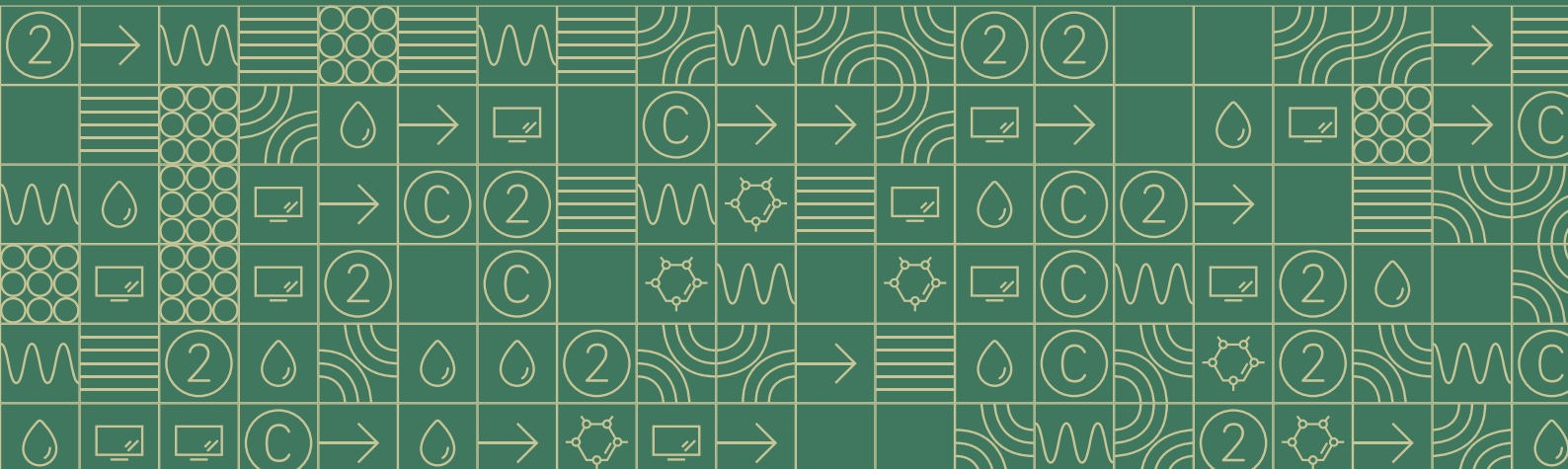
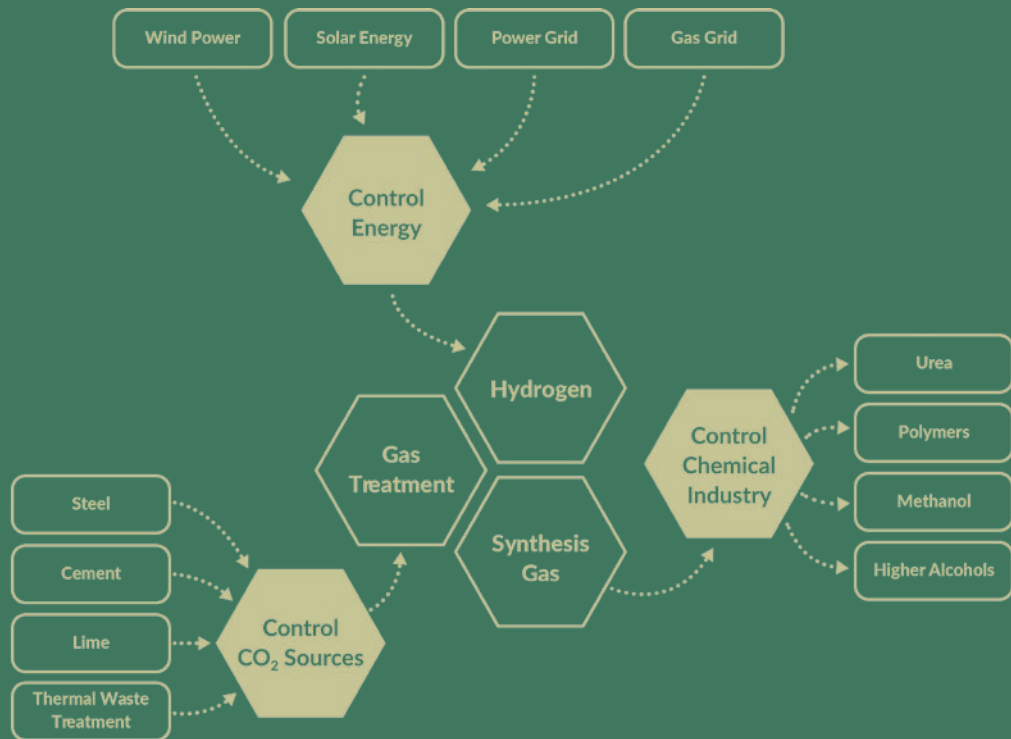


