4 feedstocks and technologies to decarbonise the oil and gas industry

beyond the obvious

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Oil industry needs alternative feedstocks

With the price of CO_2 emissions sharply rising, oil companies must create a solid strategy for decarbonisation and alternative feedstocks. Fuels made from waste plastic, biomaterials, or hydrogen are becoming even more attractive alternatives for fossil-based fuels.

It has become clear that oil companies must cut their CO_2 emissions. In addition to the environmental impact of CO_2 emissions, political pressure for cutting emissions intensifies, and the price of CO_2 emissions is increasing much faster than expected. Oil refineries emit millions of tonnes of CO_2. As the cost of emissions rises, the profitability of refining falls sharply. Refining fossil oil might not be very profitable in the coming decades. Thus, the decarbonisation of the refinery operations is a hot topic for the oil industry. At the same time, companies are looking for alternative non-fossil feedstocks.

Relying on tradition can be costly

Oil companies have reacted to the pressure with different strategies. Some rely on old methods, while others look for new approaches.

Some traditional oil companies tend to rely on long and heavy tradition and proven processes. Some companies even have the assumption that they can do at least one more profitable investment cycle in fossil raw materials.

Relying on old solutions may be a costly error. Crude oil will be phased out within some tens of years. If a company's whole business is based on fossil raw materials, financing investments will be expensive.

Oil refinery operations must be decarbonised

Oil refineries are significant emitters of CO_2. The most significant emission sources are typically the generation of process heat, hydrogen production, and fluid catalytic cracking (FCC).

The price of CO_2 emissions will rise as a part of climate change mitigation actions. Therefore, oil refiners must cut their emissions drastically in the near future.

Some strategies to decarbonise refinery operations are shifting to electrolytic hydrogen production, utilizing carbon capture and storage (CCS) in either hydrogen (blue hydrogen) or process heat production, and using electric heating applications or renewable fuels for process heat generation. However, many of these options still require significant development work and massive investments for new technologies.

Green transition has already started

A part of the oil industry started the green transition already many years ago, and the results are promising.

Some companies are already quite advanced in clean fuels. For example, the Finnish Neste has been able to recreate its own business with sustainable fuels. The company produces three million tonnes of renewable fuels annually. The revenues come practically from these renewables, not from the traditional oil refineries.

Other companies are following. The oil and gas industry is increasingly investing in green energy.

More sustainable liquid fuels are needed

Companies have many alternative strategies to choose from in their future investments. For example, they can invest in 100% electric solutions and change the existing business completely.

The second option is to expand the life cycle of internal combustion engine applications by providing more sustainable fuels made from biomass or renewable electricity and CO_2. With this roadmap, companies could maintain their present distribution channels and clients.

Only a part of transportation can be electrified in the near future. Even with massive electrified transportation, we will need alternative feedstocks. Light road transportation can be electrified, but the energy demand of heavy road transportation is still left. In maritime and aviation, the life span of hydrocarbon-based fuels is even longer. With the help of sustainable fuels, oil companies can buy time to develop new energy technologies.

Biomass has longest history

If a company is looking for alternate feedstocks, several attractive alternatives are available.

So far, biofuels have been produced commercially mainly from fatty acids, either vegetable or animal-based. Because they are already in a liquid form, it is relatively simple to transform them into sustainable transportation fuels.

Solid biomass wastes and side-streams are also an option, but they are more challenging to treat than oils and fats due to the complexity of the feedstock. However, there has been significant development in the solid biomass conversion technologies like gasification and liquefaction technologies during the past few years. As a result, many technologies are ready for commercialisation, and significant volumes of advanced biofuels are expected to be seen in the coming years.

All alternatives are needed

So far, alternative feedstocks for fuels have been mostly biomass-based. However, today, so-called e-fuels have become the hottest topic in discussion.

Several new technologies and alternative feedstocks are emerging, but all experts agree that none of these solutions will be big enough to cover the whole feedstock demand. Based on EU commission scenarios, both biofuels and e-fuels are essential.

