renewable energy summit

University of Wyoming
Sunday, June 12 – Tuesday, June 14, 2016

Conference Information

The University of Wyoming Center for Photoconversion and Catalysis, Wind Energy Research Center and School of Energy Resources are pleased to welcome you to the Renewable Energy Summit at the University of Wyoming in Laramie, Wyoming taking place Sunday evening June 12 through Tuesday afternoon June 14.

The purpose of the Summit is to bring together the solar and wind energy communities, including science and technology development through "big picture" policy and management perspectives, for a timely overview of the current state and future direction of renewable energy development.

The Summit will start with a keynote lecture on Sunday evening given by Bill Ritter, former Governor of Colorado and the founder and director of the Center for the New Energy Economy (CNEE) at Colorado State University, who will provide an overview of the present status and future of renewable energy with an emphasis on the western United States.

The Summit will continue on Monday, June 13 and Tuesday, June 14 with plenary sessions focusing on wind and solar energy respectively. The morning sessions will consist of a plenary speaker and three invited speakers discussing the societal and financial aspects of wind and solar energy with the afternoon sessions dedicated to a plenary speaker and three invited speakers focusing on the technical and scientific issues related to these renewable energy sources.

Monday evening will be a poster session where post-doctoral researchers and graduate students will have an opportunity to present their research, interact with distinguished speakers and compete for poster prizes.

Events take place at the following venues:

Hilton Garden Inn
2229 Grand Avenue
Laramie, WY 82070

The Berry Biodiversity Conservation Center
University of Wyoming
10th & Lewis
Laramie, WY 82071

Laramie Railroad Depot
1st and Kearney
Laramie, WY 82070

Schedule Overview

Sunday, June 12 – Arrivals and Welcome Dinner

Time	Function	Location
12:45 PM – 5:30 PM	Optional Wind Farm Tour	7 Mile Hill
6:00 PM – 7:00 PM	Welcome Reception	Hilton Garden Ballroom I
7:00 PM – 9:00 PM	Bill Ritter Keynote Address	Hilton Garden Ballroom II

Monday, June 13 – Wind Energy Focus

Time	Function	Location
Morning	Breakfast on Own	
8:30 AM – 10:10 AM	Morning Session	The Berry Center
10:10 AM – 10:30 AM	Morning Break	The Berry Center
10:30 AM – Noon	Morning Session *Continues*	
Noon – 1:30 PM	Lunch	The Berry Center and surrounding areas
1:30 PM – 3:10 PM	Afternoon Session	The Berry Center
3:10 PM – 3:30 PM	Afternoon Break	The Berry Center
3:30 PM – 5:00 PM	Afternoon Session *Continues*	The Berry Center
5:30 PM – 7:00 PM	Poster Session and Reception	Laramie Railroad Depot
7:00 PM	Dinner on Own	

Tuesday, June 14 – Solar Energy Focus

Time	Function	Location
Morning	Breakfast on Own	
8:30 AM – 10:10 AM	Morning Session	The Berry Center
10:10 AM – 10:30 AM	Morning Break	The Berry Center
10:30 AM – Noon	Morning Session *Continues*	
Noon – 1:30 PM	Lunch	The Berry Center and surrounding areas
1:30 PM – 3:10 PM	Afternoon Session	The Berry Center
3:10 PM – 3:30 PM	Afternoon Break	The Berry Center
3:30 PM – 5:00 PM	Afternoon Session *Continues*	The Berry Center

SUNDAY, JUNE 12

Optional Wind Tour to 7 Mile Hill
Space is limited. Please register in advance. Fruit, granola bars and bottled water will be provided.

12:45 PM Meet in the lobby of the Hilton Garden Inn
1:00 PM Transportation to depart for the 7 Mile Hill Wind Farm (located between Medicine Bow and Hanna, WY)
2:00 - 4:00 PM Tour
4:15 PM Transportation to depart from 7 Mile Hill
5:30 PM Group to arrive back at the Hilton Garden Inn

Welcome Reception
6:00 PM – 7:00 PM in Garden Ballroom I at the Hilton Garden Inn
Please join us for networking and hors d'oeuvres. Two drink tickets will be provided followed by a cash bar.

Keynote Address by Bill Ritter
7:00 PM – 9:00 PM in Garden Ballroom II at the Hilton Garden Inn
Cookies and coffee will be provided. Public welcome.

Bill Ritter
Director of the Center for the New Energy Economy (CNEE) at Colorado State University and Former Governor of Colorado

Bill Ritter Jr. is currently the Director of the Center for the New Energy Economy (CNEE) at Colorado State University. The Center started February 1, 2011 with Ritter as the founding Director. In addition to the Director the Center now employs an Assistant Director, two Senior Policy Advisors and an Executive Assistant. Ritter was elected as Colorado's 41st governor in 2006 -- the first Colorado-born governor in more than 35 years. Ritter led Colorado forward by bringing

people together to tackle some of our state's biggest challenges. During his 4 year term Ritter established Colorado as a national and international leader in renewable energy by building a New Energy Economy that is creating thousands of new jobs and establishing hundreds of new companies; enacted an aggressive business-development and job-creation agenda that is focused on knowledge-based industries of the future such as energy aerospace biosciences information technology and tourism; initiated sweeping K-12 education reforms to give Colorado children the skills and knowledge they need to compete and succeed in a 21st century global economy; and improved access to quality and affordable health care for many of the 800,000 Coloradans who lack health coverage.

