BC-SMART Low Carbon Fuels Consortium

Decarbonising Long-Distance Transport

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Decarbonising oil refineries while producing low-carbon intensive fuels

From the BC-SMART Secretariat

You should be reading this in the last days of 2024, a year when many parts of the world experienced their hottest summers and regions such as Valencia encountered unprecedented flooding. As the evidence of carbon emissions contributing to climate change is increasingly irrefutable, the world needs to decarbonise its economy!

As covered in this issue of the BC-SMART newsletter, one of the ways to both decarbonise the oil refining sector and the fuels they produce is to coprocess lower carbon-intensive (CI) feedstocks such as waste (e.g., used cooking oil, tallow, tall oil) and vegetable derived lipids. By leveraging existing infrastructure and established supply chains, co-processing allows the oil sector to use significant volumes of biogenic feedstocks such as lipids and biomass-derived-biocrudes to decarbonise their operations. As biogenic feedstocks typically require some form of hydrotreatment and subsequent "refining", oil refineries have decades of experience in exactly these areas of expertise. Members of the BC-SMART secretariat recently contributed to an IEA Bioenergy Task 39 report which highlighted the progress and challenges in making drop-in biofuels in "stand-alone" facilities, as developed by World Energy, Neste and Tidewater, as well as opportunities to coprocess biogenic feedstocks, as done by Parkland, to make lower-CI fuels. The full report is available at the IEA Bioenergy Task 39 website.

As covered in this newsletter, co-processing allows refineries to both reduce the CI of their operations and the fuels they produce, without repurposing much of their equipment.

As mentioned before, British Columbia is a world leader in the policies that have been developed to decarbonise its economy. These policies have encouraged companies such as Parkland and Tidewater to decarbonise the fuels they produce, particularly for the hard-to-electrify, long-distance transport sector such as Marine, Aviation, Rail and long-distance Trucking. In the past few weeks Air Canada (AC) and Parkland received international media attention with the announcement that low-CI jet fuel will be supplied and used by many AC flights originating in Vancouver (link). As covered by the media, it is a good start!

Thank you for reading this newsletter and participating in the BC-SMART network!

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Why co-processing of biogenic feedstocks at refineries will likely grow

The co-processing of lipids is a well-established process in several of the worlds oil refineries, with policies such as the EU's ReFuelEU and various US policies, such as the IRA, offering credits or incentives to companies that lower the carbon intensity (CI) of their operations and the fuels they produce. Although, currently, ASTM D165 limits co-processing ratios to 5% blends, there is a good chance that this ratio will be increased (to 30%?), with the high cost of lipids, competition and availability likely being the major impediments to the growth of co-processing. As a result, biomass-derived-biocrudes, which are hoped to offer greater availability, lower CI and lower costs will be needed to supplement current, waste-and-virgin, lipid feedstocks. However, as covered later, and in more detail in the IEA Bioenergy Task 39 report, technical challenges such as the high-water/oxygen content of biocrudes, their low-pH, catalyst inhibition, coking, etc., all need to be fully resolved before there is an increase in biocrude production and use. As discussed later, within the refinery, hydrocrackers rather than hydrotreaters may offer better upgrading of biocrudes, though work like this is still in development.

Other co-processing challenges include, biogenic intermediates usually being corrosive while wastewater management processes will likely have to be modified. As covered in more detail within the newsletter, co-processing offers several advantages over standalone facilities. For example, work at Washington State University (WSU) suggests CAPEX reductions of 28-39% and OPEX reductions of 10-13%. Co-processing also lowers the minimum fuel selling price (MFSP) by 10-19%, particularly for intermediates such as pyrolysis-derived biocrudes and gasification/FT-derived hydrocarbons (Tanzil et al., 2021). As demonstrated by companies such as Parkland, co-processing allows refineries to both reduce the CI of their operations and the fuels they produce.

Why co-process biogenic feedstocks?

Co-processing refers to the insertion of biogenic feedstocks, such as lipids or bio-oils/biocrudes, into existing petroleum refinery units for simultaneous processing with fossil feeds to create lower CI fuels. Recent work has shown that co-processing enables the production of low CI fuels at a lower CAPEX than building freestanding biorefineries by better utilizing existing refinery infrastructure. It will also play an important role in the energy transition of the oil and gas sector, as it enables petroleum refineries to reduce the Scope 3 emissions that result from the combustion of the final fuels.

