Opportunities for a Norwegian hydrogen value chain and synergies with the Norwegian large-scale CCS deployment

S. Roussanaly*, J. Straus, R. Anantharaman, O. Meyer - SINTEF Energy Research

G. Holmen, M. Berntsen, S. Woodhouse - Aker Solution

*Contact: Simon.Roussanaly@sintef.no

The Norwegian perspectives

- Enabling large-scale hydrogen economy is important for Norway for two perspectives

  - Norway is committed to reduce its GHG emissions
    - Norwegian ambition: -40% by 2030 and reaching a low-carbon economy by 2050
    - H_2 is seen as a key contributor especially in certain sectors

  - Norway is an energy exporting Nation
    - Current natural gas exports and proven reserves: 110 billions Sm^3/y and around 1700 billions Sm^3
    - Norway aims to remain an energy exporting but want to reduce the climate impact of the energy delivered: renewable energy, hydrogen, natural gas with CCS

- However, there are several aspects that should be better understood to efficiently deploy low CO_2 footprint H_2 from Norwegian natural gas

Focus of the Norwegian case study

1. Identify potential for H_2 export from Norway as well as potential for use of H_2 within Norway
2. Identify optimal strategy and robust first steps for the development of a Norwegian infrastructure for H_2 export and use within Norway
3. Understand the impact of potential constraints in infrastructure development of H_2 export feasibility, strategy and cost (only reuse of natural gas pipeline, new H_2 pipeline, liquid H_2 transport)
4. Understand the potential benefit the development of a Norwegian CCS infrastructure for H_2 deployment
5. Understand the potential benefit of compact H_2 technology development to decarbonize offshore CO_2 emissions
6. Create well-based foundation for discussion with stakeholders and decision-makers to enable the H_2 developments

The H_2 demand

- H_2 export is by far the main potential demand for H_2 from Norwegian natural gas
  - However it is important to also better understand and define the H_2 potential within Norway

- The potential of the Norwegian national H_2 economy
  - Fair utilisation potential in transport sector
  - Potential to produce heat and as feedstock in Norwegian industry (refining, metal reduction and methanol production)
  - Immense utilisation potential for offshore gas turbines driven by hydrogen

Offshore H_2 production

- The offshore Oil and Gas industry is a key sector for H_2 demand within Norway
  - However producing H_2 onshore and transporting it to platforms may not be a cost-efficient option especially in the case of limited number of platforms within a region and depending on distance to shore and/or production facility
  - Producing H_2 offshore could be a more cost-efficient alternative however compactness is a challenge when considering standard natural gas reforming with CCS
- Focus has thus been set on evaluating the potential of a "compact" technology for offshore production of H_2 from natural gas (including CCS)
  - Technology considered: Protonic Membrane Reformer (PMR) technology as described by Malerød-Fjeld et al.

Offshore H_2 production

- Case study
  - "Typical" ship-shaped FPSO (Floating Production, Storage, Offloading)
  - 200 km off Hammerfest in the Barents Sea
  - Energy demand:
    - 60 MW Power
    - 30 MW Heat
  - CO_2 produced must be sequestered

- Limitations
  - Conceptual cost estimates (+/- 50%) Hydrogen as FPSO fuel will require technology qualifications and HSE considerations beyond the scope of this study

Offshore H_2 production

- Performances
  - 120 MW of power must also be produced to power the PMR and CO_2 conditioning
  - Additional process space requirements increases the length of the FPSO by 75 m.
  - Additional weight introduced to FPSO = 34 889 t
    - Equipment: 6 589 Mt
    - Steel & bulk: 28 300 Mt
  - Cost performances
    - CAPEX: ~900 M$
    - OPEX: ~21 M$/y + Natural gas consumption cost

- Based on these performances, offshore hydrogen production does not appear as an attractive solution despite the use a compact concept
  - H_2 important from shore or alternative technologies (CCS, electrification) are expected to be more attractive

Norwegian case study questions investigated

- Focus: How to deliver the H_2 demand in Norway and support the German hydrogen ambition

