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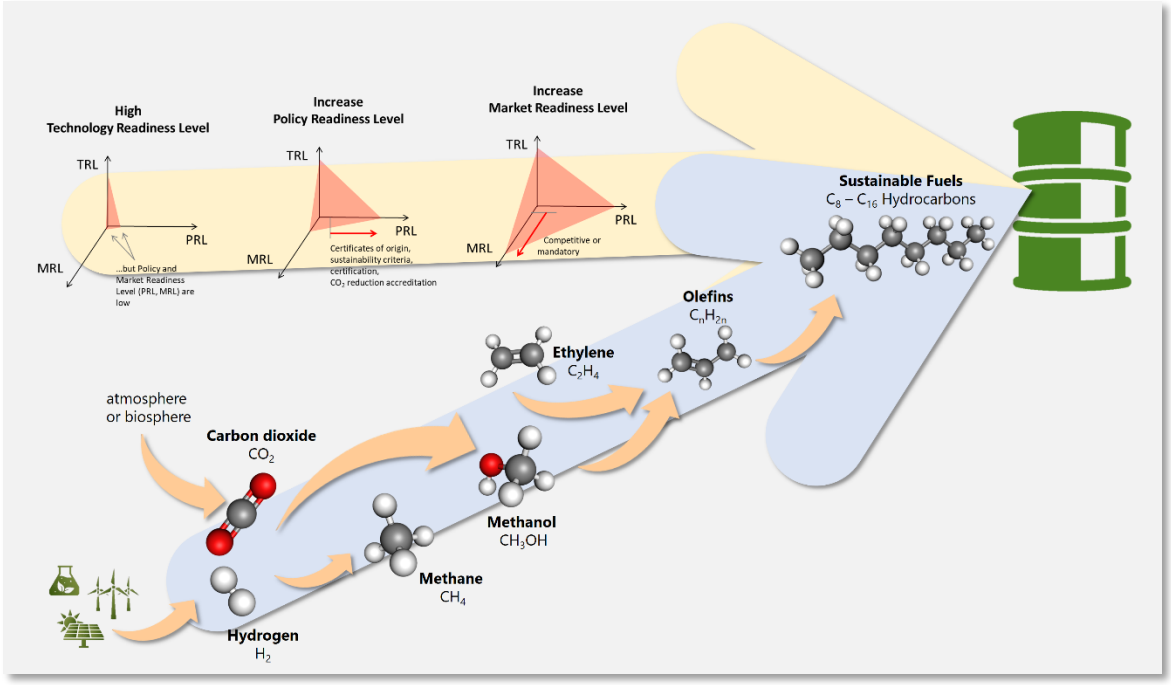
reFuel.ch



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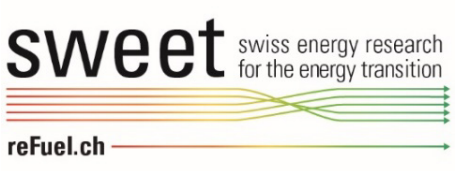
sweet swiss energy research for the energy transition



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The authors bear the entire responsibility for the content of this report and for the conclusions drawn therefrom.

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Executive summary

The reFuel.ch consortium was launched on January 1, 2024. The consortium, consisting of 15 research groups from the ETH Domain (ETH Zurich, EPF Lausanne, PSI and Empa), the universities of Basel and Italian-speaking Switzerland, universities of applied sciences (ZHAW, FHNW and SUPSI) and Casale's research and development department as an industrial partner, aims at developing the basics of robust supply paths for 30 - 60 TWh of sustainable fuels and platform chemicals. The majority of these fuels and platform chemicals will have to be imported, which is why reFuel.ch includes a strong focus on international dimensions.

The work program consists of three work packages (WP1-3), dealing with implementation-oriented challenges and, four work packages (WP4-7), dealing with the development of improved or new technologies. The set of the seven WPs is complemented by a knowledge and technology transfer WP to communicate the results obtained to market players and political decision-makers. This exchange takes place within the framework of so-called "Round Tables". Around 80 companies, NGOs, associations, authorities or research institutions from Switzerland and abroad, which have registered as cooperation partners for reFuel.ch by means of a letter of interest, are invited to exchange information and discuss ideas in this format.

