Reducing CO_2 emissions through process electrification

Hydrogen production from catalytic microwave methane reforming could jump-start the hydrogen economy

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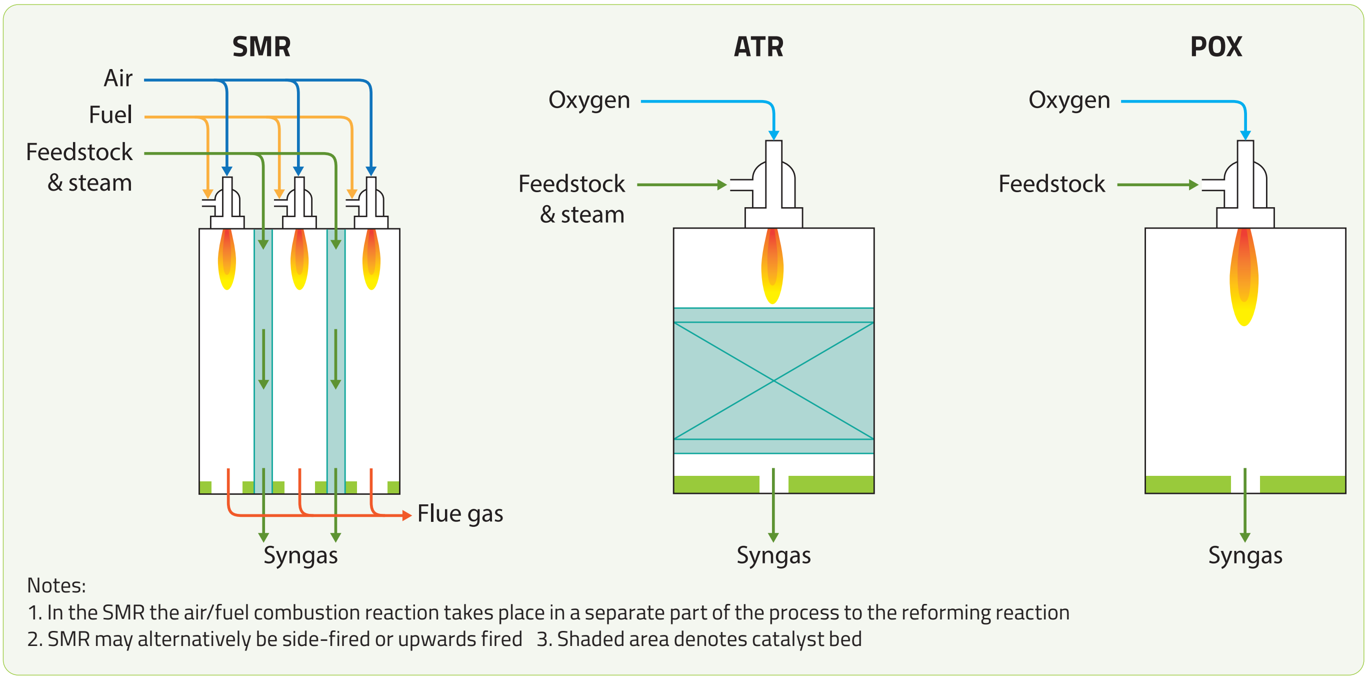
More than 95% of the hydrogen produced worldwide today is derived from thermolysis of fossil fuels. Reforming of natural gas is by far the largest source of hydrogen, accounting for around 80% of hydrogen production. In this category, steam methane reformers (SMRs) lead the way, and auto thermal reformers (ATRs) play a supporting role. Gasification of coal and petcoke is the second largest hydrogen production pathway. POX, or partial oxidation of natural gas, a process that is like gasification, is also a significant thermal process to produce hydrogen.

Electrolysers are being built at an increasing pace and on an ever-larger scale. When fed with renewable electricity from sources such as wind, hydropower or PV solar panels, 'green' hydrogen is the result. Hydrogen production on electrolysers is growing at around 50% per year; from a low base, this kind of growth is not surprising.

To meet the need for additional hydrogen required to support the decarbonisation of industry, transportation and the energy sector, hydrogen production from fossil fuels, such as natural gas, is also likely to see growth in future decades. When combined with carbon capture and utilisation or storage (CCUS), low-carbon hydrogen, or 'blue' hydrogen, is the result.

