WP 1

Social, Economic, and Policy Assessment on National Level

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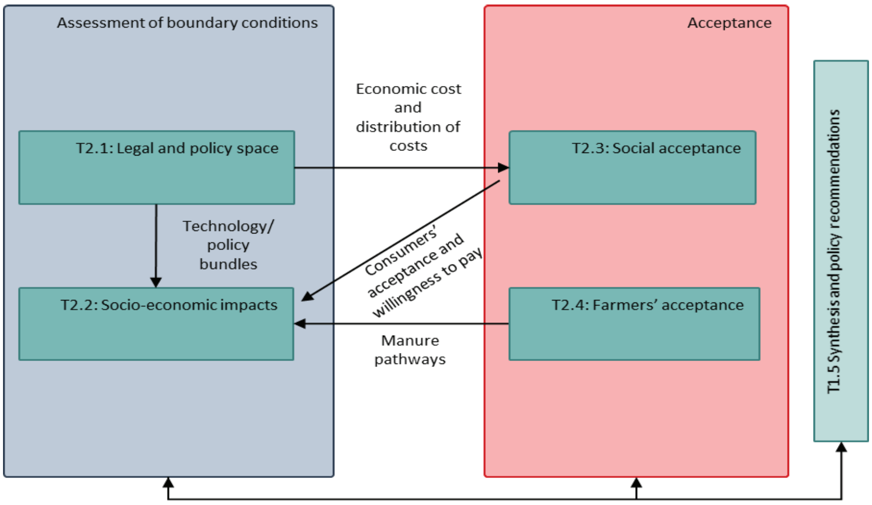
Concept

Identify, understand and resolve existing hurdles and constraints to increase **Policy Readiness Level for the development of robust and sustainable pathways for SFPC** supply in an **interdisciplinary set up** through the following <u>tasks</u>:

1. Assess **Swiss legal and policy space** for SFPC market integration and recommend the **development of policy instruments** to enable SFPC deployment in Switzerland
2. Provide a **quantitative analysis of the socio-economic impacts** of using SFPC in Switzerland
3. Assess the **social acceptance of different technological pathways** and related **environmental** and social-economic **impacts** in Switzerland
4. Assess **farmers' acceptance of manure use** in light of existing **legal and organizational constraints**



Impact

Contribute to redefining our understanding of **what regulations and policies shall be adapted and what framework conditions are required** to support the deployment of SFPC in Switzerland through the following <u>outcomes</u>:

1. **Policy recommendations on** legally sound, new and amended, **instruments and mixes** for supporting SFPC deployment in Switzerland
2. **Modeling of** the **economic costs and distributional impacts** of different technology-policy scenarios
3. Qualitative and quantitative **assessment of consumer acceptance of SFPC**
4. **Recommendations** on how to overcome obstacles to increase **farmers' willingness** to adopt manure-for-energy technologies

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WP 2

Social, Economic, and Policy Assessment on International Level

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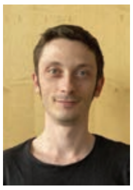

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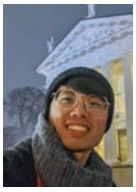

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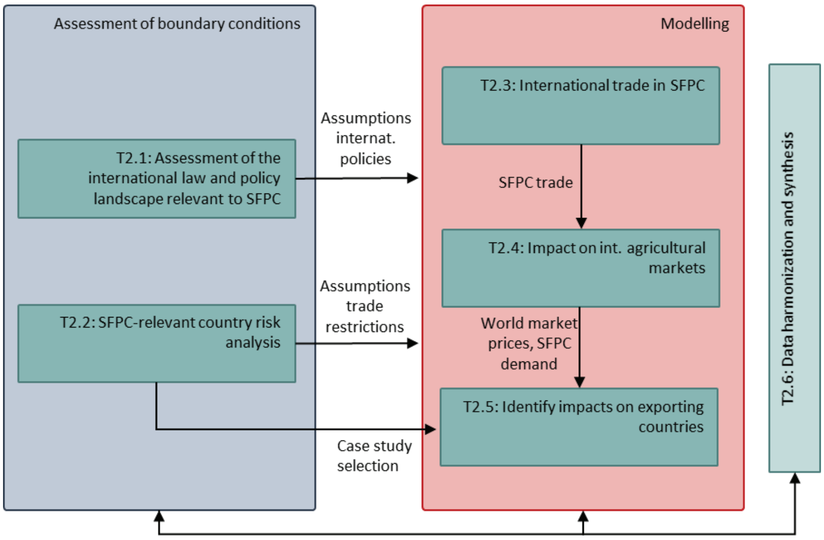
Concept

