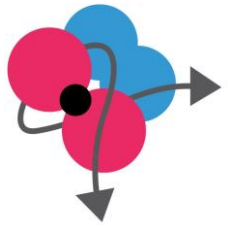


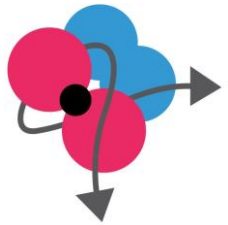
Enabling a Low-Carbon Economy via Hydrogen and CCS

Svend Tollak Munkejord, SINTEF Energy Research, project coordinator

http://www.elegancy.no/

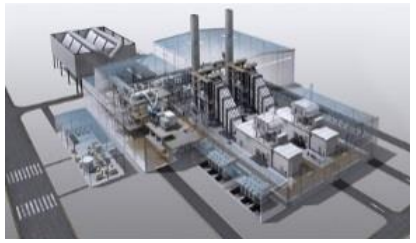
ACT knowledge-sharing workshop, Athens, 2019-11-06

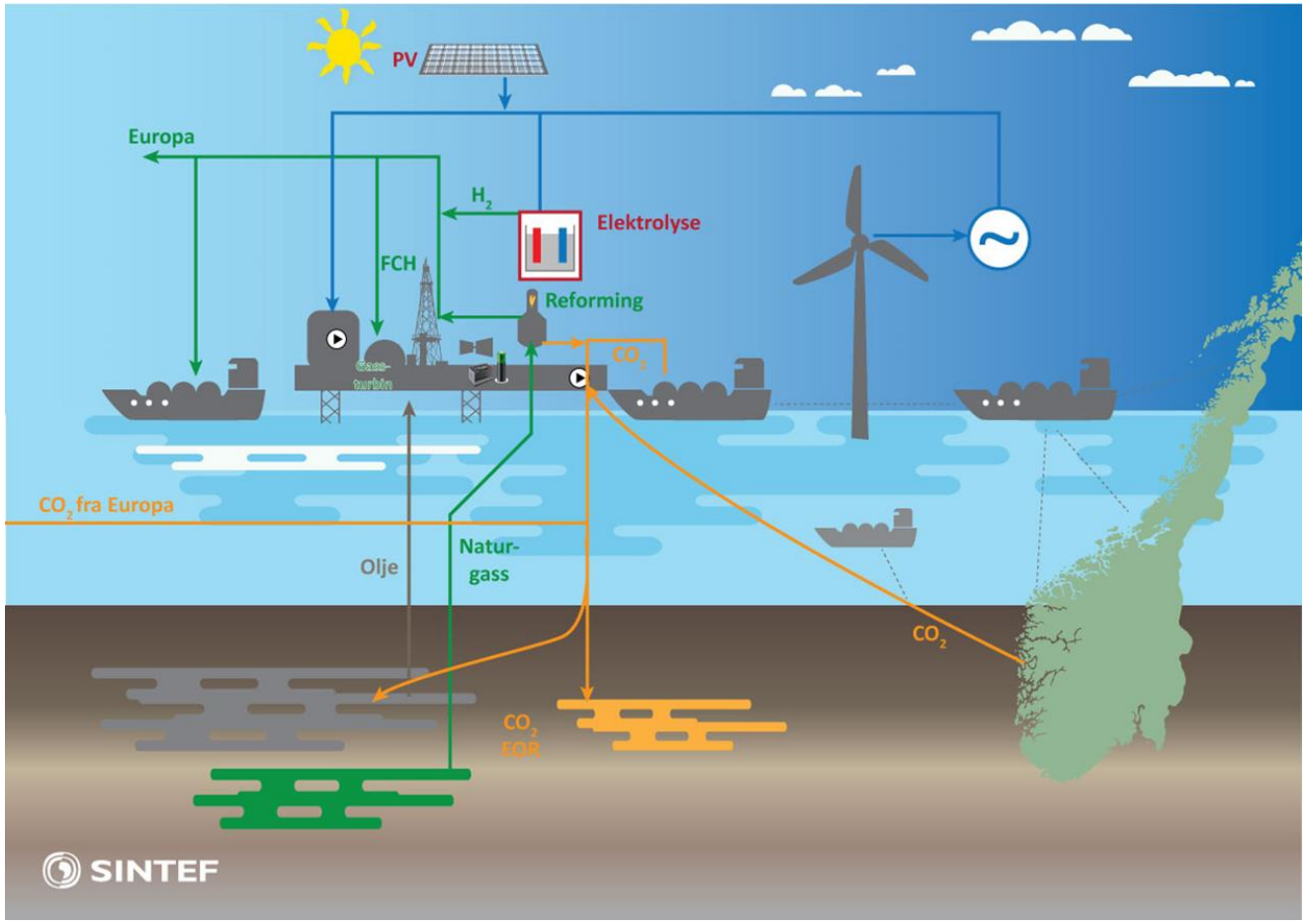
Outline of presentation



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

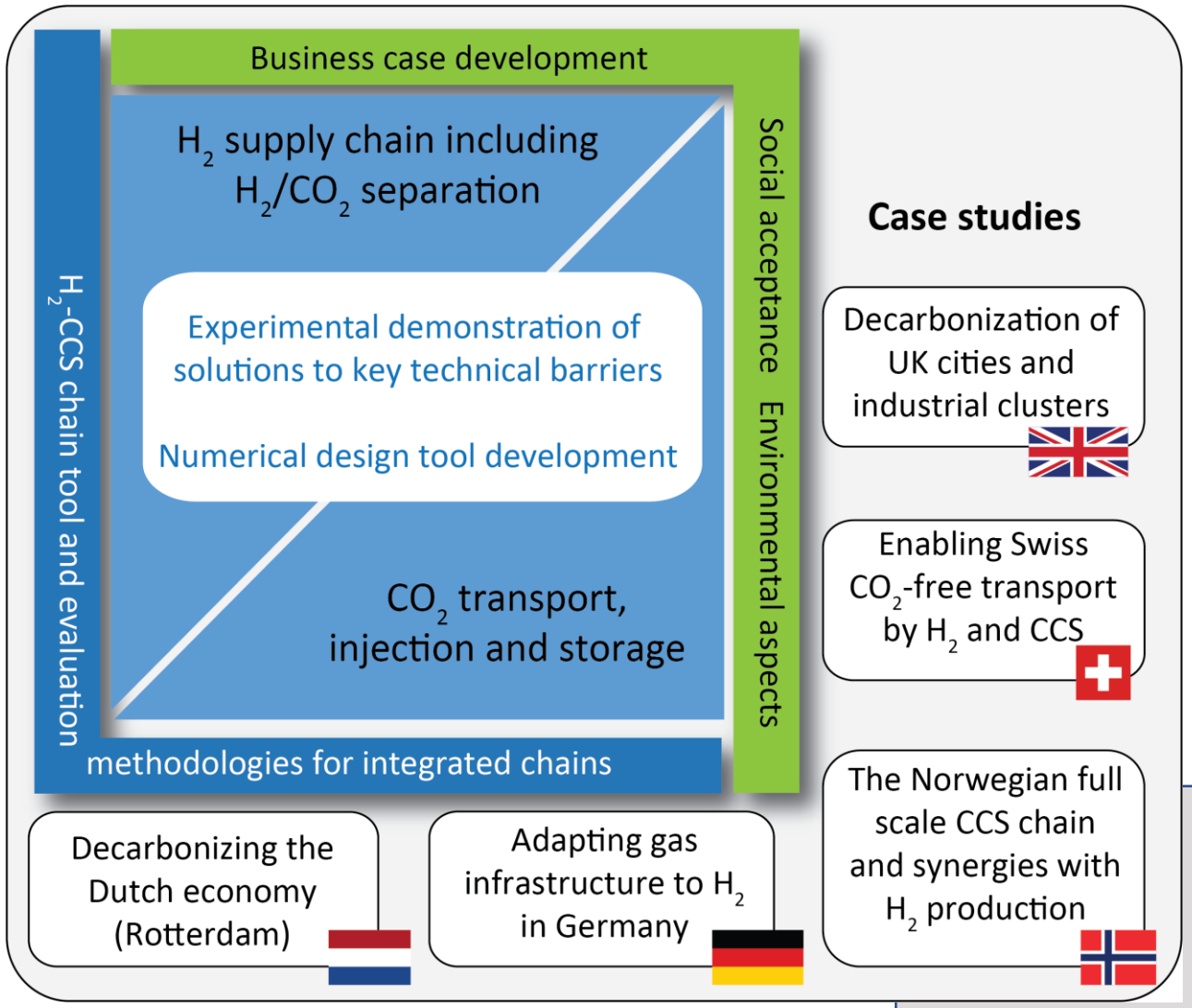
ELEGANCY – context





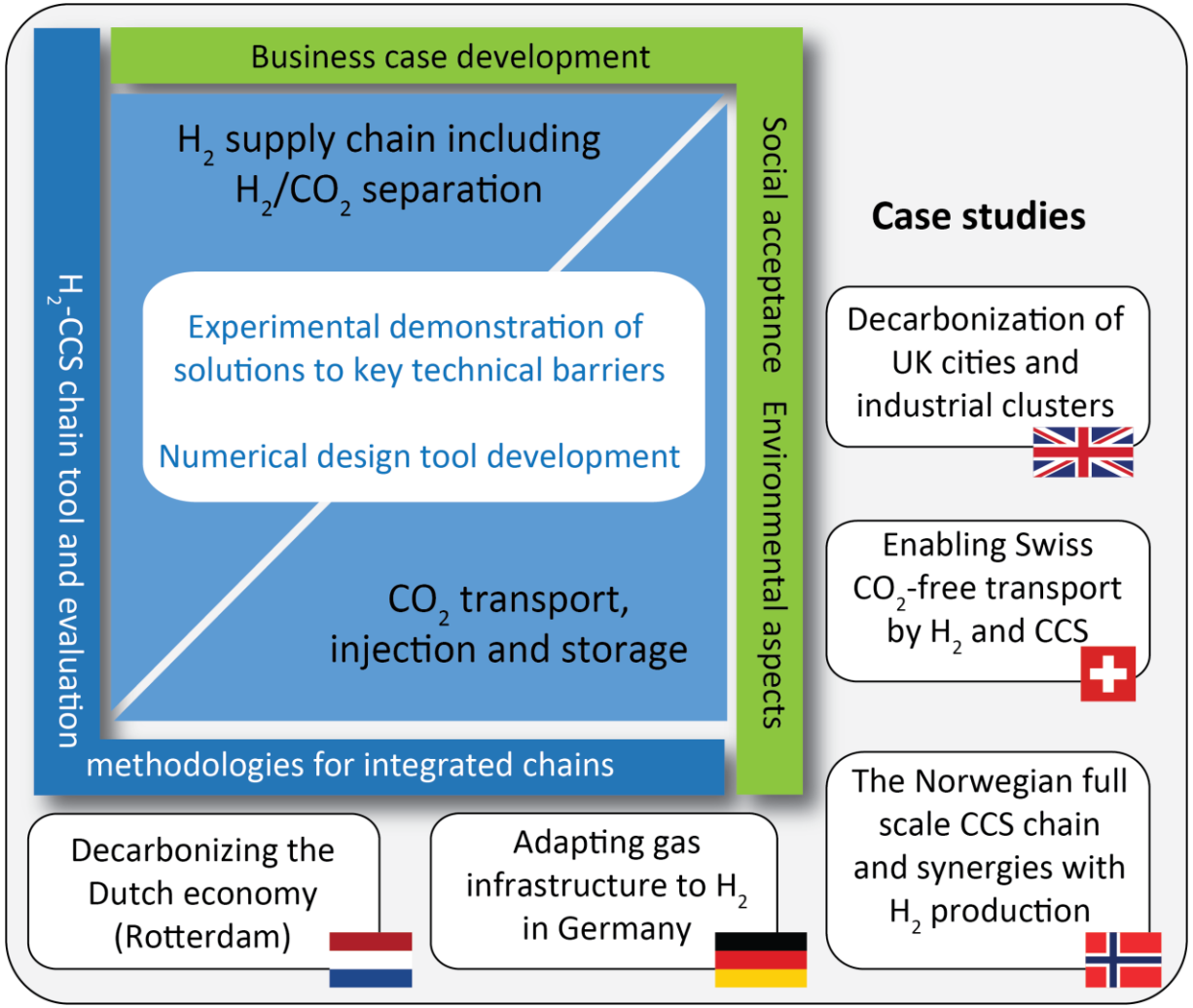
- The low-carbon economy needs H_2
- The low-carbon economy needs CCS
- Combining hydrogen with CCS offers an exciting opportunity for synergies and value creation
- ELEGANCY aims at contributing to fast-track the decarbonization of the European energy system

ELEGANCY – key information



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

ELEGANCY – Enabling a low-carbon economy via H_2 and CCS by…



1. improving the Life Cycle Analysis performance of hydrogen production with CCS;
