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Transition to net zero: steps to decarbonize the oil refining industry

A review of the solutions being employed by oil refineries to reduce their Scope 1, 2, and 3 greenhouse gas emissions

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Reprint from Digital Refining 2022

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Despite improvements in vehicle fuel economy, increasing adoption of hybrids, and EVs, petroleum-based fuel demand continues to grow, at least in the short- to mid-term! In general, demand is generated from population growth and increased car ownership, and both are increasing. However, during the pandemic, people concerned about health moved around less. Consequently, there was a sharp decline in fuel demand, which had an adverse impact on the global oil and oil refining system. However, chemicals demand was sustained, as chemicals are used in many everyday products. For a small number of refineries, who were able to convert fuel molecules to chemicals, the sustained chemicals demand allowed them to stabilise profitability during the pandemic. This provided a glimpse of the future.

In the future, we imagine demand for hydrocarbon-based fuels will decline due to increasing global efforts to fight climate change, including the introduction of a carbon tax in many countries. Therefore, refineries need solutions to decarbonise fuels production. Furthermore, as petroleum-based fuel demand decreases, chemical production is a route to stabilize and grow oil refining margins. In fact, highly profitable oil refineries already produce a high percentage of chemicals, and demand for chemicals is expected to increase. Therefore, it seems likely many oil refineries will seek solutions to expand their capability to make chemicals.

In this article, Johnson Matthey introduces solutions being employed by oil refineries to reduce their Scope 1, 2, and 3 greenhouse gas (GHG) emissions:

- **Scope 1** solutions reduce direct GHG emissions from the company's processes;
- **Scope 2** solutions reduce indirect GHG emissions from imported electricity and steam; and
- **Scope 3** solutions reduce other indirect GHG emissions, including decarbonising fuels production and increasing chemical manufacturing.

Scope 1: Reduce direct emissions from the process itself

A sensible first step is to reduce the emissions from the existing process units. Plant monitoring and benchmarking can be used to identify opportunities to improve energy efficiency. In addition, sophisticated catalyst performance monitoring allows operators to increase cycle-length, and therefore improve the utilisation of natural resources (e.g., base metals, precious metals, and catalyst materials).

In many factories, hydrogen is an important utility, used to make products, and produce electricity and steam. Presently, Steam Methane Reforming (SMR) is used to make most of the refinery hydrogen. The reformer in this process produces CO_2. Johnson Matthey offers a range of **KATALCO**™ services aimed at improving the plant reliability, efficiency, throughput, safety, and environmental performance. In addition, Johnson Matthey has recently established a Low Carbon Solution business that is addressing the decarbonisation of existing syngas facilities. Johnson Matthey is leveraging its capabilities in existing scalable technologies, especially in steam reforming. One of the early offerings is a SMR revamp that allows operators to capture the process CO_2, which can then be used as a feedstock or stored. This solution allows the hydrogen plant CO_2 emissions to be reduced by up to 95%. The cost of the revamp is significantly less than building a new hydrogen plant.

Hydrogen produced using SMR is called grey hydrogen, because it uses non-renewable feeds to produce hydrogen and CO_2, and the CO_2 is typically released to the atmosphere. More environmentally friendly alternatives are blue and green hydrogen. In the blue hydrogen flowsheet, the by-product CO_2 is available for capture, then utilisation or storage. In Johnson Matthey's Blue Hydrogen Technology (**LCH**™), an advanced reforming system comprising ATR (autothermal reformer)/GHR

JM Technologies

Brown	Grey	Blue	Green
Coal	Natural gas	Natural gas	Renewable electricity
Gasification	Steam methane reforming	Advanced reforming	Electrolysis
No CCS	No CCS	CCS	
Highest GHG emissions (19 tCO_2/tH_2)	Highest GHG emissions (11 tCO_2/tH_2)	Low GHG emissions (0.5 tCO_2/tH_2)	Potential for zero GHG emissions
\$1.2 - \$2.1 per kg H_2	\$1 - \$2.1 per kg H_2	\$1.5 - \$2.9 per kg H_2	\$3 - \$7.5 per kg H_2

Figure 1 – Comparison of hydrogen production technologies

(gas-heated reformer) is combined with carbon capture. Green hydrogen uses renewable electricity to produce hydrogen without producing any CO_2. Hydrogen produced via blue and green routes can be used to decarbonize existing fuels and chemicals production. For more information, see Figure 1.

Scope 2: Reduce emissions associated with imported electricity and steam

An oil refinery can replace imported electricity with low-carbon hydrogen that is used to decarbonize its energy requirements, and excess low-carbon energy can be exported to nearby industry. When several industries are co-located, there is the potential to create a hydrogen hub.