- No systematic analysis of policy instruments, which are needed to foster SFPC in Switzerland based on international obligations. → identification of these in Task 2.1.
- Current geopolitical tensions show need for consideration of legal, economic and geopolitical risks. → objective of Task 2.2.
- Possible globally interconnected system to supply SFPC in future → investigation of international dynamics and related energy trade patterns in task 2.3
- Task 2.3 with strong ties to WP3 and task 2.4.
- Consideration of political, legal conditions as well as risks, analysis of impacts on international energy trade, on global commodity markets, as well as on indirect impacts on land use and food security (Task 2.4).
- Assessment of socio-economic implications on potential exporting countries such as Spain as well as on international markets (Task 2.5).

Hence, in this project we contribute to this literature by analyzing the consequences of introducing SFPC in an interdisciplinary modelling framework. Contributing to O1, in this novel interdisciplinary framework information from political science, law and economics as well as engineering is combined.



Work package concept

Impact

Expected results:

A report outlining existing international best practices on SFPC promotion and implications for Switzerland, with a focus on countries that were identified as bearing the highest interest for Switzerland

A report identifying a criteria list for evaluating exporting countries based on economic, political, geopolitical and legal risks.

A report zooming in on identified risks in exporting countries emerging out of the comparative risk assessment as bearing the highest interest for Switzerland

Scenario results on international dynamics and related energy trade patterns.

Scenario results on economic impacts on international commodity markets

Scenario results on socio-economic impacts on exporting countries

A strategy for facilitating required imports in a resilient as well as ethically and economically sound manner (with WP 3)

An assessment of economic, social, and environmental impacts that informs different implementation strategies.(with WP1 and WP3)

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WP 3

Modeling of Robust Transition Paths

sweet swiss energy research for the energy transition

reFuel.ch

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Empa

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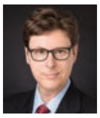

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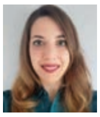

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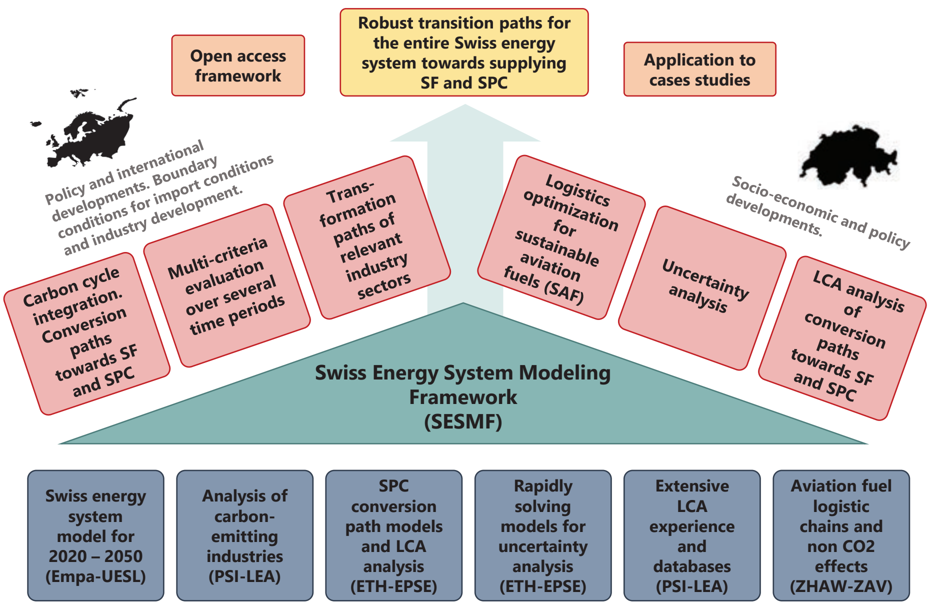
Impact

