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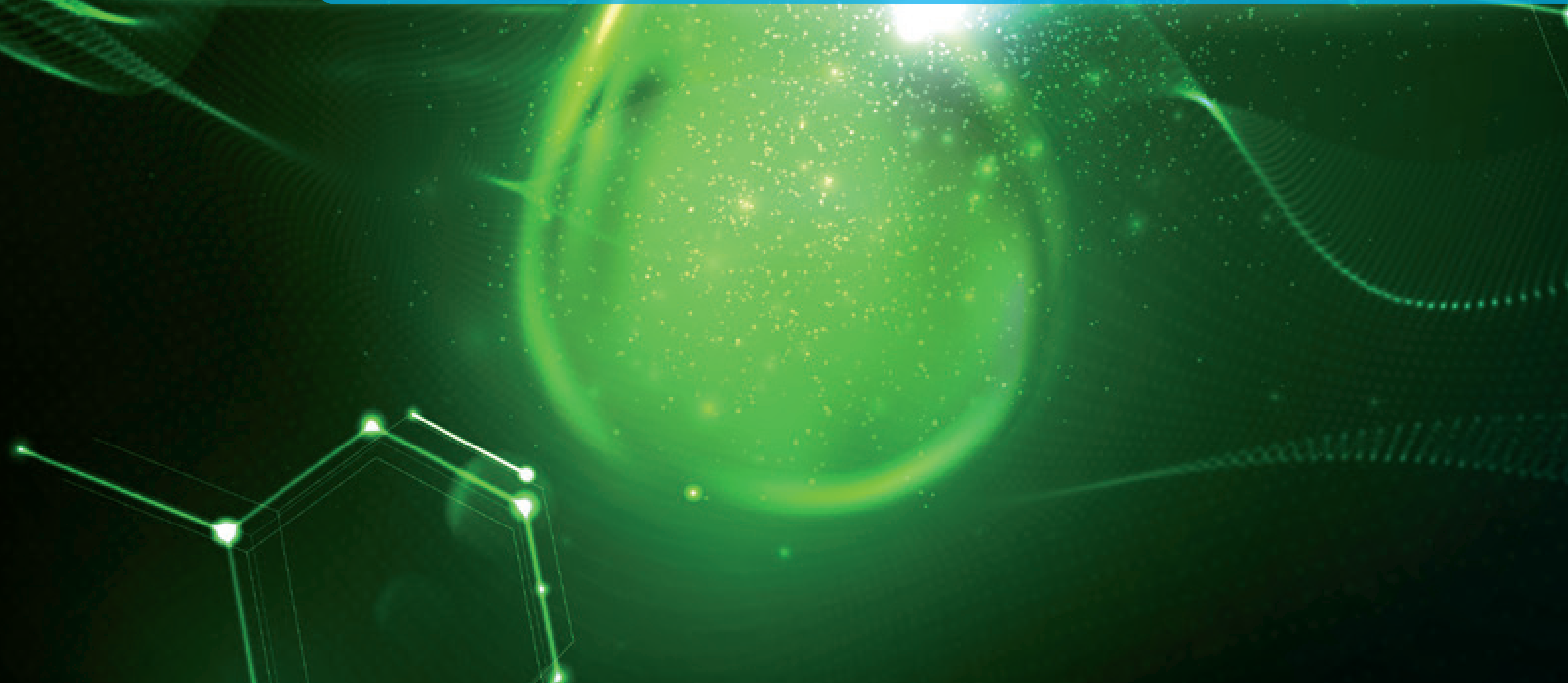
POSITION PAPER

Advanced alternative liquid fuels:

For climate protection in the global raw materials change

Position paper of the ProcessNet Working Group “Alternative Liquid and Gaseous Fuels”



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Publisher
ProcessNet-Arbeitsausschuss „Alternative flüssige und gasförmige Kraft- und Brennstoffe“

Responsible for the content in terms of press legislation
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Publication date March 2018

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Preface

The Working Group “Alternative Liquid and Gaseous Fuels” is part of ProcessNet, a joint initiative of the DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e. V. and the VDI Gesellschaft für Verfahrenstechnik und Chemieingenieurwesen e. V. (VDI-GVC). Its participants are representatives of commercial enterprises, associations and sciences in the fields of fuels, plant construction, oil refineries, bio refineries, combustion engines, automobiles, aviation, energy systems, thermochemical conversion, renewable raw materials, waste and secondary raw materials as well as other sustainable resources.

This position paper is intended to appeal to decision-makers in politics, business and science. With regard to **climate protection goals**, the paper aims at showing technological ways to achieve the **full integration of the transport and heating sectors into the energy transition** by 2050 in a realistic, sustainable and economically justifiable manner. The objective is to illustrate why **advanced liquid alternative fuels** will play a **key role**. Recommendations for action should help to meet the challenges of the required radical change from fossil fuels to sustainable resources.

In this way, the working group is supporting efforts to achieve the **energy transition in linking the areas of mobility, electricity and heat** as a contribution to climate protection, resource conservation and security of raw material supply, resource efficiency by optimizing material cycles, security of supply through independence from imports, job creation through regional added value and global technology leadership.

Accordingly, the working group pursues the goal of supporting German and European political programmes that aim for sustainability and energy transition, such as

- Climate Action Plan 2050 of the German Government [1]
- The Mobility and Fuels Strategy of the German Government (MFS) [2]
- German High-Tech Strategy [3]
- Biorefineries Roadmap of the German Government [4]
- National Policy Strategy on Bioeconomy [5]
- Germany‘s National Sustainable Development Strategy [6]
- German Resource Efficiency Programme [7]
- EU 2030 Climate and Energy Policy Framework [8]
- EU Renewable Energy Directive (RED) [9]

Summary

The comprehensive involvement of both **mobility** and the **heating market** in the reduction of greenhouse gas emissions is essential for effective future **climate protection** and for the achievement of the **energy transition**.

This paper describes why advanced alternative liquid fuels, including advanced biofuels, will play a key role in this respect. The energy transition cannot be fully implemented in the estimated time by 2050 without their support. The term “advanced” stands for compliance with the requirements of the EU Renewable Energy Directive (RED), the Biofuel Sustainability Ordinance and the European Industrial Bioenergy Initiative (EIBI) Key Performance Indicators (KPI) as well as for overcoming the limits of blending with conventional fossil fuels (blend walls).

The main reasons for the indispensability of advanced alternative liquid fuels for the energy transition are:

- In the case of a complete regenerative electrification of the road transport and heating sector, even assuming optimistically all saving potentials, the **share of regenerative** electricity would have to be increased **at least sevenfold**, which would be unrealistic for lack of time alone. In addition, there would be enormous investments for infrastructure changes and a considerable need for EU-wide coordination.
- Some transport sectors such as aviation, shipping and heavy truck transport are very difficult to electrify in the long term.
- According to relevant studies, despite all efforts in the field of electric, natural gas and hydrogen mobility, it can be assumed that **liquid fuels will play a dominant role in the transport sector** even beyond 2040.

In detail, the questions will be discussed: which routes from today’s point of view can lead to the required sustainable alternative products in sufficient quantity and which **synergy effects** can result from the interaction of different technological pathways with regard to the improvement of efficiency and **economy**. Minimizing production costs is of great importance, especially in times of low oil prices.