The implementation-oriented work packages (WP1: Social, economic and political assessment at national level; WP2: Social, economic and political assessment at international level; WP3: Energy system and life cycle assessment for robust supply paths) examine legal, environmental, climate and energy system issues. These include, for example, the analysis of national and international legal and regulatory frameworks, ranging from the Paris Climate Agreement, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) for International Civil Aviation Organization (ICAO), the Nagoya Convention on the Global Conservation of Biological Diversity and the Fair and Equitable Sharing of Benefits arising from its Utilization – to – Swiss and European Union directives on sustainability requirements for sustainable fuels (e.g. ReFuelEU Aviation, Renewable Energy Directive III and FuelEU Maritime).

The technology-oriented work packages (WP4: Co-electrolysis for chemical energy carriers; WP5: Efficient and load-flexible methanol synthesis; WP6: Conversion of farmyard manure into sustainable kerosene; WP7: Conversion of methanol into sustainable chemical energy carriers and chemicals) aim to identify and scientifically develop the potential for increasing the efficiency, selectivity and load flexibility of processes for the production of sustainable chemical energy carriers. In these work packages, an exchange with industrial partners and consortia involved in the realization of plants for the production of such energy sources and platform chemicals is planned.

The consortium-internal exchange is organized via three thematic platforms (Platform 1: Overall assessment of sustainability; Platform 2: Assessment of technological innovation and Platform 3: Design of scenarios and transition pathways). These platforms aim to establish a common understanding of sustainability and technology issues and the development of supply pathways.

Finally, the project includes Cases in Switzerland, in Europe and outside Europe in order to investigate the opportunities and challenges in the formation of consortia for the realization of plants for the production of sustainable fuels and platform chemicals.

Zusammenfassung

Das Konsortium reFuel.ch wurde am 1. Januar 2024 gestartet. Das Konsortium, bestehend aus 15 Forschungsgruppen des ETH-Bereichs (ETH Zürich, EPF Lausanne, PSI und Empa), der Universitäten Basel und der italienischen Schweiz, den Fachhochschulen (ZHAW, FHNW und SUPSI) sowie der Forschungs- und Entwicklungsabteilung von Casale als Industriepartner. Es hat zum Ziel, die Grundlagen für robuste Versorgungspfade für 30 - 60 TWh an nachhaltigen Treibstoffe und Basischemikalien zu entwickeln. Der Grossteil dieser Treibstoffe und Basischemikalien wird importiert werden müssen, weshalb reFuel.ch einen starken Fokus auf die internationale Dimension legt.

Das Arbeitsprogramm besteht aus drei Arbeitspaketen (WP1-3), die sich mit umsetzungsbezogenen Fragestellungen beschäftigen, und vier Arbeitspaketen (WP4-7), die sich mit der Entwicklung verbesserter oder neuer Technologien befassen. Ergänzt wird dies durch ein Arbeitspaket zum Wissens- und Technologietransfer, um die erzielten Ergebnisse an Marktteilnehmer und politische Entscheidungsträger zu vermitteln. Dies geschieht im Rahmen von "Runden Tischen". Rund 80 Unternehmen, NGOs, Verbände, Behörden oder Forschungsinstitutionen aus der Schweiz und dem Ausland, die sich mittels einer Interessensbekundung als Kooperationspartner für reFuel.ch angeschlossen haben, sind eingeladen, sich an diesen Runden Tischen auszutauschen und Ideen zu diskutieren.

