Summary and courses of action

Status and Perspectives of Liquid Energy Sources in the Energy Transition

A study by Prognos AG, the Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT and the Deutsches Biomasseforschungszentrum DBFZ

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MEW Mittelständische Energiewirtschaft Deutschland e. V.
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Company overview

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Table of Contents

List of figures

Abbreviations and glossary

BtL	Biomass-to-Liquid
BtX	Conversion of biomass to gaseous or liquid secondary energy carriers (Biomass-to-X)
CCS	CO_2 capture and long-term storage (Carbon Capture and Storage)
DAC	CO_2 capture from air (Direct Air Capture)
DBFZ	Deutsches Biomasseforschungszentrum (German Biomass Research Center)
FTS	Fischer-Tropsch-Synthesis
FT-Syncrude	Fischer-Tropsch-Syncrude: hydrocarbon mixture as a product of FTS
GHG	Greenhouse Gas
MENA	Middle East North Africa
PBtL	Power-Biomass-to-Liquid
PBtX	Conversion of biomass and electricity to gaseous or liquid secondary energy carriers (Power and Biomass-to-X)
PtG	Conversion of electricity to gaseous secondary energy carriers (Power-to-Gas)
PtH2	Conversion of electricity to hydrogen (Power-to-Hydrogen)
PtL	Conversion of electricity to liquid secondary energy carriers (Power-to-Liquids)
PtL-Syncrude	Hydrocarbon mixture as a product of PtL
PtX	Conversion of electricity to liquid or gaseous secondary energy carriers (Power-to-X)
RES	Renewable Energy Sources
WACC	Weight Average Cost of Capital

1 Summary

Liquid energy sources and raw materials have a major significance today

- Liquid energy sources and raw materials are easily stored and transported, their chemical properties making them very versatile, thus forming the basis for important industrial value-added chains in Germany.
- Approx. 98 % of the operating power in the transport sector and 22 % of the heating energy currently originate from liquid energy sources.
- Approx. 5.6 million oil heaters exist in Germany and approx. 20 million people live in oil-fired buildings.
- 16 % of the mineral oil is used in chemistry, thus covering 75 % of its organic raw material needs.
- The tight interconnectedness, as well as the energy- and product exchange between the major industrial sectors in Germany such as refining, petrochemistry, chemistry and plastics processing, lead to synergies and contribute towards the international competitiveness of the aforementioned industries.

In the future renewable electricity or biomass can be used to gain GHG-neutral liquid energy carriers

- Electricity from renewable energies can be converted into **liquid energy sources** by means of electrolytic hydrogen and a synthesis with carbon.
- If the carbon, required for this, is extracted from the air or from biomass, a virtually **greenhouse gas-neutral** combustible or fuel, **PtL** (power-to-liquid) or respectively BtL (biomass-to-liquid) is formed. If unavoidable concentrated exhaust gas flows exist these, too, can be utilized.
- **Biomass** based energy sources and raw materials can be diversely utilized and take up an important complementary function in reducing GHG-emissions. Furthermore, they can be combined with the PtL technology (PBtL).

Important economic sectors and consumers will continue to need liquid energy sources in the future

- Particularly in parts of the **transport sector** (e.g. aviation, shipping, long-distance road freight transport) and in the **chemical industry**, liquid energy sources and raw materials **cannot, or only with difficulty, be replaced.**
- In other areas, currently largely supplied with liquid energy sources, such as car transport and the heating sector, a **competition** between GHG neutral liquid energy sources and others, such as electricity-based systems, will arise.
- Because liquid energy sources remain needed, the development of a power-to-liquid technology path under climate protection aspects is a **no-regret measure and therefore highly recommended.**

Infrastructures and application technologies for liquid energy sources can be utilized further

- GHG-neutral liquid energy sources and raw materials can, from a technical point of view, be used in all consumption sectors, thus eliminating the need for costly modifications.

