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Operating Agent IEA-SolarPACES – Task II (Solar Chemistry Research)

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Für den Inhalt und die Schlussfolgerungen ist ausschliesslich der Autor dieses Berichts verantwortlich.

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Abstract

SolarPACES – Solar Power and Chemical Energy Systems – is an Implementing Agreement of the IEA (International Energy Agency) to facilitate technology development, market deployment and energy partnerships for sustainable, reliable, efficient and cost-competitive concentrating solar technologies by providing leadership as the international network of independent experts. The IEA-SolarPACES Task II – Solar Chemistry R&D – Operating Agent (OA), currently *PSI*, Switzerland, is responsible for task organization, operation, and reporting. International solar chemical research, development and demonstration efforts are coordinated in cost, task and/or information-sharing activities. Two annual SolarPACES ExCo Meetings, one annual SolarPACES Task II Meeting, several IEA-HIA Task 25 Meetings, and major solar conferences (SolarPACES and ASME) provide a forum for presenting and discussing major technological achievements. The SolarPACES Annual Report chapter on Solar Chemistry Research helps disseminating up-to-date technical and scientific information.

Project Goals

BFE is contracting party of the International Energy Agency (IEA) SolarPACES Implementing Agreement and has designated PSI as the Operating Agent (OA) of IEA-SolarPACES Task II (Solar Chemistry Research). The international activities of the OA are supported by the BFE [1]. The SolarPACES OA has also been designated as Swiss representative in the IEA-Hydrogen Implementing Agreement (HIA) Task 25 (High Temperature Processes for Hydrogen Production) [2],[3].

SolarPACES [4] – Solar Power and Chemical Energy Systems – is an Implementing Agreement of the IEA (International Energy Agency) [5] to facilitate technology development, market deployment and energy partnerships for sustainable, reliable, efficient and cost-competitive concentrating solar technologies by providing leadership as the international network of independent experts. The IEA-SolarPACES Task II – Solar Chemistry R&D – Operating Agent, currently PSI, Switzerland, is responsible for task organization, operation, and reporting. International solar chemical research, development and demonstration efforts are coordinated in cost, task and/or information-sharing activities by National Coordinators, making use of an efficient network, for the rapid exchange of technical and scientific information. The Task II Annual Meeting provides a forum for presenting and discussing major technological achievements. Currently, 11 countries are participating in Task II (Australia, France, Germany, Israel, Italy, Republic of Korea, Mexico, South Africa, Spain, Switzerland, and USA).

The SolarPACES Task II Program of Work provides an up-to-date description of the national and international projects. When appropriate, Task II conducts a status review on novel technologies for assessing their technical and economical feasibility. Task II is continuously striving to stimulate public awareness of the potential contribution of solar chemistry to clean, sustainable energy services. The primary purpose of Task II is to develop and optimize solar-driven thermochemical processes for the production of fuels and chemical commodities, and to demonstrate their technical and economic feasibility at an industrial scale:

- *Production of chemical energy carriers:* Thermochemical conversion of solar energy into chemical fuels offers an efficient path for long-term storage and long-range transport of solar energy.
- *Processing of chemical commodities:* Use of solar energy for processing energy-intensive, high-temperature materials such as aluminum, lime or cement.
- *Detoxification and recycling of waste materials:* Use of solar energy for detoxification and recycling of hazardous waste and of secondary raw materials.

IEA-HIA [6] – the Hydrogen Implementing Agreement of the IEA (International Energy Agency) – aims to facilitate, coordinate and maintain innovative research, development, and demonstration (RD&D) activities, through international cooperation and information exchange. The overall goal of the IEA-HIA Task 25 is to share worldwide existing know-how on high temperature processes for hydrogen production (HTP) and to develop objective criteria for the global assessment of HTPs to be integrated in a hydrogen production roadmap. Task 25 comprises technical subtasks (A, B and C) and organizational subtask D:

- *Subtask A:* Scientific/technological review and analysis of the high temperature processes, and drafting of the state-of-the-art.
- *Subtask B:* Development of a methodology approach and integration of HTPs.
- *Subtask C:* Establishment of benchmark, recommendations for HTP R&D and future industrial deployment.
- *Subtask D:* Coordination and links with other international activities; dissemination of information.

