

reFuel.ch project
The Oman Case

Christian Bach

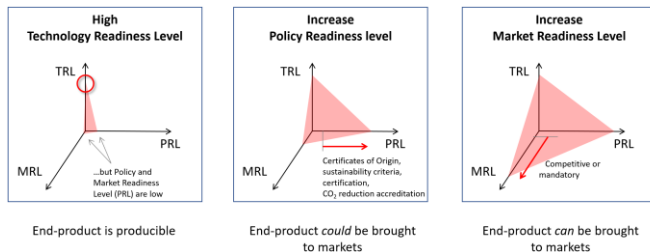
Co-coordinator reFuel.ch project; Head of Chemical Energy Carriers and Vehicle Systems Laboratory at Empa

SWEET project "reFuel.ch"

- **Task:** Development of robust supply paths for sustainable fuels to Switzerland
- **Consortium:** 15 Research groups in 9 Swiss universities and Research institutes + R&D department of one industry company
- **Approach:** Implementation oriented «high-TRL» and technology oriented «low-TRL» task with investigating implementation in a Swiss-Case, a European Case in Spain and an Extra-European Case in Oman

High-TRL part

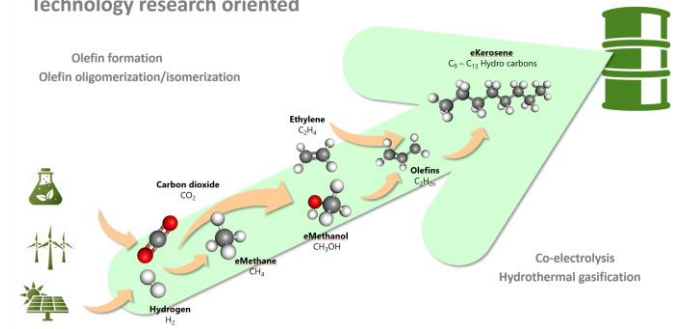
Implementation research oriented



Increase of policy and market readiness level

Low-TRL part

Technology research oriented



New, more efficient technologies

Agenda

- 1. Situation in Switzerland (energy demand)**
- 2. Situation in Oman (energy production potential)**
- 3. Delegated EU directives regarding sustainable fuels**
- 4. Upscaling of an RED-III ready approach**

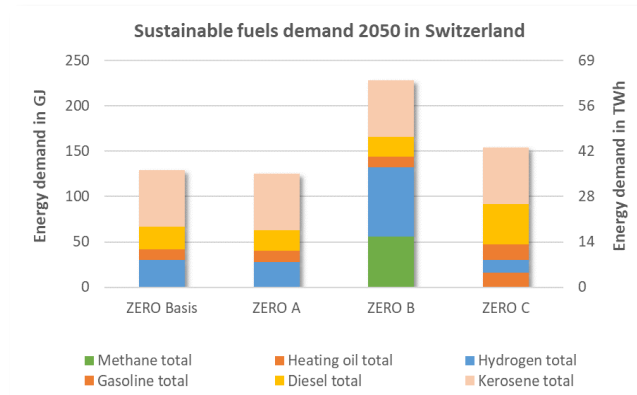
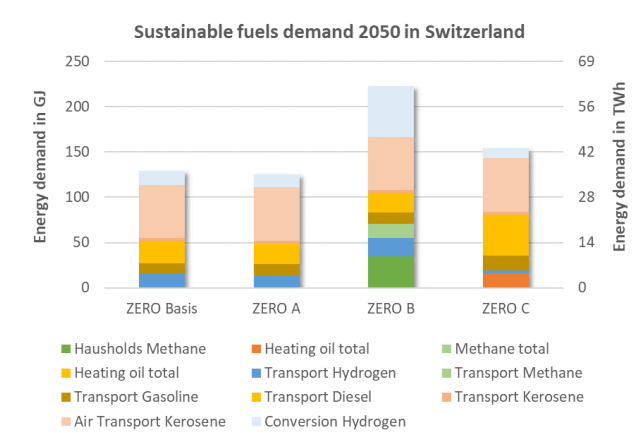
1. Situation in Switzerland

- Demand of sustainable fuels in 2050 is estimated to be between **110 – 220 GJ** or **30 – 60 TWh/a**, depending on the different scenarios.

