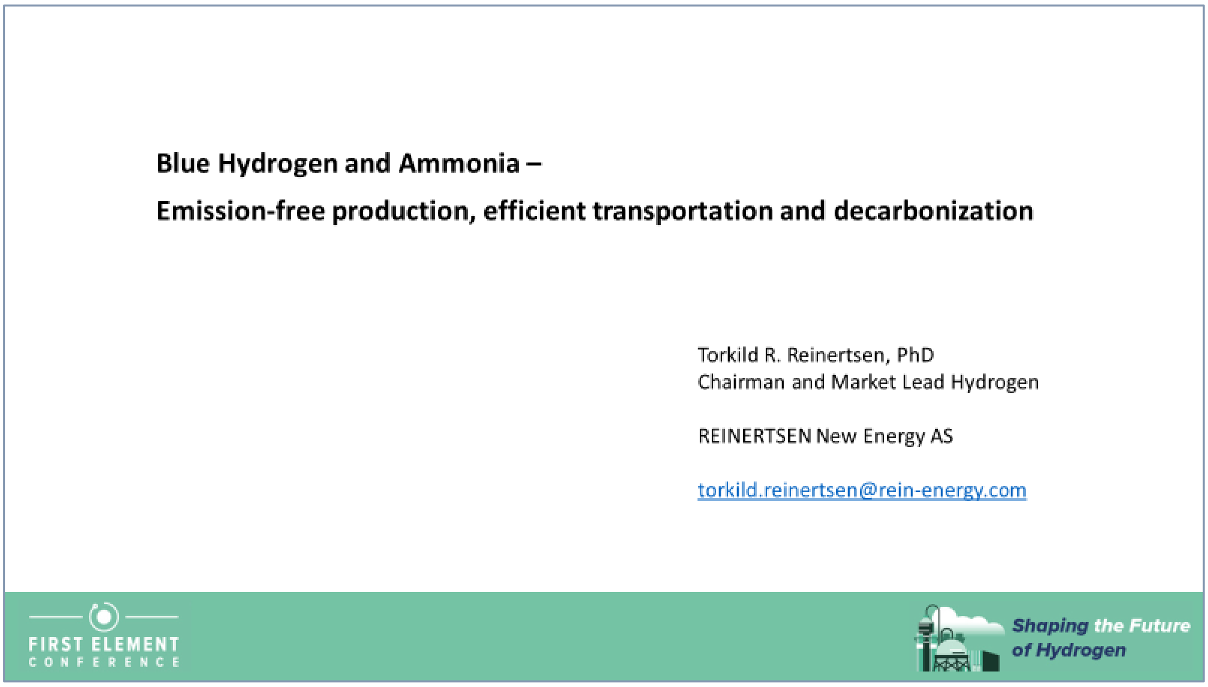
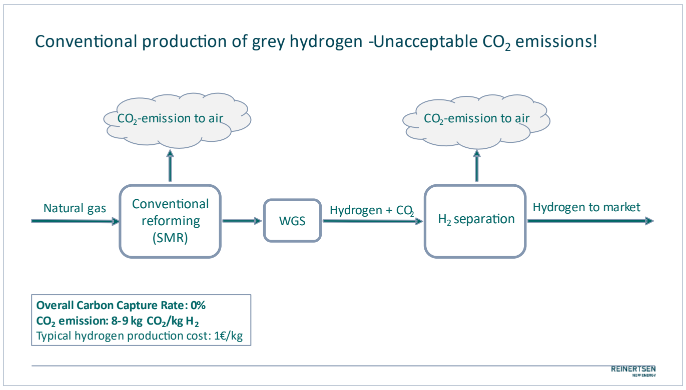


Most of today's hydrogen is produced in refineries and chemical plants, with significant GHG emissions.

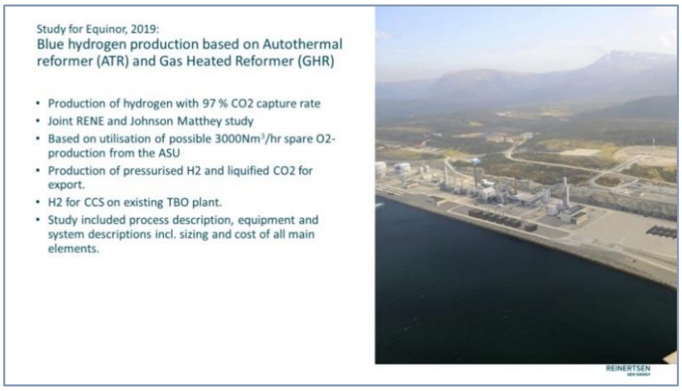
This grey hydrogen will be replaced by blue and green hydrogen in the future. For most regions and countries, the availability of renewable electricity, natural gas and CO_2 storage will dictate which hydrogen colours will develop. In many countries, both blue and green hydrogen will be produced and share the same infrastructure.



