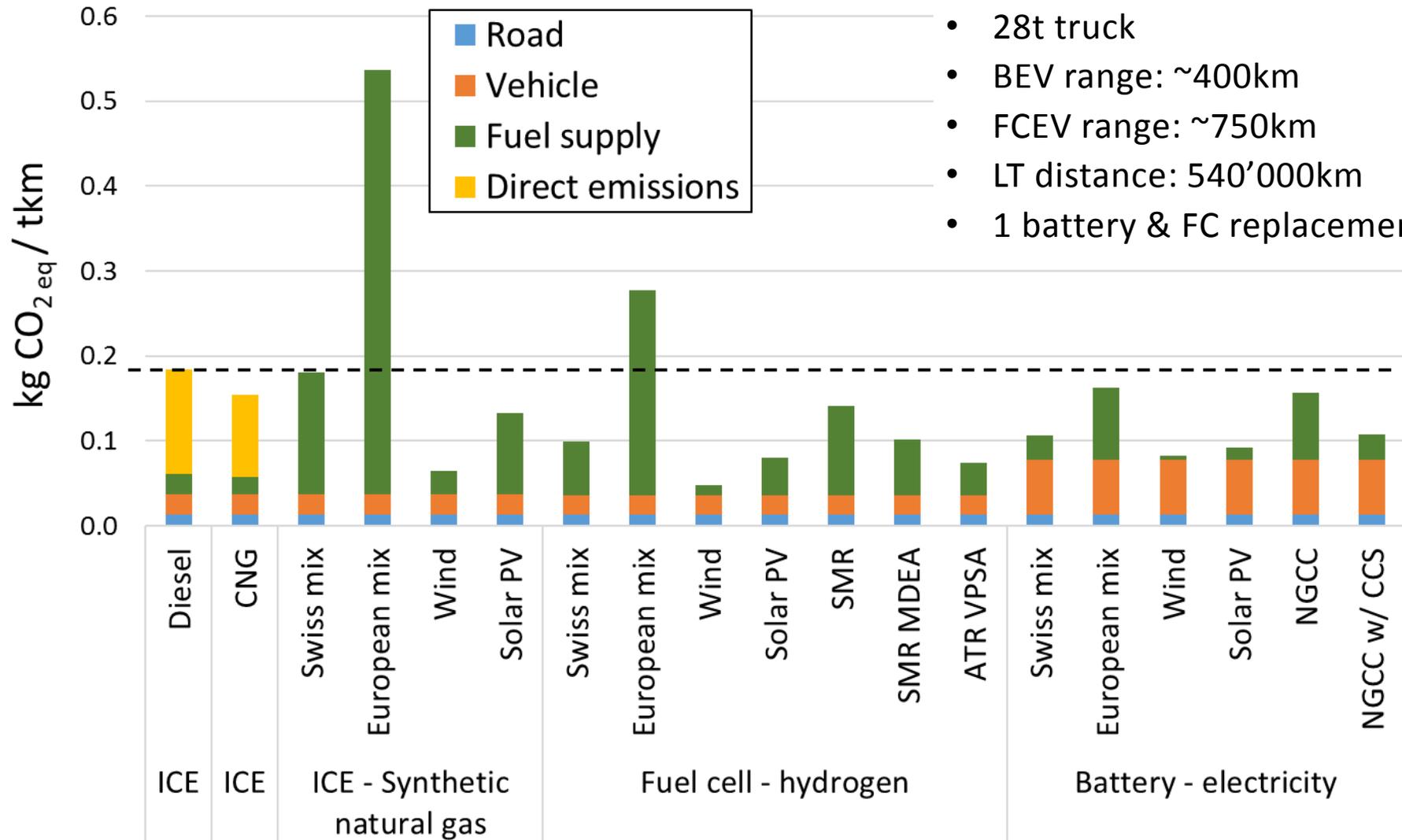
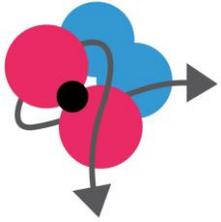
- Includes novel sampling domain restriction method
- Can be downloaded on:
<https://github.com/act-elegancy/consumet>

