Transformational potential for climate change mitigation

A broad review and some specific implications for the oil and gas sector

Stephen B. Harrison
sbh4

Non-linear, non-reversible, unpredictable trajectory calls for widespread, urgent action

The pace of climate change is exponential and many of its effects will be irreversible. The thawing tundra in Siberia is generating a layer of dry combustible material on the forest floor – tinder for wild-fires that destroy beneficial trees and generate carbon dioxide (CO_2) emissions with no useful energy capture.

Due to climate change, flooding, drought, and starvation will be inevitable, as will increased levels of poverty in many locations. Both Madagascar and Zambia are reporting their worst droughts in over 40 years, with consequential food shortages, famine, and thousands of premature deaths. The finger of blame is clearly pointing at climate change and urgent action is required to reduce CO_2, methane, and F-Gas emissions from many industrial sectors, including oil and gas processing.

There are enough solutions out there to create hope and enable the positive changes that are required. COP26 must be a platform to raise awareness of the issues, stimulate education about the solutions, and propose policy frameworks that stimulate implementation and international collaboration.

Price of prevention is less than the cost of catastrophe

The business case for prevention is clear at a conceptual level, and a myriad of technologies exists. Many can readily be implemented if there is enough inspirational corporate action, the right regulatory environment, and visionary political leadership. COP26 is the platform where the consequences of climate change must be presented impactfully and effectively. And the outcomes from the meeting must be transformative, collaborative, international solutions for immediate implementation. There is a price to be borne, but failure to act will cost the earth.

Policy leadership ahead of COP26 is coming from several directions. As an example, India could force oil refineries and urea fertiliser plants to use green hydrogen as a portion of their hydrogen production under draft plans sent for cabinet approval by the Indian Government’s Power and Renewable Energy minister, RK Singh. This is proposed as the first stage of a national plan to secure a leading role for green hydrogen in the energy transition.

Methane emissions reduction has also been in focus in the run up to COP26. On behalf of the European Union and the United States, European Commission President, Ursula von der Leyen, and President Biden used the Major Economies Forum on Energy and Climate (MEF) to announce the ‘Global Methane Pledge’ on the 18th of September. It will be launched at COP 26 in November, in Glasgow. Several other nations have already signalled their support, and countries joining the Global Methane Pledge will commit to a collective goal of reducing global methane emissions by at least 30% from 2020 levels by 2030.

To monitor and implement progress, countries that have committed to the pledge must move towards best available inventory methodologies to quantify methane emissions, with a particular focus on high emission sources. Delivering on the Pledge would reduce warming by at least 0.2°C by 2050. Major sources of methane emissions include oil and gas, coal, agriculture and landfills. Of these sectors, the greatest potential for short-term methane abatement by 2030 is within the energy sector.

Oil and gas sector can rise to the challenge

Energy usage in industrial, domestic and transportation is responsible for an overwhelming proportion of greenhouse gas emissions. The oil and gas sector is fundamentally an energy business, and it will therefore be integral to the transformation to climate neutral energy vectors and efforts to minimise the impact of fossil fuel usage.

Conversion of natural gas to blue hydrogen and low carbon ammonia or methanol is one value chain that the midstream and downstream sectors are in pole position to lead. But methane emissions must ruthlessly be eliminated. Additionally, CO_2 released with methane from the reservoir and CO_2 generated from the energy requirements of gas processing and liquefaction must also be mitigated.

Blue hydrogen relies on capturing the CO_2 that is released from the reforming process chemistry and capturing the post-combustion CO_2 emissions from the fired burner that is used to generate the heat energy, which is required to drive the reforming reactions forwards towards hydrogen production. Whether the CO_2 is then utilised or sent for permanent underground storage or mineralisation is of secondary importance – the first stage of the process relies on carbon capture.

