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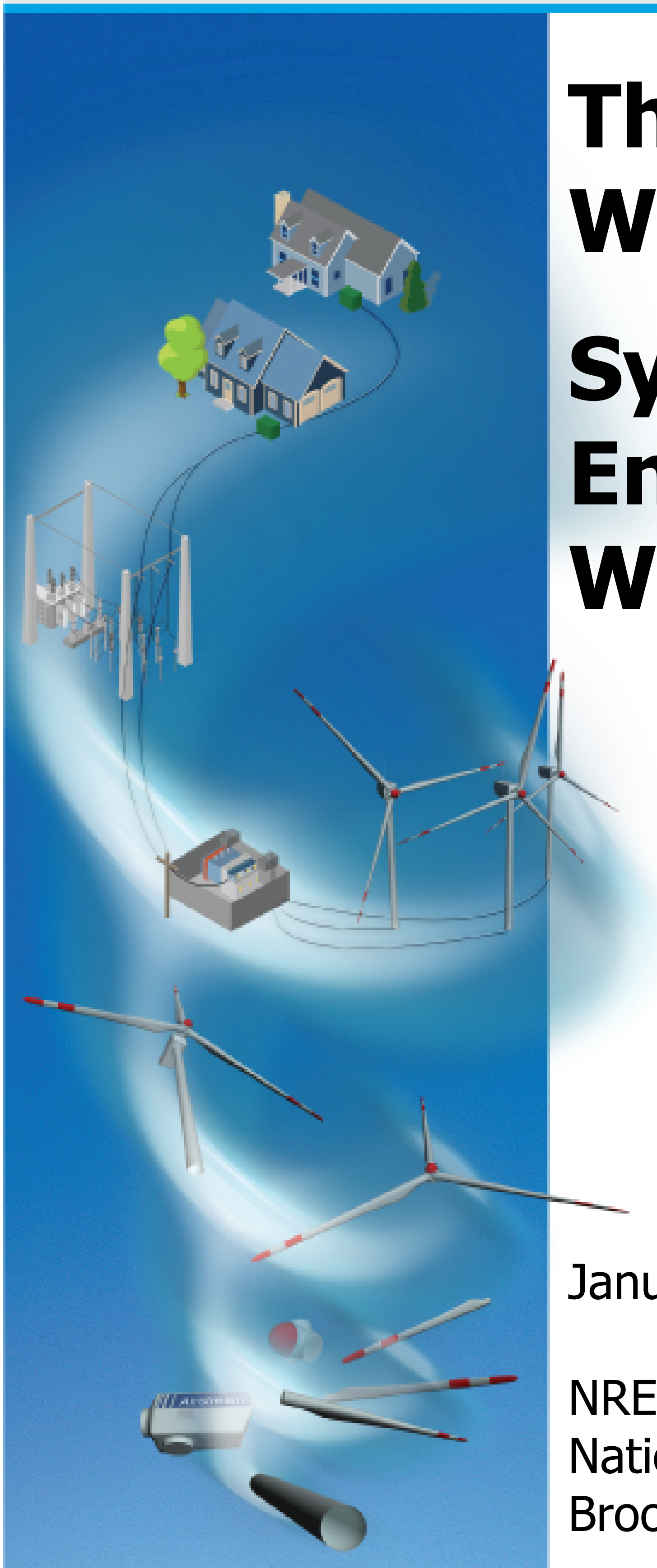

The 2nd NREL Wind Energy Systems Engineering Workshop

January 29th-30th, 2013

NREL
National Wind Technology Center
Broomfield, Colorado

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

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2nd NREL Wind Energy Systems Engineering Workshop Agenda

Overview: The 2nd NREL Wind Energy Systems Engineering Workshop will take place on the 29th and 30th of January 2013. The first workshop in December 2010 was a success in catalyzing interest in this important topic among participants from industry, the national laboratories and academia. In the last few years, the interest in systems engineering and techno-economic modeling of wind energy systems has grown substantially. At this 2 day workshop, we will showcase research and development activity in these areas and provide plenty of opportunity for discussion about potential future developments and collaborations. Follow-on meetings on the 31st of January and 1st of February will feature software tutorials smaller group meetings for discussion.

