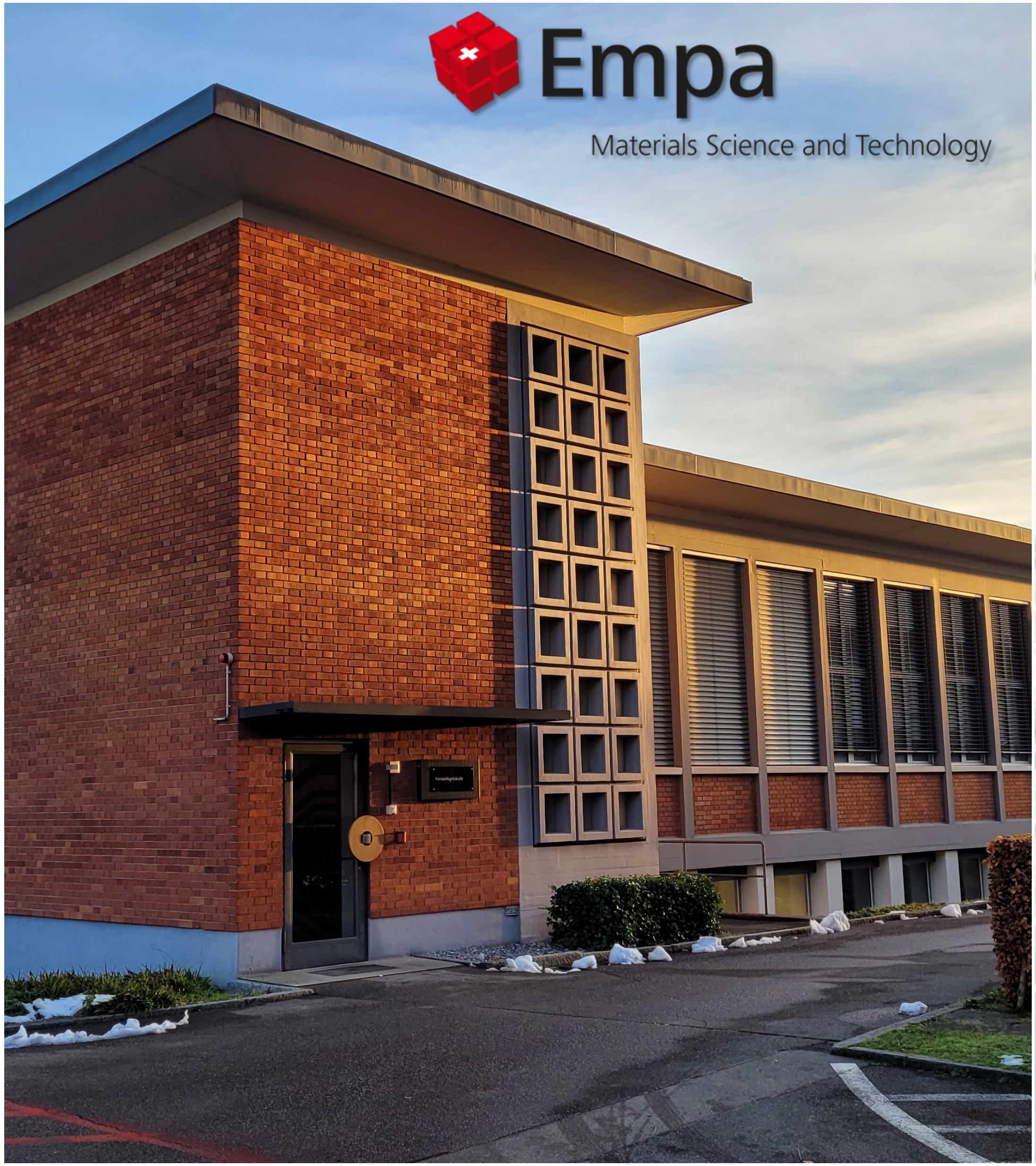


MSc Dagmara Uhl [1], Prof. Dariusz Kata [2], Dr. Gurdial Blugan [1]

1) Laboratory for High Performance Ceramics, Empa, Swiss Federal Laboratories for Materials Science & Technology, Überlandstrasse 129, CH-8600 Dübendorf, Switzerland
2) AGH University of Science and Technology in Krakow, Faculty of Materials Science and Ceramics, al. Adama Mickiewicza 30, 30-059 Krakow, Poland

Development of Ceramic Membranes for Synthetic Fuel Production

Energy Research Talks Disentis 2025

ALPENFORCE
ALPINES ENERGIE FORSCHUNGS CENTER

Disentis, 31 JANUARY 2025


Empa
Empa

Excellence times Six – the Institutions of the ETH Domain

At Empa, more than 1,000 highly motivated scientists, engineers, technicians and other employees carry out applications-oriented cutting-edge research and technology development.

% = share of base funding

Materials and Technologies for a Sustainable Future – Focusing on Solutions.

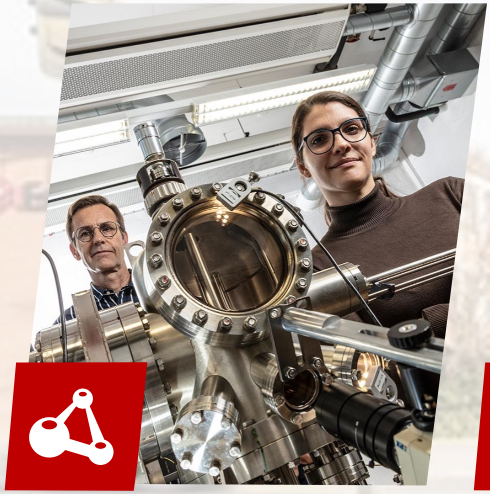
Empa research aims at practicable solutions – for Swiss industry and for society at large.
Empa core competence: interdisciplinary materials science and technology development.

