The blue hydrogen paradigm shift: Integrated optimisation of reforming and CCS

By Stephen B. Harrison | 16 March 2021

On the 27th of January 2021, the European Parliament voted that blue hydrogen produced from natural gas with CCS can be used as a bridge on the journey to the eventual widespread use of green hydrogen.

The UK has an agnostic position on blue and green hydrogen to ensure that hydrogen infrastructure can develop at-scale. That approach allows for a range of technologies from electrolysers to autothermal and steam methane reformers, and CCS.

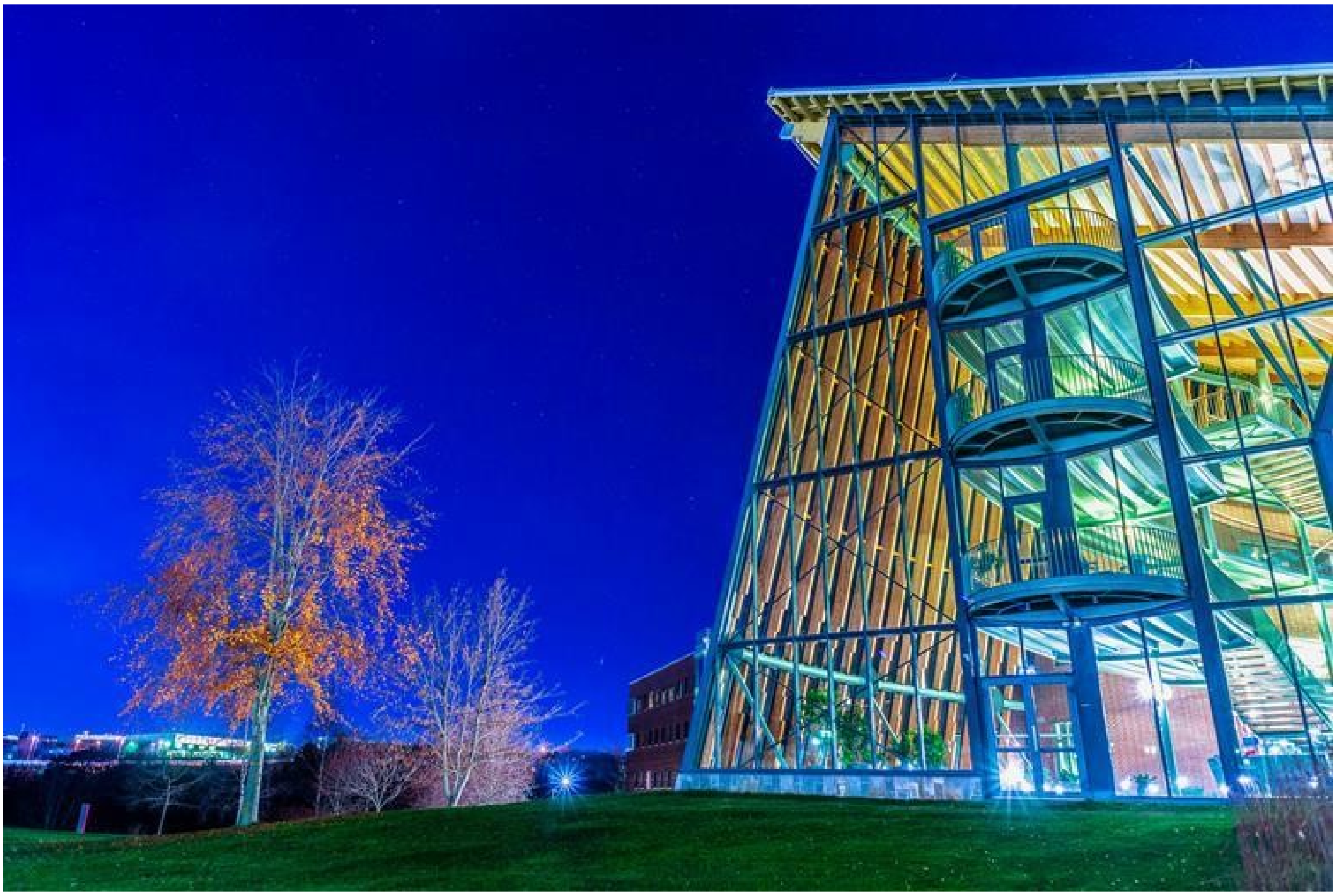
The use of blue hydrogen will stimulate progress towards deep decarbonisation in many carbon-intensive sectors. It will also drive investment in integrated blue hydrogen production schemes. These will require a holistic approach to process optimisation across reformers, air separation units, pipelines and carbon capture – the main technologies required for blue hydrogen production.