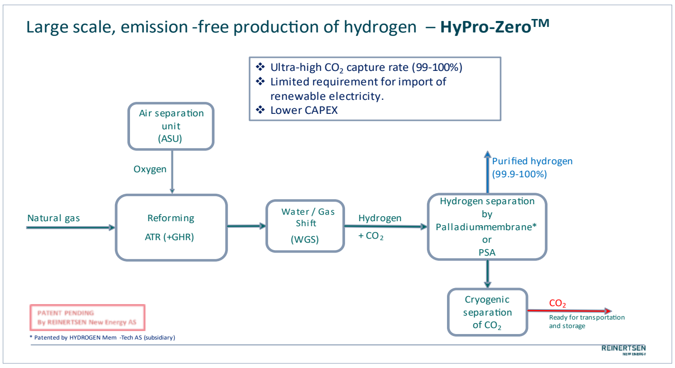
However, the main vector for decarbonisation of the globe is direct electrification. The demand for renewable energy for this purpose will have the highest priority, and the availability for production of green hydrogen will be limited.

Competitive, blue hydrogen may be produced in large volumes by alternative methods. Most existing plants are equipped with conventional Steam Methane Reformers (SMR). These plants may be retrofitted with amine-based CO2 capture of the exhaust, but the overall capture rate from such plants is rather low, 80-90%.

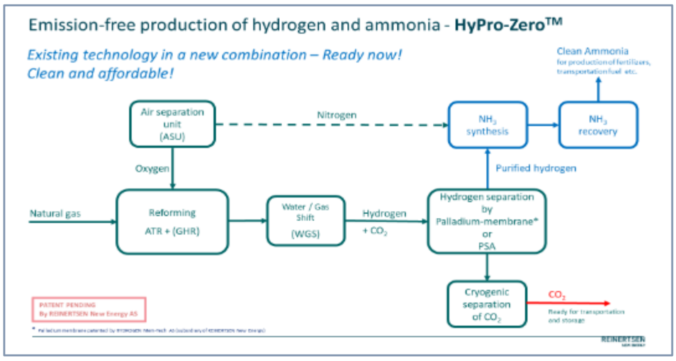
In 2018, we set out to develop a **hydrogen production process** with high CO2 capture rate. We teamed up with Johnson Matthey, specialists on reforming and we proposed and carried out a study based on ATR and GHR reformers, for Equinor. The process flow-chart was rather “standard” except for the GHR. The report indicated that a CO2 capture rate of approximately 96-97% was achievable.



Thereafter, we started a new development project in REINERTSEN New Energy. We wanted to do better!



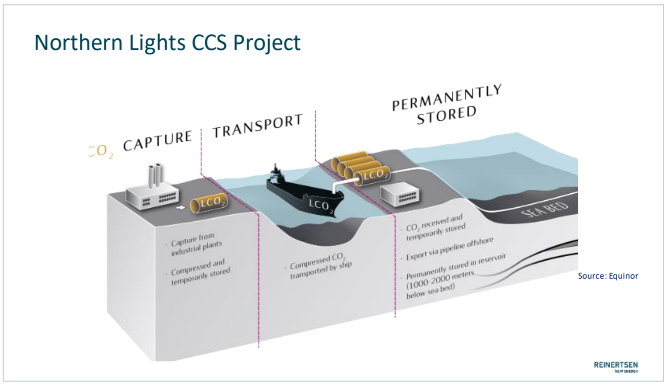
We saw the need for new, emission-free production processes and developed a process named HyPro-Zero™ that comprises Autothermal Reforming (ATR), fed with oxygen from Air Separation Unit (ASU), Palladium membrane or PSA for H2 separation, and cryogenic separation of CO2. The process solution has been further developed to an ultra-high CO2 capture rate of 99 - 100% and no need for import of renewable electricity. Furthermore, we think the CAPEX is lower.



Clean ammonia may also be efficiently produced based hydrogen production processes like the HyPro-Zero™. The bi-product, nitrogen from the ASU is combined with clean hydrogen in the production of ammonia.

REINERTSEN New Energy is a product and technology independent engineering company that will select the best solutions for our clients.

We have the competence, experience and the tools (simulation tools) to compare the new, clean processes presented over the last years, by us and others. We are independent of own patents in this work for our clients, as we are not charging royalties and fees.