Tuesday, January, 29, 2013 (Renaissance Hotel)	
1:00 pm to 5:00 pm	Afternoon Sessions
5:30 pm to 7:30 pm	Evening Reception and Poster Session (Light Faire)

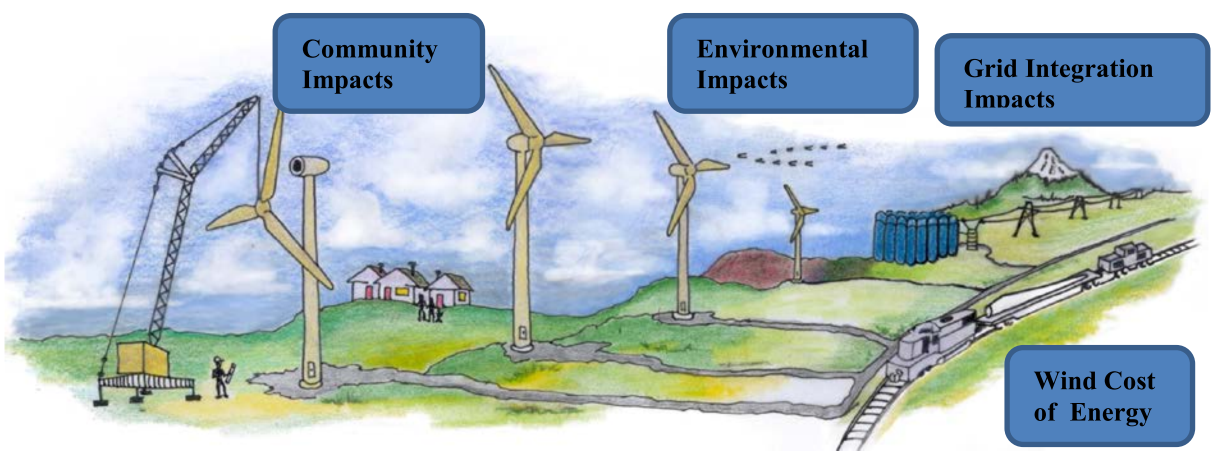
Wednesday, January 30th, 2013 (Renaissance Hotel)	
8:00 am to 8:30 am	Continental Breakfast
8:30 am to 12:00 pm	Morning Sessions
12:00 pm to 1:30 pm	Lunch (with Keynote)
1:45 pm to 5:00 pm	Afternoon Sessions

Thursday, January 31st, 2013 (At NREL NWTC)	
8:00 am to 12:00 pm	DAKOTA Tutorial: Basics
12:00 pm to 1:00 pm	NREL NWTC Tour (and Lunch)
1:00 pm to 5:00 pm	OpenMDAO Tutorial: Basics

Friday, February 1st, 2013 (At NREL NWTC)	
8:00 am to 10:00 am	Working Group Session on Standard Software Framework
10:00 am to 1:00 pm	DAKOTA Tutorial: Advanced Topics (and Lunch)
1:00 pm to 3:00 pm	NREL TWISTER Tutorial: Demonstration and Tutorial
3:00 pm to 5:00 pm	FAST Modularization Framework Presentation

2nd NREL Wind Energy Systems Engineering Workshop Agenda (Day 1)

Tuesday, January, 29, 2013 (Renaissance Hotel)	
11:00 am to 1:00 pm	Registration Open
1:00 pm to 1:45 pm	Day 1 Opening remarks: **Mr. Nick Johnson, DOE Energy Efficiency and Renewable Energy** Opening Keynote Address: "System innovation in wind energy" **Dr. Paul Veers, NREL National Wind Technology Center**
1:45 pm to 2:00 pm	Break
2:00 pm to 3:00 pm	Session I: Wind Energy System Costs from Turbines to Plants **Moderator: Mr. Ben Maples, NREL National Wind Technology Center** **Mr. Eric Lantz, NREL Strategic Energy and Analysis Center** **Ir. Bernard Bulder, ECN, the Netherlands** **Mr. Rajan Arora, RES Americas**
3:00 pm to 4:00 pm	Session II: Systems Engineering Methods Applied to Wind Energy I **Moderator: Dr. Rick Damiani, NREL National Wind Technology Center** **Dr. Carlo Bottasso, Politecnico di Milano, Italy** **Dr. Andrew Ning, NREL National Wind Technology Center** **Dr. Ryan Schkoda, Clemson Wind Turbine Drivetrain Testing Facility**
4:00 pm to 4:15 pm	Break
4:15 pm to 5:15 pm	Session III: Systems Engineering Methods Applied to Wind Energy II **Moderator: Mr. Scott Hughes, NREL National Wind Technology Center** **Dr. Joaquim Martins, University of Michigan** **Dr. Curran Crawford, University of Victoria, Canada** **Dr. Turaj Ashuri, University of Michigan**
5:15 pm to 5:30 pm	Break
5:30 pm to 7:30 pm	**Evening Reception and Poster Session**