- PtL-energy sources and raw materials can be processed, stored, transported and used in the same way as current liquid energy sources.

- After certain adjustment investments German refinery sites are ready to process PtL- “crude oil” into end products. They will thus – as today – be competing with sites in the producer countries.

- The domestic need for infrastructure is significantly lower than in scenarios with higher electrification-levels. However, considerable investments abroad are required.

Consumers apply a variety of criteria to their investment decisions

- This study compares liquid energy sources (with growing PtL proportions) with electric solutions from the **consumer’s** point of view. The following criteria were taken into account: economic efficiency, usage and environmental aspects.

- The criterion of **economic efficiency** results in a differentiated picture. Short- and medium-term (2030), in most cases, economic benefits for liquid energy carriers result from yet low PtL proportions. Long-term, the advantages for power solutions within a higher price path for PtL, with consumer electricity prices remaining at about the level of 2015, outweigh. Depending on PtL- and electricity costs, as well as usage constellations, long-term advantages for liquid energy sources can emerge. In principle, the assessment of profitability, from the consumer-point of view, also depends on the level of the tax burden. Today, liquid energy sources used for mobility, are levied with higher taxes per energy unit than electricity.

- Concerning **usage**, differences arise primarily in terms of mobility. Due to good storage properties liquid energy sources suggest long-term benefits.

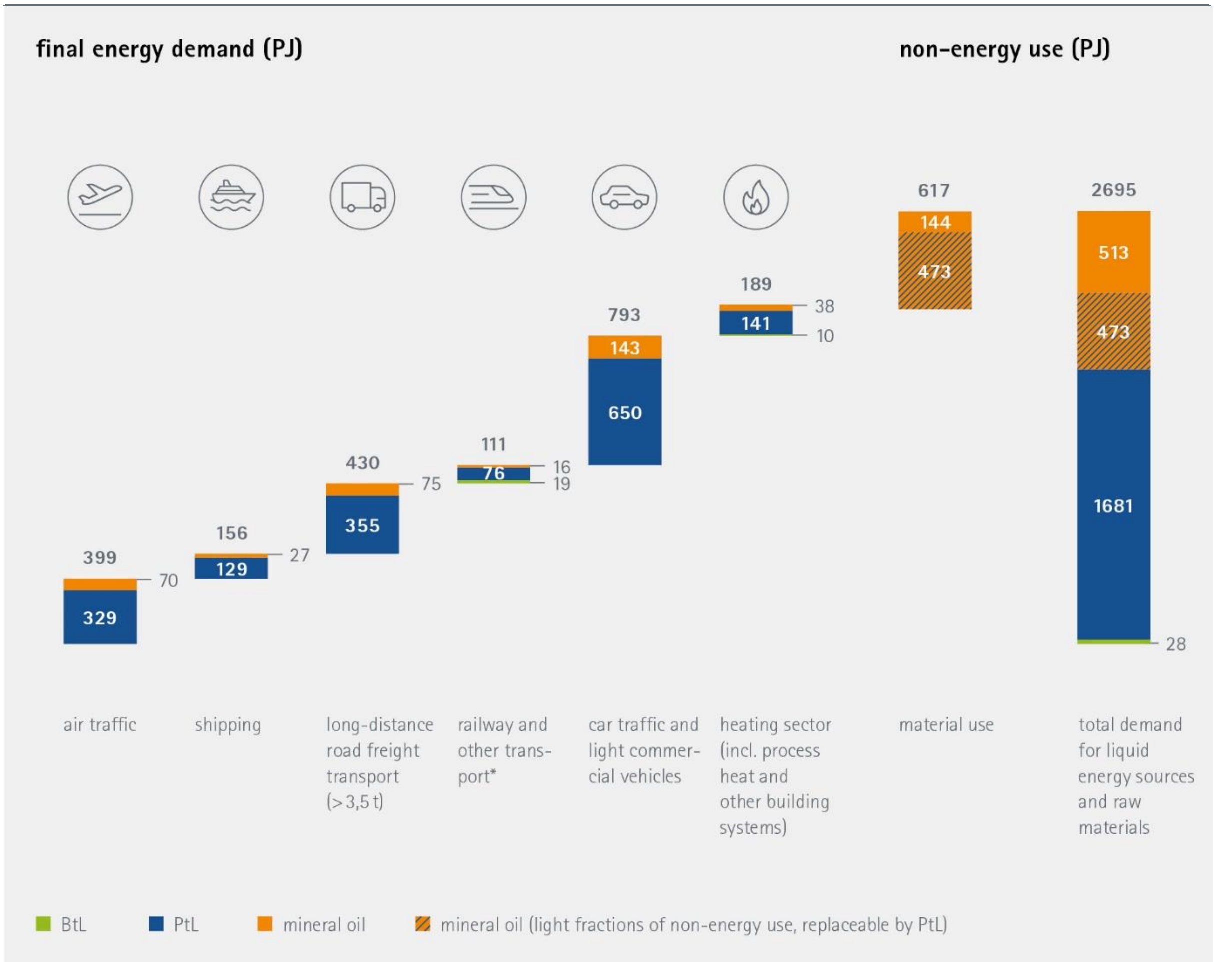
- From an **environmental** point of view, electrical solutions for heating and mobility have advantages over liquid energy source-based solutions, especially in the short- and medium-term. Inter alia do electricity solutions cause less air pollutants and GHG emissions. It should however be noted that a life-cycle-analysis for investigating pre-chain emissions was not conducted in the scope of this study. PtL combustibles are able to generate less air pollutants than fossil energy sources. In terms of greenhouse gases – if both the proportion of renewable energy in the electricity mix and the PtL admixture proportion are converging towards 100 % – a neutral evaluation can be stated in the long-term.