2. enhancing our understanding of CO_2 storage, particularly stemming from H_2 production;
3. enabling low carbon H_2 production with fossil-carbon or biomass via new market models;
4. designing cost-optimal and carbon footprint-optimal H_2 and CO_2 networks;
5. assessing country-specific challenges and opportunities, and identifying feasible country-specific pathways towards a H_2 economy coupled with CCS;
6. educating the next generation of European engineers and scientists on H_2 and CCS.

Publications and news at www.elegancy.no

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**

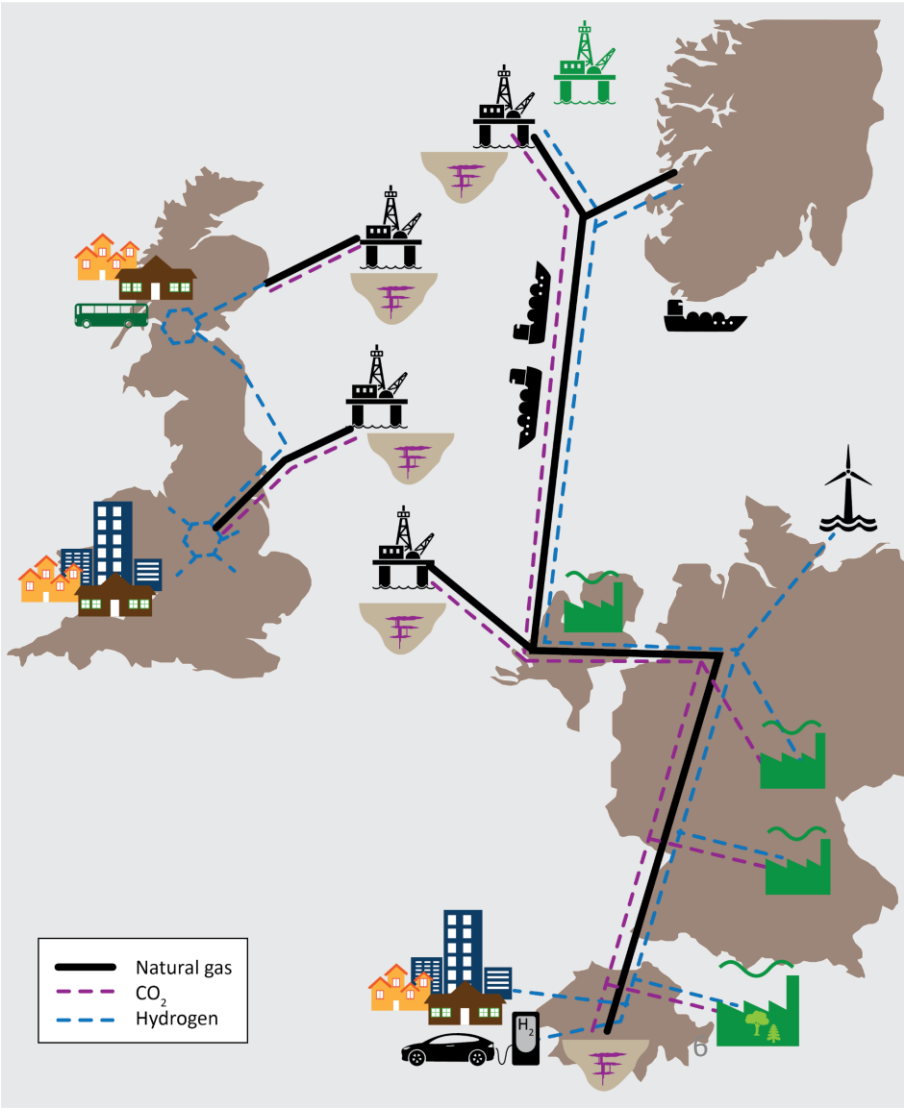
H_2 supply chain including H_2/CO_2 separation **WP1**

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

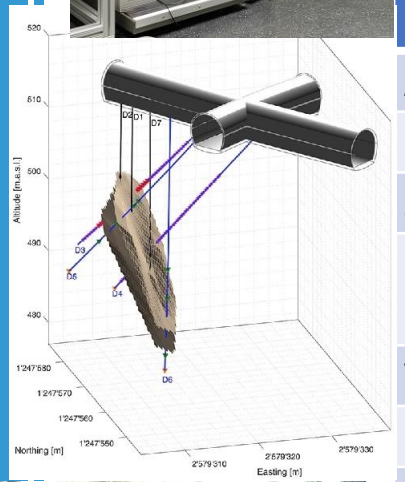
CO_2 transport, injection and storage **WP2**

- 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

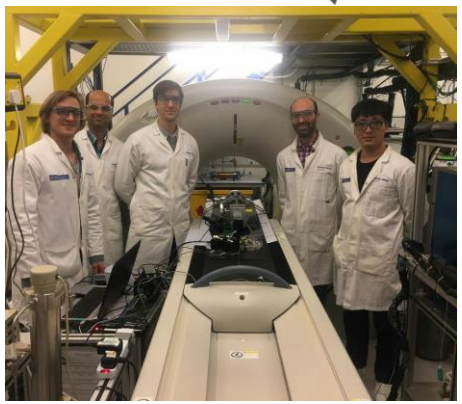
ELEGANCY project management, network building and dissemination (SINTEF) **WP6**