Wind Plant Ecosystem; Illustration by Rick Hinrichs, PWT Communications

Day 1: Opening Session

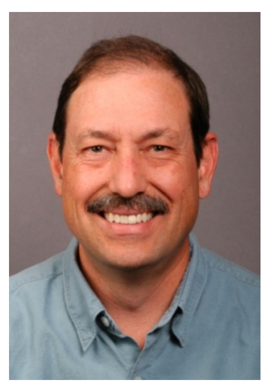
Workshop Welcome and DOE Program Overview

Abstract: The US Department of Energy (DOE) sponsors research activities at NREL, including the Systems Engineering tasks. DOE has developed a strategy for improved performance, lower cost of energy, and accelerated deployment of wind technology based on initiatives established by the White House Administration. Specifically, DOE's Wind Program seeks to enable U.S. deployment of clean, affordable, reliable and domestic wind power to promote national security, economic growth, and environmental quality. To reach these goals the Wind Program has instituted program priorities that include overall wind plant performance, offshore wind technology and deployment, mesoscale data acquisition, wind turbine inflow characterization, turbine to turbine interaction, and grid integration. The targeted outcomes of these program activities are to reduce the unsubsidized market Levelized Cost of Energy (LCOE) for utility-scale wind plants to $.057/kWh by 2020, and $.042/kWh by 2030. DOE has a unique role within the wind industry to fund high risk technology R&D and act as a liaison between industry and other branches of the federal government to address barriers to deployment. The Wind Program's strategy for reducing LCOE has changed from targeting individual turbine components to addressing the dynamic interaction of an entire wind plant.

Biography: Mr. Nick Johnson is the Modeling and Simulation lead within the US Department of Energy's Wind and Water Power Program, and has been with the program for 4 years. He holds a B.S. in Mechanical Engineering from the University of Colorado and is currently pursuing a M.S. in Mechanical Engineering from the Colorado School of Mines. Nick also supports the DOE Golden Field Office with project management duties.

System Innovation in Wind Energy

Abstract: Wind energy systems are among the class of engineered systems that exhibit a very high level of interconnection between subsystems. Research on the systems benefits are driven by the need to reduce Levelized Cost of Energy (LCOE), which is an all-encompassing goal with contributions from a wide variety of sources. No single hardware subsystem dominates the LCOE, and significant contributions come from financing and operational costs that have very little in the way of direct hardware expenses. Wind designers have gradually, but consistently expanded their abilities to engineer the turbine by engaging across subsystem boundaries moving to the point where system engineering principles are regularly used in component design and often applied to the entire turbine system. Full wind plant system engineering efforts are just beginning. One of the chief difficulties in introducing new technology into the commercial wind turbines is creating a change that is beneficial in to all the design criteria, which also have their source in a wide variety of performance, environmental and safety requirements. A technological innovation that makes an obvious improvement in one area may see that benefit erased by failure to provide an equivalent benefit for another design requirement. Some examples of this interplay are used to illustrate the need for systems engineering. The new NREL systems engineering effort is also briefly introduced.



Biography: Dr. Paul Veers is the Chief Engineer at NREL's National Wind Technology Center. He has worked in the area of Wind Energy Technology for over 30 years, 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. For twelve years, Paul 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.

Session I: Wind Energy System Costs from Turbines to Plants

Wind plant cost of energy is a metric constantly used by various parties to evaluate wind energy with respect to other energy technologies that make up an overall portfolio of assets for power system generation. Many factors contribute to wind plant cost of energy and overall assessment of these costs is non-trivial. This first session takes a big picture look at some wind energy cost trends over time, cost trends from an operational perspective and their role in wind plant design, and finally the relationship between wind plant financing / costs and wind plant design.

Moderator Biography: Mr. Ben Maples received his Master Degree in Mechanical Engineering with a focus on renewable energy and the environment. He then joined NREL as a member of the Technology Systems and Sustainability Analysis Group. His main research areas focus on developing comprehensive cost and scaling models for utility-scale wind turbines and assessing future wind technology cost and performance. Ben is currently leading efforts at NREL to develop new Balance of Station cost and scaling models for land-based and offshore wind.

Understanding Wind Power Costs: The Value of a Comprehensive Approach

Abstract: The evolution and maturity of the wind industry have often been assessed by considering changes in key metrics including capital costs, capacity factor, turbine pricing, and in some cases electricity sales data. However, wind turbines and plants represent a complex system optimization problem and each of these metrics, in isolation, fails to tell the complete story of technological progress and industry advancement. For example, an exclusive focus on capital cost data over the last decade completely masks the gains that have been made in turbine productivity as a result of shifts to taller towers and larger rotors. A focus on United States fleet-wide capacity factors also masks recent gains by hiding the gradual shift to lower quality wind resource sites that has been observed in the recent years.