There may be latent concerns about classical CCS with underground CO_2 storage, but the idea of CCS as 'Carbon Capture and Something' begins to turn the focus towards capturing the carbon, thus leaving the next steps open. At the very least that approach may get some traction behind carbon capture, whilst the debate about the long-term storage mechanism can take place in parallel to constructive action.

Displacement of coal fired power generation with pipeline natural gas or LNG is another area where the midstream sector will most likely be busy for the coming decades. LNG can connect energy producers and consumers. Through its transportability it creates international inter-dependence and stimulates trade. Amongst the range of clean energy vectors, such as low carbon hydrogen, ammonia, and methanol, all fall short of LNG when it comes to volumetric energy density, which is the important factor for long-distance shipping.

Whilst the CO_2 emissions at the power plant from gas fired electricity generation are significantly less than coal, only a tiny amount of methane leakage would give the gas fired option an equally damaging greenhouse gas footprint. It is essential to consider the full lifecycle analysis of fuels production, distribution, and utilisation.

Going underground

CCS is also an established technology. In Europe, more than 20 years ago, Equinor commenced capture and sequestration of CO_2 on the Sleipner West field in the Norwegian sector of the North Sea. 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 United States for many years.

The use of safe, permanent underground CO_2 storage in saline aquifers, depleted oil and gas reserves for CCS schemes is an area where midstream and upstream operators can rise to the decarbonisation challenge. The expertise that has been used to explore and drill for oil and gas can be applied to developing CCS reservoirs. Furthermore, the associated pipeline transmission infrastructure is likely to be adaptable to become the backbone of a CO_2 disposal network.

Most existing CCS schemes are point to point, meaning that one carbon capture location such as an ammonia plant SMR is connected to one underground geological CO_2 storage location. This simple model will transition to more complex ‘hub and cluster’ schemes where CO_2 will be captured from several plants and fed into a feeder network connected to a long-distance transmission pipeline. This will mirror the existing natural gas pipeline grids.

Sub-surface technologies can also be used for mid-term and long-term storage of energy gases. To add flexibility to integrated energy systems in the future where reliance on variable renewable energy will increase, long-term, high-capacity energy storage will be essential to balance

Ten transformational policy proposals and discussion points for COP26

❶ Clean up existing processes in parallel to developing the new clean energy infrastructure. As priorities, support investment in reduction of leaks and emissions of natural gas and other methane sources such as landfill sites.

❷ Implement carbon capture on existing CO_2 point sources with a projected operational life of more than 15 years.

❸ Place more emphasis and urgency on CO_2 capture, collection, and logistics infrastructure and business model development.

❹ Tax 'the problem' with an international CO_2 emissions tax at a fixed rate, with a clear implementation and ramp-up timeline would be the fairest mechanism, which would also allow for clear planning and investment.

❺ Use funds derived from national and international taxation to support transformational research, such as the use of direct air capture for the simultaneous capture of CO_2 and methane from the air.

❻ Implement a review of practices in agriculture and the food supply chain and stimulate the necessary research into new techniques.

❼ Focus on tighter control of F-Gases production because release to atmosphere is difficult to monitor due to the diverse range of domestic applications.

❽ At a policy level, shift the debate away from picking between apparently competing good ideas, e.g. battery electric vehicle (BEV) vs fuel cell electric vehicle (FCEV) or green hydrogen vs blue hydrogen.

❾ Motivate with a combination of hope and urgency. Current climate conditions indicate that the 1.5°C and perhaps 2°C targets will be overshot and the timeline for climate neutrality is variable around the world. COP26 must maintain the focus on achieving alignment to tougher targets and rapid action.

❿ Visionary, blame-free collective international action is required and COP26 programmes must recognise this.

seasonal changes in energy supply and demand. Underground hydrogen storage, or UHS, is ideal for this application.

Currently, two UHS pilots are planned in Germany and the Netherlands in 2021-2022. The North Sea and its nearby onshore region could also be an attractive choice for energy system integration, where CO_2 could be injected into oil and gas reservoirs and aquifers to generate blue hydrogen from local natural gas resources. Offshore wind power generation is being installed at Giga Watt scale, enabling green hydrogen production.