Carbon2Chem®

A Key Building Block for the Climate Protection





Overall objective

To provide technical solutions for implementing the transformation process in the industry as part of the energy transition that is aimed at achieving the climate goals.



Results
in our project



Details
on our website



Image film
Carbon2Chem®

With funding from the:



Federal Ministry
of Research, Technology
and Space

The Joint Project Carbon2Chem®

The Paris Climate Agreement aims to limit global warming to 1.5 degrees Celsius compared to pre-industrial levels. Reducing greenhouse gas emissions is a key element of this. For the European Union, this means reducing carbon dioxide emissions by 55 percent by 2030 and achieving climate neutrality by 2050.

However, the basic materials industry faces challenges on the road to climate neutrality. Not only is carbon dioxide produced in the provision of the necessary energy, but it is also produced during production processes. Therefore, decarbonization of processes will not be successful in all areas during the energy transition. Industrial processes will continue to emit carbon dioxide in the future, for example in the production of steel, cement or lime, and in thermal waste treatment.

Additionally, non-fossil carbon is essential to produce chemical products. The key question is how to capture unavoidable CO₂ from industrial point sources and utilize it in the chemical industry, and this is at the heart of Carbon2Chem®. The answer lies in carbon dioxide capture and utilization (CCU).

A key element of success is the defossilization of processes, which involves transforming industrial production processes during the energy transition. The Carbon2Chem® project consortium is developing cross-industrial production networks with a modular structure that enables the capture and utilization of process-related carbon dioxide in linked structures at existing industrial sites. This captured carbon dioxide can then be used as a raw material in the production of synthetic fuels, plastics, or other basic chemicals.

As well as technical development, the project focuses on combining climate protection and competitiveness, and on promoting dialogue with experts and society. By 2030, it is expected that the project's outcomes will significantly contribute to reducing greenhouse gas emissions and the use of fossil fuels in industry.

In the first phases of the project, the consortium demonstrated the feasibility of the technical solutions and their positive impact.

The consortium is convinced:

Carbon2Chem® is a key building block for climate protection.

Overall Coordination

A key element of the initiative is the close collaboration between basic research, applied research, and industry, which guarantees comprehensive coordination. This has been a constant factor throughout the project, from the initial idea to its implementation across the three phases. Alongside the project office, it ensures communication within the consortium and with the outside world.

The three areas are represented as follows:

Applied research

Prof. Dr. Göрге Deerberg
Project coordinator

Industry

Dr. Markus Oles
Project coordinator

Basic research

Prof. Dr. Robert Schlögl
Project coordinator



Consortium

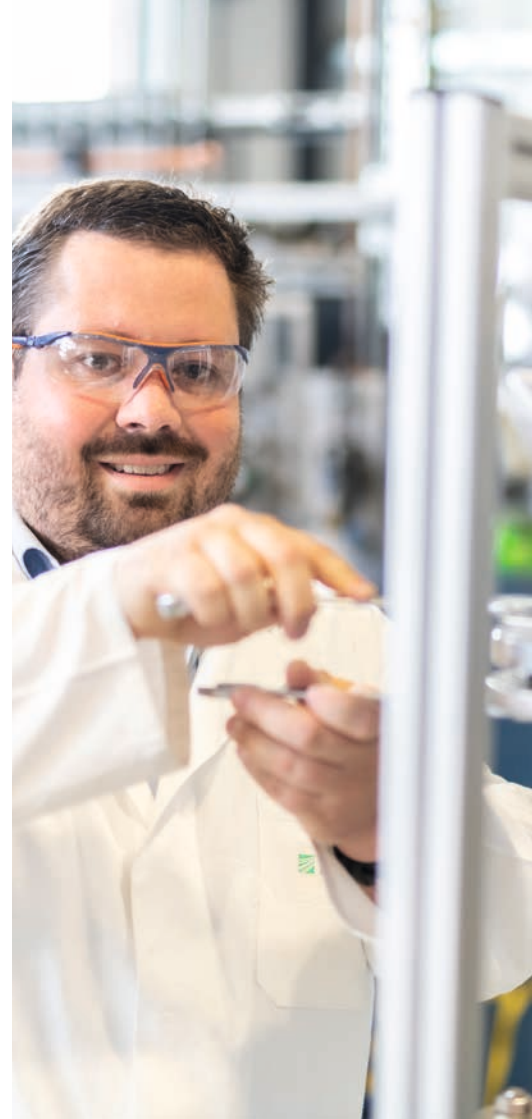
The Carbon2Chem® consortium is characterized by a diverse membership, comprising research partners who contribute their specialized knowledge. A significant aspect of this initiative is the direct collaboration between fundamental research, applied research, and industry at this scale. As the project progressed, the partners' methods, tools, and expertise were progressively integrated.