Dübendorf

St. Gallen

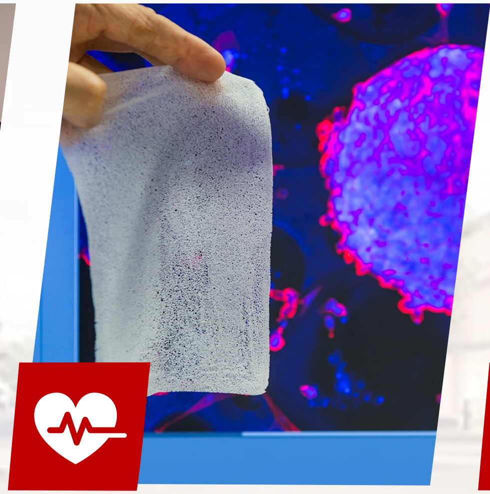
Thun

Empa Response – in four Research Focus Areas in the UN Sustainable Development Goals



Nanoscale Materials & Manufacturing Technologies

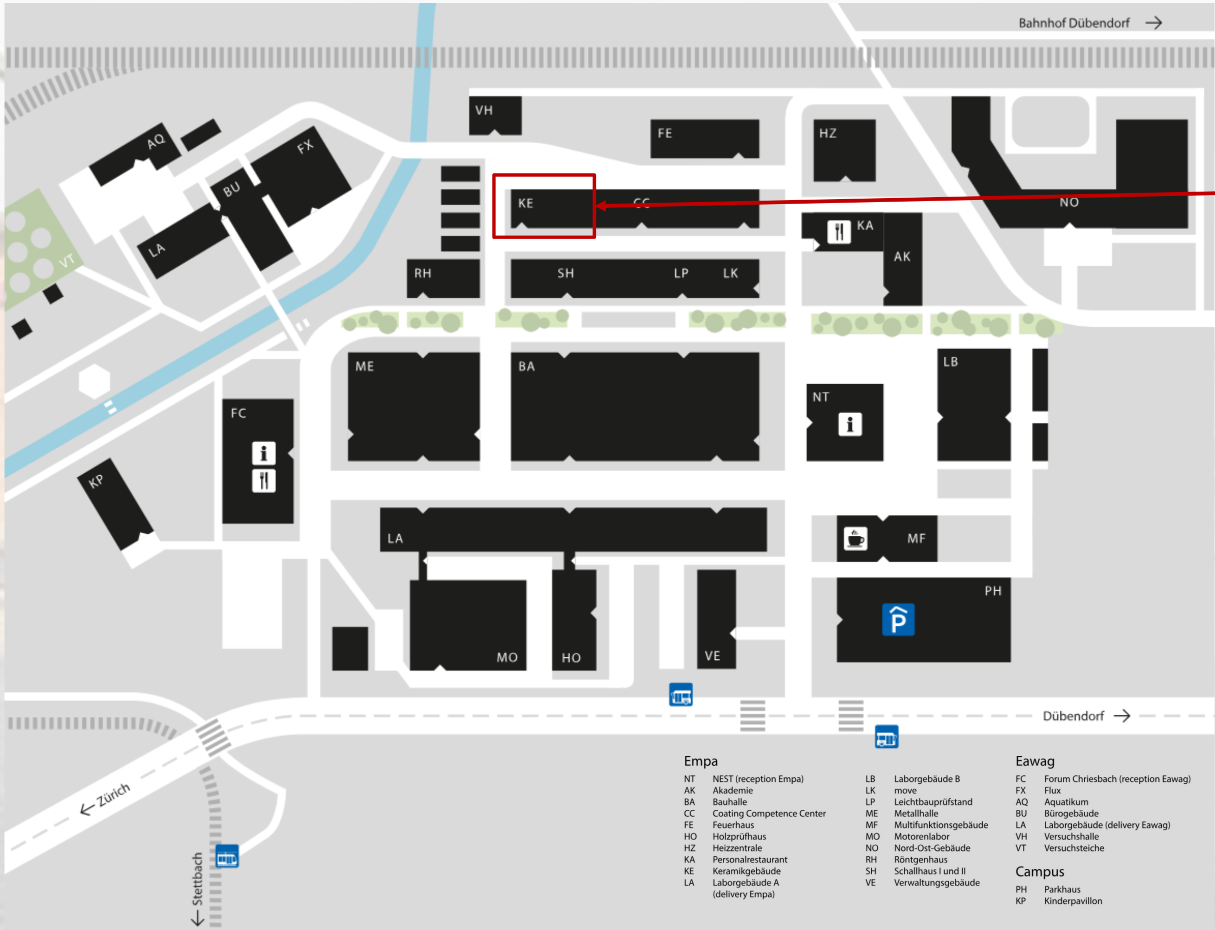
Built Environment



Health

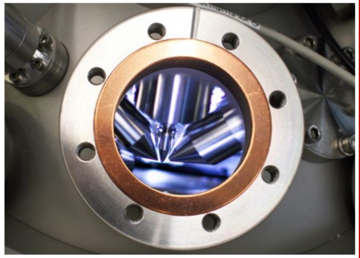
Energy, Resources & Emissions

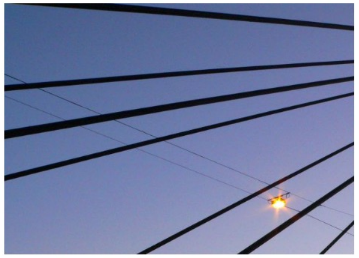
Campus Empa Eawag Dübendorf
Laboratory for High Performance Ceramics