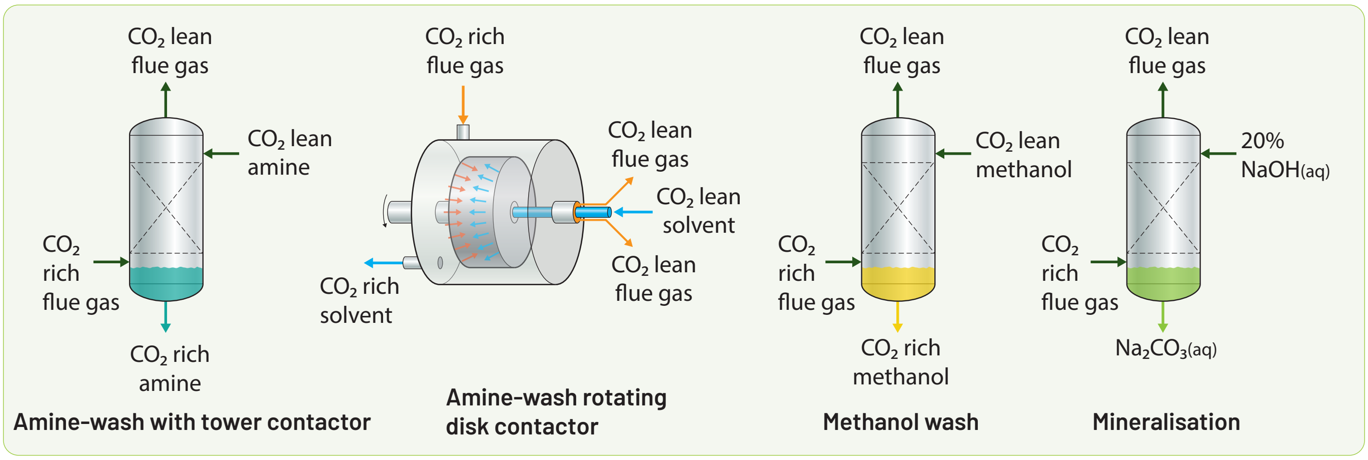
The green and blue hydrogen can be stored in multiple UHS salt caverns, thereby fully harnessing natural resources above and below the ground in the region. The North Sea Energy programme and the Zero Carbon Humber project are planning to use this region capability for a sustainable energy system.

It is possible to use underground hydrocarbon resources to produce hydrogen through in-situ gasification. This technology has the potential to be commercialised internationally due to the large volumes of oil resources globally. Instead of extracting crude oil from the underground fossil energy resources, in-situ gasification in the underground fossil fuel reservoir can be applied to create low carbon hydrogen.

To produce pure hydrogen, gas separation is achieved by installing a downhole membrane. Hydrogen is extracted from the production well, and since the carbon monoxide and CO_2 gases and other hydrocarbons remain underground, the process simultaneously results in underground CO_2 storage.

Carbon capture is at the root of all CCS or CCUS technologies

During glass, lime, cement, and refractory products making, CO_2 emissions are unavoidable. This is



A selection of CO_2 capture processes based on absorption

because the sands and minerals used contain CO_2, which is released during the melting and calcination processes. These mineral processing industries must live with the fact that this geogenic CO_2 is generated, even if heating from renewable electrical power or hydrogen is used to replace fossil fuel fired burners. However, there are many things that can be done to mitigate CO_2 emissions to the atmosphere. Decarbonisation may be ‘difficult’, but it will be possible.

Due to the geogenic CO_2 emissions, part of the decarbonisation solution in glass making and other mineral processing industries must therefore include ‘carbon capture’. Disposal of the captured CO_2 in underground reservoirs may become an important service and new business model for the oil and gas sector. CCS schemes that they operate can become the CO_2 sink for these industrial CO_2 emitters.