A key focus of research is the treatment of process gases and the systemic interaction of the solutions found. The necessity for research and development is particularly pronounced in the context of the hundreds of different trace substances that can be detected in industrial process gases. The presence of dynamic effects along the process chain on different time scales poses a significant challenge in the effort to couple the technical components.

The elimination of fossil fuels from industrial processes necessitates the development of novel methodologies that facilitate the utilization of carbon dioxide. A novel synthesis of processes is essential, particularly for the establishment of a circular carbon dioxide economy.

For this endeavor, the partners are combining their knowledge from a variety of specialized fields. The development of communities has occurred along the boundaries of the individual subprojects. Consequently, the results emanating from the domains of process design, analytics, simulation, and system evaluation are consolidated by the respective experts.

Following the initial focus on fundamental research in 2016, Phase III, which commenced in January 2025, has shifted its emphasis toward the implementation of these concepts in industrial settings.



Carbon2Chem[®] Laboratory

A central component of the project is the Carbon2Chem[®] laboratory. Situated on the Fraunhofer UMSICHT campus in Oberhausen, the facility encompasses an area of around 500 square meters and has approximately 30 office workstations. It is predominantly used for fundamental research in catalytic production, gas purification and analytical process development. The space is available to the consortium for joint laboratory-scale research and development.

The researchers are focusing on the behavior of various catalysts and the dynamics of the operating processes. The results of this study lay the foundation for research conducted at the Carbon2Chem[®] technical center. This process involves scaling up components and processes, determining operating points and control strategies, and identifying operating modes.

The first phase of the project involved developing analytics to record important key components and trace substances. Additionally, a gas generator system was configured to emulate gas mixtures (e.g., metallurgical gases) to coordinate the analytics. The instrument's analytical capabilities allow for the identification of potential contaminants (e.g., catalyst poisons), even in complex structures within the parts-per-billion (ppb) to parts-per-trillion (ppt) range. Additionally, the instrument can analyze and quantify critical components.

The effects of trace gases on catalysts are being investigated. This includes assessing their impact on product quality. It provides insight into gas purification design, which impacts the economic efficiency of process concepts.



Information about the
Carbon2Chem[®] laboratory

Carbon2Chem® Technical Center

The 3,700 m² Carbon2Chem® technical center is located adjacent to the thyssenkrupp site in Duisburg, with access to metallurgical gases for the real-world testing of concepts. Since going into operation in fall 2018, the technical center has demonstrated a cross-industrial network with the complete process chain, showcasing sector coupling between steel and chemicals.

The present research endeavors are concentrated on two principal aspects: the purification and conditioning of authentic metallurgical gases, and the electrolytic water splitting process, with the objective of generating supplementary hydrogen for chemical synthesis. The synthesis gases are converted into methanol, ammonia, and higher alcohols in the pilot plant setting.

The investigations in the technical center aim to verify the catalyst performance and stability of synthesis gases

derived from authentic metallurgical gases. The configuration enables the validation of gas purification for synthesis gas production by contrasting experiments with real and artificial synthesis gases.

Like the Carbon2Chem® laboratory, the technical center provides partners with the opportunity to collaborate in one location with consistent standards.