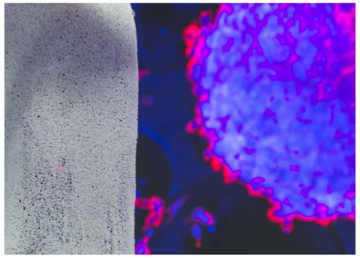


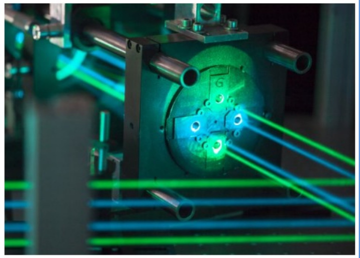
Department of Advanced Materials and Surfaces

Laboratory for High Performance Ceramics

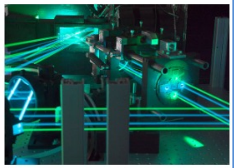

Advanced Materials and Surfaces


Engineering Sciences


Materials Meet Life


Energy, Mobility and Environment

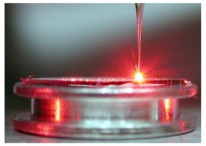

Corporate Services

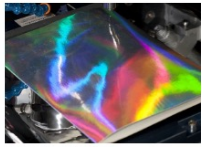

Chemical Energy Carriers and Vehicle Systems

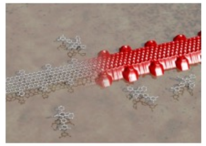

Materials for Energy Conversion

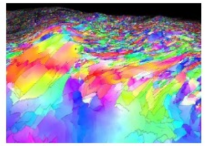
GROUP OF PHOTOVOLTAICS

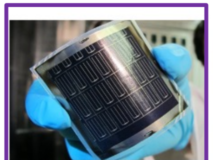

High Performance Ceramics

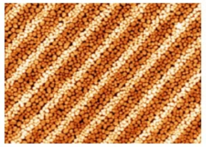

Joining Technologies & Corrosion

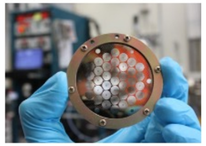

Advanced Materials Processing

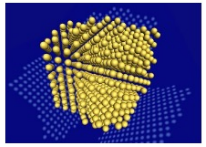

nanotech@surfaces


Mechanics of Materials & Nanostructures


Thin Films & Photovoltaics


Functional Polymers


Surface Science & Coating Technologies


Electron Microscopy Center

Coating Competence Center


Head of Department Dr. Lorenz Herrmann

Joint PSI-Empa Synfuel Initiative

Initiated SWEET reFuel.ch as follow up of collaboration between PSI and Empa

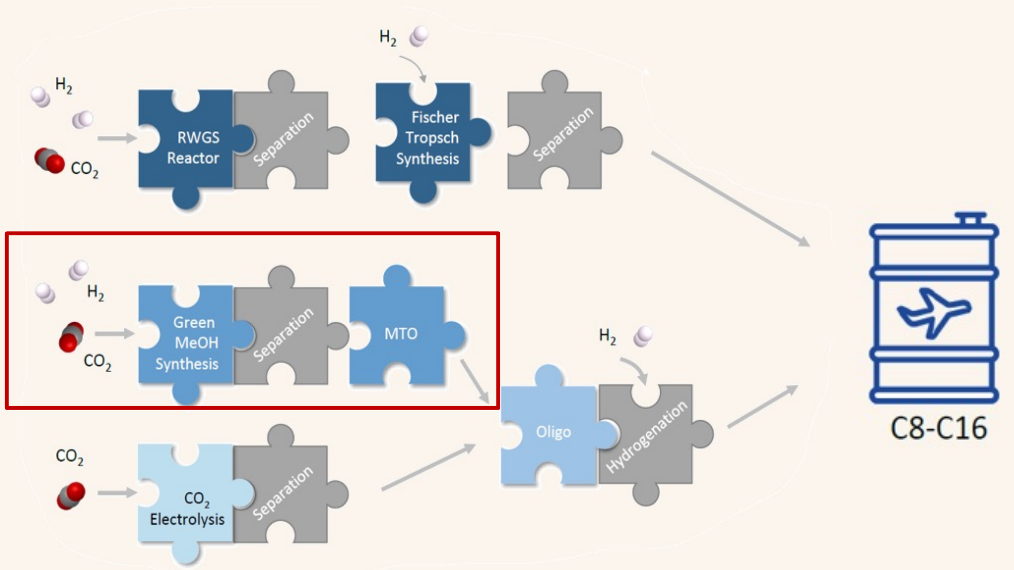
Highlights and Lessons Learned

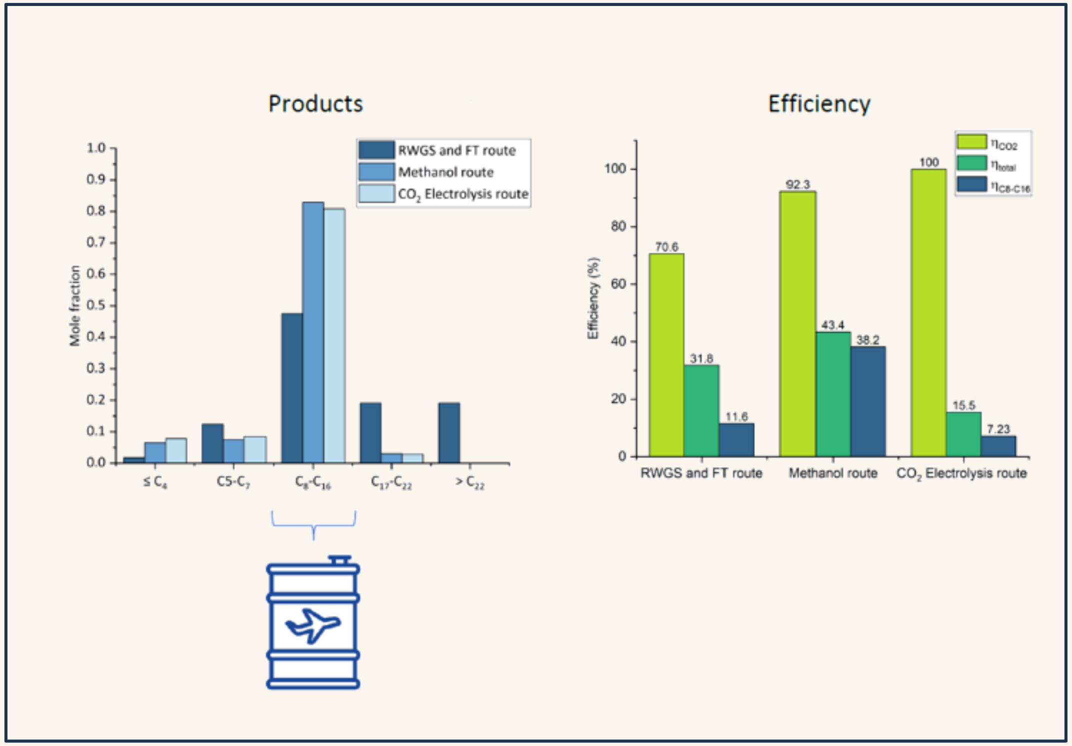
- Comprehensive pathway comparison
- Requirements on novel technologies from process perspective
- Recommendations for technology improvement and upscaling

- Coupling of process engineering and component development is key for upscaling
- Challenges in fixed bed oligomerization reactors: exothermic reaction, continuous regeneration necessary

Joint PSI-Empa Synfuel Initiative

Synthesis Routes Comparison and Process Integration





