Rapid pyrolysis enabling decarbonisation to net zero

Dr Neil Hindle, chief technical officer of **Nova Pangaea Technologies**, shares insights into rapid pyrolysis for a net zero world

Emissions of CO_2 in 2021 are predicted at the time of writing to have returned to 2019 levels. This is despite the ongoing COVID pandemic and multitude of pledges to net zero by 2050 made around the time of the COP26 meeting in November 2021.

In October 2021, 290 members of the International Aviation Transport Association, including the major airlines, made a pledge to achieve net zero emission by 2050. Other ambitious pledges have been made by several speciality and consumer companies, including Unilever's pledge to be net zero on its own operations by 2030 and Scope 3 by 2039.

Although there are many opportunities to reduce carbon emissions towards net zero, there are relatively few methods of having net negative emissions. One area of focus is the direct capture of CO_2 from the atmosphere followed by underground storage. A recent €13 million unit in Iceland demonstrates the concept, being able to capture 4,000 tonnes of CO_2/ year equivalent to 870 cars. To make a significant impact, however, this technology will need substantial scale-up.

Another potential carbon capture methodology is the use of biochar from pyrolysis units in an application where the carbon remains captured. Each tonne of permanent carbon present in the biochar is equivalent to 3.6 tonnes of CO_2 that has been absorbed from the atmosphere.

Emissions to produce, transport and use the biochar are needed to be considered in the net calculation.

This conversion has the potential to be a net negative carbon process. In some applications further savings are made, for example by reduced use of fertilisers in biochar-treated soils.

Nova Pangaea Technologies' (NPT) Refnova process (Figure 1) provides an opportunity to convert lignocellulosic biomasses to both a monosaccharide stream and biochar. Unlike many other pyrolysis processes that generate biochar, this rapid process generates a co-product that can be further converted to many base chemicals for use in sustainable products.

Over the years there have been many attempts to make an economic process to convert lignocellulosic material to usable organic products. The main focus currently is to gasify the organic material to syngas, then convert this to long-chain organic products, such as renewable diesel and kerosene for sustainable aviation fuel (SAFs).