Europe still has the potential to become a technology leader in this field. However, stringent dynamics have been observed outside Europe for some time now, especially in the field of advanced biofuels. **There is a danger that Europe will be surpassed and miss the connection.**

The following recommendations for action have been derived from these facts:

1. Expand the resource base on biomass, waste and residual materials as well as CO_2

It is advised to approve the following resources as a basis for advanced alternative fuels (gaseous and liquid):

- Biogenic waste and residual materials (e.g. straw, waste and construction timber, sewage sludge, waste grease and other food wastes)
- Waste and residual materials, secondary raw materials and by-products from waste treatment (e.g. plastic and rubber waste, lubricants recycling residues, solvent residues)
- Hydrogen from renewable resources
- CO_2 from biogenic and non biogenic processes as well as from the air

2. Approve co-processing

To ensure quality assurance and to accelerate the raw materials change, fuels from co-processing should be approved and certified as alternatives. Examples are:

- Co-processing of fats and fatty oils, waste fats, plastic waste and residual materials together with fossil raw materials in refineries
- Co-processing of biomass, waste and residual materials together with fossil raw materials in gasification and liquefaction processes

3. **Pay greater attention to the production of advanced alternative liquid fuels in advanced biorefinery concepts**

4. **Identify synergies of processes for the production of advanced alternative liquid fuels with PtX (Power to X) concepts**

5. **Intensively support research and development with the aim to accelerate the market introduction of advanced alternative liquid fuels and create reliable legal frameworks with a perspective beyond 2020**

1. Introduction

By 2050, global warming is to be limited to well below 2 °C and preferably to 1.5 °C compared with the pre-industrial level. The 195 participating states agreed on this goal at the UN Climate Change Conference in Paris in December 2015. However, the global climate protection measures promised so far are not sufficient. For example, the transport sector's share of greenhouse gas (GHG) emissions is increasing in Germany, in Europe and globally. The heating market is barely doing better in this respect.

Considerable quantities are involved worldwide. Approximately 31.7 billion tonnes of carbon dioxide (CO_2) were emitted into the atmosphere in 2012, mainly by burning coal (43.9 %), crude oil (35.3 %) and natural gas (20.3 %) [10]. Mobility, apart from a relatively small energy share of 4 % biofuels [11], is almost entirely based on crude oil and consumes around 56 % of crude oil production [12, 13]. Therefore, mobility alone accounts for almost 20 % of anthropogenic CO_2 emissions. In view of the growing earth's population and rising living standards, global demand for fuels will increase even more sharply.

Achieving climate protection targets therefore requires the immediate introduction of effective solutions with a high probability of implementation and a high impact contribution.

In the area of mobility, a turn away from private transport towards environmentally friendly public transportation is currently not conceivable. Furthermore, even in industrialised countries a rapid move from fuels to renewable electricity in both sectors of transport and heating will not be realistic. Considering Germany as an example, the complete renewable electrification of both road traffic and the heating sector would result in doubling total electricity consumption from the current 648 TWh [14] to at least 1,320 TWh by 2050, even taking all potential savings into account [15]. In the same course the renewable electricity must be increased sevenfold at least from current 194 TWh [14] to the 1,320 TWh mentioned above. Therefore, such a scenario would not be feasible within the framework of the energy transition, especially since considerable time and enormous costs for the necessary far-reaching infrastructure changes would have to be added, and rapid and very fundamental EU-wide coordination in this direction would have to be achieved.

On the contrary, relevant studies for the **mobility sector** in Germany show that **liquid fuels** will be **of crucial importance in the long term** despite of all efforts for electric, natural gas and hydrogen mobility. For example, research studies published by DENA conclude that liquid fuels in transport will only decline very slowly over the next decade [16,17]. Even by 2030, more than 85 % of energy consumption in the whole transport sector is expected to be liquid fuel based [17]. And in the subsequent decade nothing significant will change in this trend according to a study published by DLR [18]. These results are quite understandable in view of the durability of existing car fleets and the rather conservative, price-conscious consumer behaviour. For example, the average operating time of passenger cars is around 12 years in Germany [19]. Furthermore, heavy truck transport, shipping and most of all air traffic will also continue to rely on liquid fuels with a high energy density in the coming decades even to a greater extent than car transport [20-25].

Consequently, it could be assumed that there will be considerable demand for liquid fuels in the transport sector beyond the year 2040.

Regarding energy transition and climate protection, especially for reasons of time, it is urgently necessary to replace the existing fossil liquid fuels by advanced alternative liquid fuels in an effective and rapid manner. This action would immediately and directly reduce greenhouse gas emissions from the entire transport sector in a measurable manner.

This would have the additional advantage that also the **heating market** could directly contribute to energy transition and climate protection by introducing alternative heating oil. For example, the German annual demand for light heating oil is approx. 17 million tonnes or 16 % of the entire crude oil consumption [26] and will represent at least a significant quantity in the future despite a declining tendency [17].

Therefore, advanced alternative liquid fuels, including advanced biofuels, will be essential for the successful implementation of the energy transition and the achievement of climate change mitigation targets while fully integrating the transport and heating sectors.

“Advanced” stands for the following characteristics:

- Compliance with the requirements of the European RED [9] through production from sustainable resources that are not in direct competition with food and feed, such as straw, wood, algae, waste or carbon dioxide (CO_2).
- Compliance with the requirements of the German Biofuel Sustainability Ordinance [27] and the European EIBI KPI [28] by reducing greenhouse gas emissions by at least 60 % compared to fossil fuels.
- Overcoming limitations of blending with conventional fossil fuels (blend walls) through improved compatibility.
- No adverse impact on the long-term stability in the case of blending with conventional fossil fuels.

The latter point, for example, is becoming increasingly important in conjunction with the introduction of hybrid vehicles, where the average storage time of the fuels in the tank increases. This point is of further importance in the areas of application for fire brigades, civil protection and armed forces.

In the case of full compatibility or miscibility with corresponding conventional products derived from crude oil, alternative products have a **drop-in quality**. Their properties are almost identical to those of conventional products and thus overcome limitations in blending with conventional fuels. This applies notably to pure hydrocarbons such as alkanes, which consist of the chemical elements carbon and hydrogen only without any heteroatoms such as oxygen.

In summary, it can be assumed that the demand for advanced alternative liquid fuels will increase dramatically over the next 30 years for climate protection reasons. Products with drop-in qualities will be particularly in demand. Advanced alternative liquid fuels will play a key role in the implementation of the energy transition and the achievement of climate protection targets. Policy makers are requested to step up R&D funding in this area, particularly in order to meet the considerable demand for liquid fuels in the transport sector over the next decades.

2. Facts about advanced alternative liquid fuels

The following section explains the main features of advanced alternative liquid fuels and outlines strategies for efficiently obtaining these fuels from sustainable resources.

2.1 Highest energy density

In comparison with other alternative energy sources, liquid fuels achieve the highest volumetric energy densities. As shown in Fig. 1, these include alcohols such as methanol, ethanol and similar oxygenates as well as liquid hydrocarbons. The latter reach peak values of more than 30 GJ/m³ [29].

The energy densities for the gases methane and hydrogen, depicted in Fig. 1, refer to the usual storage conditions in the frame of its application for mobility. In the case of methane, the conditions are either 200 bar at ambient temperature or -162 °C at ambient pressure. In the case of hydrogen, the variants are either 700 to 800 bar at ambient temperature or -253 °C at ambient pressure, respectively. Both kinds of storage condition require an energy input, which reduces its degree of efficiency.

Liquid fuels are therefore predestined for use in mobility, since energy density is a very important factor in transportation. This is notably important for **aviation, shipping** and **heavy truck transport**. Therefore, at least for these sectors it can be assumed that liquid hydrocarbons will be required in the long term.

Furthermore, taking the efficiencies of modern combustion engines into account, Fig. 1 also illustrates that the extremely low energy density of electrical battery systems cannot be compensated by higher efficiencies in propulsion systems. This will remain a long-term challenge for battery-based electric mobility. Electric fuel cell vehicles powered by hydrogen perform much better in this respect.

