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4th Roadmap of the Kopernikus project P2X.
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4th Roadmap
of the Kopernikus project P2X
Phase II

OPTIONS FOR A SUSTAINABLE ENERGY SYSTEM WITH POWER-TO-X TECHNOLOGIES

Transformation – Applications – Potentials

Editors:
Florian Ausfelder
Dinh Du Tran

KOPERNIKUS
P2X PROJEKTE
The Future of Our Energy

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PREFACE

Dear reader,

the four Kopernikus projects, P2X, SynErgie, ENSURE, and ENavi, which started in 2016, were new territory in terms of concept and content. Equipped with extensive funding in large consortia and with the promise of a duration of up to ten years, they were to be enabled to develop appropriate solutions to fundamental challenges of the energy transition. Each of the projects has its own focus and evolved differently over the years.

The claim of the P2X project is to research, develop and demonstrate power-to-X technologies from the fundamentals up to an industrial scale. This also reflects the central aspect of the originally planned project structure over the three funding phases. In the conception phase, it already became clear that such a project could not be planned for 10 years in advance from a desk.

Therefore, mechanisms of dynamic project control are needed to allow adaptability and flexibility of the project to react to new developements and delays, as well as new findings inside or outside of the project. Dynamic project control is not a concept that can be easily reconciled with the funding conditions, but it is indispensable due to the planned funding period and the diversity of technology developments within P2X.

The central instrument for dynamic project control in the Kopernikus project P2X is the roadmap, which now has been published in its fourth version. In addition to supporting dynamic project control, the roadmap has other tasks: Presentation of the project progress for an interested public, comprehensive and transparent evaluation of the investigated technologies, and classification of the development progress of power-to-X technologies in the changing context of the energy transition.

Unlike others, our roadmap does not focus on predictions and forecasts of, e.g., to which extent a certain technology will be deployed in the future. Instead, the roadmap describes the status of work in the project, places it in the context of the energy system, and does not shy away from pointing out uncertainties, naming obstacles, and presenting those areas in which no reliable statements can currently be made. It does not claim to be a conclusive presentation but is always a "work-in-progress".

Within the P2X project, the roadmap that is now available, is only the result of the "roadmapping" work package. The term already makes it clear that the focus is on the process. It is precisely this process that lays the foundation for dynamic project control through coordination.

Technologies do not exist in a vacuum. According to the scope of the P2X project, the technologies under investigation were at a maturity level of fundamental research. This made it impossible to predict if they would meet expectations or would play the same role years into the project as they did at the start during the conceptual phase.

In a consortium of this size, the interests of the partners involved are not necessarily completely coherent. The concept of pursuing the most promising technologies, albeit unspoken, at the expense of the less promising technologies, leads to internal pressure to perform within the project. Hence, the representatives of the respective technology paths have an intrinsically strong interest in the success of the work and in presenting it as positively as possible.

The task of the roadmapping was therefore to develop a common level that allows the different technologies, which also addresses different fields of application, to be evaluated both in terms of their progress and their importance. Thus, the roadmapping approach is rather a process of accompanying throughout the project rather than a final evaluation of the investigated technology. This is necessary because, in addition to the technology development within the project, the requirements of the potential application fields are also subject to constant change. It requires a dynamic process to capture these constant changes and adjust the work in the project accordingly.

In addition to the resulting requirements for the development of the technical work, the roadmap has also been continuously developed and adapted. Some evaluation criteria for these technologies were sustainability assessments. These included ecological, economic and social acceptance aspects, which were based on scenarios for the German energy system. Moreover, international aspects are now considered to a greater extent in the form of a methodology for a potential analysis. For this, explicit country analyses for possible implementation of power-to-x technologies are included, to validate the assumptions and structure of the methodology.

The roadmapping process involves all partners of the P2X consortium. This is done on different levels. Individual technical findings are incorporated into a comprehensive sustainability assessment, which in turn identifies critical aspects of the technologies from a sustainability perspective. The scenario analysis and the potential assessments work out what contribution the respective technologies could make and give indications of possible further fields of application. The resulting intensive, moderated dialogue between the various project partners is central to the development of the roadmap, for joint project identification, but also the transparency and acceptance of decisions in the sense of dynamic project control and the further setting of priorities in the project.

There is no silver bullet within PtX technologies. Although a certain technology might result in a more significant reduction of carbon dioxide emissions, it might not be useful in all application fields. Hence, different technologies will not be ranked against one another.