In a paradigm shift away from conventional reforming processes and post-combustion CCUS, Nu:ionic, a start-up based in Atlantic Canada, has a new take on hydrogen production. Their process uses catalytic microwave reforming of methane to generate hydrogen. Only one-quarter



Notes:
1. In the SMR the air/fuel combustion reaction takes place in a separate part of the process to the reforming reaction
2. SMR may alternatively be side-fired or upwards fired 3. Shaded area denotes catalyst bed

Figure 1 SMR, ATR and POX processes for syngas production of the electrical power that an electrolyser would consume is required. Methane consumption is reduced by about 30% compared to conventional reforming techniques. The result is low-cost, low-carbon hydrogen.

Gas-fired steam methane reforming, with CO_2 emissions from the combustion heating

An SMR is fed with methane from natural gas or biomethane and steam. The reaction proceeds inside an array of vertical tubes filled with a nickel-based catalyst to produce syngas, which is around 70% hydrogen and 30% carbon monoxide. To drive the reaction kinetics, heat energy must be applied at a high temperature. This is achieved by burning natural gas in the air to heat the outside of the reactor tubes. Approximately 75% of the natural gas flows through the reactor, and the balance of 25% is fired in the burners.

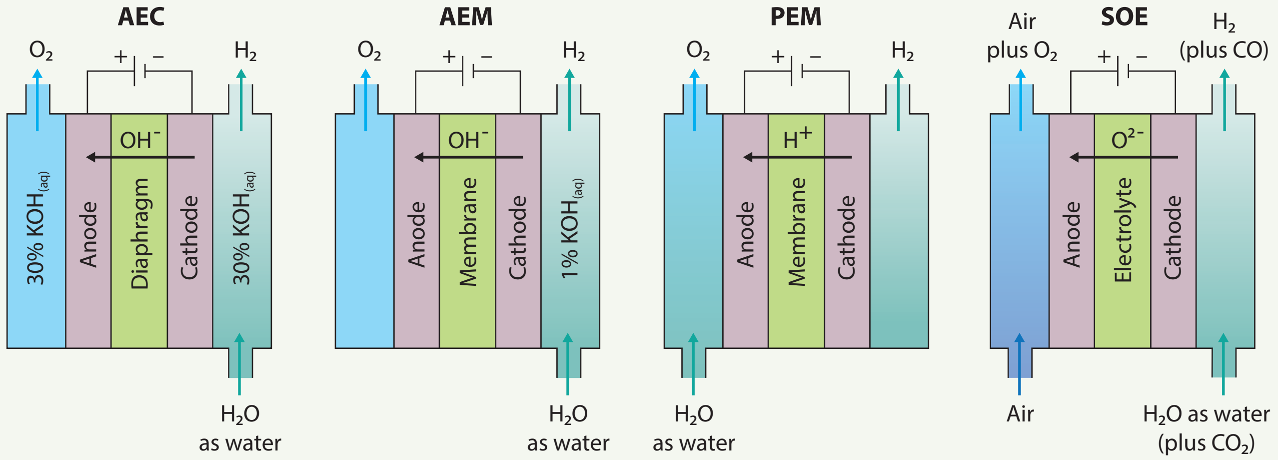
Subsequent catalytic reactors are used to combine more steam with the carbon monoxide in the syngas to produce carbon dioxide and hydrogen. The components of this stream are then separated on a pressure swing adsorption (PSA) unit to generate pure hydrogen and ‘tail gas’. The tail gas contains carbon dioxide, unreacted methane and residual quantities of carbon monoxide, in addition to some hydrogen. These energy gases are combined with fresh methane to fire the burners. The burner flue gas is rich in carbon dioxide and can be processed using an amine wash or other suitable carbon capture system.

In regions where natural gas is abundant, and CCUS is possible, this natural-gas intensive process for hydrogen production can be viable. The South Eastern United States or the West coast of Norway are two example locations that would fit these conditions. The emergence of abundant, low-cost renewable power from super-scale, ideally located onshore and offshore wind farms and GW scale solar parks allows for the use of electricity in new ways to reduce our reliance on fossil energy sources.

