Syngas: A foundation to decarbonisation

The chemical sector constitutes the third largest carbon dioxide (CO_2) emissions among industrial sub-sectors, according to the International Energy Agency (IEA). A large share of these emissions stems from using fossil fuel-based feedstocks. To combat these emissions, there is a growing push to switch from traditional fossil fuels to low-carbon alternatives. One of the most important intermediaries in this transition is low carbon **synthesis gas** or **syngas**.

Syngas is primarily comprised of hydrogen (H_2) and carbon monoxide (CO), often with traces of carbon dioxide (CO_2) and methane (CH_4). It is a key resource in producing ammonia, methanol, hydrogen, and synthetic hydrocarbon fuels through the Fischer-Tropsch process. The exact composition of syngas varies based on the feedstock and production method.

While syngas has traditionally been produced from reforming or gasification of fossil fuel-based feedstock, decarbonising its production processes is essential for reducing the emissions of the sectors that rely on its availability.

A wide variety of hydrocarbon feedstock and processes can be used to generate syngas

Steam Methane Reforming (SMR), where syngas is produced through the catalytic conversion of methane and steam, is the predominant technology for syngas production from natural gas. This dominance is in large part due to the process producing a high ratio of hydrogen to carbon monoxide, otherwise known as the 'syngas ratio', which in turn can be an advantage for hydrogen production. However, SMR requires substantial heating, met by the combustion of natural gas. If employing carbon capture and storage to decarbonise, the emissions from the combustion process necessitate additional costly carbon capture from flue gas with low concentration CO_2.

Partial oxidation, where hydrocarbons react with oxygen, also produces syngas. Autothermal reforming combines this oxidation with catalytic steam reforming in one reactor. The heat generated from the partial oxidation can match the heat requirement for steam reforming for 'autothermal' operation. The output of this ATR process is syngas with a H_2:CO ratio favourable for gas to liquid applications. As most of the carbon dioxide produced by autothermal reforming is contained in the output process stream, a higher carbon capture rate can be achieved at lower costs compared to SMR.

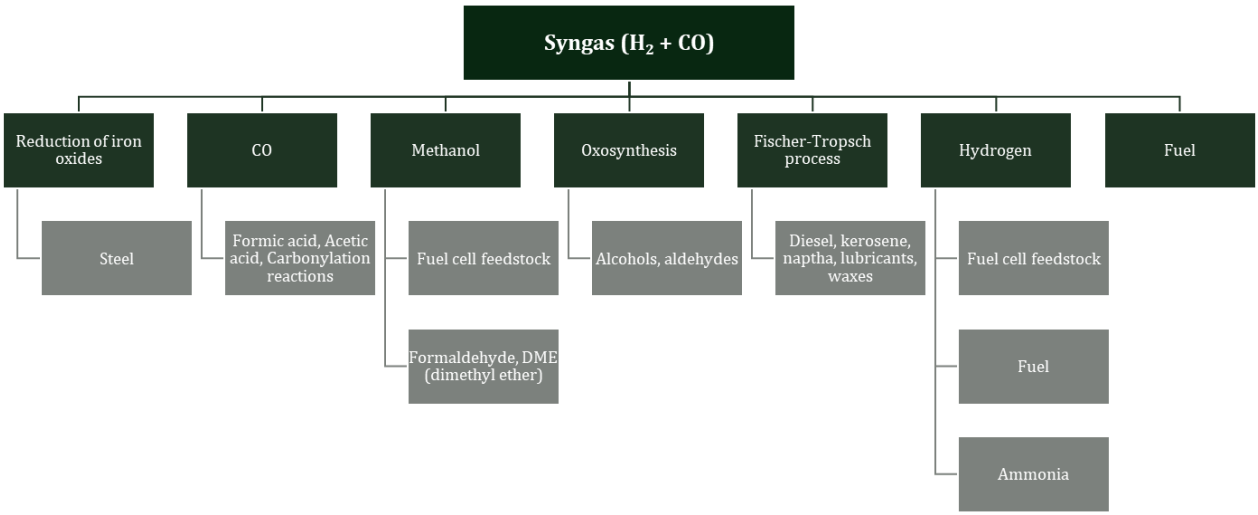
Coal gasification is also widely employed for syngas production, and its feedstock accounts for 48% of global syngas production[1]. This process uses oxygen and steam to gasify the solid carbon contained in

[1] Bachmann et al, 2023, Link

coal to syngas. Although this is a mature process, the GHG emissions and relative energy intensity affect its competitiveness in a low-carbon market.