ZERO Basis: extensive electrification
 ZERO A: more extensive electrification
 ZERO B: use of renewable gases (PtH₂/PtG)
 ZERO C: use of renewable liquids (PtL)

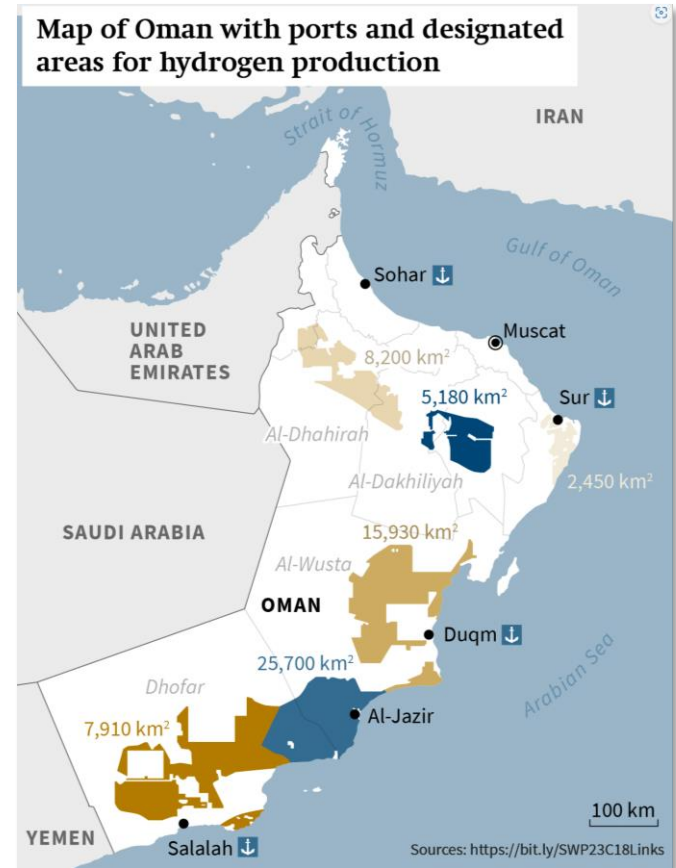
Source: SFOE, Energy perspectives 2050+

- It is expected, that >90% thereof has to be imported.
- One main target of the reFuel.ch project is to develop robust supply pathways for sustainable fuels to Switzerland.



2. Situation in Oman

- Oman has designated 50'000 km² of desert land for H₂ and derivatives production (rated among the top 10 areas on earth regarding solar radiation and wind).
- Oman aims to produce 1 Mt_{H₂}/a by 2030, 3.75 Mt_{H₂}/a by 2040 and up to 8.5 Mt_{H₂}/a by 2050. The 2040 hydrogen target would represent 80% of Oman's current LNG exports in energy-equivalent terms.
- In deserts one may produce **100 - 120 GWh_{el}/km²_{Land}/a**¹⁾ by PV. To achieve the 8.5 Mt_{H₂}/a aim of Oman, a PV equipped land demand of 4'500 - 5'500 km² would result.
¹⁾[Solar Power Spatial Planning Techniques \(irena.org\)](https://www.irena.org/publications/2019/04/Solar-Power-Spatial-Planning-Techniques)
- The 50'000 km² of desert land for H₂ production is split in 145 sub-areas, which are made available by tenders. First tenders have already been issued and have been awarded to a consortium of bidders. The first one is the AMNAH consortium led by Mark Geilenkirchen, who joined the reFuel.ch Oman Case Idea Consortium.



3. EU directives regarding sustainable fuels

Main requirements (according to EU):

■ Additionality of renewable energy

The electricity must be generated by new power production systems (max. 3 years old)

■ Direct coupling with renewable electricity production

The PtX plant has to be directly coupled to the renewable electricity power plant or – in case of grid supply – has to follow the electricity production profile.

■ CO₂ supply after 2035 by Direct Air Capture

Permitted carbon sources for the production of synthetic fuels

- Direct air capture
- Biogenic CO₂

■ 70% of CO₂ reduction in whole path

FuelEU Maritime Regulation – How does it affect the maritime sector?

In 2023, the European Union (EU) adopted the FuelEU Maritime Regulation, which sets mandatory limits for the greenhouse gas (GHG) emissions of commercial passenger transport and cargo ships in ports. The regulation will be mandatory from 2025.

Who will be affected by the obligations of FuelEU Maritime?

- All ships in the EU with a gross tonnage above 100,000 t, engaged in commercial passenger transport or cargo reg. of their flag will be affected.
- A greenhouse gas (GHG) reduction target of 14.5% for all energy used during voyages within the EU, which applies to 50 percent of the energy used for voyages entering or leaving the EU.

Mandatory specifications in this regulation include:

- Limit on GHG emission intensity: The average amount of greenhouse gases produced per unit of energy used must decrease over time.

GHG threshold in gCO₂-eq/MJ

Year	GHG reduction
2025	14.5%
2030	25%
2035	35%

ReFuelEU Aviation Regulation – How does it affect the aviation sector?

In 2023, the European Union (EU) adopted the ReFuelEU Aviation Regulation, which sets mandatory blending quotas for sustainable aviation fuels (SAF). It will be mandatory for all Member States from 2025 onwards.