Activities

The duties of the IEA-SolarPACES Task II Operating Agent (OA) include reporting to the SolarPACES ExCo, organization of the annual Task II Meeting, participation at the IEA-HIA Task 25 Meetings, attending the annual SolarPACES Conference and related events, as well as preparing/editing the SolarPACES Annual Report and related publications. Occasionally, Dr. Daniel Gstöhl from *PSI* and Dr. Peter Loutzenhiser from *PSI/ETHZ* acted as substitutes of Dr. Anton Meier, officially appointed OA.

This report covers the activities of the SolarPACES OA in 2009-2011. A proposal for project continuation during the next five years term (2012-2016) has been submitted to BFE.

Meetings

SolarPACES ExCo Meetings

- March 31 to April 2, 2009:
76th ExCo Meeting, *ETH* Zurich, Switzerland.
Meeting organization: S. Giamboni (*Planair*), C. Daum (*PSI/ETHZ*), A. Meier (*PSI*).
OA activity: OA Report.
19 participants.
ExCo Host Country Day, with visit to *PSI* Solar Facilities. 20 participants from Swiss industries.
- September 13, 2009:
77th ExCo Meeting, Berlin, Germany. In conjunction with SolarPACES Conference.
OA activity: OA Report.
- April 13-15, 2010:
78th ExCo Meeting, Jeju Island, Korea.
OA: Participation cancelled on short notice (personal reasons).
- September 19, 2010:
79th ExCo Meeting, Perpignan, France. In conjunction with SolarPACES Conference.
OA activity: OA Report.
- April 4-6, 2011:
80th ExCo Meeting, Vienna, Austria.
OA: OA Report. *PSI/ETHZ* Report.
- September 18, 2011:
81st ExCo Meeting, Granada, Spain. In conjunction with SolarPACES Conference.
OA activity: OA Report.

SolarPACES Task II Meetings

- September 14, 2009:
23rd Task II Meeting, Berlin, Germany. In conjunction with SolarPACES Conference.
OA activities: Meeting Chair, OA Report, Country Report.
19 participants.
- September 20, 2010:
24th Task II Meeting, Perpignan, France. In conjunction with SolarPACES Conference.
OA activities: Meeting Chair, OA Report, Country Report.
15 participants.
- September 19, 2010:
25th Task II Meeting, Granada, Spain. In conjunction with SolarPACES Conference.

OA activities: Meeting Chair, OA Report, Country Report.
17 participants.

IEA-HIA Task 25 Meetings

- June 4-5, 2009:
3rd Task 25 Meeting, Cadarache, France.
Swiss representative: Dr. Daniel Gstöhl (*PSI*). Country Report.
- October 8-9, 2009:
4th Task 25 Meeting, Zaragoza, Spain.
Swiss representative: Dr. Daniel Gstöhl (*PSI*). Country Report.
- September 26-27, 2011:
7th Task 25 Meeting, Almería, Spain.
Swiss representative: Dr. Anton Meier (*PSI*). Country Report.

Conferences

Participation at conferences is an important activity of the SolarPACES OA (or a substitute) to maintain international contacts, to initiate collaborations, and to disseminate information.

SolarPACES Conferences

- September 15-18, 2009:
15th SolarPACES Conference, Berlin, Germany.
OA poster presentation [7]. Three papers from *PSI/ETHZ* [7]-[9].
- September 21-24, 2010:
16th SolarPACES Conference, Perpignan, France.
OA invited talk [10]. Four papers from *PSI/ETHZ* [11]-[14].
- September 20-23, 2011:
17th SolarPACES Conference, Granada, Spain.
OA invited talk [15]. Three papers from *PSI/ETHZ* [16]-[18].