An example of a hydrogen hub is HyNet North West, based in England (UK). The heart of the project is Johnson Matthey's **LCH**. This hydrogen hub will produce blue hydrogen. This blue hydrogen will be used to replace fossil fuels used by industry and transportation, and the hydrogen will also be used to heat nearby homes. The by-product CO_2 captured from the **LCH** process and CO_2 captured from nearby factories will be safely stored in an existing offshore well. The consortium includes Progressive Energy, Essar Oil (UK) Limited, ENI, Johnson Matthey, and other valued partners. This project is progressing fast and will be onstream circa 2025[1]. The complexity of this ground-breaking project is illustrated in Figure 2.

Figure 2 – HyNet North West: Hydrogen hub based in England (UK) [Image courtesy of HyNet]

Green hydrogen goes a step further. Hydrogen is produced via the electrolysis of water, using renewable electricity (e.g., wind, solar, etc.). The water is split into oxygen and hydrogen, without producing any CO_2. The development of green hydrogen is moving fast. Although renewable energy output is variable, Proton Exchange Membrane (PEM) electrolysers are engineered to cope with varying energy input. At the heart of every PEM electrolyser is a catalyst coated membrane (CCM) which is responsible for the production of hydrogen. These membranes consist of precisely engineered layers of structured catalysts typically platinum and iridium oxide. The catalysts are applied to solid membranes in a way which maximises potential hydrogen production. At Johnson Matthey, we design and manufacture high-performance CCMs at scale, building on our decades of experience in fuel cells which use very similar technologies. Green hydrogen coming out of the electrolyser contains up to 1% of oxygen, which is detrimental for most applications. However, oxygen can be economically removed by catalytic oxidation of hydrogen using Johnson Matthey's **PURAVOC™** GREEN catalysts. As the world's largest secondary refiner of platinum group metals, Johnson Matthey is also committed to the creation of an efficient recycling system to help unlock future capacity and support a sustainable energy transition.

Green hydrogen is available and oil refineries are starting to explore its use. One example is Shell's Rhineland refinery in Germany where green hydrogen is produced using a PEM electrolyser, powered by renewable electricity from offshore wind. Green hydrogen will be used initially to decarbonize fuels production at the refinery[2].

Although green hydrogen is more expensive to produce than grey or blue hydrogen today, the key input – renewable electricity – is both increasing in capacity and reducing in cost. What is beyond doubt is that green hydrogen will play an increasing role in the transition to net zero as the cost of renewable electricity continues to fall, and the cost of electrolysers reduces

Scope 3: Decarbonise fuels and chemicals production to reduce emissions from the products use

Technologies are available to allow refineries to use bio- and waste streams to decarbonise fuels and chemicals production, and grow chemicals production as fuels demand declines, thus reducing Scope 3 emissions. In addition, as an oil refinery increases its percentage chemicals production, the refinery margin tends to increase.

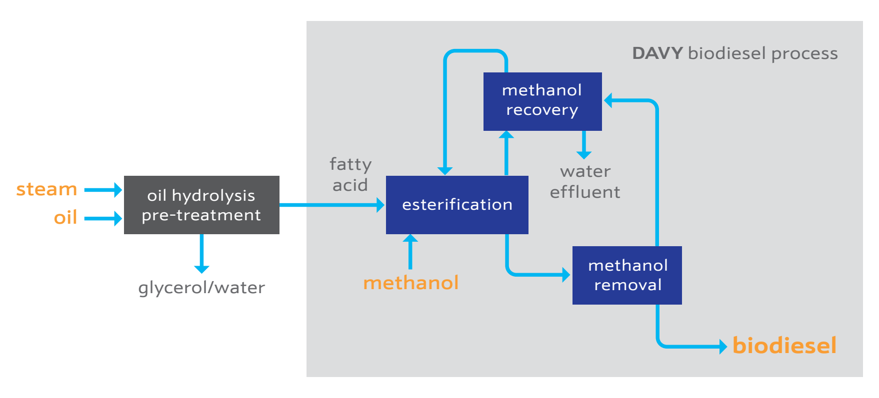

Figure 3 – Johnson Matthey's **DAVY™** biodiesel process

For some time now, oil refineries have been including bio-components in fuels production; the bio-component is typically added at the fuel blending stage. For example, Valero Corporation produces bioethanol on a large-scale in the USA[4]. Globally, bioethanol is produced from corn, wheat, sugarcane, beetroot, or similar, and is a popular choice for decarbonising gasoline production. Different solutions are available for diesel. For example, Johnson Matthey's biodiesel process uses fatty acids, obtained from the hydrolysis of bio-based oils, and converts them to FAME (fatty acid methyl esters, typically FAME is a mixture of several esters). See Figure 3 for a process flowsheet. So far, Johnson Matthey has licensed eight plants globally. Furthermore, renewable diesel, a hydrocarbon diesel fuel produced by hydroprocessing of fats, vegetable oils, or waste cooking oils, can be used as a direct substitute for conventional diesel fuel. Several units have recently been built in the USA.

