PeakMetal
Covering Winter Peaks of Heat and Electricity Demand by «Renewalbe Metal Fuels»

Renewable Metal Fuels (ReMeF) are long-term energy storage solutions with the potential to deliver renewable heat and electricity for buildings and reduce greenhouse gas emissions by replacing fossil fuel based peak load or backup systems in winter.

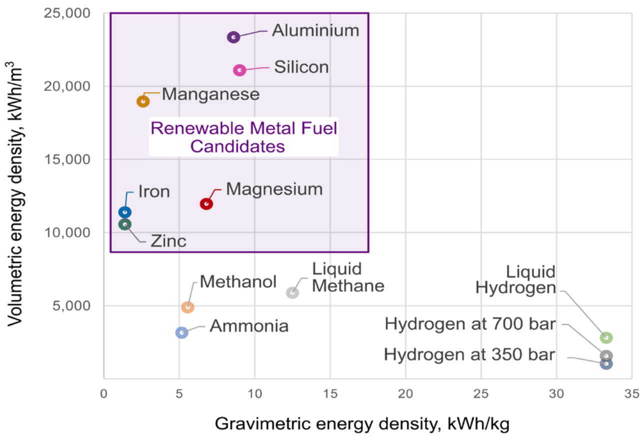
Game changer for seasonal renewable energy storage?

Energy scenarios for 2050 show that Switzerland will be able to produce more than enough renewable energy in summer, but will still need to import energy for the winter. To fully replace fossil fuels, alternative renewable energy carriers providing flexibly in both location and time will be essential. Metals are particularly well suited for use as solid-state chemical energy storage because of the large amount of energy that can be absorbed and released during their reduction and oxidation, and because they can be stored without loss over long periods of time. Within the PeakMetal project, funded by the Swiss Federal Office of Energy (SFOE), the following research questions were addressed:

- Screening and rating metallic elements as candidates for ReMeF, selecting the most promising ones
- Evaluating the potential to reduce possible future winter energy gaps with the most promising ReMeF candidates for low temperature metal-water reactions

Identification of ReMeF options

Aluminium, **iron**, and **silicon** are considered the most promising candidates for ReMeF. Their main advantages are high abundance - they are the most abundant elements in the earth's crust besides oxygen - low cost and ease of handling (not toxic, not highly reactive).



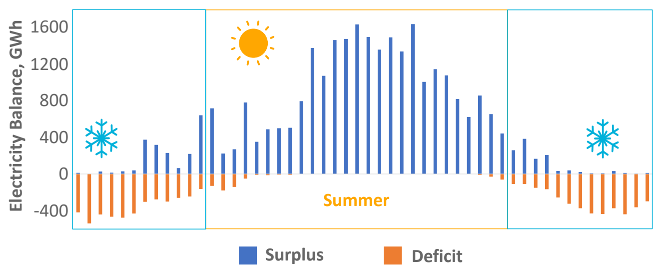
Gravimetric (x-axis) and volumetric (y-axis) energy densities of different options for storing energy chemically over a longer time.

The discharge process consists of reacting these metals with water to produce hydrogen and heat (i.e., oxidation). The share of stored energy converted to hydrogen compared to heat during discharge is highest for iron; thus the share of electricity after hydrogen conversion in a fuel cell is much higher for iron than for aluminium and silicon.

On the other hand, the energy density is considerably higher for aluminium and silicon in comparison to iron, on both volumetric and gravimetric bases.

Advantages of ReMeF

- Extremely high volumetric storage density
- Relatively low cost
- Non-toxic and non-explosive (Al as granules)
- No cryogenic, pressurized storage vessel or pipelines required
- No storage losses and easy and safe transport
- No carbon involved that needs to be (re)-captured



Weekly balance of the Swiss electricity system simulated for the year 2050 (OST-SPF scenario: HighPV+,30°). The electricity surplus accumulated in summer (Apr - Sep) is estimated at 25.5 TWh_e, while the electricity deficit in winter (Oct - Mar) is calculated at 8.2 TWh_e.

Further information and contact
www.spf/peakmetal.ch

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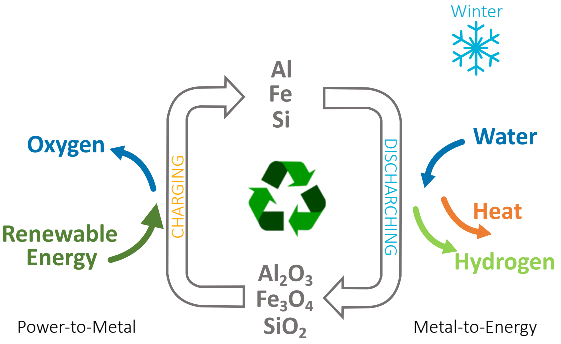
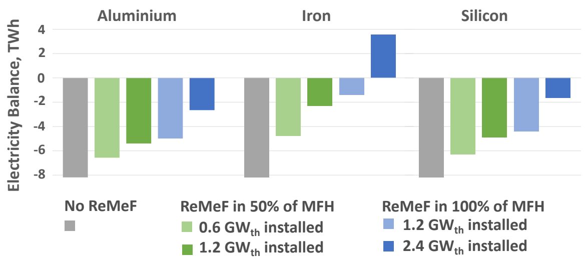
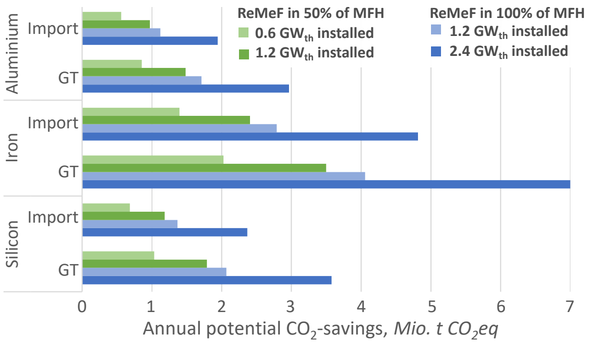


Concept of the ReMeF seasonal energy storage cycle with metals produced from their oxides by removing oxygen in a process consuming renewable electricity for the charging process (Power-to-Metal). The discharging process (Metal-to-Energy) produces both heat and electricity in buildings after conversion of hydrogen in a fuel cell.