By contrast, the levelized cost of energy (LCOE) provides a more comprehensive and nuanced perspective on industry trends. LCOE can be used to analyze the effect of individual changes (by holding other variables constant) or to understand the complex interactions that might occur for example between turbine costs and productivity. Moreover, LCOE offers a reflection of the total production costs and required revenue for wind plants. This presentation will provide examples of how a narrow focus on individual industry metrics can provide inaccurate representations of industry trends while also demonstrating how LCOE captures the array of critical industry variables to provide a greater level of insight.

Biography: Mr. Eric Lantz is an analyst in the Markets and Policy Analysis group at the National Renewable Energy Laboratory. His primary research includes study of current and future costs of wind energy and economic development impacts from wind energy. In addition, Eric represents the U.S. in a collaborative effort of the International Energy Agency focused on understanding public perceptions of and responses to wind power. Eric holds a master’s degree in Energy Policy from the University of Colorado.

Integrated Wind Farm Design & Optimization

Abstract: In the presentation is shown what the approach is at ECN to design an offshore wind farm looking at the wind farm aerodynamic losses, the electrical losses and the wind farm induced effects on the mechanical losses. Based on this information it is investigated whether wind farm control can be applied to optimize the performance of a wind farm where the optimization objective can be e.g. yield optimization or yield optimization limited by constraints. These constraints can be any of the parameters that are determined. For a cost optimization it will be necessary to include O&M due to its large impact on the Cost of Energy. Problems to be solved are how to express higher wind farm induced fatigue loading in such an equation.

Biography: Dr. Bernard Bulder is a Research Coordinator at Energy Research Centre of the Netherlands, ECN. Bernard Joined ECN in 1988 and work since 1990 in wind energy research. Participated in numerous EU and national funded projects and is a member of the IEC-TC88 WG 1 and 3. He coordinated the Dutch wind energy research program InnWind (2006 – 2012). Presently active as project leader for the development of wind farm design tool for the optimization offshore wind farms based on yield, fatigue loads using wind farm control.

Impact of Project Financing on Wind System Design

Abstract: Project Financing is an asset based debt financing method where debt is only secured by project assets and is non-recourse to the sponsor. The lenders look towards project cash flows for servicing the debt and the certainty of that income stream is the most important criterion for securing that financing. Since the cash flows of the project are dependent upon the performance of the project which is driven by the wind farm system design, lenders perform thorough due-diligence on this aspect of the project. The lenders look very closely at design aspects of the project with a special emphasis on turbine technology. While evaluating turbine technology they focus on three main areas: the manufacturer, the wind turbine, and the performance warranty being provided by the turbine vendor.

On the manufacturer side they look towards the credit strength and track record of the manufacturer, and any known intellectual property issues. While evaluating the turbine they look at items such as the deployment history of the turbine, any known turbine issues, the suitability of the turbine for the specific project site, and any known serial defect issues. Finally on the performance warranty side they look at the term of the warranty being provided by the turbine vendor, the actual availability vs. the power curve, and the availability of turbine spare parts.

Biography: Mr. Rajan Arora has been in the renewable energy industry for over ten years. He started working for RES Americas in 2002 after graduate school. From 2002 to 2009 he worked in a technical role where he lead a team of engineers responsible for assessing the wind resource related to his company's multi-gigawatt North American development portfolio. During this time he was directly involved in the wind resource assessment of over 1,800 MW of operational wind farms in the U.S. and Canada. In 2009 he joined the Strategy and Transactions group of RES Americas where he currently serves as a Director. He and his team are responsible for bidding, winning and financing the company's pipeline of advanced-stage and construction-ready wind power and solar power projects. In past three years he has helped close and finance over $1.1 billion of wind power projects in the U.S and Canada. Mr. Arora holds a bachelors degree in Mechanical Engineering from the Maharishi Dayanand University, India, a Master of Science in Engineering Mechanics from The University of Texas at Austin, and an MBA in Finance from McCombs School of Business at The University of Texas at Austin.

Session II: Systems Engineering Methods Applied to Wind Energy I

This is the first session in a series focused on systems engineering methods applied to wind energy research, design and development. Generally, the series focuses on the use of a variety of methodologies such as multi-disciplinary design analysis and optimization (MDAO) and uncertainty quantification (UQ) to the design and evaluation of wind turbine technologies and wind plant performance and cost. The talks in this first session provide examples of such analysis by considering automated design tools and their potential, the role of analysis design in a rotor optimization, and an overview of integrated design and testing capabilities for a new wind turbine drivetrain testing facility.