As an alternative to green blending components, bio- and waste streams can be used as a feedstock to produce gasoline and diesel. A low capital option involves using existing hydrotreaters to co-process bio- and waste streams to make fuels and olefins, which are partially green. Leading-edge oil refiners have been exploring this opportunity for some time and have discovered it is possible to co-process up to 10-20% bio- and waste component. For example, Parkland Corporation's Burnaby refinery has successfully converted canola oil and oil derived from animal fats to fuels.4 In addition, a growing number of Fluid Catalytic Cracking (FCC) units are exploring co-processing. For example, Preem AB Lysekil refinery has successfully converted biomass-based pyrolysis oil to fuels and olefins[5].

Another way to decarbonise fuels and chemicals is to convert municipal solid waste and other renewable biomass to low-carbon fuels. For example, the FT **CANS™** Fischer-Tropsch technology developed by Johnson Matthey in collaboration with bp converts synthesis gas into long-chain hydrocarbons. The resulting FT products need upgrading, which can be done by an oil refinery, to produce low-carbon gasoline, diesel and jet fuels. Fulcrum are employing the FT **CANS** technology in their new Sierra BioFuels plant located in Nevada, USA. The Sierra plant is the first commercial scale plant in the US to convert municipal waste, that would otherwise be sent to landfill, into a low-carbon synthetic crude oil (syncrude). Fulcrum plans to sell the syncrude to nearby oil refineries. The syncrude can be used to reduce the carbon intensity of the transportation fuels. Furthermore, Johnson Matthey and MyReChemical have commercially developed a "waste-to-methanol" technology. The methanol derived from this process is an important intermediate product used to produce many goods that play a vital role in everyday life such as resins, plastics, insulation, and fibres. Besides, the methanol can be used to decarbonise fuels too, e.g., methanol as a gasoline blending component, methanol to power ships, etc.

Another option to reduce Scope 3 emissions is to grow chemicals production. This transition repositions the oil refinery and makes it fit for the future. For example, FCC units use ZSM-5 based additives to convert gasoline range molecules into propylene and C4s. There are several outlets for these high value olefins, including conversion to clean burning fuels, chemical-grade olefins, and polymer-grade olefins. To improve the quality and value of the refinery olefins, catalysts and absorbents can be used. Catalyst and absorbent are used to remove contaminants such as carbonyl sulphide, hydrogen sulphide, chlorides, arsine, phosphine, and mercury. After contaminant removal, these olefins are suitable for chemicals production. Johnson Matthey provides purification catalyst and technology for gas and liquid stream purification, and services designed to take care of all aspects of operation, maintenance and spent absorbent reprocessing. JM's **PURASPEC™** adsorbents are in operation in many locations.

Other technologies also exist to allow oil refineries to maximise high-value chemicals production. For example, the **LP OXO**^{SM} Technology, licensed in collaboration with Dow, is used to produce alcohols from propylene, butenes, or higher olefins. Incorporating this technology into the refinery flowsheet can deliver significant value. End products are plasticiser alcohols, acrylates, acetates,