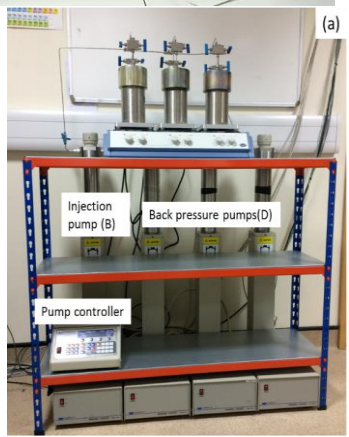


World-class research infrastructure

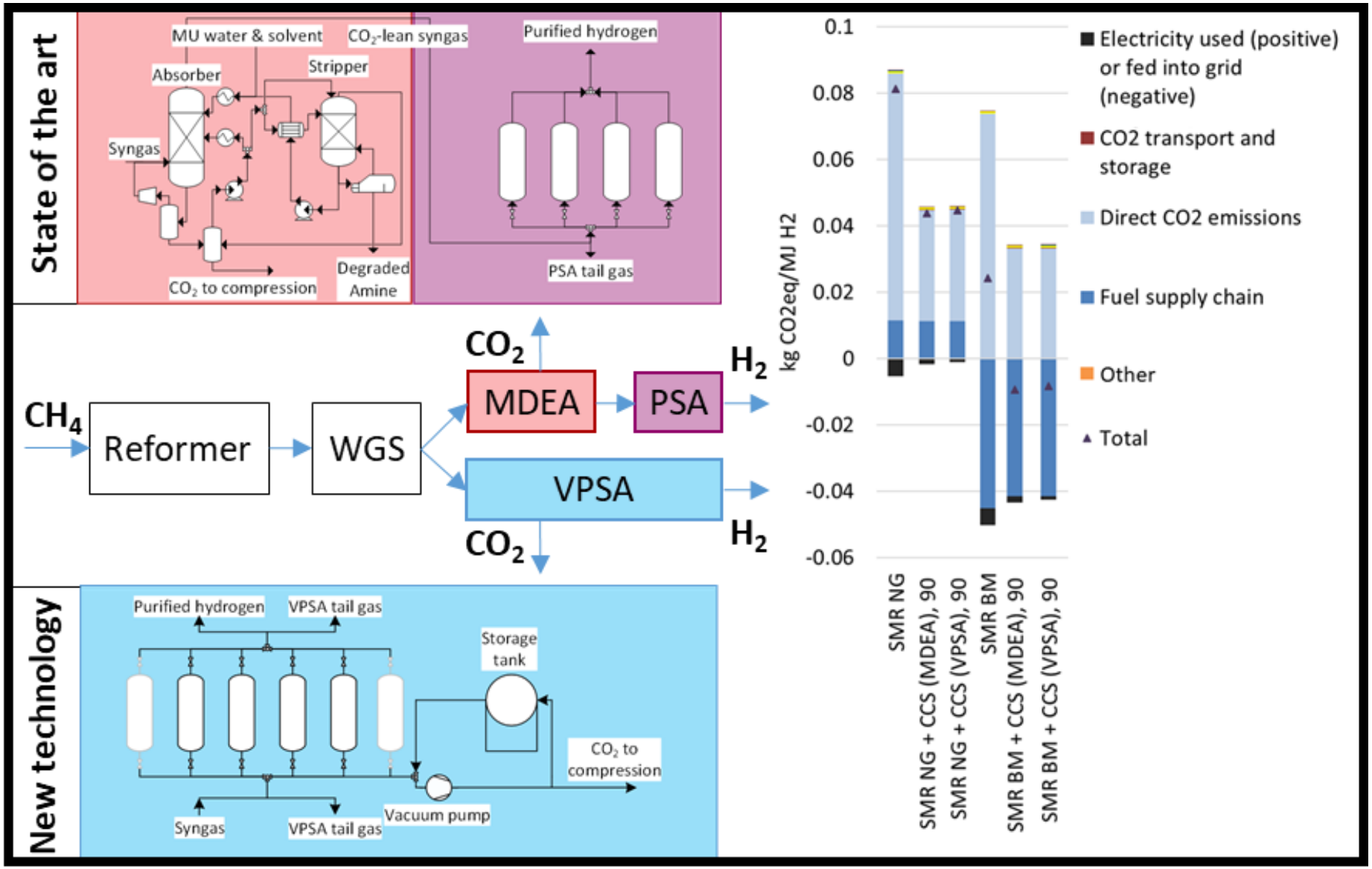


Description	Scale	Partner
Adsorption infrastructure (ECCSEL)	Lab-scale	ETH
Cycling adsorbent analyser	Lab-scale	ECN
Single- and multi-column reactive PSA/TSA equipment	Pre-pilot, TRL 5	ECN
Equipment for measurements of density, speed of sound and dielectric permittivity	Lab-scale	RUB
Vertical flow facility	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



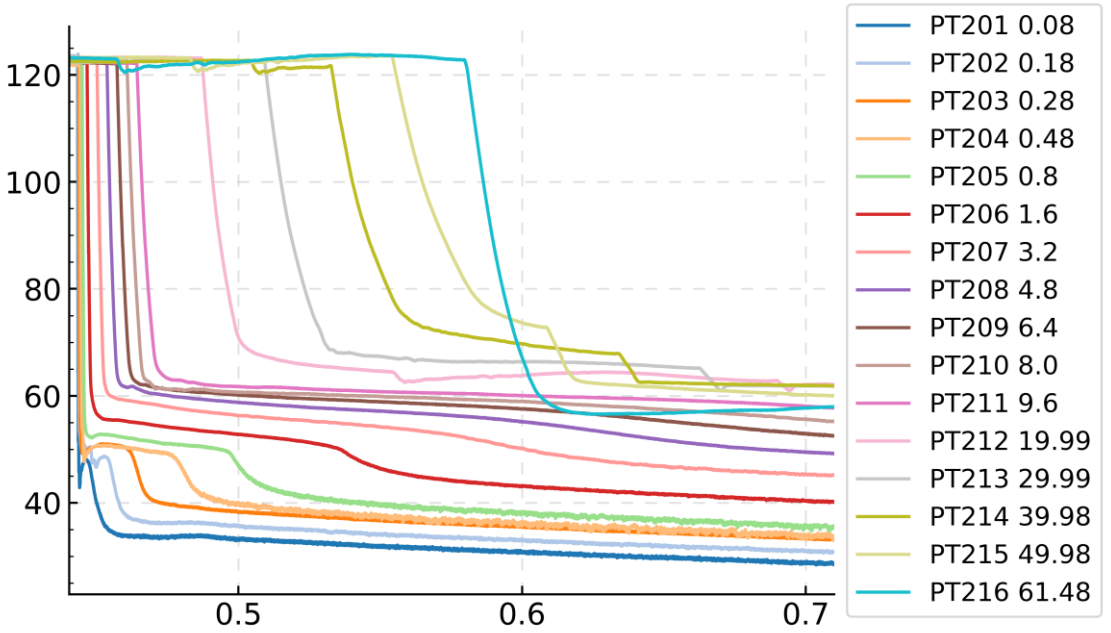


H_2 supply and H_2-CO_2 separation

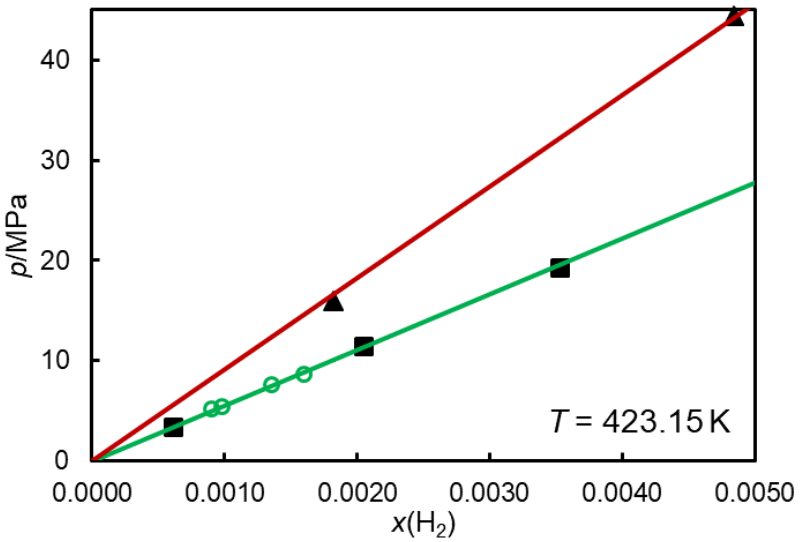


CO_2 transport, injection and storage

- 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 CO_2-rich mixtures in a tube under way. (SINTEF – top right).

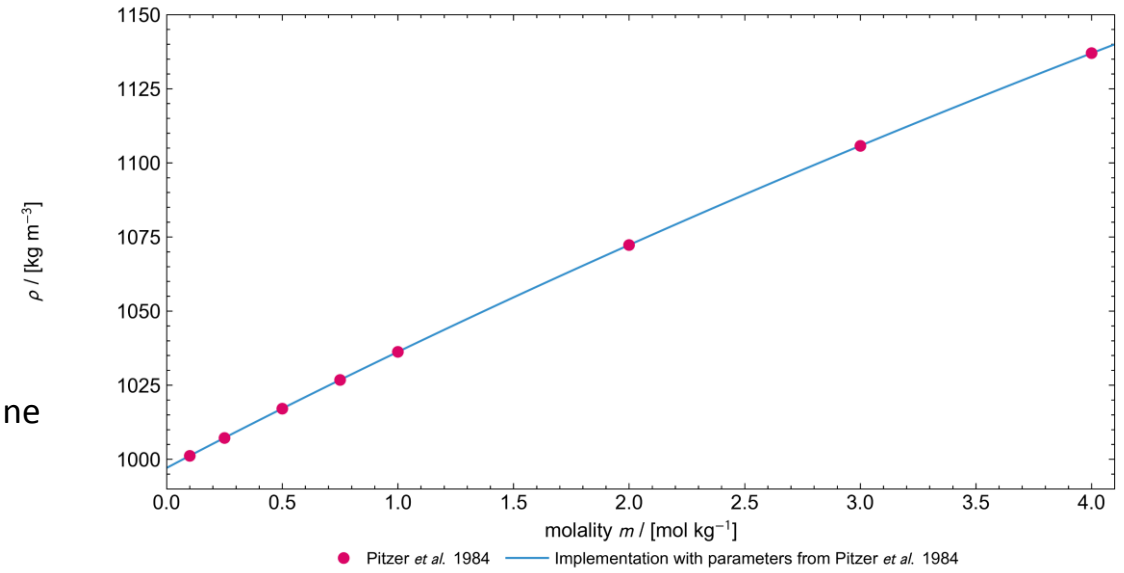


Decompression of CO_2 with 2 mol% N_2 in a tube. Measured pressure (bar) vs time (s) for different positions.



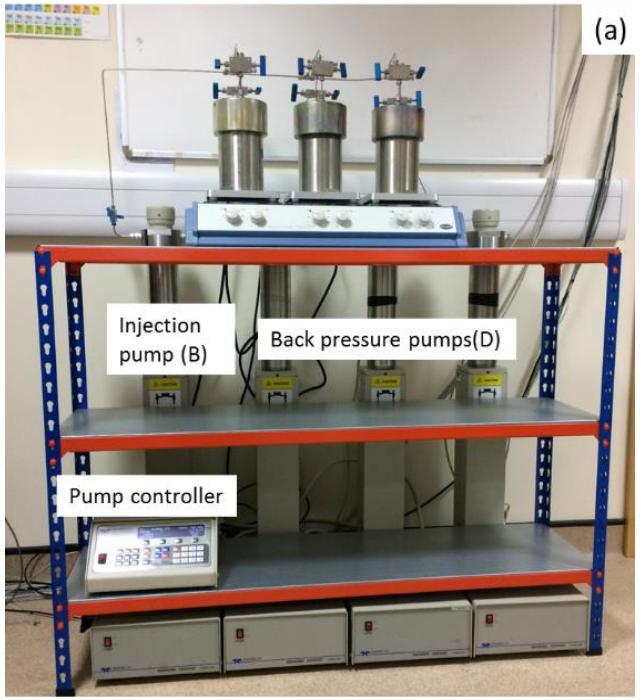
■, ▲, this work in water and NaCl(aq) (2.5 mol/kg);
○, Kling and Maurer [1] H_2 in water.

