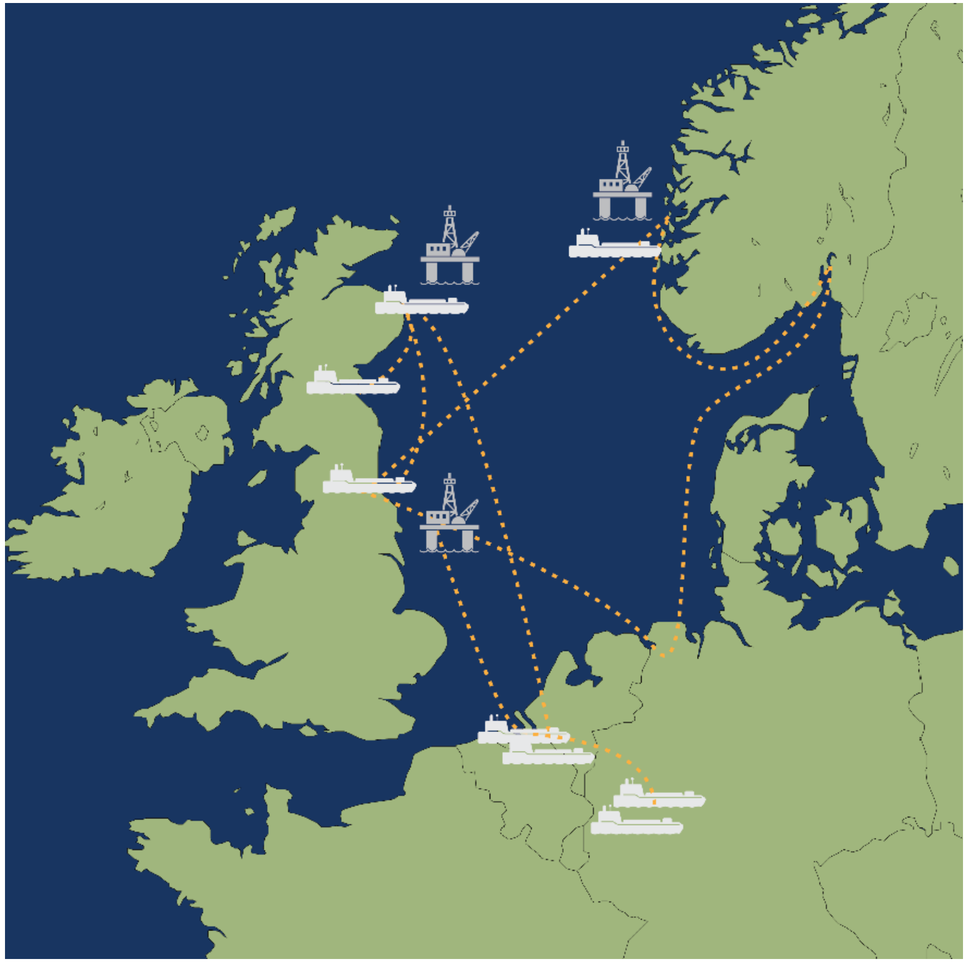
Interdependencies in the Development of Hydrogen and CCS Infrastructure

Source: Betterenergy.org



Source: ACOShip Proposal / http://ec.europa.eu/energy/infrastructure/transparency_platform/map-viewer/main.html

EERA-CCS Subproject Transport

Steering Committee Meeting EERA-FCH – October 28, 2020

EERA
European Energy Research Alliance
CCS - Carbon Capture and Storage

The Joint Project EERA-CCS

- 26 full participants, 9 associated partners
- See: https://www.eera-set.eu/component/projects/projects.html?id=41
-
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- SP2 - CO_2 Storage: Jonathan Pearce, BGS (jmpe@bgs.ac.uk)
- SP3 - CO_2 Transport: Roland Span, RUB (roland.span@thermo.rub.de)
- SP4 – Communication and Outreach: Hannah Chalmers, UKERC / UoE (hannah.chalmers@ed.ac.uk)

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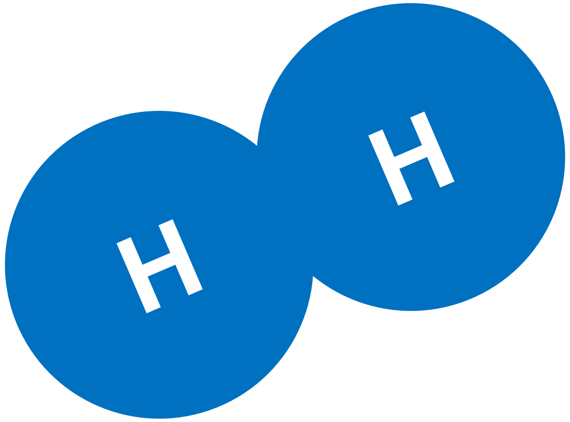
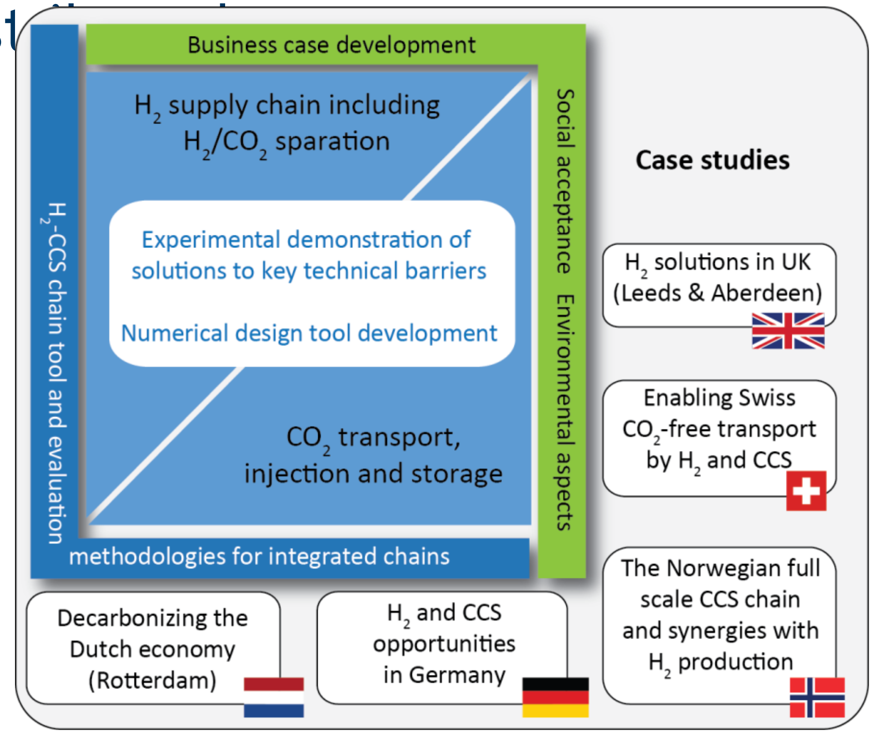
Blue Hydrogen as a Bridging Technology