P2X is dedicated to technologies that are used in three application fields: Energy carriers, chemical feedstocks, and fuels. Each application field has different technical challenges, regulatory frameworks, and economic structures along the value chain. Therefore, an "either-or" selection of technologies does not do justice to the complexity of the challenge. In this sense, the roadmap is not the sole decision-making basis for dynamic project management, but rather provides the basis for discussion, which in turn is based on an intensive technical discourse within the project. Therefore the roadmap is a central element in the decision-making process for the further development of the project.

With this in mind, we wish you a stimulating read.

Florian Ausfelder

Dinh Du Tran

EXECUTIVE SUMMARY

GENERAL

The publication of this Roadmap 4.0 concludes the assessments in the second project phase of the Kopernikus project P2X. As one of four Kopernikus projects, P2X kicked-off in 2016 with the aim of developing the technological basis for solutions that can be used to produce molecular energy storage, energy carriers and chemical products for applications in the lead markets of energy, transport and industry using renewable energy. Within this process, special consideration was always given to alignment with environmental, economic and societal needs. In the first project phase (2016 – 2019), the areas of activity and fields of application were interlocked with regard to their content in order to identify the most promising options. The second project phase is based on these results and identifies two energy vectors – hydrogen and synthesis gas – on which value chains from the co-/electrolysis to the final product or the application can be built in a targeted manner for the application fields of mobility, chemical feedstocks and industry. Within the corresponding eight technical work packages, 42 project partners from science, industry and civil society are collaborating in P2X II to further develop the technologies within the value chains, with the aim of reaching market readiness.

This process is – and was already in the first project phase – accompanied by the roadmapping process, which documents and analyzes the technical progress of the research and development work together with the partners and places it into the context of the transforming energy system. This Roadmap 4.0 continues the previous publications of the first phase (Roadmap 1.0, Roadmap 2.0) as well as Roadmap 3.0 and shows the final results of the second phase of the Kopernikus project P2X.

A special feature and major advantage of this roadmapping process in P2X is the consistent basis of the analyses. The energy system models that were developed in the project comprise an energy model for the power plant development and deployment planning (urbs) and a demand model (SPIKE), which was developed as a result of the satellite project during the first project phase of P2X. It includes detailed hydrogen as well as PtX products and pathways. This ensures a consistent basis across all analyses, so that the results of the different value chains can be made comparable with each other.

In a back-casting approach, the achievement of climate protection targets and further constraints are defined, such as compliance with the CO_2 budget, among others, and finally the overall system is optimized according to the most cost-effective pathways to achieve this target (e.g., climate neutrality in Germany by 2045). In the baseline scenario, the German government's target corresponds to reducing GHG emissions to 65 %, 88 %, and climate neutrality in the target years 2030, 2040, and 2045, respectively, compared to 1990. This scenario also includes hydrogen transport within Europe, as those have already been investigated in Roadmap 3.0. This scenario serves as the basis for the detailed ecological (LCA) and economic (TEA) as well as the potential analyses, which carried out and present their analyses for the same base years. In addition, other scenarios are considered to give the system more flexibility in the optimization process. The focus is placed on global hydrogen infrastructures (import scenario MENA) or alternatives to a strong expansion of power transmission capacities in Europe (storage scenario), in which the expansion of electricity transmission lines is limited to the current plans until 2030 and hydrogen transport and energy storage expansion, on the other hand, are not restricted. Furthermore, in this scenario, the expansion of salt caverns is carried out in accordance with the geological capacity constraints. Finally, the sufficiency scenario examines how changes in behavior affect the energy savings potential and, consequently, the use of PtX. Here, changes are assumed in the areas of transport, housing, consumption and food, among others.

However, the result of all scenarios of the energy model is unambiguous in that PtX technologies and products are indispensable in a defossilized energy system of the future. They are particularly necessary in those areas where there is no other efficient technology available or where carbon-based energy sources are needed. A corresponding classification into the application fields of transport, basic chemicals and industry is carried out analogously to the value chains investigated in the project. The specific demand for PtX products depends to a large extent on the climate targets and the associated degree of defossilization: Accordingly, a more ambitious target will mean that PtX technology will have to be deployed earlier. Essentially, the PtX ramp-up is primarily related to the German electricity mix and consequently its development in line with the expansion targets of the German government. An almost, if not complete, decarbonization of the electricity supply must precede the implementation of PtX technologies.