SWEET reFuel.ch

sweet swiss energy research for the energy transition

reFuel.ch

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Federal Office of Energy SFOE

SWEET – "SWiss Energy research for the Energy Transition" – is a funding program of the Swiss Federal Office of Energy (SFOE). SWEET's purpose is to accelerate innovations that are key to implementing Switzerland's Energy Strategy 2050 and achieving the country's climate goals. SWEET focuses on solution-oriented research and on demonstrations of the results achieved.

SWEET reFuel.ch

- SWEET Call 2-2022: "**Sustainable Fuels**"
- **reFuel.ch – Renewable Fuels and Chemicals for Switzerland (Host Institution: Empa)**

The overarching goal of the reFuel.ch project is to develop robust and practical pathways for introducing sustainable fuels and platform chemicals to markets and the Swiss energy system using an inter- and transdisciplinary approach. The project **aims** to enhance investment security by improving policy and market readiness. In addition, it aims at strengthening novel and innovative technologies which possess significant efficiency improvement potential and fosters the exchange between researchers and the private and public sector on a national and international level.

The overall target of reFuel.ch is to improve the sustainability and reduce the costs of sustainable fuels and platform chemicals by increasing the efficiency, selectivity, and load-flexibility of production plants to comply with long-term climate policy goals.

- **The consortium is composed of:**

  Host institution: Empa

  Members: PSI, ETH, EPFL, USI, UniBS, FHNW, SUPSI, ZHAW, Casale SA

Empa PSI EPFL n|w Fachhochschule Nordwestschweiz usi zhaw Universität Basel ETH zürich SUPSI CASALE

