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 $\text{H}_2$
- 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 H₂. 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 H₂ 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 H₂ production and H₂-CO₂ separation
- De-risk storage of CO₂ from H₂ 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 H₂ as energy carrier
- Assess societal support of key elements of CCS
ELEGANCY – key information

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

Business case development

**WP3**
- Economic drivers and key risks in business models
- Technical and operational characteristics
- Business case template
- Regulatory, fiscal and macro-economic background for each case study
- Business risk matrix
- Business models and commercial structures for case studies

H₂-CCS chain tool and evaluation methodologies for integrated chains

**WP4**
- First version, chain design and simulation tool
- 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

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
- 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

- **Open source framework**
  - Providing consistent model assumptions and framework for uncertainty estimation

- **H$_2$ production**
  - Reforming process
  - Shift reaction

- **CO$_2$ separation**
  - First generation technologies (amines)
  - (V)PSA/TSA
  - Low temp. sep.

- **Ship transport**
  - Liquefaction of CO$_2$
  - Management of impurities
  - Injection

- **Pipeline transport**
  - Impact of impurities
  - Power consumption
  - Injection

- **Storage**
  - Injectivity
  - Capacity

- **Market Behaviour**
  - Multi-product optimization
  - Market dynamics response
World-class research infrastructure

<table>
<thead>
<tr>
<th>Description</th>
<th>Scale</th>
<th>Partner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adsorption infrastructure (ECCSEL)</td>
<td>Lab-scale</td>
<td>ETH</td>
</tr>
<tr>
<td>Cycling adsorbent analyser</td>
<td>Lab-scale</td>
<td>ECN</td>
</tr>
<tr>
<td>Single- and multi-column reactive PSA/TSA equipment</td>
<td>Pre-pilot, TRL 5</td>
<td>ECN</td>
</tr>
<tr>
<td>Equipment for measurements of density, speed of sound and dielectric permittivity</td>
<td>Lab-scale</td>
<td>RUB</td>
</tr>
<tr>
<td>Vertical flow facility</td>
<td>Pilot-scale</td>
<td>SINTEF</td>
</tr>
<tr>
<td>Pipe and vessel depressurization (ECCSEL)</td>
<td>Lab-scale</td>
<td>SINTEF</td>
</tr>
<tr>
<td>Core-flooding laboratory</td>
<td>Lab-scale</td>
<td>ICL</td>
</tr>
<tr>
<td>Batch-reactor for mineral-dissolution kinetics</td>
<td>Lab-scale</td>
<td>ICL</td>
</tr>
<tr>
<td>Equipment for measurements of CO₂-brine-mineral contact angle, interfacial tension and phase behaviour</td>
<td>Lab-scale</td>
<td>ICL</td>
</tr>
<tr>
<td>Hydrothermal laboratory (ECCSEL)</td>
<td>Lab-scale</td>
<td>BGS</td>
</tr>
<tr>
<td>Geo-microbiology laboratory (ECCSEL)</td>
<td>Lab-scale</td>
<td>BGS</td>
</tr>
<tr>
<td>Rock deformation laboratory (ECCSEL)</td>
<td>Lab-scale</td>
<td>SCCER</td>
</tr>
<tr>
<td>Micro-seismic monitoring arrays</td>
<td>Lab-scale</td>
<td>SCCER</td>
</tr>
<tr>
<td>Mt. Terri research rock laboratory (EPOS)</td>
<td>Pilot-scale</td>
<td>SCCER</td>
</tr>
</tbody>
</table>
WP1: H₂ supply chain and H₂-CO₂ separation

• **ETH**, PSI, ECN, MEFOS, RUB, UU
  
• Enable efficient H₂ production and CO₂ capture at different plant sizes.

• Find ways to increase the efficiency and productivity of natural gas/biogas reforming and CO₂/H₂ separation independently of the plant size.

• Integrate H₂ production and CO₂ capture with significant industrial processes such as steel production

• Characterize the properties of H₂ mixed with CO₂, CO, and CH₄.

• 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)

\[ \text{max. } PUR_{H_2} \& REC_{H_2} \text{ subject to } PUR_{CO_2} > 95 \% \& REC_{CO_2} > 90 \% \]
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)
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$_2$O 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 Deliverables 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 prototype 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 H₂ markets
- Established the use industrial user group for port Rotterdam (NL)
- Established an overview of regional requirements and potentials of H₂ 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.