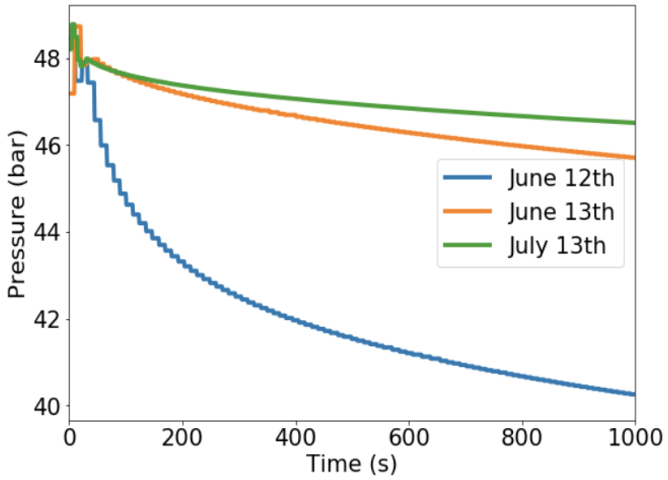
Density NaCl-brine
T = 298.15 K
p = 0.1 MPa

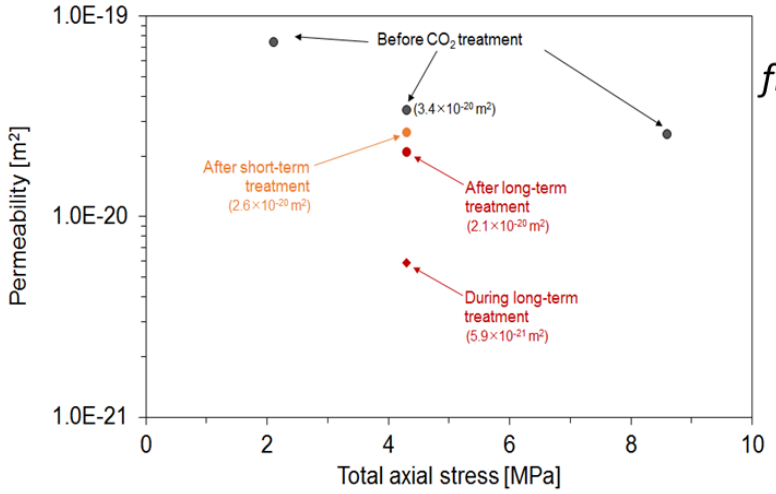


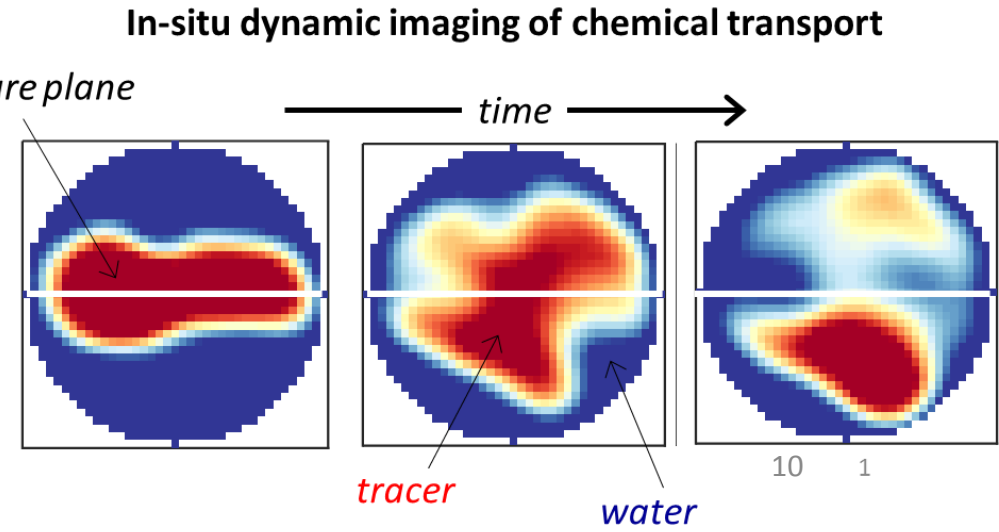
CO_2 transport, injection and storage

- Experimental geomicrobiology set-up will help understanding whether the hydrogen in the CO_2 stream could stimulate microbial activity. The batch tests to investigate the effect of CO_2 and CO_2/5%H_2 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 CO_2-rich water. The impact of two month exposure to CO_2-rich water on rock permeability has been shown to be negligible in laboratory experiments at EPFL (SCCER, below).



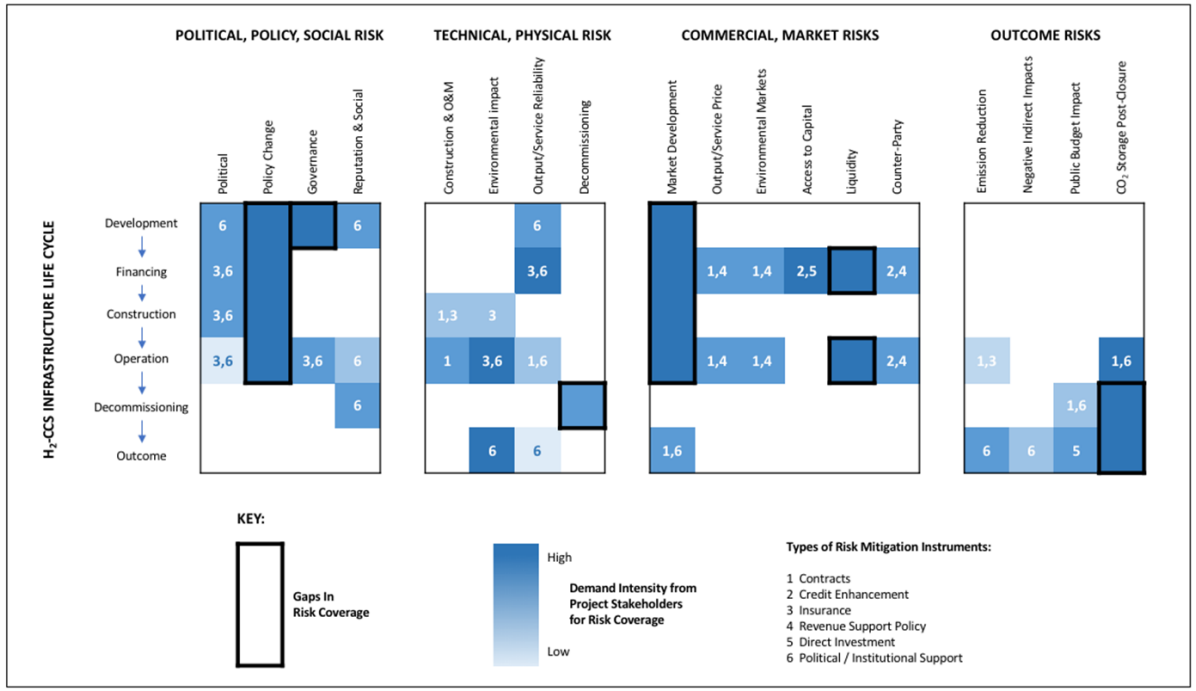






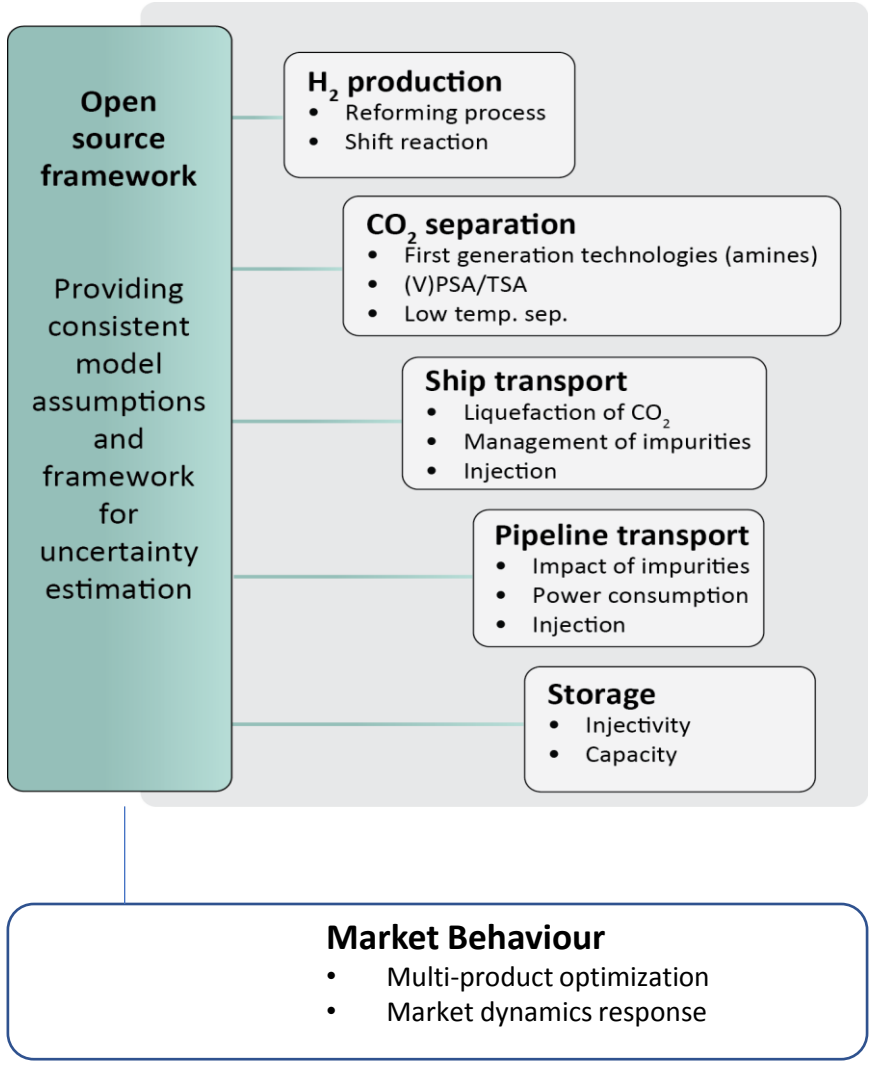
Business case development and legal aspects

- **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.