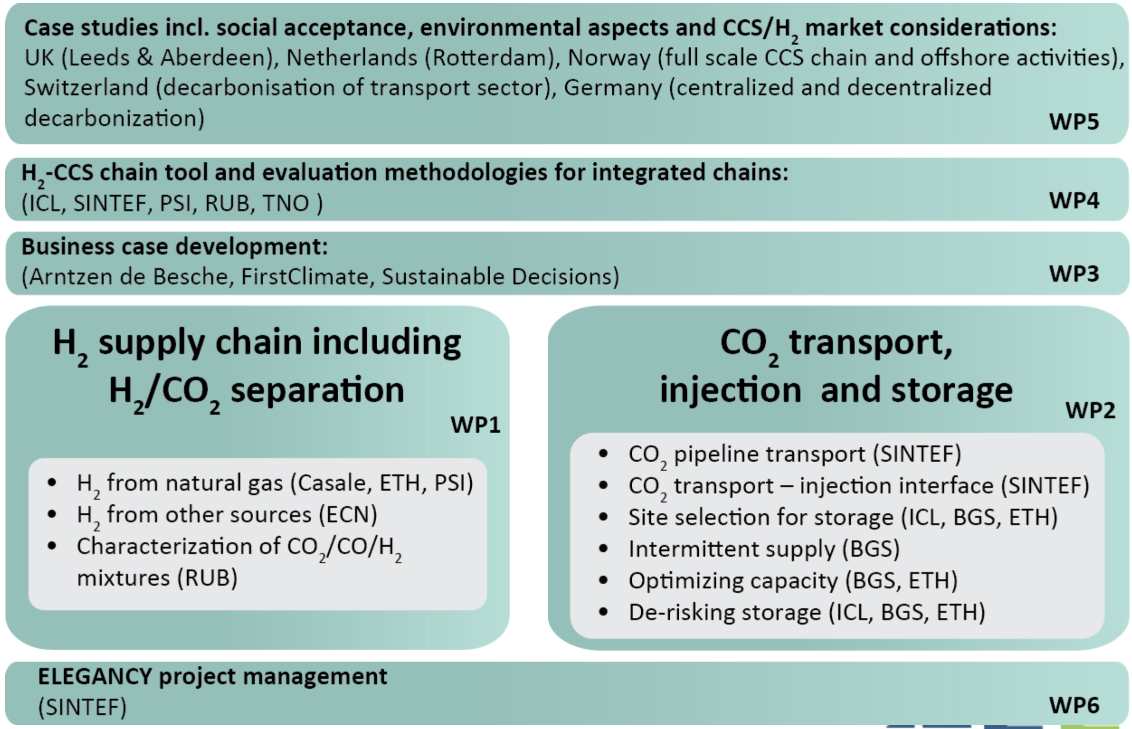


- To establish a hydrogen infrastructure and hydrogen based processes in industry based on fluctuating (and initially limited) hydrogen supply is difficult
- From beginning on requirements on hydrogen storage
- In Germany different projects aim at electrolytic hydrogen generation from grid power ⇨ mitigation effect questionable
- Hydrogen synthesis from natural gas in combination with CCS is a promising bridging technology
- Once hydrogen infrastructure and applications are established, the replacement of blue hydrogen by green hydrogen is entirely flexible
- Different European projects aim at the introduction of blue hydrogen

Blue Hydrogen as a Bridging Technology – ELEGANCY

- ELEGANCY – Enabling the Low Carbon Economy by Hydrogen and CCS
- Multinational project in the EERA-ACT program
- Scenario: Hydrogen is generated from natural gas with CCS, hydrogen is dist