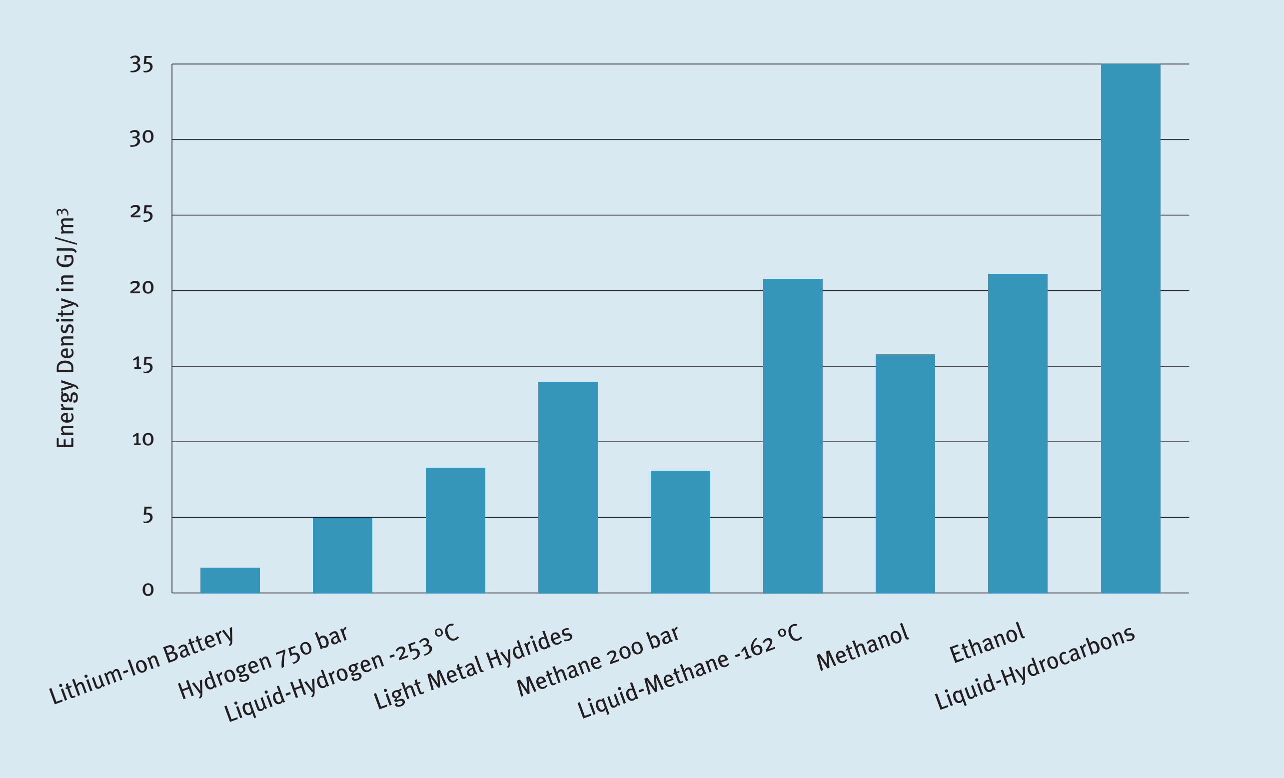


Fig. 1: Volumetric energy densities of alternative energy sources [29]

2.2 Handling, transport and storage

In comparison to gaseous fuels, liquid fuels can be handled very easily at ambient temperature and atmospheric pressure and can be transported and stored very efficiently.

2.3 Use of existing infrastructure

Alternative liquid fuels can continue to use the entire existing infrastructure from refinery processing and transport right through to delivery to the end customer. This avoids both high investments and high running costs for new infrastructures.

2.4 Compatibility with conventional fuels

Advanced alternative liquid fuels can readily be processed and mixed in refineries as drop-in products with conventional fuels. Usually they can be added in any ratio without the need to modify or adapt e.g. existing burner or motor concepts.

If waiving a complete miscibility of alternative products with conventional products, new degrees of freedom are provided in the long term such as possibilities to develop fuels with optimized properties. These optimized forms could be oxygenates, for example, (see section 2.13 “PtL path 5”) which may then no longer qualify as drop-in products, with the consequence that they could not been mixed in arbitrary proportions with conventional products, but they may also be used instead of conventional products. In order to ensure market acceptance, however, these products must also be compatible with the existing infrastructure and vehicle fleet.

2.5 High level of development of optimized emission minimization

If alternative drop-in fuels are used, the already technically achieved high level of exhaust gas quality can be ensured without modification in engine and exhaust gas post-treatment systems, irrespective of the proportion of admixture. In the long term, emissions can even be reduced significantly, if alternative liquid fuels are used in optimized forms, independent of drop-in quality as described in section 2.4.

2.6 Quality improvement due to admixture

Advanced alternative liquid fuels offer the opportunity to improve the quality of conventional fuels in terms of performance and emissions (see also sections 2.4 and 2.5).

2.7 Quality assurance with regard to stability

In terms of long-term stability, advanced alternative liquid fuels offer the opportunity to ensure the quality of conventional fuels. As described before (see section ‘Introduction’), this aspect is gaining importance.

2.8 Important basis for certain transport sectors

From today’s perspective, liquid fuels are a long-term economic livelihood for some transport sectors. This applies in particular to the **aviation** sector. This sector relies on fuels of the highest energy density and will not be able to waive them within the foreseeable future [20-24]. This situation is similar with other transport sectors such as **maritime shipping, long-distance truck freight transport** and probably **long-distance car transport** [18, 20-24].

2.9 Avoidance of usage competition through utmost application flexibility

Alternative liquid fuels are the only non-fossil option that can be used in all transport sectors [20]. In this respect, their provision would at least mitigate competition in the various application sectors, or even avoid it, if available in sufficient quantities. This concerns, for example, a possible conflict between the sectors of **road transport** and **aviation**, as both sectors require middle distillates. Another usage competition may arise from the transition of shipping to use low-sulphur fuels. Thereby overlaps with heating oil and diesel fuel may occur.

2.10 Backward compatibility

Advanced alternative liquid fuels used as drop-in products, are the only option that can offer comprehensive backward compatibility for old systems. This would avoid problems with old systems and the need to provide special fuels for these sectors of application.

2.11 Public acceptance

Experience has shown that every fundamental change in the fuel sector requires intensive persuasive efforts to the public, whose outcome is difficult to assess. Advanced alternative liquid fuels offer the opportunity to avoid this problem.

2.12 Required resource potential exists in principle

Relevant studies confirm that German, European or global energy potentials of renewable raw materials as well as residual and waste materials are sufficient to cover at least a significant portion of the respective future fuel requirements, even if the strictest sustainability criteria and the legally prescribed waste hierarchy are applied [13, 31-37].

These potentials can be supplemented by the exploitation of new resources such as algae, renewable electricity, hydrogen from renewable electricity as well as the use of carbon dioxide (CO_2), e. g. from fermentation processes or from the air (see following section). In particular, the manifold potentials of algae are described in relevant papers from IRENA [37], IEA [38] and DECHEMA [39].

2.13 Technology pathways to alternative liquid fuels

In Fig. 2 numerous examples of integrated cross-linked pathways for the production of **advanced alternative liquid fuels** from sustainable resources are shown. No claim is made to completeness, especially as research and development are constantly proceeding and new ideas and approaches are constantly being added. Each indicated path has on the one hand a meaning for itself and on the other hand a meaning in the cross-linking with other pathways, represented by transverse arrows.

Fig. 2 shall give an impression from today's point of view of the huge number of technological pathways to advanced alternative liquid fuels, and the manifold opportunities for synergies (transverse arrows). The figure is also exemplary in this respect and does not claim to be complete.

By exploiting synergies through linking of these technology pathways, there is a high optimisation potential for future efficiency enhancements to improve economy. This aspect of minimizing production costs is particularly important in times of low oil prices.

Furthermore, the gap between decentralized generated raw material and large product volumes can also be bridged, for example, by linking decentralized, smaller-scale primary treatment steps and centralized secondary processing steps that can be realized in large production units.

Due to their redundancy, the implementation and interlinking of a large number of process lines also offer an opportunity for a high degree of supply reliability.

Additionally, it is possible to provide regeneratively produced hydrogen from the process lines for a future hydrogen economy and mobility. Furthermore, many synergies with other gaseous alternative fuels such as methane can be exploited.