Ritter served as Denver's District Attorney from 1993 to January 2005. He earned a national reputation as one of the country's most effective and innovative prosecutors and several of his programs continue to serve as state and national models.

The sixth of 12 children Ritter was raised on a small farm in Arapahoe County. He was a member of the first graduating class of Gateway High School (1974) and he earned his bachelor's degree in political science from Colorado State University (1978) and his law degree from the University of Colorado (1981).

Ritter is married to Jeannie and before his serving as District Attorney he and Jeannie operated a food distribution and nutrition center in Zambia. They have four children; August, Abe, Sam and Tally.

Powering Forward: What Everyone Should Know About America's Energy Revolution
A historic energy revolution is underway in the United States. Wind, sunlight, and other sustainable resources are now the fastest growing sources of energy in the U.S. and worldwide. American families are installing power plants on their roofs and entire communities are switching to 100 percent renewable energy. Author Bill Ritter, Jr., the 41st governor of Colorado and one of America's key thought leaders on this topic, will discuss the forces behind the energy revolution, the new ways we must think about energy, and the future of fossil and renewable fuels. His new book is an essential read for any who want to understand one of history's biggest challenges to peace, prosperity, and security in the United States. Written in partnership with the Center for a New Energy Economy.

MONDAY, JUNE 13 - WIND ENERGY FOCUS

8:30 AM	Welcome
8:35 AM – 9:30 AM	Plenary Lecture **Scott Beyer**, *Director of Transmission Planning, PacificCorp* Transmission Planning and Variable Generation Integration
9:30 AM – 10:10 AM	**Dr. John Pierre**, *Professor of Electrical & Computer Engineering, University of Wyoming* Applications of Synchrophasor Measurements for Improved Power System Reliability
10:10 AM – 10:30 AM	Morning Break
10:30 AM – 11:10 AM	**Dr. Jonathan Naughton**, *Professor and Director of the Wind Energy Research Center, University of Wyoming* Geographical Diversity for Enhanced Production and Deployment of Renewable Energy
11:10 AM – Noon	**Ryan Jacobson**, *Director of Engineering and Construction, Power Company of Wyoming* Developing Wind Energy Projects: Lessons Learned from the Chockcherry and Sierra Madre Wind Energy Project
Noon – 1:30 PM	Lunch available to enjoy in areas surrounding the Berry Center Opportunity to view the Berry Center's roof-top solar panels

1:30 PM – 2:30 PM	Plenary Lecture Paul Veers, *Director, Chief Engineer, National Renwable Energy Laboratory* NREL's National Wind Technology Center takes on the challenge of enabling wind energy to supply a major portion of the US electricity needs
2:30 PM – 3:10 PM	Dr. Sue Ellen Haupt, *Director, Weather Systems Assessment Program, National Center for Atmospheric Research (NCAR)* Meteorology Models Enabling Wind Energy
3:10 PM – 3:30 PM	Afternoon Break
3:30 PM – 4:10 PM	Dr. Dimitri Mavriplis, *Max Castagne Professor, Department of Mechanical Engineering, University of Wyoming* Multidisciplinary Blade Resolved Wind Farm Simulations using High Performance Computing
4:10 PM – 4:50 PM	Dr. Manjinder Singh, *Senior Researcher, Envision Energy* Wind Turbine: Field Validation and Aeroacoustics
4:50 PM – 5:00 PM	Wind Energy Wrap Up
5:30 PM – 7:00 PM	Reception and Poster Session at the Laramie Railroad Depot
7:00 PM	Dinner on Own

SPEAKER BIOGRAPHIES AND CONFERENCE ABSTRACTS *(IN ORDER OF PRESENTATION)*

Scott Beyer
Director of Transmission Planning, PacificCorp

Scott Beyer is Director of Transmission Planning for PacifiCorp - an electric generation, transmission and distribution utility serving customers in six western states. Scott's area of responsibility includes planning of the main grid transmission and sub-transmission systems in Washington, Oregon and California.

Areas of expertise include evaluation of generation interconnection requests, transmission service requests and new large load additions; long term transmission system planning to support changing loads and resources over a large geographic area; NERC reliability transmission planning assessments and path ratings studies. Scott is a member of the Western Electricity Coordinating Council Planning Coordination Committee and the Northwest Power Pool Transmission Planning Committee.

Transmission Planning and Variable Generation Integration
Recent challenges and successes with integration of variable generation resources into the western regional transmission system can help inform future transmission planning and generation interconnection studies. This presentation provides examples and case studies of transmission planning challenges and operational issues experienced during the wind resource interconnection boom of the early 2000's. Various solutions implemented to address those operational issues are presented, along with a discussion of the ability to apply those experiences to better mitigate similar concerns in the future. Additionally, the presentation provides a look ahead toward upcoming transmission planning efforts associated with the potential for large amounts of new distributed and utility scale solar generation projects displacing conventional generation resources in the western United States.

Dr. John Pierre
Professor of Electrical & Computer Engineering, University of Wyoming

Professor John Pierre earned his B.S. degree in Electrical Engineering with a minor in Economics from Montana State University in 1986. After working as an electrical design engineer for Tektronix, he continued his education at the University of Minnesota earning his M.S. and Ph.D. degrees in EE in 1989 and 1991, respectively, with a minor in Statistics. He joined the faculty at UW in 1992.

Dr. Pierre's research interests include electric power grid reliability monitoring, applied statistical signal processing, and digital signal processing education. Since joining UW, he has received over $7 million in external grants as principal or co-principal investigator. This funding has come from a variety of sources including the National Science Foundation, the Department of Energy, NASA, Bonneville Power Administration, Tektronix, Power Systems Research Consortium, and the Rockwell Foundation. He has one patent and a second pending.