The various fields of application for the direct use of electricity and the PtX technologies lead to a high total demand for renewable energies, which cannot be covered by Germany's renewable energy production capability in either the short or long term alone. A self-sufficient supply of energy carriers and raw materials for Germany cannot be achieved, which is why imports will be indispensable, as they are already at this point in time. Instead of fossil fuels, however, more electricity and green downstream products such as hydrogen will be imported in the future.

PtX technologies already experience a broad approval from the population, which is shown by the surveys conducted within the project. A panel survey was conducted to explore social acceptance, with a sample size of 1,076 young adults aged 16 to 25 years and 1,676 aged 25 and older. Some of the respondents were the same persons who already attended the first panel survey in 2020. The questionnaire covers various content levels related to the assessment of the various PtX technologies in the application areas already described, together with the associated usage intentions and sustainability orientations, as well as the willingness to pay, level of knowledge, environmental awareness, etc.

In addition to these detailed analyses, a potential analysis is carried out within the roadmapping process. The methodology developed in the second project phase and presented in Roadmap 3.0 was published as a publicly available web tool. It was used to determine the potentials for Germany shown in this roadmap. For the P2X value chains, the supply and demand potentials were determined accordingly and the various volume potentials and electricity, water and, where applicable, CO_2 requirements were shown. Due to the holistic top-down approach of the tool, regional impact factors are not yet taken into account. Nevertheless, a technically correct assessment of the quantitative requirements is possible.

In addition, different PtX potentials of very different exemplary countries were investigated within the scope of the potential analysis. Using a bottom-up approach, local experts on-site (Chile, Costa Rica, Kazakhstan and Madagascar) were interviewed and, based on this, development paths were identified that potentially play a role in the further development of a country-specific hydrogen/PtX economy. In terms of data availability, there are major differences between the countries, although a methodological structure was used to ensure the greatest possible degree of comparability of the structural characteristics studied. A common feature of the results is that an effective and comprehensive defossilization strategy would accelerate economic development, while at the same time providing different spans of application options: For the "early adopter" Chile, the focus lies on the export of green hydrogen and PtX products in particular, as already shown by other projects currently underway. In contrast, the "newcomer" Costa Rica and the "transition country" Kazakhstan are still focusing their defossilization plans on the fossil-based transport sector and, in the latter case on large fossil-based domestic energy reserves. Finally, the current debates around energy colonialism can be illustrated by the "newcomer" Madagascar, which faces extreme challenges such as poverty, a low electrification rate and a lack of infrastructure before it can effectively leverage the H_2/PtX potentials in the future. It was clearly demonstrated during the case studies that each country faces its own very different challenges for entering the green hydrogen/PtX economy. In the case studies, a deliberate decision was made not to summarize the import potential for Germany.

In Germany, however, as already described, the ramp-up of PtX technologies is particularly related to the share of renewable energies in the German electricity mix. In the results of the LCA, the ecological break-even point is determined. This point indicates how far the power sector has to be decarbonized in order for the investigated PtX technology to achieve a GHG emission reduction compared to the (fossil) reference process. Specifically, it was shown that electricity-related GHG emissions must be reduced to below about 150 – 200 g CO_2 eq./kWh (see Section 4.2) for a net GHG savings potential to occur. This amount of electricity-related emissions would already be undercut before 2030. Depending on the value chain investigated, however, the break-even point can also be reached significantly earlier, or the chain can even make a direct contribution to achieving climate neutrality for Germany at the present time. Analogous to the electricity-related emissions, the results of the techno-economic analyses can also be attributed to the composition of the electricity price, which is essential for the comparison against the fossil reference and thus the entry into a PtX economy.

In addition to the source of electricity, the choice of the CO_2 source also has a major impact on the economic and environmental assessments. While in Roadmap 3.0 only CO_2 capture from air (DAC) was considered and evaluated as a CO_2 source, the influences of industrial point sources are now examined using a cement plant as an example, since these process emissions can only be reduced by means of long-term storage of the CO_2. This is followed by a methodical explanation of the assignment of the CO_2 source to the system boundary. The effects on the respective P2X value chains and the comparison to the provision of CO_2 via DAC are described in the respective chapters.