Strategic alternatives for oil companies

Oil companies have to make a strategic choice: how much to invest in the research and production of non-fossil fuels? Here are the options.

Staying fossil

The refining of crude oil is the core competence of almost all oil companies. The companies are also accustomed to staying competitive when refinery marginals are low. Proven oil reserves are still substantial, and transportation needs liquid fuels for tens of years. Therefore, it is possible to continue to work with existing refineries, maybe even do one more investment round based on fossil feedstock.

Pros:

- The technologies needed are proven
- The distribution network is up and running
- The market of liquid fuels is still prominent

Cons:

- The price of CO_2 emissions is rising steadily and faster than expected
- The cost of financing goes up
- The decarbonisation of tradi-tional processes is costly
- Regulations regarding the use of oil are coming

Start with existing bio feedstocks

This is the strategy that companies who are already active in the bio-fuels market have utilised. The supply of liquid bio feedstocks like vegetable oil is already available, and the technologies are proven and commercial. Therefore, the ramp-up phase of production can be reached in a relatively short time.

Pros:

- The easiest way to bio-fuel market
- Bio-fuels production is more profitable than traditional oil-refining

Cons:

- The sustainability of certain bio feedstocks like palm oil is questionable
- The price of easily accessible raw materials may rise

Go to waste and other solid materials

There is a plentiful of solid biomasses which can be converted to liquid fuels. The feed-stocks are pretty cheap, but the challenge is the processing of the very diverse feedstock. The technologies needed in the conversion to liquid fuels are not yet ready for commercial use.

Pros:

- The supply of raw materials is extensive

Cons:

- Investments needed in technology
- The sorting of raw materials requires a complex supply chain

Develop e-fuels

The technique utilises the most abundant raw material reservoir: CO_2, either from industrial processes or the Earth's atmosphere. The processes of manufacturing hydrocarbons from CO_2 and hydrogen are at pre-commercial level. The problem is the vast amount of clean electric energy the process needs. However, the supply of renewable energy is rising, and its price is falling fast.

Pros:

- Unlimited availability of CO_2

Cons:

- The industrial ecosystem often needed in the production of hydrogen
- Technology unfamiliar to oil companies

Fuels from plastics

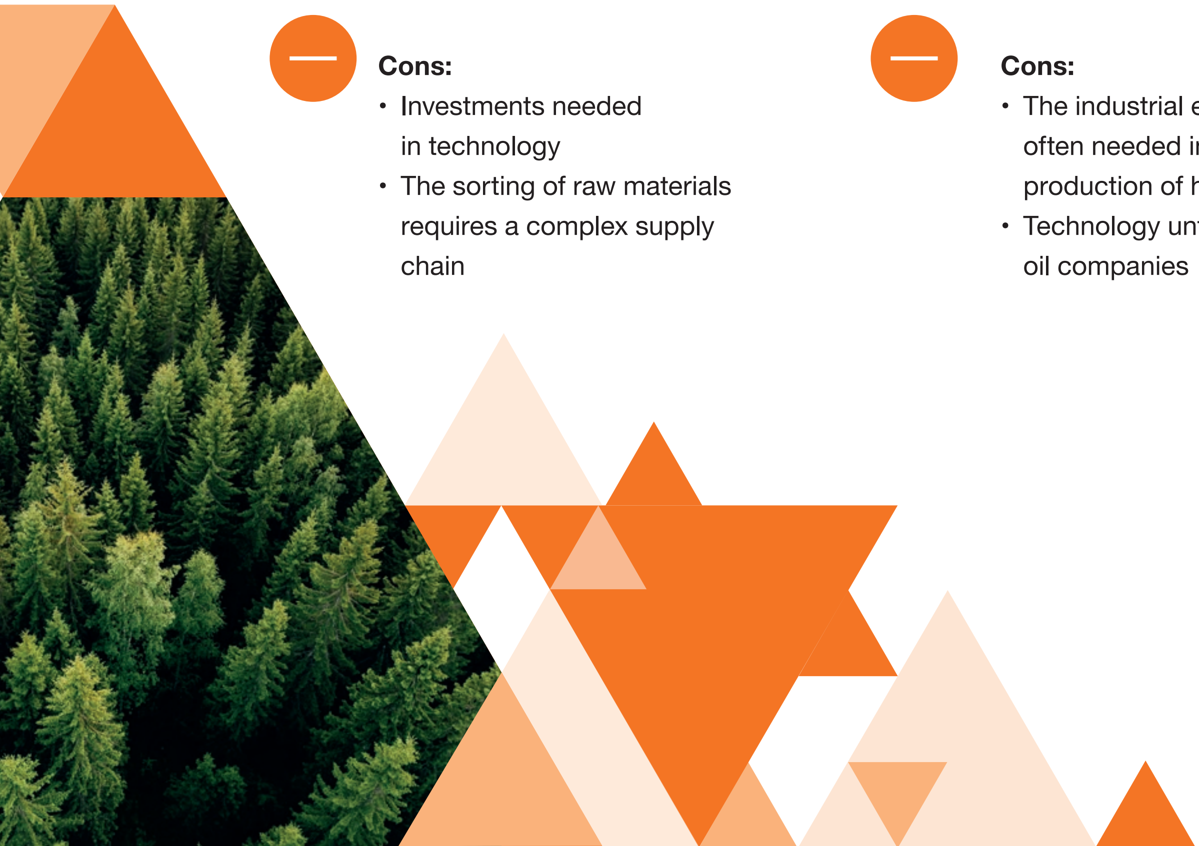
Chemically recycled plastics can be converted into transportation fuels or new plastics material with pyrolysis or gasification. The technology exists, but no big-scale plants are yet operational.