ASME Conferences

- July 19-23, 2009:
3rd ASME International Conference on Energy Sustainability, San Francisco, CA, USA.
Solar Thermochemistry Track Chair: Dr. Peter Loutzenhiser (*PSI*). Paper presentation [19].
In conjunction with the ASME Conference, Dr. Peter Loutzenhiser (*PSI*) visited the Sandia National Laboratories (*SNL*) both in Albuquerque, NM, and in Livermore, CA. Overall, the trip was a chance to strengthen relationships and collaboration efforts within SolarPACES and familiarize participants with the ongoing research at *PSI/ETHZ*.
- May 17-22, 2010:
4th ASME International Conference on Energy Sustainability, Phoenix, NM, USA.
Solar Thermochemistry Track Chair: Dr. Peter Loutzenhiser (*ETHZ*). Paper presentations [20]-[21].
- August 7-10, 2011:
5th ASME International Conference on Energy Sustainability, Washington D.C., USA.
Solar Thermochemistry Track Chair: Dr. Peter Loutzenhiser (*ETHZ*). Paper presentation [22].

Reports

The SolarPACES Task II OA is reporting on international activities by editing the chapter on Solar Chemistry Research in the SolarPACES Annual Report. In the reporting period, the OA was also preparing a SolarPACES special report and a SolarPACES brochure on solar fuels.

SolarPACES Annual Report

- A. Meier: **Task II: Solar chemistry research**. International Energy Agency – SolarPACES Annual Report 2008, C. Richter ed., Chapter 4, 2009.
<http://www.solarpaces.org/Library/AnnualReports/docs/ATR2008.pdf>
- A. Meier: **Task II: Solar chemistry research**. International Energy Agency – SolarPACES Annual Report 2009, C. Richter ed., Chapter 4, 2010.
http://www.solarpaces.org/Library/AnnualReports/documents/AnnualReport2009Final_web.pdf
- A. Meier: **Task II: Solar chemistry research**. International Energy Agency – SolarPACES Annual Report 2010, C. Richter ed., Chapter 4, 2011.
http://www.solarpaces.org/Library/AnnualReports/docs/AnnRep_2010.pdf

SolarPACES Special Report

- A. Meier, C. Sattler: **Special report on solar fuels**, International Energy Agency – SolarPACES Annual Report 2008, C. Richter ed., Chapter 2, 2009.
<http://www.solarpaces.org/Library/AnnualReports/docs/ATR2008.pdf>

SolarPACES Brochure

- A. Meier, C. Sattler: **Solar fuels from concentrated sunlight**, International Energy Agency – SolarPACES, Brochure, 2009. [23]

National Cooperation

National cooperation is performed within the framework of

- *Hydropole – Swiss Hydrogen Association* (PSI Representative: Dr. Christian Wieckert)

Current collaboration and synergism with other Swiss research laboratories:

- Switzerland *ETH* Zürich – Professorship in Renewable Energy Carriers (Prof. A. Steinfeld)
- ETH* Zürich – Particle Technology Laboratory (Prof. S. Pratsinis)
- EMPA* Dübendorf – Laboratory for Solid State Chemistry and Catalysis (Prof. A. Weidenkaff)

International Cooperation

International cooperation is being performed within the framework of *IEA's SolarPACES Implementing Agreement* (Task II – **Solar Chemistry Research**; Operating Agent: Dr. A. Meier) with

- *IEA's Hydrogen Implementing Agreement* (Task 25 – **High Temperature Hydrogen Production Processes**; Swiss Representative: Dr. A. Meier)
- *Strategic Alliance between PSI and CIEMAT* (Spain) – **Roadmap to Solar Hydrogen Production**.
- *IPHE – International Partnership for the Hydrogen Economy* (Project: **Solar driven high temperature thermochemical production of hydrogen**; Swiss Representative: Prof. Dr. A. Steinfeld). Participants: *CIEMAT* (Spain), *CNRS* (France), *DLR* (Germany), *U. Colorado* (USA), *ETHZ & PSI* (Switzerland), *NU & TIT* (Japan), *WIS* (Israel).
- *SOLLAB – Alliance of European Laboratories on solar thermal concentrating systems*. Collaboration of five leading European solar research laboratories, namely *CIEMAT* (Spain), *CNRS* (France), *DLR* (Germany), *ETHZ & PSI* (Switzerland); Swiss Representative: Prof. Dr. A. Steinfeld.
- *EERA – European Energy Research Alliance*. Joint Program on Concentrated Solar Power (CSP). Participants: *CEA* (France), *CIEMAT* (Spain), *CNRS* (France), *DLR* (Germany), *ENEA* (Italy), *ETHZ* (Switzerland), *FhG-IDE* (Germany), *IMDEA* (Spain), *LNEG* (Portugal), *PSI* (Switzerland), *Uni Perpignan* (France). Swiss Representative: Prof. Dr. A. Wokaun; Swiss Representative for CSP Joint Program: Dr. A. Meier.
- *SFERA – Solar Facilities for the European Research Area* (EU Project). Partners: *CIEMAT* (Spain), *CNRS* (France), *DLR* (Germany), *ENEA* (Italy), *PSI* (Switzerland), *WIS* (Israel)