ELEGANCY case studies





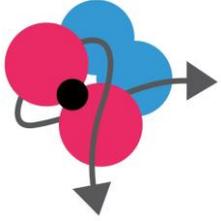
LCA results: GHG emissions of trucks



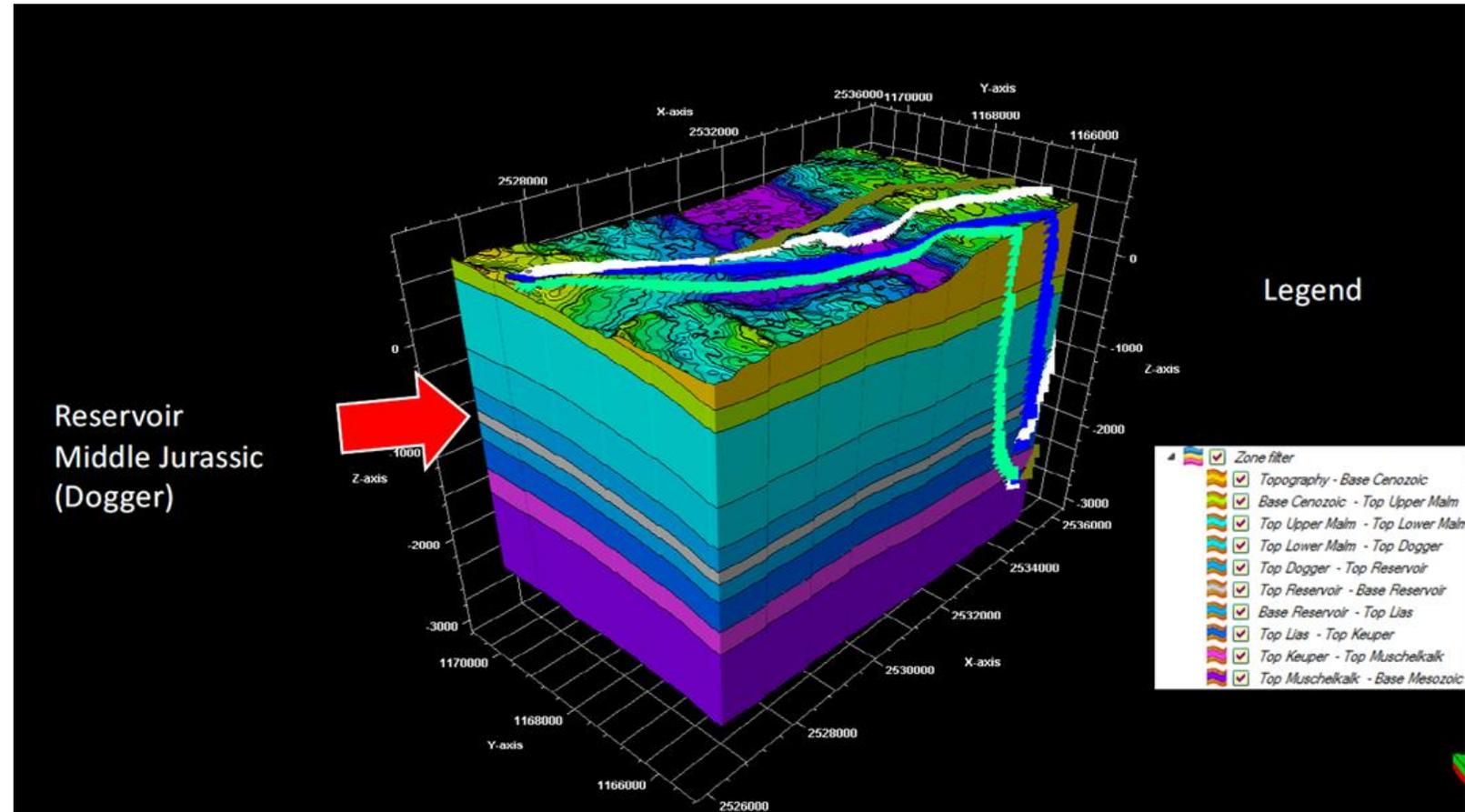
Enabling Swiss
CO₂-free transport
by H₂ and CCS