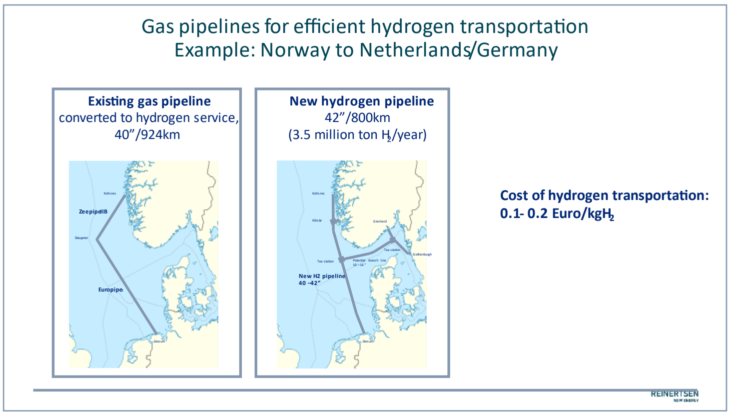


CO2 storage is a prerequisite for clean hydrogen production from natural gas and several projects are being developed in Norway, Netherlands, UK, US and other countries.

Transportation and distribution

Blue hydrogen and ammonia may be produced locally (with CCUS) or be imported. Currently, several projects for transportation of H2 and CO2 are emerging in EU, UK, theUSA and Australia.

Transportation of hydrogen, 100% or blended in new or re-purposed gas pipelines and networks are being developed, European Hydrogen Backbone (EHB) and others. The H_2 transportation cost for such systems might be very competitive.

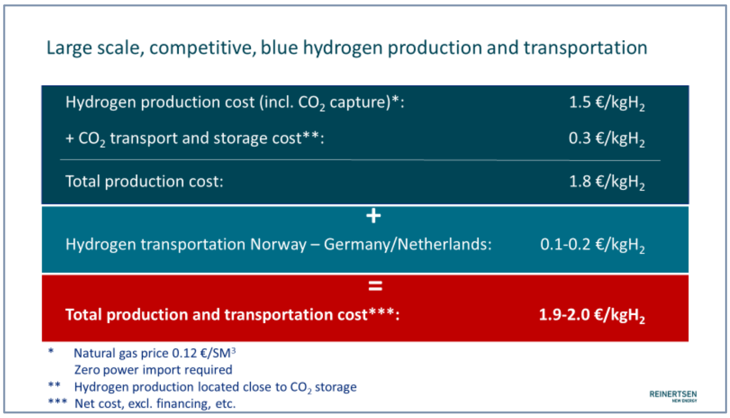


We have 40 years' experience from many of the most challenging gas pipeline projects.

Several projects for transportation of hydrogen, 100% or blended in new or repurposed gas pipelines and networks are being developed. For many of the pipelines it is feasible to repurposed from natural gas to hydrogen service.

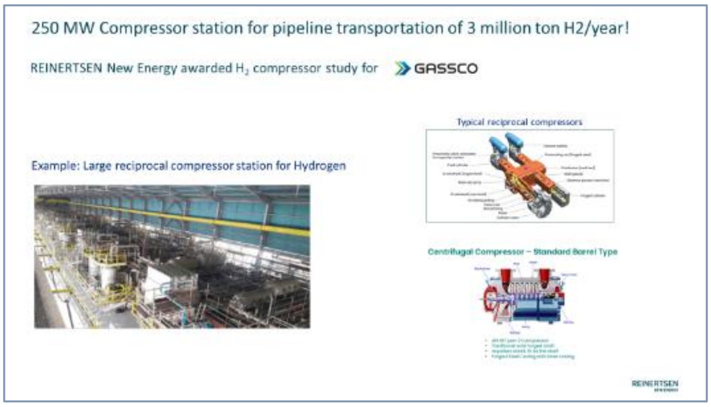
The H2 transportation cost in such systems might be very competitive. Studies of an existing, repurposed 40-inch gas pipeline from Norway to Germany or alternatively a new 42-inch pipeline indicate a transportation cost as low as 0.1 – 0.2 Euro/kg H2! The main cost element is compression energy.

Repurposing the natural gas networks seem to be very competitive, as well.



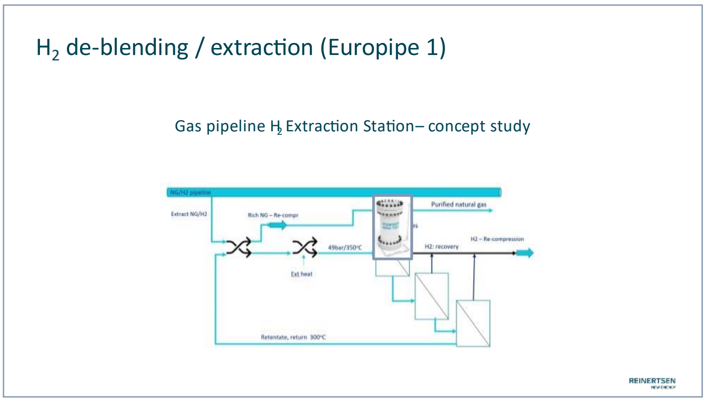
This table indicate a total production and transportation costs of 2.0 Euro/kgH2 for large-scale, blue hydrogen, based on a natural gas cost of 0.12 Euro/SM[3].