In den umsetzungsorientierten Arbeitspaketen (WP1: Soziale, wirtschaftliche und politische Bewertung auf nationaler Ebene; WP2: Soziale, wirtschaftliche und politische Bewertung auf internationaler Ebene; WP3: Energiesystem- und Ökobilanzierung für robuste Versorgungspfade) werden rechtliche, ökologische, klima- und energiesystemtechnische Fragen untersucht. Dazu gehört beispielsweise die Analyse nationaler und internationaler rechtlicher und regulatorischer Rahmenbedingungen, die vom Pariser Klimaabkommen, dem Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) der Internationalen Zivilluftfahrt-Organisation (ICAO), dem Nagoya-Übereinkommen über die weltweite Erhaltung der biologischen Vielfalt und die gerechte Aufteilung der sich aus ihrer Nutzung ergebenden Vorteile bis hin zu den Richtlinien der Schweiz und der Europäischen Union zu Nachhaltigkeitsanforderungen für nachhaltige Treibstoffe (z.B. ReFuelEU Aviation, Renewable Energy Directive III und FuelEU Maritime) reichen.

Die technologieorientierten Arbeitspakete (WP4: Co-Elektrolyse für chemische Energieträger; WP5: Effiziente und lastflexible Methanolsynthese; WP6: Umwandlung von Hofdünger in nachhaltiges Kerosin; WP7: Umwandlung von Methanol in nachhaltige chemische Energieträger und Chemikalien) zielen darauf ab, die Potenziale zur Steigerung der Effizienz, Selektivität und Lastflexibilität von Prozessen zur Herstellung nachhaltiger Treibstoffe zu identifizieren und wissenschaftlich zu erarbeiten. Dabei ist ein Austausch mit Industriepartnern und Konsortien geplant, die an der Realisierung von Anlagen zur Herstellung solcher Energieträger und Basischemikalien beteiligt sind.

Der konsortiumsinterne Austausch wird über drei thematische Plattformen organisiert (Plattform 1: Gesamtbewertung der Nachhaltigkeit; Plattform 2: Bewertung der technologischen Innovation und Plattform 3: Entwurf von Szenarien und Übergangspfaden). Diese Plattformen zielen darauf ab, ein gemeinsames Verständnis für Nachhaltigkeits- und Technologiefragen und die Entwicklung von Versorgungspfaden zu schaffen.

Schliesslich umfasst das Projekt Fallstudien in der Schweiz, in Europa und ausserhalb Europas, um die Chancen und Herausforderungen bei der Bildung von Konsortien für die Realisierung von Anlagen zur Produktion von nachhaltigen Treibstoffen und Plattformchemikalien zu untersuchen.

Résumé

Le consortium reFuel.ch a été lancé le 1er janvier 2024. Le consortium, composé de 15 groupes de recherche du Domaine des EPF (ETH Zurich, EPF Lausanne, PSI et Empa), des universités de Bâle et de Suisse italienne, des hautes écoles spécialisées (ZHAW, FHNW et SUPSI) et du département de recherche et développement de Casale en tant que partenaire industriel, a pour objectif de développer les bases de voies d'approvisionnement robustes pour 30 à 60 TWh de carburants durables et de produits chimiques de plateforme. La majorité de ces carburants et produits chimiques de plateforme devront être importés, c'est pourquoi reFuel.ch met fortement l'accent sur les dimensions internationales.

Le programme de travail se compose de trois groupes de travail (WP1-3), qui traitent de la mise en œuvre, et de quatre groupes de travail (WP4-7), qui traitent du développement de technologies nouvelles ou améliorées. Ces groupes sont complétés par un groupe de travail sur le savoir-faire et le transfert de technologie, qui vise à communiquer les résultats obtenus aux acteurs du marché et aux décideurs politiques. Ces activités se déroulent dans le cadre de "tables rondes". Environ 80 entreprises, ONG, associations, autorités ou institutions de recherche de Suisse et de l'étranger, qui se sont inscrites comme partenaires de coopération pour reFuel.ch par le biais d'une lettre d'intérêt, sont invitées à échanger des informations et à discuter d'idées dans ce format.