CO₂ storage site selection and risk assessment for the Eclepens area



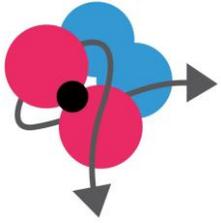
- A realistic subsurface model was created that represents the geological situation at the Eclépens Area in N/W Switzerland.
- The model will now be populated with realistic porosity and permeability values obtained from core samples
- The established workflow will find application to other sites when characterizing their suitability for future CCS project.



Adapting gas infrastructure to H₂ and CCS in Germany



Multi-discipline research

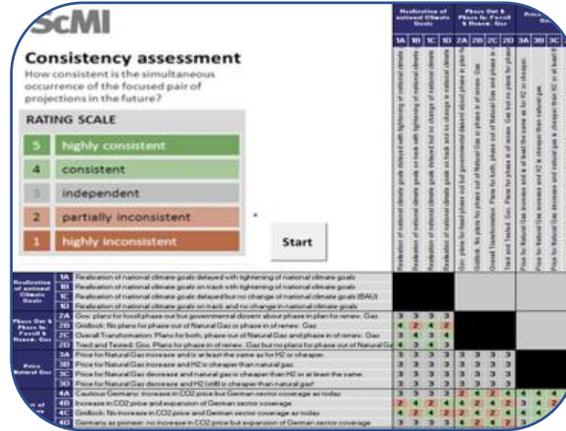


This has been achieved

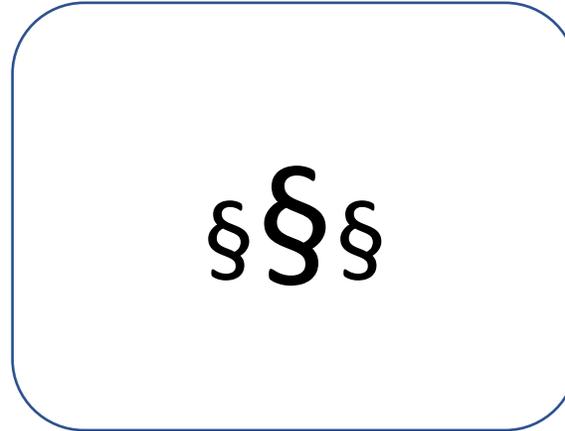
Final in-depth analysis within the four disciplines in preparation for the internal workshop to bring the results together in a joint framework.



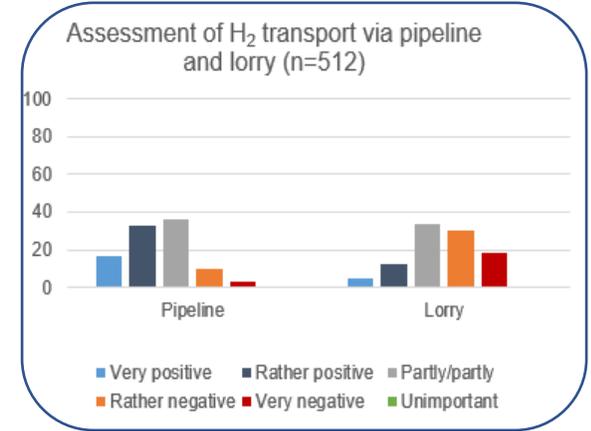
The calculation of the regional distribution of hydrogen demand is currently carried out on the basis of many statistical regional factors.