The following **groups of pathways** are addressed here:

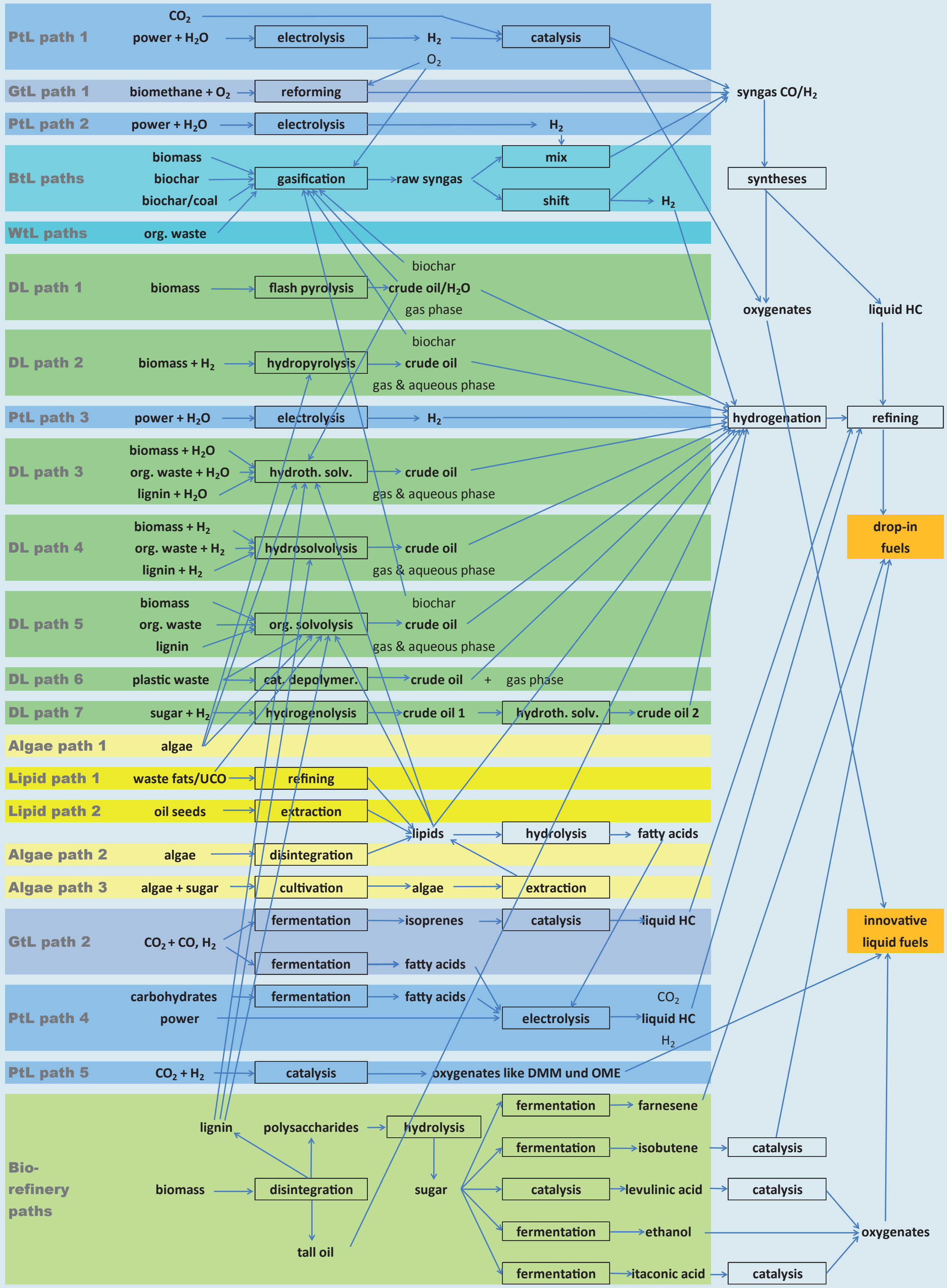
- » **XtL** (Ressource X to Liquid) like **BtL** (Biomass to Liquid), **WtL** (Waste to Liquid), **GtL** (Gas to Liquid) and **PtL** (Power to Liquid), mainly in each case via the intermediate stage of a synthesis gas, in the case of BtL in the meaning of a 'synthesis gas biorefinery' according to the biorefinery group No. 4 of the 'Biorefineries Roadmap' [4].

- » **DL** (Direct Liquefaction) via the intermediate stage of an oil, which in each case is further processed to standard-compliant alternative liquid fuels.

- » **Lipid**, based on triglycerides such as fats and oils, either in the meaning of the 'vegetable oil biorefinery' within biorefinery group No. 2 of the 'Biorefineries Roadmap' [4] or based on waste fats.

- » **Algae** (cultivation und processing of algae), mainly in the meaning of the 'algae oil biorefinery' within biorefinery group No. 2 of the 'Biorefineries Roadmap' [4].

- » **Biorefinery** via pretreatment of solid biomass and further processing of the fractions in the meaning of the „lignocellulose biorefinery" according to the biorefinery group No. 3 of the 'Biorefineries Roadmap' [4].



cat. depolymer. = catalytic depolymerization
HC = hydrocarbons
hydroth. = hydrothermal
solv. = solvolysis

org. = organic
PtL = Power to Liquid
GtL = Gas to Liquid
BtL = Biomass to Liquid

WtL = Waste to Liquid
DL = Direct Liquefaction
UCO = used cooking-oil
DMM = Dimethoxymethane

OME = Oxymethylene ether

Fig. 2: Pathways to advanced alternative liquid fuels (examples) [29]

Biotechnology processing steps such as fermentations are included in many of these groups of pathways. The **processing of biogenic and non-biogenic organic waste** is also integrated. Organic waste is explicitly addressed in the WtL path. An example of biogenic organic waste would be food waste, while plastic waste would be an example of non-biogenic organic waste. The term 'organic' refers to the category of 'organic chemistry', which refers to 'carbon chemistry'. In this context, 'organic' means 'carbon-containing' or 'based on carbon-containing compounds'.

Tab. 1 provides a summary of the technology pathways for the production of advanced alternative liquid fuels with regard to essential technical characteristics, the stage of development and the actors, without claiming to be exhaustive. The pathways are explained below.

PtL Paths:
For all PtL pathways, the resources are both excess electricity from renewable sources and a carbon source. A major challenge of all PtL pathways is to link the fluctuating electricity supply with preferential continuously running conversion processes of materials.

Techno-economic assessments of PtL pathways in Germany, for example, can be provided by DLR among others. Extensive research on various PtX pathways is being carried out as part of the Kopernikus project "P2X" under the coordination of RWTH Aachen University, Forschungszentrum Jülich and DECHEMA.

PtL path 1
In "PtL path 1", the carbon source is carbon dioxide (CO_2), which can originate, for example, from fermentation processes or from the air. Hydrogen (H_2) is supplied from electricity via electrolysis of water. CO_2 and H_2 are catalytically converted into synthesis gas (syngas = mixtures of CO and H_2) via the so-called reverse shift reaction ($CO_2 + H_2 \rightarrow CO + H_2O$). It is subsequently converted into either liquid hydrocarbons (HC) or oxygenates via different synthesis pathways (e.g. Fischer-Tropsch (FT) synthesis, methanol synthesis or dimethyl ether (DME) synthesis), which then form the basis for the production of alternative liquid fuels. Alternatively, the catalytic conversion of CO_2 and H_2 to methanol can also take place in one step directly without the need for a detour via the reverse shift reaction [44]. Oxygen (O2), which is always produced as a by-product in the electrolysis of water, can be used advantageously in other pathways, e.g. in the reforming stage of GTL path 1 or in the gasification step of the BtL pathways.

In Germany, for example, the companies Sunfire GmbH, Südzucker AG and Solvay GmbH as well as the research institutions Albert-Ludwigs-University in Freiburg and Fraunhofer ISE are engaged in this PtL path.

GtL path 1:
A typical resource of this GtL path is methane (CH_4). Methane can be produced from conventional biogas in a renewable way, e.g. as biomethane. Alternatively, it could also be synthesized from CO_2 and H_2. In the latter case however, if finally targeting at liquid products, one would prefer "PtL path 1".

