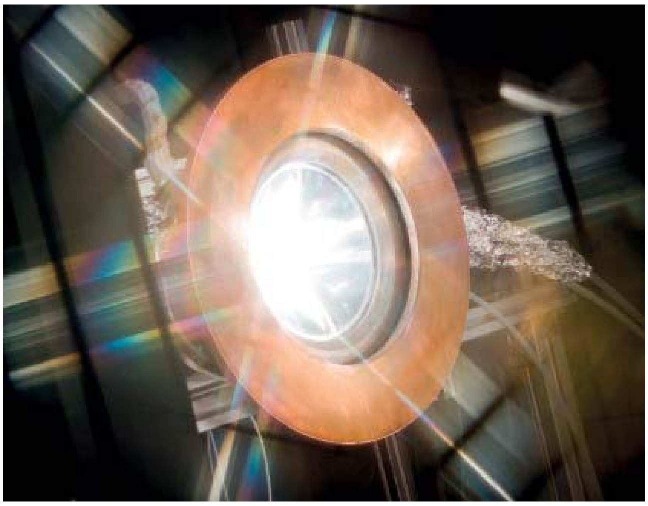
Renewable Energy Carriers

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 emerging fields of renewable energy engineering, operates state-of-the-art experimental laboratories, offers advanced courses in fundamental/applied thermal sciences, and produces qualified scientists and engineers with expertise in renewable energy technologies.



A solar thermochemical reactor prototype for splitting H_2O and CO_2 via redox cycles, exposed to concentrated solar radiation.

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 focus comprises high-temperature heat/mass transfer phenomena and multi-phase reacting flows, with applications in solar power and fuels production, decarbonization and metallurgical processes, CO_2 capture and recycling, energy storage and sustainable energy systems. PREC pioneers the development of solar concentrating technologies for efficiently producing clean power, fuels, and materials.

At the fundamental level, the research themes encompass heat/mass transport phenomena and multi-phase reacting flows in high-temperature energy conversion processes. These involve basic thermodynamic and kinetic analyses, computational fluid dynamics and heat transfer modeling, materials development, and the engineering design, fabrication, testing, optimization, and scale-up of efficient thermal converters and chemical reactors. Advanced experimental methodologies, e.g. synchrotron tomography and spectroscopic goniometry, are applied to characterize complex porous materials 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), under similar radiative heat transfer characteristics of highly concentrating solar systems.

At the applied level, the research themes are grouped in 4 categories:

1) Solar power generation

Novel and more efficient technologies are being developed for concentrating solar power (CSP) and concentrating photovoltaics (CPV), with the goal to reach significant electricity cost reduction. 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 promise higher efficiencies, e.g. via Brayton-Rankine combined cycles. 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 energy inherently operate at high temperatures and utilize the entire solar spectrum, and as such provide thermodynamic favorable paths to efficient solar fuel production. The targeted solar fuel is syngas: a mixture of H_2 and CO that can be further processed to liquid hydrocarbon fuels (e.g. diesel, kerosene, gasoline) for the transportation sectors. Solar syngas is produced from H_2O and CO_2 via 2-step thermochemical redox cycles, consisting of the solar endothermic reduction of a metal oxide followed by the exothermic oxidation of the reduced metal oxide with H_2O/CO_2. 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. This category also includes projects dealing with decarbonization processes – i.e. reforming, pyrolysis, gasification – with focus on syngas production by the thermochemical conversion of carbonaceous feedstocks such as biomass and other carbon-containing wastes.

3) Solar-driven metallurgical processing

The production and recycling of metals (e.g. Al, Si, Zn, Mg, Fe) are energy-intensive processes characterized by their concomitant vast emissions of greenhouse gases and other pollutants. These emissions can be eliminated by the use of concentrated solar thermal energy as the source of high-temperature process heat. R&D involves thermodynamic and kinetic analyses for determining optimal operating conditions and identifying reaction mechanisms, and solar thermochemical reactor engineering for performing the carbothermic reductions with high thermal efficiency and product yield.

4) Thermal energy storage

Sensible, latent, and thermochemical heat storage is applied to intermittent renewable energy sources to enable continuous power dispatchability. R&D includes dynamic heat transfer and fluid flow modeling, experimental demonstration and model validation, parametric optimization of the design and operation, scale-up and system integration.

Key publications

- "Solar Thermochemical Process Technology", *Encyclopedia of Physical Science and Technology*, Academic Press, Vol. 15, pp. 237–256, 2001.
- "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.

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 micrography.

A spectroscopic goniometry system enables the measurement of directional and spectral radiative properties of semi-transparent media, such as complex porous materials 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 I
- Fundamentals of CFD Methods
- Fuel Synthesis Engineering

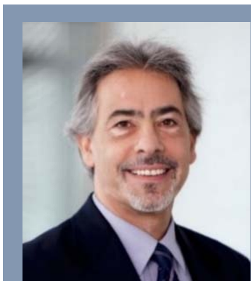
Master specialization – The Master program in Mechanical Engineering with specialization in renewable energy technologies is aimed at providing in-depth education and independent research training, with emphasis in the application of the fundamentals of thermal and chemical engineering sciences for the development of clean and efficient energy technologies.

Fostering young academics

Awards to PREC's students: ASME Graduate Student Award to PhD thesis of T. Osinga (2002); 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), and A. Reinhart (2015); 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 thesis of S. Haussener (2011); 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); ASME Graduate Student Award to PhD thesis of T. Cooper (2014); Hans-Eggenberger Prize to PhD thesis of T. Cooper (2014); Chorafas Prize to 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).

PREC's alumni with faculty positions: Prof. W. Lipinski, Australian National University; Prof. J. Petrasch, University of Applied Sciences Vorarlberg; Prof. P. Loutzenhiser, Georgia Institute of Technology; Prof. S. Haussener, EPFL; Prof. J. Scheffe, University of Florida; Prof. E. Galvez, University Piere et Marie Curie.

PREC's spin-off companies: Climeworks (2009); Sunbiotec (2011).



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Aldo Steinfeld (PhD University of Minnesota, 1989) is 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 from 2005–2007 and Associate Head of the Department of Mechanical and Process Engineering from 2007–2009. He was 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 300 research articles in refereed scientific journals, filed 28 patents, and supervised 34 PhD theses. His contributions to science and education have been recognized with the ASME Rice Award (2006), the Yellott Award (2008), the ERC Advanced Grant (2012), the ISES Farrington Daniels Award (2013), and the ASME Heat Transfer Memorial Award (2013). Prof. Steinfeld is member of the Swiss Academy of Engineering Sciences and of the International Solar Energy Society's Board of Directors.