PtX complements other solutions such as renewable energies and efficiency. Ambitious GHG reductions are more solidly achievable through the use of PtL

- The PtX 80- and PtX 95-scenarios of this study show that achieving the GHG reduction targets is possible even if energy efficiency merely increases along today’s levels, and if the expansion of renewable energy in Germany, and the increasing electrification of applications reaches its limits with consumers.

- Causes for this could be insufficient restoration speeds or delays in the expansion of electricity grids.

Figure 1: Usage of liquid energy sources in Germany in the year 2050 in the PtX 80-scenario in PJ



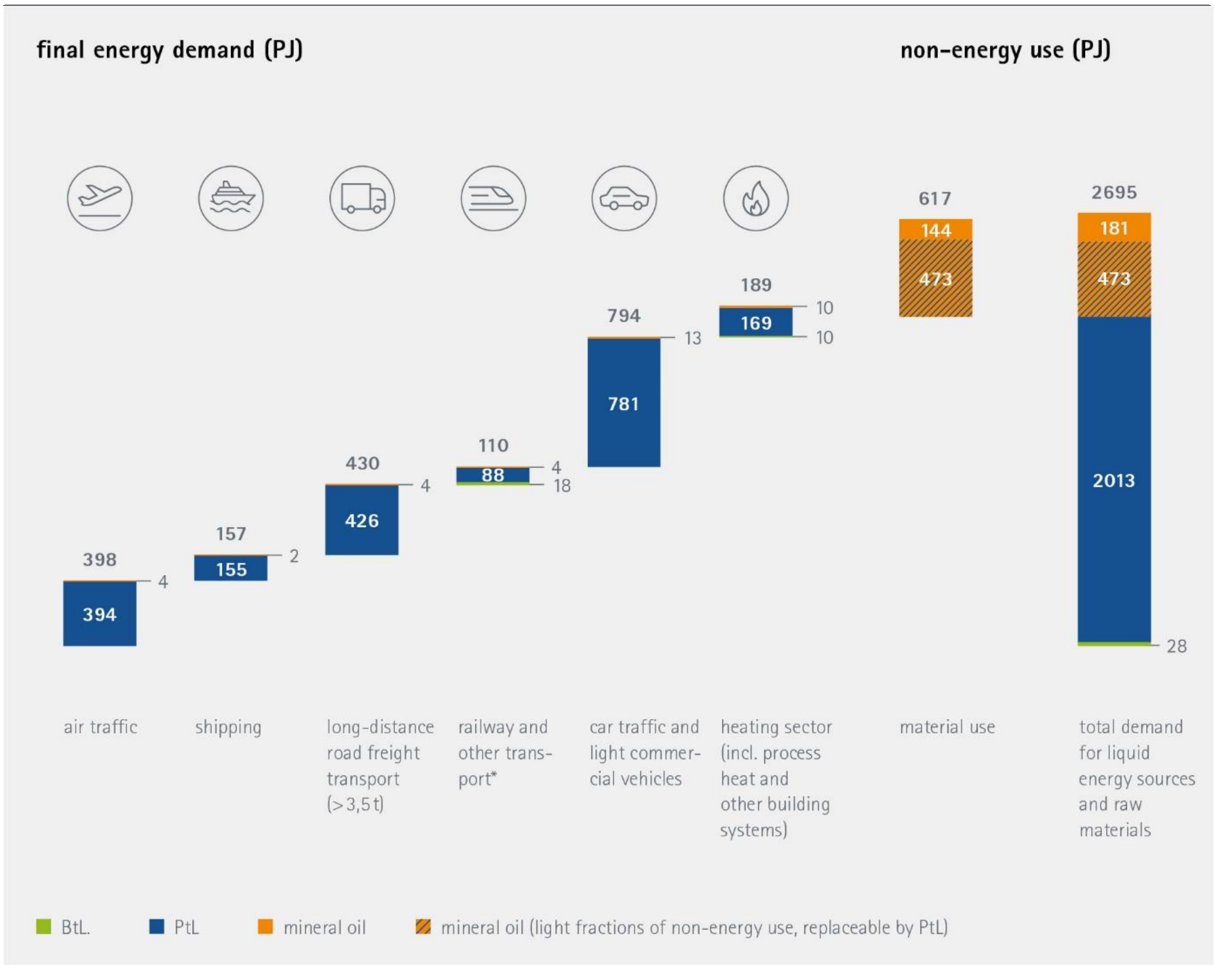
Source: own presentation, *agriculture, construction industry, public administration, military, NEV: non-energetic demand

In 2050 the PtL demand in the scenarios range between 555 and 2,000 PJ

- With ambitious climate protection goals (95 % GHG reduction), the **minimum PtL demand** – here equated with the demand of aviation and sea traffic – amounts to 555 PJ. If the electrification of motorways in Germany is not implemented, this would result in a minimum PtL demand of approx. **985 PJ** (both amounts resp. to needs in the year 2050, cf. Figure 1 and Figure 2).
- If PtL is used as a solution strategy pro rata in all sectors, it results in a PtL demand of approx. **1,700 PJ** (corresponds to 39.5 million tonnes in the PtX 80-scenario, cf. Figure 1) or of approx. **2,000 PJ** (46.5 million tonnes in the PtX 95-scenario, cf. Figure 2) in the year 2050. Depending on the scenario, approx. 1,000 PJ (26 billion m³) or about 1,600 PJ (41 billion m³) of PtG and PtH_2 would be added to this. For comparison,

Germany's current oil demand amounts to approx. 104 million tonnes.

Figure 2: Usage of liquid energy sources in Germany in the year 2050 in the PtX 95-scenario in PJ



Source: own presentation, *agriculture, construction industry, public administration, military, NEV: non-energetic demand

- In the PtX 95 scenario it was assumed that in parts of the industry and in the field of waste incineration carbon dioxide capture/-storage is used together with **CCS** (carbon capture and storage). To reduce the **CCS usage**, also in the petrochemical industry fossil raw materials **could partially be replaced with PtL.** In this case, the PtL demand rises by approx. 470 PJ (cf. Figure 2).