- No regret robust transition paths for the Swiss energy system
- LCA evaluation of SF and SPC conversion paths
- Logistics analysis and optimization of SAFs
- Dissemination strategies based on regional to international case studies

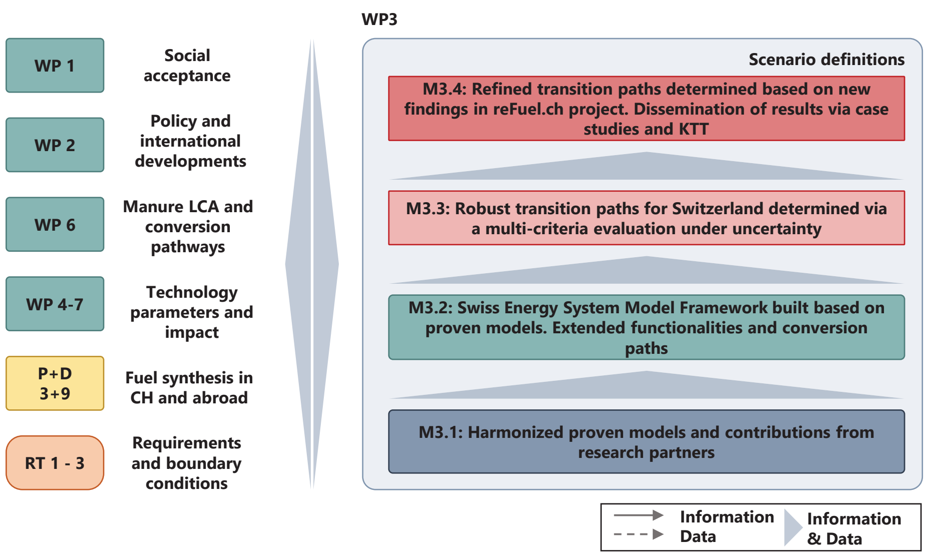
Concept

- **In WP3, we aim to determine robust transition scenarios towards the Swiss goals, including the production or provision of sustainable fuels (SF) and platform chemicals (SPC) in the required quantities.**
- A holistic energy system analysis, including all sectors of the energy system, will be conducted.
- This WP plays a central role in reFuel.ch by connecting technical developments and socio-economic boundary conditions and quantifying their impact and benefits on the transformation of the Swiss energy system.
- The expected results form the basis for an informed decision toward deployment of the transition paths

Building blocks of Swiss Energy System Modeling Framework



Data and information flow within WP3 and with other WPs in reFuel.ch



WP 4

Co-Electrolysis for Synthesis Gas Production

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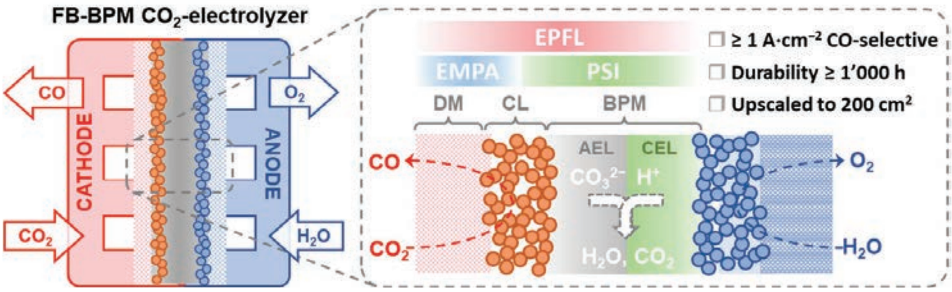
Concept

The well-established Fischer-Tropsh process could be used to produce green fuels if the synthetic gas (i.e., a mixture of CO and H_2) used as its reactant were produced through the electrochemical reduction of H_2O and CO_2 powered with renewable electricity. However, the operative current density, durability and CO-selectivity of these so-called co-electrolyzers remain insufficient for their industrial use.