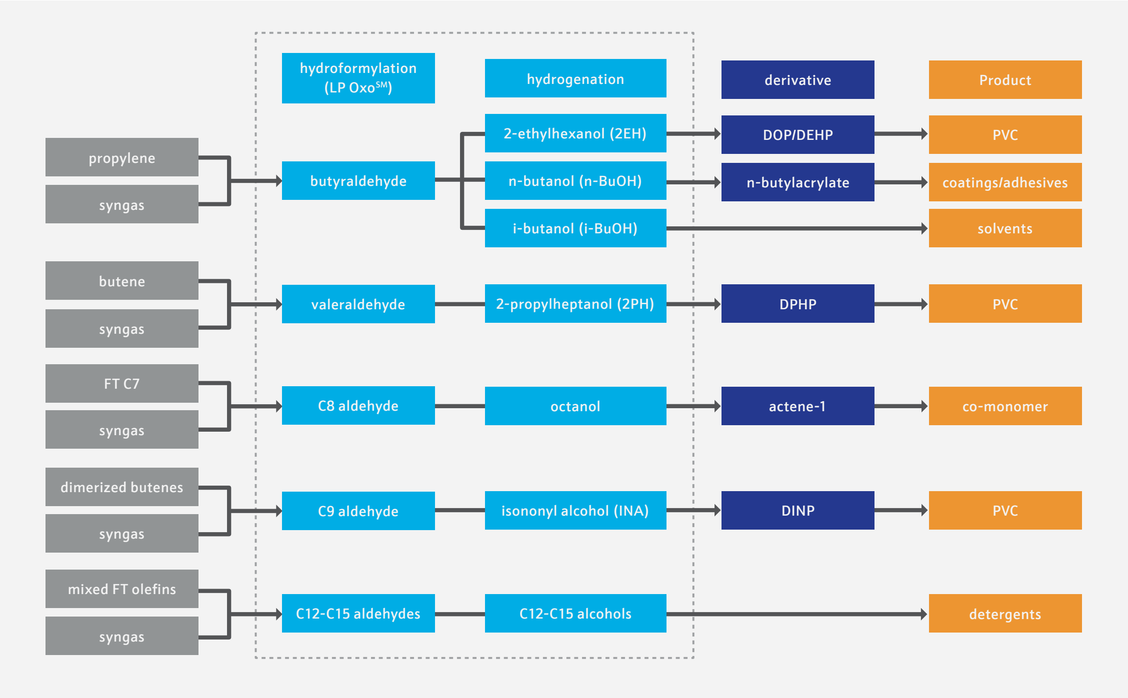

Figure 4 – The feedstock flexibility of **LP OXO** processes

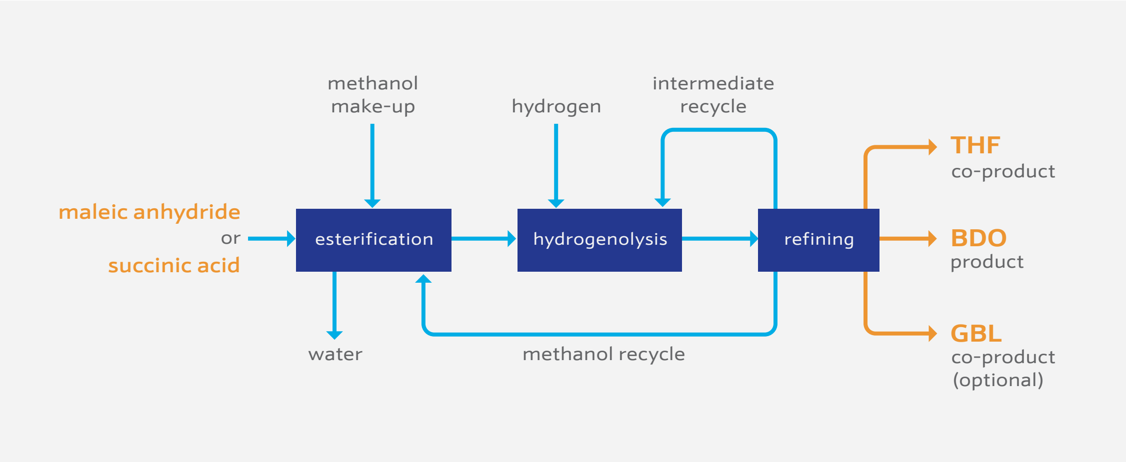

Figure 5 – Johnson Matthey's **DAVY** BDO process upgrades the value of butane

and solvents, as illustrated in Figure 4. It is also possible to improve the value of the oil refinery butane streams. Presently, butane is a low-value intermediate product that is obtained from various refinery units or from LNG sources. As fuels demand decreases, butane can be used to produce maleic anhydride which in turn can be converted into butanediol (BDO), tetrahydrofuran (THF) and gamma butyrolactone (GBL), using Johnson Matthey's **DAVY**™ BDO process. See Figure 5 for a process flowsheet. The end applications are engineering plastics, elastomer fibres, and solvents. BDO is currently in high demand in China, where it is being used to make bio-degradable plastics, such as PBAT (polybutylene adipate terephthalate) and PBS (polybutylene succinate). Alternatively, the process can be designed to produce bio-BDO from succinic acid, which can be obtained from sugar-based sources. This opens the door to produce 'green' PBS.

Conclusion:

To fight climate change, and make the world cleaner and healthier today, and for future generations, oil refineries must adapt. Carbon taxes are being implemented, and these will significantly erode refinery margins. This creates urgency for action. An obvious first step is to use available expertise, catalysts, technologies, and services to decarbonise processes and utilities. In addition, increasing the capability to use bio- and waste feeds and green blending components will further decarbonise fuels production. Finally, increasing the percentage of chemicals production will significantly increase refinery margin and reduce Scope 3 emissions associated with how products are used. Consequently, decarbonisation has the potential to be a strong value driver for the oil refining industry.

Acknowledgement:

The authors thank Johnson Matthey colleagues for their help and suggestions, and for providing a wide range of examples, and project details available in the public domain.

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