Energy imports provide opportunities

- The **production of renewable energies** will play an increasingly important part in reducing GHG emissions. Germany has big technical potential for the generation of electricity from renewable energies. However, the amount of feasible potential remains unclear due to possible spacial restrictions.

- Many countries have (significantly) greater potentials and more favourable production conditions for renewable energies than Germany. Consequentially, it suggests itself to consider the option of **importing** renewable energy to ensure the supply of energy and raw materials in Germany.

- This study examined countries in North Africa and the Middle East (MENA), as well as Kazakhstan. A worldwide search for ideal PtL sites was not conducted.

- Liquid energy sources can be stored at low cost and be transported worldwide. This provides an advantage over gaseous energy sources or electricity. It also provides a high degree of flexibility regarding the choice of PtL supply regions, extending beyond the scope of this study

In the year 2050 PtLs can be generated with an interest rate of 7 % at costs ranging from € 0.7 to 1.3 2015/litre

- Depending on the specific conditions of a renewable power generation site and its efficiency, greenhouse gas-neutral PtL can be produced considering a capital interest rate of 2 % amounting to approx. $€_{2015}$ 0.5 to 0.9 /litre crude oil equivalent in the year 2050. It should be noted that the search area of this study is restricted to merely a number of sites available where the above-mentioned low-costs could be implemented.

- At an interest **rate of 7 %,** the same rate also applied in other studies, production costs are expected to amount to **$€_{2015}$ 0.7 to 1.3 /litre**.

- A prerequisite for this is a **large-scale industrial entry** into PtL technology, so that learning effects can be achieved and thus costs be reduced.

- Thus, PtL and PtG achieve similar cost levels (cf. Fig. 12 to 15 of full report).

Due to existing infrastructure usable on a wider scale, scenarios with high PtX proportions require lower investments in Germany. However higher energy costs must be expected

- By the year 2050, the cumulative domestic **investments** are only slightly above the reference scenario, amounting to € 34 bn (PtX 80) resp. € 59 bn (PtX 95).

- However, resulting from PtL and PtG imports the annual **expenditure on energy sources** in Germany doubles in the year 2050 opposed to a reference scenario in which the GHG targets are not achieved.

- The accumulated costs for energy sources, adding up all years, in the PtX 80-scenatio amount to 44 % above the reference scenario (PtX 95: similar magnitude).

PtL creates economic prospects in producer countries

- For generating the PtL quantities of both scenarios, electricity generated **abroad** amounting to 900 TWh (PtX 80) and up to 1080 TWh (PtX 95) would be required in the year 2050. This corresponds to 1.5 to 1.8 times the volume of the current German net electricity generation.

- Abroad — for the Germany PtL supply alone, on average over the years up to 2050 — investments amounting to approx. € 44 bn per year (PtX 80) resp. € 58 bn (PtX 95) (excluding infrastructure investments) would be necessary. These investments comprise great opportunities and major challenges, thus requiring comprehensive international support during implementation.

- The future generation of PtL in solar- and wind-rich countries, currently exporting fossil energy, offers them an alternative business model. It is to be assumed that commodity-rich countries – without such an alternative – will try to exploit their fossil oil and gas reserves to a large extent.