Moderator Biography: Dr. Rick Damiani is a Sr. Engineer at the NWTC, working on aeroelasticity and turbine structural dynamics. He owns a PhD in Aeronautical Engineering, and since 1999 he has worked on different aspects of wind engineering: from wind loads analysis on civil structures, to resource assessment and project development for utility scale wind power generation, to aero-structural design for small and mid-size wind turbines. His research interests are: design and analysis of composite structures, structural design of offshore turbine supports, and development of computer-aided-engineering tools.

Multidisciplinary Design Optimization of Wind Energy Systems

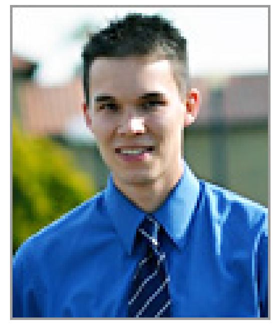
Abstract: It is expected that the exploitation of off-shore resources will be achieved by very large wind turbines in the 10-20 MW class. By going off-shore, one can access large wind resources, often located in deep waters, avoiding some of the environmental and public acceptance concerns raised on-shore. Many innovative ideas are being proposed for the reduction of the cost of energy produced by these machines, including novel configurations at the system level, improved sub-components, advanced generators, cost-effective support structures, light-weight low-solidity and high-speed rotors equipped with active and passive load mitigation technologies.

The understanding of the effectiveness of all such innovations calls for advanced design tools and their validation, that can capture the relevant physical processes and allow for designers to explore with confidence the solution space, understanding all necessary trade-offs. This is spurring a new wave of development of automated design methods that improve on the capabilities that have supported so far the design of wind turbines. In this talk we will review some recent developments in this field, present some relevant applications, and highlight future needs and areas where progress still needs to be made.

Biography: Dr. Carlo L. Bottasso (Ph.D. '93) is a Professor at the Department of Aerospace Science and Technology of the Politecnico di Milano in Italy, where he directs the Poli-Rotorcraft and Poli-Wind research labs. His research interests are in flexible multibody dynamics with application to the modeling and design of rotary wing vehicles and wind energy systems, and corollary modeling and numerical technologies. On these topics he has co-authored over 280 publications, including over 90 peer reviewed journal papers and book chapters.

Objectives and Constraints for Wind Turbine Optimization

Abstract: Efficient extraction of wind energy is a complex multidisciplinary process. This presentation explores common objectives used in wind turbine optimization problems. The focus is not on the specific optimized designs, but rather on understanding when certain objectives and constraints are necessary, and what their limitations are. Maximizing annual energy production, or even using sequential aero/structural optimization, is shown to be significantly suboptimal compared to integrated aero/structural metrics. Minimizing the ratio of turbine mass to annual energy production can be effective for fixed rotor diameter designs, as long as the tower mass is estimated carefully. For variable diameter designs, the predicted optimal diameter may be misleading. This is because the mass of the tower dominates the total turbine mass, but the cost of the tower is a much smaller fraction of overall turbine costs. Minimizing cost of energy is a much better metric, though high-fidelity in the cost modeling is as important as high-fidelity in the physics modeling. Furthermore, deterministic cost of energy minimization can be inadequate, given the stochastic nature of the wind and various uncertainties associated with physical processes and model choices. Optimization in the presence of uncertainty is necessary to create robust turbine designs.



Biography: Dr. Andrew Ning is a postdoctoral researcher at NREL investigating system level optimization methods applied to wind energy applications, and wind turbine aeroelastic model development. Currently, he is responsible for developing aerodynamic/structural models and a common framework for wind turbine/plant analysis. Prior to joining NREL, Andrew was a PhD student at Stanford University. His doctoral dissertation focused on formation flight of aircraft, and his research encompassed the fields of aerodynamic modeling, multi-fidelity optimization methods, and aircraft design.

Systems Engineering Activities at Clemson University's International Center for Automotive Research (CU-ICAR) and Wind Turbine Drivetrain Testing Facility

Abstract: Two of Clemson University's satellite campuses are engaging in large scale system design, analysis, and operation. Clemson University's Wind Turbine Drivetrain Testing Facility (WTDTF) in Charleston, SC will house two of the largest dynamometer test benches in the world. In addition to torque, the test beds will be equipped with load application units capable of applying non-torque bending moments, and radial and axial forces. The test benches are being designed specifically for the wind industry but are capable of testing any drivetrain or piece of turbo machinery that operates at low speed and high torque. The test benches are complex electrical-mechanical-hydraulic-systems. The addition of full scale wind turbine nacelles further increases system complexity. In order to help understand this complexity, the systems are being modeled in their entirety with the end goal being a set of modular, capable, and reconfigurable dynamic models. Additionally, Clemson University's International Center for Automotive Research (CU-ICAR) has core research areas which require system level analysis and integration. Much of automotive engineering has moved beyond fundamental applications and has embraced a holistic, systems level approach. Engineers must consider system interaction and coordination as opposed to focusing solely on isolated system performance.