Microwave catalytic reforming – CO_2 emissions reduction through electrification

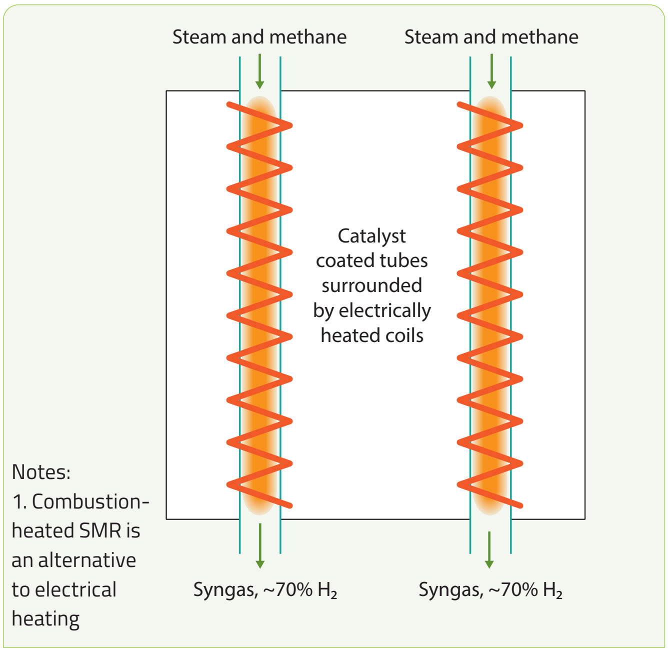
Microwave energy is produced from electricity and is used in our homes to heat food. Radio communications masts also transmit information using microwave frequencies. Industrial microwaves are used for drying pharmaceutical powders, cereal grains and timber. Microwaves are now also being used to provide the energy to drive steam methane reformers.

Jan Boshoff is the CEO of Nu:ionic Technologies, a company based in New Brunswick in Eastern Canada. Boshoff says that “using microwaves from renewable power instead of burning natural gas or biomethane to create the energy required for the reforming reaction can reduce gas consumption by 25-30%. It also reduces the fossil fuel footprint by a similar amount. By eliminating the fired heater, which is the most polluting part of steam methane reforming, through electrification we are



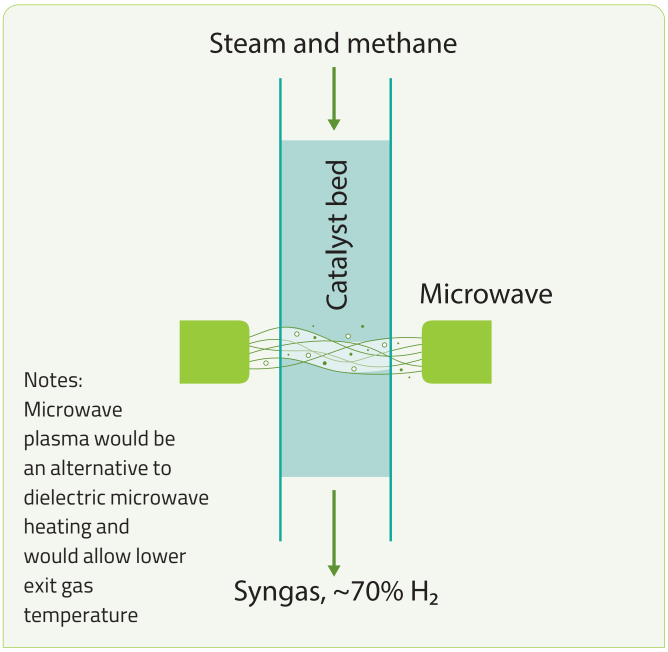
Notes:
1.In the AEC, AEM and PEM, lye or water flow from the electrolyser cell with the oxygen and/or hydrogen gases. Those liquids are mixed and recirculated to the electrolyser.
2. Air is used to purge the SOE anode to avoid oxygen accumulation which may present a hazard at the high operating temperature.
3. Bipolar plates made of stainless steel (titanium for PEM) are usod to stack adjacent cells in each electrolyser type.

Figure 2 Electrolysers: AEC, AEM, PEM and SOE for hydrogen (and syngas) production



Notes:
1. Combustion-heated SMR is an alternative to electrical heating

Figure 3 Electrical catalytic steam methane Reforming (eSMR)



Notes:
Microwave plasma would be an alternative to dielectric microwave heating and would allow lower exit gas temperature

Figure 4 Dielectric microwave catalytic steam methane reforming (μSMR)

reinventing gas conversion for a cleaner future.”

Nu:ionic has developed and validated steam methane reforming based on microwave energy input, a form of electrical reforming. Microwave energy is applied directly into the reforming reactor and penetrates deep into all the catalyst pores. This overcomes one of the issues with traditional reforming where heat and temperature distribution through the catalyst bed is uneven and results in reaction slow spots, meaning that lots of catalyst and a very large reactor are required.