The RECYCLE (REthinking low Carbon hYdrogen production by Chemical Looping rEforming) project uses chemical looping reforming to produce syngas. Unlike other processes, the RECYCLE technology inherently separates carbon dioxide and does not require capture processes based on solvents, potentially lowering capital and operational costs. The carbon capture of the process not only reduces released emissions but also results in a syngas product with lower traces of carbon dioxide that does not require significant processing and purification before use in downstream fuel and chemical production. The technology also produces nitrogen as a co-product, which can then be used for producing ammonia.

Syngas forms the starting point for multiple routes of chemical and fuel production.



PATHWAYS FOR SYNGAS UTILISATION

Syngas is an incredibly versatile mixture that is used in several industrial applications, a selection of which is outlined below:

- **Hydrogen production:** Syngas, after being processed through a water gas shift reaction (which converts carbon monoxide to carbon dioxide and hydrogen) and purification, produces hydrogen that can be used as a fuel, chemical feedstock, or in various industrial and mobility applications.
- **Synthetic fuels:** Syngas is required for the the conversion of gases to liquid fuels through the Fischer-Tropsch (FT) process. The FT process further broadens the applicability of syngas as it is used to produce a variety of synthetic hydrocarbons, e.g. diesel and naphtha and Sustainable

Aviation Fuel. Syngas can also be used to produce methanol or ethanol for conversion to synthetic hydrocarbons via alcohol-to-jet or alcohol-to-gasoline processes.

- **Power generation:** Syngas is combustible and can be burned in gas turbines or internal combustion engines to generate electricity. It is increasingly being considered for use in Integrated Gasification Combined Cycle (IGCC) plants, which combine syngas production with power generation while capturing emissions.
- **Ammonia and methanol:** Hydrogen produced from syngas is an essential feedstock for producing ammonia, which can be used as a fuel or fertiliser. Methanol can also be produced either directly from syngas or reacting the produced hydrogen with carbon dioxide. In addition to their potential for use as feedstock for the chemical industry, both ammonia and methanol may play important roles in decarbonizing maritime transport.

The market for synthetic fuels and chemicals is only expected to grow, driven by policy support and decarbonization mandates. Synthetic fuels such as Sustainable Aviation Fuels and methanol are crucial to reducing the emissions of hard-to-abate sectors such as aviation and maritime transport. Policies such as ReFuelEU and the UK SAF mandate for aviation and the FuelEU Maritime GHG reduction targets will likely incentivize the development of technologies utilizing low-carbon fuels and thus encourage growth in these markets. Furthermore, the adoption of the Carbon Border Adjustment Mechanism (CBAM) across the EU (from 2026) and the UK (from 2027), which aims to incorporate the price of carbon emissions into the cost of imported carbon intensive goods, will also drive the markets for chemical feedstock such as methanol and ammonia.

Potential scale of the market for a selection of syngas fuels by 2050

Methanol
Source: International Renewable Energy Agency

Ammonia
Source: International Renewable Energy Agency

Hydrogen
Source: International Energy Agency

SAF
Source: International Air Transport Association (IATA)

The RECYCLE project enables low-carbon syngas production and can be integrated into multiple downstream industrial applications.

As the world moves toward decarbonization, syngas will play a pivotal role in producing clean fuels, chemicals, and energy. Technologies such as RECYCLE will be important in ensuring the availability of low-carbon syngas. Its inherent carbon capture and production of valuable co-products such as nitrogen also make it well-suited for integration into downstream industrial applications.