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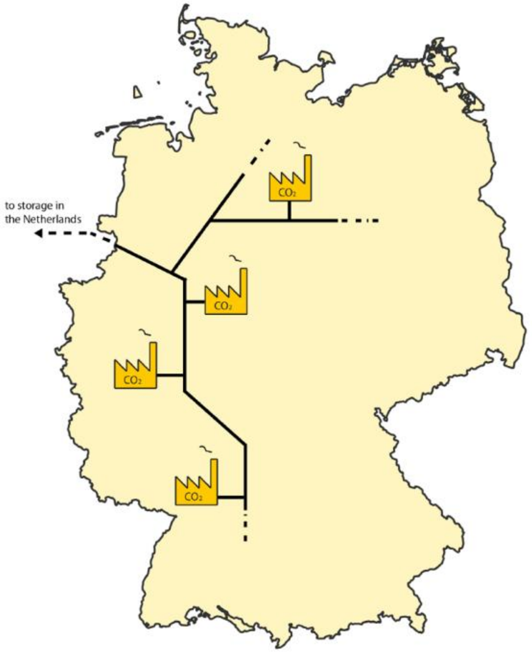
ELEGANCY – the German Case Study

- Hydrogen is supplied by Norway, generated from reforming natural gas with CCS

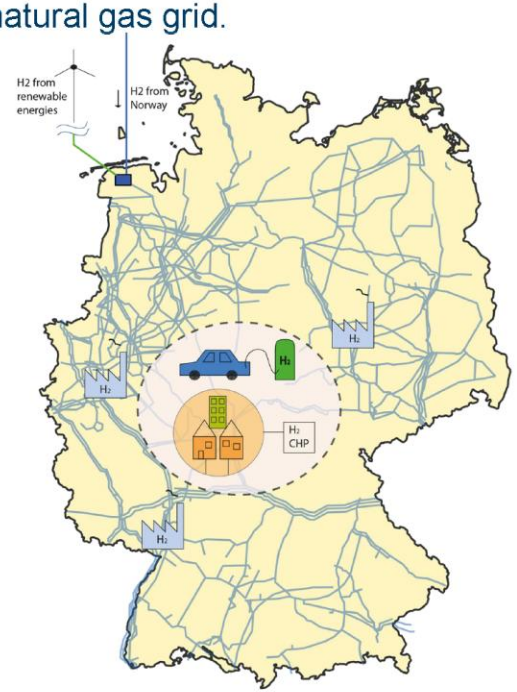
Option 1 – Carbon capture & transport

Large CO_2 point sources are being decarbonised, the captured CO_2 is transported via a new CO_2 transport infrastructure to a storage site abroad.



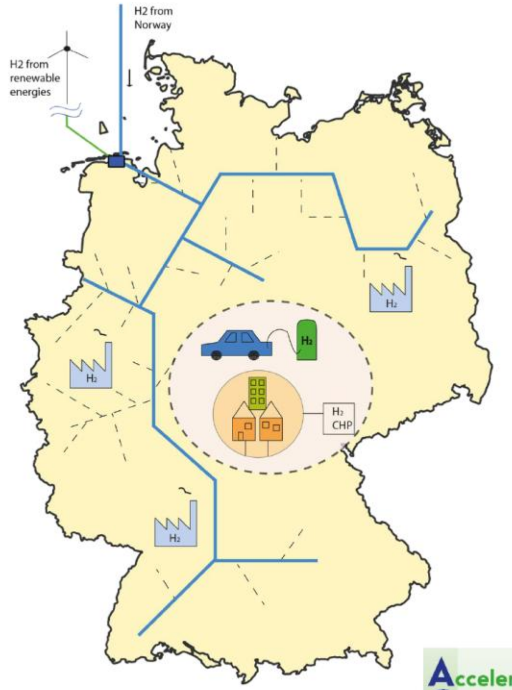
Option 2 – H_2 Admixture

Natural gas is decarbonised at the point of production, hydrogen is imported to Germany and admixed into the existing natural gas grid.



Option 3 – H_2 Network

Clean hydrogen is imported as in option 2 and distributed to the end-users via a new H_2 transport infrastructure.



ACT ELEGANCY, Project No 271498, has received funding from DETEC (CH), the German Federal Ministry for Economic Affairs and Energy (DE), RVO (NL), Gassnova (NO), BEIS (UK), Gassco AS and Statoil Petroleum AS, and is cofunded by the European Commission under the Horizon 2020 programme, ACT Grant Agreement No 691712.

