ETH zürich

PREC Professorship of Renewable Energy Carriers

Renewable Energy Carriers

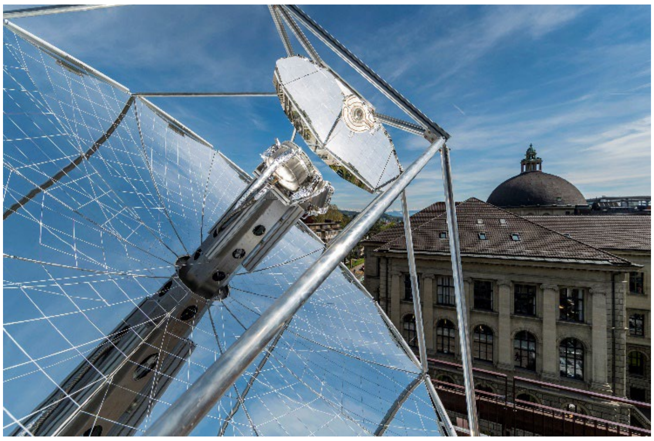
The Professorship of Renewable Energy Carriers (**PREC**, **www.prec.ethz.ch**) is committed to excellence in research and education. It performs pioneering R&D projects in solar energy engineering, operates state-of-the-art experimental laboratories, offers advanced courses in fundamental/applied thermal and chemical sciences, and contributes to the education of qualified scientists and engineers with expertise in renewable energy technologies.

Research

PREC's research program is aimed at the advancement of the thermal and chemical engineering sciences applied to renewable energy technologies. The fundamental research focusses on high-temperature heat/mass transfer phenomena, multi-phase reacting flows, thermochemistry and functional redox materials. These are applied in the development of technologies for concentrated solar power and solar fuels production, solar-driven thermochemical processing of energy-intensive chemical commodities, direct air capture of CO_2 and its utilization, energy storage and sustainable energy systems. PREC pioneers the development of solar concentrating technologies for efficiently producing clean power, fuels, and materials.

R&D involves basic thermodynamic and kinetic analyses, computational fluid dynamics and heat transfer modeling, materials development and characterization, and the engineering design, fabrication, testing, optimization, and scale-up of efficient thermal converters and chemical reactors. Advanced modelling and experimental methodologies, e.g. synchrotron tomography and spectroscopic goniometry, are applied to characterize complex porous structures and determine their effective transport properties.

Experimentation at the High-Flux Solar Simulator – Solar thermal receivers and thermochemical reactors are subjected to high radiative fluxes (> 5,000 suns), and tested at high temperatures (> 1000˚C) and heating rates (> 1000˚C/s), mimicking the radiative heat transfer characteristics of highly concentrating solar systems.



Fuels from Sunlight and Air – The solar mini-refinery mounted on the roof of ETH Machine-Laboratory demonstrates the entire process chain to carbon-neutral fuels. Using concentrated solar radiation, a high-temperature solar reactor splits CO_2 and H_2O extracted directly from ambient air and produces syngas – a tailored mixture of H_2 and CO – which is finally processed into drop-in hydrocarbons such as methanol or kerosene. These transportation fuels are carbon neutral because solar energy is used for their production and because they release only as much CO_2 during their combustion as was previously extracted from the air for their production. In particular, solar kerosene can contribute towards making long-haul aviation sustainable.

At the applied level, the research themes are grouped in 5 categories:

1) Solar power generation

Novel and more efficient technologies are being developed for concentrating solar power (CSP) and concentrating photovoltaics (CPV). For CSP, the investigations are centered on innovative solar parabolic trough, dish, and tower systems with integration of thermal storage and hybridization with fossil-fuel backup. The next generation of solar receiver concepts based on volumetric radiative absorption and alternative thermal fluids operate at high temperatures/high fluxes and yield high energy conversion efficiencies. For CPV, ray-tracing numerical techniques are applied to optimize optical configurations using non-imaging concentrators.

2) Solar fuels production

Solar thermochemical approaches using concentrating solar radiation inherently operate at high temperatures and utilize the entire solar spectrum, and as such provide thermodynamic favorable paths to solar fuel production with high rates and efficiencies. The targeted solar fuel is syngas: a tailored mixture of H_2 and CO that can be further processed to drop-in hydrocarbon fuels (e.g. kerosene, gasoline, methanol) for the transportation sectors. Solar syngas is produced from H_2O and CO_2 via 2-step thermochemical redox cycles. Advanced redox materials and solar reactor concepts are developed for enhanced heat/mass transport, fast reaction kinetics, and high specific fuel yields. Solar reactor modeling guides the engineering design and optimization. Solar reactor prototypes experimentally demonstrate the efficient production of solar fuels and their suitability for large-scale industrial implementation.

3) Solar-driven thermochemical processing

The production and recycling of energy-intensive chemical commodities (e.g. metals, cement, and ammonia) are characterized by their concomitant CO_2 emissions. These emissions can be eliminated by the use of concentrated solar energy as the source of high-temperature heat for the calcination and carbothermic reduction processes. In addition, decarbonization processes – i.e. reforming, pyrolysis, gasification – are investigated with focus on the thermochemical conversion of carbonaceous feedstocks such as agricultural wastes.

4) Thermal energy storage

Sensible, latent, and thermochemical heat storage is applied to intermittent renewable energy sources to enable continuous dispatchability. R&D includes dynamic heat transfer and fluid flow modeling, thermocline/phase-change/thermochemical based systems, experimental demonstration, parametric optimization, and system integration.