Comparison of the Swiss electricity balance in the winter half-year (Oct - Mar) in 2050 in comparison to various scenarios using ReMeF to produce heat and electricity in multifamily homes (MFH). Negative values mean electricity imports or other electricity producing technologies were needed to fulfill electricity demands.



Annual CO_2-savings of ReMeF, produced with PV electricity, replacing winter electricity produced by Gas Turbine (GT) with 204 gCO_2eq/MJe and/or imported electricity from neighbouring countries with projected 153 gCO_2eq/MJ_e in 2050.

ReMeF energy storage cycle concept

ReMeF are high density energy carriers that can be stored loss free for as long as needed and transported over long distances. When or where energy is needed, ReMeF can be oxidized again in a single step using oxygen, or in two steps, first via a metal-water reaction producing hydrogen and metal-hydroxide, and second via oxidation of the hydrogen producing electricity and heat. In order to close the metal material cycle, metal hydroxide is converted to metal oxide. The metal oxide is then used to produce new ReMeF again. This closes the material cycle and meets the criteria of a circular economy.

Potential to reduce the winter energy gap

Different scenarios of the Swiss energy system in the year 2050 were simulated, starting from the energy perspectives 2050+ of SFOE. Instead of electrolysers and fuel cells based on hydrogen, the potential to produce ReMeF in summer as well as to use these in CHP (combined heat and power units) in buildings was evaluated.

The analysis showed that for a Swiss energy system with high solar penetration (45 TWh/a), as simulated by the HighPV+, 30° scenario, there would be a remaining winter electricity gap of 8 to 9 TWh_e if ReMeF is not used. Limiting the energy output of the Metal-to-Energy conversion units to a thermal capacity of 10 kW_{th} installed in each Swiss multifamily home, the winter electricity gap could be reduced to 2 to 3 TWh_e if aluminium- or silicon-water reactions were used to produce heat and electricity.

Using the iron-water reaction to produce hydrogen, which has a much higher proportion of electric output than thermal output, Switzerland could even export 2 to 4 kWh_e in winter with the same installed heating power.

In reality, not all multifamily homes will be equipped with a ReMeF system. However, there is additional potential for ReMeF in district heating and industrial heat and electricity applications that were not included in the results presented here. Regardless of which assumption and scenario was considered, any use of ReMeF resulted in substantially reduced electricity deficit in winter and thus also reduce the need for gas-fired power plants, other Power-to-X energy carriers, or winter electricity imports.

Projected CO_2 emission savings

For Power-to-Metal based on carbon-free metal production (TRL 4 - 7), the climatic effect of all considered ReMeF was dominated by the greenhouse gas emissions of the electricity used for the charging process. This value must be lower than 35 to 50 gCO_2eq/MJ in order to reduce global warming when replacing a mini CHP (Combined Heat and Power) unit using natural gas. Electricity generation with much lower GWP can be achieved with hydro and wind energy (1 to 3 gCO_2eq/MJ) or with rooftop PV (10 gCO_2eq/MJ).

Thus, installing ReMeF CHP units with an average of 10 kW_{th} in multifamily homes in Switzerland could save greenhouse gas emissions of more than 3 Mio. tCO_2eq per year by 2050 if they are used instead of natural gas turbine power plants to reduce the winter gap by the same magnitude.

Power-to-Metal	Aluminium	Iron		Silicon
Technology	Inert electrolysis	Direct reduction with hydrogen	Inert electrolysis	Inert electrolysis
Material input	Aluminium oxide	Ferric oxide (haematite, magnetite)		Silica
Emission	Oxygen	Water	Oxygen	Oxygen
Reduction output	Al (liquid)	Sponge iron (solid)	Fe (liquid)	MG-Si (liquid)*
Metal eduction efficiency, max. %	65	60	65	65
Technology Readiness level, TRL	4-7	6/7	6/7	4
Power-to-Storage efficiency, max. %	**63**	**57**	**57**	**63**
Gravimetric energy density, kWh/kg	8.6	2.0	1.85	9
Volumetric energy density, kWh/m^3	~ 23'300	~ 11'300		~ 21'000

* metallurgical grade

Key parameters of the Power-to-Metal processes analyzed. The gravimetric energy density is the maximum amount of energy that can be transferred to heat and hydrogen in the oxidation, discharge reaction (Metal-to-Energy).

Renewable Metal Fuel research projects at OST:

- **This project: www.spf.ch/peakmetal**
- **Collaborative EU project on aluminium storage: www.reveal-storage.eu**
- **Recycling-Aluminium: www.spf.ch/alencycles**
- **First Alu-to-Energy prototype: www.spf.ch/hybridstock**
- **Feasibility study on aluminium energy storage: www.spf.ch/hepostal**