Biography: Dr. Ryan Schkoda is a post-doctoral fellow at Clemson University's Wind Turbine Drivetrain Testing Facility in Charleston, SC. He is developing a robust modeling framework for system level, dynamic analysis including multi-body dynamic simulation, control system simulation, hydraulic simulation, and test profile optimization. Dr. Schkoda grew up in Rhode Island and is a graduate of Rochester Institute of Technology (BS '06, MS '07 Mech Eng) and Clemson University (Ph.D. '12 Mech Eng). Past research activities include optimal control of over actuated systems, and clustering and classification of multivariate stochastic time series.

Session III: Systems Engineering Methods Applied to Wind Energy II

This is the second session in a series focused on systems engineering methods applied to wind energy research, design and development. Generally, the series focuses on the use of a variety of methodologies such as multi-disciplinary design analysis and optimization (MDAO) and uncertainty quantification (UQ) to the design and evaluation of wind turbine technologies and wind plant performance and cost. The talks in this second session provide examples of such analysis by considering optimized turbine design for a cost of energy objective coupling of high-fidelity design tools for optimized wind turbine rotor design at different sizes.

Moderator Biography: Mr. Scott Hughes, NREL, is the Supervisor of the Test Methods Research and Development at the National Wind Technology Center, with responsibilities for managing the structural test facilities. Since starting at NREL in 1997, Scott has been the technical lead in over 75 full-scale structural wind turbine blade tests, actively researching and demonstrating test methodology for turbine blades. Scott holds a B.S. and M.S. in mechanical engineering.

Aeroservoelastic design optimization of large wind turbines

Abstract: Issues related to environmental concern and fossil fuel exhaustion has made wind energy a widely used resource of renewable energy. Despite several advancements in wind turbine technology, its design uses typically a single-discipline isolated approach. In this approach, either the structural or aerodynamic design is carried out first and based on this optimized configuration the other discipline is designed next. Additionally, the design focus is on optimizing only one component at a time.

To cope with more complex future wind turbines, this approach does not seem to be appropriate. An integrated multidisciplinary design approach is needed to cover all the interdisciplinary aspects of the design and decrease the costs. This work presents an integrated approach to design simultaneously the blade and tower of a wind turbine, with aerodynamic and structure as the main disciplines.

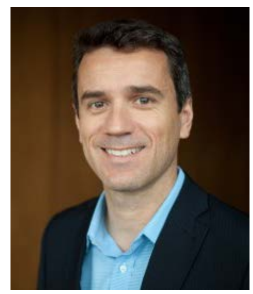
The application of the integrated methodology to optimize the 5 MW NREL wind turbine shows a reduction in the levelized cost of energy, while satisfying all the constraints. Therefore, the integrated design methodology is vital for the development of future wind turbines that have to be more optimized than they are today.

Biography: Dr. Turaj Ashuri is a postdoctoral research fellow at University of Michigan in Multidisciplinary Design Optimization Laboratory (MDOLAB). He holds a PhD from Delft University of Technology for his work on integrated aeroservoelastic Design and Optimization of Large Offshore Wind Turbines, and an MSc from Sharif University of Technology for developing a Computational Model for Wind Turbine Composite Blade Design and Optimization using Finite Element. Turaj has several years of R&D experience; senior wind turbine design analyst at SIEMENS, gas turbine professional engineer at MAPNA and structural design engineer at locomotive rebuilding factories.

Towards High-Fidelity Optimal Aeroelastic Tailoring of Wind Turbine Blades

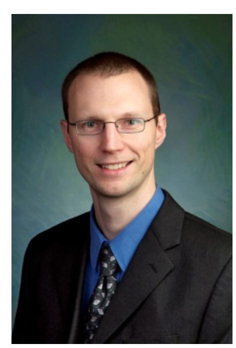
Abstract: Multidisciplinary design optimization (MDO) has found many applications in engineering and is now positioned to make major contributions in the design of the next generation of aircraft as well as wind turbines. In particular, the simultaneous optimization of the outer mold line of a lifting surface and its structural sizing and composite stacking sequence yields an optimal aeroelastic tailoring. However, due to the computational cost of computational fluid dynamics (CFD) and computational structural mechanics (CSM), as well as the number of cases that need to be considered, high-fidelity MDO of lifting surfaces remains a challenge. A framework for high-fidelity aerostructural optimization will be presented along with the theory developed to address the inherent challenges. The framework combines a three-dimensional CFD solver, a finite-element solver capable of modeling composite layups, a geometry modeler, and a gradient-based optimizer to compute the deformed shape of lifting surfaces and to optimize them with respect to aerodynamic shape and structural variables. The theoretical developments to be presented include coupled sensitivity analysis methods, and an automatic differentiation adjoint approach. The algorithms resulting from these developments are all implemented to take advantage of massively parallel computers. Applications to the optimization of aircraft wings and wind turbine blades will demonstrate the effectiveness of these approaches and motivate a speculation on future research directions.