Refinery steam methane reformers (SMRs) consume natural gas to make hydrogen. The vast majority make grey hydrogen and emit CO_2. In the long term, this can be mitigated with ‘green’ hydrogen production using electrolysers fed with renewable electricity or reformers fed with biogas. In the short term, retrofitting carbon capture to SMRs to make so-called ‘blue hydrogen’ will make a step change reduction to CO_2 emissions and take a big step towards carbon neutrality.

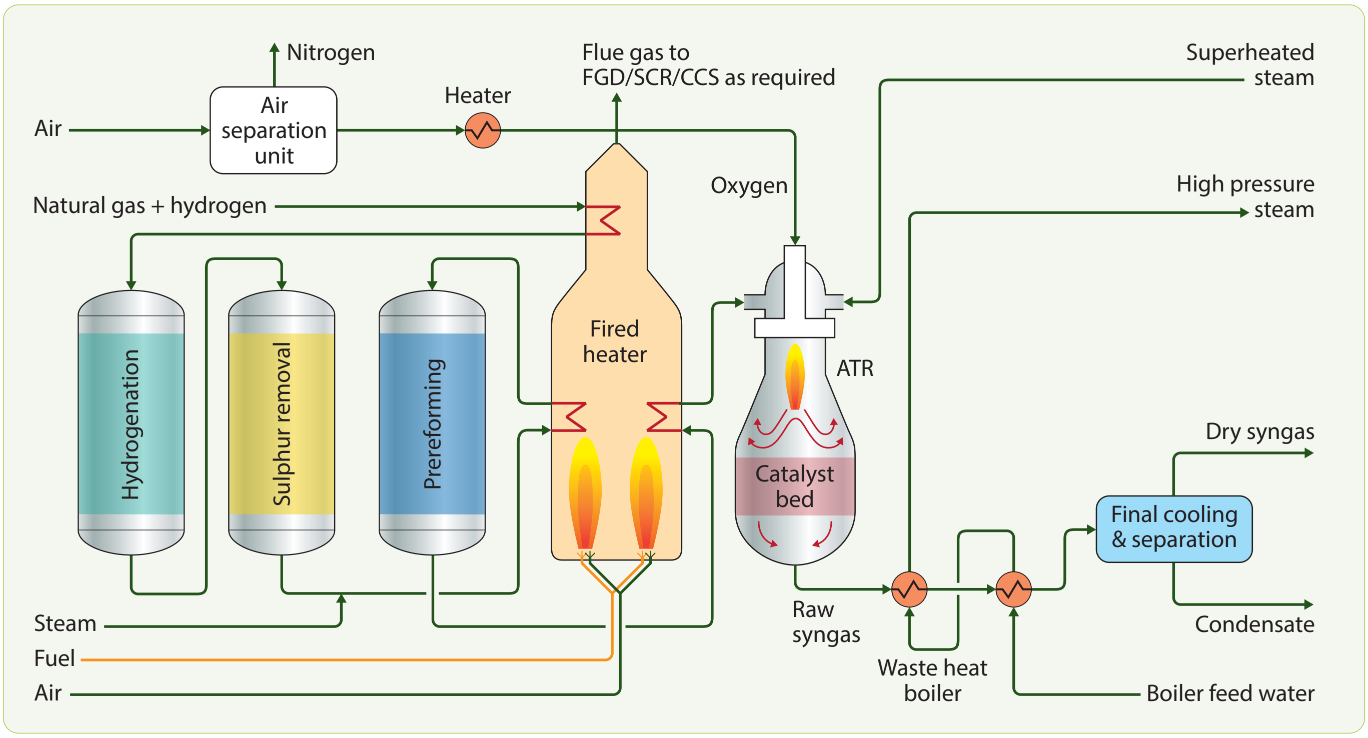
SMRs are used to produce more than half of the world’s hydrogen today. ATRs are also used extensively for syngas production. They tend to operate at a slightly higher pressure and the product is richer in carbon monoxide than the gases produced on an SMR. Fine-tuning of blue hydrogen production technology 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 H_2H Saltend project is focused on producing hydrogen for industry, power, and ammonia. 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. Operating pressure, and therefore product gas delivery pressure, is another aspect that differentiates SMRs and ATRs. The ATR can operate at a higher pressure, which is a benefit if hydrogen must be injected into a high-pressure gas pipeline for transmission to cities in Yorkshire and beyond.