Co-processing activities worldwide

Current commercial co-processing efforts have primarily focused on producing low-CI diesel and aviation fuels using lipid feedstocks, such as used cooking oil or vegetable oil. The main insertion point has been at the hydrotreater. However, a few companies are carrying out co-processing at the fluid catalytic cracker (FCC) (e.g., Preem, Parkland, Phillips 66) with Preem currently assessing the potential of co-processing biocrudes at the FCC. In this case, the biocrude is produced via fast pyrolysis at Pyrocell's facility, which is a joint venture between

Preem and Setra. However, although co-processing has been approved for lipids and Fischer-Tropsch liquids at higher ratios, to date, it has been restricted to a 5% ratio for aviation applications.

Some of the companies that are currently or soon will be co-processing are summarised in Table 1 and Figure 1.

Table 1. Companies engaged in co-processing activities

Company name	Location	Status
Phillips 66	Humber, UK	operational
TotalEnergies	Normandy	operational
BP	Lingen, Germany	operational
OMV	Schwechat, Austria	operational
OMV	Petrobrazi, Romania	operational
ENI	Taranto, Italy	operational
Repsol	Tarragona, Spain	operational
BP	Castellon, Spain	operational
Repsol	Teronor, Spain	operational
Repsol	Puertollano, Spain	operational
Cosmo Oil	Sakai, Japan	planned
Repsol	Petronor, Bilbao, Spain	planned
Tupras	Izir, Turkey	Planned
Preem	Sweden	Operational
BP	Cherry Point, Washington	operational
Parkland	Burnaby, Canada	operational

Figure 1. HEFA and co-processing operational plants (Argus, 2024)

Technical challenges in co-processing lipids and biocrudes

As mentioned earlier, co-processing of **lipids** is already fully commercial, widely implemented and requires minimal modifications of refineries which produce low-CI diesel and jet fuels. However, it should be noted that higher blend ratios will likely require more infrastructure investment, primarily to handle the increased heat produced during hydrotreatment. In contrast, co-processing of **biocrudes** is still in development with challenges such as the high oxygen content (up to 45% compared to 11% for lipids) of biocrudes and their complex, heterogeneous chemical composition, which can vary significantly, still needing to be fully resolved. These characteristics can result in technical difficulties such as increased hydrogen demand, higher heat release, more wastewater production and greater risks of corrosion and catalyst deactivation. Biocrudes typically require more intensive hydrotreatment or hydrocracking due to their higher aromatic content and elevated total acid number (TAN). While lipids typically have TAN numbers under 2 mg KOH/g, fast pyrolysis biocrudes can range from 55–65 mg KOH/g. These and other factors highlight the complexities in the future use of biocrudes, particularly when co-processing (Oasmaa & Peacocke, 2010).

The main "insertion points" that are used

Biogenic feedstocks can be inserted at various points within the refinery, such as the hydrotreater, hydrocracker or FCC (Figure 2). Typically, the specific insertion point depends on the type of biobased intermediate and the type of processing required. Refineries will also have different configurations while other considerations may be relevant in the selection of an insertion point.