Who will be affected by the obligations of ReFuelEU Aviation?

- Aviation Fuel Suppliers must supply a certain amount of SAF according to mandatory quotas.
- EU Airports with passenger traffic above 100,000 passengers or freight traffic above 100,000 tonnes must make the refueling of SAF positions for small remote airports available. It should also establish alternative ground handling services (e.g., electricity, hydrogen).
- Aircraft Operators departing from airports are obliged to refuel at least 90 percent required aviation fuel within the EU. This was introduced to prevent 'tankering' (i.e., loading more fuel than needed in flight).

From 2025, a SAF flexibility mechanism allowing operators to average across EU airports means that targets can be over-achieved at some ports and that in other (e.g., smaller) airports to be blended initially. The details of the SAF flexibility mechanism will be defined by the European Commission by 1 July 2024.

Renewable Energy Directive III (RED III) – Targets for Renewable Fuels in Transport

In 2023, the European Union (EU) adopted an amendment of the Renewable Energy Directive, which is referred to as "RED III". It thereby raised the collective target for renewable energy consumption across all sectors in Europe significantly to at least 42.5% in 2030.

The RED III target for transport was ambitiously increased and additional energy sub-targets were set for individual fuel fulfillment options (see table below). As in RED II, RED III allows multipliers for certain fuels and use cases, when they comply with the energy targets. This incentivizes these options and puts them on a level playing field with others.

The directive must be transposed into Member State's national law within 18 months after its publication in the Official Journal of the EU. Member States need to oblige fuel suppliers to meet the set goals for the transport sector. However, they have some flexibility in national implementation and can, for example, set higher targets for fuel suppliers.

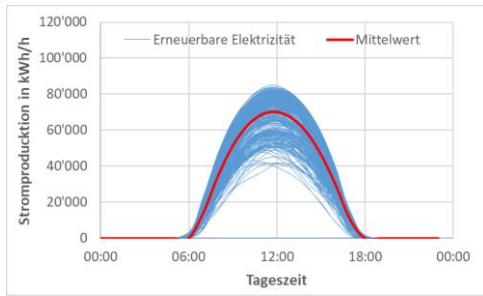
Main changes concerning the transport targets

Targets 2030	Targets in RED II (2018)	Targets in RED III (2023)
Renewable energy in transport	At least 14% share of renewable energy in final consumption of all energy used in transport	At least 29% share of renewable energy in final consumption of all energy used in transport
Fossil fuel comparator (reference value to calculate baseline for GHG reduction target)	94 gCO ₂ -eq/MJ for all energy used in transport	183 gCO ₂ -eq/MJ for electricity used in transport and 94 gCO ₂ -eq/MJ for all other energy used in transport
Electricity used in transport	No sub-target	No sub-target
	Multiplier of 4 for renewable electricity used in road vehicles and of 1.5 for renewable electricity in rail	Multiplier of 4 for renewable electricity used in road vehicles and of 1.5 for renewable electricity in rail

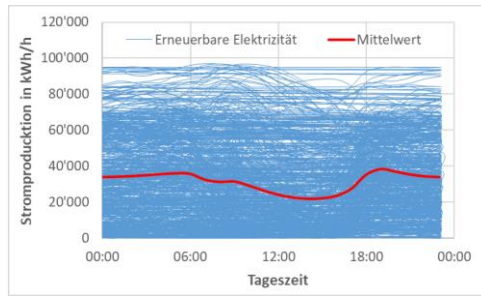
Factsheets for Download:
[NOW factsheets on EU legislation for renewable fuels - NOW GmbH \(now-gmbh.de\)](#)

3. EU directives regarding sustainable fuels

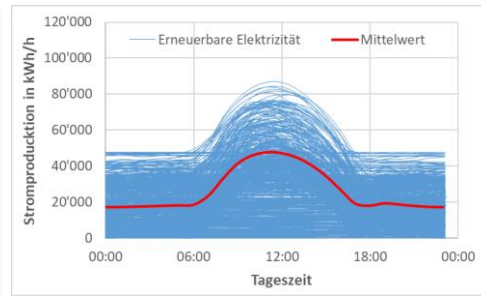
Direct coupling of PtX plant with PV, wind or PV/wind is demanding a high load flexibility of the entire PtX system (PV only: 100 – 0%; Wind only: 100 – 10%; PV/wind combined: 100-20%)



