Oxygen and nitrogen for waste-to-hydrogen

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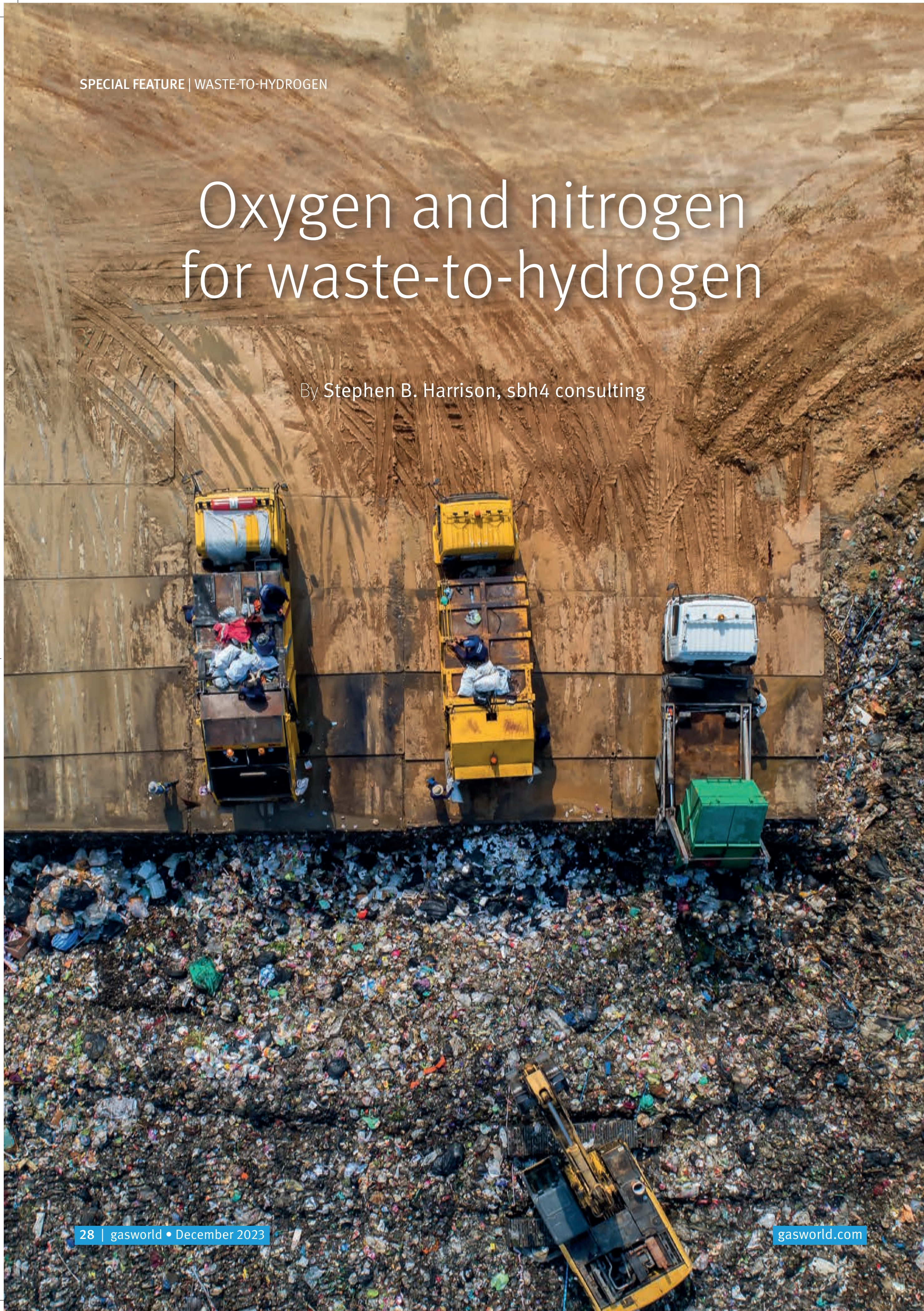

Gasification of coal has been implemented on many facilities in China and South Africa to yield syngas for conversion to liquid fuels, olefins, or methane. Partial oxidation of natural gas is a gasification process which is becoming common to make syngas or blue hydrogen for low-carbon ammonia. Gasification of municipal solid waste (MSW) to yield syngas is also increasingly popular.

The syngas produced from the gasification of MSW can be used to make methanol or liquid fuels through Fisher Tropsch Synthesis (FTS). Alternatively, syngas can be upgraded to enrich the hydrogen content using the water gas shift (WGS) reaction. If required, the crude hydrogen flowing from the water gas shift reactors can be further purified using pressure swing adsorption (PSA) to yield fuel cell grade hydrogen.