Les work packages axés sur la mise en œuvre (WP1: évaluation sociale, économique et politique au niveau national; WP2: évaluation sociale, économique et politique au niveau international; WP3: évaluation du système énergétique et du cycle de vie pour des voies d'approvisionnement robustes) examinent des questions juridiques, environnementales, climatiques et relatives au système énergétique. Il s'agit, par exemple, de l'analyse des cadres juridiques et réglementaires nationaux et internationaux, allant de l'Accord de Paris sur le climat, du système de compensation et de réduction des émissions de carbone pour l'aviation internationale (CORSIA) de l'Organisation de l'aviation civile internationale (OACI), de la Convention de Nagoya sur la conservation mondiale de la diversité biologique et le partage juste et équitable des avantages découlant de son utilisation, aux directives de la Suisse et de l'Union européenne sur les exigences de durabilité pour les carburants durables (par exemple, ReFuelEU Aviation, Directive sur les énergies renouvelables III et FuelEU Maritime).

Les groupes de travail axés sur la technologie (WP4 : Co-electrolyse pour les vecteurs énergétiques chimiques; WP5: Synthèse efficace et flexible du méthanol; WP6: Conversion du fumier de ferme en kérosène durable; WP7: Conversion du méthanol en vecteurs énergétiques chimiques durables et en produits chimiques) visent à identifier et à développer scientifiquement le potentiel d'augmentation de l'efficacité, de la sélectivité et de la flexibilité de la charge des processus de production de vecteurs énergétiques chimiques durables. Dans le cadre de ces work packages, un échange avec des partenaires industriels et des consortiums impliqués dans la réalisation d'installations pour la production de ces sources d'énergie et de produits chimiques de base est prévu.

L'échange interne au consortium est organisé via trois plateformes thématiques (Plateforme 1: Évaluation globale de la durabilité; Plateforme 2: Évaluation de l'innovation technologique et Plateforme 3: Conception de scénarios et de voies de transition). Ces plateformes visent à établir une compréhension commune des questions de durabilité et de technologie et à développer des voies d'approvisionnement.

Enfin, le projet comprend des études de cas en Suisse, en Europe et en dehors de l'Europe afin d'étudier les opportunités et les défis liés à la formation de consortiums pour la réalisation d'usines de production de carburants durables et de produits chimiques de plateforme.

Riassunto

Il consortium SWEET reFuel.ch è stato lanciato il 1° gennaio 2024. Il consorzio, composto da 15 gruppi di ricerca del settore dei PF (ETH di Zurigo, EPF di Losanna, PSI e Empa), delle università di Basilea e della Svizzera italiana, delle scuole universitarie professionali (ZHAW, FHNW e SUPSI) e del dipartimento di ricerca e sviluppo di Casale in qualità di partner industriale, mira a sviluppare le basi di solidi percorsi di approvvigionamento per 30-60 TWh di carburanti e prodotti chimici di piattaforma sostenibili. La maggior parte dovrà essere importata, ed è per questo che reFuel.ch si concentra in modo particolare sulle dimensioni internazionali.

Il programma di lavoro consiste in tre pacchetti di lavoro (WP1-3), che si occupano dell'implementazione, e quattro pacchetti di lavoro (WP4-7), che si occupano dello sviluppo di tecnologie migliori o nuove. L'insieme dei sette WP è completato da un WP di trasferimento del know-how e della tecnologia per comunicare i risultati ottenuti agli attori del mercato e ai decisori politici. Ciò avviene nell'ambito delle cosiddette "tavole rotonde". Circa 80 aziende, ONG, associazioni, autorità o istituti di ricerca svizzeri e stranieri, che si sono registrati come partner di cooperazione per reFuel.ch tramite una lettera di interesse, sono invitati a scambiare informazioni e discutere idee in questo formato.