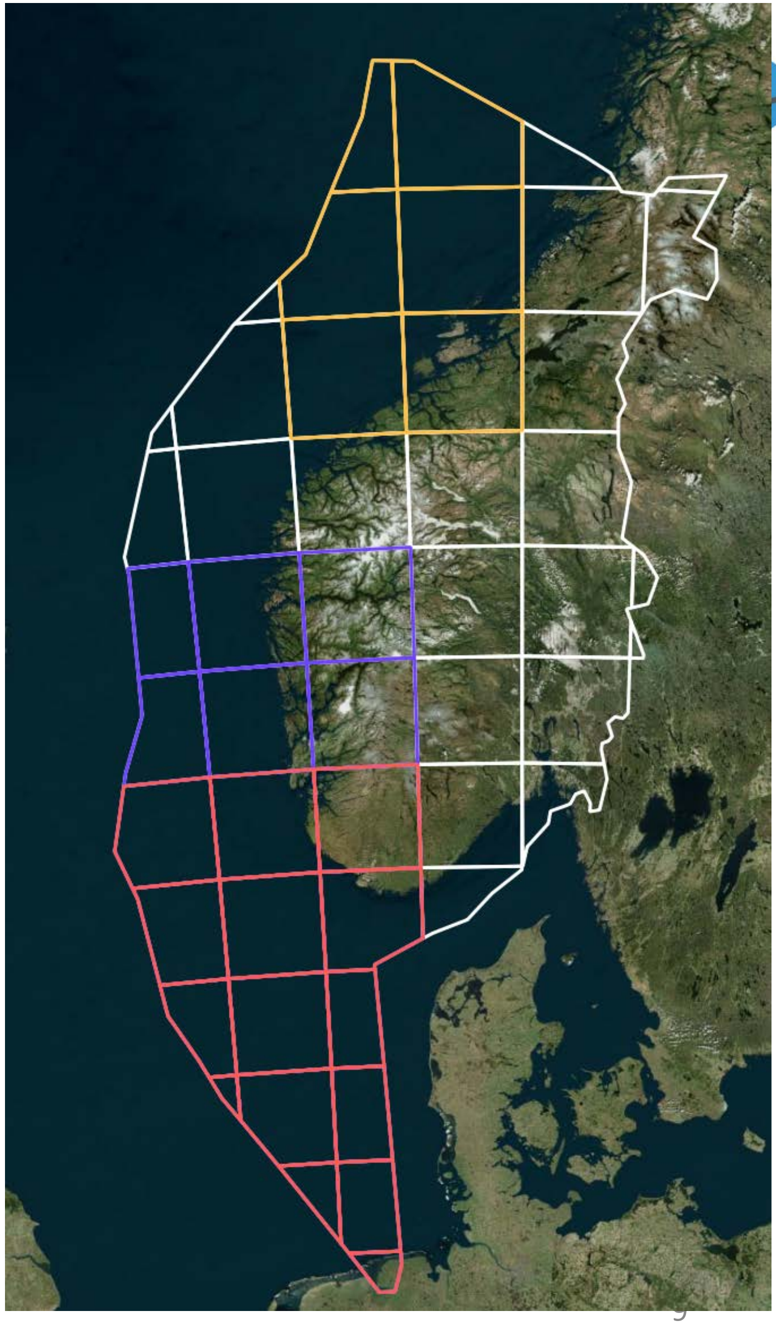
- Questions:
  - How should H_2 be produced and transported for both markets?
  - Shall H_2 for Germany be produced in Norway or in Germany?
  - Shall existing natural gas pipeline be converted to transport H_2?
  - What synergies do exist between producing H_2 in Norway and the development of a Norwegian CCS infrastructure

Methodology

- The investigation was conducted using the ELEGANCY value chain tool
  - Tailored to the Norwegian case study in term of:
    - Possible technologies
    - Natural gas resources and CO_2 storage potential
    - Cost
    - etc.