Accelerating CCS Technologies

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

ELEGANCY – the German Case Study

- Hydrogen is supplied by Norway, generated from reforming natural gas with CCS

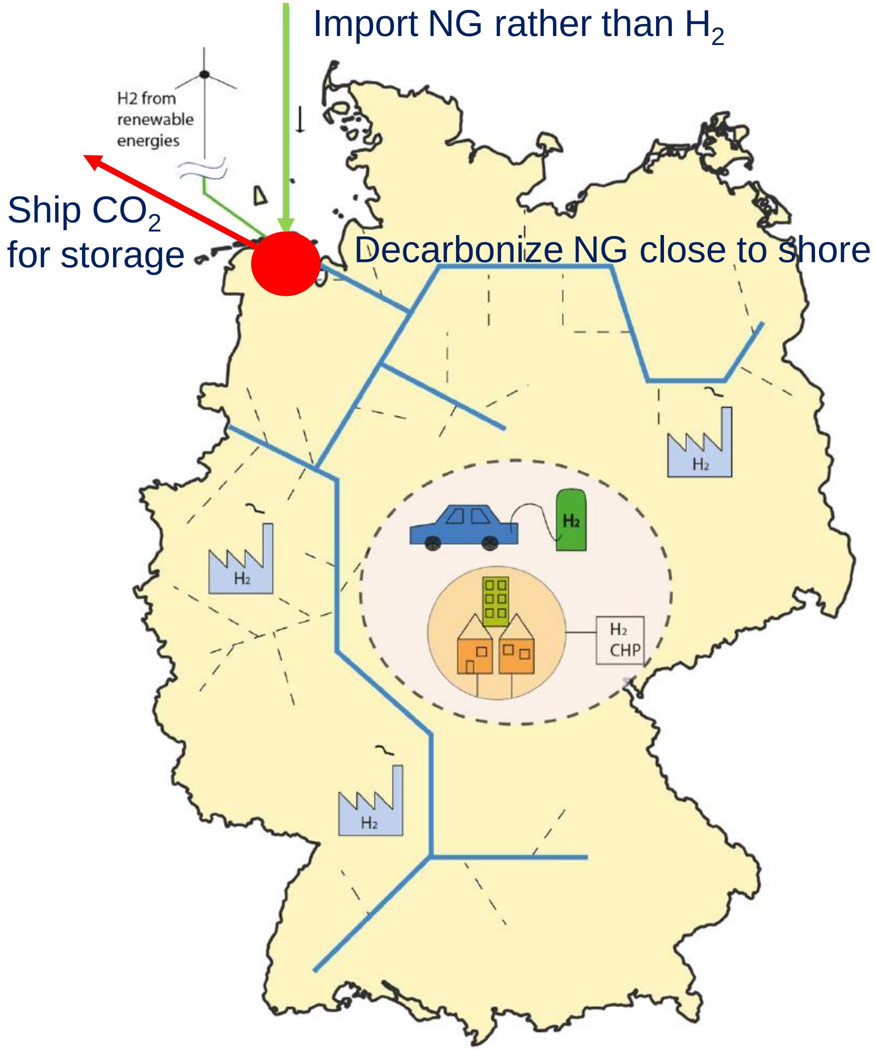
Technical approach:
- Aim: evaluation of the three infrastructure options in terms of their CO_2 reduction potential and abatement costs, on which basis a best case scenario could be designed
- Approach: GIS-based model for the three infrastructure options, consisting of future framework conditions and specific data on the H_2/CO_2 sites under consideration. The infrastructure is planned based on the routing of the natural gas network.

Macroeconomic approach:
- Aim: to assess the conditions that foster or hinder the transition towards a low-carbon economy by evaluating the different infrastructure options
- Approach: stakeholder-centred economic analysis that provides macroeconomic descriptive scenarios for decision making
- Criterion for evaluating the infrastructure options: political and economical realisability

Sociological approach:
- Aim: to identify chances and risks for public acceptance of the options and to work out possible approaches to their implementation
- Approach: mixed-methods-design including interviews with stakeholders and quantitative online survey
- Focus: state of awareness and knowledge, technology perception/evaluation, factors influencing the acceptance

Legal approach:
- Aim: regulatory framework relevant for infrastructure options (restrictions, costs, barriers, support) in current law and in legal perspective
- Approach: analysis of existing law; systematic lines and legal constraints for further development
- Focal points: special rules for H_2 and CO_2 transport; re-use of existing infrastructure; cross border frictions

Thinking Further …



- Natural gas is supplied by Norway, decarbonization takes place close to shore in Germany
- CO_2 is shipped to platforms in the North Sea for offshore storage

Advantages are:

- Natural gas pipeline can still be used for natural gas, a part flow is decarbonized in the beginning
- Infrastructure hubs can be build close to sites where large scale excess power / water hydrolysis is expected in future

Thinking Further – Interactions of Blue and Green Hydrogen

- To compensate for fluctuations in green hydrogen production, blue hydrogen production needs to become flexible
- What are realistic gradients, current demands, and future developments?
- Where should hubs be located, how do we dimension hubs / grids to balance initial investments and future requirements on growth?
- Where is the economic optimum between H_2 storage and flexibility / scale of blue H_2 production for different H_2-coverage scenarios?

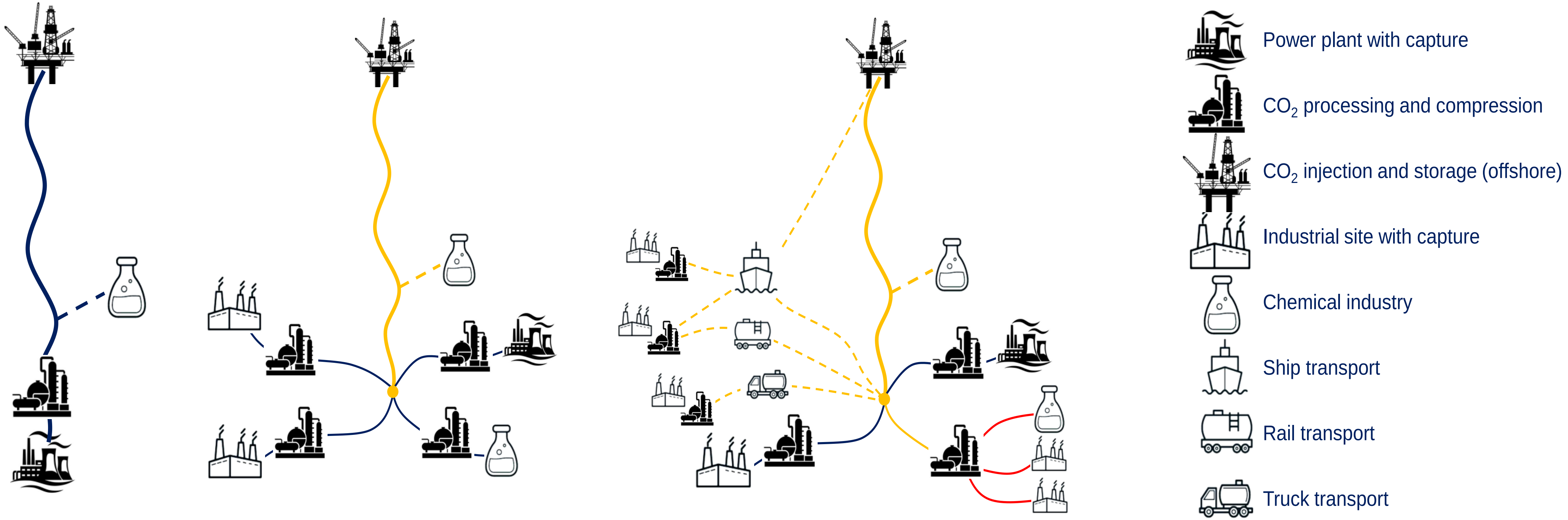
- Requirements on H_2 purity – impurities in green and blue H_2 are different
- Optimization of H_2 processing – upfront of pipeline or upfront of sensitive