I pacchetti di lavoro orientati all'implementazione (WP1: Valutazione sociale, economica e politica a livello nazionale; WP2: Valutazione sociale, economica e politica a livello internazionale; WP3: Valutazione del sistema energetico e del ciclo di vita per percorsi di approvvigionamento solidi) esaminano questioni legali, ambientali, climatiche e del sistema energetico. Questi includono, ad esempio, l'analisi dei quadri giuridici e normativi nazionali e internazionali, che vanno dall'Accordo di Parigi sul clima, al Sistema di compensazione e riduzione del carbonio per l'aviazione internazionale (CORSIA) per l'Organizzazione internazionale dell'aviazione civile (ICAO), alla Convenzione di Nagoya sulla conservazione globale della diversità biologica e sulla giusta ed equa condivisione dei benefici derivanti dal suo utilizzo, fino alle direttive svizzere e dell'Unione europea sui requisiti di sostenibilità per i combustibili sostenibili (ad esempio ReFuelEU Aviation, Renewable Energy Directive III e FuelEU Maritime).

I pacchetti di lavoro orientati alla tecnologia (WP4: Co-elettrolisi per vettori energetici chimici; WP5: Sintesi di metanolo efficiente e flessibile al carico; WP6: Conversione di letame di fattoria in cherosene sostenibile; WP7: Conversione di metanolo in vettori energetici chimici e prodotti chimici sostenibili) mirano a identificare e sviluppare scientificamente il potenziale per aumentare l'efficienza, la selettività e la flessibilità del carico dei processi per la produzione di vettori energetici chimici sostenibili. In questi pacchetti di lavoro è previsto uno scambio con partner industriali e consorzi coinvolti nella realizzazione di impianti per la produzione di tali fonti energetiche e prodotti chimici di piattaforma.

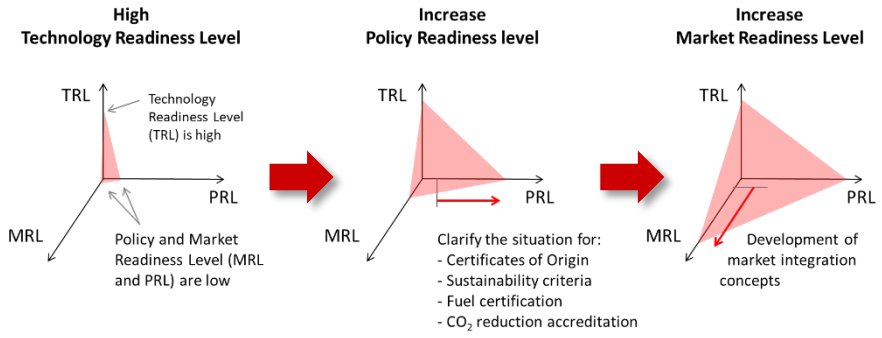
Lo scambio interno al consorzio è organizzato attraverso tre piattaforme tematiche (Piattaforma 1: Valutazione complessiva della sostenibilità; Piattaforma 2: Valutazione dell'innovazione tecnologica e Piattaforma 3: Progettazione di scenari e percorsi di transizione). Queste piattaforme mirano a stabilire una comprensione comune delle questioni relative alla sostenibilità e alla tecnologia e allo sviluppo di percorsi di approvvigionamento.

Infine, il progetto include casi di studio in Svizzera, in Europa e al di fuori dell'Europa, al fine di indagare le opportunità e le sfide nella formazione di consorzi per la realizzazione di impianti per la produzione di carburanti sostenibili e prodotti chimici di piattaforma.