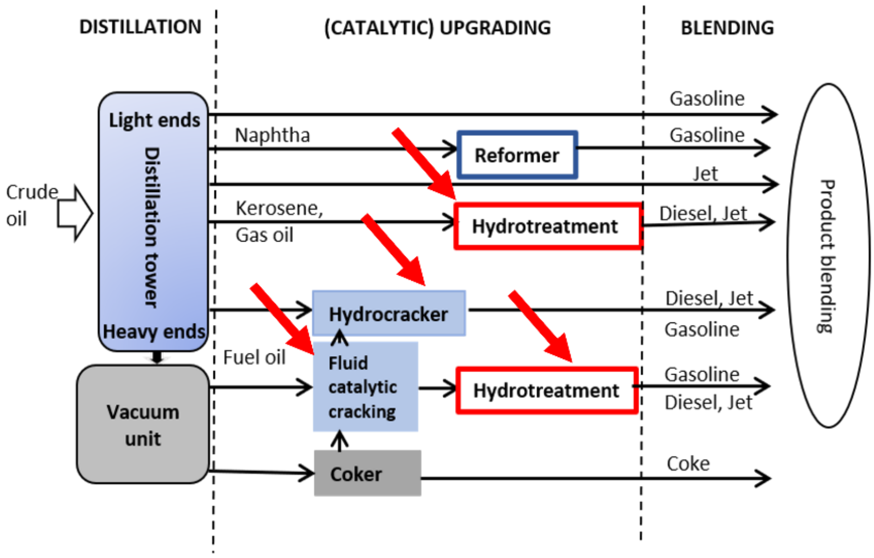

Figure 2. Main insertion points used when co-processing biogenic feedstocks

Co-hydrotreatment

Hydrotreating is primarily used in petroleum refineries to remove heteroatoms, such as nitrogen and sulfur, from petroleum product streams. The process typically involves high temperatures and pressures, using specialized catalysts. Challenges in hydrotreating renewable feedstocks include increased wastewater production, heat release during hydrotreatment and catalyst deactivation due to contaminants with these types of problems resulting in significant operational and economic challenges for refineries (Zhu et al., 2022). However, companies such as Petrobras have developed the H-BIO process for industrial-scale co-hydrotreatment of soybean oil with mineral oil, using CoMo/Al2O3 or NiMo/Al2O3 catalysts, while using multi-zone catalytic beds to manage heat release through cold nitrogen injection (Cárdenas-Guerra et al., 2023). Others have used Haldor Topsøe's Hydroflex process to address issues such as temperature increases and catalyst deactivation. Refineries have also used TK-339 and TK-341 catalysts in multi-reactor systems to improve cold flow properties and manage exothermic reactions. In Sweden, Preem has used various approaches to neutralize acids by blending fossil and renewable feeds, they have managed heat release with effluent quenching and prevented coke formation through catalyst grading (Cárdenas-Guerra et al., 2023). As co-processing becomes more prevalent, it is highly likely that more solutions will be developed to deal with the associated challenges.

Co-processing at the Hydrocracker

Earlier work has shown that hydrocrackers were not well suited for co-processing unless the biogenic feedstock was pretreated to remove oxygen and impurities (Van Dyk et al., 2018). However, more recent work has shown that hydrocrackers are more capable of handling renewable feedstocks such as pyrolysis-derived biocrudes as they typically require "cracking reactions" due to their complex chemical structures (Bouzouita et al., 2022). Hydrocrackers

can also better manage operational challenges such as heat generation and contaminants and can process more complex feedstocks, such as pyrolysis-derived biocrudes. These feedstocks often contain aromatics and other ring structures which require cracking reactions (Nymann & Lahiri, 2023). However, while hydrocrackers offer significant potential for co-processing biocrudes, further research is needed to optimize reactor and catalyst conditions, as well as the extent of pretreatment required for oxygen, nitrogen and sulfur removal before hydrocracking.

Co-processing at the Fluid Catalytic Cracker (FCC)

Co-processing in the FCC is attractive as it does not require hydrogen addition and it uses a continuously regenerated catalyst. Consequently, only minor refinery modifications are needed, such as a separate injection nozzle for biocrudes (due to their poor thermal stability and immiscibility with fossil feed) (Lindfors et al., 2023). Early pilot-scale FCC studies by Petrobras showed that raw pyrolysis oil could be coprocessed at room temperature with up to 10% blends (A. D. R. Pinho et al., 2015; A. de R. Pinho et al., 2017). More recent work, using 20% blends, showed the high production of biogenic carbon as coke (40-54%) which limited the production of low-CI, liquid fuels (A. de R. Pinho et al., 2022) (Su et al., 2022). Although partial hydrodeoxygenation might act as a stabilization step, to improve FCC co-processing and liquid yields, the optimal level of deoxygenation has yet to be fully resolved. Recent work has suggested that further research is needed to identify cost-effective pretreatments for fast pyrolysis biocrudes (Lindfors et al., 2023).