Turquoise hydrogen, biochar & solid carbon

Turquoise hydrogen is produced by methane pyrolysis (also known as methane splitting or cracking) and is another pathway to produce low carbon hydrogen. Methane pyrolysis is endothermic, meaning that it requires heat energy to convert methane to hydrogen and solid carbon. There are different options for the heat supply. Indirect heating using burners fuelled by hydrogen or natural gas as a fuel is one option. Indirect electrical heating or direct heating with an electrical plasma are also possible.

A question that arises from methane pyrolysis with hydrogen as the target is: what happens with the various forms of solid carbon that are produced? If turquoise hydrogen production becomes a mainstream pathway to hydrogen, the amount of solid carbon produced will greatly exceed demand from current applications. If carbon black becomes abundant at low cost, it



ATR process flow sheet for syngas production

might find additional application as a soil improver in agriculture.

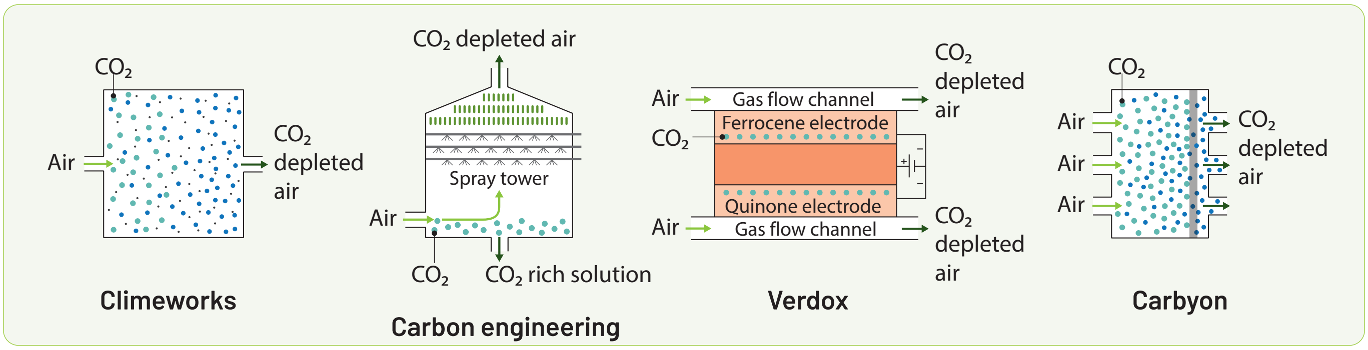
The use of biochar and wood acid (produced in a sustainable way from gasification or pyrolysis of wood) as alternatives or supplements to conventional fertilizers in rice paddies is reported to reduce N_2O emissions by more than 50%. As an additional benefit, methane emissions are reduced by more than 30%. Additional research in these areas and subsequent education and roll-out of such programmes to change agricultural practices is an area the international community can focus on at COP26 and other forums for climate change prevention.

Direct air capture of CO_2 and methane

CO_2 accumulation in the atmosphere has been through industrial and human activity. CO_2 removal is mainly through biological photosynthesis in plants, where the CO_2 is converted to starchy hydrocarbons.

Various mechanical direct air capture (DAC) processes have been developed to simulate the action of plants and remove CO_2 from the air. A DAC facility rated at 1 million tonnes of CO_2 capture per year does the equivalent work of 40 million trees. With such huge potential, it is no surprise that a massive amount of development activity has taken place to research, scale up, and commercialise these technologies in the past decade.