Gasification uses a controlled amount of oxygen in the chemical reactions. The oxygen can either be supplied from air or as pure oxygen. Pure oxygen for waste to hydrogen gasification can be generated on site using PSA or cryogenic distillation to separate oxygen from nitrogen in the air. Alternatively, since many waste to hydrogen processes are at relatively small scale, liquid oxygen can be delivered and stored in cryogenically insulated tanks and vaporised prior to use on the gasifier.

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For MSW, gasifiers shutdowns for cleaning and de-slagging must be scheduled at regular intervals to ensure reliable operation over the long-term. As part of the shutdown routine, purging with nitrogen to remove oxygen and flammable gases will be required. Nitrogen is therefore essential for the safe operation of the gasifier, as it is for many other chemical processes. Alongside cooling water, steam, and electrical power, nitrogen is a ubiquitous utility in the energy and chemicals sectors.

Waste-to-hydrogen

Hydrogen is notoriously difficult to store and transport. As a compressed gas at 700 bar pressure in a modern composite Type 4 carbon fibre cylinder on a road trailer, the payload of hydrogen is only one tonne.

Conversion of the hydrogen to liquid can increase the payload of hydrogen on an articulated bulk road tanker to 3.5 tonnes, but there is an additional power penalty associated with the liquefaction.

Distribution of hydrogen by pipeline, either as a pure gas or blended into existing natural gas transmission and distribution networks, is likely to be cost-effective in the future. However, the infrastructure for hydrogen pipeline distribution does not exist today.

Generating hydrogen close to where it will be consumed avoids the cost of distribution. Waste-to-hydrogen can be implemented in urban locations where MSW is abundant. The hydrogen can then be used for heavy-duty mobility applications, for example running the fleet of garbage trucks to collect the MSW or local bus fleets or trains.

In the realm of zero-emission mobility, hydrogen is currently competing with battery-electric vehicles. When hydrogen is used on a

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fuel cell electric vehicle, it must be very pure at around 99.999% and the cost of producing hydrogen at this purity is high.

An alternative to fuel cell electric vehicles is to fire hydrogen on specially designed internal combustion engines. In this case, 1 or 2% of impurities such as nitrogen, methane or carbon monoxide in the hydrogen can be tolerated. Hydrogen at this lower purity can be produced at a lower cost, potentially less than $2 per kg, a highly affordable cost of clean mobility.

Syngas to clean liquid fuels

As an alternative to producing hydrogen from MSW, syngas from the gasifier can be used to make liquid fuels such as methanol, synthetic crude (syncrude) or synthetic aviation fuel (SAF). Unlike hydrogen, each of these has a very high volumetric energy density and is therefore easy to transport and store.

Fulcrum Bioenergy is a leading user of the MSW gasification pathway to SAF. Fulcrum has implemented Linde Hot Oxygen Technology to generate the heat required in the gasifier to convert the MSW to syngas. The syngas is then cleaned, the hydrogen content is enriched, and then syncrude is made from the syngas using Fisher Tropsch Synthesis.

Fulcrum Bioenergy operates a demonstration site at Sierra, Nevada and has three large projects in development: Trinity Fuels Plant, US Gulf Coast, start-up 2025; Gary, ▸

Indiana, start-up 2026; NorthPoint, Cheshire, UK, start-up 2027. Each will convert circa 600,000 tonnes of MSW per year to circa 100 million litres of synfuels per year.

The syncrude can either be processed on site to make the mix of refinery products such as SAF and green diesel. Alternatively, it can be sent to an established refinery for refining on their existing equipment to leverage existing refinery infrastructure and reduce the cost of stranded assets.

In the US, landfill has been used for MSW disposal for many decades. This means there in addition to the fresh daily flows of MSW, there is abundant MSW feedstock available in existing landfill sites. These old landfill sites can be thought of as 'crude oil reservoirs' in the context of this MSW to SAF pathway.

In Indonesia, Jakarta's main landfill site in Bantar Gebang, receives 7,000 tonnes of MSW per day and has a total estimated volume of MSW of around nine million cubic metres available for landfill mining. The SAF production potential from such a large landfill site is tremendous.

Electrification with renewables

Gasification is an endothermic reaction, meaning that it requires heat input to proceed. It also takes place at high temperatures which means the heat must be applied at a high temperature. During partial oxidation of natural gas some of the natural gas is burned to generate the high temperature flame to drive the gasification chemistry.

For MSW gasification, plasma at around 3,000°C is an ideal high-temperature heat source. Plasma can be generated from renewable power sources to reduce the CO_2 footprint of hydrogen and syngas from MSW gasification.