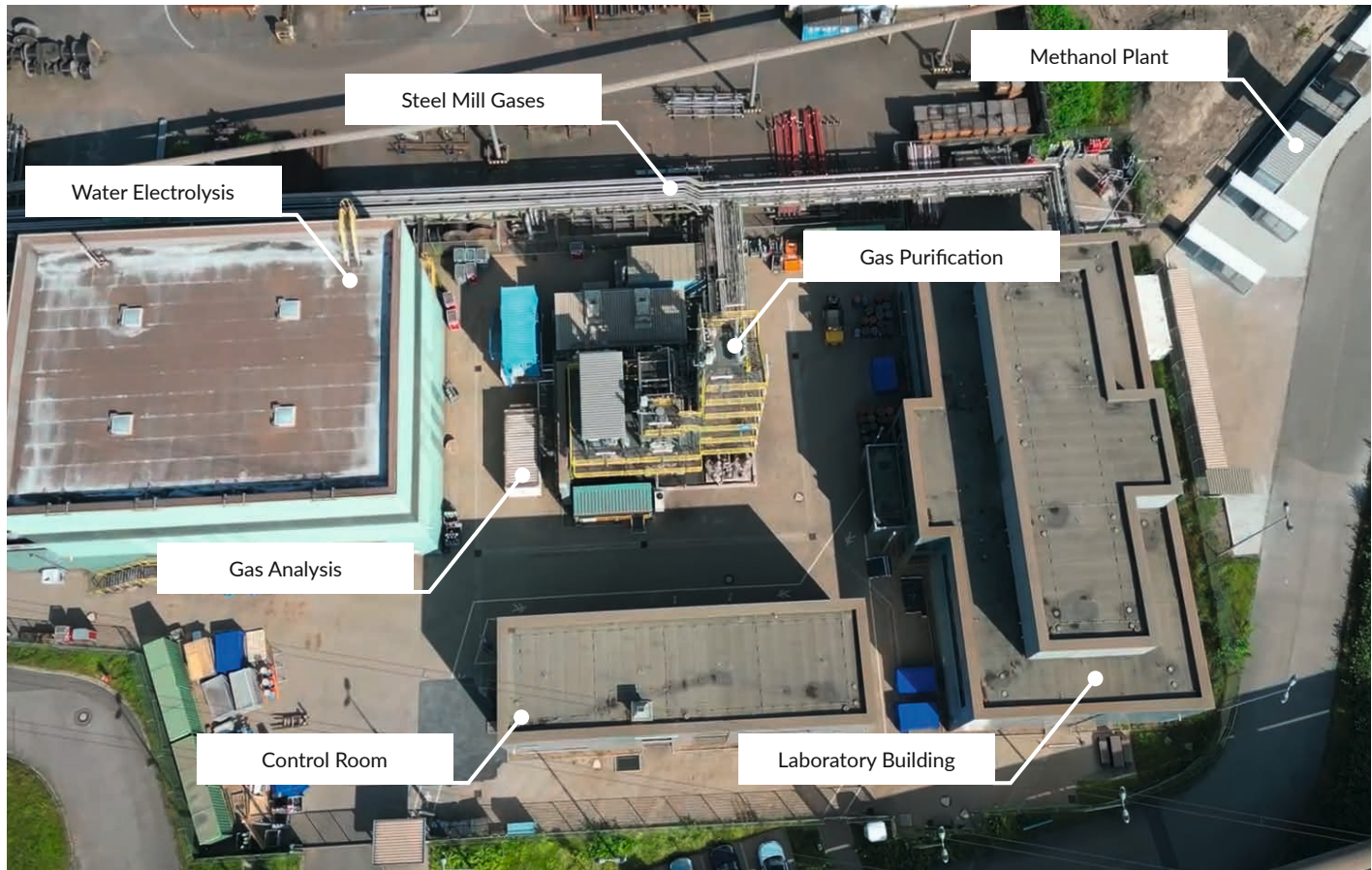
This collaboration of different disciplines lays the groundwork for large-scale industrial solutions. Planned expansions will enable the future demonstration of methanol downstream processes.