Current collaboration and synergism with international research laboratories of SolarPACES member and non-member states:

Australia	<i>ANU</i> – Australian National University, Canberra <i>CSIRO</i> – Commonwealth Scientific and Industrial Research Organisation, Newcastle, NSW
France	<i>CNRS</i> – Centre National de la Recherche Scientifique, Odeillo
Germany	<i>DLR</i> – Deutsches Zentrum für Luft- und Raumfahrt, Köln & Stuttgart
Israel	<i>WIS</i> – Weizmann Institute of Science, Rehovot
Italy	<i>ENEA</i> – Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Roma
Japan (no member)	<i>TIT</i> – Tokyo Institute of Technology, Tokyo
Korea	<i>KIER</i> – Korea Institute of Energy Research, Daejeon
Mexico	<i>CIE-UNAM</i> – Centro de Investigación en Energía – Universidad Nacional Autónoma de México, Temixco
South Africa	<i>CSIR</i> – Council for Scientific and Industrial Research, Pretoria
Spain	<i>CIEMAT</i> – Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Madrid & Almería <i>IMDEA Energías</i> – Instituto Madrileño de Estudios Avanzados, Móstoles
USA	<i>Caltech</i> – California Institute of Technology, Pasadena, USA <i>NREL</i> – National Renewable Energy Laboratories, Golden, CO <i>SNL</i> – Sandia National Laboratory, Albuquerque, NM, & Livermore, CA <i>UC</i> – University of Colorado, Boulder, CO

Evaluation 2009-2011 and Outlook 2012-2016

Achievements 2009-2011

During the current term of the SolarPACES Implementing Agreement (2007-2011), special focus was on solar thermal production of hydrogen and synthesis gas (syngas, i.e., mixed gases of H_2 and CO), the latter being the precursor of liquid transportation fuels such as Diesel or jet fuel. Although solar fuel production technologies are in an earlier stage of development than commercial solar thermal electricity generation plants (CSP), they make use of the same solar concentrating infrastructure. The solar chemical reactor technology is being developed at a laboratory scale of 1-10 kW_{th} solar power input. Scaleup of thermochemical processes for hydrogen production to the 100 kW_{th} power level has been reported for metal-oxide-based cycles, such as a mixed iron oxide water-splitting cycle (European project *HYDROSOL-2*) and the solar thermal dissociation of ZnO as part of the two-step ZnO/Zn cycle (Swiss P&D project *Solar2Zinc*). Pilot plants in the power range of 300-1000 kW_{th} have been built for carbothermal reduction of ZnO (European *SOLZINC* Project, 300 kW_{th}), steam reforming of methane (European project *SOLREF*, 400 kW_{th} ; Australian project *SolarGas*, 250 kW_{th}), and steam gasification of various carbonaceous feedstocks to produce high-quality syngas: (a) petcoke, a derivative of heavy crude oil (*SYNPET* industrial project, 500 kW_{th}); (b) coal and low-grade carbonaceous waste (Swiss industrial project *SOLSYN*, 250 kW_{th}); (c) wood waste and other forms of biomass (US industrial project *SundropFuels*, 1000 kW_{th}). Life cycle analyses and economic assessments indicate that solar fuels produced by thermochemical processes can become competitive with conventional fossil-fuel-based processes at current fuel prices, provided credits for CO_2 mitigation and pollution avoidance are applied.