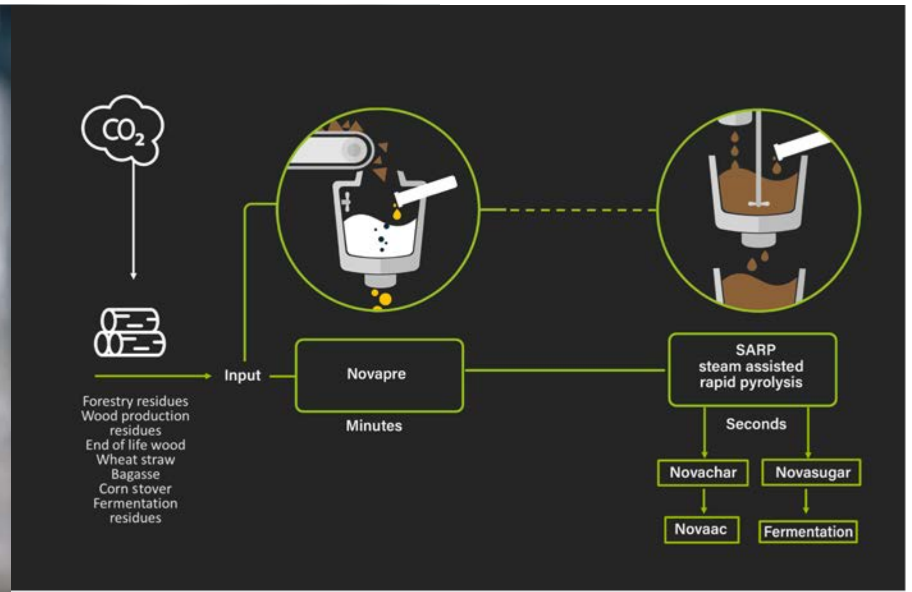

Figure 1 - Refnova process

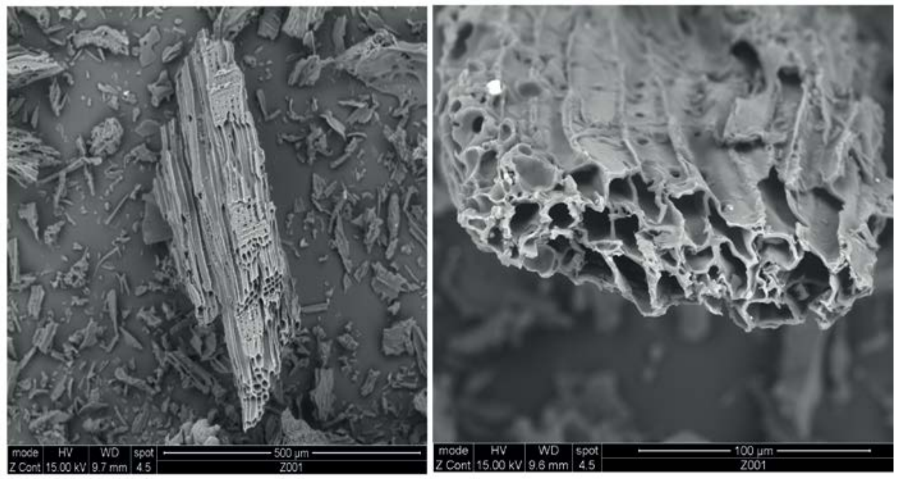

Figure 3 - SEM of NovaChar

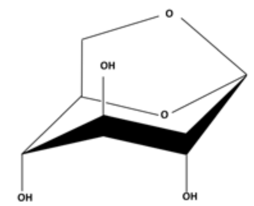

Figure 2 - Levoglucosan

The key issue with this process is the amount of syngas clean-up required and the high levels of energy required to make a relatively narrow range of products.

Refnova

Refnova is distinct in the use of a steam-assisted rapid pyrolysis unit. After a simple pre-treatment to reduce the particle size and reduce the level of active alkali and alkali earth metals, the biomass is entrained in a reactor with super-heated steam. This rapid increase in temperature to above 300°C avoids many of the ring cleavage reactions that occur at lower temperatures and enables the pyrolysis reactions to begin occurring almost instantaneously.

During the pyrolysis cleavage is at the glycosidic bond. This cleavage is rapidly followed by closure of the primary hydroxyl group of the sixth carbon to form a bi-ring system called levoglucosan, a dehydrated form of glucose (Figure 2).

Levoglucosan itself is an interesting compound, which can be used as a chiral intermediate. It is also easily converted to glucose by a hydrolysis process. This hydrolysis step has the advantage of converting any remaining cellobiose produced in the pyrolysis to glucose.

The lignin portion of the feedstock is primarily converted to biochar. This is due to the decomposition of the aromatic lignin monomers. The onset temperature of the decomposition of the lignin is dependent on the metal salts present.

Due to the speed of Refnova's heating process, the lignin does not melt before the char processes start. This means that the original open structure of the biomass remains in the biochar (Figure 3).

Current trials are focused on pyrolysis of wood products and the open lumen structure gives rise to a surface area of approximately 100 m^2/g directly out of the pyrolysis reactor with a carbon content of 75%. This has been increased to 1,000 m^2/g and >90% carbon by a further thermal activation. ➤

NPT currently operates a Refnova precommercial unit on Teesside, UK. This has a capacity of 5,000 tonnes/year, split equally between sugars and biochar. The pre-commercial unit operates on sustainable softwood products. Previous trials have been performed on hardwoods, wheat straw and bagasse.

Markets & applications

Although levoglucosan is an interesting molecule for chiral synthesis, there is currently no established market for its supply. Therefore, the route to a current commercial market is via hydrolysis to glucose. Once converted, it can be used directly as a binding agent or feedstock for sugar surfactants.

Glucose can be further processed into a large variety of valuable products. A key product is ethanol. A change of micro-organism in the fermentation step can switch the product to butanol, lactic acid or many other naturally occurring products. Known technologies can convert the ethanol to ethylene, which can then feed a standard petrochemical process. The focus currently is on the move by the aviation sector to SAFs as part of their pledge to achieve net zero.

The ethylene is polymerised over selective catalysts and with a touch hydrogenation produces a mix of kerosene which can be separated by distillation. As well as the SAFs, a second fuel stream of renewable diesel is produced.