Conclusions

- According to today's knowledge PtL is **indispensable** for an extensive greenhouse-gas-neutral energy supply.
- From the consumer's point of view, liquid energy sources containing PtL are able to compete in respect to price with electricity-based solutions.
- PtL **offers consumers an additional alternative** in finding an optimal low-carbon solution.
  At the same time PtL can be connected to already existing infrastructures.
- In order to develop this alternative and to have sufficient quantities available in due time, a **gradual but steady market launch** should be aspired. Depending on the phase, various regulatory and economic measures and instruments are appropriate and necessary.
- For their part, companies and science are asked to **increase research and development efforts** as well as to develop alternatives. Especially, carbon dioxide extraction from air, electrolysis and synthesis are important research fields.
- The future generation of PtL in solar and wind-rich countries can offer them **a promising growth perspective.**

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2 Conclusions and possible courses of action

2.1 General

Liquid energy sources and raw materials have a **substantial significance** in today's energy mix and form the basis for important industrial value-added chains in Germany (i.a. for the chemical production).

Especially in important parts of the national and international transport sector, and the chemical industry, it is difficult or impossible to replace liquid energy sources and raw materials. This, for example, applies to aviation, ship- and parts of heavy duty transport in the construction-, agriculture- and forestry industries as well as other areas of application. In other areas currently mainly supplied with liquid energy sources, such as car traffic and the heating sector, a competition between GHG neutral energy sources and systems (incl. Power-to-Liquid, PtL) will occur.

Because liquid energy sources are still going to be needed, the development of a Power-to-Liquid technology path under climate protection aspects is a no-regret measure. In Germany an overall PtL demand of up to 2,000 PJ could be revealed. For aviation and ship traffic originating from Germany alone the scenarios show a PtL demand of approx. 550 PJ. Additionally, a demand of up to approx. 1,600 PJ for PtG and PtH_2 is shown.

PtX-technologies increase the robustness of a demanding GHG reduction path. This applies especially if the existing barriers in Germany against alternative technologies cannot be overcome. The required PtX-quantities grow alongside the increasing climate protection requirements. Especially abroad this calls for significant investments in order to create the required production capacities. Required investments in Germany however, are comparatively low according to the scenarios of this study.

2.2 Possible courses of action

Development of a PtL Roadmap

What is to be done for PtL to be established as a viable option for GHG reduction? Hereafter measures and instruments enabling a perspective establishment of PtX-, especially a PtL, are described. The list is understood to neither be complete nor was it investigated whether or not it is sufficient to facilitate the minimum quantities of PtL in due time. In order to systematically assess barriers and possible measures for a PtL-market launch a PtL-roadmap listing, assessing and chronologically ordering instruments should be developed. In this a sufficient consultation with relevant stakeholders is to be ensured.

Creating R&D capacities and setting up Real-Labour

In order to expand competences in the PtL-field and to create timely decision-making tools for a PtL market launch the provision of research- and development budgets in economy and science is recommended, especially with participation of important sectors, such as the petroleum-, automotive- and chemical industries, mechanical- and plant engineering and the public sector. Since the availability of cost-efficient RES-power as part of the PtL value chain is essential, a search for potentially suitable sites is recommended.

Establishing research funding

The PtL-production on an industrial scale requires technologies, which at the time being yet have to undergo considerable learning curves. Some technologies are still in the early phases of development and are not yet used on industrial scales. Thus, the appropriate research funding should be ensured early on to make sure that the assumed learning curve takes place. Specific research areas have been addressed in the following chapter.

Supporting the PtL market launch

As with the market launch of renewable energies for electricity generation in the 90s, the implementation of an innovative and promising energy source such as PtL first requires a suitable framework. The first industrial scale facilities generating PtL will require far greater investments than subsequent facilities. Tendering models could become a suitable instrument to incite investments in this first phase. The regulatory- and, especially the financial framework for this is to be developed.

Adjusting the regulatory framework for PtL-admixing

A graduate increase in the use of PtL is reasonable. This can be achieved through admixtures to conventional energy sources, thus enabling a graduate market launch. The admixing of sustainably and renewably generated PtL should be deductible in all energy source related regulations. On a European scale this has already been scheduled in the Renewable Energy Directive II. Additionally, an option would be to allow the deductibility of PtL from the emission limits for fleets on short notice.

