Waste-to-hydrogen to play 'major role' in circular economy of the future

By Anthony Wright | 30 September 2022

With the adoption of decarbonisation, decentralisation, and digitisation – also known as the three D's – global industry is entering a period of energy transition, where conventional fossil-fuel-based sources are gradually being replaced by sustainable, renewable alternatives, driving forward, and reshaping the way global energy systems work.

Led by innovations in lower-carbon energy sources such as liquefied natural gas (LNG), hydrogen, and biomethane, decarbonisation is one of the main drivers of the so-called Fourth Industrial Revolution.

A key aspect of decarbonisation is reducing emissions in sectors of industry that are notoriously hard-to-abate, such as cement manufacture, the steel industry, and waste – the fourth largest source sector of emissions.

A form of sustainable waste management using thermochemical processes such as gasification, reforming, and pyrolysis can be used to convert hydrocarbon-rich solid wastes to useful hydrogen.

One such process, known as chemical recycling, or chemcycling, also yield pyrolysis oil (pyoil) – a liquid fuel similar to diesel, and syngas which can be further processed to hydrogen or greenhouse gas (GHG)-free ammonia.

Speaking at **gas**world's 'Sustainability and Circular Economies' webinar, industrial gas and clean energy expert Stephen B. Harrison of sbh4 Consulting explained the role waste-to-hydrogen could play in the circular economy of the future.

According to Harrison, chemcycling can be used as an alternative to incineration, in which waste is combusted to yield steam, CO2 and ash.

"Integrated pyrolysis, reforming and gasification have a significant environmental advantage over incineration: the oxygen-deficient atmosphere prevents the formation of dioxins and furans which are highly toxic pollutants," he explained.

Although some CO2 is produced by thermochemical processing, the International Panel on Climate Change (IPCC) regards incineration of the biogenic fraction of waste as CO2-neutral, a definition that encompasses waste such as animal carcasses, scrap wood, waste vegetable oils and post-consumer wastepaper.

Waste-to-hydrogen can be used as an alternative to landfill sites, notorious for releasing harmful methane emissions.

Hydrogen from waste process

Municipal solid waste (MSW) contains around 50% biomass, so a large portion of the hydrogen produced from MSW can be regarded as renewable.

According to Zero Waste Europe, each tonne of MSW incinerated typically releases between 0.7 and 1.7 tonnes of CO2, including emissions of both fossil CO2 from burning materials such as plastics and from burning biomass.

After recyclable material is removed, the waste is shredded and dried – a process that can be optimised in terms of energy efficiency by using waste heat from the subsequent processes.

“The dry material is then fed into the first thermochemical processing reactor stage which is often a pyrolysis reactor,” explained Harrison. “Pyrolysis operates at around 750C in the absence of air.”

Once the feedstock is thermally decomposed into gaseous, solid, and liquid components, the gases leave the pyrolysis reactor and steam is added to initiate reforming and cracking reactions.

With reforming taking place at around 950C, the process generates hydrogen and breaks down heavy tars into short-chain hydrocarbons.

“As a third thermochemical processing stage, a partial oxidation reactor (POX) can be used. The POX reactor is fed with pure oxygen, rather than air, to avoid NOx (nitric oxide) generation.”

In addition to polluting the air, NOx also presents materials selection challenges for the process equipment.

To ensure that carbon monoxide is produced in higher amounts than CO2 in the POX reactor, a controlled amount of oxygen is added – less than the amount required for complete combustion.

By combining a controlled amount of oxygen with high temperatures, POX destroys tars and other large hydrocarbons. POX allows for the high temperature syngas that leaves the exothermic reactor to be used for heat recovery with a radiant/convective heat exchanger or through the use of direct quench to improve overall process efficiency.

To clean up and condition syngas, cyclones and filters are used for particulates removal followed by wet scrubbing, whereas solid absorbents such as activated carbon can be used to remove mercury and trace heavy metals.

The next stage involves feeding this syngas to water gas shift (WGS) reactors, which involves a high-temperature shift (HTS) at 300-450C followed by a low-temperature shift (LTS) reaction at 180-230C.

Harrison explained, "Different catalysts are used in the two shift reactors to optimise the conversion of CO to hydrogen. Steam injection can be used to optimise the reaction conditions."

The final stage uses pressure swing adsorption (PSA) to separate pure hydrogen from the residual syngas. To create the energy required for the endothermic pyrolysis and reforming reactions to take place, CO and some hydrogen exit the PSA as 'tail-gas' which can be burned with some additional natural gas.

"The PSA can generate fuel cell grade hydrogen at up to 'five nines' or 99.999% purity. This grade of hydrogen can be used in PEM fuel cells for cars, buses, trucks, boats and trains."

If necessary, the process can be taken a step further. By feeding the hydrogen into a Haber-Bosch reactor, ammonia can be produced. As a suitable carrier of hydrogen, the ammonia can be harnessed to transport hydrogen over long distances, satiating the needs of export markets.

What is the Haber-Bosch process?

Essential in the manufacture of plant fertilisers, Haber-Bosch works by fixing nitrogen from the air with hydrogen from natural gas to produce ammonia. It is thought that the process accounts for the Earth's current population explosion. It is also estimated that approximately half of the protein in today's humans originated with nitrogen fixed through the Haber-Bosch process (Rae-Dupree, 2011).

Are there alternatives?

Aside from waste-to-hydrogen for waste disposal, there are alternatives such as sending waste to landfill – a process that Harrison states must be avoided, as it's likely to generate harmful methane emissions.

He explained that several waste-to-hydrogen projects have already been developed to use older landfill sites as energy resources, a development that could provide enough waste to feed a waste-to-hydrogen plant for more than a decade.

"In this way, waste-to-hydrogen can help to avoid additional methane emissions that may result from these landfill sites."

"Waste-to-hydrogen is one of the most sustainable ways of processing municipal solid waste, which is an inevitable consequence of human activity. The process will therefore have a major role in the circular economy of the future."