By reforming with partial oxidation using oxygen (O_2) methane will be converted into synthesis gas, which undergoes the same further processing as in "PtL path 1". The required oxygen can be obtained e.g. from air or as a by-product of the electrolysis of water from PtL pathways.

This GtL path is particularly used by large companies such as Shell, Sasol and Air Liquide. The currently largest production plant in the world is Pearl GTL in Ras Laffan Industrial City in Qatar. It was commissioned in 2012 by Shell with a capacity of 140,000 barrels per day. The required methane originates from natural gas.

PtL path 2:
"PtL path 2" is linked to the BtL pathways described below by contributing renewable hydrogen for increasing the fuel yield of BTL pathways. This is another example of **increasing efficiency by interlinking** different process lines.

BtL paths:
The BtL pathways correspond in the systematics of the Biorefineries Roadmap [4] to the "synthesis gas biorefinery" according to Biorefinery Group 4.

Via BtL pathways, solid renewable carbon sources such as biomass (e.g. wood and straw), biochar (possibly in **co-processing** with fossil coal) can be processed with or

Tab. 1: Overview of the state of development and actors for different pathways to advanced alternative liquid fuels (examples) [40-42]

Path	Process	Raw materials	Products	Status	Stakeholders (examples)
PtL path 1	RSOC + FT synthesis	H_2O, CO_2, power/H_2	diesel, jet fuel	pilot in operation	Sunfire
PtL path 4	Kolbe electrolysis	carbohydrates, fatty acids, power	liquid hydrocarbons	laboratory	Infinite Fuels, HAW Hamburg, FhG ICT-IMM
PtL path 5	catalysis	power/H_2, CO_2	Oxygenates e.g. DMM, OME	laboratory (“Kopernikus” project)	RWTH, FZJ, DECHEMA
GtL path 1	partial oxidation + FT synthesis	CH_4, O_2	diesel, jet fuel	production	Shell, Sasol, Air Liquide
GtL path 2	fermentation	CO_2, CO, H_2	ethanol	TRL 8 demo in operation	LanzaTech/USA
BtL path	pyrolysis + gasification + synthesis	lignocellulosics, notably straw	DME, gasoline	TRL 6-7 demo in operation, bioliq® project	KIT, Air Liquide, CAC
BtL path	torrefication + gasification + FT synthesis	lignocellulosics, notably wood	diesel, jet fuel	TRL 4-5 Pilot in operation, “BioTfueL” project	e.g. Total, ThyssenKrupp
BtL path	gasification + FT synthesis	lignocellulosics	e.g. diesel	pilot in operation	CUTEC
BtL path	gasification + FT synthesis	lignocellulosics	e.g. diesel	TRL 6-7 demo in operation	TU Freiberg, Air Liquide, CAC
WtL path	gasification + synthesis	biomass, domestic waste	methanol, ethanol	TRL 8 demo in operation	Enerkem/Can
DL path 1	flash pyrolysis + hydrogenation	biomass	gasoline	demo under construction	Ensyn/Can
DL path 1	flash pyrolysis + hydrogenation	biomass	gasoline	pilot	BTG BioLiquids/NL
DL path 2	hydropyrolysis	biomass	gasoline	TRL 4-5 pilot in operation	GTI/USA
DL path 3	hydrothermal liquefaction	biomass	biooil	TRL 6-7 demo in operation	Licella/Australia
DL path 3	hydrothermal liquefaction	biomass	biooil	TRL 4-5 pilot in operation	Steeper Energy/DK
DL path 4	hydrosolvolysis	biomass	biooil	laboratory	Nexxoil, HAW Hamburg
DL path 5	organic solvolysis	biomass	biooil	laboratory	Nexxoil, HAW Hamburg
DL path 6	catalytical depolymerization	plastic waste	oil	pilot	wastecon-Solvorec
DL path 7	multi-stage catalysis	carbohydrates	diesel	TRL 6-7 demo in operation	Virent/USA
Algae path 1	drying + DL path 2 or 5	algae biomass	diesel		see “DL path 2 + 5”
Algae path 1	DL path 3	algae biomass	diesel		see “DL path 3”
Algae path 2	lipid extraction	algae lipids	diesel, jet fuel		see “Lipid path 2”
Algae path 3	fermentation + lipid extraction + HVO process	algae + sugar	diesel, jet fuel	TRL 8 demo in operation	Solazyme/USA
Lipid path 1	refining + HVO process	waste fats/used cooking-oils	diesel, jet fuel	production	Neste, UOP, ENI
Lipid path 1	CVO process	waste fats/used cooking-oils	diesel, jet fuel	TRL 4-5 pilot in operation	Nexxoil, HAW Hamburg
Lipid path 2	HVO or CVO process	fats and fatty oils	diesel, jet fuel	production	see “Lipid path 1”
Bio-refinery path	hydrolysis + fermentation	lignocellulosics	farnesene	TRL 8 demo in operation	Amyris, Total
Bio-refinery path	hydrolysis + fermentation	lignocellulosics	isobutene	TRL 6 demo in operation	Global Bioenergies
Bio-refinery path	hydrolysis + fermentation	lignocellulosics	ethanol	TRL 6-8 demo in operation	various, see text
Bio-refinery path	hydrolysis + fermentation + catalysis	lignocellulosics	oxygenates	laboratory	RWTH
Bio-refinery path	hydrogenation + fractionation	tall oil	diesel	TRL 8 demo in operation	UPM

TRL = Technology Readiness Level according to EU Horizon 2020 [43]; RSOC = Reversible Solid Oxide Cell; FT = Fischer Tropsch

without further accompanying substances. For economic reasons, the core processes are generally carried out in larger, centrally operated production units.

Also here, efficiency increases are possible through cross-linking with other process pathways. For example, biochar can be provided from the DL pathways described below. In particular, biooil-biochar slurries originate from “DL path 1”, e.g. in the KIT bioliq® process in Karlsruhe in cooperation with Air Liquide and Chemieanlagenbau Chemnitz (CAC). The upstream connection of smaller decentralised DL facilities can significantly reduce the transport costs for raw materials. This again demonstrates the exploitable **synergy potential through intelligent interlinking** different pathways. The bioliq® process consists of a fast pyrolysis stage for obtaining a biooil-biochar slurry, which is then fed to gasification for synthesis gas production with subsequent syntheses. Synthesis products are e.g. DME, methanol and gasoline. Raw material throughput is 0.5 t/h straw. Production capacities are 600 t/a DME and 100 t/a gasoline. [42]

In the case of the BioTfueL project in France involving Total, ThyssenKrupp Industrial Solutions among others, the biomass (e.g. wood) is first torrefied, then converted into synthesis gas in gasifiers that have already proven themselves in coal gasification and finally liquefied to fuels such as diesel and jet fuel by Fischer-Tropsch (FT) synthesis. A pilot plant in Dunkirk/France is designed for 4000 t/a FT products.

In principle, raw material in BtL pathways is converted by gasification in a temperature range from 800 to 1400 °C into synthesis gas respectively initially into raw synthesis gas (raw syngas). A number of technically proven reactor concepts, e.g. from Air Liquide or ThyssenKrupp, are available for this purpose and various process pathways can be used, e.g. “allothermal” (external heat supply) or “autothermal” (internal heat supply by partial oxidation with oxygen) processes up to steam reforming.

To adjust the CO/H_2 ratio in the crude synthesis gas, the addition of external H_2 (e.g. from “PtL path 2”) or the so-called water gas shift reaction ($CO + H_2O \rightarrow CO_2 + H_2$) is used. The synthesis gas obtained in this way is processed in the same way as in “PtL path 1” or “GtL path 1”.

The shift technology can also be used to produce hydrogen for the hydrogenation reaction of all DL pathways. This type of hydrogen production is very efficient and much cheaper than electrolysis of water, as long as no low-cost excess power is available.