In the term 2007-2011, Task II has intensified cooperation on R&D of solar fuels, and hydrogen in particular, with other organizations to leverage technical expertise, benefit from synergism, and avoid duplication of efforts:

- Under IEA-HIA Task 25 “High Temperature Processes for Hydrogen Production” (2007-2011), an existing R&D roadmap for the development of high-temperature technologies for massive hydrogen production has been updated and various high-temperature thermochemical process factsheets have been prepared. The OA is preparing the final report on the Swiss activities.
- Under the umbrella of the IPHE (International Partnership for the Hydrogen Economy), a consortium of SolarPACES and other partners has initiated an international cooperative effort to research, develop, and demonstrate high-temperature solar thermochemical hydrogen production using a lower-cost receiver/reactor technology. This project is currently on hold due to a lack of funding and intellectual property issues.
- Under the EERA (European Energy Research Alliance) CSP Point Program, the OA has prepared a proposal for a Solar Thermochemical Fuel Production Project including seven solar research institutes from five SolarPACES member countries. The project is expected to take off in 2012.

Task II is continuing high-level international collaboration by exchanging technical and scientific information at annual Task meetings, disseminating technological achievements through scientific publications, web sites, annual reports, and actively participating in international conferences and workshops.

In the reporting period 2009-2011, the OA of SolarPACES Task II has attended the annual ExCo meetings and reported on the task activities. He has organized the annual Task II Meeting. He has welcomed three new member countries (Italy, Republic of Korea, South Africa), which increases the number of countries participating in Task II to 11 (Australia, France, Germany, Israel, Italy, Republic of Korea, Mexico, South Africa, Spain, Switzerland, USA). The OA also participated at the annual SolarPACES conferences in Berlin (2009),

Perpignan (2010), and Granada (2011), where he established contacts with industry and academia for future collaboration.

Participation at the IEA-HIA Task 25 and the ASME conferences broadens the field of solar chemistry research and solar fuels applications. Thus, the concentrating solar community benefits from synergisms of these collaborations.

A comprehensive report on *Solar Fuels from Concentrated Sunlight* [23] was published in 2009 to provide an overview of goals, current status, and future perspectives in this emerging field.

Outlook 2012-2016

During the next term of the SolarPACES Implementing Agreement (2012-2016), an important future activity will be to develop and demonstrate solar thermochemical technologies to produce liquid fuels from water and CO₂. Another central field of research will be the development of novel thermochemical storage (TCS) systems, in addition to thermal energy storage (TES). Cross-cutting activities will take advantage of the unique expertise of the SolarPACES members in solar chemical technologies:

1. Advancement of solar thermochemical technologies for the production of solar fuels such as hydrogen and syngas:
 - Pilot demonstration at 200-500 kW_{th} solar power input and pre-commercialization at the MW_{th}-scale with industrial participation of the most successful near-term transition processes like solar cracking or steam reforming of NG, solar gasification of carbonaceous materials, and solar carbothermal reduction of metal oxides.
 - Demonstration of technical feasibility of high temperature steam electrolysis (HTSE) and multi-step thermochemical processes like iodine sulfur (IS) and hybrid sulfuric acid (WH) cycles for massive production of hydrogen.
 - Scaling up the solar reactor technology to the power level of 100-500 kW_{th} and conceptual design for commercial application of two-step metal oxide redox systems based on Zn/ZnO, SnO/SnO₂, CeO₂/Ce₂O₃ (and Ce-based mixed oxides), MnO/Mn₂O₃, FeO/Fe₃O₄, and mixed iron oxide (Ferrites), which in the long term offer high potential but also high risk of failure.
2. Assessment of environmental impact and economic potential:
 - Life cycle analysis and economic assessment of solar thermochemical processes using concentrated solar radiation as the main or sole source of high temperature process heat.
 - Comparison with conventional processes for H₂ and syngas production.
3. Identification of main technological challenges:
 - Development and testing of improved reactor materials and components for safely and efficiently running thermochemical processes in a solar chemical plant.
 - Implementation of industrially proven heat exchangers in advanced heat recovery systems that are essential for the economics of solar thermochemical processes.
 - Development of enhanced solar concentrating optics including high precision heliostats, secondary concentrators (compound parabolic concentrator, CPC), and specific heliostat field layout for obtaining high solar flux intensities and high temperatures in solar chemical reactors for the production of fuels.
4. Development and optimization of dedicated research infrastructure:
 - Design and construction of 1-10 MW_{th} concentrating solar research and demonstration facilities for large-scale testing of high-temperature thermochemical processes to produce solar fuels.

- Development of strategies for the operation of high-temperature solar chemical demonstration plants.