For CO_2 / H_2 transport we can already point out synergies and competition between CCUS and H_2 in more detail!

Joint Working Group Transport by EERA-CCS and ZEP

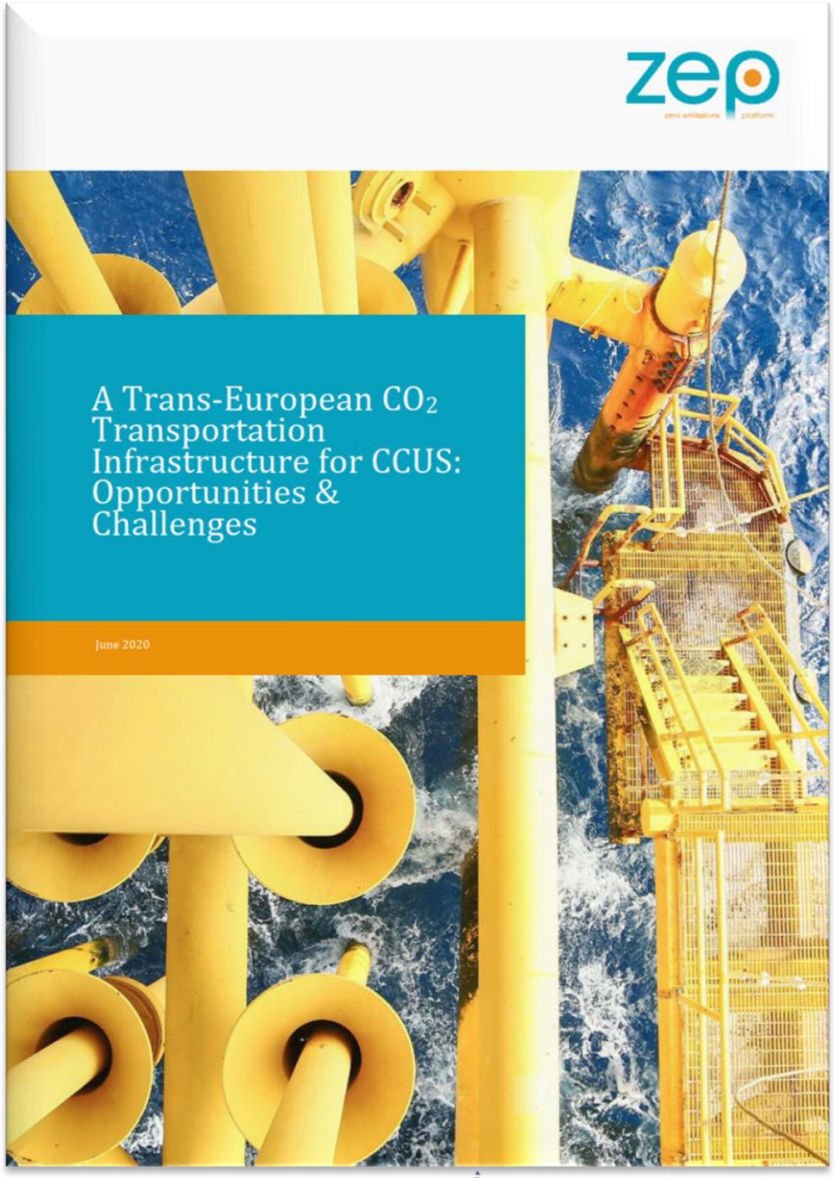
- Initiative by Filip Neele on behalf of **ZEP (Zero Emission Platform)**
- Development of a status report on CO_2 transport, four to five pages
- Focus in particular on **transport networks**
- Haroun Mahgerefteh (UCL, ZEP) and Roland Span (RUB, EERA-CCS) as co-chairs
- Formation of a working group including experts from different areas, from academia and industry
- First meeting in October 2019, multiple Skype conferences until April 2020
- Release of the report in June 2020

Joint Working Group Transport by EERA-CCS and ZEP



- From point to point (source to sink) to industrial networks – increasing complexity of CO_2- / CCUS-transport solutions

Content of the Report



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Open Questions that Require Action / Research

- Demonstrate the feasibility of industrial CO_2 transport networks as soon as possible to gain technical experience and to strengthen confidence
- Accurate dynamic flow modelling (incl. phase distribution / compositions) along the whole pipeline is important for safe and economic design and operation
- Strategies for CO_2 injection into (low pressure) depleted oil and gas fields need to be investigated further
- The use of existing natural gas pipelines and offshore platforms can be an attractive option for the development of CO_2 networks
- Economic solutions for reliable fracture control need further investigations