Dr. Pierre is an Institute of Electrical and Electronics Engineers (IEEE) Fellow, which is the highest standing in the IEEE professional society for electrical engineers. He has published over 135 professional journal and conference papers. Over 60 percent of those have been co-authored by graduate students involving 29 students. He has advised or co-advised many graduate students including 12 Ph.D. students. His graduate students have gone on to take jobs in industry, government laboratories, and universities. Dr. Pierre teaches courses at every level from freshman through graduate. He has taught nine different undergraduate and eight different graduate courses. He received the Mortar Board Top Prof Award in 2000, 2002, and 2012. In 2005, he received UW's College of Engineering Sam Hakes Research and Graduate Teaching Award.

Applications of Synchrophasor Measurements for Improved Power System Reliability

People have come to expect reliable electric power transmission and distribution. When large outages occur, the disruption to business, daily life, and human safety is tremendous. Power grids are becoming more complicated with increased demand for electricity, more sophisticated loads, increased renewable generation, and limited expansion of the transmission system. The behavior of such large interconnected grids is becoming more difficult to model. The Department of Energy (DOE) and utilities are investing heavily in new measurement equipment, which are GPS synchronized to provide control centers with high data rate system measurements intending to improve grid reliability. Researchers at UW have been involved with these measurements since their infancy in the mid 1990's. UW has collaborated with DOE, WECC, Pacific Northwest and Sandia National Laboratories, Bonneville Power Administration, many utilities, other universities, and control center vendors. Researchers at UW are some of the first to develop applications for these new measurements. This talk explores those applications, including monitoring electromechanical oscillations which can cause wide area blackouts, and detection of forced oscillation which can disrupt the system and cause equipment failure leading to larger problems if not addressed. Success stories from control centers will also be presented.

Dr. Jonathan Naughton

Professor and Director of the Wind Energy Research Center, University of Wyoming

Jonathan W. Naughton has been a faculty member in the Mechanical Engineering Department at the University of Wyoming since 1997 and is currently a Professor and Director of the Wind Energy Research Center. Dr. Naughton obtained his B.S. from Cornell University and his Ph.D. from Pennsylvania State University in the area of compressible fluid dynamics. Dr. Naughton's research includes the development measurement techniques and their application to unsteady flows. As the director of the Wind Energy Research Center, Dr. Naughton interacts with industry, government labs, state organizations, and academic institutions involved in developing the understanding and technology necessary for expanding the penetration of wind energy into the electricity market with a particular focus on the development of Wyoming wind resources. Faculty from the center were recently awarded a 4.25 million dollar grant considering the interaction between wind farm efficiency, transmission stability, and economics of transmission.

Geographical Diversity for Enhanced Production and Deployment of Renewable Energy

As renewable energy continues to increase the percentage of electricity supplied to the North American market, issues such as resource variability, economic impacts, and decisions about transmission expansion grow in importance. In the past, utilities, balancing authorities, and state regulators have had difficulty making informed decisions about what resources to add and what transmission proposals to support due to the lack of tools available to assess such questions. Over the past several years, researchers at the University of Wyoming have been developing a number of tools to help with such decisions. One example is a means of assessing the best combination of renewables to add to a current renewable portfolio. This data-based tool that determines Renewable Energy Quality Metrics (REQMs) shows that geographic and resource diversification is important to developing renewable energy resources that facilitate their integration into the grid. However, for this to be realized, the ability to move power between locations is critical. In addition to this specific tool, this talk will discuss the range of tools under development that can assist in better developing and using our renewable energy and transmission assets.

Ryan Jacobson
Director of Engineering and Construction, Power Company of Wyoming

Ryan Jacobson is the Director of Engineering and Construction for the Power Company of Wyoming. In this role Mr. Jacobson coordinates the technical development, design, and construction of the Chokecherry and Sierra Madre Wind Energy Project, a planned 1,000 wind turbine project in Carbon County, Wyoming. Ryan has been in the wind energy industry for 20 years, and prior to his current role was the Manager of Wind Energy Services for the international engineering firm Black & Veatch, and tested prototype wind turbines for the National Renewable Energy Lab.

Developing Wind Energy Projects: Lessons Learned from the Chockcherry and Sierra Madre Wind Energy Project
The presentation will discuss the primary issues involved in wind energy development, especially in the Western US. Critical issues including landowner concerns, wildlife, wind resource, transmission, and government requirements will be discussed. Examples will be pulled from the development of the Chokecherry and Sierra Madre Wind Energy Project, a Wyoming wind development that, when completed, will be the largest wind energy project in North America.

Paul Veers
Director, Chief Engineer, National Renwable Energy Laboratory
Paul Veers is the Chief Engineer at NREL's National Wind Technology Center and is responsible for the portfolio of research projects conducted by NREL on behalf of the US Department of Energy. He has worked in the area of wind energy technology since 1980, conducting research on wind energy systems including atmospheric turbulence simulation, fatigue analysis, reliability, structural dynamics, aeroelastic tailoring of blades, and the evaluation of design requirements. Prior to his role at NREL, he was a Distinguished Member of the Technical Staff at Sandia National Laboratories. Paul has authored over 70 articles, papers, book chapters and reports and for twelve years was the Chief Editor for *Wind Energy*, an international journal for progress and applications in wind power. He has a M.S. in Engineering Mechanics from the University of Wisconsin and a Ph.D. in Mechanical Engineering from Stanford University.