Tax-, duty- and levy relieves for CO_2-free energy sources

It is to be examined to what extent a tax-, duty- and levy relieve for CO_2-free energy sources can occur, so that renewably generated PtL products become competitive on the market and long-term are able to gain competitiveness in term of price in their respective applications without further funding.

It is to be noted that the framework which is to accompany the reconstruction towards a GHG neutral energy supply, by no means only takes into account environment related aspects, but also social aspects and acceptance limits while considering sector specific features.

Promoting usage of renewably generated hydrogen in refineries

The usage of hydrogen in refining processes generated in electrolysis facilities with the help of renewable energies, reduces the GHG emission in the production of petroleum products. This promotes the run up of using industrial scale electrolysis facilities, later also essential for PtL-generation. For PtL to reach a climate protection effect the usage of additional power generation facilities, not simultaneously promoted by the German Renewable-Energies-Act, is required. Deducing the GHG reduction created by using renewable hydrogen in refining processes from the greenhouse gas reduction quota presents itself as an instrument for promoting the measure. In order to prevent double deductions accounting issues are to be resolved.

Substantiating the degree of national biomass usage

Liquid energy sources and resources made from biomass can be applied diversely and can take up an important complementary function in reducing GHG emissions. Additionally, biomasses can be used in combination with PtL-technologies (PBtX), but the domestic potential for this is limited. Due to this, in the sense of an ideal allocation path for the future GHG neutral energy mix in Germany, an analysis of the long-term positioning of nationally available biomasses would be helpful.

Promoting international cooperation within RES-regions

The development of renewable resources in countries suitable for it plays a key part in the construction of the PtL-infrastructure. Alliances between countries, exchanges of knowledge and an intensification of economic- and political ties ought to be necessary for it. Since PtL-products can cost-efficiently and flexibly be transported over long distances from the location of production to the location of usage, the development of renewable resources in countries especially suitable for it, is recommended. International cooperation creates opportunities for both parties – countries producing PtL and countries purchasing it. This cooperation should be initiated earliest possible.

Developing criteria matrices for PtL-production sites

Comprehensive criteria matrices should be developed for selecting suitable PtL-generation sites, making chances, risks and potentials sufficiently transparent for investors. A variety of factors can be pivotal for the location decision. Among them e.g. climatic on-site conditions, land availabilities, already existing infrastructures usable for PtL-generation, cost of capital (WACC), controllability options for potential default risks (e.g. trough loan guarantees). Furthermore, possible local state support is relevant for the construction of PtL-infrastructures. Additionally, political-, economic- or socioeconomic developmental potential should be considered.

Defining standards for the sustainability of synthetic fuels

As with other energy sources, sustainability standards for synthetic fuels and combustibles should be phrased. For example, a required certification of origin for the sources of hydrogen and carbon, or the electricity needed for the electrolysis. With the help of binding, internationally agreed standards the sustainability of synthetically generated fuels and combustibles can be proven transparently.

2.3 Research questions

In the following, specific research needs are identified so as to contribute towards the realisation of the technology developments presumed in the scenarios. Other research questions regarding the future of liquid energy sources and resources are not covered in this study and should hence be mentioned here for the sake of completeness. Crucial research fields are listed and described. The order corresponds to the synthetic pathway of liquid energy sources and raw materials, and it is not to be equated with a prioritization.

Renewable power generation and -potentials worldwide

Renewable electricity with high full load hours creates the starting point for PtL. In-depth analyses concerning **renewable energies worldwide** can refine the knowledge about effective available renewable energy potentials. A focus should be put on the Cost-Supply-Curves to strengthen the knowledge base about PtL production costs.

This study consults combined PV- and wind potentials at reference sites as a basic principle for the structures of production of electrolysis facilities. In this respect as well, an in-depth worldwide analysis can contribute towards identifying sites with especially favourably combined RES-potentials.