Open Questions that Require Action / Research

- Monitoring and control requires new types of (composition) sensors
- Accurate / traceable flow metering is critical in particular in two phase flow
- Design of large CO_2 tankers (ships) requires further work and new standards
- Uncertainty and complexity of property models for liquid transport of CO_2 (CO_2-rich mixtures) requires further work
- Development of appropriate business models for transportation infrastructure is a key requirement for successful rollout
- The current legal situation is not well developed for the installation and operation of CO_2 pipeline networks, in particular if networks are transnational

Synergies / Competition to Hydrogen Transport

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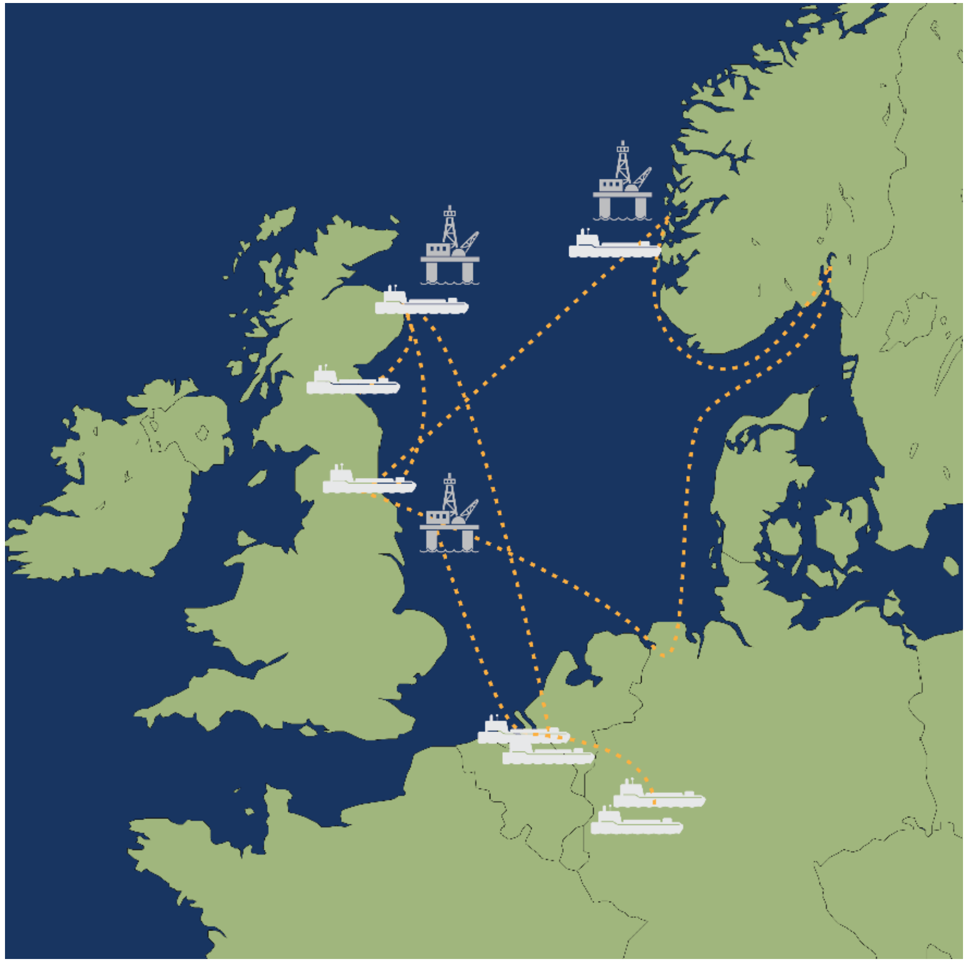

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CO_2 Purity and Quality, Techno-Economic Assessment

- CO_2 quality is highly relevant for pipeline integrity and operation
- Impurities result from burned fuel and from capture process
- Extreme demands on purity become an economic problem

- In transport networks a complex mix of impurities is to be expected (different fuels and different capture technologies)
- Chemical reactions may form impurities present in none of the primary streams
- Quality control becomes an issue under theses conditions
- Knowledge on phase equilibria and chemistry of flows is mandatory to determine economically optimal solutions

Monitoring of Impurities

- Online monitoring of impurities is essential for transport networks – fast response essential if limits are exceeded by one source
- Limits for non-condensable gases are rather high, probably no big deal
- Components like O_2, SO_2, H_2S at < 10 ppm (in some definitions < 1 ppm) are difficult to measure with available technology
- Measurements usually at low pressure; expansion may lead to two phase systems with largely different concentration of impurities in both phases
- Residuals of amines or other capture agents may react in the flow – even difficult to tell what kind of impurities to search for
- In two phase flows monitoring of impurities becomes an even bigger challenge