We are currently studying what could be the worlds largest compressor station for H2, for Norwegian state-owned Gassco. We are talking 3 million tons of H2 per year. The study confirms the costs for compression included in the previously, presented pipeline study.



In case its challenging to source 250 MW of renewable power, the power generation may be based on H2 from the nearby blue, H2 production plant!

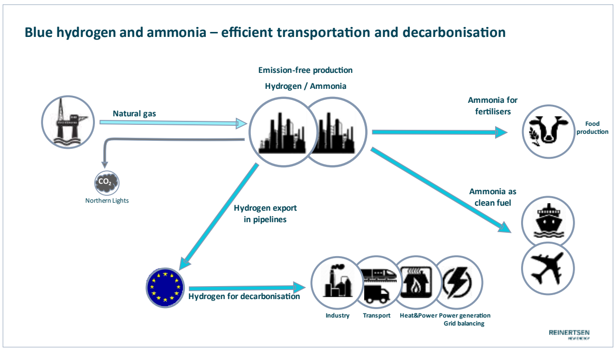
We are currently studying H2-extraction station for H2/natural gas blended pipelines, based on Palladium membrane separators. The Palladium separators previously developed by us, and now by HYDROGEN Mem-Tech might be very efficient, compared to other technologies. They might be used in small and large de-blending stations.



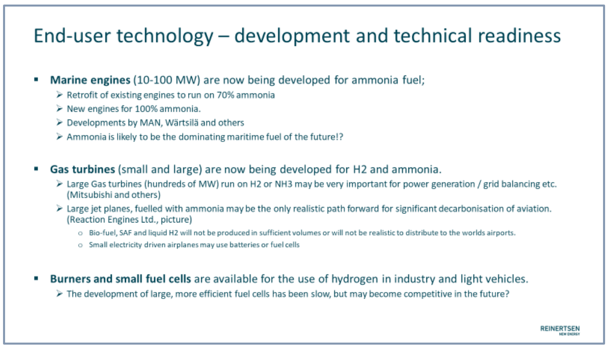
In summary, hydrogen may most economically be transported and distributed as compressed hydrogen in pipelines. Alternatively, the hydrogen can be transported to the market by expanding the existing infrastructure (ships, road tankers, storage tanks and pipelines)

Markets and end user technologies

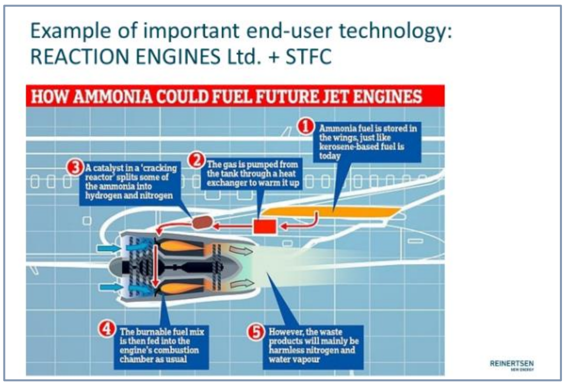
As we see it, the most relevant markets for clean, compressed hydrogen will be industry, heat&power and transportation. For clean ammonia the main markets will be marine shipping and possibly aviation. Power generation and grid balancing might be an important market for both blue hydrogen and blue ammonia.



The current, end user technology developments include 100% hydrogen and 100% ammonia as fuel for turbines and internal combustion engines (ICE). As fuel cells are very limited in capacity, the development of turbines and ICEs are important for power generation, compression, marine shipping and possibly aviation (jet engines).



Aviation emits about 1 billion tons of CO2 per year, about the same level as marine shipping. The development of low-carbon fuels for aviation has been focused on biofuel, synthetic fuel and Sustainable air fuel but the decarbonisation seems to be marginal. Airbus and others are designing aircrafts for liquid hydrogen, but the logistics of transporting H2 and storing at airports, at minus 253 Celsius, is in our opinion not a realistic path forward. Recently, NASA, Boeing, UCF and Reaction Engines have started a programme for using clean ammonia as aviation fuel. Ammonia can be transported and stored efficiently at the world's airports. We are publishing an article about ammonia as aviation fuel in Hydrocarbon Energy / H2Tech in Q3/2022.



Ammonia is to be stored in the aircraft as regular airfuel. Part of it will have to be cracked to hydrogen. The mixture is fed to the jet engines. The heat required for the cracking comes from the exhaust.

Thank you for your attention!
We find it most motivating to work with our clients to develop these solutions. We also think it is important to involve the future hydrogen generations in this work. They are going to live with and off the solutions!