In Germany, for example, in addition to the aforementioned players, the companies Chemieanlagenbau Chemnitz (CAC), CUTEC in Clausthal-Zellerfeld and the Technical University of Freiberg are also involved in research with BtL pathways and with syntheses from synthesis gases of all XtL pathways. LIKAT in Rostock develops corresponding catalyst systems.

WtL path:
WtL pathways are used for “Waste to Liquid”. The fuel products are also referred to as RDF (Refuse Derived Fuels). Raw materials are waste such as household waste or industrial waste similar to household waste, residual waste from sorting and plastics as well as plastic mixtures.

As in the BtL pathways (see above), the raw materials are usually converted into a raw synthesis gas at very high temperatures above 1000 °C, combined with the subsequent adjustment of the CO/H_2 ratio and the synthesis to fuel products.

The Canadian company Enerkem has already commissioned two commercial demonstration plants with an annual raw material throughput of 100,000 t based on biomass and household waste in Edmonton/Canada and Pontotoc/USA. The synthesis products are methanol and ethanol [42].

PtL path 3:
“PtL path 3” is linked to all DL pathways described below by feeding renewable hydrogen into e.g. biooil hydrogenation as an alternative to shift reaction based hydrogen from BtL pathways

DL paths:
Direct liquefaction (DL) can process highly diverse solid carbon sources such as biomass (e.g. wood and straw), organic waste (e.g. plastic waste and biological waste) or sewage sludge and challenging residues such as lignin. The intermediate product is always an oil that can be fur-

ther processed into advanced alternative liquid fuels. DL processes are characterized by high energy-efficiency due to moderate temperatures (below 500 °C) and the direct single-stage generation of liquid energy sources (oil). This offers the opportunity to process the distributed incurring raw materials economically in smaller, decentralised plants in order to minimize transport costs on the raw material side. This also offers opportunities for **synergies** to significantly improve the **economics** of overall concepts for the production of advanced alternative liquid fuels, e.g. **by linking** a first decentralized DL step with centralized industrially operated steps from other processing pathways. Such a concept is described, for example, under the section of the BtL pathways in the context of the bioliq® process from KIT.

DL denotes thermochemical transformation processes at temperatures between 300 and 500 °C. In the case of biogenic raw materials, the oil produced as an intermediate product is also called bio oil or bio crude oil (BCO). In addition, biochar, gas and a water phase are usually obtained. The gas can be used to power the process. The biochar can be fed into BtL processing, while the water phase is suitable for biogas production. The oils need hydrogenation and refining for the upgrading into advanced alternative liquid fuels, possibly after intermediate deoxygenation. The required hydrogen can be produced using synergy opportunities, e.g. via “PtL path 3” or from the by-products biochar and water phase via the steps steam reforming and shift reaction. These steps are described under the section of the BtL pathways.

In addition to these overriding common features, the individual DL pathways listed below exhibit characteristic differences in their reaction conditions.

DL path 1:
“DL path 1” is technically the most developed DL path due to its comparatively simple technical concepts. The core process is flash or fast pyrolysis, in which the feedstock, preferably wood or straw, is usually converted at atmospheric pressure under extremely rapid heating-up conditions into a bio crude oil at high yield in addition to biochar and gas. The properties of the resulting crude oil are very exceptional. It is very polar and miscible with water, and therefore it contains the reaction water dissolved in one phase. Its calorific value is about 16 to 17 MJ/kg, which is generally even slightly lower than that of the feedstock. Therefore, the expenditure for the treatment of such bio crude oils in the direction of high-quality fuels is the highest among all DL pathways.

The slurry of crude oil and biochar, containing about 80 % of the raw material energy, can be further processed via BtL pathways. This combination is described under the section BtL pathways in connection with the bioliq® process of the KIT.

This DL path is the object of companies such as the BTG Biomass Technology Group in the Netherlands and the Canadian company Ensyn, which founded the technology company Envergent as a joint venture with Honeywell/UOP. A demonstration plant for 65,000 t/a wood throughput and 36,000 t/a petrol production is under construction by Ensyn in Ontario/Canada [42].

On the research side, a large number of groups worldwide are working on this DL path.

DL path 2:
“DL path 2” differs from “DL path 1” in that the rapid pyrolysis is carried out under hydrogen pressure as hydropyrolysis. This significantly improves the quality of the bio crude oil, so that the expenditure of its hydrogenation to hydrocarbons is considerably lower.

The Gas Technology Institute (GTI) in Chicago/USA in cooperation with Shell is following this path. In Des Plaines/USA a pilot plant for a biomass throughput of 50 kg/d is in operation, designed for a gasoline production of 4 t/a [42].

DL path 3:
Hydrothermal solvolysis is performed in “DL path 3”. The term “solvolysis” refers to the reaction medium acting as a solvent. The reaction takes place in a water phase under near-critical or supercritical conditions (150 to 250 bar, 320 to 380 °C). This suppresses the formation of biochar almost completely. The bio crude oil possesses an increased calorific value of about 30 MJ/kg and has a tarlike consistency. This must be taken into account when further processing to fuels.

In Germany, for example, the KIT in Karlsruhe is working on this pathway as well as the DBFZ in Leipzig, which is developing a multi-stage hydrothermal liquefaction. On an international level, some companies such as Licella in Australia, Altaca in Turkey (Catliq process), Steeper Energy Group in Denmark and Canada as well as Applied Research Associates Inc. (ARA) in the USA are engaged in this pathway. A Licella demonstration plant for the production of 350 t/a of bio oil is in operation in Somersby/Australia [42]. A Steeper Energy pilot plant for the production of

30 t/a bio oil from wood is in operation in Aalborg/DK [42]. The Dutch company BTG is engaged in the hydrothermal deoxygenation of flash pyrolysis oils, another example of production cost reduction through **synergies**.

DL path 4:
In "DL path 4", organic solvolysis (compare to "DL path 5") is carried out under hydrogen pressure. The term "solvolysis" refers again (compare to "DL path 3") to the reaction medium acting as a solvent. The reaction typically takes place in a heavy oil phase (so called sump phase), which ideally regenerates itself, i.e. does not have to be supplied from outside or only slightly. The reactor works according to the principle of reactive stripping. Instead of a heavy oil phase, other organic solvents to be externally contributed, such as tetralin, are also conceivable.

This pathway of solvolysis can suppress the formation of biochar similar to hydrothermal solvolysis (see "DL path 3"). The crude oil reaches calorific values above 30 MJ/kg and is of low viscosity. This minimizes the effort for further processing. Basically the same **synergy** opportunities exist here as described under "DL path 5".

In Germany, for example, "DL path 4" is handled in particular by Nexxoil in cooperation with HAW Hamburg (Hamburg University of Applied Sciences).

DL path 5:
DThe "DL path 5" refers to the pure variant of organic solvolysis. No compressed gases are used. In contrast to "DL path 4", "DL path 5" can be operated under atmospheric pressure when heavy oil is used as the reaction medium (so called sump phase). This minimizes the equipment costs required. If other organic solvents are used, the required pressure depends on their vapour pressure at reaction temperature. The reactor operates at the boiling point of the sump phase and therefore by the principle of reactive distillation.

Under these conditions, a certain amount of biochar is formed. The crude oil has a fairly high calorific value between 25 and 30 MJ/kg and is of low viscosity. This minimizes the expenditure for further processing.

Both biomass and waste of a biogenic or non-biogenic nature (e.g. plastic waste) can be used as feedstock. In addition, this process step allows **synergies** with other pathways, e.g. by applying it for the deoxygenation of lipids including algae or other bio oils. In particular, unpurified waste fats or used cooking-oils from "lipid path 1" can be processed. Further **synergy** potentials with other pathways described here are offered by the conversion of lignins, which are generated as a by-product in biorefinery pathways.

In Germany, for example, "DL path 5" is handled in particular by Nexxoil in cooperation with HAW Hamburg (Hamburg University of Applied Sciences).