With this motivation, work package 4 aims at developing a forward bias bipolar membrane (FB-BPM) CO_2-electrolyzer with enhanced CO_2-to-CO conversion performance and durability, and at an application-relevant size by:

- ❒ **Developing new catalysts, diffusion media and membranes;**
- ❒ **Identifying the best-performing and stable combination of materials with the aid of advanced microscopy;**
- ❒ **Proving the technological relevance by upscaling to a cell size of 200 cm².**



Schematic representation of an FB-BPM CO_2-electrolyzer fed with humidified CO_2 vs. water as the cathode and anode reactants, respectively. By searching for the best combination of diffusion media (DM), catalyst layer (CL) and bipolar membrane (BPM), the three teams involved in the work package will deliver a highly-performing, stable and selective co-electrolyzer that will be upscaled to an industrially relevant size of 200 cm².

In collaboration with other ReFuel.ch WPs and P+Ds, this work package will also explore the use of biomass-derived or air-captured CO_2 as the co-electrolyzer reactant, along with the subsequent upgrade of the produced CO into methanol or synthetic aviation fuels.

PAUL SCHERRER INSTITUT PSI

Empa

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Impact

- ❒ **Novel insights on how cell performance and durability are determined by the interplay among its key components (BPM, CL, DM) will result in beyond-state-of-the-art co-electrolyzers;**
- ❒ **Subsequent cell upscale to an application-relevant size will portray this technology's true commercialization potential;**
- ❒ **Additional lessons on device integration within full processes through the use of realistic CO_2-sources and by considering the downstream utilization of the produced CO.**

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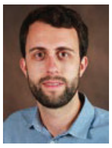
WP 5

High-Conversion and Load-Flexible Methanol Synthesis

Team

Empa
Materials Science and Technology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Concept

Background: The shift from natural gas to CO_2 and hydrogen as feedstock for methanol synthesis brings new challenges in catalyst, reactor, and process design.

Challenge: The limited conversion of CO_2 to methanol leads to challenging reaction conditions. Further, catalyst degradation due to high water loads is observed

Aims: We aim at identifying the best sorption-enhanced catalytic approaches to develop a selective, stable, and economic catalyst system. From this we design a reactor and process for flexible operation and demonstrate it on lab-scale.

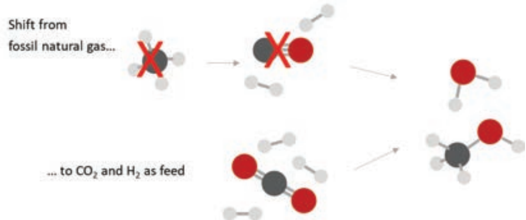

Figure 1: Shifting methanol synthesis from fossil natural gas to CO_2 and hydrogen

Tasks: Develop concepts from TRL 0-2 to TRL 4

- Asses fixed-bed sorption-enhanced and membrane-based approaches
  → Technology overview and rating
- Design, produce, and screen catalysts & membranes
  → Catalyst system desinged & benchmarked
- Implement physical models for catalytic reactor
  → Experimentally verified reactor model
- Develop reactor & process concept
  → Reactor & process designed & benchmarked
- Demonstrate process concept on laboratory scale
  → Lab demo (5-20 Nl/min CO_2 conversion)
- Process scale-up to industrial-scale system (large-scale & small-scale system)
  → Simulation-based scale-up & process benchmark
  → Integration into LCA and socio-economic assessment

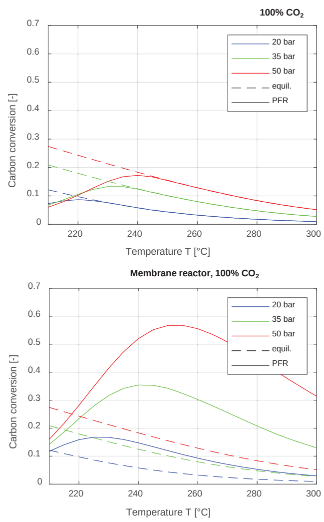

Figure 2: CO_2 fed plug flow reactors with and without sorption-enhancement simulated as methanol and water selective membrane.

