# **PROCEEDINGS OF**



# World Renewable Energy Forum (WREF) 2012

Including 41st ASES Annual Conference 37th National Passive Solar Conference 7th Renewable Energy Policy and Marketing Conference World Renewable Energy Congress XII Colorado Renewable Energy Society (CRES) Annual Conference

> Denver, Colorado May 13-17, 2012

# **Presented By**





World Renewable Energy Network



ISES International Solar Energy Society





Editor Cheryl Fellows The Fellows Group for the American Solar Energy Society

Copyright © 2012 by American Solar Energy Society. All rights reserved.

### NOTICE

Neither the American Solar Energy Society, Inc., nor any one of the co-sponsors of WREF 2012 makes any warranty, express or implied, or accepts legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately on rights of others. The contents of articles express the opinion of the authors and are not necessarily endorsed by the American Solar Energy Society or by any of the co-sponsors of WREF 2012. The American Solar Energy Society does not necessarily condone the politics, political affiliation and opinions of the authors or their sponsors.

# Copyright © 2012 by the American Solar Energy Society, Inc.

All rights reserved. Printed in the United States of America. No part of the publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without permission of the publisher, except in the case of brief quotations embodied in critical articles and review or where prior rights are preserved.

# LIBRARY OF CONGRESS CATALOGING IN PUBLICATION DATA

Main entry under title: Solar Energy, ASES 2012, Annual Meeting of the American Solar Energy Society, Annual and Passive Proceedings, 2012, World Renewable Energy Forum 2012, World Renewable Energy Congress XII

# 1. Solar Energy Congresses

I. Annual Meeting - American Solar Energy Society
II. Series International Solar Energy Society, American Section, Meeting (2012, DENVER, COLORADO).
III. World Renewable Energy Congress XII

Proceedings of the Annual, Passive and Policy and Marketing Conferences, Denver, Colorado

ISBN: 978-1-938547-04-1 (online resource) ISBN: 978-1-938547-05-8 (CD/DVD)

# **American Solar Energy Society**

The American Solar Energy Society (ASES) is the national individual membership organization dedicated solely to promoting solar energy technologies.

ASES members are engineers, architects, scientists, researchers, educators, builders, planners and interested individuals who support the development and utilization of solar energy technologies. Founded in 1954, ASES is also the United States Section of the International Solar Energy Society (ISES) and works closely with ISES to promote the use of solar energy technologies worldwide. ASES also has over 30 chapter affiliates throughout the U.S.

The ASES mission is to advance the use of solar energy for the benefit of U.S. citizens and the global environment.

To accomplish its mission, ASES operates the following programs:

- ASES publishes SOLAR TODAY, the award-winning magazine providing engaging articles on practical solar technologies. In addition to distribution to members, SOLAR TODAY is available by subscription and in digital formats.
- ASES sponsors the National Solar Energy Conference. This conference showcases the state-of-the-art in solar technologies and features over 300 presentations. The 2013 meeting will be in Baltimore, Maryland, April 18-21, 2013.
- ASES sponsors the National Solar Tour in October each year. Over 150,000 people visit solar installations in homes and businesses across the country at this event.
- ASES publishes briefing papers on the development of solar energy technologies. Written for non-technical audiences, these papers provide excellent background information for people unfamiliar with the field.
- ASES uses the media to educate the public on renewable energy technologies.

American Solar Energy Society 4760 Walnut Avenue, Suite 106 Boulder, CO 80301 USA 303-443-3130 ases@ases.org www.ases.org

# World Renewable Energy Forum 2012

# May 13-17 Denver, Colorado

For the very first time, the American Solar Energy Society's National Solar Conference was held in conjunction with the biennial World Renewable Energy Congress. The combined event, WREF 2012, drew prominent speakers and technical presentations from universities, renewable energy laboratories, installations and industries around the world. WREF 2012 examined how renewable energy technologies address the world's economic, environmental and security challenges at every scale, from off-grid villages to gigawatt power plants.

**WREF 2012** is presented by the American Solar Energy Society, the World Renewable Energy Network, the Department of Energy's National Renewable Energy Laboratory, the Colorado Renewable Energy Society and the International Solar Energy Society. Conference program chair is Dr. Chuck Kutscher, principal engineer and group manager of NREL's Thermal Systems Group. Co-chairs are Susan Greene, president of ASES, and Professor Ali Sayigh of the World Renewable Energy Congress.

# **International Organizing Committee**

Chair: Chuck Kutscher, NREL, Golden, Colorado Co-Chair: Susan Greene, American Solar Energy Society, Boulder, Colorado Co-Chair: Ali Sayigh, World Renewable Energy Network, London, England

> David Hill, American Solar Energy Society David Renne, International Solar Energy Society Paulette Middleton, International Solar Energy Society Lorrie McAllister, Colorado Renewable Energy Society

# World Renewable Energy Forum 2012

# May 13-17 Denver, Colorado

### **The Technical Review Committees**

Members of the Technical Review Committees (TRC's) review all abstracts for their particular conference (and tracks), make final decisions as to which authors will be invited to write papers and present their work at the conference, organize accepted abstracts into technical sessions, schedule the sessions, and select chairs for each session. In addition, they help to publicize the conference to their own colleagues and networks. Members of the TRC's are experts in their respective fields.

#### Annual Technical Review Committee Co-Chairs : David Renne and Thomas Stoffel

Energy Generation, Distribution,	Low Temperature Solar Thermal Technologies and
and Transportation	Renewable Electric Technologies
Melinda Marquis	Jay Burch
Jazaer Dawody	Robert Critoph
Jan Kleissl	Steve Sargent
AJ Rossman	Jan Olof Dalenback
David Borton	Phil Eames
John Boland	Tom Lane
Terry Penney	Carl Bingham
Don Swift-Hook	Neelkanth Deere
Scotte Elliott	Veere Gude
	Aaron Godwin
	Marlene Brown
	A Lejeune
	Arthur Williams
	Rolf Hanitsch
	Thorsten Sigfusson
	David Milborrow
	Bakr Bahaj
	Giuliano Premier

(continued)

#### **Passive Technical Review Committee**

**Co-Chairs:** Doug Balcomb, Bill Watts Walter Grondzik Margot McDonald Vikram Sami Liliana Beltran Dennis Andrejko Rob Pena Kirsten Sandler

#### **Policy and Marketing Technical Review Committee**

**Co-Chairs:** David Hill, Rainer Hinrichs-Rahlwes Larry Sherwood Jeff Peterson Heidi Van Genderen D.A. Elliott

### Energy Access, Social Dimensions and Environmental Benefits Technical Review Committee

**Co-Chairs:** Paulette Middleton, Giuliano Premier Brian Allen João Tavares Pinho

### Energy and Gender Technical Review Committee Chair: Barbara Farhar

Shannon Cowlin Priyadarshini Karve Mercy Thomas Long Seng To

### Climate Change Technical Review Committee Chair: Chuck Kutscher Melinda Marquis Bakr Bahaj

### World Renewable Energy Congress - Special Papers in Renewable Energy Technical Review Committee Chair: Phil Eames John Boland A. Lejeune Ali Sayigh

Thorsten Sigfusson

Copyright © 2012 by American Solar Energy Society. All rights reserved.