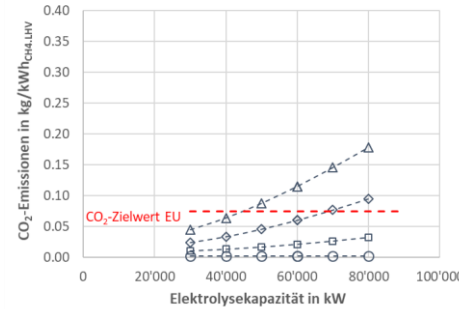
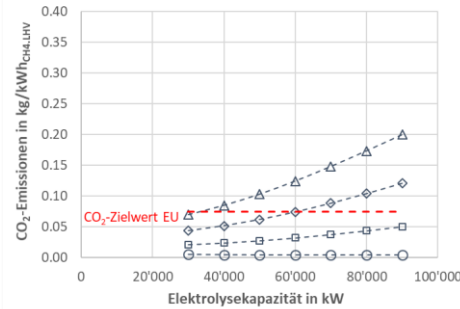
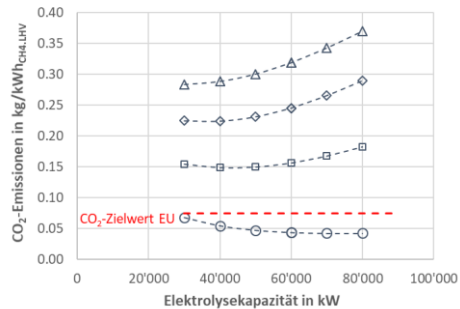
100 MW_p PV



100 MW_p wind



50 MW_p PV and wind each



- Δ - Lastflex.: 30-100%
- ◇ - Lastflex.: 20-100%
- □ - Lastflex.: 10-100%
- ○ - Lastflex.: 0-100%

4. Development/upscaling RED-III ready approach

Target: supply costs of synth. methane at the boarder below 0.20 EUR/kWh_{HHV} (Swiss biogas as reference) assuming liquefaction, regasification, transport and trade costs at 0.05 - 0.06 EUR/kWh_{HHV}.

	Investment (including system integration)		Production costs and quantity	Approach	
Step 1 RED III-ready Large scale RTTP plant 2026/27	12 MEUR PV 25 MEUR Ely 6 MEUR Meth 50 MEUR DAC ¹⁾ <small>¹⁾ 50% of DAC for Step 1 and Step 2 (resulting in 750 EUR/t_{CO2})</small>	93 MEUR	43 GWh _{el} /a (0.4 km ² Land); 6 kt H ₂ O/a; 4 ktCO ₂ /a 25 MW_{el,p} PtG P _{el} : 13 MW _{el} ; 1'900 Full-load h/a Electricity: 20 EUR/MWh; H ₂ : 6.1 EUR/kg	8.0 MEUR/a CAPEX 1.0 MEUR/a OPEX 19 GWh/a eMethane (0.60 EUR/kWh (incl. CAPEX)) 0.17 EUR/kWh (w/o CAPEX)	Hardware sponsored
Step 2 RED III-ready "small" large scale plant 2031/32	48 MEUR PV 92 MEUR Ely 12 MEUR Meth 50 MEUR DAC ¹⁾ <small>¹⁾ 50% of DAC for Step 1 and Step 2 (resulting in 750 EUR/t_{CO2})</small>	202 MEUR	173 GWh _{el} /a (1.7 km ² Land); 24 kt H ₂ O/a; 15 ktCO ₂ /a 100 MW_{el,p} PtX P _{el} : 51 MW _{el} ; 2'000 Full-load h/a Electricity: 20 EUR/MWh; H ₂ : 4.0 EUR/kg	14.4 MEUR/a CAPEX 3.5 MEUR/a OPEX 77 GWh/a eMethane 0.23 EUR/kWh (incl. CAPEX)	Additional costs accepted by market actors
Step 3 RED III ready "large" large scale plant 2036/37	740 MEUR PV 675 MEUR Ely 125 MEUR Meth 750 MEUR DAC <small>resulting in 300 EUR/t_{CO2})</small>	2'290 MEUR	3'400 GWh _{el} /a (34 km ²); 500 kt H ₂ O/a; 300 ktCO ₂ /a 2 GW_{el,p} PtX P _{el} : 1'100 MW _{el} ; 2'100 Full-load h/a Electricity: 13 EUR/MWh; H ₂ : 2.1 EUR/kg	196 MEUR/a CAPEX 44 MEUR/a OPEX 1'700 GWh/a eMethane 0.14 EUR/kWh (incl. CAPEX)	Market transformation

4. Idea ("RED III ready" demonstrator at Empa)



**Future Mobility
Demonstrator
«move»**

battery-electric
hydrogen
synthetic fuels



**PV coupled
system**

Flexible thin-film
based PV



**Battery buffer
storage**

Molten-salt
battery storage
system



**Onsite hydrogen
production**

PEM electrolyser
and hydrogen
storage system



**Atmospheric CO₂
supply (DAC)**

Coupled over
waste heat
recovery system
with electrolyser



**Sorption enhanced
methanation**

Load flexible
approach
(demonstrator
under construction)

Thank you for your attention

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