Challenges with corrosion when making low-CI diesel via co-processing

Renewable feeds such as lipids and biocrudes, (especially waste oils, e.g., used cooking oil) contain high levels of free fatty acids, resulting in TAN ranges from 2–200 mg KOH/g. Crude oils typically have TAN levels below 1.0 mg KOH/g (Bezergianni et al., 2018). This high acidity can result in significant corrosion within the refinery, requiring changes to the metallurgy of equipment. Other risks include CO_2 corrosion, wet chloride corrosion, sulphidation, and stress corrosion from effluents (Integrated Global Services, 2023). While small-scale equipment replacement is feasible, larger-scale replacements can be prohibitively expensive (Van Dyk et al., 2022). Effluent composition also impacts corrosion. For instance, higher CO_2 levels in the hydrotreating recycle gas can alter the operation of amine absorbers, shifting from H2S- to CO_2 -dominated gases. It should also be noted that, during FCC processing, small organic acids such as formate and acetate can accumulate in amine solutions, adding to corrosion concerns solution (Sayles, Caserta, DeLude, & Keller, 2022).

Wastewater challenges when co-processing biogenic feedstocks

During hydrotreatment of biogenic feedstocks, oxygen removal via hydrodeoxygenation and decarboxylation results in the production of CO_2, CO and water. This alters the wastewater composition and increases its volume. Contaminants such as nitrogen (N) and sulfur (S) can also form corrosive compounds (e.g., ammonium chloride and bicarbonate) (Integrated Global Services, 2023; Sayles, Caserta, DeLude, & Keller, 2022). This results in fouling, acidic effluents and disruptions in amine absorbers due to CO_2 dominance.

Stand-alone vs co-processing operation, to make low-CI fuels

In earlier work, five potential biogenic feedstocks produced by either Virent Bioforming long-chain hydrocarbons (VB), alcohol-to-jet ethanol (ATJ), direct sugars to hydrocarbons-derived farnesene (DSHC), fast pyrolysis-derived bio-oil (FP) and gasification and Fischer-Tropsch products (GFT) were compared (Tanzil et al., 2021). A midsize petroleum refinery with a crude oil capacity of 120,000 barrels per day was used for this case study and three scenarios were modelled. These scenarios involved either, sharing outside battery limits (OSBL) infrastructure (co-location), co-processing intermediates with refinery-derived gas oil or, repurposing a petroleum refinery. Sharing OSBL infrastructure reduced the minimum fuel selling price (MFSP) by 3–14% relative to standalone cases. Co-processing intermediate products reduced the MFSP by 10–19%, while repurposing scenarios resulted in MFSP reductions of 16–34%. The scenarios, modeled with corn stover as the feedstock, showed reductions in capital costs (CAPEX) of 28–39% and operating costs (OPEX) by 10–13% (Tanzil et al., 2021). The study location for both the production of intermediates and the co-processing scenarios, was the US Midwest. When earlier work compared co-processing of fast pyrolysis bio-oil and catalytic pyrolysis oil in an FCC (Wu et al., 2019), partial hydrotreatment carried out before FCC insertion added $111.4 MM to the investment and resulted in a total capital cost of $1.15 MM. This was slightly higher than the catalytic pyrolysis scenario. Despite the additional costs, the minimum fuel selling price (MFSP) for gasoline was similar for both scenarios, with $2.63 for fast pyrolysis and $2.60 for catalytic pyrolysis (Wu et al., 2019).

Policies that have impacted the production of low-Carbon-intensive (CI) fuels

Decarbonizing oil refineries is not easy, particularly regarding scope 3 emissions, as the fuels produce are used for transportation and this accounts for about 80-95% of the total life cycle emissions. Within the refinery itself, direct (scope 1) and indirect (scope 2) emissions from stationary combustion contribute up to 70% of the internal emissions. Operation of the FCC and steam methane reformer (SMR) units adds 15-35% and 10-30%, respectively. Although mitigation strategies, such as efficiency improvements, can potentially reducing emissions by 3-5%, other strategies such as transitioning to renewable power, low-carbon hydrogen, and process electrification should, substantially, decrease emissions. Although some oil companies are exploring carbon capture technologies, such as absorption, adsorption, membranes and cryogenics, this approach, typically, does not generate revenue, is expensive, and will likely require financial/policy incentives to be commercially viable.