The structure of the Roadmap 4.0 is based on the previous publication: After a classification of the future energy system from an interdisciplinary perspective, detailed descriptions follow in the application fields from the perspective of the acceptance and potential analysis. The technologies in the value chains that are specifically researched and further developed in the second phase of P2X are examined in depth by means of life cycle analysis (LCA) and techno-economic analysis (TEC) with regard to their ecological and economic advantages and disadvantages and compared with a fossil reference route.

FIELD OF APPLICATION TRANSPORT

The transport sector represents one of the greatest challenges for the energy transition and thus for Germany's GHG neutrality. Emissions have been high and almost constant since 1990. From a systemic point of view, technical, modular shift as well as traffic avoiding measures will be necessary to be able to reduce emissions.

From an energy system modeling perspective, the final energy demand in the transport sector will decrease significantly by 2050 (even more so in the sufficiency scenario than in the baseline scenario), but in addition to a directly electrified transport system, hydrogen and PtX fuels will be necessary to achieve a reduction in GHG emissions in line with the climate targets. While for passenger transport the entire passenger car fleet is directly electrified, synthetic fuels are primarily used in shipping and aviation or for freight transport. In total, about 236 TWh of H_2/PtX fuels will be required for all modes of transportation.

According to the results of the acceptance survey, there is a basically positive perception in society for the use of PtX fuels in the transport sector. However, cannot be seen independently of other strategies, such as modal shift. For a more informed opinion and presumably more positive perception, increased communication and education about interrelationships and interdependencies in the production and use of PtX fuels would make a valuable contribution.

This also includes the result that the production generation of synthetic fuels with solely German electricity potentials is not high enough, and to fully cover the demand, additional imports from abroad would be necessary, either in the form of electricity or energy carriers such as hydrogen. This does not change until 2050. Taking into account the results described above for the transport sector with regard to direct electrification, the demand for synthetically produced gasoline and diesel in particular will decrease, so that these can be covered with about 10 % (equivalent to about 17 TWh) of the PtX electricity available in Germany. The PtX electricity refers to the renewable electricity potential after deduction of the original electricity demand, i.e. including the electricity demand for the directly electrified means of transport.

However, the demand for non-electrifiable air traffic in particular of around 7 million t of kerosene will only be able to be provided partially with synthetically produced fuels in Germany (via Fischer-Tropsch production) even in 2050.

From the perspective of the life cycle analysis, the electricity and heat requirements have the largest influence on the environmental impact, so that consequently the share of renewable energies in the electricity input plays an essential role for the net GHG emissions of Fischer-Tropsch (FT) fuels. In the "environmental impact" category, this leads to a break-even point at about 122 g CO_2 eq/kWh compared to the fossil references. In this Roadmap 4.0, besides the use of CO_2 from air (DAC), CO_2 from emissions from an industrial point source (using a cement plant as an example) was also evaluated. The latter can be considered with different allocation methods. While in a present-day scenario, net GHG emissions from FT fuels using CO_2 from industrial point sources are still lower than production using CO_2 from DAC, this difference decreases by 2050, at which time emissions from both CO_2 sources are nearly identical. The advantage of the point source here is based on considering CO2 as "waste for disposal," so the results are only valid for the selected allocation method.

The CO_2 source also affects the techno-economic analyses, so that in this case, as well, the costs with CO_2 from point sources are significantly more favorable in a present-day scenario. However, under the assumptions made, these differences from DAC (from 65 % in 2020) can decrease to about 7 % by 2050. The biggest driver for the cost of FT fuels is the investment cost, which decreases over time through further development, coupling and scaling to the point where electricity costs become the decisive factor.

FIELD OF APPLICATION BASIC CHEMICALS

In the sector of basic chemicals, energy sources are primarily required due to their material use, which continues to be largely based on fossil, in particular mineral oil-based, raw materials that are largely covered by imports. The chemical industry is one of the most energy-intensive sectors in Germany and therefore requires special consideration of the technological options for achieving climate neutrality. In the context of the roadmapping process, the technological contributions to the industry are divided into the chemical and other energy-intensive industries.

Due to the complex diversity of products and feedstocks, in the context of the roadmap this part of the overall analysis of the energy system is limited to a selection of energy-, feedstock-, and GHG-intensive commodities. Some of these High Value Chemicals (HVC) can be derived from naphtha, which in turn can be produced synthetically via the Fischer-Tropsch route. Final energy demand in the chemical industry changes little in the different scenarios and over time to 2050, with a shift in feedstocks toward hydrogen (121 TWh) and the PtX products methane (48 TWh) and naphtha (75 TWh). These are primarily relevant as carbon carriers and are accordingly necessary to achieve defossilization of the chemical sector. Another approx. 100 TWh are covered by other energy sources or raw materials.