A new paradigm must emerge

The most common means to produce hydrogen today is from natural gas, using steam methane reformers. Carbon dioxide (CO_2) is generated from the process chemistry and energy requirements. 'Blue hydrogen' is produced through the integration of carbon capture with steam methane reformers (SMRs) or autothermal reformers (ATRs).

The captured CO_2 may either be captured and utilised (CCUS) or captured and stored (CCS) in permanent underground storage in natural geological formations.

SMRs have benefited from 40 years of continuous improvement and optimisation. ATRs are newer but have had more than a decade of commercial scale operation to allow fine tuning. In some cases, SMRs and ATRs are integrated in 'combined reforming' or 'two stage reforming'.

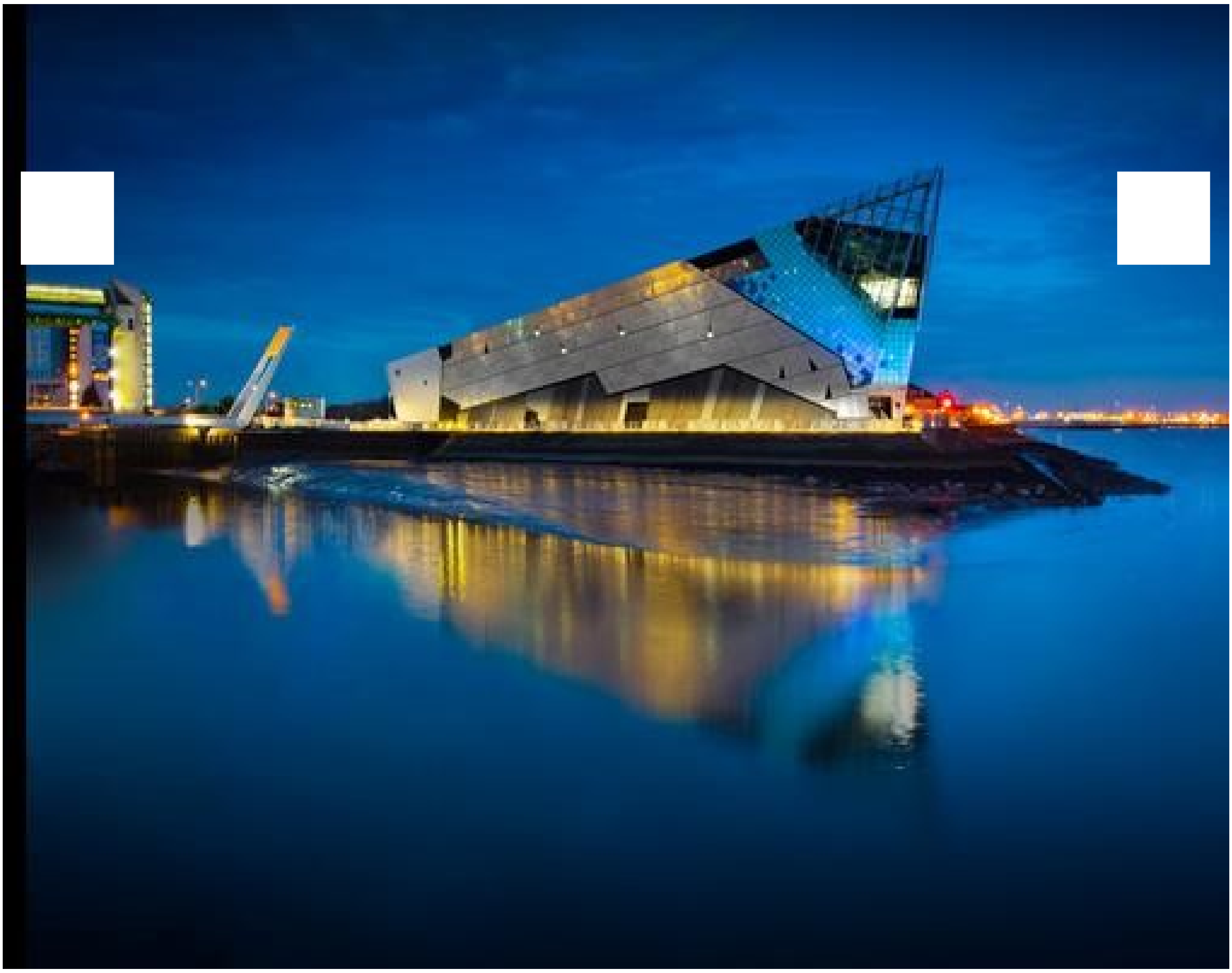


Equinor offices, Norway

CCS is also an established technology. In Europe, Equinor commenced capture and sequestration of CO_2 on the Sleipner West field in the Norwegian sector of the North Sea more than 20 years ago. The components of a CCS scheme, from the absorption tower to the multi-stage CO_2 compressor with integrated drying system, are highly developed.

Beyond Norway, CCS has also been used in Australia, Canada, and the US for many years. Most major CCS schemes implemented up to now have been retrofits onto carbon-intensive processes, such as decarbonisation of existing coal fired power plants; carbon capture from existing steam methane reformers; and amine wash systems on existing ammonia plants.

Reforming technologies and CCS have been optimised, but they have been optimised in parallel. They have never been optimised synergistically in an integrated process. For new investments, a paradigm shift is required: blue hydrogen production must be optimised in its own right.



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United in a vision of carbon-neutrality