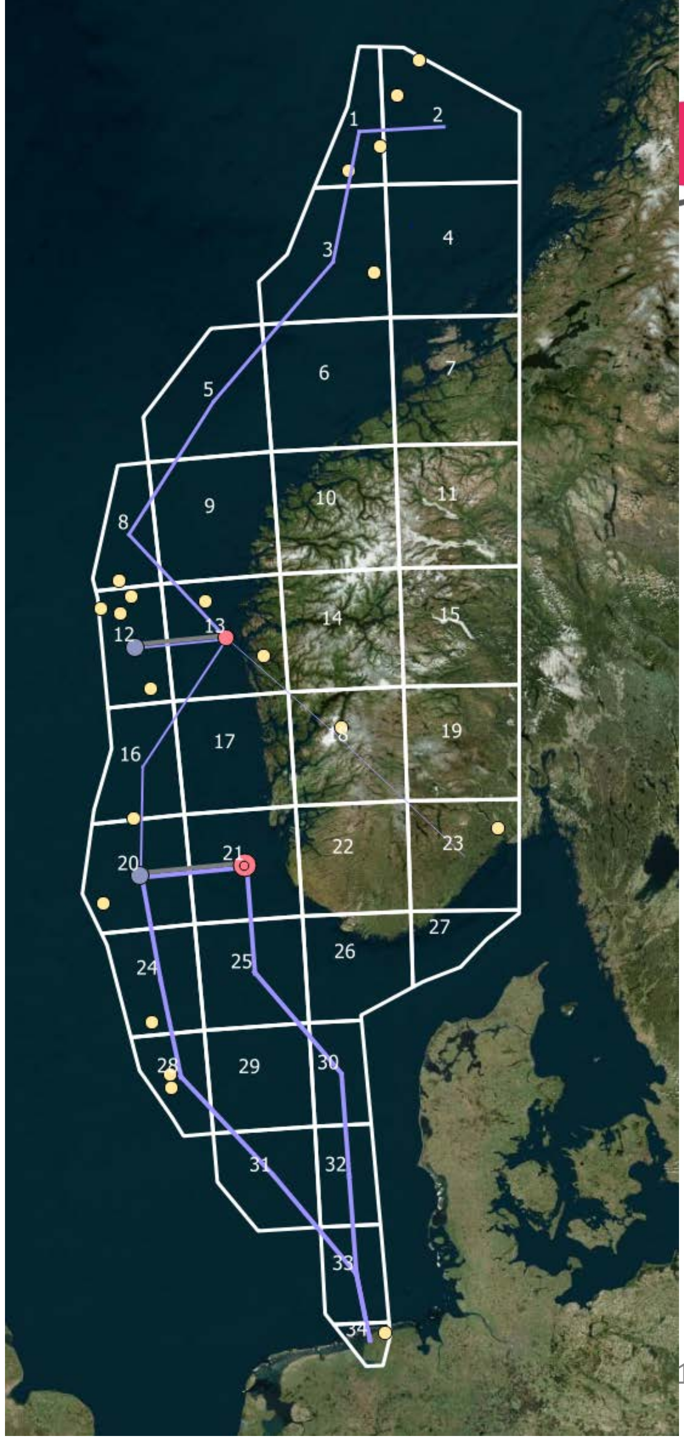
- H_2 demand focus
  - Norway: Offshore oil and gas, industry – 897 kt/y
  - German H_2 demand: <u>3730</u> to 5580 kt/y