Pros:

- Plastics have the same components as crude oil

Cons:

- Plastic recycling technologies are still in the early stages of industry scale use



1. Chemical recycling transforms plastics into oil industry feedstock

Waste plastic could be used in the oil industry to replace fossil crude oil. The main technologies needed are pyrolysis and gasification.

A pyrolysis system unit typically consists of the equipment for pre-processing, the pyrolysis reactor, and equipment for down-stream processing.

Reactors used for pyrolysis are most commonly classified depending how the solids move through the reactor during pyrolysis. Movement can be caused by a moving bed, mechanical forces, or fluid flow. Reactors can also be classified depending on the way the heat is supplied.

In practice, many different combinations of solid movement and heat transfer are possible. Several different pyrolysis reactor designs are also available, for example, fluidized bed and rotating cone.

VTT launched the world's first integrated fast pyrolysis plant

In pyrolysis, the challenges related to the feedstock quality, segregation, reactor operations, and stability and standardization of the product should be solved.

Fast pyrolysis is one of VTT's focus areas in chemical recycling, something the research organization has been developing since the early 1980s. The experimental work has included a large variety of feedstocks and yielded a range of products.

The evolution was capped off by the launch of the world's first integrated fast pyrolysis plant in 2015 in Joensuu, Finland. Since then, the Joensuu plant has had several successors, and today, there are already several pilot plants that can produce 10 tons of fuel per day.

In 2018, approximately 30 million tons of plastic packaging waste was collected in Europe, of which 12 million tons were used for energy recovery and 7.2 million tons were landfilled.

Collection can be drastically improved, and recycled plastics could be used as a valuable feedstock to make various products.

However, the number one option is to utilise mechanical recycling and use plastic waste to make plastic products. Still, a high share of plastics cannot be mechanically recycled. Chemical recycling could significantly increase the recycling rates of plastics, as it can utilise mixtures of waste plastics, unlike mechanical recycling. With chemical processes, the manufacturing of refinery feeds for fuels and oils becomes viable, and the use of plastic as an alternative feedstock represents a new business opportunity to the oil industry.

Pyrolysis is thermal cracking

Pyrolysis, or thermal cracking, is the thermal degradation of long-chain polymer molecules into less complex smaller molecules. The process takes place in the absence of oxygen at increased pressure and temperature.