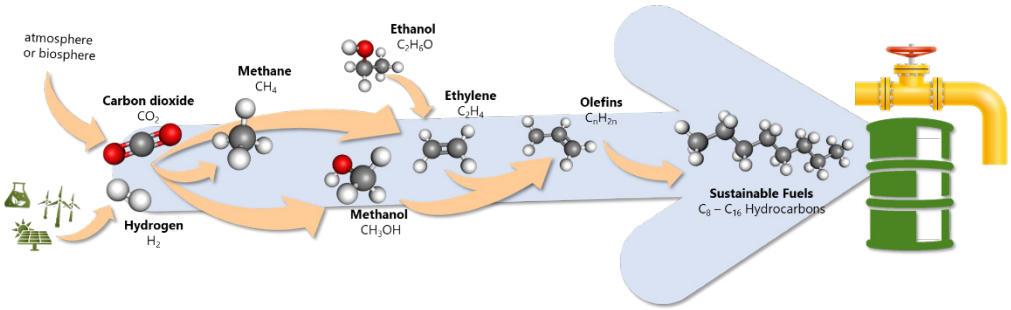
1 Work programme overview

The reFuel.ch consortium aims to develop robust supply pathways for annually 30-60 TWh of sustainable fuels and platform chemicals by 2050, determined by the Energy Perspectives 2050+ of the Swiss Federal Office of Energy (SFOE), whereof the vast majority is expected to be imported. This gives reFuel.ch an international focus, which may be different to that of other SWEET consortia. The international nature of supply pathways makes it also necessary for Switzerland to take sustainability criteria in the supply chain of those fuels and platform chemicals into account, including the European regulations, such as FuelEU Maritim, the ReFuelEU Aviation or the Renewable Energy Directive III. The project is divided into an implementation and a technology research-oriented part:

a) Within the implementation-oriented part, including WP1-3, research activities towards an increase of policy and market readiness is targeted. This will be achieved by analysis and scenario developments as well as an exchange with industry, market actors and policy makers. Thereby, cooperation partners are invited for exchanges in Round Tables, where information around sustainable fuels and platform chemicals is shared and discussed and a common view on the substitution of fossil resources by sustainable ones will be developed.



b) Within the technology research-oriented part, including WP4-7, research on novel technological approaches is done. This includes *i)* advanced processes for methanol synthesis, methanol-to-olefins and olefin-to-fuel conversion, *ii)* direct electrochemical CO_2 reduction (co-electrolysis) and *iii)* the manure-to-SAF conversion by hydrothermal liquefaction.



Besides scientific analysis and technical developments within the work packages, application-oriented research is approached in Case studies. Within a Swiss Case, a European Case (Iberian Peninsula) and an extra-European Case (Oman), the production of sustainable fuels and platform chemicals were initiated. The target of these Cases is to investigate the formation of consortia for the production of sustainable fuels and platform chemicals together with potential project developers, plant suppliers, plant operators and off-takers and to identify hurdles on the way to implementation.

2 Progress of activities

2.1 Work packages

WP1 is focused on the assessment of Swiss legal and policy space for SFPC market integration and a first Swiss legal screening was done by June 2024. In order to facilitate the legal and policy mapping, the development of an overview over the technological pathways was started.

Within **WP2**, a screening of international legal regimes and regulatory initiatives was started, such as instruments as the Paris Agreement and Article 6 arrangements concluded by Switzerland, the Montreal Protocol, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), WTO Agreements, or bilateral investment agreements concluded by Switzerland. In addition, recent European initiatives such as the EU Fit for 55 package, REpowerEU, Hydrogen Strategy and Net Zero Industry Act, the Renewable Energy Directive, the Directive establishing a system for greenhouse gas emission allowance trading (ETS) and the relative Linkage Agreement on the ETS of the EU and Switzerland, the Carbon Border Adjustment Mechanism (CBAM) and the ReFuelEU Aviation Regulation are taken into consideration.

WP3 started with the evaluation of proven models and contributions to identify adjustments and requirements to build the holistic "Swiss Energy System Modelling Framework" (SESMF). Key Performance Indicators (KPI) and Interfaces to the models within WP1-3 were defined as well as the incorporation of national/international, socio-economic, and regulatory boundary conditions. The prototype of a technology database is developed to enable data exchange with WP4-WP7 on the parameterization of conversion paths and impact analysis of the corresponding paths regarding their potential contribution to the transition paths will be established.

The activities in **WP4** rely heavily on experimental work for which the corresponding workforce needed to be enrolled. Three PhD student vacancies were advertised shortly after the official launch of reFuel.ch. The candidates have been selected and will join the respective institutions in the beginning of October/November of this year. Candidates for the third PhD student position are in the evaluation process, with the aim of having the selected person start in their new role at the End of this year.