More than six years after the Paris Agreement, President Biden signed a decree that recommitted the US back into to that agreement after several years of absence. A carbon-neutral future must materialise, and John Kerry has been made responsible for delivering the vision.

Scores of other nations are signatories to the Paris Agreement. The UK has embraced blue hydrogen as part of its vision to mitigate the effects of climate change. A project in East Yorkshire known as Zero Carbon Humber is an embodiment of the UK's drive to use blue hydrogen to enable a greener future.

Henrik Anderson is a Vice-President, responsible for Low Carbon Solution Technology at Equinor. He says that, "Equinor sees a future for both blue and green hydrogen, but each will be developed at different pace and scale based on regional feedstock availability, geology, markets and policies. However, to develop the hydrogen value chain at scale and kick-start the hydrogen economy, we believe that blue hydrogen will play a vital role."

East of the Humber, in the North Sea, Equinor is also heavily invested in large-scale renewable power generation. Its wind farms on the Dogger Bank will generate more than 3 GW of renewable electricity when complete.

The North Sea is also integral to blue hydrogen production for the Zero Carbon Humber project because it is the source of natural gas to feed the reformers. The project will also use a huge saline aquifer known as 'Endurance' to permanently store the CO_2 that is to be captured from heavy industries on the banks of the Humber.

Fine tuning the technology

"A couple of years ago, I was involved in writing the H21 North of England report*," says Andersen. "We analysed the cost, performance, and energy efficiency of SMR and ATR technologies. But that was a conceptual study and a forerunner of the tangible project we are now working on."