Pyrolysis allows plastics to be recycled even when the plastic waste consists of different types of plastic or composites or contains other organic or inorganic materials or impurities. The end products of pyrolysis can be monomers, heating oils, refinery feeds, transportation fuels, and chemicals.

Many new material innovations are either composites consisting of several types of polymeric materials or completely novel polymer resins. For them, integrated pyrolysis with feedstocks from several polymeric waste streams (e.g. plastics) could provide a quite feasible means for recycling.

This holds especially in the emerging phase where the volumes of the new materials on the market are low, and thus the separate collection of waste is not yet a cost-efficient option. On the other hand, this bodes well for pyrolysis since it is a very flexible method that allows the use of various feedstocks.

The main methods of pyrolysis are slow pyrolysis, fast pyrolysis, and ultra-fast pyrolysis. The most significant difference between methods is the residence time of the solid phase in the reactor where the process takes place: is hours, minutes, or seconds.

Flexible gasification

Gasification technology offers feedstock flexibility and customisation for generating a wide range of desirable products.

The main product of gasification is synthesis gas (syngas, CO and H_2) which can be further processed into various final products like gasoline, diesel, methanol, and synthetic methane chemicals.

Many different generic types of gasifiers can also be used for waste plastic gasification. The basic design of each type is built around the gasification reactor with feedstock feeding. The main differences are related to the heating mechanism, the entry of gasification agents, and the location of syngas output.

The selection of an optimal gasifier type for a particular application depends on several variables, for example, feedstock requirements, required syngas characteristics, possible heat integration, and desired final product type and quality.

Life cycle assessment is needed

What can one do to optimize the whole value chain from waste to products? First and foremost, the efficiency of collection, monitoring, and sorting need to be improved to produce more suitable feeds to target products.

For the best results, a holistic approach combining mechanical and chemical recycling should be applied. The eventual target should be the integration of mechanical and chemical recycling.

Another critical tool is lifecycle assessment, which should be used to analyse potential impacts and benefits related to alternative routes of plastics recycling and identify environmentally sound options.

2. E-fuels are emerging

As the market for synthetic fuels keeps growing, wide-spanning research is targeting new alternatives. E-fuels have become the hottest topic in discussion.

The market for synthetic fuels that has emerged in the wake of an acute need to reduce emissions is expected to grow to millions of tons by 2030 in Europe alone. According to European Environmental Agency, transport accounted for 25 % of EU greenhouse gas emissions in 2018.

Biofuels are a good option, but their supply is limited. Hydrogen requires considerable changes in fuel distribution and engine technology. However, if electrolytic hydrogen and carbon dioxide are used in the production of liquid fuels, they will fit into the existing infrastructure. These kinds of fuels are called electro-fuels, or e-fuels.

Key technology is electrolysis

For the production of carbon-based e-fuels, electricity and carbon dioxide are needed. In electrolysis, electricity is used to split water into oxygen and hydrogen. The hydrogen produced by electrolysis is combined with carbon dioxide to form gaseous or liquid hydrocarbons through synthesis processes. Methane, methanol and Fischer-Tropsch hydrocarbons for kerosene, gasoline, and diesel can be created via catalytic conversion processes using CO_2 and H_2. Methane can be utilised as gaseous fuel; from methanol, one can make chemicals and fuels.

There are three possible sources of carbon dioxide:

- CO_2 emitted through fossil fuel burning or from other processes using fossil raw materials is captured and re-used.
- CO_2 from biomass processing such as bioenergy production, fermentation or anaerobic digestion is captured and re-used.
- CO_2 is directly captured from the air and re-used.

A surplus of raw material

E-fuels have a surplus of potential raw material, and their conversion to fuels is simple. Limitations come from the price and availability of clean electricity, and hydrogen. The main issue has been the high price of hydrogen, which links it to the high demand and price of clean electricity needed to produce hydrogen.

So far, e-fuels have not been commercialised widely. However, the supply of clean electricity is rising fast, and the price is accordingly coming down. In this context, it is obvious hydrogen and e-fuels are at the center of the conversation.