5) Direct air capture

The separation of CO_2 directly from atmospheric air – known as “direct air capture” – enables closing the carbon-cycle for the production of drop-in hydrocarbon fuels for transportation. R&D involves fundamental thermodynamic and kinetic studies of the adsorption-desorption cyclic process using an amine-based sorbent operated in a temperature-vacuum swing mode.

Key publications

- “High-Flux Solar-Driven Thermochemical Dissociation of CO_2 and H_2O using Nonstoichiometric Ceria”, *Science*, Vol. 330, pp. 1797–1801, 2010.
- “Concentrating Solar Thermal Power and Thermochemical Fuels”, *Energy & Environmental Science,* Vol. 5, pp. 9234–9245, 2012.
- “Drop-in Fuels from Sunlight and Air”, *Nature*, Vol. 601, pp. 63-68, 2022.

Funding

- European Union
- Swiss Federal Office of Energy
- Swiss National Science Foundation
- Swiss Commission for Technology and Innovation
- Private industry

The ***Solar-driven Thermogravimeter*** enables the analysis of reaction kinetics during direct exposure to concentrated irradiation. Gas product composition is monitored on-line by gas chromatography and mass spectrometry. Solid products are characterized by X-ray diffractometry and scanning electron microscopy.

The ***Spectroscopic Goniometer*** enables the measurement of directional and spectral radiative properties of semi-transparent media, such as complex porous structures applied in thermal and thermochemical energy conversion processes.

Teaching

Undergraduate courses:

- Thermodynamics III
- Energy System & Power Engineering
- Experimental Methods for Engineers.

Graduate courses:

- Radiation Heat Transfer
- Renewable Energy Technologies
- Fuel Synthesis Engineering

Fostering young academics

Awards to PREC’s students: ASME Graduate Student Award to PhD theses of T. Osinga (2002), T. Cooper (2014), and S. Ackermann (2016); ETH Medal to MSc theses of R. Weiss (2004) , H. Ly (2004), F. Meier (2007), J. Wurzbacher (2009), D. Marxer (2013), F. Dähler (2014), R. Khanna (2014), A. Reinhart (2015) and S. Sas (2020); ASME Best Paper Award to T. Osinga (2003), A. Z’Graggen (2004), and L. Schunk (2007); Hilti Prize to PhD theses of W. Lipinski (2006) and A. Z’Graggen (2009); Excellent Scholarship Award to M. Kruesi (2008) and Ph. Good (2009); Shell She Study Award to PhD thesis of V. Nikulshina (2009); Swisselectric Research Award to PhD thesis of I. Hischier (2011); Verein Deutscher Ingenieure Prize to MSc thesis of C. Falter (2011); Chorafas Prize to PhD theses of S. Haussener (2011) and T. Cooper (2014); TMS Best Paper Award to A. Stamatiou and W. Villasmil (2012); European Talent Award for Innovative Energy Systems to MSc thesis of P. Pozivil (2012); ABB Forschungspreis to PhD thesis of S. Haussener (2012); Solar Energy Journal Best Paper Award to T. Cooper and F. Dähler (2013); Hans-Eggenberger Prize to MSc thesis of S. Suter (2013) and PhD thesis of T. Cooper (2014); Runner-up Zuger Wissenschaftspreis to MSc thesis of F. Dähler (2015); ASME Swiss Section Young Engineer Award to MSc thesis of N. Ettlin (2015); Journal of Metals Best Paper Award to N. Tsouganatos (2016); SGVC-Preis to MSc thesis of P. Roos (2017); Materials Research Society Best Oral Presentation to M. Gigantino (2021); BASF Sustainability Poster Award to D. Notter (2022).

PREC’s alumni with faculty positions: Prof. J. Petrasch, Michigan State University; Prof. P. Loutzenhiser, Georgia Institute of Technology; Prof. S. Haussener, EPFL; Prof. J. Scheffe, University of Florida; Prof. E. Galvez, Sorbonne Université; Prof. C. Muhich, Arizona State University; Prof. T. Cooper, York University.

PREC’s spin-off companies:

- Climeworks (www.climeworks.com): technology for CO_2 direct air capture.
- Synhelion (www.synhelion.com): technology for solar fuels production.

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Aldo Steinfeld (PhD University of Minnesota, 1989) is Full Professor at the Dept. of Mechanical and Process Engineering of ETH Zurich, where he holds the Chair of Renewable Energy Carriers. From 1995–2014 he directed the Solar Technology Laboratory at the Paul Scherrer Institute. At ETH Zurich, he served as the Head of the Institute of Energy Technology (2005–2007) and Associate Head of the Dept. of Mechanical and Process Engineering (2007–2009). He was member of the Board of Directors of the International Solar Energy Society (2015-2019).

He served as the Editor-in-Chief of the Journal of Solar Energy Engineering (2005–2009), co-Editor of the CRC Handbook of Hydrogen Energy (2014), and is currently serving in several editorial boards. He has authored over 350 refereed journal papers, filed 27 patents, and supervised 56 PhD theses. His contributions to science and education have been recognized with the ASME Rice Award (2006), the Yellott Award (2008), the European Research Council Advanced Grant (2012), the Int. Solar Energy Society’s Farrington Daniels Award (2013), the Heat Transfer Memorial Award (2013), the ASME Kreith Energy Award (2016), the SOLARIS Life-Long Contribution Award by Japan’s Heat Transfer Society (2021), and the AIChE Sustainable Engineering Research Award (2022). Prof. Steinfeld is member of the Swiss Academy of Engineering Sciences and the Pan-American Academy of Engineering.