From the point of view of acceptance, the complexity of the different production processes also contributes to the uncertainty of the assessments. Consumers see the risk primarily in concerns about the rising costs of these "premium products". However, a significant proportion of interviewees also see this uncertainty as an opportunity. It is expected that a scientific and communication-based dissemination of the PtX technology and its advantages will help to eliminate these uncertainties.

From the point of view of the potential analysis, many of the already existing plants can and should be used for the processing of the synthetic feedstocks. A simple potential analysis from the point of view of the electricity resources led to the conclusion that from 2040 onwards the demand for FT-naphtha can be covered, yet high shares of the PtX electricity would be necessary for this purpose (367 TWh). It would therefore make sense to utilize and/or link dedicated PtX plant with their own RE supply.

The electricity grid mix has a significant influence in terms of environmental and economic assessment on the P2X value chains. For the production of butanol, the P2X route is only favored over the fossil reference below a GHG intensity of 200 g CO_2 eq/kWh of the electricity mix, and in 2030, production can even be GHG-neutral if, for example, nearby cement plants are used as a carbon source. However, linked to the electricity supply here (and also for all other value chains considered) is the increased burden in the environmental impact category of ozone depletion, and in particular metal and land consumption.

If lower electricity costs could be applied, the P2X route for butanol production would also be economically viable, so that the question arises for adequate locations in order to limit the hydrogen and CO_2 costs in this course as well.

PME polyols are among other things suitable as a precursors for polyurethanes and would thus be used for the production of plastics. The electricity mix had very limited influence on the LCA of the reference route via fossil-based propylene oxide. For the energy systems modeling Scenario "today", the fossil-based para-formaldehyde (pFA) route is already advantageous compared to the reference in terms of GHG emissions. From 2030 onwards, the other PME manufacturing route studied, in which the feedstock para-formaldehyde (pFA) is synthesized via PtX, would then also be advantageous due to the decreasing GHG intensity of the electricity mix from "today" to 2050. The choice of the pFA production route highly influences the costs, although concrete cost predictions for the PtX route are very difficult to make due to the price fluctuations for CO_2 and H_2.

FIELD OF APPLICATION INDUSTRY

Considering the industrial sector as a whole, this sector accounts for about a quarter of Germany's total final energy demand. The basic material industries, such as metal production, chemicals and the mineral oil processing industry, which not only have energy-related, but also process-related GHG emissions, dominate here. It is therefore important to ensure that sustainable, alternative energy sources are not only used for heat generation, but can also substitute for the use as reducing agents in the steel industry, for example.

In the energy model, the non-energy consumption of raw materials was therefore included in the balance sheet in addition to the final energy demand. Most of today's energy sources are used to provide process heat and, in some cases, simultaneously to achieve the required chemical process conditions. The challenge is therefore to switch as far as possible to GHG-free or process-related low-GHG processes . The share of fossil sources such as coal, mineral oil and natural gas to cover the total demand of the industry is currently about 605 TWh (60 %), including both energy and material use. The total final energy demand by 2050 decreases to approximately this value, due to improved energy and raw material efficiency, conversion to alternative processes with lower energy demand and GHG emissions, and the use of secondary materials, among other factors. At this point, about 40 % of the supply will come from PtX products (hydrogen, naphtha, methane), making them a unavoidable option for defossilization of the industrial sector. The remaining demand will be met via direct use of electricity and biogas and biomass, among others.

If the supply for PtX downstream products is taken into account, the cumulative demand for hydrogen in the industrial sector increases to about 650 TWh by 2050. From the perspective of the potential analysis, this demand will not be covered exclusively by the German PtX electricity potentials, i.e. the RE electricity potentials that remain after deduction of the original electricity demand. It will therefore still be necessary to import electricity or hydrogen for the numerous industrial applications.

Already at this point in time, the versatile and complex application possibilities of PtX products in the industrial sector experience a somewhat higher approval in society, in contrast to the acceptance surveys on PtX technologies in the chemical sector Here, the high acceptance for "green" steel and glass production should be emphasized in particular.