Development of qualitative socio-technical scenario. The overall transformation determines the feasibility of infrastructure modification.

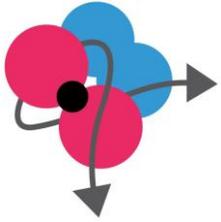


State of German procedural law increases the urgency of early deployment of CO₂ pipelines. TSO system responsibility on H₂ and interoperability - H₂ from renewable sources is given priority

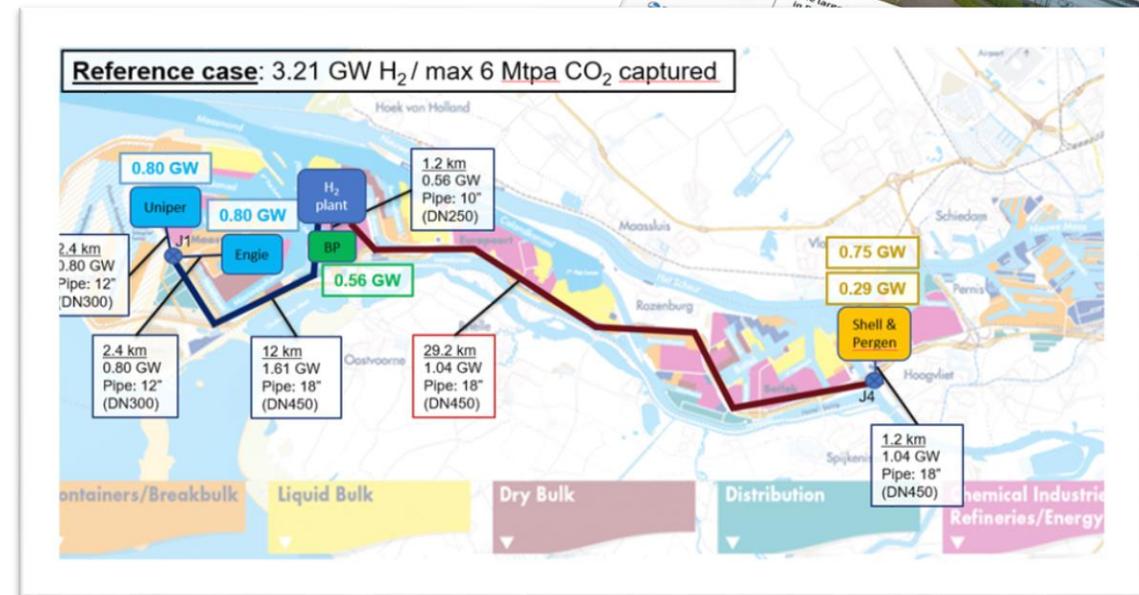


Analysis of online survey on acceptance. The transport of H₂ via pipeline is assessed quite positively.

Next step: Refining the disciplinary results and using them for the interdisciplinary and final evaluation of the three options.

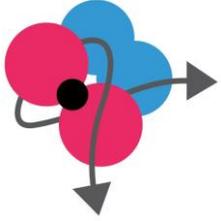


- The H-vision project (industrial platform of Rotterdam harbour) completed
- The industrial partnership has agreed upon a reference case of hydrogen production, transport infrastructure and industrial application
- ELEGANCY NL case study has contributed with adaptation and implementation of WP3 & WP4 tools, as well as development of specialized tools for the local energy market