Impact

Methanol is currently one of the most important platform chemicals. Its impact and use is expected to increase significantly, as green hydrogen carrier, sustainable fuel, and platform chemical for transition to green chemicals. This is why efficient, flexible, and low-cost production coupled with sustainable renewable resources supply is of utmost importance.

Through joint efforts in materials, reactor and process development, we aim at meeting these new requirements and ensuring a fast increase in TRL. We aim at developing the technologies to a maturity that allows for industrial implementation.

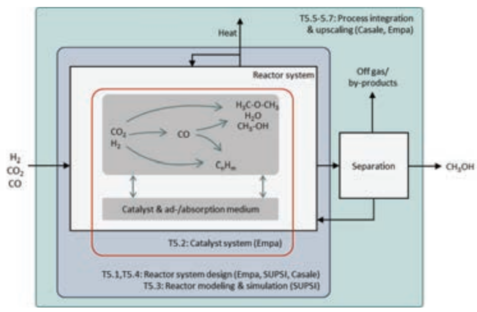

Figure 3: Work package concept

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WP 6

Manure to Sustainable Fuels and Platform Chemicals

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Concept

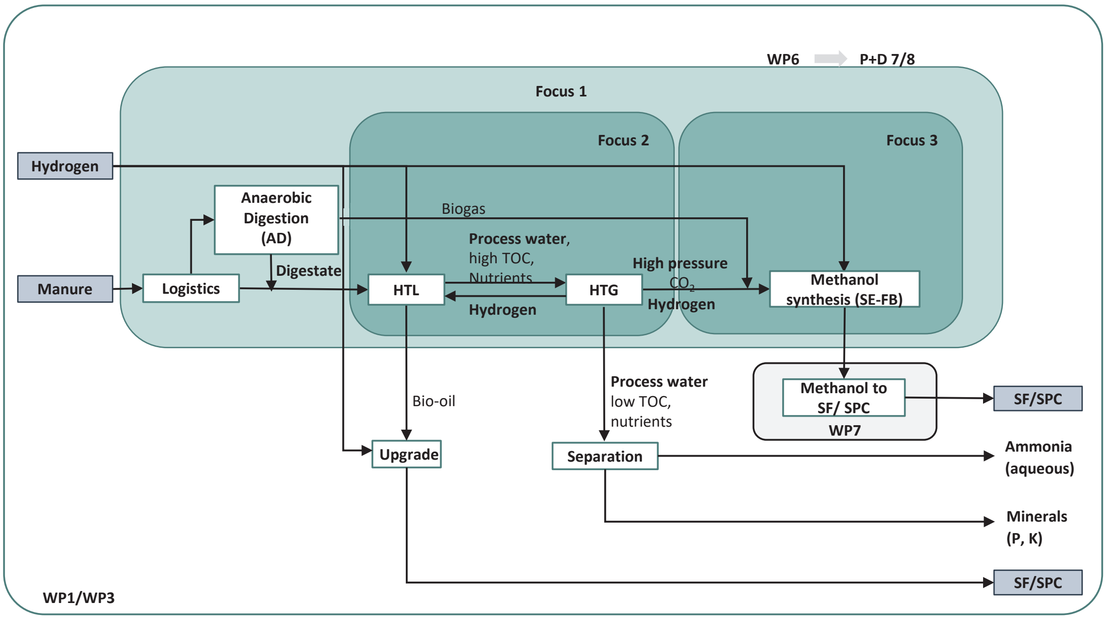
Background: Manure holds significant untapped energy potential: 25 PJ/a. Challenges include low energy density and structural aspects unique to Swiss agriculture.