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

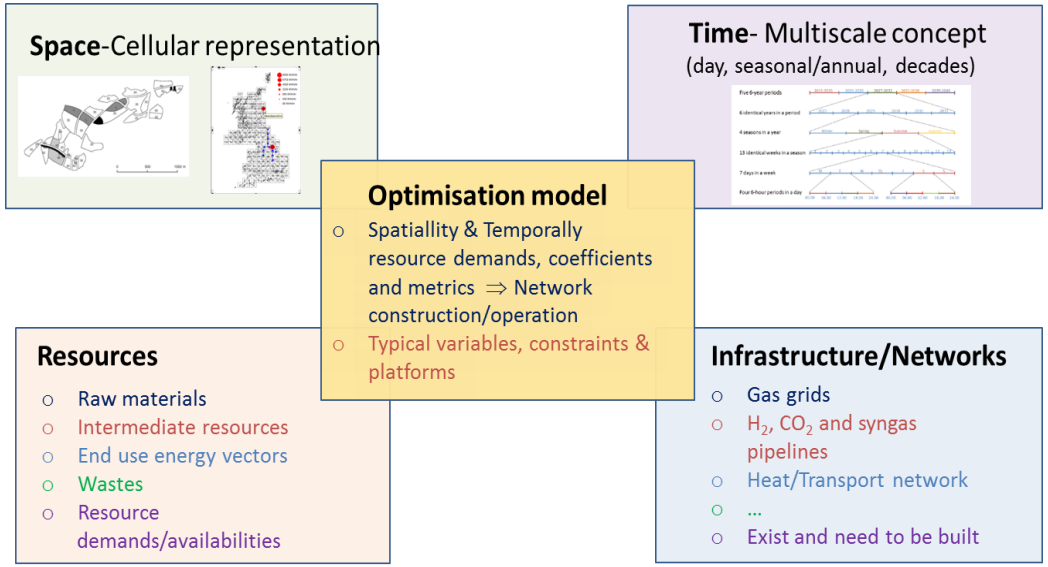


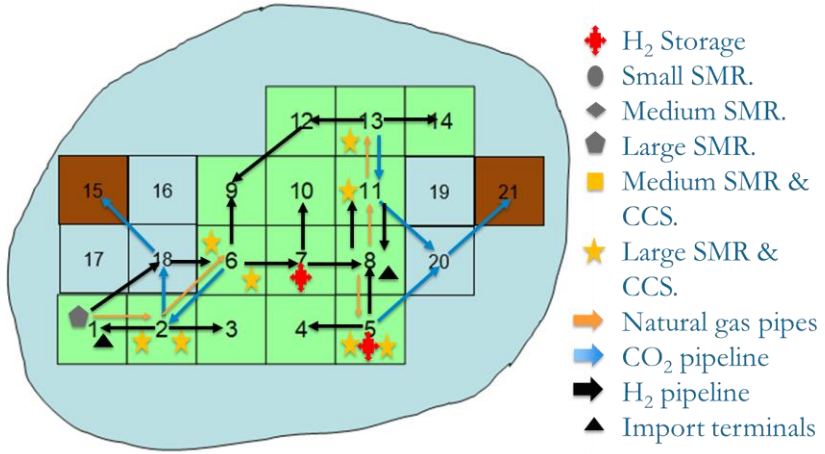
H_2-CCS chain tool

Design mode:

- Able to represent “real world” scenarios using past data.
- Capable of designing infrastructure for all key resources, whilst ensuring that CO_2 emissions are constrained as the total cost of the network is minimized.
- The model incorporates geographical input data relating to H_2 demands, geological storage volumes, natural gas infrastructure, to be used in the optimization.

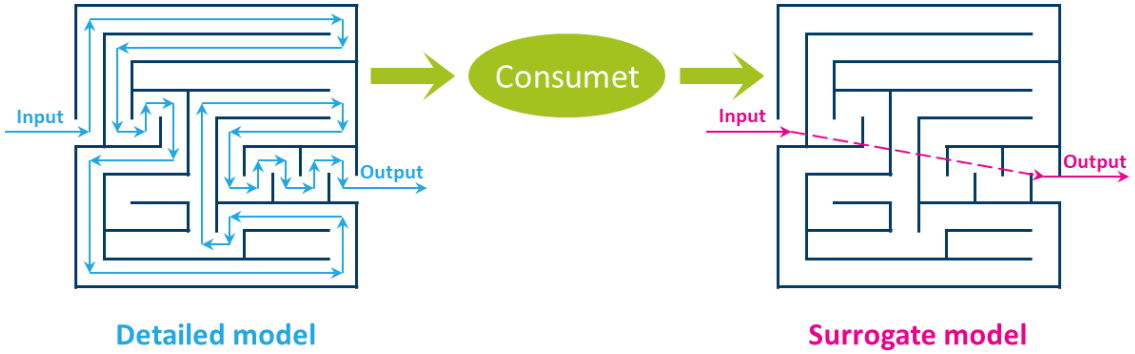
Resource Technology Framework:





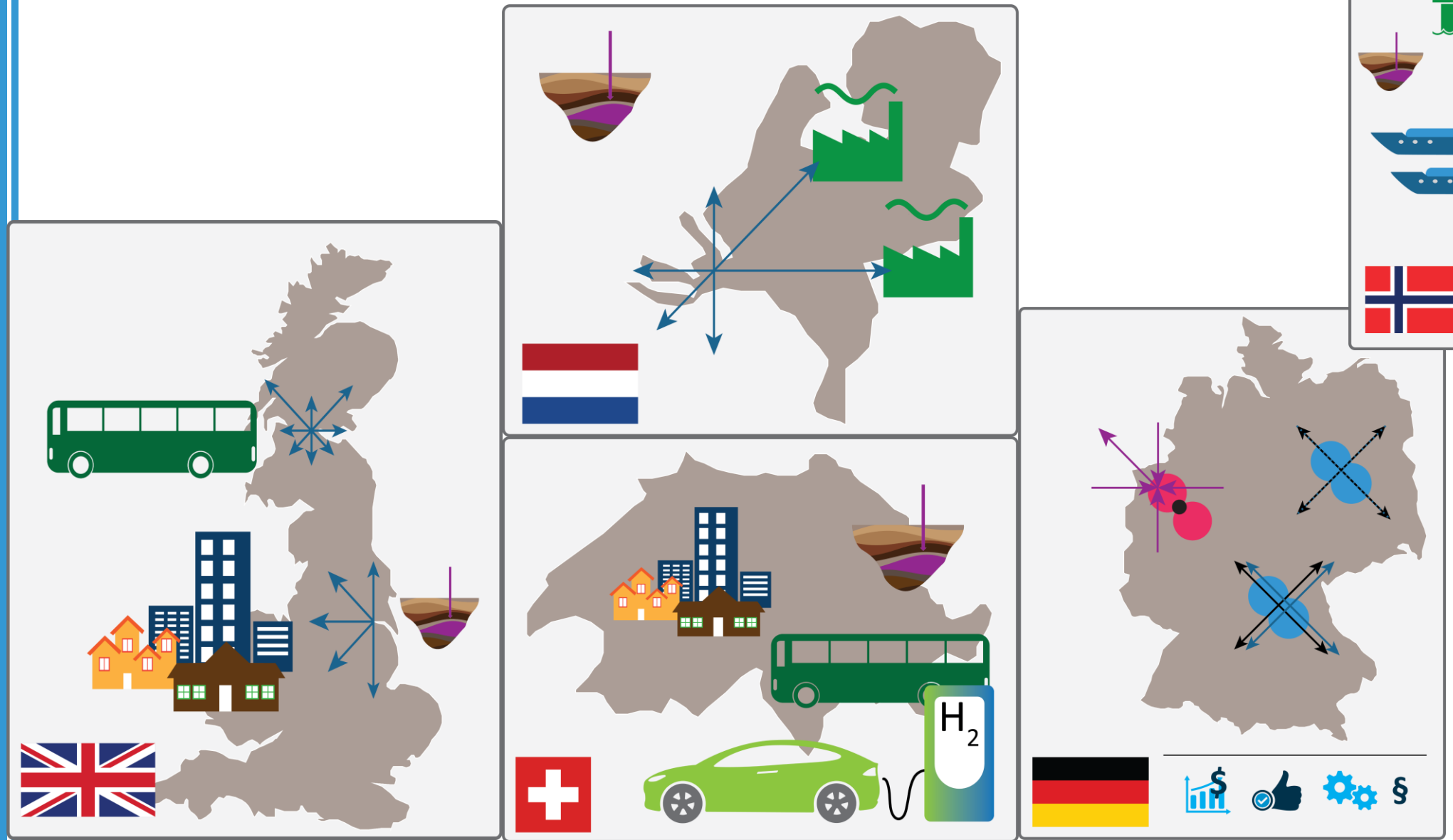
Constructor of surrogates and metamodels