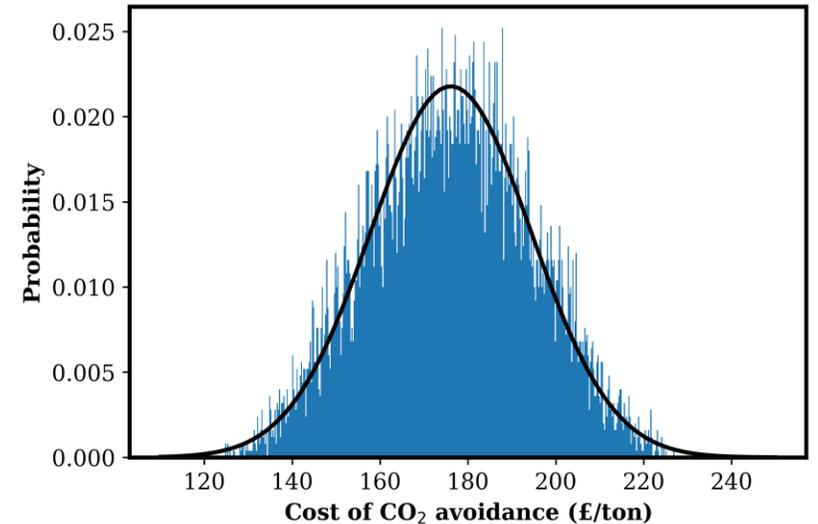
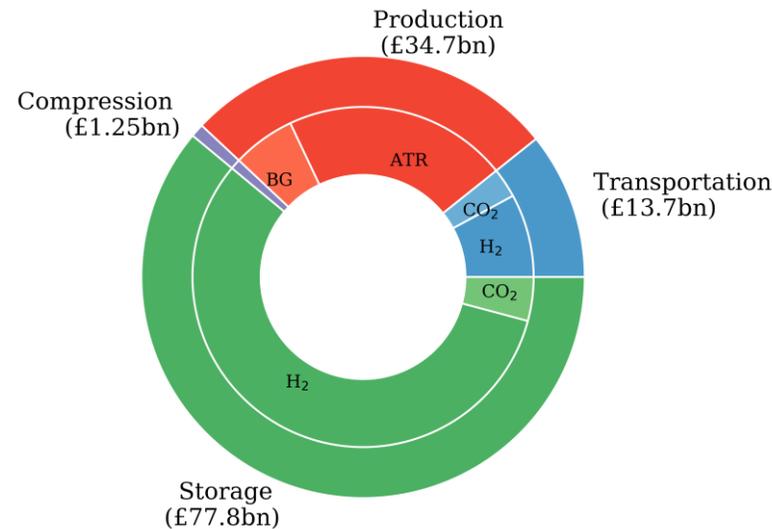
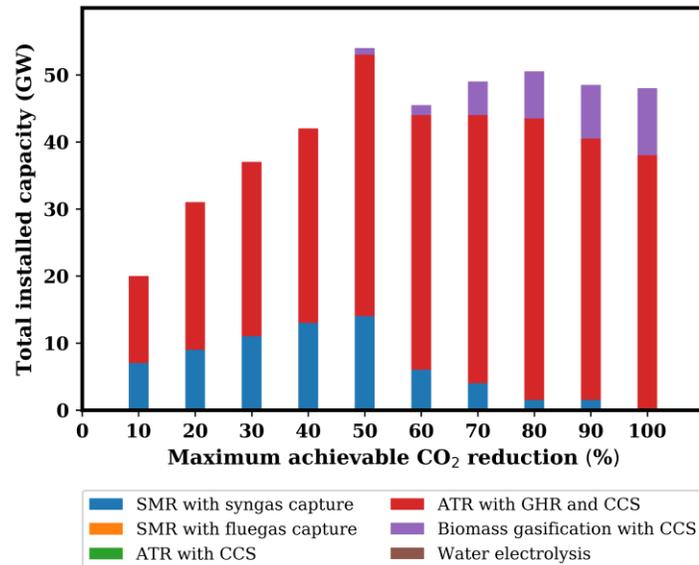


Application of ELEGANCY chain tool



Application of the H₂-CCS chain tool from WP4 to UK conditions has revealed:

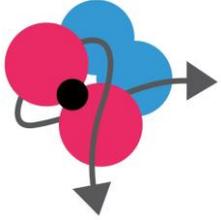
- Methane-based production technologies with CCS are necessary for cost-effective decarbonisation.
- Investment capital requirements are dominated by H₂ storage CapEx.
- Cost of CO₂ avoidance may vary significantly based on natural gas and biomass feedstock prices.