NREL's National Wind Technology Center takes on the challenge of enabling wind energy to supply a major portion of the US electricity needs
The National Renewable Energy Laboratory (NREL) operates the National Wind Technology Center (NWTC) for the US Department of Energy (DOE). The NWTC, established in1977 near Boulder, Colorado, is home to approximately 150 staff from NREL and both domestic and international partners. The NWTC operates testing capabilities including modern utility- and distributed-scale research turbines, structural blade testing, dynamometer drivetrain testing, controls research turbines and a controllable grid interface to mimic a variety of potential grid faults and dynamics. DOE has a vision of wind energy supplying 35% of the US electricity demand by 2050. Enabling such a high penetration of wind will require significant advances in basic science of wind technology, transmission-level grid support, international standards, and simulation tools. The recent DOE initiative in High Fidelity Modeling, called Atmosphere to Electrons (A3e) is supported through computational modeling efforts already being applied to full wind plant simulations of the atmospheric flow. These calculations show how wind turbine wakes interact with other turbines, and have provided insight into how they can be controlled. Some recent research results are summarized to illustrate how NWTC is making a bright future for wind energy possible.

Dr. Sue Ellen Haupt
Director, Weather Systems Assessment Program, National Center for Atmospheric Research (NCAR)

Dr. Sue Ellen Haupt is a Senior Scientist and Director of the Weather Systems and Assessment Program with the Research Applications Laboratory of the National Center for Atmospheric Research. She also serves as Director of Education for the World Energy and Meteorology Council, Adjunct Professor of Meteorology at Pennsylvania State University, and a Councilor for the American Meteorological Society. She earned her Ph.D. in Atmospheric Science from the University of Michigan (1988), M.S. in Mechanical Engineering from Worcester Polytechnic Institute (1984), M.S. in Engineering Management from Western New England College (1982), B.S. in Meteorology from Penn State (1978), and did a postdoctoral fellowship with the Advanced Study Program of NCAR.

She has also been on the faculty of the University of Colorado/Boulder; the U.S. Air Force Academy (visiting); University of Nevada, Reno; and Utah State University and previously worked for the New England Electric System and GCA

Corporation. She is an expert in meteorology applied to renewable energy, boundary layer meteorology, large scale atmospheric dynamics, dynamical systems, numerical methods, artificial intelligence methods, and computational fluid dynamics. Dr. Haupt has authored and edited several books and published numerous journal articles on these topics.

Meteorology Models Enabling Wind Energy

Understanding meteorology is critical to developing and utilizing the variable wind resource. For resource planning and wind farm siting, it is important to quantify the mean resource, its interannual variability, and potential changes to the resource under potential future climate conditions. Understanding variability and site-specific turbulence characteristics enables optimizing wind farm operations and micrositing of wind turbines. It additionally provides information about extreme events that helps in planning for maintenance and reliable power production. Real time forecasting on scales ranging from minutes to weeks aid utilities in integrating this variable renewable energy into their unit commitment planning and grid operations. This talk will provide examples of how modeling and forecasting for each of these needs provides information that facilitates deployment of larger amounts of renewable energy, leading to a more sustainable, clean, secure, and economically competitive energy future.

Dr. Dimitri Mavriplis

Max Castagne Professor, Department of Mechanical Engineering, University of Wyoming

Dimitri Mavriplis is the Max Castagne Professor in Mechanical Engineering at the University of Wyoming. He obtained his Bachelor and Master degrees in Mechanical Engineering from M^{c}Gill University in Montreal Canada, and his PhD in Mechanical and Aerospace Engineering from Princeton University. He spent over 15 years as a research scientist at the Institute for Computer Applications in Science and Engineering (ICASE) at NASA Langley Research center in Hampton VA, prior to joining the University of Wyoming in 2003. At the University of Wyoming, he leads a research group focused on the development of CFD algorithms and software for high performance computing focused on aerodynamic and aeroelastic analysis and design methods for aerospace and wind energy applications. He has been closely involved with the development of HPC on campus throughout his tenure at UW, both in relation to the inception of the NWSC and the ARCC at UW. He is also the director of the recently formed Computational Science and Engineering Cluster under the Wyoming Engineering Initiative.

Multidisciplinary Blade Resolved Wind Farm Simulations using High Performance Computing

Wind plant modeling involves multiple physics which span many scales, from the millimeter size thin aerodynamic blade boundary layers, to the complete wind plant scale of several kilometers. Until recently it was assumed that simulations capturing all relevant scales were unfeasible. However, recent advances in high performance computing hardware, coupled with novel algorithms, and more rigorous software development procedures have enabled high fidelity multidisciplinary simulations of complete wind farms. These capabilities can be used to provide a better understanding of individual wind turbine performance and service life, as well as to assess and optimize the performance of complete wind plants. This talk will discuss some of the technologies required to build a complete wind farm simulation capability and will emphasize the multidisciplinary nature of these technologies, which must draw on expertise in diverse areas including applied mathematics, computer science and mechanical engineering. The formulation of efficient numerical solvers, which minimize the number of arithmetic operations required to solve systems of non-linear equations, as well as techniques for achieving scalability of these algorithms on massively parallel computer architectures will be discussed. A flexible software structure that enables tight coupling of multiple disciplines within a single simulation will then be described and the application of these technologies to large aerodynamic and aeroelastic analysis and optimization problems including individual wind turbines as well as complete wind farms will be shown. The talk will conclude by discussing the prospect for future advances in simulation capability as we advance towards the exascale era.