- Focus on 2030/2035 investments



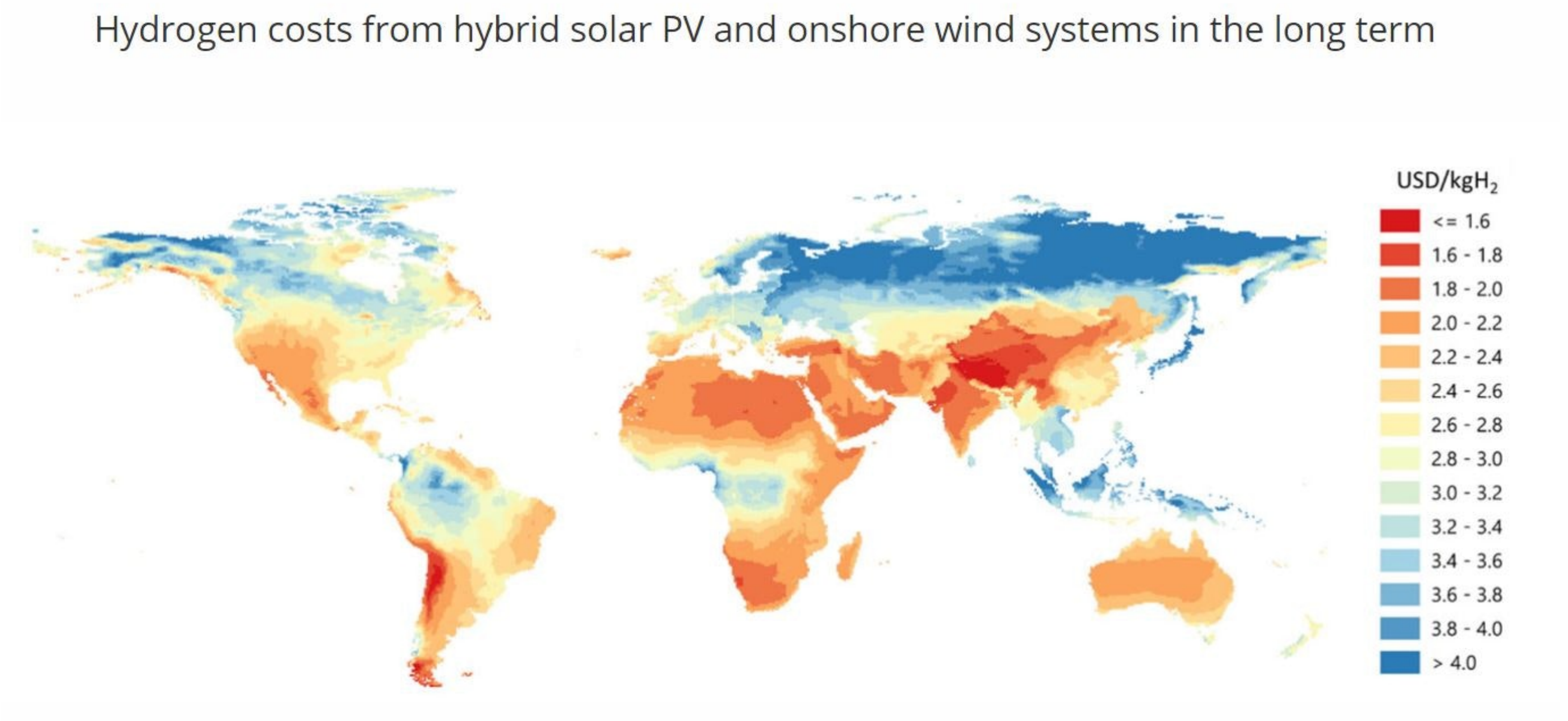
Delivering H_2 to Norway and Germany – Best way forward

- From the results of the case study, we observe that:
  - H_2 is produced directly in Norway
  - Centralised production in a few sites close to natural gas resources
    - Kårstø as production site of H_2 for Germany
    - the location of the Norwegian national demands does not influence its location
  - Export via pipeline to the H_2 demand location
    - Converting the Europipe natural pipeline to a H_2 pipeline would be cost beneficial
  - Average delivered H_2 cost (LCOH): 1.55 €/kg
    - Key contributor: natural gas cost (~60%)
  - CO_2-intensity: 0.67 kg CO_2/kg H_2
    - Equivalent to H_2 from electrolysis guaranteeing that 95% of its electricity consumption comes from renewable energy



Delivering H_2 to Norway and Germany

- How do these costs compare with long-term H_2 production costs from renewables



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Producing H_2 in Norway or Germany? Converting natural gas pipeline?

- Delivering H_2 to Germany
    - Converting existing natural gas pipeline to transport hydrogen
        - Europipe pipeline can accommodate part of the require H_2 transport and the rest would need to be handled via a new H_2 pipeline
        - LCOH is rather similar to a case based solely on a new H_2 pipeline
        - Natural gas pipeline conversion could however be used to start a switch from natural gas to H_2 pipeline at low costs
    - LCOH is slightly higher if H_2 is produced in Germany
        - Transporting back $50 MtCO_2/y$
    - However, the differences remain rather small
        - More detailed evaluation would be valuable
        - The final choice may also be affected by political support and other factors not considered in the model