SWEET reFuel.ch

WP1
Social, Economic, and Policy Assessment on **National** Level

WP2
Social, Economic, and Policy Assessment on **International** Level

WP3
Energy System and Life Cycle Assessment for Robust Pathways

WP5
High-Conv. and Load-Flexible Methanol Synthesis

WP6
Manure to Sustainable Fuels

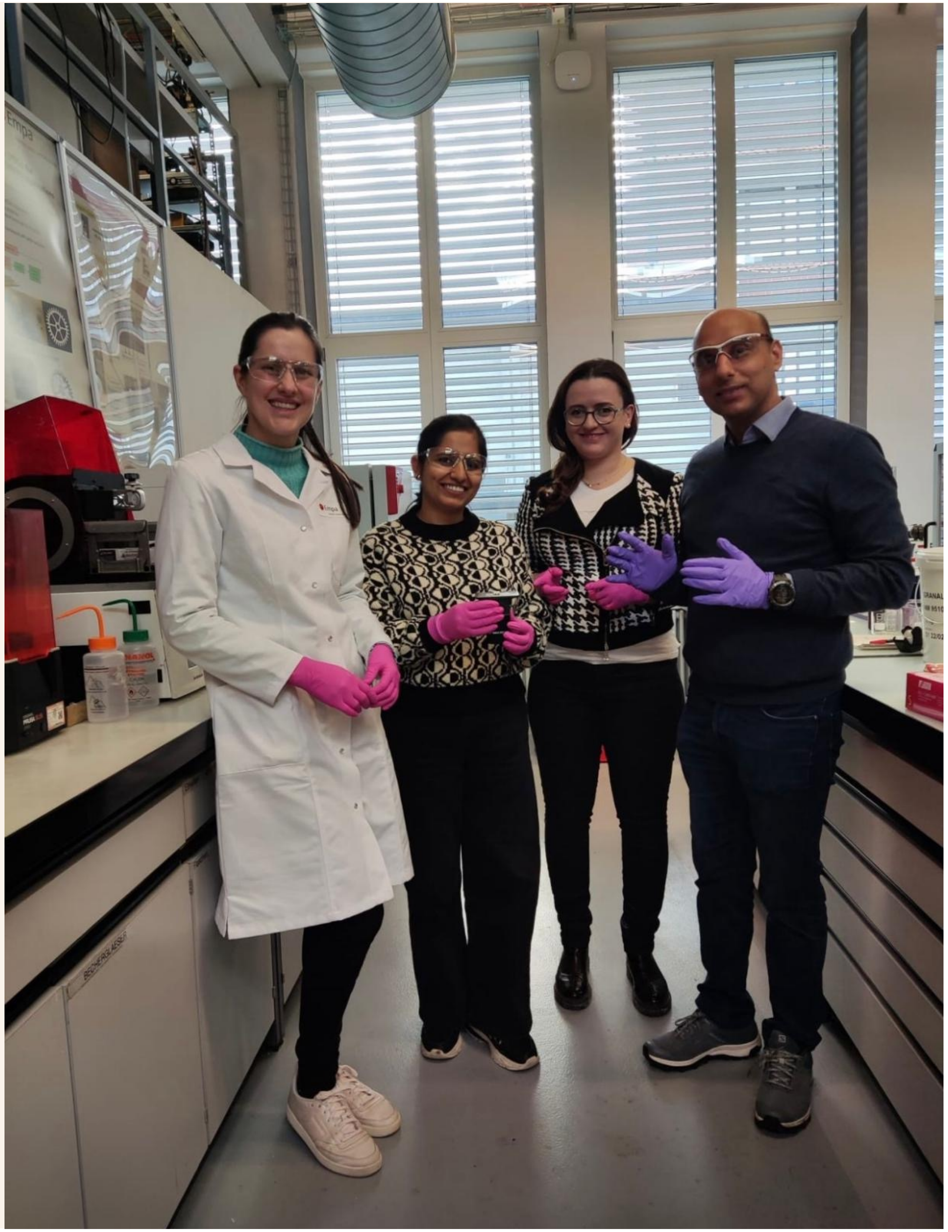
WP7
Methanol to Sustainable Fuels and Chemicals

WP4
Co-Electrolysis for Synthesis Gas Production

The consortium will investigate how investment security can be improved by closing the knowledge gap between technical and non-technical aspects of sustainable fuels. Robust and practical pathways for the introduction of sustainable fuels and platform chemicals into markets and the Swiss energy system will be developed. To achieve this, inputs from social and natural sciences and engineering as well as from the dialogue with relevant stakeholders will be included. A second aim is to strengthen innovative technologies currently at low technology readiness level.

Development of Ceramic Membranes for Synthetic Fuel Production

This presentation explores the cutting-edge development of ceramic membranes to produce synthetic fuels, focusing on their unique advantages and potential applications.



Synthetic Fuels: Definition and Importance

Synthetic fuels, also known as e-fuels, are fuels produced from non-biological sources, such as carbon dioxide and hydrogen. These fuels offer a potential pathway to decarbonize the transportation sector, reducing our reliance on fossil fuels.

The Role of Synthetic Fuels

Synthetic hydrocarbons, such as methanol, are crucial for reducing CO_2 emissions.

They act as versatile resources for energy storage, fuels, and chemical feedstocks.

Current Production Challenges

Dependence on Natural Gas

Current synthetic fuel production methods rely heavily on resource-intensive natural gas and synthesis gas.

Greenhouse Gas Emissions

This dependence exacerbates greenhouse gas emissions, hindering sustainability goals.

Efficiency Limitations

Processes using CO_2 and hydrogen face efficiency limitations due to high water content, which deactivates catalysts and restricts conversion efficiency - thermodynamic inefficiencies.

Ceramic Membrane Advantages in Reactors for Synthetic Fuel Production

Selective Water Removal

Ceramic membranes can selectively remove water and methanol directly from reactors.

Enhanced Conversion

This shift in thermodynamic equilibria enhances product formation and improves overall efficiency.

Introduction to Ceramic Membranes

What are ceramic membranes?

Ceramic membranes are thin, porous materials made from inorganic compounds like oxides, carbides, or nitrides. These materials are known for their exceptional thermal and chemical stability, making them ideal for high-temperature and corrosive environments.