DL path 6:
"DL path 6" concerns the catalytic depolymerization of plastic-based wastes to hydrocarbon-rich crude oils, which are subsequently processed, like in the other DL pathways, via hydrogenation and refining into fuels or drop-in fuels. In addition, gas is produced which can be used to supply energy to the process.

In Germany, for example, the catalytic depolymerisation of polyolefins is handled in particular by the wastecon AG-Solvorec GmbH-group in the Hamburg region.

DL-path 7:
"DL-path 7" represents a special case because specifically sugar molecules are converted multi-stage via hydrogenolysis, hydrothermal solvolysis and hydrogenation in combination with other catalytic steps to liquid hydrocarbons, especially alkanes.

For example, Virent/USA in cooperation with Shell is following this pathway with the "BioForming" process. A Virent demonstration plant for the production of 30 t/a diesel from carbohydrates is in operation in Madison/USA [42].

Algae and lipid paths (HEFA, HVO, CVO):
Usually, algae and lipid pathways are closely linked together, as far as lipids are the main material basis.

Lipids (triglycerides) are an intermediate product that can be further processed into liquid hydrocarbons and products like diesel or jet fuel using various methods such as the CVO process (see "lipid path 1") or hydrothermal solvolysis (see "lipid path 1") for deoxygenation or the HVO/HEFA process (see "lipid path 1").

Another option is the hydrolysis of triglycerides to fatty acids and their conversion to alkanes via the "PtL path 4" described below.

Many research institutes and companies worldwide are involved in the cultivation and processing of algae. A particular challenge is to improve economic efficiency by reducing cultivation and processing costs [37-39].

Algae path 1:
In “Algae path 1”, the total mass of algae is processed either in dried form via hydropyrolysis/”DL path 2” (GTI/USA) or organic solvolysis/”DL path 5” (HAW Hamburg) or in non-dried form via hydrothermal solvolysis/”DL path 3” (ARA/USA with Chevron Lummus Global/USA, Sapphire/USA with Linde/Germany). On the research side, for example, the TU Freiberg and BTU Cottbus/Senftenberg are involved in the hydrothermal solvolysis of algae.

Lipid path 1:
This lipid pathway concerns the processing of waste fats or used cooking-oils.

In a first variant, the lipids are directly processed without purification using the CVO process (Nexxoil with HAW Hamburg), which corresponds to organic solvolysis/”DL path 5”. CVO stands for Cracked Vegetable Oils. For this purpose, a 200 kg/week pilot plant is in operation in Hamburg. The CVO process primarily leads to diesel products. If jet fuel products shall be manufactured, a catalytic isomerization has to be added afterwards to improve the cold stability.

A second variant leads via refining (purification) of the feedstock to pure lipids, which are then further processed by the the catalytic HVO process (Neste/Finland, UOP-Honeywell/USA, ENI/Italy). HVO stands for “Hydrotreated Vegetable Oils”. Instead of HVO, the abbreviation HEFA (Hydroprocessed Esters and Fatty Acids) is also used if generally fatty acid-based raw materials and not triglycerides in particular shall be processed. The HVO process is essentially a catalytic hydrogenation and cracking of the oils, which primarily leads to diesel products. Catalytic isomerization may follow to improve cold stability. This last step is particularly necessary if kerosene shall be produced as aircraft (jet) fuel. The HVO process is already on the market on a production scale. Neste is the leading company in Finland with a worldwide production capacity of 2.6 million t/a.

On the research side, the hydrogenation of lipids is a topic e.g. at the Technical University of Freiberg/Germany.

Further options are the hydrothermal solvolysis/”DL path 3” (e.g. ARA/USA with Chevron Lummus Global/USA) and the new combination of hydrolysis of lipids to fatty acids and their further processing via Kolbe electrolysis in “PtL path 4” (e.g. Infinite Fuels with HAW Hamburg).

Lipid path 2:
This lipid pathway starts with the classical oil extraction from oilseeds and corresponding further processing, as described in section “Lipid path 1”.

Algae path 2:
The “Algae path 2” follows the conventional method of disintegration of the algae and subsequent separation and processing of the lipids, as described in section “Lipid path 1”. On the research side, the AUFWIND project conducted by a consortium of FZJ, EADS, DBFZ, TUM, FhG (UMSICHT), RWTH and others and the “AlgenFlugKraft” project conducted by a consortium of TUM, Bauhaus Luftfahrt, Airbus, Clariant, Conys and others are developing this pathway with regard to kerosene (jet fuel) production.

Algae path 3:
In this pathway, algae are cultivated in the absence of light while sugar is added (heterotrophic growth), whereby the lipid yield becomes particularly high. In this case, the extraction of the lipids for further processing is comparatively easy. A disadvantage of this pathway is the use of the foodstuff sugar, unless the sugar derives from cellulose by hydrolysis.

In particular, Solazyme in California/USA is following this pathway. Further processing of the lipids takes place as described under “Lipid path 1”. In Clinton/USA there is a Solazyme demonstration plant in operation for the production of 20,000 t/a HVO diesel from carbohydrates [42].

GtL path 2:
The “GtL path 2” refers to the fermentation of CO_2 in connection with CO and/or H2 as energy source. Possible sources include synthesis gases, CO-rich industrial exhaust gases, CO_2 from fermentation processes or CO_2 from the air in combination with H2 from PtL or BtL pathways.

Alcohols, in particular ethanol, hydrocarbons, such as isoprene, or fatty acids can be obtained from the fermentation of the gases. Isoprene can catalytically be converted into gasoline components, while fatty acids can be converted into liquid hydrocarbons such as olefins and alkanes via “PtL path 4” by Kolbe electrolysis.

The company LanzaTech in Chicago/USA is engaged in this GtL pathway. A demonstration plant is already in operation in Soperton/USA which produces 15,000 t/a of ethanol from biomass derived synthesis gas [42]. No major projects for the production of isoprene or fatty acids are known so far.

PtL path 4:
The core process of “PtL path 4” is the Kolbe electrolysis, which converts fatty acids into liquid hydrocarbons like olefins and alkanes while releasing CO_2 and H_2. The aforementioned algae and lipid pathways in combination with hydrolysis and the fatty acid producing “GtL path 2” are possible sources of fatty acids. Alternatively, fatty acids can also be obtained by fermenting carbohydrates.

This innovative pathway is being investigated in particular by Infinite Fuels in cooperation with HAW Hamburg (Hamburg University of Applied Sciences) and Fraunhofer ICT-IMM as well as the Technical University of Braunschweig.

PtL path 5:
In “PtL path 5” the generation of oxygenates like dimethoxymethane (DMM) or oxymethylene ethers (OME) is considered. Carbon dioxide (CO_2) serves as the carbon source. The conversion of CO_2 and H_2 to DMM and OME does not take place via the synthesis gas pathway, but instead the following process pathways are the subject of investigation: A direct way to convert CO_2 and H_2 to DMM and OME shall be found by means of homogeneous catalysis. A second possibility is the recovery of DMM and OME via formic acid/methanol. As a third variant, the known route via formaldehyde/methanol shall be optimized.

This pathway is part of the “Kopernikus” project named “P2X”, coordinated by RWTH Aachen University, Forschungszentrum Jülich and DECHEMA.

Biorefinery paths:
Typical biorefinery pathways, based on lignocelluloses as substrates like wood and straw, begin with the pulping and fractionation into polysaccharides as intermediates, as well as lignin and possibly tall oil as by-products. Lignin can be processed efficiently via DL pathways. Polysaccharides can be converted into oxygenates or liquid hydrocarbons in many innovative ways.

For instance, after hydrolysis of the polysaccharides to simple sugars, numerous pathways are available such as catalytic conversion to levulinic acid or fermentation to ethanol, itaconic acid, isobutene or farnesene.

In particular, at RWTH Aachen University, the “Tailor-Made Fuels from Biomass” (TMFB) cluster of excellence is investigating the itaconic and levulinic acid pathways among others. In both cases, catalytically oxygenates can be obtained for new fuels or additives.