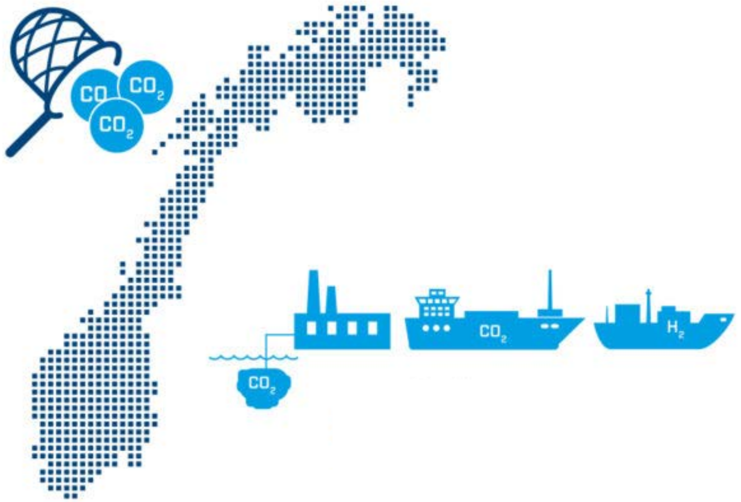
Case	H_2 production in	H_2 transport	CO_2 transport	LCOH [€/kg]
1	Norway	Europipe + 52-inch H_2 pipe	Pipeline with 50 Mt/a capacity	1.54
2	Norway	54-inch H_2 pipe	Pipeline with 50 Mt/a capacity	1.54
3	Germany	-	Pipeline with 50 Mt/a capacity to Agder, pipeline with 50 Mt/a capacity to the shelf	1.57

Synergies with the development of a Norwegian CCS infrastructure

- Norway aims to be a key player in permanently storing European CO_2 emissions
  - Would the development of such a Norwegian H_2 value chain also benefit the development of a CCS infrastructure?

- CO_2 receiving hub (5, 10 or 15 $MtCO_2/y$) located in Norway was included
  - Costs reduced when a shared CO_2 transport and storage infrastructure are considered for H_2- and non H_2-related CO_2
  - Cost reductions mainly benefit to the non H_2-related CO_2 as large economies of scale have already been reached for H_2-related CO_2
  - Synergy however may strongly influence the CO_2 receiving hub location

- These synergies would make Norway furthermore attractive for large-scale CO_2 storage for European CO_2 emissions.



Take-away messages

- Decarbonisation of offshore oil and gas platform through offshore production and use of H_2 seems to have a limited potential even with a compact H_2 production technology
    - However, hydrogen from shore or other non-H_2 based options (CCS, electrification, etc.) would be more promising

- Production of low-carbon footprint H_2 from natural gas in Norway is a bit cheaper to deliver H_2 to both Norway and Germany
    - The H_2 production and transport cost can compete with long term cost of H_2 from renewable
    - H_2 production is centralised in a limited number of sites in Norway
    - Converting natural gas pipeline to transport hydrogen can reduce cost and be a good strategy to start switching export of natural gas to hydrogen with low investment
    - However, overall, the differences remain rather small: More detailed evaluation would be beneficial, and the final design may also be affected by political support and other factors not considered in the model

- Large-scale hydrogen production in Norway for export and national demand can help to enable significant economies for scale in the development of a Norwegian CCS infrastructure
    - The economies of scale could lower cost of storing Norwegian and imported European CO_2 emissions thus making Norway furthermore attractive for large-scale CO_2 storage for European CO_2 emissions

Webinar on "Hydrogen from Norwegian natural gas to decarbonise Europe and Norway"

- Join us for a webinar on Jun 24, 2020 at 9:00 AM CEST.

- 9.00 Welcome – Nils Røkke, Executive Vice President Sustainability at SINTEF
- 9.10 Importance of H_2 from natural gas – Dr. Stefania Gardarsdottir, Research Manager at SINTEF Energy
- 9.30 Developing an infrastructure to deliver H_2 to Europe and the Norwegian market - Simon Roussanaly, Research Scientist at SINTEF Energy Research
- 9.50 Legal aspects of enabling hydrogen – Prof. Catherine Banet, Professor at University of Oslo, Faculty of Law
- 10.10 H_2 from Norway - A Germany perspective – Stefan Flamme, Research Assistant at the Rhur University Bochum

- 10.30 Break

- 10.50 The role of hydrogen in decarbonisation – Sylfest Myklatun, Lead Engineer Downstream Technology at Equinor
- 11.10 Enabling large-scale LH_2 transport of hydrogen – David Berstad, Research Scientist at SINTEF Energy Research
- 11.30 Hydrogen sustainable development program – Svein-Erik Losnegård, Principal Engineer at Gassco
- 11.50 Conclusions – Nils Røkke, Executive Vice President Sustainability at SINTEF

Register here: https://register.gotowebinar.com/register/6607035415832391793

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