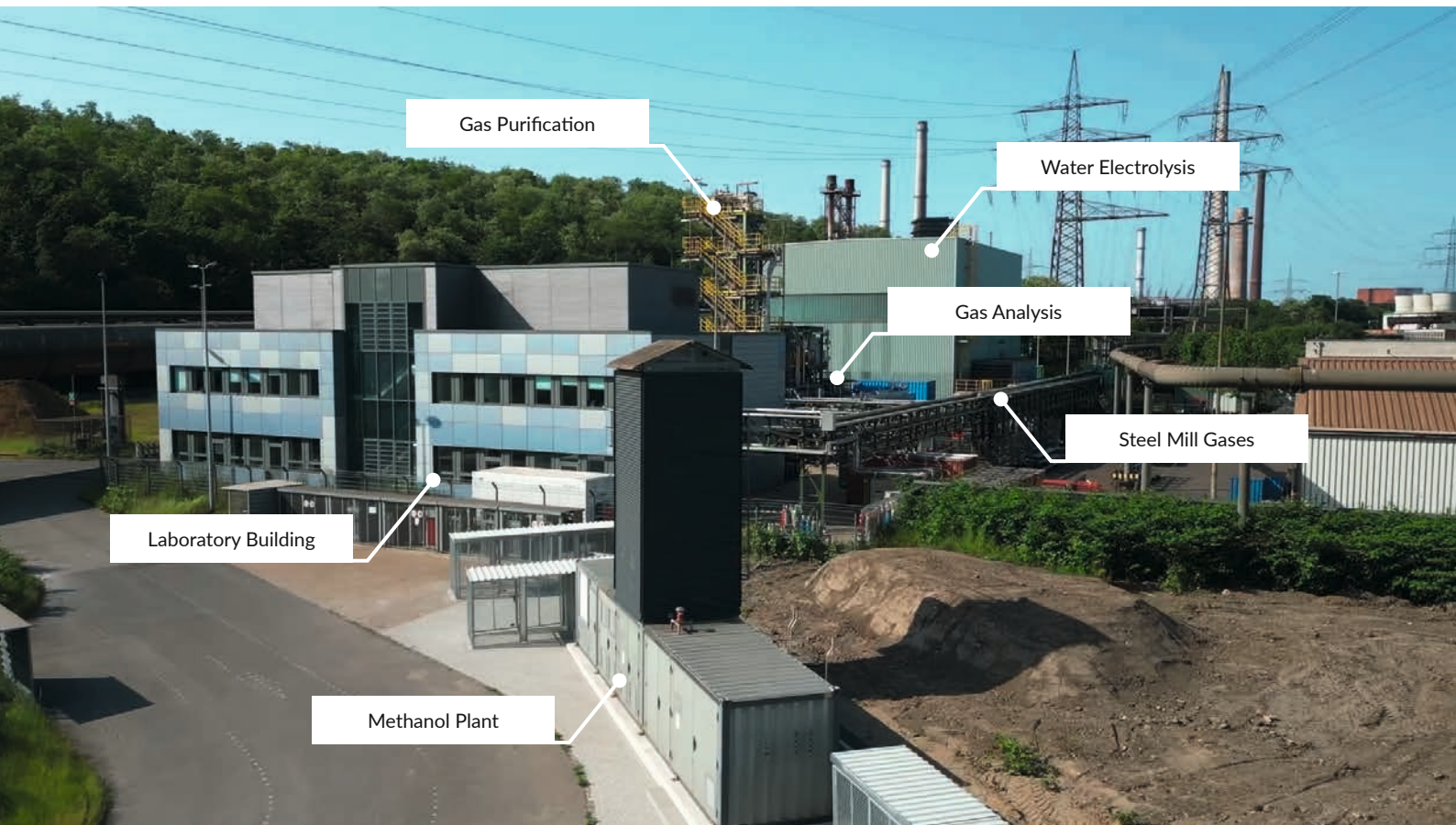


Video "Virtual tour of the Carbon2Chem® technical center"



View of the Carbon2Chem® Technical Center in Duisburg





Gas Purification

Water Electrolysis

Gas Analysis

Steel Mill Gases

Laboratory Building

Methanol Plant

Water Electrolysis

Integrating renewable energies, specifically green hydrogen, into chemical synthesis is vital for CCU applications, employing water electrolysis technology to generate hydrogen from water. A two-megawatt electrolysis plant was constructed within the technical center.

For CCU projects to have a positive carbon footprint, it's crucial that the electricity for electrolysis comes from renewables rather than fossil fuels (volatility issues).

A key objective is to examine the plant's response under fluctuating energy supplies.

The findings provide significant insights into strategic hydrogen supply planning, preparing for large-scale future implementation.