- 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



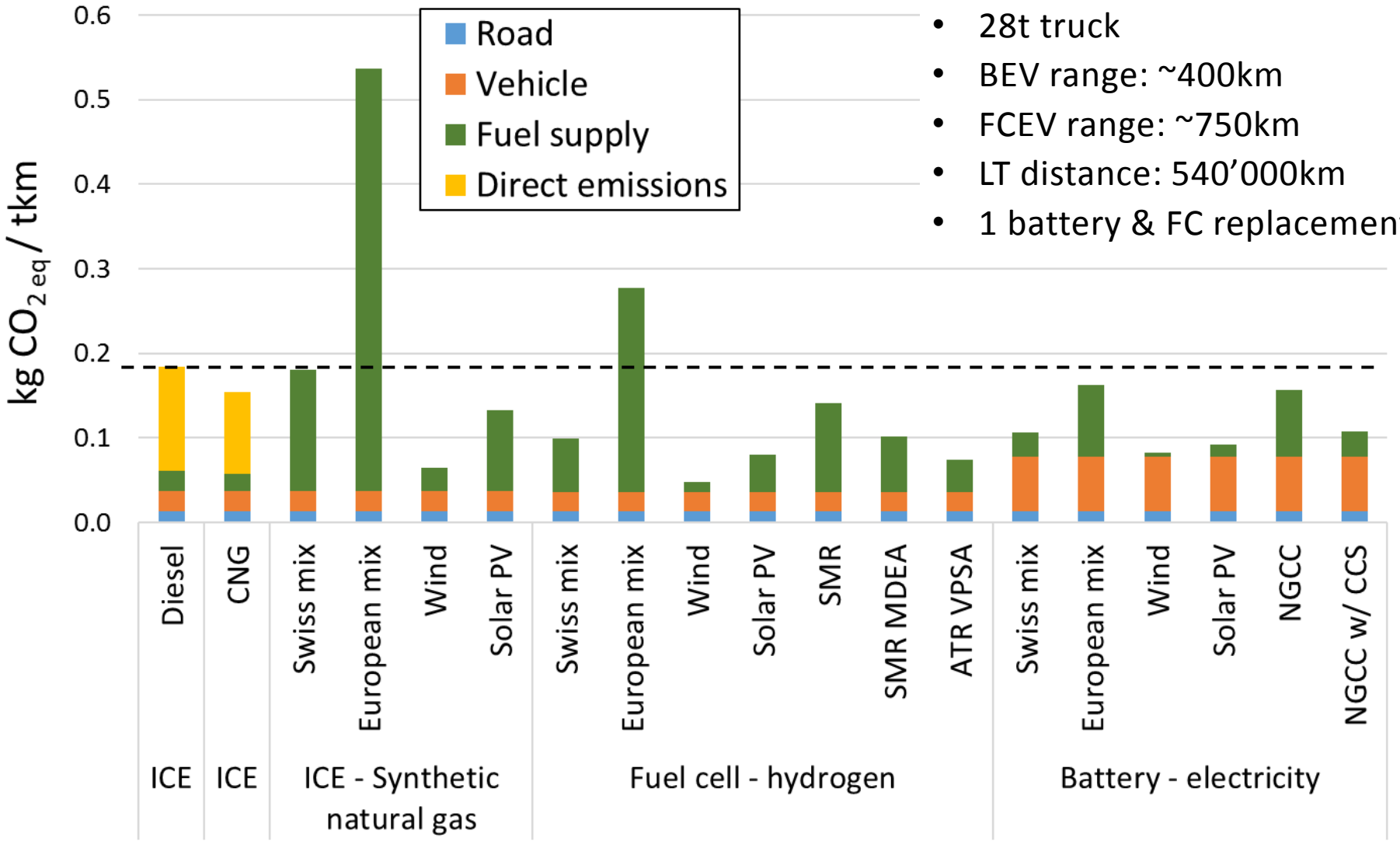
- Includes novel sampling domain restriction method
- Can be downloaded on: https://github.com/act-elegancy/consumet

ELEGANCY case studies



Enabling Swiss CO_2-free transport by H_2 and CCS

LCA results: GHG emissions of trucks

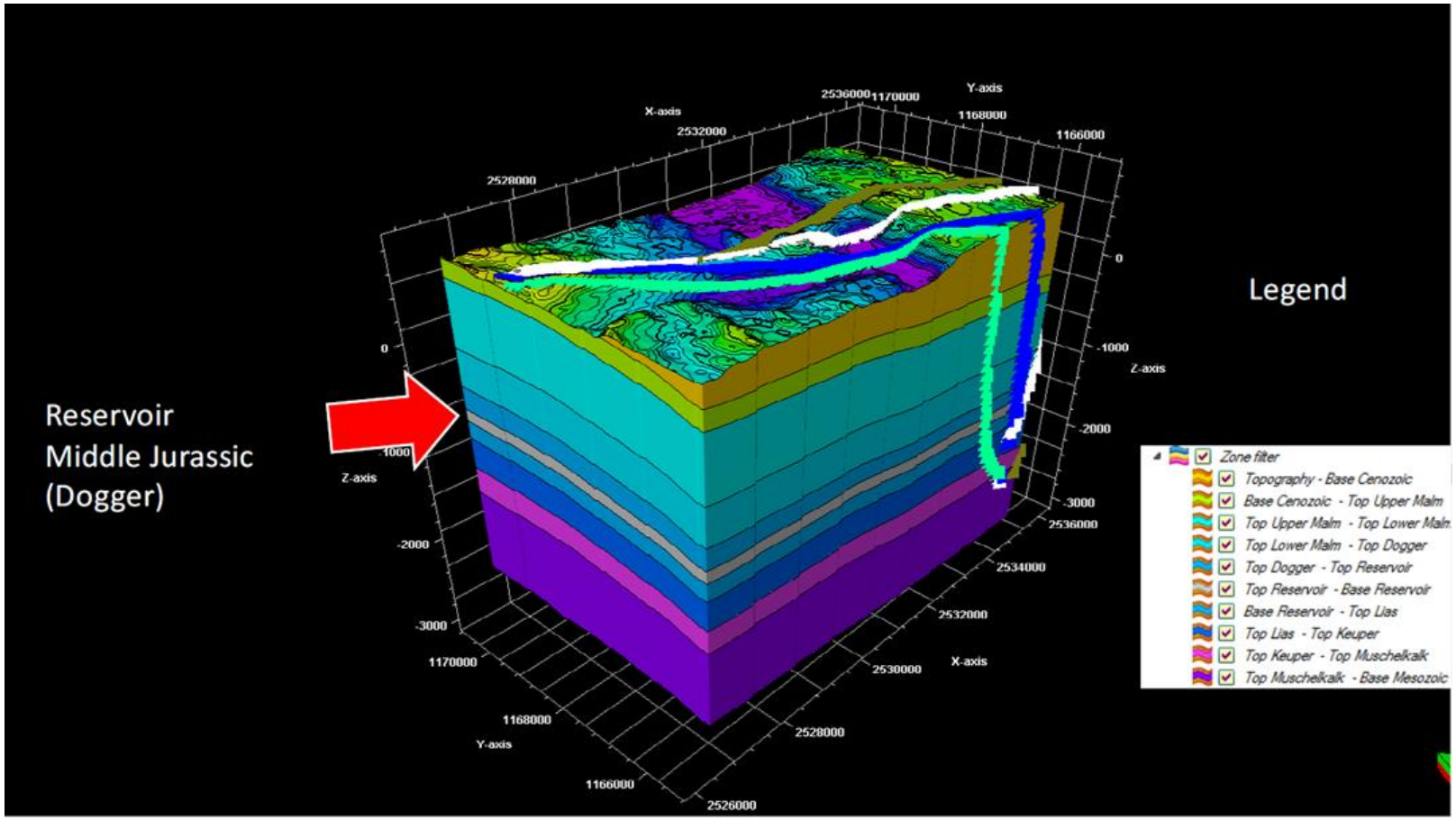


- 28t truck
- BEV range: ~400km
- FCEV range: ~750km
- LT distance: 540'000km
- 1 battery & FC replacement

Enabling Swiss CO_2-free transport by H_2 and CCS

CO_2 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.



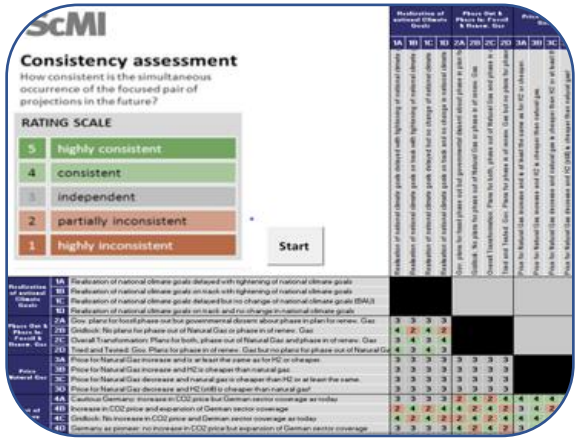
Adapting gas infrastructure to H_2 and CCS in Germany

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.

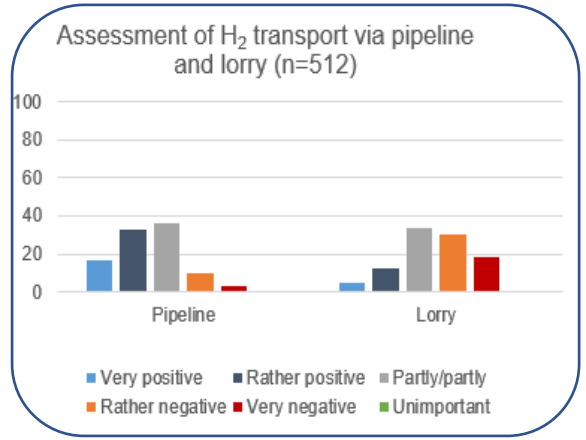
The calculation of the regional distribution of hydrogen demand is currently carried out on the basis of many statistical regional factors.