"H21 considered nine trains of ATRs with a massive throughput. The equivalent thermal rating of the hydrogen to be produced on the current project, called 'H2H Saltend', is smaller, at 600 MW."

H2H Saltend is a key component of the Zero Carbon Humber vision.

Andersen continues to say that, "We are running a competitive process to select technology providers and project execution partners for the blue hydrogen scheme. Their ideas will build on our vision and will determine the details of what gets built. We want a safe, low-carbon, low-risk process that will operate reliably and efficiently as part of the UK energy infrastructure in the coming decades. We are open to explore the most effective route to achieve those goals."

Fine tuning of blue hydrogen production technology will, in part, come from a detailed understanding of the energy and chemical feedstocks required in any scheme. Both SMRs and ATRs can be combined with downstream shift reactors to optimise production of hydrogen or syngas. "The H2H Saltend project is focused on producing hydrogen for industry, power and ammonia", says Anderson. "The major advantage of using an ATR would be the scale that can be achieved, with a high carbon capture rate and high energy-efficiency."

A fundamental difference between the SMR and the ATR is that the heat for the reaction is produced within the ATR, whereas the SMR requires external heating from natural gas combustion. This means that the ATR has a single high pressure flue gas stream for carbon capture processing, whereas the SMR has both high and low pressure flue gas streams which require carbon capture. The size and cost of the carbon capture equipment can be reduced through high pressure operation, and this makes ATRs highly compatible with blue hydrogen production.

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The perfect pressure

Operating pressure, and therefore product gas delivery pressure, is another aspect that differentiates SMRs and ATRs. The ATR can operate at a higher pressure. This is a benefit if hydrogen must be injected into a high-pressure gas pipeline for transmission to cities throughout Yorkshire and beyond.

At some point in the overall CCS scheme, carbon dioxide (CO_2) must be pressurised to around 200 bar for injection underground. The carbon capture process yields CO_2 at close to atmospheric pressure. The operating pressure of the envisioned carbon capture pipeline network at the Humber industrial cluster has not yet been determined and various options are under consideration.

It is conceivable that CO_2 may be gathered at between 20 and 80 bar into a feeder pipeline network from carbon capture schemes associated with several industrial and chemical hubs on the Humber estuary. There may then be a single compression station to elevate the pressure to 200 bar for transmission offshore. The optimum network will depend on the mix and location of captured CO_2 sources and the precise location of the CCS pipeline landfall.

Andersen confirms that, "High pressure pipelines are essential for long transmission distances to allow for the pressure drop as the gas flows." They are also narrower, so they require less steel. But being at high pressure, the pipes require stronger walls meaning more metal or more expensive alloys.

"Deciding upon the perfect operating pressure for each leg of the CO_2 pipeline grid is a complex task and the decision cannot be taken in isolation of other process parameters."

Integrating air separation…

SMRs do not require pure oxygen. On the other hand, ATRs do. This means an air separation unit

(ASU) must be built if the ATR technology is used.

To enable 600 MW of hydrogen production, the ASU would need to produce between 1,200 and 1,300 tonnes of oxygen per day. That would make it one of the largest in the UK.

Downstream of the reformer, some blue hydrogen schemes will also integrate a blue ammonia plant. This would require nitrogen as a chemical feedstock to react with the hydrogen to make ammonia. The nitrogen would be produced on the ASU alongside the oxygen. The ATR, ASU and ammonia processes are highly integrated and interdependent.

Integrated process optimisation of the scheme to produce hydrogen, syngas and ammonia, combined with the associated air separation and CCS will be a highly complex process. Optimising blue hydrogen production requires a paradigm shift to focus on synergies and move beyond bolt-on solutions. But energy efficiency and competitive economics will be the result. The result of holistic process integration will be significantly more than the sum of the parts.

About the author

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Harrison has over 30 years' experience of the industrial and specialty gases business.

Source

**H21 North of England report https://www.equinor.com/en/what-we-do/hydrogen.html#:~:text=H21%20North%20of%20England*