Electrolysis expanding

Electrolysis technology is considered to be a key in the production of synthetic fuels – and predicted to grow more than 20-fold during the next five years.

In a larger scale, the emerging carbon reuse economy is a significant tool in fighting climate change. By 2040, three gigatons of carbon dioxide a year can be converted into fuels, chemicals, materials, and food globally.

E-fuel research project

In the E-fuel research project, integration of hydrogen produced by high-temperature electrolysis (SOEC), carbon dioxide capture from an industrial source, and Fischer-Tropsch hydrocarbons synthesis are being developed with the aim of achieving a breakthrough technology in the growing market for synthetic fuels. Fourteen companies are taking part in the project, which VTT coordinates.

The aim of the project is to boost both the synthesis concept of e-fuels and the commercial readiness of high-temperature electrolysers closer to electrolyser technologies based on low temperatures. The E-fuel project aims at an efficiency improvement by 10-15 percentage points compared to the efficiency of current technologies in the production of e-fuels by utilising innovative high-temperature electrolysis technology and the developed heat integration of electrolysis, carbon dioxide sequestration and fuel synthesis.

The project is public-funded by Business Finland and a part of Green E2 Ecosystem administered by Clic Innovation, and continuation for VTT's power-to-X research.

3. Climate-neutral fuels from lignocellulose

Lignocellulosic biomass is a potential renewable raw material for future liquid transport fuel. It is sustainable, low-cost, and ready for large-scale fuel production.

EU´s ambitious Green Deal vision requires a climate-neutral transport sector by 2050. Many roadmaps have been created to achieve this goal, but one factor is common in all scenarios. Electrification alone is not enough. Climate-neutral liquid fuels are also needed. For example, sustainable aviation fuels for long haul flying are necessary for decades.

Advanced climate-neutral fuels like high-octane fuels, advanced biofuels, e-fuels, ethanol,100% bio-ethers, and biodiesels, can be blended seamlessly into the liquid fuel mix. They are also compatible with existing and future engine technologies.

Climate-neutral liquid fuels can be produced from various raw materials. The most abundant of them are renewable biomasses containing lignocellulose.

Lignocellulose comprises the two carbohydrate polymers, cellulose and hemicellulose, and one non-carbohydrate phenolic polymer, lignin. To produce fuel or chemicals from lignocellulose, the polymers must be separated. This can be achieved by thermochemical conversion or by biotechnical processes.

Fuel from polymers

In thermochemical conversion, the methods used are pyrolysis and gasification.

Pyrolysis involves using heat and anoxic conditions to break down lignocellulose into smaller molecules. In pyrolysis the main product is bio-oil that can be called also pyrolysis oil.

In the process, bio-oil yield is maximised. Bio-oil has still relatively high oxygen content, and also inorganic impurities may be present, and it needs upgrading. Upgrading can be either co-processing at oil refinery or separate upgrading by hydrotreatment.

The main research topic is how to meet bio-oil quality requirements at co-feeding to oil refinery or how to optimise pyrolysis and hydrotreatment processes.

Gasification is a thermochemical process where lignocellulose is converted into a gaseous form. This is achieved by decomposing the feedstock material at high temperatures by controlling the amount of oxygen and steam present in the reaction.

The most important product of gasification is synthesis gas (syngas), containing H_2, CO, and CO_2. Syngas can be used as an intermediate to be processed into various final products like gasoline, diesel, and methanol. In the gasification of lignocellulose, the purpose is to maximise the yield of syngas.

The thermochemical technologies are ready for upscaling. The conversions can utilise various feedstocks in a flexible way.

Also low-cost materials like residues from agriculture and forestry, sludges, manures and waste wood can be transformed into high-value products. However, to optimise the processes further, industrial-scale production is needed.

Biotechnical production requires pre-treatment

Biotechnical treatment of lignocellulose is based on the use of microbial cells and enzymes.