Goals for 2012. The following goals are set for 2012:

1. The OA will participate and report at the following SolarPACES Meetings in 2012:
 - The 82nd ExCo Meeting will be held in Tel Aviv, Israel (March 2012).
 - The 83rd ExCo Meeting will be held in Marrakech, Morocco (September 9, 2012), followed by the 25th SolarPACES Task II Meeting (September 10, 2012), both in conjunction with the 17th SolarPACES Conference (September 11-14, 2010).
2. The OA will prepare a proposal to the ExCo for funding a Task II activity on “Roadmap to Solar Fuels” (for explanations see below):
 - Preparation of “road show” (written documents and oral presentations)
 - Travel of SolarPACES representatives to host countries (e.g., Australia, South Africa)
 - Workshops and meetings with industry and government representatives in the host countries.
3. A working group lead by the OA will prepare a “road show” that is telling the story of solar fuels. With a well-developed case (e.g. solar reforming/gasification processes for the production of hydrogen or liquid fuels), targeted industry will be approached and informed about the various options for solar fuels production and, thus, CO₂ mitigation.
4. Potential industrial players (oil, gas, coal industry) as well as governments in sunbelt countries will be identified and contacted. SolarPACES representatives will travel to various countries (e.g., Australia, South Africa) and present to local industries and governments the state-of-the-art and the market potential (as far as possible) of the most advanced technologies for solar fuels production.

Publications

Dissemination of information is an important aspect of *SolarPACES* [1] and in particular of the OA. In the following, book chapters co-authored by the OA and invited talks of the OA and co-workers are presented.

Book Chapter

- A. Meier, A. Steinfeld: ***Chemische Brennstoffe aus Solarenergie***, In: Energie, P. R. von Rohr, P. Walde, B. Batlogg Eds., vdf Hochschulverlag AG an der ETH Zürich, ISBN 978-3-7281-3219-2, pp. 107-114, 2009.
- P.G. Loutzenhiser, D. Gstoehl, A. Meier, A. Steinfeld: ***CO₂ splitting via the solar thermochemical cycle based on Zn/ZnO redox reactions***, In: Advances in CO₂ Conversion and Utilization, ACS Books, ISBN: 978-0-8412-2596-1, Chapter 3, pp. 25–30, 2010.
- A. Meier, A. Steinfeld: ***Solar thermochemical production of fuels***, In: Advances in Science and Technology, Trans Tech Publications, Switzerland, **74**, pp. 303-312, 2010.
- A. Meier: ***Solar Fuel Production***, Contributing Author to Chapter 3 “Direct Solar Energy” in: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. v. Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2011.
<http://srren.ipcc-wg3.de/report>

Invited Talks

2009

- D. Gstöhl: **Wasserstoff aus Wasser und Sonnenenergie**, Technikwoche, Kantonsschule Romanshorn, Romanshorn, May 13, 2009.
- A. Meier: **Electricity and hydrogen from concentrated solar energy**, Project Management Institute, Villigen PSI, May 7, 2009.
- A. Meier: **Sonnenenergie – Neue Technologien mit Zukunft**, Ringvorlesung Stern Sonne, Volkshochschule Zürich, University of Zurich, June 4, 2009.
- A. Meier: **Hochtemperatur-Solartechnik – Technologien der Zukunft**, AMI-Kolloquium, Villigen PSI, August 26, 2009.
- A. Meier: **Hochtemperatur-Solartechnik – Sonnenenergie konzentrieren und speichern**, Lions-Club Brugg, Untersiggenthal, September 8, 2009.
- A. Meier: **Towards industrial solar production of zinc and hydrogen**, Swiss Research Program on Industrial High-Temperature Solar Energy (BFE), CSEM, Neuchâtel, November 3, 2009.
- A. Steinfeld: **Solar fuels – Thermochemical processes and reactor technology**,
(a) The Caltech Center for Sustainable Energy Research, Caltech, Pasadena, USA, January 14, 2009.
(b) AIChE Annual Meeting, Nashville, November 12, 2009.
- A. Steinfeld: **Solar fuels**, Eilat Energy Conference, Israel, February 17, 2009.
- A. Steinfeld: **Renewable energy technologies**, Università della Svizzera Italiana, Lugano, May 18, 2009.
- A. Steinfeld: **Solar thermochemical production of fuels for CO₂ mitigation**, Ohio State University, Columbus, USA, June 5, 2009.
- A. Steinfeld: **Fuels from sunlight, water, and CO₂**,
(a) Keynote at ASME 3rd International Conference on Energy Sustainability, San Francisco, USA, July 22, 2009.
(b) UCLA Thermo-fluids Research Seminar Series, Los Angeles, USA, October 16, 2009.
- A. Steinfeld: **Solar fuels and materials**, University of Delaware, Newark, USA, August 12, 2009.