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 CO_2 pipelines.
TSO system responsibility on H_2 and interoperability - H_2 from renewable sources is given priority



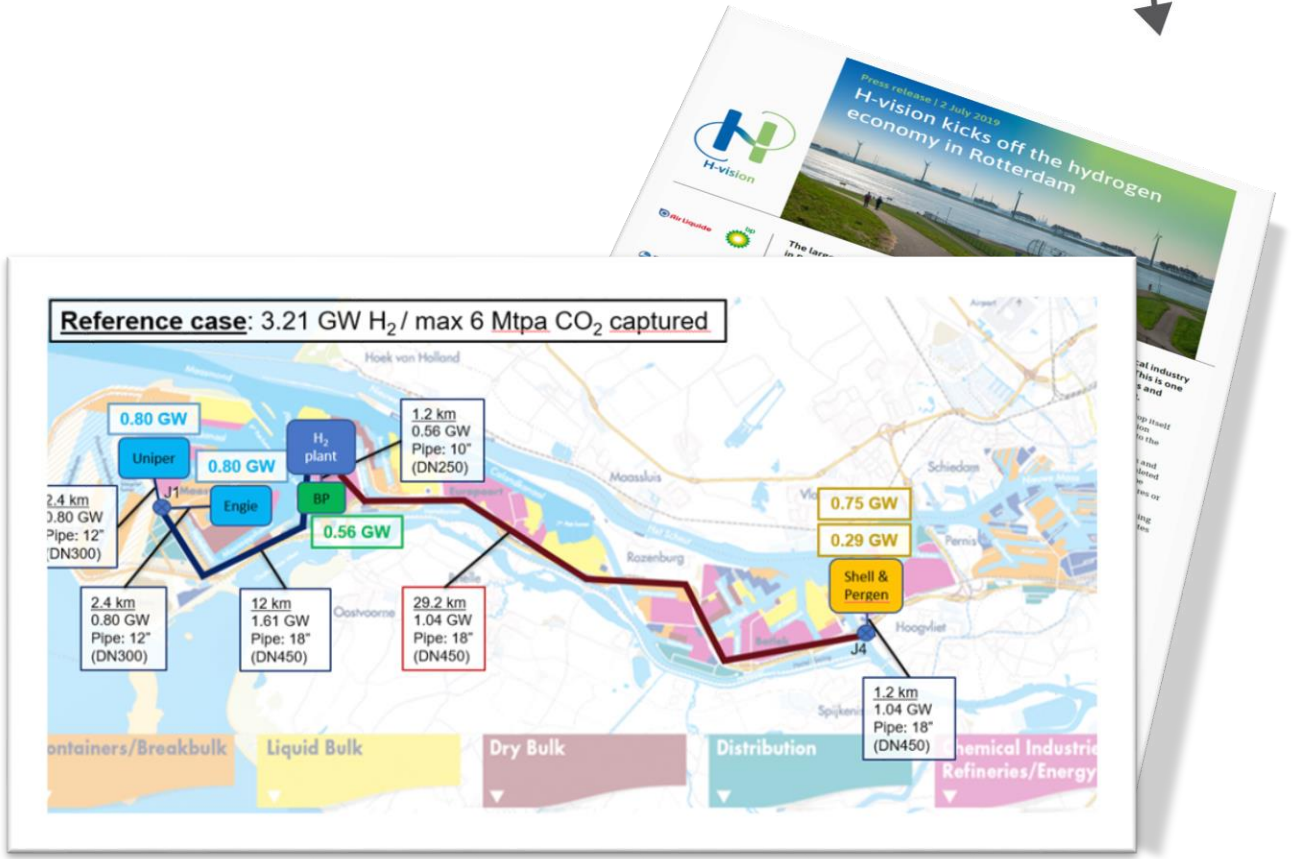
Analysis of online survey on acceptance.
The transport of H_2 via pipeline is assessed quite positively.

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

Decarbonizing the Dutch economy (Rotterdam)

Rotterdam harbor cluster

- 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



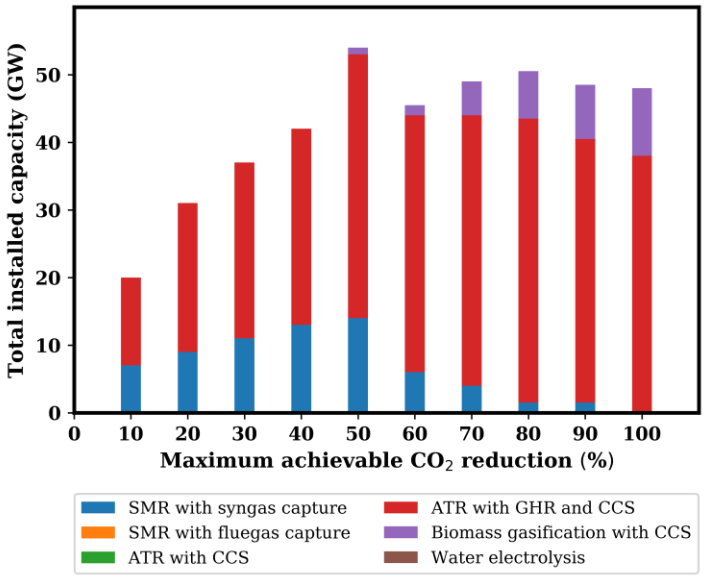
- ELEGANCY NL case study has contributed with adaptation and implementation of WP3 & WP4 tools, as well as development of specialized tools for the local energy market

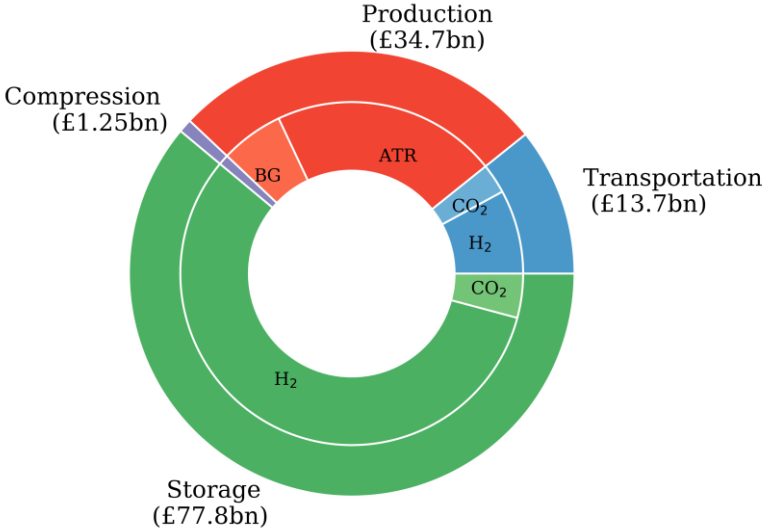
Decarbonization of UK cities and industrial clusters

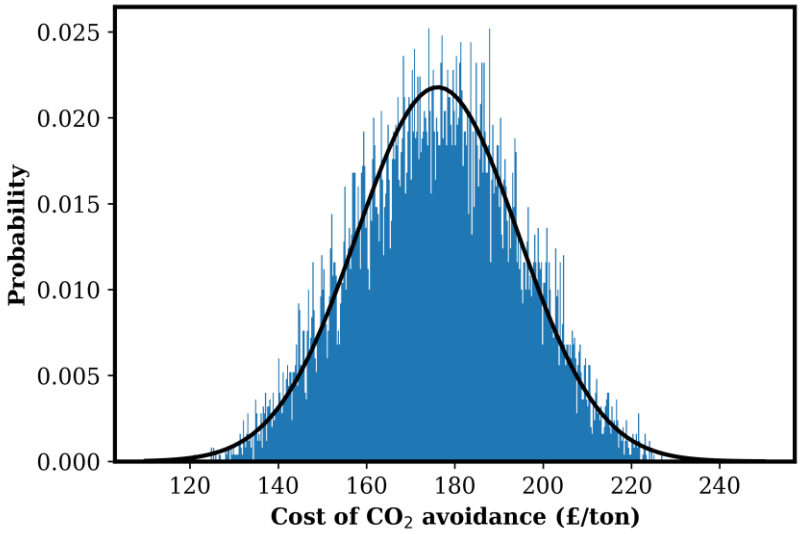
Application of ELEGANCY chain tool

Application of the H_2-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 H_2 storage CapEx.
- Cost of CO_2 avoidance may vary significantly based on natural gas and biomass feedstock prices.