As discussed previously, British Columbia is in a relatively good position, with most of its electricity already green (Hydro), the Carbon Tax largely accepted and policies such as the Low Carbon Fuels Standard (LCFS) encouraging the decarbonisation of refineries and the fuels they produce. While the Trump administration might change things, within the United States and starting 1st January, 2025, the Clean Fuel Production Credit (CFPC), will replace the existing SAF Blender's Tax Credit and offer tax incentives to US producers based on the carbon intensity of their fuels (Stillwater Associates). Concerning the aviation sector, this policy has goal of lowering production costs and stimulating increased SAF output in the U.S.

The CFPC is part of the Inflation Reduction Act's (IRA's) broader strategy to promote clean energy and reduce carbon emissions across various sectors, including aviation.

BC Refineries are Canadian leaders, with their decarbonization efforts (Co-Processing/Stand-alone) leading to the production of low-CI fuels

As mentioned earlier, government policies has-and-will-play a pivotal role in providing the economic structure to support decarbonisation. The expiration of the U.S. biodiesel and renewable diesel blenders tax credit (BTC) and its replacement with the 45Z credit is exclusive to U.S. producers. This will create economic challenges for Canadian renewable fuel producers with, for example, Newfoundland's Braya Renewables, (with a refinery capacity of nearly 260 million gallons annually) considering a temporary shutdown. This situation reflects the broader difficulties renewable fuel producers face amidst shifting policies and market uncertainties (Braya).

Despite these possible challenges, both Parkland's Refinery in Burnaby and Tidewater's Refinery in Prince George are at the forefront of efforts to make low-CI, drop-in fuels.

Tidewater (Figure 3) is already producing 2,849 barrels per day (bbl/d) of renewable diesel and, since starting commercial operations in November 2023, over 140 million liters of renewable diesel have been produced and supplied to the British Columbia market (TIDEWATER RENEWABLES). Tidewater continues to make progress on the front-end engineering design (FEED) of its proposed 6,500 bbl/d SAF project, leveraging existing infrastructure at the Prince George Refinery. A final investment decision (FID) is expected in 2025 (SAFINVESTOR).

Figure 3. Tidewater-Prince George Refinery (Tidewater)

As also recently announced, Parkland (Figure 4) produced Canada's first commercial batch of low-carbon aviation fuel at its Burnaby, BC, refinery with approximately 100,000 litres made using non-food grade canola and tallow as feedstocks (Global News). This initiative, supported by the Government of British Columbia, will reduce the aviation sector emissions (Parkland). The entire batch has been purchased by Air Canada (CityNews Halifax). The various media releases note that similar low-carbon fuels can be used in other vehicles, such as buses and ferries, with these fuels containing one-eighth of the carbon content compared to traditional fuels. As reported, with ongoing government support, local development and production, the use of low-carbon fuels this should benefit everyone in BC (CBC, bc.ctvnews).

Figure 4. Parkland Burnaby refinery (bing)

Conclusions

Co-processing of biogenic feedstocks offers a way to both decarbonise refineries and the fuels they produce. Both of BC's refineries are walking-the-talk, with provincial policies, such as the LCFS, playing a key role in encouraging these company investments. The recent Air Canada/Parkland announcements have garnered a substantial amount of media attention, with the enhanced profile increasing the publics realization on how difficult it will be to decarbonise the long-distance transport sector, particularly aviation. Although lipid co-processing is already fully commercial, there is hope that BC's substantial forest sector can supply the biomass-derived-biocrudes that might soon supplement current lipid/oleochemical feedstocks.

The same way that innovation-and-investment were key in how Canadians learned how to unlock the potential of Alberta's oil-sands, co-processing offers a way where these same characteristics (innovation-and-investment) can help us decarbonise our refining sector.

If you would like to be part of the **"Coalition of the Willing"** and continue to receive our newsletter and occasional updates about BC-SMART consortium, please contact us at:

The BC-SMART secretariat (***www.BC-SMART.ca***)

Upcoming Workshop

The BC-SMART invitation only workshop that was held in 2024 was entitled, *"Where will we be by 2030: Biojet/SAF?"*. In 2025, BC-SMART will be hosting a workshop entitled "*Decarbonising Refineries and the production of Low-CI fuels, particularly for the aviation sector"*. Please let us know if you would like to attend this forthcoming workshop.

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