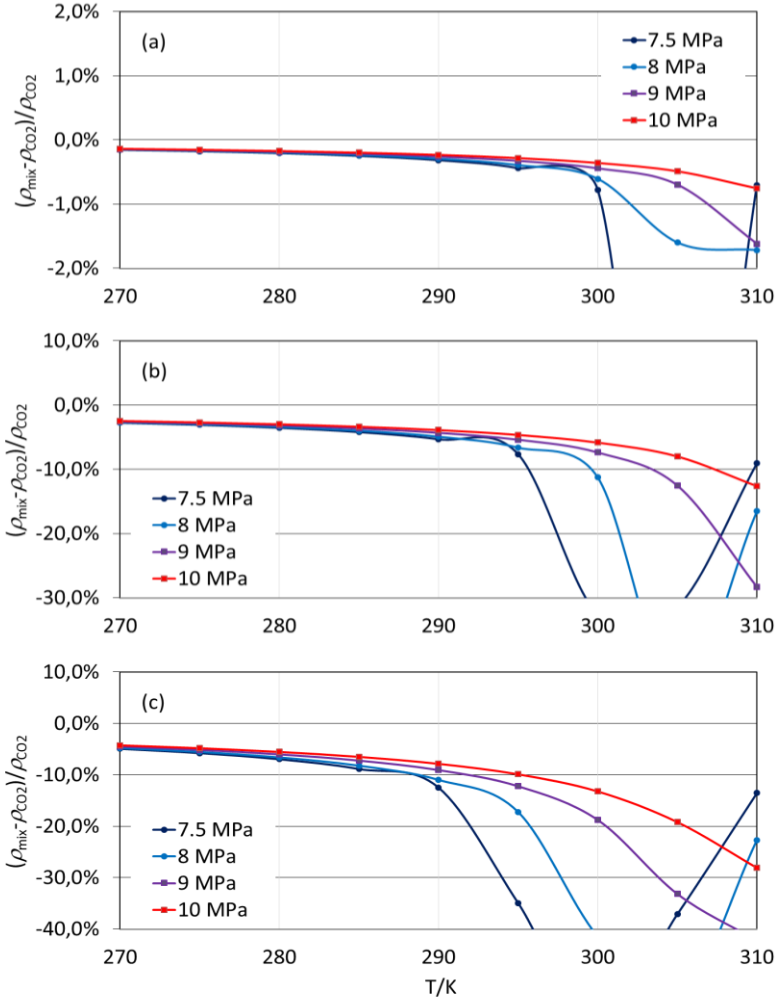
Flow Metering

- In transport networks flow metering becomes a fiscally relevant task
- Involved taxes and avoidance of allocation errors result in high, but not yet clearly defined (and internationally harmonized) demands on accuracy
- In principal orifice plates, ultrasonic time of flight, and Coriolis meters are considered suitable for flow metering in single phase flows
- None of the methods is suitable for all applications
- None of the methods is suitable for two-phase flow
- Orifice plates and time of flight methods require accurate knowledge of density and acoustic properties
- Large scale facilities for testing and calibration of flow meters are missing

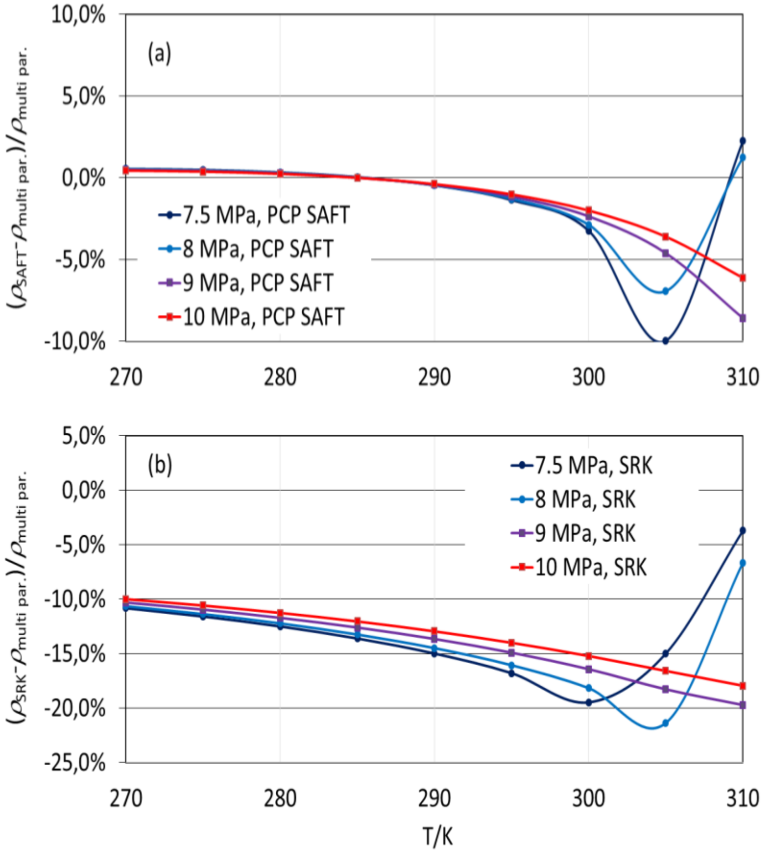
Thermophysical Properties

- High demands on accuracy in density (and speed of sound) for flow metering
- Qualitatively correct description of phase envelopes not only for non-condensable components but for all relevant impurities
- Consideration not only of VLE, but also of LLE and VLLE
- Thermal effects in injections with fluctuating pressure / flow rates require half way accurate knowledge of caloric properties as well
- Solid formation becomes an issues when streams are expanded
- Consideration of ice, dry ice and hydrates