Dr. Manjinder Singh

Senior Researcher, Envision Energy

Manjinder Singh is currently working with Envision Energy as Senior Researcher with an emphasis on Wind Turbine Acoustics and Field Validations tools. Before Joining Envision Energy in November of 2015, Manjinder Singh was employed as a Senior Engineer with Siemens Wind Power for a period of almost 5 years. While with Siemens, Manjinder Singh worked on various aspects of wind turbine design and operation. This included prototyping and acoustic validation, development of acoustic mapping techniques, aerodynamic validation using real time pressure measurement on a wind turbine blade, etc. He worked very closely with National Wind Technology Center (NWTC) to develop models essential for processing of real time pressure data acquired on a large utility scale wind turbine rotor.

Prior to his career in the wind industry, Manjinder Singh joined Wind Energy Research Center of University of Wyoming as a Post Doc in 2008, where he focused on developing low order representations of Large Eddy Simulations of atmospheric boundary layer using techniques like, Proper Orthogonal Decomposition (POD) and Linear Stochastic Estimation (LSE). The project was conducted in collaboration with National Center for Atmospheric Research (NCAR). Manjinder finished his PhD from University of Wyoming in 2008, with an emphasis on Flutter Control Using High Speed Mechanical Actuators.

Wind Turbine: Field Validation and Aeroacoustics
In the last few years, design objectives of wind turbines have evolved to place a greater emphasis on capacity factor. This in turn demands bigger rotor diameters (and therefore naturally flexible) and higher towers. However, the need for faster design tools in the industry dictates use of low fidelity models that may or may not be able to capture the complexity of the physics involved. Thus, a higher priority must be put on validation of these tools. Part of this talk will highlight current activities for tool validation within the industry.
Unfortunately, bigger rotor also come at the cost of higher tip speed. This translates into higher acoustic emissions from the turbine, which are currently very tightly regulated by either national or local regulations. To meet the regulations, wind turbines are often de-rated leading to heavy losses in Annual Energy Production (AEP). In addition to the tool validation, this talk will layout the factors that control the acoustic behavior of a utility scale turbine and mitigation measures that are used in industry today.

TUESDAY, JUNE 14 - SOLAR ENERGY FOCUS

8:30 AM	Welcome
8:35 AM – 9:30 AM	Plenary Lecture **Dr. Michael Woodhouse**, *Energy Economics Analyst, The National Renewable Energy Laboratory Strategic Energy Analysis Center* An overview of the global solar market, and technology innovations needed to achieve widespread grid price parity
9:30 AM – 10:10 AM	**Gregory Stark**, *Gregory Stark, Senior Engineer, National Renewable Energy Laboratory (NREL)* Putting Renewable Generation Integration Costs into Perspective
10:10 AM – 10:30 AM	Morning Break
10:30 AM – 11:10 AM	**Dr. Carrick Eggleston**, *Professor in the Department of Geology and Geophysics and Associate Director of the Center for Photoconversion and Catalysis, University of Wyoming* Solar Energy in Developing Countries - Challenging Assumptions
11:10 AM – Noon	**Dr. Carl Koval**, *Professor and Chair, Dept. of Chemistry and Biochemistry, and Fellow and Founding co-Director, Renewable and Sustainable Energy Institute, University of Colorado at Boulder* Solar Energy Storage, Hydrogen Economy, Solar Fuels and Artificial Photosynthesis
Noon – 1:30 PM	Lunch available to enjoy in areas surrounding the Berry Center Opportunity to view the Berry Center's roof-top solar panels
1:30 PM – 2:30 PM	Plenary Lecture **Dr. William Tumas**, *Associate Laboratory Director, Material and Chemical Science and Technology, National Renewable Energy Laboratory* Advances in Solar Energy R&D at NREL
2:30 PM – 3:10 PM	**Dr. Reuben Collins**, *Associate Director of the Renewable Energy Materials, Colorado School of Mines* Silicon Photovoltaics: Today, Tomorrow and Beyond

3:10 PM – 3:30 PM Afternoon Break

3:30 PM – 4:10 PM **Dr. James Sites**, *Senior Associate Dean for Research, College of Natural Sciences, Colorado State University*
Thin-Film Solar Cells

4:10 PM – 4:50 PM **Sean Shaheen**, *Associate Professor and Associate Chair for Education, Electrical, Computer, and Energy Engineering Institute and Renewable and Sustainable Energy Institute (RASEI), University of Colorado Boulder*
Recent Advances and Future Prospects for Organic and Hybrid Organic-Inorganic Perovskite Photovoltaics

4:50 PM – 5:00 PM Solar Energy Wrap Up

SPEAKER BIOGRAPHIES AND CONFERENCE ABSTRACTS *(IN ORDER OF PRESENTATION)*

Dr. Michael Woodhouse
Energy Economics Analyst, The National Renewable Energy Laboratory Strategic Energy Analysis Center

Michael Woodhouse holds a dual PhD in Physical Chemistry and Materials Science from Colorado State University. Under the supervision of Professor Bruce Parkinson, he developed a methodology to rapidly produce combinatorial libraries of novel metal oxide semiconductors by inkjet printing. Through a process known as photoelectrolysis, the materials were then screened and optimized to produce hydrogen using water and visible wavelength light. After graduate school he went on to Postdoc at the National Renewable Energy Laboratory (NREL), where his primary research focus was on the development of novel, air-stable materials and architectures for organic-based solar cells. Prior to graduate school he served for several years as a Physics and Chemistry instructor.