The Norwegian full scale CCS chain and synergies with H₂ production

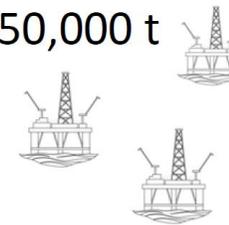


H₂ utilization and export

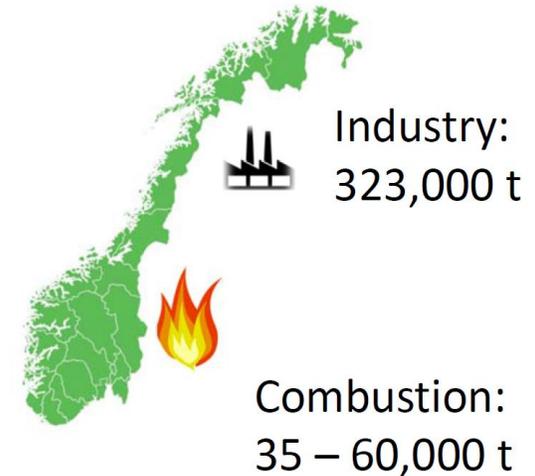


- A detailed analysis of the potential for H₂ utilization in Norway was conducted based on data available from open literature.
- Scenario topics of interest for the Norwegian case study has been identified in collaboration with industrial partners:
 - Level of H₂ demands individual levels for Norway, Europe and Japan/World
 - Successful development of a Norwegian CCS infrastructure
 - Constraints on development of a H₂ transport infrastructure
 - Cross-boundaries transport of CO₂ legal status
 - Learning rate level considered (impact cost reduction over the development horizon)
- Development/collection of a consistent set of data for the evaluation of the Norwegian case study has been initiated.

Offshore:
150,000 t



Industry:
323,000 t



Web

- elegancy.no
 - 20 news items
 - 7 videos
 - 40 deliverables (reports, etc)
- @ELEGANCY_ACT
 - weekly (re)tweets

The screenshot shows the ELEGANCY website's 'News and Events' page. The browser address bar displays 'https://www.sintef.no/projectweb/elegancy/news/'. The website header features the ELEGANCY logo and a navigation menu with links for 'ELEGANCY', 'Partners', 'Project programme', 'News and Events', 'Publications', 'Internal pages', and 'Contacts'. A breadcrumb trail indicates 'You are here: ELEGANCY > News and Events'. On the left side, there is a vertical stack of social media icons for Facebook, LinkedIn, Twitter, and Email. The main content area is titled 'News and Events' and 'ELEGANCY news'. It features a large diagram on the left illustrating a process flow from 'Technical contribution' to 'Feasible concepts recommendations'. Below the diagram is a news article titled 'A framework for interdisciplinary collaboration and evaluation of infrastructure transformation in Germany', dated 09 October 2019. To the right of the diagram is a group photo of project members. Further right is another news article titled 'ELEGANCY: From Helmholtz-type Equations of State to Legal Conditions', dated 05 September 2019. On the far right, there is a section titled 'ELEGANCY Dutch Case Study: TNO initiates industrial participation with H-Vision project', dated 23 May 2019, which includes a table with three columns: 'Grey hydrogen', 'Blue hydrogen', and 'Green hydrogen'. The table describes the production process and CO2 handling for each type of hydrogen.

News and Events

ELEGANCY news

Technical contribution
Macroeconomic contribution
Legal contribution
Sociological contribution

Analysis of base options
Combined analysis of base options
Determining best-case options
Feasible concepts recommendations
Analysis of best-case options

A framework for interdisciplinary collaboration and evaluation of infrastructure transformation in Germany

09 October 2019

The German Case Study within the ELEGANCY-project examines ways to decarbonise the German infrastructure with H₂-CCS chains, focusing on pipeline-based options for CO₂...