Combination with solar thermal processes

Complementary to renewable electricity a combination with solar thermal processes for PtL generation could be useful and should be examined for the following reasons:

a) With this the full load hours of the electricity production could possibly be further increased (solar thermal power-plants with thermal storage)

b) The required process energy can possibly be facilitated solar thermally

Renewable resource base for synthetic energy sources and raw materials

Water and **CO_2**, as well as biomass constitute the resource base for synthetic GHG neutral energy sources. Because water is scarce in many potential generation regions **seawater desalination plants** will play a crucial part in the provision of water for the electrolysis and should thus be further developed.

Capturing CO_2 from air, **Direct-Air-Capture** (DAC), is a young, still cost-intensive technology currently merely used in sporadic pilot facilities. Especially in sight of the assumed cost-degression of DAC, a fast development of the technology is necessary. The evaluation of DAC will blend into the general discussion about the evaluation of negative emissions, which are assumed in many scenarios regarding climate gas reduction. It is to be examined in this context which concentrated CO_2-sources are inevitable and thus could, and should, be utilized.

The possible contributions by **BtX and PBtX-applications** are in competition with the application of biomass in other sectors. An analysis on the sustainably applicable biomass potentials for BtX generation worldwide can deliver important insights. PBtX-applications are able to use the scarce resource biomass better due to the elevated carbon dioxide efficiency and should thus be further developed as a priority.

Plastic waste could also be considered as an alternative resource base for liquid energy sources. Synthesis and potentials falling under the category **Waste-to-liquids** were not examined in this study, however they could contribute a part towards future liquid energy sources and raw materials and simultaneously provide a solution to the worldwide "plastic waste problem".

Water electrolysis

Water electrolysis, independently of the concrete technology, is a central step of going from electric energy to the chemical energy source of hydrogen and is thus of great importance for the PtX-generation. Simultaneously it is a very sensitive cost-factor. In order to implement the assumed learning-curve big advancements and cost-savings in the production are necessary. Also, when it comes to load flexibility, long-term stability, life-time and efficiency much potential remains for the various technologies involved in water electrolysis.

Synthesis on a renewable energy- and raw material basis

Industrially the **Fischer-Tropsch-Synthesis** has so far only been put to test on the basis of various fossil carbon suppliers and hydrocarbons, not however on an **electrolytic hydrogen and CO_2 basis.** The activation of CO_2, an initially "inactive element", for the chemical synthesis differs from the hitherto used gasification of a fossil energy source. Amid the assumed cost degression for FT-syntheses there is a specific need for research. The focus hereby should be on the generation of a stabile **synthesis gas from electrolytic hydrogen and CO_2**.

Other synthesis of liquid energy sources, e.g. the methanol synthesis, are not in the focus of this study, they should however be developed further parallelly to the Fischer-Tropsch-Synthesis. The same applies for the **catalysator research** needed for the various synthesis.

Also, so-called direct **Power-to-Chemical-procedures** present the potential to shorten pathways from renewable energies to target substances, especially for basic chemicals. Thus, process energy can be saved versus a synthesis pathway utilizing a synthetic hydrocarbon mixture such as a PtL-syncrude.

System integration and -optimization

Generation units of synthetic energy sources and raw materials are based upon a number of systems and auxiliary units. The adjustment of the renewable energy generation unit, the water treatment plant, the CO_2-extraction unit, the electrolysis unit and the synthesis unit, into an **integrated production process** is a continuous optimization task and central field of research. The **integration** of the volatile RES-generation into an as continuous as possible synthetic energy source production process requires an ideal adjustment of components. Various parts will require **storage technologies**, e.g. hydrogen buffers.

Further **upscaling** is required for the plant sections, and also for the overall process of the PtL-facility, meaning that findings from a laboratory- and technology-scale should be transferred to an industrial scale and be tested and utilized in real facilities. For only on an industrial scale the required quantities can be generated, and the cost saving potentials enhanced.

Imprint

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