The basic process starts with a strong pre-treatment with temperature, alkaline, acid, or organic salt. The pre-treatment opens up the structure of the lignocellulose to lignin, cellulose, and hemicellulose fractions.

Biomass requires proper pre-treatments for enabling efficient biotechnical production. The primary purpose of the pre-treatments is to improve the accessibility of biomass for enzymes and provide high yield and purity for the products during the downstream processing.

In the second phase, cellulose and hemicellulose are degraded into sugars and moved to a fermentation where enzymes from microbes transform them into ethanol used as a transition product in the process.

The recent focus of research has been on the pre-treatment and the use of enzymes. Pre-treating can turn biomass into a form that can be the basis for platform chemicals. One of the most promising biorefinery concepts is based on the alkaline oxidation method developed by VTT.

The applying of enzymes and modification of microbial cells allow the transferring of carbon into wanted platform chemicals and end products.

Large-scale production of lignocellulose-based fuels with enzymes requires biorefineries where all side-streams can be utilised, and many end products are viable. In addition to fuels, biorefineries can produce, for example, biochemicals, proteins, and lactic acid. Lactic acid can be polymerised into bio-based plastics.

Recent research has concentrated on biorefineries that enable the complete fractionation of renewable raw materials into their main components.

VTT Bioruukki accelerates innovation

VTT Bioruukki is a piloting centre for new bio-based products in Espoo, Finland.
In the lab and pilot plant, customers of any size can develop and scale up innovations and processes and thus accelerate their product and process innovation cycles.

Bioruukki is a unique combination of pilot-scale process development units, multi-purpose reactors integrated to downstream processing units, experts, and R&D services for thermochemical conversion, biomass processing, and sustainable chemistry. VTT Bioruukki delivers optimal solutions from initial development to end products with all the required expertise, modelling, and piloting capability.
Bioruukki has a versatile research infrastructure for developing innovations to treat and modify bio-based raw materials such as wood, bark, or straw for novel biotechnical and material applications.

The benefits of using ligno cellulose:

- The technology is ready or near ready for commercial installations
- Biofuels can be produced sustainably
- Significant potential for carbon-neutral biofuels in the market
- In addition to fuels, other chemicals can be manufactured in biorefineries

How VTT can support you:

- Developing of holistic biomass processing
- Bringing in conceptual knowledge and information about recent development in research
- Developing and testing concepts
- Transferring our knowledge to client companies
- Support in upscaling the production
- Optimizing bioprocesses by applying genetic engineering

4. From solid waste to liquid fuel

Integration with electrolysis adds efficiency to gasification and opens up new commercial possibilities to transform Municipal Solid Waste and biomass into transportation fuels in a large commercial scale.

When the oil and gas industry looks for alternative feedstocks, Municipal Solid Waste (MSW) is an obvious choice. Landfilling of the waste is prohibited, and incineration is phasing out. It is estimated that a potential of 44 million tonnes of MSW could be available in the EU in 2030. (Source: ETIP Bioenergy).

MSW is generally used to describe most non-hazardous solid waste from a city, town, or village that requires systematic collection and transport to a processing or disposal site. Sources of MSW include private homes, commercial establishments, and institutions, as well as industrial facilities, excluding waste from industrial processes.

Technically, MSW can be converted into liquid and gaseous biofuels to be used as a transport fuel. MSW is also a cheap feedstock.

Challenges arise from the fragmented composition of the waste material. Municipal solid waste can consist of almost any discarded materials. Some of them are suitable for conversion to fuels, while some are not.

Management of municipal wastes involves separation at source into:

- Recyclable materials - used for the manufacture of recycled products.
- Organic fraction - may be converted to gas or fuels.
- Solid recovered fuel (SRF) - the fraction of MSW that cannot be recycled - can be combusted or converted to syngas and then be used for energy purposes or be processed into advanced biofuels

Gasification process is similar to all feedstocks

MSW can be converted to fuels with many techniques like gasification, pyrolysis, or biochemical pathways like fermentation and enzymatic hydrolysis treatment.