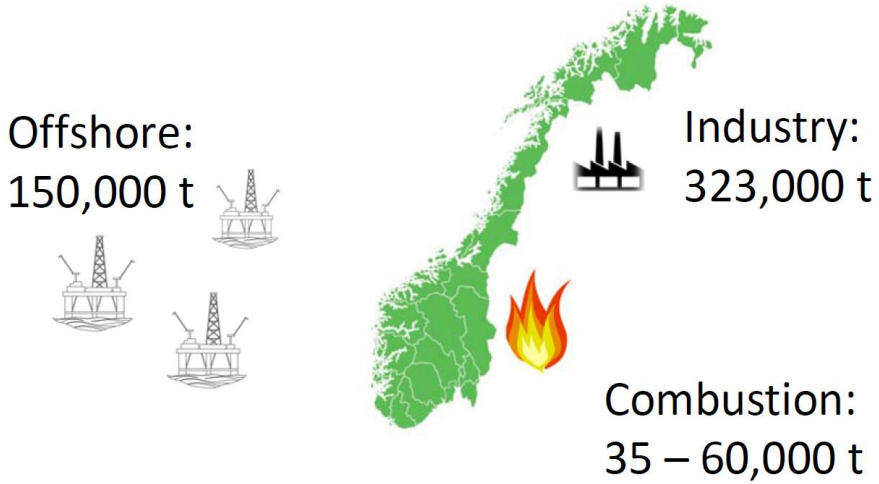




The Norwegian full scale CCS chain and synergies with H_2 production

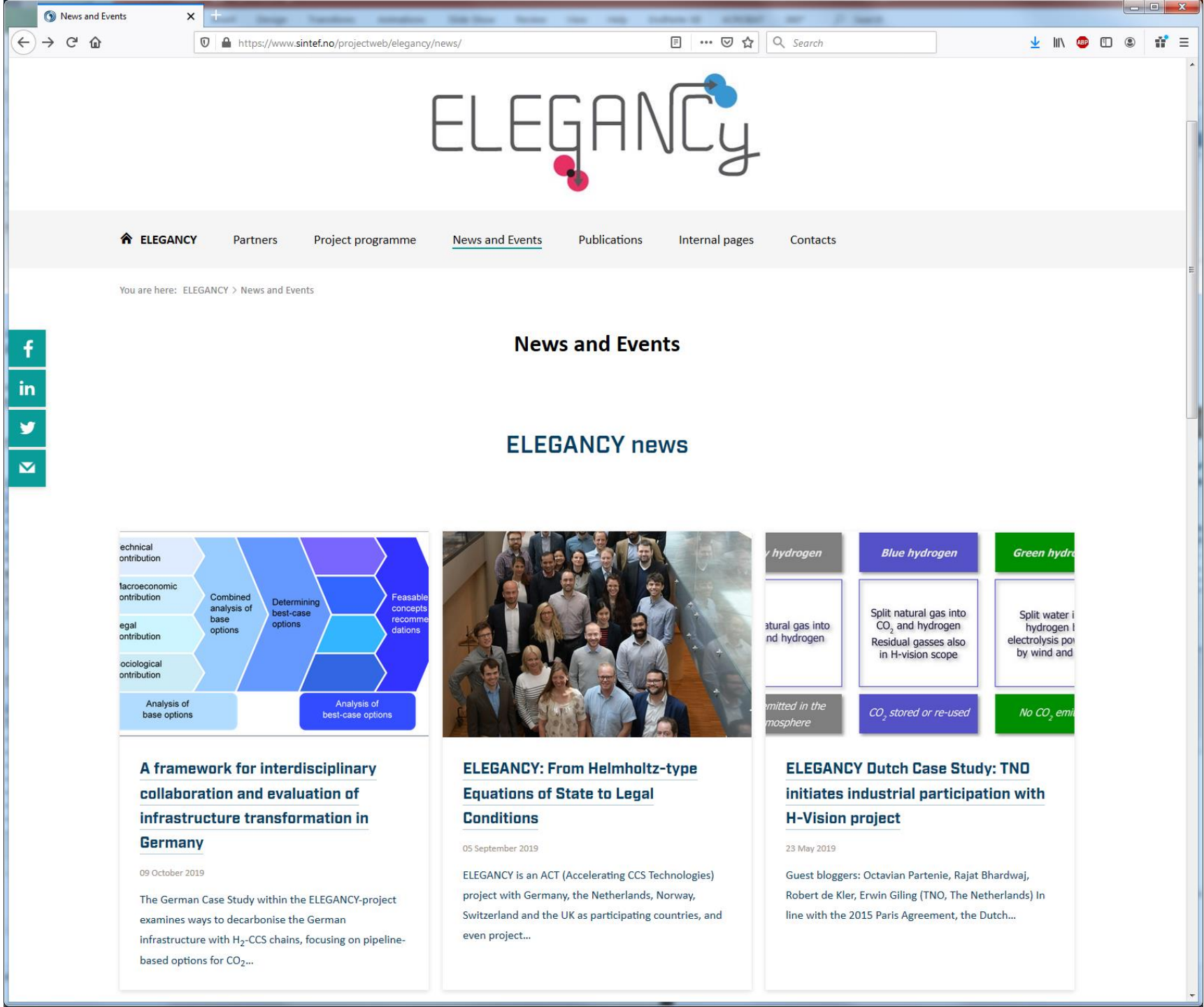
H_2 utilization and export

- A detailed analysis of the potential for H_2 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 H_2 demands individual levels for Norway, Europe and Japan/World
  - Successful development of a Norwegian CCS infrastructure
  - Constraints on development of a H_2 transport infrastructure
  - Cross-boundaries transport of CO_2 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.



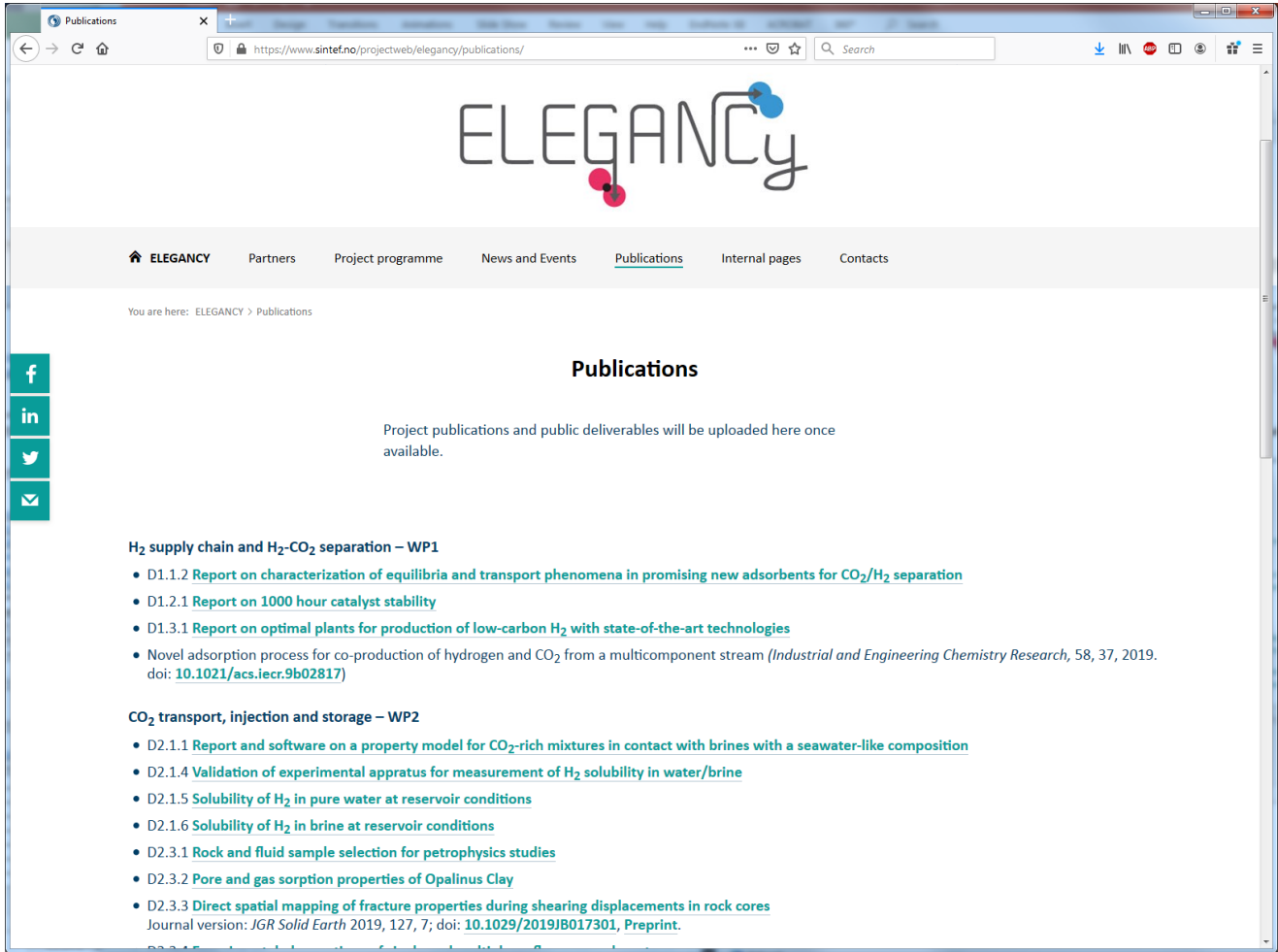
Web

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



Deliverables and publications

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



ELEGANCY Conference

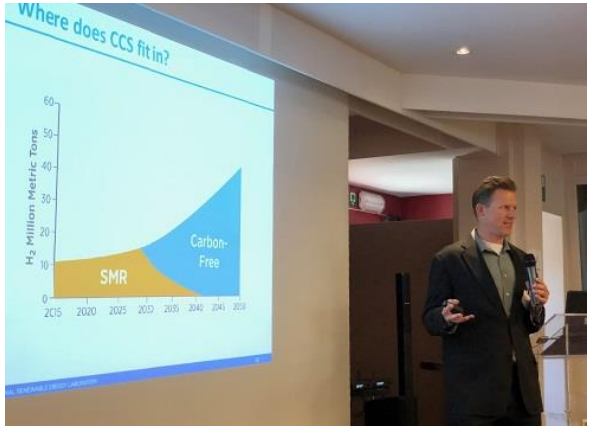
Brussels, 8 November 2018 – 85 participants from industry and academia.

Read all about it on www.elegancy.no

09:00	**Registration**
09:30	• *Welcome, HSE and introduction* Nils A. Røkke, SINTEF/EERA
09:50	• *ELEGANCY overview* Svend T. Munkejord, SINTEF • *Low carbon solutions* Steinar Eikaas, Equinor
10:40	Coffee break & Poster session
11:00	• *H21* Dan Sadler, Northern Gas Networks • *ELEGANCY case studies* Gunhild A. Reigstad, SINTEF • *Climate effects of various CCU and CCS measures* Ana Serdoner, Bellona
12:30	Lunch
13:30	• *H2@Scale* Bryan Pivovar, National Renewable Energy Laboratory • *Laboratory studies to understand the controls on flow and transport for subsurface CO_2 storage* Ronny Pini, Imperial College London Anne Obermann, ETH Zürich
14:30	Coffee break & Poster session
15:00	• *Accelerating the energy transition – EU perspective* Vassilios Kougionas, European Comission • *Economic and legal barriers and opportunities* Catherine Banet, University of Oslo • *Blue hydrogen: The future role of decarbonised gases in Europe* Jorgo Chatzimarkakis, Hydrogen Europe
16:30	End of session
19:30	Dinner at Conference Hotel Restaurant

Outreach (partial list)

- Tekna CO_2 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 H_2 as an enabler for a decarbonized Europe
- Enable the use of H_2 in different industrial sectors and countries – at an economically viable cost.
- De-risk CO_2 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 H_2-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 H_2
  - By overcoming specific scientific, technological and economic/legal barriers
  - By undertaking five national case studies adapted to the conditions in the partner countries.

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