Types of ceramic membranes

Ceramic membranes can be classified based on their pore size and structure. They can be dense, where the pores are very small, or porous, where the pores are larger and interconnected.

Advantages of Ceramic Membranes over other Membrane Types

High Thermal Stability

Ceramic membranes can withstand high temperatures without degradation, unlike polymers, making them suitable for applications involving high-temperature processes.

Chemical Resistance

Ceramic membranes exhibit excellent resistance to harsh chemical environments, making them suitable for corrosive feed streams.

Mechanical Strength

Ceramic membranes possess high mechanical strength and durability, enabling them to withstand high pressures and harsh conditions.

Long Lifespan

Ceramic membranes can operate for extended periods without significant deterioration, offering a cost-effective solution for long-term applications.

Source: www.membracon.co.uk

Challenges and Limitations in Ceramic Membrane Fabrication

Fracture Resistance

Ceramic membranes are prone to cracking and fracture during fabrication.

Cost

The fabrication of ceramic membranes can be expensive, making their widespread adoption challenging.

Scaling Up

Scaling up the fabrication process to produce large-scale membranes is a major challenge.

Emerging Trends and Future Prospects

1

Advanced Materials

The development of new materials with improved properties is crucial.

2

Improved Fabrication Techniques

Advanced fabrication techniques are needed to reduce defects and enhance membrane performance.

3

Hybrid Membranes

Combining ceramic membranes with other materials, like polymers, offers promising opportunities.

4

Integration with Renewable Energy

Integrating membrane reactors with renewable energy sources for sustainable fuel production.

Production of Ceramic Porous Membranes for CO_2 and H_2 to Methanol Synthesis

Ceramic porous membranes can be utilized in the synthesis of methanol from CO_2 and H_2. The membrane acts as a selective barrier, allowing the permeation of water while blocking gases, leading to higher methanol yields.

Key Properties of Ceramic Membranes for Synthetic Fuel Applications

1. **Porosity**

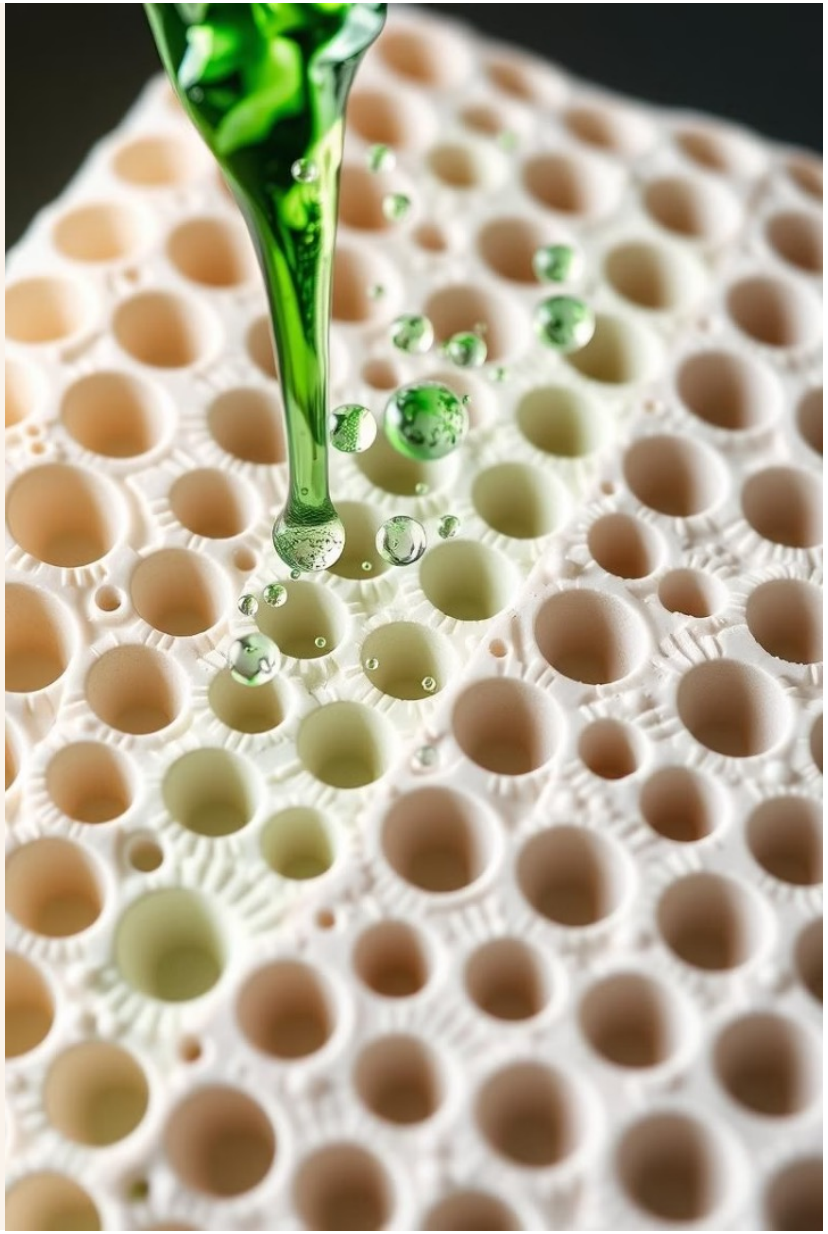
   The porosity of the membrane determines the amount of gas that can permeate through it.

2. **Pore Size**

   The pore size dictates the selectivity of the membrane, allowing only specific gases to pass through.