Video on
water electrolysis



Gas Purification

Gas purification is vital to CCU applications and is a key part of the process chain at the technical center. The system can process approximately 240 cubic meters of metallurgical gas per hour. It is essential that the gas is purified to meet the stringent purity requirements for synthesis gas. Operations management is based on impurity analyses and the lab results of potential catalyst poisons.

The lab is testing ways to remove trace substances, including thermocatalysis, non-thermal plasma and electric swing adsorption (ESA). These were successfully validated in phase I. The tech center provides a specialized environment for scaling up processes and testing with real gases, as used in phase II.

The analytical methods developed in the laboratory are used in the Carbon2Chem® technical center to control and monitor gas purification

regarding trace substances. The established infrastructure is characterized by the continuous online measurement of purified gases and the identification of main compounds (percent range), minor compounds (ppm range) and trace compounds (ppb to ppt range). Consequently, this facilitates the implementation of long-term campaigns and the optimization of process parameters (e.g. pressure and temperature).



[Article on
gas purification results](#)



[Video gas purification
at the Carbon2Chem®
technical center](#)



Methanol Plant

A milestone was achieved at the Carbon2Chem® technical center in September 2018 when the first methanol was produced from real blast furnace gases. The demonstration plant for methanol synthesis was commissioned at the Carbon2Chem® laboratory in Oberhausen in July 2019. This represented a significant advancement in the development of methanol synthesis. Since the beginning of 2022, the plant at the Carbon2Chem® technical center in Duisburg has been producing up to 75 liters of raw methanol (a mixture of methanol and water) per day from real gases from the steelworks.

Despite its comparatively low production capacity, the plant exhibits all the essential design features of a large-scale plant. The reactor tube possesses a diameter of 42 millimeters and a length of six meters. After the separation of the liquid products, unreacted synthesis gas is returned to the reactor.

The analytics installed along the reactor axis provide precise insight into the process and allow for detailed evaluation of catalyst activity across the entire reactor height.

In conjunction with process simulation, the plant facilitates the production of methanol from synthesis gas, irrespective of the carbon dioxide to carbon monoxide ratio. Consequently, the simulation of known fluctuations in the composition of real process gases becomes a viable proposition. The plant symbolizes the progressive scaling from the laboratory to the application stage.



Results for
the methanol plant



Overview film about
the demonstration plant



Downstream

Overall view

The subsequent application of the products is essential for developing the necessary processes and technologies. The market for CCU process products is growing, and the consortium is collaborating with potential users of these technologies.

The project's central product routes are methanol, urea, higher alcohols, and polymers. These products serve as the basis for the chemical industry and as raw materials for producing synthetic fuels.

Scaling

As planned, the project is gradually approaching industrial scale. The consortium took an important step in scaling up methanol production with the demonstration plant. Production increased from a few milliliters in the laboratory to several liters per day.

While the initial focus was on designing the process itself, the focus has shifted to optimizing and controlling the processes. The dynamics at the CO₂ point source must also be considered. The composition and quantity of gases from production vary depending on the source and production cycle.

The provision of renewable energies is the central element in considering these issues. The supply of green hydrogen is a crucial component of the system analysis at each subsequent scaling step. The importation and storage of hydrogen in sufficient quantities plays an integral role in the project's planning.

Transport Application

One such application involves using the methanol produced directly for transport. Obrist GmbH is currently developing a series hybrid drive that can produce renewable energy in the form of methanol when utilized in con-

junction with an electric drive. As part of the Carbon2Chem® project, the team is involved in conceptualizing methanol, formulating specifications for it, and testing the first vehicles in practice.

Circular Economy

Efficient use of raw materials and energy is essential for achieving a positive overall balance when implementing planned cross-industrial networks. Circular thinking is an integral part of industrial transformation during the energy transition. The project will support the implementation of a circular economy with the next development steps.



Overview film about the MtX plant



Video "From CO₂ to Application"

Project Partners

Partners from industry and science are working together to lay the foundation for a circular carbon economy.



PUBLISHING NOTES

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www.umsicht.fraunhofer.de/carbon-cycle

#Carbon2Chem

Image Sources

C1, C2, C4: Fraunhofer UMSICHT/MANX

Page 2: Fraunhofer UMSICHT/Paul Hahn

Page 3, 4, 8, 9: Fraunhofer UMSICHT/Mike Henning

Page 5, 6, 7: thyssenkrupp Steel Europe

Page 10: Fraunhofer UMSICHT