Figure 1. Electronically Powered Plasma Gasification of Waste

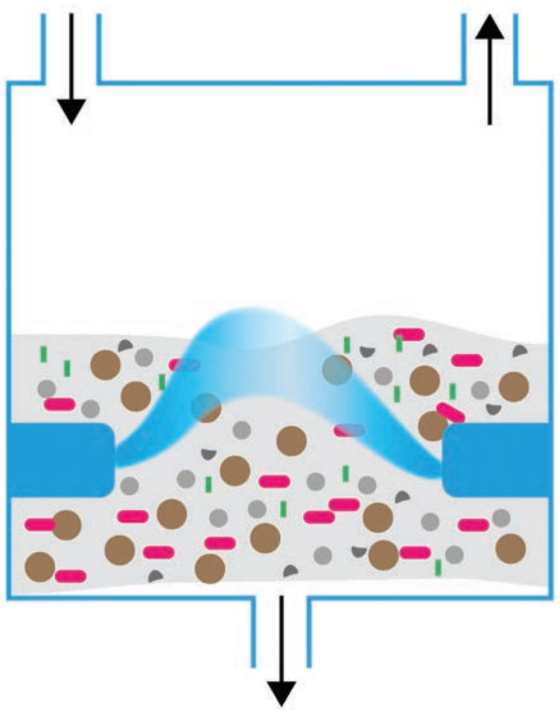

	Figure 2. Plasma Gasification of Solid Hydrocarbons (waste, for example)
Carbon feedstock	Municipal solid waste, dried waste water treatment sludge, biomass, waste paper, tyres, etc
Target chemical reactions	Hydrocarbon + O2 $\rightarrow$ 2CO + $4H_2$ Hydrocarbon + H_2O $\rightarrow$ CO + $3H_2$
Additional side reactions	Hydrocarbon + $2O_2$ $\rightarrow$ CO_2 + $2H_2O$
Carbon produced as	CO, CO_2, char, slag and ash
Product gas pressure	Close to atmospheric pressure
Product gas temperature	~1000°C

Plasma is sometimes referred to as the fourth state of matter. It is like a gas that has been excited to a very high energy state. Argon plasma is well known in the industrial gases sector for cutting and welding metals. Argon plasma can also be used to destroy persistent F-Gases and thereby avoid greenhouse gas (GHG) emissions. The plasma torch used in most waste-to-energy systems is either an air plasma or nitrogen plasma. An oxygen plasma could also potentially be used.

Lessons from the past

Between 2013 and 2016 Air Products was involved in the TV1 and TV2 waste-to-energy gasifiers at

Billingham, in the Tees Valley of the UK. The project was planned prior to the current focus on hydrogen and the process was intended to use oxygen-fed plasma gasifiers to create heat and power. The same technology could have been used to generate hydrogen or syngas.

The Tees Valley waste-to-energy plants were based on Alter NRG plasma gasifiers. The plasma torches were provided by Westinghouse Plasma Corporation which was a division of Alter NRG. Canada's Alter NRG was acquired by Harvest International Energy in 2015. Harvest is wholly-owned by China's Sunshine Kaidi New Energy Group.

Unfortunately, the TV1 and TV2 projects were cancelled due to technical failures that resulted from the poor mixing of MSW and gases within the gasifier. Smaller units had been implemented using the same technology, but the challenges of scale-up defeated the Tees Valley projects. In principle, plasma gasification is possible, but careful materials handling and flow management of MSW within the gasifier is essential. This flow distribution phenomenon is likely to limit the scale of operation of waste-to-hydrogen gasifiers.

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The future of plasma gasification

The plasma technology provider SG H_2 Energy is planning to build a waste-to-hydrogen plant in Lincoln, California. The plant is proposed to generate 12 tonnes per day of hydrogen from 120 tonnes per day of wastepaper. With biogenic paper being the feedstock, green hydrogen will be produced.

In Sweden, Plagazi has planned a sophisticated waste to energy facility that will generate 12,000 tonnes per year of fuel-cell grade hydrogen and provide steam for 10 MW of district heating. The feedstock will be 66,000 tonnes per year of non-recyclable MSW. Additionally, the Plagazi process will capture and liquefy 150,000 tonnes per year of carbon dioxide (CO_2).

Plagazi has integrated InEnTec

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plasma gasifiers into its process flow sheet. These have been proven over many years on 13 reference sites operating with MSW or biomass feedstocks. To keep the plasma gasifiers at a reasonable scale and avoid the issues that confronted the TV1 and TV2 gasifiers, three Plagazi HE-2000 units will be operated in parallel. The facility will consume 10 MW of electrical power in total.

The Plagazi gasifiers will be oxygen-fed. High temperature, oxygen-fed gasification reduces the amount of tar that is formed, which simplifies syngas clean up. The use of oxygen instead of air avoids the unnecessary flow of nitrogen through the process. This means that smaller and therefore less expensive equipment can be used. It also simplifies recovery of CO_2 at the back end of the process. gw