The overall objective of **WP5** is to develop a catalytic process combining high CO_2 conversion with wide load flexibility, aiming at energy-efficient small- and large-scale systems for power-to-methanol applications for direct coupling with intermittent feed supply. In this context, a first literature review and high-level assessment is completed and the development of KPIs for benchmarking of new technologies was initiated. Furthermore, the planning of laboratory setups for membrane and sorbent testing was started. For the planned CFD activities, the development of numerical tools employing a common formalism and interface to published models for methanol production has started.

WP6 aims to develop efficient and environmentally sustainable pathways for harnessing the energy potential of manure. To make use of the CO_2 in the biogas, a cold flow model of the fluidized bed methanol synthesis was created, allowing reliable qualitative investigations. Initial experiments for direct, H_2-assisted hydrothermal liquefaction (HTL) of manure and digestate have been conducted. Additionally, techno-ecological descriptions of the manure pathways have been started. Therefore, a GIS-based information tool, designed to identify local manure pooling possibilities for biogas production, has been initiated. This tool incorporates life cycle assessment (LCA) considerations, as well as technical and legal restrictions, to select optimal locations for agricultural biogas plants in Switzerland.

WP7 focuses on the conversion of methanol to SF. Within this reporting period, a specific zeolite material has been identified as an interesting novel catalyst for the Methanol-to-Olefin (MtO) reaction, which exhibits unusual product distribution profile comprising both alkenes and higher aromatics. Concerning the targeted development of improved reaction designs for the MtO process, a cold-flow model of circulating fluidized beds was successfully improved for reliable qualitative observations. A neural network potential was developed for the description of methanol molecules and linear alkanes dynamics in zeolites, which will support the investigation of the formaldehyde formation mechanism and the description of linear alkanes diffusion and adsorption properties, respectively.

2.2 Internal Exchange Platforms

Platform 1, "Overall Sustainability Assessment": This platform will start soon. WP1-3 will work together and are exchanging results. Platform 2, “Technology Innovation Assessment” organizes exchanges between the technical WPs. Its purpose is to *i)* identify interfaces between the WPs, *ii)* provide a forum to discuss work in progress openly, and *iii)*, to exchange and discuss upcoming trends in research. The platform members decided to meet two times a year in person. Platform 3, “Design of Scenarios and Transition Pathways” started in February 2024. During the first platform meeting, three subgroups were formed, for which specific research questions were collected. These will present their results at the next platform meeting. Their topics are *i)* “Demand of fuels and petrochemicals”, *ii)* “non-CO_2-effects of aviation”, and *iii)* “harmonization of assumptions". Each subgroup has a lead and organizes its meetings autonomously.

2.3 External Exchange (Round Tables)

reFuel.ch involves their cooperation partners in "Round Tables". A 1st Round Table was held at ETHZ on the 7th of February, 2024. This first event focused on the dialogue with the cooperation partners. More than 100 participants from 50 different entities entered the exchange on the topics of Industrial Power-to-X plants, manure and biomass as feedstock for energy carriers, energy and chemical sector, industrial applications, transports and logistics. The central outcome was that risks hinder the industry from installing relevant production capacities for Sustainable Aviation Fuels (SAF) and other sustainable energy carriers or chemicals. The risks mainly comprise the unknowns of the large capital expenditures for early production facilities, future market structure, the availability of feed (CO_2 and electricity/H_2), and main trade-offs at the interface of the agricultural and energy sectors.

2.4 Cases

While the Swiss and the European Case just started with reFuel.ch beginning of 2024, the Oman Case was started half a year before at the Green Hydrogen Summit in December 2023 in Muscat/Oman where the participants formed a Swiss delegation. The Oman case consortium developed and evaluated a conceptual idea of an approach, which is scalable, compliant with the Renewable Energy Directive III and offtake-ready. Now, the transformation of the idea consortium into a concept consortium is planned, for the further development of the idea into a project, followed by a pre-feasibility study and a full feasibility study.

For the Swiss and the European Case, consortia formation is in progress and the development of ideas started.

3 Highlights of outputs

N.A.

4 References

N.A.