ELEGANCY: From Helmholtz-type Equations of State to Legal Conditions

05 September 2019

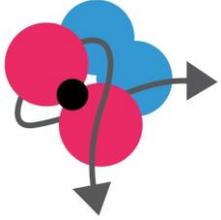
ELEGANCY is an ACT (Accelerating CCS Technologies) project with Germany, the Netherlands, Norway, Switzerland and the UK as participating countries, and even project...

ELEGANCY Dutch Case Study: TNO initiates industrial participation with H-Vision project

23 May 2019

Guest bloggers: Octavian Partenie, Rajat Bhardwaj, Robert de Kler, Erwin Giling (TNO, The Netherlands) In line with the 2015 Paris Agreement, the Dutch...

Grey hydrogen	Blue hydrogen	Green hydrogen
Natural gas into steam and hydrogen	Split natural gas into CO ₂ and hydrogen Residual gasses also in H-vision scope	Split water into hydrogen by electrolysis powered by wind and solar
CO ₂ emitted in the atmosphere	CO ₂ stored or re-used	No CO ₂ emitted

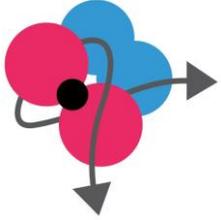


Deliverables and publications

- 40 deliverables completed so far
- All public deliverables at elegancy.no
- 5 scientific publications
 - Several under review

The screenshot shows a web browser window displaying the 'Publications' page of the ELEGANCY project website. The URL is <https://www.sintef.no/projectweb/elegancy/publications/>. The page features the ELEGANCY logo at the top, a navigation menu with 'Publications' selected, and a sidebar with social media icons for Facebook, LinkedIn, Twitter, and Email. The main content area is titled 'Publications' and contains a message: 'Project publications and public deliverables will be uploaded here once available.' Below this, there are two sections of publications:

- H₂ supply chain and H₂-CO₂ separation – WP1**
 - [D1.1.2 Report on characterization of equilibria and transport phenomena in promising new adsorbents for CO₂/H₂ separation](#)
 - [D1.2.1 Report on 1000 hour catalyst stability](#)
 - [D1.3.1 Report on optimal plants for production of low-carbon H₂ with state-of-the-art technologies](#)
 - Novel adsorption process for co-production of hydrogen and CO₂ from a multicomponent stream (*Industrial and Engineering Chemistry Research*, 58, 37, 2019. doi: [10.1021/acs.iecr.9b02817](https://doi.org/10.1021/acs.iecr.9b02817))
- CO₂ transport, injection and storage – WP2**
 - [D2.1.1 Report and software on a property model for CO₂-rich mixtures in contact with brines with a seawater-like composition](#)
 - [D2.1.4 Validation of experimental apparatus for measurement of H₂ solubility in water/brine](#)
 - [D2.1.5 Solubility of H₂ in pure water at reservoir conditions](#)
 - [D2.1.6 Solubility of H₂ in brine at reservoir conditions](#)
 - [D2.3.1 Rock and fluid sample selection for petrophysics studies](#)
 - [D2.3.2 Pore and gas sorption properties of Opalinus Clay](#)
 - [D2.3.3 Direct spatial mapping of fracture properties during shearing displacements in rock cores](#)
Journal version: *JGR Solid Earth* 2019, 127, 7; doi: [10.1029/2019JB017301](https://doi.org/10.1029/2019JB017301), Preprint.



ELEGANCY Conference

Brussels, 8 November 2018 – 85 participants from industry and academia.