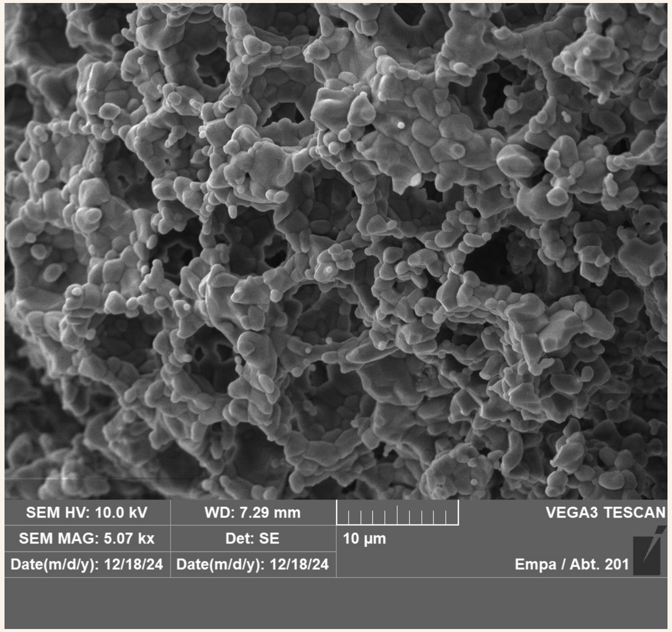
3. **Gas Permeability**

   Gas permeability refers to the ease with which gases can permeate through the membrane.



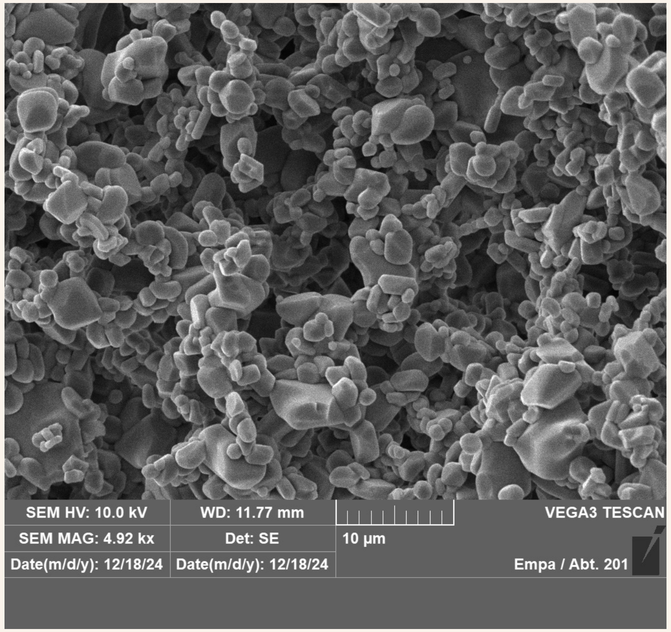
SEM images of porous ceramic membrane structure

Pressed



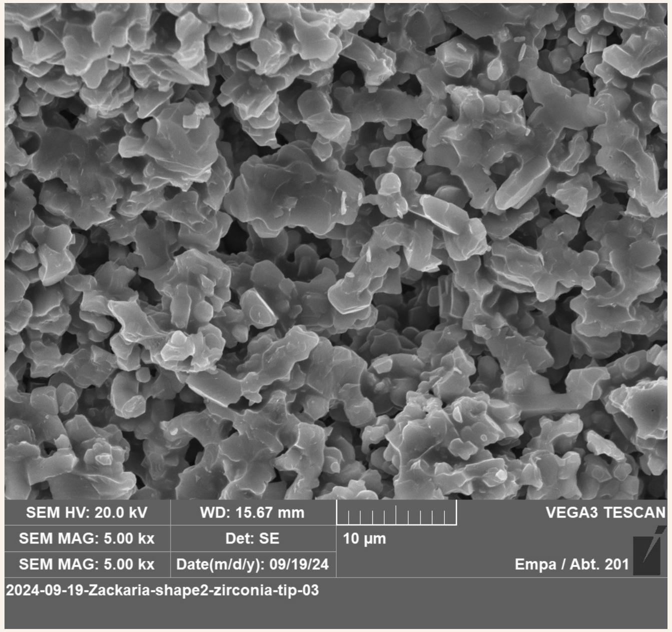
Planar membrane made from alumina powder with pore former, sintered at 1600C with the dwell time 1h, cross-section

Slip casted



Planar membrane made from alumina powder with pore former, sintered at 1600C with the dwell time 1h, cross-section

Commericial membrane



SEM image of commercial tubular membrane, cross-section

Ceramic Membrane Reactors for Synthetic Fuel Production

1

Membrane Separation

The ceramic membrane separates the desired product from the reaction mixture.

2

Increased Conversion

The membrane separation can drive the reaction towards higher conversion and yield.

3

Reduced Energy Consumption

The membrane reactor can operate at lower temperatures and pressures, reducing energy consumption.

Thermodynamic Considerations

1. ## Equilibrium Shifts

   Ceramic membranes can shift thermodynamic equilibria by selectively removing products from the reaction mixture.

2. ## Increased Efficiency

   This shift favors product formation, enhancing conversion efficiency and reducing energy consumption.

3. ## Process Optimization

   The use of membranes allows for optimization of reaction conditions, leading to improved yields and reduced waste.