Biography: Dr. Joaquim R. R. A. Martins is an Associate Professor at the University of Michigan, where he heads the Multidisciplinary Design Optimization Laboratory (MDO Lab) in the Department of Aerospace Engineering. His research involves the development and application of MDO methodologies to the design of aircraft configurations, with a focus on high-fidelity simulations that take advantage of high-performance parallel computing. Before joining the University of Michigan faculty in September 2009, he was an Associate Professor at the University of Toronto Institute for Aerospace Studies, where from 2002 he held a Tier II Canada Research Chair in Multidisciplinary Optimization. Prof. Martins received his undergraduate degree in Aeronautical Engineering from Imperial College, London, with a British Aerospace Award. He obtained both his M.Sc. and Ph.D. degrees from Stanford University, where he was awarded the Ballhaus prize for best thesis in the Department of Aeronautics and Astronautics.



Progress towards a mid-fidelity wind turbine MDO capability for advanced aeroelastic rotors

Abstract: In order to continue to drive down the costs of wind energy by moving to ever larger machines, and larger rotors for low-wind speed sites, advanced structural and aerodynamic rotor concepts are required. These designs must also be optimized together with the rest of the wind turbine structure, generator and power electronics, and the controller. Most current design tools utilize BEM for the rotor aerodynamics and linear structural models with simplified composite material properties, models which are not capable to accurately modeling more flexible concepts with non-planar rotors. This talk will present ongoing work in the Sustainable Systems Design Lab (SSDL) at the University of Victoria (UVic) aimed at developing an MDO capability for advanced machine concepts. The aerodynamics models are a flavor of Lagrangian vortex methods, specifically tailored for optimization work in terms of accuracy, computational expense and with gradient calculations via complex step. The structural models use Geometrically Exact Beam Theory together with Variational Asymptotic Beam Section analysis to yield a non-linear blade model, with detailed cross-section layup capabilities along with adjoint gradient calculations. The codes are coupled and wrapped in an MDO framework, and some initial design explorations for the Sandia 100m rotor will be presented.



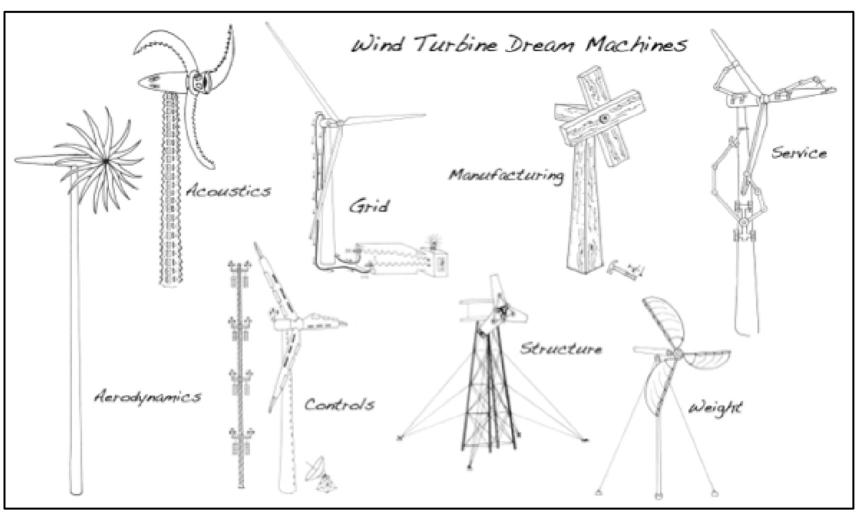
Biography: Dr. Curran Crawford is an Assistant Professor in the Department of Mechanical Engineering at the University of Victoria. He is a member of the Institute for Integrated Energy Systems (IESVic) and director of the Sustainable Systems Design Lab (SSDL). His key interests lie in the design of sustainable systems using multidisciplinary optimization techniques, specifically in energy-related technologies including wind turbines, tidal turbines and plug-in hybrid vehicles. He also works in the area of grid-integrated probabilistic energy-systems modeling and demand side management.