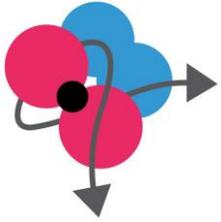
Read all about it on www.elegancy.no

09:00	Registration
09:30	<ul style="list-style-type: none">• <i>Welcome, HSE and introduction</i> Nils A. Røkke, SINTEF/EERA
09:50	<ul style="list-style-type: none">• <i>ELEGANCY overview</i> Svend T. Munkejord, SINTEF• <i>Low carbon solutions</i> Steinar Eikaas, Equinor
10:40	Coffee break & Poster session
11:00	<ul style="list-style-type: none">• <i>H21</i> Dan Sadler, Northern Gas Networks• <i>ELEGANCY case studies</i> Gunhild A. Reigstad, SINTEF• <i>Climate effects of various CCU and CCS measures</i> Ana Serdoner, Bellona
12:30	Lunch

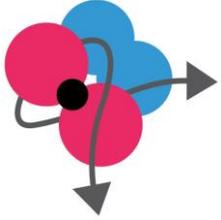
13:30	<ul style="list-style-type: none">• <i>H2@Scale</i> Bryan Pivovar, National Renewable Energy Laboratory• <i>Laboratory studies to understand the controls on flow and transport for subsurface CO₂ storage</i> Ronny Pini, Imperial College London Anne Obermann, ETH Zürich
14:30	Coffee break & Poster session
15:00	<ul style="list-style-type: none">• <i>Accelerating the energy transition – EU perspective</i> Vassilios Kougionas, European Commission• <i>Economic and legal barriers and opportunities</i> Catherine Banet, University of Oslo• <i>Blue hydrogen: The future role of decarbonised gases in Europe</i> Jorgo Chatzimarkakis, Hydrogen Europe
16:30	End of session
19:30	Dinner at Conference Hotel Restaurant

Outreach (partial list)

- Tekna CO₂ Conference, Oslo, January 2018
- ZEP Network Technology Meeting, Brussels, February 2018
- CSLF Meeting, Venice, April 2018
- Energy Technology Partnership Meeting, Glasgow, May 2018
- Joint workshop on CCS risk and liability sharing, Brussels, September 2018
- GHGT-14, Melbourne, October 2018
- ELEGANCY Conference, Brussels, November 2018
- CCUS Summit, Edinburgh, November 2018
- CLUSTER Symposium, Berlin, November 2018
- Radio, TV and newspaper appearances, Mt Terri (CH), January 2019
- CLIMIT Summit, Oslo, February 2019
- Joint workshop on CCS risk sharing and business model selection, Brussels, March 2019
- Romanian International Gas Conference, Bucharest, March 2019
- ZEP Advisory Council Meeting, Brussels, June 2019
- TCCS-10, Trondheim, June 2019
- Hydrogen storage and liquefaction symposium, Perth, September 2019
- European Utility Week, November 2019

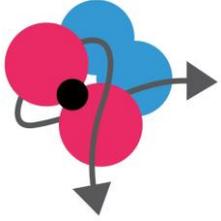


Impact

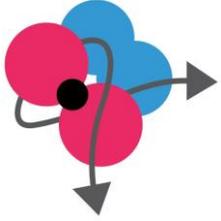


- Increased acceptance for H₂ as an enabler for a decarbonized Europe
- Enable the use of H₂ in different industrial sectors and countries – at an economically viable cost.
- De-risk CO₂ injection and storage, thus reducing a major hurdle to CCS deployment.
- The development of business models and business-case templates will facilitate economically viable deployment of CCS; it will also identify any requirements for regulatory and policy development.
- A new open-source evaluation tool for H₂-CCS integrated chains will facilitate a transparent and consistent evaluation of CCS development options including uncertainty analysis of key parameters.
- The five national case studies will promote CCS development by taking national considerations into account, while at the same time providing insights across borders.
- The inclusion of industry partners that operate across many of the ELEGANCY countries will also strengthen pan-European insights.

Conclusion



- ELEGANCY helps fast-tracking the decarbonization of Europe's energy system by combining CCS and H₂
 - By overcoming specific scientific, technological and economic/legal barriers
 - By undertaking five national case studies adapted to the conditions in the partner countries.



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.



<http://www.elegancy.no/>