Dr. Woodhouse is currently a member of NREL's Strategic Energy Analysis Center, where his analysis activities are focused on solar energy technologies, economics, and policy. He also serves as Associate Editor for the American Institute of Physics peer-reviewed *Journal of Renewable and Sustainable Energy*, where he is responsible for selecting and coordinating papers for publication in the areas of energy economics and policy. In addition, he is the lead economics analyst for the Bay Area Photovoltaics Consortium, a program of university and U.S. national lab research administered by Stanford University.

An overview of the global solar market, and technology innovations needed to achieve widespread grid price parity
It seems compelling to many that, by harvesting solar energy, humankind may be able to make valiant strides toward the challenges and opportunities associated with reducing carbon emissions and providing greater diversity in the global energy supply. But, in addition to the grid-integration difficulties associated with its intermittent nature, there are also numerous economic barriers that must be overcome before there can be energy-significant Terawatt adoption levels. Primary among these economic barriers is that, across much of the globe, harvesting solar energy is still a relatively expensive option for power generation.

In this seminar the recent trends in solar photovoltaics module and system prices will be highlighted, as will discussion of how those trends are helping to make the economic barriers less daunting. As a basis for comparison to other renewable and traditional energy options, the metric of focus will be total lifecycle cost-of-energy (LCOE). Several innovations to traditional photovoltaics technologies (including crystalline silicon, CdTe, and CIGS) and developing technologies (including organics and perovskites) that may close the gaps in LCOE will be discussed.

Gregory Stark
Gregory Stark, Senior Engineer, National Renewable Energy Laboratory (NREL)

Greg Stark is a senior engineer at the National Renewable Energy Laboratory in Golden, Colorado where he works in the Power Systems Design Studies group. His research primarily focuses on two areas: the optimization of energy use across multi-domain systems, and the commercial and engineering aspects of integrating new generation into existing electrical grids, approaching both subjects from a combined systems engineering and economics perspective.

Greg received his MSEE (Control Systems) and BSChE from Purdue University and his MS from Krannert Graduate School of Management. He is a registered electrical engineer in the State of Colorado.

Putting Renewable Generation Integration Costs into Perspective
The variability and uncertainty associated with renewable generation affects power system operating costs, especially as increasing amounts of wind or solar generation are incorporated into a system's generation mix. Likewise, changing operating procedures or adding new baseload generation to an existing system impacts costs, too. How do these costs compare? This talk explores how the system operating costs associated with renewable generation compare with those of other system changes. The study examines seven areas: variable generation, baseload generation, generation mix, gas prices, self-scheduling, and faststart generation, and a comparison of the cost impacts is presented to help analyze and understand how various system changes can affect operating costs. The information should prove useful to market designers, regulators, utilities, and others who want to better understand how changes to an existing system can affect its production costs.

Dr. Carrick Eggleston
Professor in the Department of Geology and Geophysics and Associate Director of the Center for Photoconversion and Catalysis, University of Wyoming

Carrick Eggleston is professor in the Department of Geology and Geophysics at the University of Wyoming. His research focuses on chemical interaction between rocks/minerals and our chemical environment. He is a graduate of Dartmouth College (BA, 1983) and Stanford (PhD, 1991), and was a postdoctoral fellow at ETH Zurich (EAWAG, 1991–1994) and Lawrence Livermore National Laboratory (1994–1995) before starting a faculty position at the University of Wyoming (1995).

He has been a visiting professor at EPFL, Switzerland (Laboratory for Photonics and Interfaces) and the Université Henri Poincaré (CNRS Laboratoire de Chimie Physique et Microbiologie pour l'Environnement) and more recently at Pondicherry University, Puducherry, India (Madanjeet School of Green Energy Technology) on a Fulbright fellowship. He has just returned from a fellowship at the Rachel Carson Center for Environment and Society at the University of Munich where he is working on a textbook entitled "The Earth System in the Anthropocene".

Solar Energy in Developing Countries - Challenging Assumptions
Recent renewable energy development in general, and solar energy development in particular, has been very rapid. Solar energy used to avoid carbon emissions is key to climate mitigation. Projections indicate rising energy demand to 2040, led by countries in which large portions of the population currently have little or no access to electricity. Our global ability to meet the Paris COP21 climate target depends not only on our own choices but also on choices being made in developing countries in the next decade. This presentation outlines the scope of energy needs, summarizes solar energy projects already underway, and gives examples of local and regional solar energy development in the context of broader social systems. Climate mitigation is often not the proximal reason for solar energy development. Energy transitions are not just large-scale, top-down technical events in which current energy sources are replaced with new ones with no impact on members of society. All energy sources have both environmental and social impacts.

Dr. Carl Koval
Professor and Chair, Dept. of Chemistry and Biochemistry, and Fellow and Founding co-Director, Renewable and Sustainable Energy Institute, University of Colorado at Boulder

Carl Koval is currently Chair of the Dept. of Chemistry and Biochemistry at the Univ. of Colorado at Boulder. He received his Ph.D. in Chemistry from the California Institute of Technology and was a Departmental Assistant Scientist at Purdue University. He joined the faculty at CU-Boulder in 1980 and was promoted to Professor in 1992. He was the Faculty Director for the Initiative on Renewable and Sustainable Energy at CU from 2006-09 and the founding Co-Director and later Assoc. Director for Research of the Renewable and Sustainable Energy Institute (RASEI), a joint institute between CU-Boulder and the National Renewable Energy Laboratory (NREL), from 2009-12. From 2012-14, Prof. Koval was the Director of the Joint Center for Artificial Photosynthesis (JCAP), a DOE Energy Innovation Hub dedicated to the development of an artificial solar-fuel generation technology. Prof. Koval's research interests include electron transfer processes, photoelectrochemistry, membrane and electrochemical separations, and non-mechanical fluid pumping. He has been the thesis advisor for 26 Ph.D. students, 5 M.S. students and 5 research associates, and his research has

resulted in 114 publications and 11 patents. His research has been supported by 47 separate research contracts and grants.