Goal: Develop efficient and environmentally sustainable pathways to exploit this potential

Focus 1: Evaluation of spatial (logistical) constraints of manure utilization and LCA to assess different manure pathways

Focus 2: Development of direct, H_2-assisted, hydrothermal liquefaction (HTL) of manure and digestate

Focus 3: Development of sorbent-enhanced fluidized bed methanol synthesis



Impact

- Facilitate the unlocking of substantial energy potential in manure, while recovering valuable nutrients.
- Contribute to sustainable domestic fuel production, reducing reliance on imported fossil fuels.
- Help mitigate greenhouse gas emissions from fossil fuels and conventional manure management.
- Drive technological innovation with sorbent-enhanced fluidized bed methanol synthesis and H_2-assisted hydrothermal liquefaction.
- Promote a circular economy through efficient manure valorization.

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WP 7

Methanol to Sustainable Fuels and Chemicals

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Concept

The Fischer-Tropsch route is an advanced process for the production of sustainable fuels (SF) today. However, it has limited product selectivity and requires the reversed water-gas shift reaction to utilize CO_2. In addition, the production of kerosine requires additional steps, which makes this route inefficient.

The alternative methanol route has better selectivity to diesel and gasoline, which has already been demonstrated in commercial plants in New Zealand and China. This route has great potential for the production of SF directly from CO_2. Although the process from methanol to fuels is in principle known, it is still in its infancy with respect to its role in the global energy system. There is huge innovation potential for all aspects of the process chain that WP7 will address by new approaches at the TRL levels 1 to 3. This comprises

(i) better understanding of the involved reactions over zeolite catalysts by high-end analytics of the so-called hydrocarbon pool in the zeolite pores,

(ii) support of the mechanistic studies by molecular modelling of the decisive reaction intermediates by enhanced sampling ab initio molecular dynamics

(iii) development of composite zeolite catalysts based on the gained knowledge,

(iv) new reaction concepts suitable for small-scale production of SF and

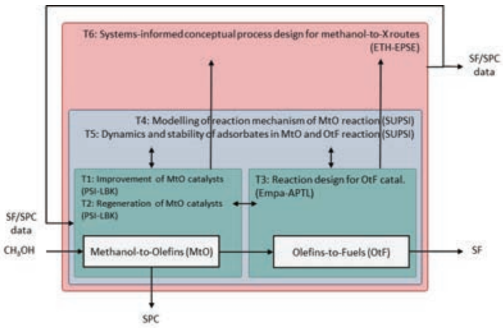
(v) process modelling that not only allows rapid upscaling from basic catalyst research to catalytic processes, but also proposes new process routes and closes the feedback loop to the system level metrics in WP3.

WP7 aims at the conversion of sustainable methanol to kerosine and sustainable platform chemicals (SPC), focusing on the development of suitable catalysts and optimal reaction conditions. The main objectives of catalyst development are high activity, selectivity and optimum stability of the catalysts at minimum cost.

Another aim of WP7 is the investigation of innovative reaction concepts such as inductively heated reactors and sorption-enhanced synthesis. These concepts can reduce production costs, as they offer better energy efficiency, higher conversion and less product processing steps.

The intermediates of the methanol route are the platform chemicals ethylene and propylene, which can be used as feedstocks for the production of plastics and many chemicals. Therefore, WP7 will investigate the potential of methanol, ethylene, propylene and higher olefins as SPCs.

WP7 research tasks



WP7 team

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EMPA	APTL APTL = Automotive Powertrains Technologies Laboratory	Olefins to Sustainable Fuels (OtF)
SUPSI	MEMTI MEMTI = Institute of Mechanical Engineering and Materials Technology	Computational reaction and reactor modeling
ETH zürich	EPSE EPSE = Energy and Process Systems Engineering	Sustainable chemicals supply