2010

- A. Meier: **Concentrating solar fuels (CSF) for storage and transport of solar energy**, 16th SolarPACES Conference, Perpignan, France, September 23, 2010.
- A. Meier: **Scale-up of solar reactor technology for zinc oxide dissociation**, Symposium 2010 on Industrial High-Temperature Solar Energy, CSEM, Neuchâtel, October 27, 2010.
- A. Steinfeld: **Fuels from sunlight, water, and CO₂**,
 - Arizona State University, Tempe, USA, January 15, 2010.
 - James and Catherine Patten Seminar, University of Colorado, Boulder, USA, January 26, 2010.
 - Universidade de São Paulo, São Paulo, Brazil, May 12, 2010.
- A. Steinfeld: **Measurement instrumentation for high-temperature solar reactor technology**, Sundrop Fuels, Inc., Louisville, Colorado, USA, February 4, 2010.
- A. Steinfeld: **Syngas production via the solar thermal gasification of carbonaceous materials**, Sandia Livermore, USA, February 11, 2010.

- A. Steinfeld: **Present and future R&D projects for concentrated solar power, fuels, and materials**, Symposium 2010 on Industrial High-Temperature Solar Energy, CSEM, Neuchâtel, October 27, 2010.

2011

- I. Alxneit: **Temperature measurement in solar furnaces and solar simulators**, 2nd SFERA Winter School (Solar Fuels & Materials), ETH Zürich, March 24-25, 2011.
- M. Chambon: **Solar thermochemical cycles based on the ZnO/Zn or SnO₂/SnO redox couples**, 2nd SFERA Winter School (Solar Fuels & Materials), ETH Zürich, March 24-25, 2011.
- C. Hutter: **Treibstoffe aus konzentrierter Sonnenenergie**,
 1) Runder Tisch in Zürich – Vortrag und Diskussion, ASPO Schweiz, April 27, 2011.
 2) Volkshochschule Bad Zurzach, December 1, 2011.
- C. Hutter: **Benzin aus Wasser, CO₂ und Sonnenlicht**, F. Hoffmann-La Roche AG Engineering Platform, December 1, 2011.
- A. Meier: **The Zn-based thermochemical cycle for splitting H₂O and CO₂**, 2nd SFERA Winter School (Solar Fuels & Materials), ETH Zürich, March 24-25, 2011.
- A. Meier: **Trends in solar chemistry**, 17th SolarPACES Conference, Granada, Spain, September 23, 2011.
- A. Steinfeld: **Liquid fuels from water, CO₂, and solar energy**,
 1) IMDEA Energy, Madrid, Spain, April 4, 2011.
 2) The University of New South Wales, Sydney, Australia, July 20, 2011.
- A. Steinfeld: **Concentrated solar energy for high-temperature applications**, Keynote, Arica, Chile, June 24, 2011.
- A. Steinfeld: **Fuels from sunlight, water, and CO₂ via thermochemical processes**, Keynote, APCSEET 2011 - 8th Asia Pacific Conference on Sustainable Energy & Environmental Technologies, Adelaide, Australia, July 12, 2011.
- A. Steinfeld: **Solar thermochemical processes for the extractive metallurgical industry**, Swinburne University of Technology, Melbourne, Australia, July 18, 2011.
- A. Steinfeld: **Flüssige Treibstoffe aus Wasser, CO₂, und Sonnenlicht**, Schweizer Technion-Gesellschaft, Zürich, October 26, 2011.
- C. Wieckert: **Konzentrierte Sonnenenergie – Optionen für die zukünftige Energieversorgung**, Rotary Club Baden, January 11, 2011.
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References

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