Applications in Synthetic Fuel Production

•Methanol synthesis optimization

Ceramic membranes remove water during synthesis, enhancing yields. This has a direct impact on cost-effectiveness and sustainability.

•Hydrogen production

In processes like steam reforming, membranes enable selective hydrogen removal, making the process more efficient.

•Integration in membrane reactors

By combining chemical reactions with gas separation, these reactors optimize the production of synthetic fuels while reducing emissions.

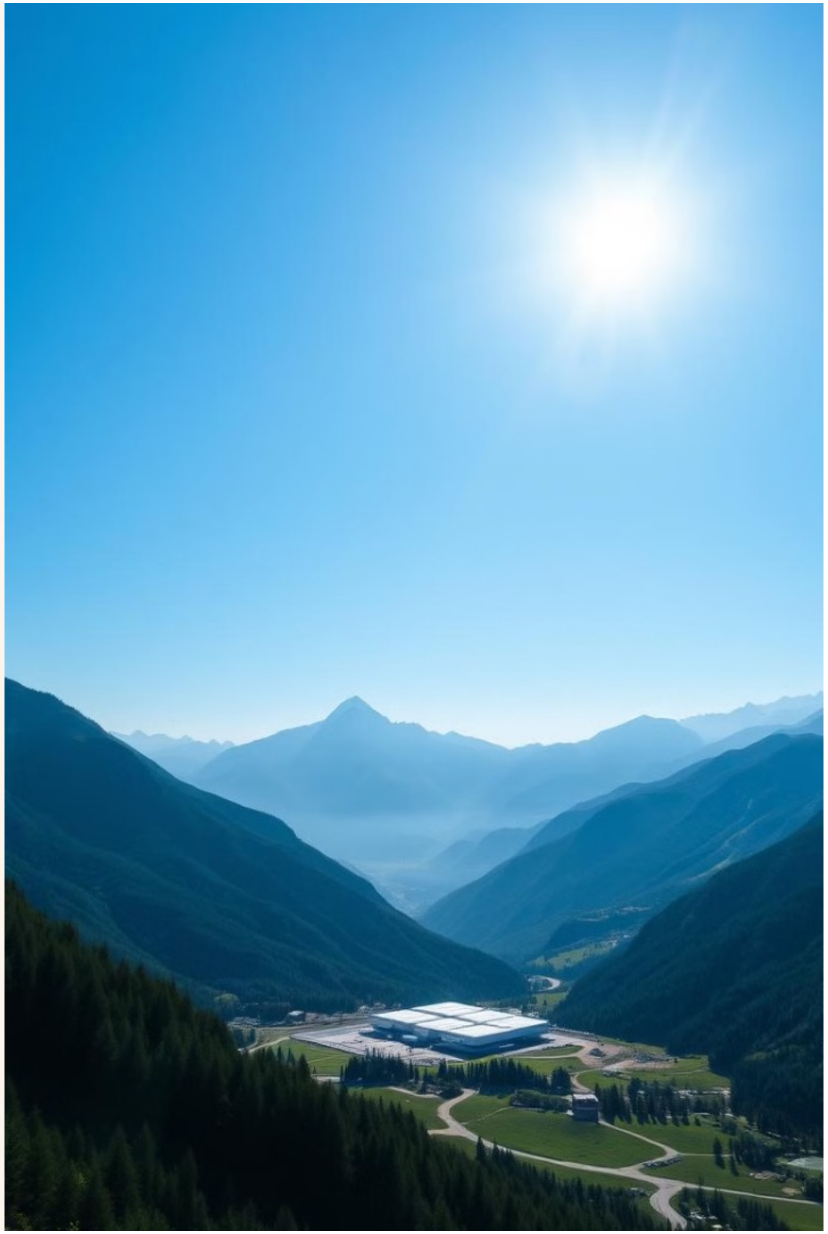
Environmental Benefits

Sustainability Gains

•Reduced greenhouse gas emissions.

•Lower energy consumption in production.

•Contribution to climate goals.



Challenges and Future Directions

Path to Industrial Scale

•Technology readiness levels (TRLs).

•Material development.

•Scaling and cost reduction.

1. **Advanced Membranes**

   Further development of advanced ceramic membranes with improved selectivity and stability.

2. **Process Integration**

   Integration of ceramic membranes into existing and novel synthetic fuel production processes.

3. **Pilot Scale Studies**

   Conducting pilot scale studies to validate the performance and scalability of the membrane technology.

Conclusion

Ceramic membranes offer a promising avenue for advancing synthetic fuel production, aligning with sustainability goals and addressing critical challenges in energy production. Their potential to enhance conversion efficiency, reduce greenhouse gas emissions, and promote sustainable energy solutions holds great promise for the future of energy.

A Promising Future

- Ceramic membranes enhance efficiency and sustainability.
- Align with SWEET ReFuel and AlpEnForCe's missions.
- Next steps in research and industrial adoption.

Empa – The Place where Innovation Starts

Dagmara Uhl
PhD Student

+41 587 656 116
dagmara.uhl@empa.ch

www.empa.ch

Laboratory for High Performance Ceramics
Empa - Swiss Federal Laboratories for Materials Science and Technology
Überlandstrasse 129
8600 Dübendorf
Switzerland


Thank you!
Do you have any questions?
Empa
Materials Science and Technology
ALPENFORCE
ALPINES ENERGIE FORSCHUNGS CENTER