Scaling-up syngas with gasification and autothermal reforming

Giga-scale hydrogen schemes driving ASU growth

By Stephen B. Harrison, sbh4 consulting

As hydrogen production ramps up, we are leaping orders of magnitude from mega-scale to giga-scale projects. The largest hydrogen electrolysers operating today are in the 10 to 20 megawatt (MW) range. Plans already exist for gigawatt (GW) systems. Scale up is also the order of the day for hydrogen production from natural gas.

As an example, the H21 North of England project proposes nine auto thermal reactors (ATRs) to convert North-Sea natural gas to hydrogen. Each ATR would be rated at 1.35 GW of hydrogen energy production and would require an air separation unit (ASU) capable of 2,900 tonnes per day (tpd) of oxygen.

The emergence of hydrogen as an energy vector represents a tremendous growth opportunity for industrial gases for two reasons: the production of hydrogen and the production of oxygen to feed some hydrogen production processes. Not all processes that generate hydrogen from natural gas will require oxygen, but the biggest schemes using ATRs and gasification will consume oxygen in vast quantities.

Gasification of coal has been used for more than 100 years to produce syngas. Gasification of natural gas to produce syngas is a newer technology and is generally referred to as partial oxidation, or POX. The use of oxygen, instead of air in these gasification processes, is beneficial for precise control of the oxidation chemistry and avoids costly flue-gas de-NOx systems. It also makes the integration of carbon capture and utilisation or storage (CCUS) more cost-effective.

2,900

Each ATR would need an ASU capable of 2,900 tpd of oxygen

In the past, iron and steelmaking and the oil and gas processing sectors were major drivers of the industrial gases 'tonnage and pipeline' businesses. In the future, hydrogen production will drive the growth of the large-ASU segment of our industry.

Hydrogen for heating

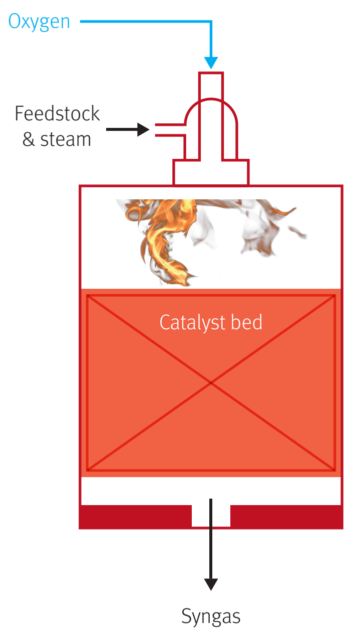
In continental Europe, green hydrogen is favoured in EU and national hydrogen strategies. The UK is a major natural gas producer and has the potential to implement CCS schemes in the North Sea to mitigate carbon dioxide emissions from natural gas-based hydrogen production. For the UK, blue is likely to become an abundant colour for hydrogen in the coming decades.

The UK's plentiful natural gas reserves have also led to the development of a sophisticated natural gas transmission and distribution pipeline network and reliance on gas as a cooking and heating fuel in many homes. Decarbonisation of this infrastructure without the costly implications of stranded assets can be achieved using hydrogen in the pipeline network and domestic applications.

The H21 North of England project

Figure 1. ATR for Syngas Production

	Auto Thermal Reforming – ATR (Oxidative Steam Reforming)
Carbon feedstock	Natural gas or light gaseous hydrocarbons
Oxygen feedstock	Oxygen from ASU fed with controlled stoichiometry to limit CO_2 generation
Steam feedstock	Yes, often from combined SMR
Catalyst required	Yes, Nickel, Cobalt and others
Target chemical reactions	$CH_4 + H_2O \rightarrow CO + 3H_2$ $2CH_4 + O_2 \rightarrow 2CO_2 + 4H_2$
Additional side reactions	$CH_4 + O_2 \rightarrow 2CO_2 + 2H_2$
Energy required/released	Balance of endothermic and exothermic
Hydrogen content in syngas	~65%
Syngas pressure	30 to 50 bar
Syngas temperature	1000 °C



Source: sbh4 consulting

is a huge giga-scale project. But it would produce only enough hydrogen to substitute approximately 15% of the UK's current natural gas demand. Considering this project must be replicated eight times to serve only the UK, the international potential for ASU growth becomes abundantly clear.

Pathways to hydrogen

About 90% of hydrogen produced globally today uses the process of steam methane reforming (SMR). This technology has served small to mid-scale requirements for syngas and hydrogen well for the past 40 years.

There has been a good fit with SMRs and the hydrogen demand on small to mid-size refineries. As refineries are scaling up and other applications for hydrogen in methanol and ammonia production are scaling up, the supremacy of the SMR technology is being challenged by ATRs and POX reactors.