Solar Energy Storage, Hydrogen Economy, Solar Fuels and Artificial Photosynthesis
Due to its diffuse nature, regional availability and temporal intermittency, increasing utilization of solar energy requires effective storage. Tradeoffs associated with various solar energy storage options will be briefly reviewed, but the focus of this presentation will be to describe technological options for storing solar generated electricity through the formation of chemical bonds. By far, the most advanced of these options is solar-driven electrolytic generation of hydrogen, either via so-called PV-electrolysis or integrated photo-electrochemical approaches. Recent research efforts to mimic natural photosynthesis, in which sunlight is used to produce fuels and chemicals from carbon dioxide, will also be discussed.

Dr. William Tumas
Associate Laboratory Director, Material and Chemical Science and Technology, National Renewable Energy Laboratory

Dr. William Tumas is the Associate Laboratory Director for Material and Chemical Science and Technology (MCST) at the National Renewable Energy Laboratory (NREL), which has a broad R&D portfolio in renewable energy and energy efficiency including solar energy conversion, hydrogen production and storage, energy storage and fuel cells, materials science, chemical/nanoscience, and technology reliability. Bill has been actively engaged in research as well as technical management and leadership positions over the last 25 years in industry and at national laboratories. He has extensive experience in managing multidisciplinary technical organizations, leading multi-institutional projects, and developing and coordinating fundamental and applied research programs. He is the Director of the Center for Next Generation of Materials by Design Energy Frontier Research Center, which aims to integrate high-throughput theory, experiment, and data mining to develop a rapid search and design methodology to accelerate the discovery of new functional materials.

Bill was the Director the Center for Inverse Design EFRC (2011-2014) and is the managing deputy director of the Solar Energy Research Institute for India and the United States (SERIIUS). Prior to joining NREL in 2009, Bill worked at Los Alamos National Laboratory for 17 years where his last position was Program Director for Applied Energy Programs, where he was responsible for renewable energy, infrastructure, energy efficiency, and fossil energy. Before Los Alamos, he was a research chemist, then a project leader in environmental and oxidation catalysis at DuPont Central Research for 6 years where he was an active member of the DuPont Corporate Catalysis Center and the Corporate Environmental Technology Panel. Bill received his B.A. in Chemistry from Ithaca College (1980) and his Ph.D. in Chemistry from Stanford University (1985). He was an NIH and Chaim Weizmann Postdoctoral Fellow at Caltech.

His research activities have included materials discovery, solar energy conversion, chemical hydrogen storage, homogeneous and phase-separable catalysis, supercritical fluids, green chemistry, and waste treatment technology development and assessment. He has helped organize a number of international conferences on chemistry, materials and energy. He has 50 peer-reviewed publications, 12 patents, and has given over 80 invited presentations.

Advances in Solar Energy R&D at NREL
Meeting future global energy needs in an environmentally responsible way is one of the greatest challenges facing the world in the twenty first century. Remarkable advances have been made in solar energy research, technology development and deployment. Development of the needed terawatts of solar energy will require further improvements in current devices and systems as well as new materials for disruptive technologies for energy conversion, delivery, storage, and use. An overview of NREL's extensive R&D program in photovoltaics will be presented along with remaining challenges for large-scale deployment of solar energy. This presentation will also present results from the Next Generation for Materials by Design (CNGMD) Energy Frontier Research Center (EFRC) and the previous Center for Inverse Design EFRC where we tightly couple theory, experiment and characterization to discover and understand new inorganic semiconductor materials for photovoltaic absorbers, transparent conductors, and photoelectrochemical water splitting.

Dr. Reuben Collins
Associate Director of the Renewable Energy Materials, Colorado School of Mines

Reuben Collins is a Professor of Physics at the Colorado School of Mines, Associate Director of the Renewable Energy Materials Research Science and Engineering Center (REMRSEC), and the Editor-in-Chief of Applied Physics Letters. He is a condensed matter physicist who for twenty years has specialized in renewable energy research. He received a BA in Physics and Mathematics from the University of Northern Iowa, and MS and PhD degrees in Applied Physics from the California Institute of Technology.

He held positions of increasing responsibility at the IBM T.J. Watson Research Center before joining the Colorado School of Mines. Collins' research has spanned many areas of photovoltaics including organic solar cells, transparent conducting oxides, thin film CdTe photovoltaics, silicon-based solar cells, the development of novel absorbers and next generation quantum dot PV concepts.

He has close collaborations with the National Renewable Energy Laboratory and extensive experience working with industrial partners. He has organized numerous symposia and written several review articles on next generation photovoltaics and helped develop and participated in K-12 outreach programs organized around developing competency in energy concepts. He has authored or co-authored more than 130 publications and is a co-inventor on 4 patents. He is a Fellow of the American Physical Society, a Center for Revolutionary Solar Photoconversion Distinguished Colleague, a session organizer for the Electronic Materials Conference, a past Chair of the American Physical Society topical Group on Energy Research and Applications, and has served as a volume organizer for the Materials Research Society Bulletin.

