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.

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 thermochemical processing, CO2 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 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 materials/structures and determine their effective transport properties.

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 H2 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 H2O and CO2 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 H2O/CO2. 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 thermochemical processing
The production and recycling of energy-intensive material commodities (e.g. metals, cement, and ammonia) are 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 and calcination reactions 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 dispatchability. R&D includes dynamic heat transfer and fluid flow modeling, thermocline/phase-change/thermochemical based systems, experimental demonstration, parametric optimization, and system integration.

Key publications

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 diffractionometry 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 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 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

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 Pierre et Marie Curie; Prof. C. Muhlich, Arizona State University; Prof. T. Cooper, York University.

PREC spin-off companies: Climeworks; Sunbiotec; Sunredox.

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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 1999–2014, 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 29 patents, and supervised 48 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), the ASME Heat Transfer Memorial Award (2013), and the ASME Kreith Energy Award (2016). Prof. Steinfeld is member of the Swiss Academy of Engineering Sciences and of the International Solar Energy Society’s Board of Directors.