So far, the mainstream technology has been gasification. Gasification converts any carbon-containing matter like MSW or biomass residues into clean syngas (CO,

H_2). Syngas can be utilised to make different products, for example via Fischer-Tropsch synthesis to produce feedstock for refineries. The process is similar for all feedstocks, and gasification is not limited to any specific feedstock like some other processes. Advanced transportation biofuels made by gasification have been at the focus of intensive development since early 2000. However, industrial deployment has been rather slow. The reason is the relatively high capital expenditure required for an integrated gasification system and fuels synthesis facility to convert syngas to gasoline, diesel, jet fuel, synthetic natural gas or methanol/ethanol.

At the same time, in response to the growing share of solar and wind power in the energy systems and the consequent need to converting surplus electricity into a storable form, power-to-gas (P2G) and power-to-liquids (P2L) concepts have been suggested for managing the temporal mismatch between solar energy supply and heat and power demand.

As a solution to these challenges, hybrid systems have been suggested. Electrolysis technology is used to boost biomass gasification and chemical synthesis plant.

FlexCHX utilizes local power plants

VTT has studied concepts of compact gasification and synthesis for flexible production of transport fuels, heat, and electricity for several years.

Now the idea is crystallised into a concept where the primary conversion of biomass and solid waste is done at small to medium size units located close to waste or biomass resources. Intermediate products like methanol, synthetic hydrocarbons, synthetic methane, or bio-hydrogen are transported to large-scale refineries or chemical factories for final conversion. The end products could be transportation fuels, olefins for renewable packaging, or basic chemicals.

The last phase of the development work has been the EU-funded FlexCHX project that started in March 2018.

FlexCHX produces heat, power, and an intermediate energy carrier, Fischer-Tropsch (FT) wax, which can be refined to transportation fuels using existing oil refining equipment. In the summer, renewable fuels are produced from biomass and hydrogen. The hydrogen is made from water via electrolysis that is driven by low-cost excess electricity from the grid. During the dark winter season, the plant is operated with just biomass to maximise the production of heat, electricity, and FT wax.

Four test campaigns of FlexCHX were realised at the pilot plant by the end of March 2020. The pilot plant was operated continuously without any interruptions in these test runs. Now the key technologies of the project have been validated in an industrially relevant environment (Technology Readiness Level 5).

Intermediate products for oil industry

The FlexCHX process can be realised at a large scale using pressurised fluidised-bed gasification developed in Finland or at a smaller size range using the new staged fixed bed (SBX) gasifier developed in an ongoing European Union (EU) Horizon 2020 project.

In both gasification systems, the feedstock is gasified at moderate temperatures to generate a tar-containing raw gas, which is filtered at high temperature, and led to the catalytic reformer, where tars and hydrocarbon gases are reformed, and the yields of hydrogen and carbon monoxide are increased.

After a final cleaning, the gas can be led into chemical synthesis units producing intermediate products, which can be refined to transportation fuels or chemicals in large-scale industrial units.

Catalytic reformer increases efficiency

The catalytic reformer plays a vital role in this process by converting tars and light hydrocarbon gases into synthesis gas (syngas) and bringing the main gas constituents towards equilibrium.

With catalytic reformer, the gasification can be done in relatively low temperatures because optimising the gas quality in the gasifier is not necessary.

About 50 percent of the energy content of the MSW or biomass is converted into hydrocarbon gases which can not be converted directly into transportation fuels. In the reformer, these gases are transformed into carbon monoxide and hydrogen, which can be processed into fuels. This increases the efficiency of the transformation from Fischer-Tropsch fractions to fuels quite dramatically, 40-50% in the energy level.

Key assets of VTT as a partner:

- Decades of experience from development of synthetic gas technology.
- Experience from close co-operation with companies to realise technologies in commercial scale.
- Reliable track-record in new technology piloting and demonstration.
- Bioruukki piloting centre for new bio-based products with modelling and piloting capabilities under one roof.

Get in touch!

Irene Coronado
Customer Account Lead
+358 406 682 831
irene.coronado@vtt.fi

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