One of the attractions of DAC is that CO_2 can be recovered close to where it is required for EOR. The use of DAC to remove CO_2 from the air can also be used to offset CO_2 emissions from certain aspects of oil and gas processing that are very difficult to decarbonise. For example, amine wash CO_2 recovery systems operate most cost-effectively at up to 96% of CO_2 removal from the flue gas. The



A selection of technologies for direct capture of CO_2 from air (DAC)

5(ish)% residual CO_2 emissions from ATR and CCS for blue hydrogen can be offset in some way (e.g. BECC or DAC).

Furthermore, of great interest to the downstream sector, production of e-fuels could be a major application of CO_2 from DAC in the future. In the simplest case, captured CO_2 and hydrogen from an electrolyser are synthesised to methanol. Methanol acts as a hydrogen carrier and remains liquid under ambient pressure and temperature. Thus, the storage and transport of methanol is much easier and cheaper than liquid or compressed hydrogen distribution.

Whilst several commercial DAC technologies for atmospheric CO_2 removal exist, there is not yet one that has been implemented for methane capture from the air. It would be a good idea to capture these gases in parallel, since a major energy consumer in the system is the power requirement to drive the fan that moves air through the equipment. Using this power once to remove both gases would perhaps be the most efficient way to reverse the historical damage that has been done from CO_2 and methane emissions.

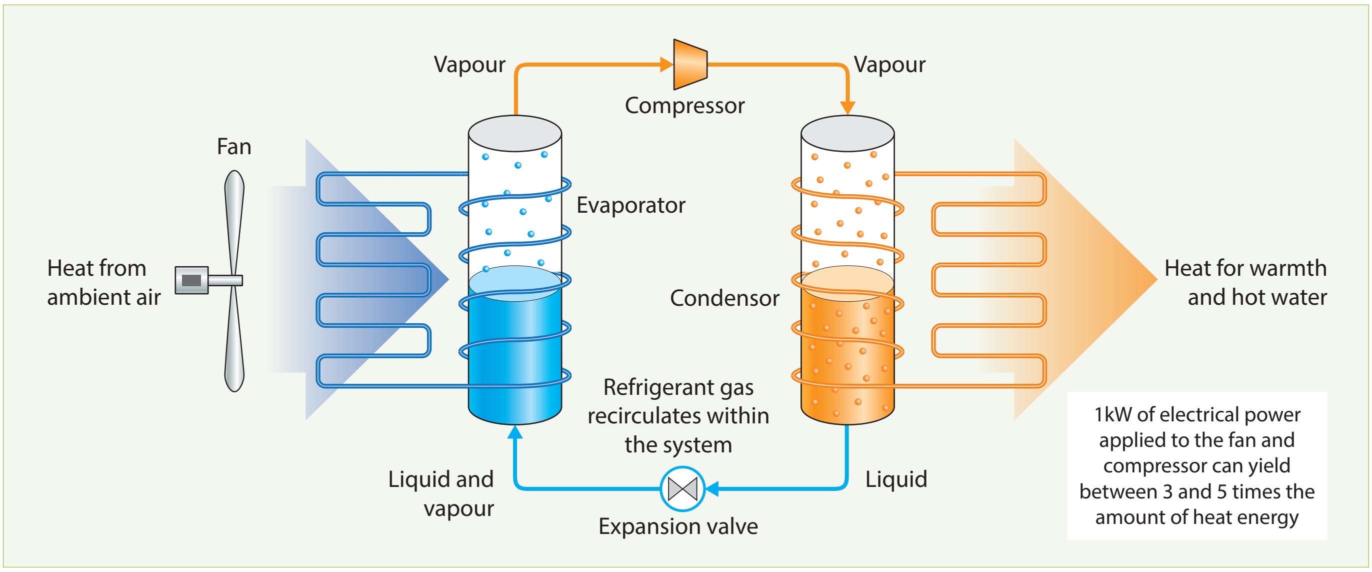
Electrification of industrial processes will play a leading role