Farnesene and isobutene, on the other hand, are suitable platfoms for the production of drop-in fuels. For example, the Farnesen product line is pursued by Amyris/California/USA with Total/France, and the Isobutene product line by Global Bioenergies/France.

Second generation lignocellulosic bioethanol is produced in Germany by Clariant in a demonstration plant with TRL 6-7 in the frame of its Sunliquid project. However, there are already numerous TRL-8 demonstration plant projects outside Germany. One plant is running in Europe (Beta Renewables in Italy), four plants are under construction in Europe (St1 in Finland, EnergoChemica in Slovakia, Clariant in Slovakia and Clariant in Romania) and four plants are already in operation in North and South America (POET-DSM and DuPont in the USA as well as GranBio and Raizen Energia with Shell in Brazil). [42, 45]

A special feature is the processing of tall oil to biofuel. Tall oil is a by-product of pulp production and consists mainly of resin and fatty acids. UPM claims to operate a TRL-8 demonstration plant in Lappeenranta/Finland for the production of 100,000 t/a diesel substitute from tall oil via hydrogenation and fractionation.

2.14 Possibility of Co-Processing

There are particular opportunities in the joint processing of fossil and renewable resources.

On the one hand, technologies that have already been proven technically in the fossil sector can be gradually converted to the latter by increasing the share of renewable resources. This increases both the operational reliability and the speed of the transition. An example of this approach is shown in Fig. 2 using the joint processing of coal and biochar within the BtL pathways. Proven and tested coal gasification technologies can be applied here. This is, for example, the approach in the BioTfueL project, conducted by an international consortium including ThyssenKrupp Industrial Solutions, Total and other partners (see “BtL paths”).

Another example is the co-processing of flash pyrolysis oil and vacuum gas oil in refinery operations such as the Fluid Catalytic Cracking (FCC) process. BTG/Empyro, for example, is carrying out such a project in cooperation with Petrobras.

On the other hand, completely new ways are opening up to increase regenerative shares in fossil products. One example is BDI's BioCRACK pilot project in cooperation with OMV in Schwechat near Vienna. Here biomass is pyrolysed in fossil heavy oils. The heavy oil is cracked during this process and significant amounts of bio-oil dissolve in the produced middle distillates. These are suitable as a base for diesel production. This process has a certain procedural relationship to "DL path 5" in Fig. 2.

3. Recommendations for action

The research and development of advanced alternative liquid fuels up to the technical production scale, as shown in Fig. 2 (see section 2.13), is accompanied and supported by the ProcessNet Working Group "Alternative Liquid and Gaseous Fuels".

For the vast majority of pathways and process lines, there are already very good procedural approaches in Germany and Europe, most of them based on long lasting experiences. The BtL (Biomass to Liquid) and DL (Direct Liquefaction) pathways originate even from German developments in the 1920s, which were taken up again after the oil crises of the 1970s. The technical feasibility in this area has already been proven in many pilot and demonstration plants. There is also no shortage of innovative approaches. Lastly, the modern Tailor-Made-Fuels-from-Biomass (TMFB) pathway is the focus of an excellence cluster at RWTH Aachen University, and the conversion of CO_2 and H2 to modern fuels is to be intensively researched in the "Kopernikus" projects. In Europe, some TRL-8 commercial demonstration plant projects are well under way as mentioned above in section 2.13 under "Biorefinery paths".

However, outside Europe, a great dynamic in research and technology development can be observed (cf. Tab. 1). **There is a danger that Europe will be passed and miss the connection.**

Therefore, an urgent need for action exists and strong support from business and politics is needed.

For this reason, the following recommendations for action are formulated on the basis of the facts listed above – in addition to many other approaches – which aim at the fastest possible market introduction of advanced alternative liquid fuels:

1. Expand the resource base on biomass, waste and residual materials as well as CO_2:

There is an urgent need to talk not only about bio-based products, but also about alternative products that have been derived, for example, from non-biogenic waste and residual materials, from the joint processing of regenerative and fossil raw materials or from other sustainable resources such as CO_2 from different sources. It is highly probable that only then all available synergy effects can be exploited and the required quantities of alternative products can be made available in the foreseen period. In addition, the comprehensive consideration of waste and residual materials, secondary raw materials and by-products from waste treatment is an important pillar of future consistently closed material cycles as part of climate protection and resource conservation.

Therefore, it is recommended to approve the following resources as a basis for advanced alternative fuels (gaseous and liquid):

- **Biomass (e.g. lignocelluloses, algae)**
- **Biomass fractions (e.g. lignin, tall oil und non-food lipids)**
- **Biogenic waste and residual materials (e.g. straw, waste and construction timber, sewage sludge, waste fats and other food wastes)**
- **Waste and residual materials, secondary raw materials and by-products from waste treatment (e.g. plastic and rubber waste, lubricants recycling residues, solvent residues)**
- **Hydrogen from renewable resources**
- **CO_2 from biogenic and non biogenic processes as well as from the air**

2. Approve co-processing:

The joint processing of alternative and fossil materials (co-processing) offers major opportunities. For example, by co-processing material flows from alternative sources, it is possible to use existing plants and procedures both in oil refining processes and in coal gasification processes. In the case of refinery processes, the processing of these materials to standard-compliant products is also guaranteed. In addition, the transition from fossil to alternative resources can be accelerated by gradually increasing the share of the latter through co-processing using proven technologies.

It is therefore recommended that fuels from co-processing processes should be approved and certified as alternatives.

Examples are:

- **Co-processing of fats and fatty oils, waste fats, plastic waste and residual materials together with fossil raw materials in refineries**
- **Co-processing of biomass, waste and residual materials together with fossil raw materials in gasification and liquefaction processes**

3. Pay greater attention to the production of advanced alternative liquid fuels in advanced biorefinery concepts:

The increased integration of the extraction of advanced alternative liquid fuels in future biorefinery concepts will allow further synergy effects to be exploited in the sense of increasing efficiency. Therefore, future support programmes should take into account the link between biorefineries and liquid fuel production or give added weight to it. For example, in the context of the Federal Government's Biorefineries Roadmap of May 2012 [4], there are particular opportunities for Germany and Europe to play a pioneering role.

4. Identify synergies of processes for the production of advanced alternative liquid fuels with PtX concepts:

The storage of regenerative surplus electricity in the form of liquid energy sources with high energy density is regarded as an important contribution to the solution of future storage problems. However, in these PtL (Power-to-Liquid) concepts, as well as in the PtG (Power-to-Gas) concepts, the challenge is to combine the unsteady accruing current with preferably continous running processes.

New ideas are required here. The large number of connections shown in Fig. 2 offers an opportunity to make certain processes more flexible as a link in the sense of "smart processing". Therefore, processes for the production of advanced alternative fuels should be increasingly taken into account for system integration in new or ongoing funding programmes within the framework of PtX concepts such as "Kopernikus".

5. Intensively support research and development with the aim to accelerate the market introduction of advanced alternative liquid fuels and create reliable legal frameworks with a perspective beyond 2020:

Among other solutions, the significance of advanced alternative liquid fuels for the success of the energy transition and climate protection should not be underestimated in view of the facts.

Germany and Europe already have very good process engineering approaches, innovative ideas, long-standing experience and research traditions. But there is a lack of support and dynamics in research and technology development up to market maturity. Funding is indispensable to bring all necessary process steps up to production scale as quickly as possible and to unlock the additional risk capital required. In particular, the financial risk for the first of its kind production facilities must also be reduced.

With focus on the necessary investments beyond 2020, there is now a need for a long-term reliable and coherent funding policy framework. However, at present this not available against the background of the current discussion on a funding policy in the field of biofuels from renewable resources. Otherwise, it is to be feared that Germany and Europe will take a back seat with regard to the foreseeable global development of biofuels.

A funding programme supported jointly by politics and industry and reliable legal framework conditions with a perspective beyond 2020 do offer the opportunity to achieve both political goals and technological leadership and thus create new jobs for Europe.

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