Silicon Photovoltaics: Today, Tomorrow and Beyond
Among PV technologies, silicon-based solar modules dominate the market with a 90% share. Silicon PV has also undergone a dramatic drop in manufacturing cost. Module prices have fallen from over $3.00/Wp in 2006 to near $0.50/Wp today, and this has happened in parallel with a significant shift of manufacturing to China. As cost continues to drop relative to the other expenses involved in installing a solar power system, continued declines in module price yield diminishing returns. This increases the emphasis on efficiency gains which are effectively integrated across the entire system and on increases in system lifetime in the field. While we tend to think of silicon PV as a mature technology, innovation is alive and well in this field. Advanced cell architectures minimize shading by contacts, series resistance, and carrier loss at interfaces. A new cell design, the heterojunction cell, now holds the efficiency record. New ways of forming wafers that minimize losses due to sawing offer the potential of flexible panels. Further into the future, Si nanostructures hold the hope of even higher efficiency devices. This talk will summarize the status of today's silicon based photovoltaic technology, describe on-going research in this field, and conclude by discussing some of the exciting science that may make its way into silicon solar cells in the future.

Dr. James Sites
Senior Associate Dean for Research, College of Natural Sciences, Colorado State University

James Sites (Physics Department, Colorado State University) studies the device physics of low-cost CdTe and CIGS thin-film solar cells. He received his PhD from Cornell in 1969 and has been on the Colorado State faculty since 1971. His photovoltaics lab makes precision electrical and optical measurements on solar cells fabricated at Colorado State and by several partners in the U.S. and abroad. The goals of his laboratory are to separate the various solar-cell losses, to explain the losses on a fundamental basis, to make numerical simulations when appropriate, and to suggest strategies for improved solar-cell performance.

Prof. Sites works closely with NREL and several PV companies, and he has a recognized leadership role in the U.S. thin-film solar-cell community. He has published 180 papers, including co-author of the chapter on CdTe solar cells in the *Handbook of Photovoltaic Science and Engineering*. 47 of his students have completed their M.S. degree and 29 their Ph.D.

Thin-Film Solar Cells
Thin-film solar cells are making a major impact on the generation of electricity with energy from the sun, in large part because they offer several advantages in the manufacturing of large-area solar panels. Two materials, Cu(In,Ga)Se2 (often referred to as CIGS) and CdTe, are responsible for most of the current thin-film industrial production. At the cell level, both materials have achieved efficiencies over 22%, and for full-sized panels, efficiencies now exceed 18%. These

values are higher than those for multi-crystalline silicon, the most common commercial photovoltaic material. The research program at Colorado State University has two components. One laboratory uses a highly flexible thin-film deposition system to fabricate a large number of CdTe solar cells with a variety of novel approaches and has been highly successful with its own cell efficiencies. The second laboratory makes extensive measurements with both CdTe and CIGS cells to quantitatively determine the factors determining and limiting their performance. Both laboratories gain considerable benefit from productive collaborations with a number of manufacturing companies and other laboratories.

Sean Shaheen

Associate Professor and Associate Chair for Education, Electrical, Computer, and Energy Engineering Institute and Renewable and Sustainable Energy Institute (RASEI), University of Colorado Boulder

Sean Shaheen is Associate Chair for Learning in the Department of Electrical, Computer, and Energy Engineering and a Fellow in the Renewable and Sustainable Energy Institute at the University of Colorado Boulder. His research interests focus on organic photovoltaic (OPV) and hybrid organic-inorganic photovoltaic (HOPV) materials and devices for low-cost, renewable energy harvesting. His group and collaborators engage in a wide range of activities in OPV/HOPV research, including studying fundamental aspects of energy transfer and exciton dynamics, measurements of charge transport and recombination behavior, and modeling of device physics using various numerical techniques. More broadly, his group is interested in renewable energy from a global perspective and in applying concepts from complex systems science and engineering to emergent problems in sustainability.

Shaheen works closely with staff scientists at the National Renewable Energy Laboratory, where he was previously employed, through RASEI. He is a Scialog Fellow of the Research Corporation for Science Advancement and a member of the Board of Governors for the Institute for Complex Adaptive Materials (ICAM).

Recent Advances and Future Prospects for Organic and Hybrid Organic-Inorganic Perovskite Photovoltaics

Solar cells using solution-based methods for their fabrication provide the near-term possibility for application in markets not currently exploited by silicon photovoltaics, and the long-term possibility for low-cost pathways to higher efficiencies. Two of the leading approaches to this are Organic Photovoltaics (OPV's) and Hybrid Organic-Inorganic Perovskite Photovoltaics (HOPV's). Recent advances in OPV's have brought the power conversion efficiencies beyond 11% for single-junction devices, and encouragingly this is being done routinely with a variety of material systems. Of particular note is that materials that do not rely on fullerenes as the electron-transporting component are also achieving this efficiency, which overcomes the constraints placed by the optical and electronic properties of fullerenes, as well as the cost of their synthesis. With these new advances has come greater understanding of the device physics of OPV's, and clear pathways to single-junction efficiencies >20% can been delineated. However, recent advances in the efficiencies of lead halide HOPV's already to >21% have created enormous interest in these materials and devices. The astonishingly optoelectronic properties of Perovskites provide a wonderful playground to probe and develop photovoltaic mechanisms, and encouraging progress in increasing their stability and removing the lead component has also been made recently.