Beyond the reduction in methane consumption, the process benefits from a significantly more compact reforming reactor size, simpler materials of construction and an almost instantaneous ramp rate. This means the process is ideal to be combined with variable renewable power such as wind or solar. A traditional SMR takes hours to ramp up due to the heating requirement, and once it is on the flexibility to turn up and down is very limited.

“The innovations that we have packed into our process go beyond the microwave,” says Boshoff. “The catalyst must allow the microwave energy to freely flow through it. We do use a nickel-based catalyst because that is a readily available metal, but the trick lies in our choice of catalyst support and the way we have mounted the catalyst on that support.”

The process can be fed with low-pressure natural gas or biomethane from the distribution grid. A compressor boosts the gas up to between 12 and 18 bar in a compact reforming reactor, where the catalyst is directly heated to the reforming temperature by microwave energy.

In a conventional steam reformer, a fired heater is required. In that fired heater, combustion superheats the stack gases to 150-300°C above the required process temperature. By directly heating the catalyst with the microwave, energy is efficiently applied in the exact amount required by the reaction. This results in an improvement in overall system efficiency and eliminates the excess heat that is wasted in the reformer stack.

After the reformer, a typical chain of shift reactors enriches the hydrogen concentration to around 85%. After those, Nu:ionic has introduced a further innovation: an amine-wash carbon capture system, which removes the carbon dioxide gas prior to hydrogen purification in a traditional PSA system. The PSA tail gas is used to generate the steam that is required to feed the reformer. The carbon capture system effectively removes all the carbon dioxide produced by the process, enabling low-carbon hydrogen production and minimising the size and cost of the PSA equipment.

Jump-starting the hydrogen economy

It is hard to imagine what could derail the development of the emerging hydrogen economy. Positive sentiment and momentum related to the use of hydrogen as a renewable energy vector are

Biogas plant with biomethane upgrade

at an all-time high. Admittedly, some applications, such as passenger cars, may be a mix of hydrogen fuel cell vehicles and battery electric vehicles, but many industrial applications will inevitably pull for more hydrogen to displace fossil fuels. Aviation and heavy transportation, for example shipping, long-distance trucks and trains, are still in a dynamic zone with many possible solutions under consideration.

The conviction to use hydrogen will stimulate major infrastructure investments, such as hydrogen distribution pipelines. Liquid hydrogen storage and distribution networks may also emerge. However, the infrastructure is not yet in place. Boshoff adds that "the great thing about the Nu:ionic hydrogen generator is that it is a small to mid-scale plug-and-play solution for on-site hydrogen supply."

"All you need is water, methane, and power. These utilities are ubiquitous today and mean that we can put hydrogen in the places where it is needed, even before the hydrogen transmission and distribution infrastructure is ready. We are jump starting the hydrogen economy."

A team on the move

Boshoff is keen to see his company's technology develop further: "We will be building a 1 tonne per day hydrogen reformer this year. That will have a 500 kW microwave unit and will be based on our proven pilot plant in New Brunswick. Beyond that, we intend to leverage our experience in the development of world-scale gas-to-liquids processes to scale up to plants capable of 100+ tonnes per day of hydrogen. We have had interest from several investors to support our growth trajectory and we are always open to enter into partnership and financing discussions."

Dry reforming, where most of the steam that is fed to the reformer is replaced with carbon dioxide (CO_2), is also on the radar. "We had some encouraging results with CO_2 injection," confirms Boshoff. "Microwave catalytic chemistry allows unique solutions to the conventional challenges associated with dry reforming."

Boshoff adds that there is further room for optimisation on the reactor design and operation, including sulphur-tolerant reforming and non-equilibrium operation: "But as we are taking this one step at a time we can bring the cost and efficiency benefits associated with the electrification of fired heating to market sooner. However, we have a robust innovation pipeline and will implement further developments to the technology for future generations of the equipment."

The track record of the team at Nu:ionic is remarkable. Boshoff himself was a senior executive at Sasol, with responsibility for gas conversion to synthetic fuels processes. His co-founder and CTO, Jim Tranquilla, has more than 40 years of expertise under his belt. He was the CTO at Atlantic Hydrogen, where microwave pyrolysis was proven to be a potential means for turquoise hydrogen production, splitting methane to hydrogen and solid carbon.

"In addition to our openness for financial sponsors, we are developing strategic partnerships in biogas utilisation, hydrogen for mobility as well as renewable energy storage markets," adds Boshoff. "For example, we could imagine high levels of synergy with a play that could support us with access to the European market. We believe that the decarbonisation focus, biomethane availability, CCUS readiness, and the gas/power cost mix in some regions there will be highly compatible with our process."

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