The second output from the Refnova process also has many uses. The applications for biochar are rapidly developing. There are two clear categories for its use; firstly, where it is used and remains intact and secondly, where it is used as an energy source through combustion (Figure 4). If combusted, the captured CO_2 is released back to the atmosphere.

Although this could be claimed to be carbon-neutral, consideration over the time lag to re-grow the biomass needs to be included in the assessment. For example, if wood is used, then a fast-growing tree such as spruce will take 30 years to capture the CO_2 and replace the biomass used. If a quick-growing crop is used, such as sugar cane, the biomass and therefore the carbon can be replaced within a season.

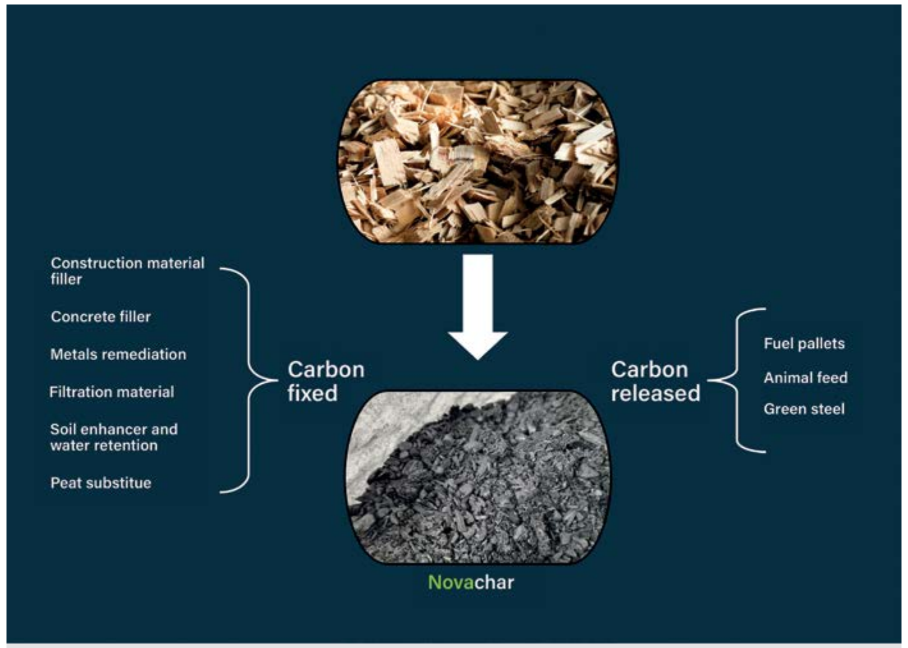

Figure 4 - Applications of biochar

When the biochar is used and the carbon remains intact, such as when it is used as a soil enhancer, the carbon can remain trapped for hundreds or thousands of years. The equivalent CO_2 capture is dependent on the amount of recalcitrant carbon present. For each tonne of permanent carbon storage, 3.6 tonnes of CO_2 would have been removed from the atmosphere.

In some of these applications, such as soil enhancement, further CO_2 savings are made. Its porosity means that it retains water. This retention means that valuable nutrients are not washed away out of the soil and hence less additional fertilisers are required. Another saving would occur if the feedstock biomass is normally allowed to rot, releasing both CO_2 and the more potent greenhouse gas, methane.

Net negative

Considering a Refnova unit with capacity of 20,000 tonnes/year using sawmill residues from an existing sustainably managed forest, when turning the sugars into ethanol and sequestrating the biochar product, there is a 189% greenhouse gas saving compared to a fossil fuel comparator. This means the process is carbon negative, removing 83 g CO_2 equivalent/MJ of ethanol produced. The annual production would remove 12,000 tonnes/year of CO_2 equivalent to 2,600 cars, as well as producing over 6 million litres of ethanol.

The sustainability of a process needs to include more than just the greenhouse gas emissions to Scope 3. Consideration of any changes to land use and the effects on biodiversity need to be included. As previously mentioned, this includes the time lag of CO_2 emissions and its absorption as new biomass must also be considered. This is particularly important if new forests are established to feed processing units.

** - REFNOVA is a trade mark of Nova Pangaea Technologies*

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