As described above, the chemical sector is excluded in the description of the industries, as it was already described in the previous chapter. In the roadmap, only the use of hydrogen is considered from an ecological and economic perspective, with its production via PEM electrolysis and use in specialty glass production being the two key areas of application considered. The production of hydrogen with electricity from the German electricity system has an ecological break-even point before the year 2030 compared to the production by means of steam reforming of methane, specifically when the GHG emissions of the electricity mix are below 200 g CO_2 eq/kWh. Beyond the environmental impact "climate change", however, the technology change results in a trade-off in other impact categories. Among others, the category "land use" worsens, which in turn is attributed to the electricity mix (specifically the PV expansion). Something that remains unconsidered in the impact categories, but is nevertheless important and therefore worth noting, is the effort to reduce the iridium content in the ongoing development of the PEM electrolyzer, which is motivated by the criticality and availability of the material. The comparison of hydrogen production by PEM electrolysis with the fossil reference in terms of economics only leads to cost parity as a result of the increasing prices of CO_2 emission certificates. However, TEA is a method for assessing microeconomic costs so that macroeconomic effects are not yet taken into account in an overall assessment.

The use of hydrogen in specialty glass production can also lead to an ecological and economic added value much earlier, provided that the oxygen which is also produced in PEM electrolysis is used, e.g. in oxy-fuel combustion.

TRANSPORT ALTERNATIVES FOR HYDROGEN

Due to the fact that hydrogen cannot always be produced where it is needed, the roadmap considers transport alternative for hydrogen. Due to its physical properties, the transport of pure hydrogen is only possible in liquid or gaseous form and is complicated. In a chemically bound form, e. g. via a conversion to another molecule or by means of liquid organic hydrogen carriers (LOHC), the expected high volume demands and the associated transport requirements can then be met. In the context of this roadmap, an evaluation of the further use of already existing infrastructure alternatives or distribution structures for hydrogen is not carried out.

Within the project, the supply of a hydrogen filling station by means of LOHC is considered as a specific example and compared with a transport of gaseous, compressed hydrogen (CGH_2) by means of pressure tank trucks (500 bar). Overall, transporting compressed hydrogen remains more beneficial than providing it using LOHC in all environmental impact categories, although this result also depends on the pressure of the compressed hydrogen. At low transport pressures (250 bar), the choice of waste heat utilization for dehydrogenation may result in an advantage for LOHC technology in some environmental categories.

From an economic perspective, transport via compressed hydrogen is also profitable, although this is reversed in the 2050 scenario. However, the slight advantage of LOHC technology over CGH_2 transport is within the range of accuracy of estimation. Finally, it should be noted that in all scenarios studied, direct supply to an H_2 refueling station via PEM electrolysers is the most economical.

SUMMARY AND OUTLOOK

The further development of promising technologies leads to an increasing focus and specification during the course of the project. Accompanied by the evaluation of these technologies, at the end of the second project phase and with the publication of this Roadmap 4.0, the project is facing the next major step of taking these developments to the demonstration stage. With the P2X technologies for Fischer-Tropsch fuels, the direct use and fermentation of CO to butanol, the PME polymers, the hydrogen production by means of PEM electrolysis as well as the transport with LOHC, which have been further developed in the project and presented in this roadmap, a continuation as a demo project is recommended for all value chains.

Due to different milestones such as the National Hydrogen Strategy, the resulting establishment of the hydrogen flagship projects, 'Reallabore' and also the IPCEI projects, there is a focus on a large number of projects and connection opportunities around hydrogen and power-to-X. In order to enable cross-linking with other initiatives, two projects (PEM electrolyser and LOHC transport) will be decoupled and continued using other BMBF funding instruments.

Within the framework of the Kopernikus project P2X, the three projects for the production of synthetic kerosene, CO_2 electrolysis for CO direct use and the production of PME polymers are expected to enter the third project phase in order to ultimately reach the next higher stage before industrial realization. The planned projects will continue to e accompanied by a continuation of roadmapping and flanked by a newly established sub-project for educational work, the latter including both acceptance education and professional training.

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Editors
Dr. Florian Ausfelder
Dr. Dinh Du Tran

DECHEMA Gesellschaft für Chemische
Technik und Biotechnologie e.V.
Theodor-Heuss-Allee 25
60486 Frankfurt am Main
Germany

Responsible according to the German Press Law and the Media
Dr. Florian Ausfelder
DECHEMA Gesellschaft für Chemische
Technik und Biotechnologie e.V.
Theodor-Heuss-Allee 25
60486 Frankfurt am Main
Germany

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