An SMR feeds steam and natural gas downwards through many thin vertical steel tubes filled with catalyst. This produces syngas, a mixture of carbon monoxide (CO) and hydrogen. If hydrogen is the target, the syngas is further processed in a water shift reactor to convert the carbon monoxide to hydrogen and carbon dioxide (CO_2). The reactions in the SMR require a significant heat input to drive them forwards. For this, natural gas is burned with air in a fired heater within the SMR unit.

The reason behind the name 'auto thermal' reforming is because this process produces its own energy to drive the chemical reactions. The process is also known as 'oxidative steam reforming'. The burner is fed with oxygen, not air, and provides the heat for the reaction, and immediately following the burner chamber, these gases flow through a catalyst bed to yield syngas. Unlike the SMR, where the burners are separated from the hydrogen production reaction by the steel tubes, in the ATR all the action takes place in a single vessel.

Partial oxidation is like auto thermal reforming because the reaction takes place in one unit, to which oxygen and natural gas are supplied. But it differs from both the SMR and ATR processes because neither catalyst nor steam are used. When wood, coal, or petcoke are used as feedstock, this process is called 'gasification'. The term POX is generally reserved for the partial oxidation, or gasification, of natural gas. As with the ATR and SMR, a shift reactor may be used to enrich the hydrogen content of the syngas produced by the POX reactor, if desired.

ATR and gasification

A subtle difference between the SMR, ATR, and POX processes is the optimum

The Oryx GTL Facility, Ras Laffan, Qatar

pressure at which they operate. Pressure is a critical aspect of process plant design. High pressure results in smaller process equipment, which can save CAPEX. Pressure also influences the chemical reactions taking place. Whilst SMRs typically operate in the range of 15 to 40 bar, ATRs are more comfortable in the 30 to 50 bar range and POX reactors operate in the range of 40 to 80 bar.

If hydrogen is intended for injection into high pressure gas transmission pipelines, producing it at high pressure is a tremendous benefit because a hydrogen compressor after the SMR can be avoided. This reduces both CAPEX and electrical power demand. This is one of the drivers for the selection of ATRs in proposed giga-scale projects where hydrogen will substitute natural gas.

ATRs for gas to liquids, methanol, and ammonia

Whilst SMRs have been dominant for hydrogen production on refineries, ATRs have been making in-roads in other processes. The presence of oxygen in the ATR yields syngas with a higher CO-to-hydrogen ratio than the SMR. This is suitable for some chemical pathways, such as the Fischer-Tropsch process, which produces liquid fuels from natural gas.

In 2006 the Oryx gas to liquids (GTL) project in Qatar was built to add value to natural gas and produce an energy-dense export product. Oryx has two large ATRs. Each is fed by a large ASUs, rated at 3,500 tpd of oxygen. The two ASU cold boxes for Oryx were built by Air Products at Acrefair in Wales and were shipped from Ellesmere Port. In a similar project, the Escravos GTL facility in Nigeria started up in 2014. It is of a similar configuration to Oryx and also uses two Air Products ASUs rated at 3,500 tpd of oxygen to produce syngas on ATRs.

Shell's Pearl GTL facility was constructed at Ras Laffan in Qatar, close to the Oryx plant, and started up in 2011. It is fed by eight Linde ASUs, each one rated at 3,500 tpd of oxygen. In contrast to Oryx, Pearl uses POX to convert natural gas to syngas. The combination of POX gasification technology for GTL in use at Pearl was first used by Shell in 1993 at the Bintalu GTL plant on the island of Sarawak. At Bintalu, oxygen for the POX gasification reactor is supplied by a 3,200 tpd ASU supplied by Air Liquide.

Methanol production also relies on syngas. A common technology combination used in mega-methanol plants is an SMR followed by an ATR. This is known as 'combined reforming' and has been implemented at the world's largest methanol facility located at Kaveh in southern Iran.

Methanol to gasoline (MTG) is an alternative route for liquid fuels production that also uses ATRs. The Turkmengaz natural gas to gasoline facility, which came on-stream in 2019, is the world's largest MTG plant that uses an oxygen-fed ATR for syngas production.

Ammonia production is the largest consumer of hydrogen globally. Around 50% of the world's hydrogen production is aligned to the ammonia value chain. Modern ammonia facilities are being built in locations where natural gas is available at low cost, such as the middle east and Russia. Liquid ammonia or urea can efficiently be exported. The use of an ATR for ammonia production offers a high degree of synergy because oxygen from the ASU can feed the ATR, and nitrogen from the ASU can be used in the ammonia production process. Like hydrogen, ammonia is a carbon-free energy vector. Use of ammonia as fuel will expand its range of applications and drive significant growth in ammonia production – generating demand for major new ASU projects. gw

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Stephen B. Harrison is Managing Director of sbh4 Consulting. Harrison has over 30 years' experience of the industrial and specialty gases business.