Heat pumps are common for space heating. They use ambient air or soil as a heat sink and produce heat at about 50°C, which is ideal for heating buildings. High temperature industrial heat pumps (HTIHPs) are based on a similar operating principle and have been recognised for their potential to generate steam for process heating in the food, brewing, sprits distillation, paper making and chemicals sectors. An HTIHP requires a heat sink at a temperature of between 60°C and 120°C to generate steam. Waste heat is widely available from many processes at these temperatures.

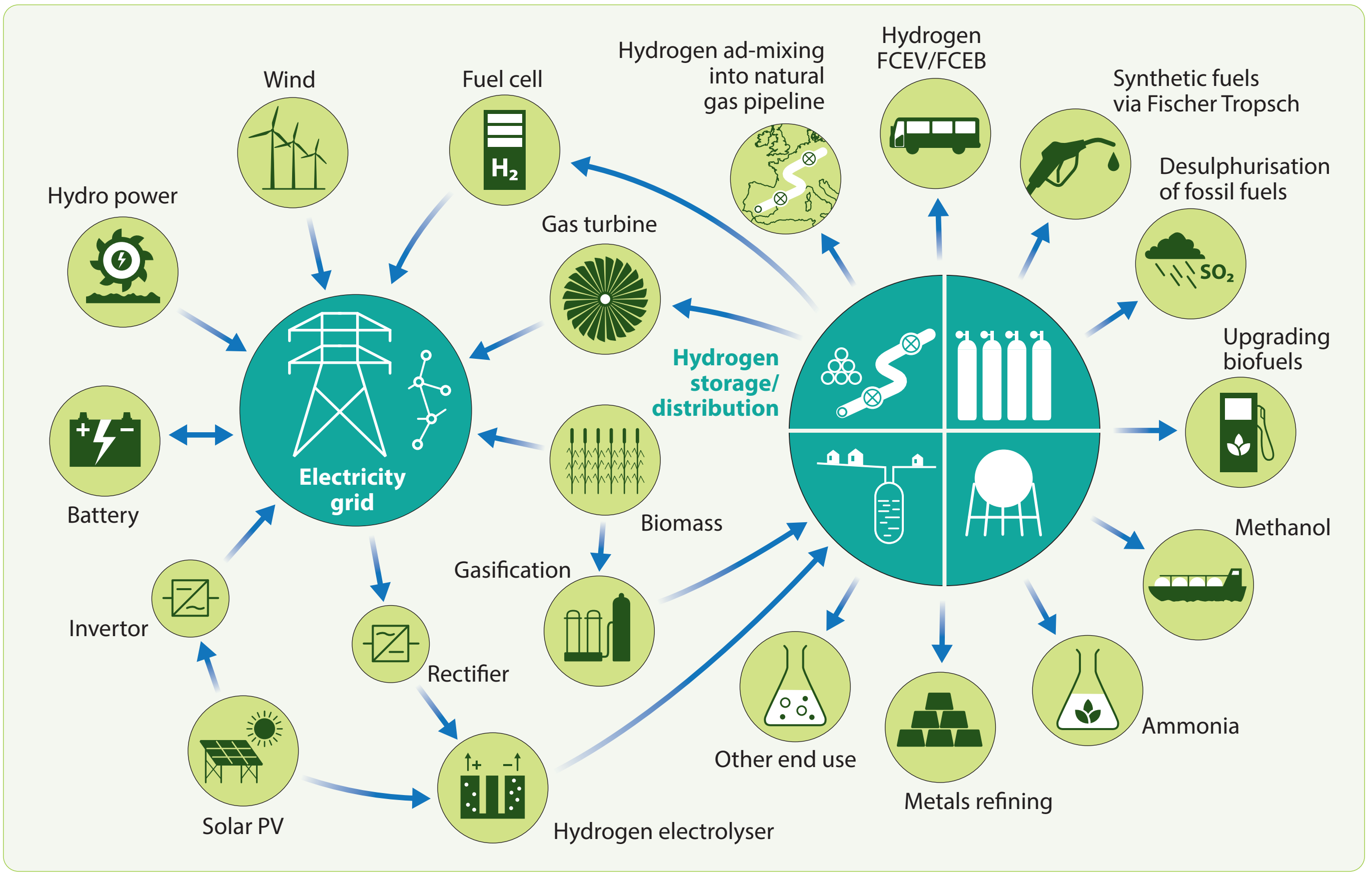
From a sustainability perspective, HTIHPs are attractive for steam generation because they do not create CO_2 greenhouse gas emissions for boiler operation. This is because the combustion of fossil fuels is not required. However, the heat pump must be supplied with renewable electrical power for the full environmental benefits to be realised.