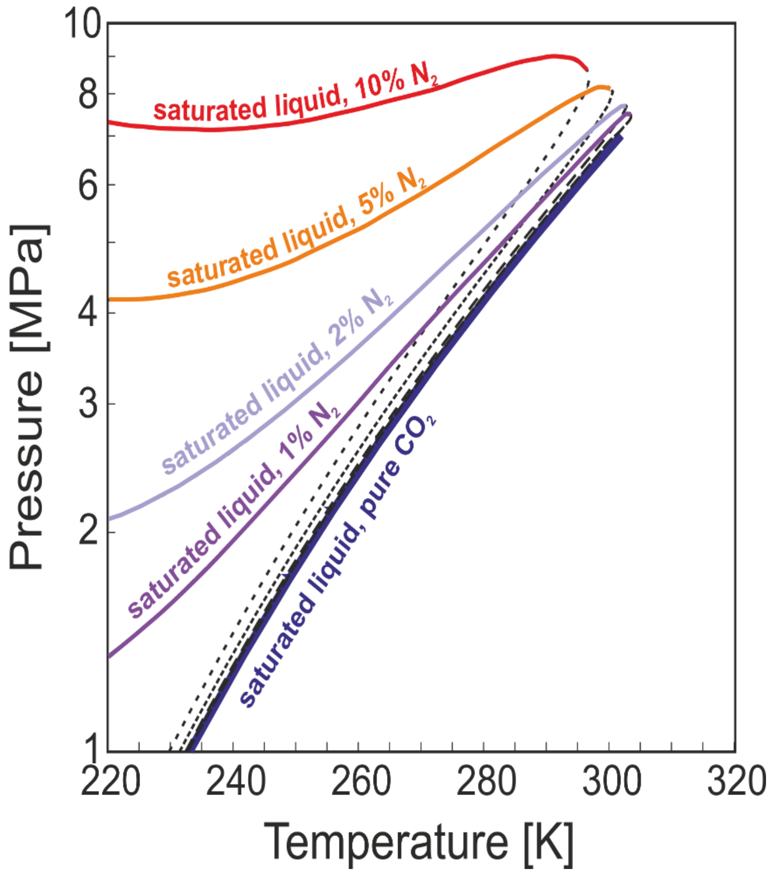
Thermophysical Properties



Impact of allowable impurities on density
a) Only minor components & CO, b) plus H_2, c) plus 5% N_2



Differences in density for different property models



Impact of N_2 on the phase envelope

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Transient Flow Modelling

- Transient flow modelling essentially established for single phase flow in point to point connections between power plant and storage site
- In transport networks higher amount of fluctuations, composition of the CO_2-rich mixture changes over time and location in the network
- Two phase flow may not always be avoidable, but needs to be avoided at metering stations and at points where the composition is monitored
- Accurate model of flows in the transport network is essential to ensure stable operation when additional suppliers / storage sites are connected

Injection in Depleted Gas-Fields and Aquifers

- Injection in aquifers is essentially state of the art for transport, but needs to be extended to much bigger scale
- Injection in depleted gas fields results in initially low backpressure, which increases during operation
- Existing equipment may partially be used (pipelines, platforms, …)
- Conversion of natural-gas pipelines to CO_2-rich mixtures is not impossible, but requires very detailed analysis of mechanical strength, corrosion issues, health and safety issues and so on
- Permission for reuse will depend on detailed analysis in every single case, no general statements possible

Pipeline Network Safety

- Running ductile fracture still is an issue
- Current regulation requires prove by experimental tests for pipeline designs that were not tested before
- Established models do not describe pipelines containing CO_2-rich mixtures
- Advanced models would ease reuse of existing pipelines and planning of transport networks
- Corrosion remains an issue for transport networks – for reasons discussed avoiding the formation of corrosive phases is more difficult
- Permission process involves a number of points that are not entirely technical – safety assessment may become a stepping stone

Business Models

- Business models are central for the development of transport networks
- Market will likely be monopolistic – Regulated Asset Base or Public Ownerships are the most often discussed options for pipelines

- Discussion focusses on large transport pipelines so far
- Very little consideration of …
  - Ship transport to hubs or to offshore CO_2 sinks (EOR)
  - Low pressure grids for collecting CO_2 from remote sources
  - Truck or rail transport for collecting CO_2 from remote sources

Marine Transportation

- Small scale (1000 – 2000 to) ship transport is state of the art for decades
- Transport as saturated liquid at rather high temperature and pressure
- For large scale transport lower pressure and temperature are considered ideal
- Issues like allowable impurities at low temperature need to be addressed

- Existing codes (LPG / LNG) do not cover LCO_2 carriers – density and pressure are out of spec.

- Loading and unloading equipment can likely be adapted to large scale LCO_2

Stranded Emitters

- The contribution of small emitters to the total CO_2 emissions of the EU is not negligible – emitters < 500 kT/a need to be included to meet targets
- Different options for transport, largely depending on geographical aspects: gas phase pipelines at relatively low pressure, transport by ship, truck or rail
- Economy of scale makes CO_2 processing particularly expensive
- Hub based concepts with central processing seem economically attractive (of course capture itself needs to remain local)
- Transport of unprocessed CO_2 to hubs raises several technical questions

Legal and Regulatory Considerations

- London Protocol hindered export of CO_2 for off-shore storage
- By now provisional amendment from 2009 can be applied in this case

⇨ Problems can be solved, but a strong political will is required

- National legislation for CO_2 pipelines is not existent in most European countries
- Regulative approaches are inconsistent
- Problems are to be expected with regard to permissions for transnational pipelines
- European harmonization of legislation / regulation becomes urgent

Conclusion

After all, the transportation of CO_2 rich mixtures in 'point to point' type pipelines and also in transportation networks based on pipelines and ships is technically feasible without any doubt. However, in particular transportation networks designed, approved, build and operated based on current knowledge cannot be optimised in many regards due to limited technical experience and incomplete scientific knowledge. Ultimately, these limitations result in increased costs for infrastructure and operation. First movers have to be compensated for these disadvantages and focussed research and development has to be strengthened to come to commercially optimal solutions as soon as possible.