The electrification of industrial processes will only be climate neutral if the power is generated using renewable technologies. Wind, solar, and hydro-electric power dominate here. Geothermal and biomass-based power generation are also relevant. So-called 'green' hydrogen can be produced through the electrolysis of water using renewable power. Reforming of biogas or gasification of biomass can also yield 'green' or renewable hydrogen.

There is the possibility that renewable power generation in the future will far exceed the total level of electricity production today. Imagine that all existing power from all sources is produced by renewables, plus a similar amount of power is used to generate hydrogen, and an additional third of the total is used to drive CO_2 and methane reduction equipment. For example, DAC technology to reverse the damage of the past and return the air to sustainable levels of these greenhouse gases.



Heat pumps can generate warmth for space heating from ambient air, or higher temperatures for steam generation from waste process heat



Electrolysis can convert renewable electricity to hydrogen, which can be used as a low carbon energy vector, as a reducing agent for steel making or to synthesise e-fuels, methanol, and ammonia

Methane monitoring and emissions mitigation matters

According to the European Pollutant Release and Transfer Register (E-PRTR), refineries in Europe that reported data to the public domain emitted between circa 100 and 2000 tonnes of the greenhouse gas methane per facility in 2017. The E-PRTR also reveals that methane emissions from gas pipelines, terminals, processing stations, and offshore platforms are in the range of 100 to 1200 tonnes per year per facility.

Natural gas leaks during extraction, storage, and transport are estimated to total in the order of 9 million tonnes per year in the USA alone. Natural gas is mostly methane, a greenhouse gas that traps 56 times more heat than carbon dioxide over a 20-year period. In addition to the greenhouse warming potential of these methane emissions and the lost opportunity to provide valuable energy to consumers, methane is a flammable gas and intensive leaks present a safety risk. So, for a host of reasons, methane emissions monitoring is a 'must'.

Elimination of methane emissions from landfill sites is also essential. Technologies exist to capture landfill methane, which can be used as an energy vector or be converted to hydrogen using a reformer.

F-Gases – low tonnage, high climate impact

The Paris Agreement on climate change sets a framework for the control of greenhouse gas emissions. It has been a catalyst for many efforts related to decarbonisation. Interestingly, it does not explicitly mention CO_2 once. It also does not mention methane, N_2O, nor fluorinated hydrocarbons (known as F-Gases), which are all potent greenhouse gases. However, in recognition of their potentially harmful impact, legislation has been implemented around the world to focus on the processing and use of F-Gases, such as Regulation (EU) No 517/2014.

Refrigerant gases are used in the oil gas sector for process chilling and to support liquefaction of hydrocarbons. A transition to low GWP F-Gases or so-called 'natural' refrigerant gases such as CO_2 or ammonia in mechanical refrigeration cycles will be essential to ensure sustainable refining and gas processing operations.

Stephen B. Harrison
sbh@sbh4.de