Poster Session Presentations

This poster session highlights a variety of system approaches to wind energy research including research for grid integration and power stystem operations, wind resource assessment and turbine performance assessment, wind plant design and balance-of-station costs, stakeholder engagement to address community concerns, the role of sensing in wind plant operations, and even education for the next generation of wind energy professionals.

Poster Title	Authors	Organization
DC Wind Farm Collection System	Michael Johnson, Hao Chen, and Dionysios Aliprantis	Iowa State University
Preliminary Lake Erie Offshore Wind Farm Monte Carlo Simulation of Maintenance and Repair for Three and Two Bladed Rotors	Brett Andersen and Larry Viterna	University of Toledo
Wind Energy Curriculum at Texas Tech University	Padriac Fowler	Texas Tech University
Modeling the Impact of Landowner Participation in Wind Farm Layout Optimization	Le Chen and Erin MacDonald	Iowa State University
Wind Farm Layout Optimization Under Uncertainty	Le Chen and Erin MacDonald	Iowa State University
Ramping Reserves with High Wind Penetration	Nicholas Brown, Michael Johnson and Ashley Mui	Iowa State University
An Assessment of Offshore Wind Energy Potential Considering Economic Feasibility in Kanto Area of Japan	Yuka Kikuchi	University of Tokyo

Wind Energy Cost Production Modeling	Huiyi Zhang and David Jahn	Iowa State University
Estimating the endogenous power curve – a system-level metric for wind turbine performance analysis	Yu Ding	Texas A&M University
A Case Study on the Effects of Predicted Wind Farm Power Outputs on Unscheduled Flows in Transmission Networks	Manish Mohanpurkar	Colorado State University
Offshore Wind Plant Balance-of-Station Cost Drivers and Sensitivities	Genevieve Saur, Ben Maples, Rebecca Meadows, Maureen Hand, and Walt Musial	National Rewable Energy Laboratory
Sensor requirements for wind systems	Scott Hughes, Shawn Sheng and Jonathan White	National Rewable Energy Laboratory & Sandia National Laboratories



Wind Turbine Dream Machines; Illustration by Rick Hinrichs, PWT Communications

2nd NREL Wind Energy Systems Engineering Workshop Agenda (Day 2)

Wednesday, January 30th, 2013 (Renaissance Hotel)	
8:00 am to 8:30 am	Registration and Continental Breakfast
8:30 am to 9:30 am	Day 2 Opening Remarks: **Dr. Maureen Hand, NREL Strategic Energy and Analysis Center** Opening Keynote Address: Reducing the cost of wind energy **Mr. Henk-Jan Kooijman, GE Energy**
9:30 am to 10:15 am	Session IV: Systems Engineering Methods Applied to Wind Energy III **Moderator: Mr. Justin Gray, NASA** **Dr. Gianluca Iaccarino, Stanford University** **Dr. Mike Eldred, Sandia National Laboratories**
10:15 am to 10:30 am	Break
10:30 am to 12:00 pm	Session V: Systems Engineering Application to Industry Wind Turbine Design **Moderator: Dr. Scott Schreck, NREL National Wind Technology Center** **Dr. Chris Halse, Romax Technology** **Dr. Eddie Mayda, Siemens Energy Inc.** **Mr. John Leahey, Vestas – American Wind Technology, Inc.** **Dr. Charu Mehendale, GE Global Research**
12:00 pm to 1:30 pm	Lunch Keynote Address: "Offshore energy system design" **Mr. Jim O'Sullivan, Technip**
1:30 pm to 1:45 pm	Break
1:45 pm to 2:45 pm	Session VI: Wind Plant Design and Optimization I **Moderator: Dr. Pat Moriarty, NREL National Wind Technology Center** **Mr. Philippe Giguere, GE Energy** **Dr. Matt Churchfield, NREL National Wind Technology Center** **Mr. Jake Frye, DNV KEMA Energy & Sustainability**
2:45 pm to 3:00 pm	Break
3:00 pm to 4:00 pm	Session VII: Wind Plant Design and Optimization II **Moderator: Mr. Ryan King, NREL National Wind Technology Center** **Mr. Matt Filippelli, AWS Truepower** **Mr. Scott Haynes, Iberdrola Renewables** **Mr. Matthew Lynn, GL Garrad Hassan**
4:00 pm to 5:00 pm	Session VIII: Integrated Wind Turbine and Plant Modeling **Moderator: Dr. Peter Graf, NREL Computational Sciences Center** **Ms. Katherine Dykes, NREL National Wind Technology Center** **Dr. Frederik Zahle, DTU Wind Energy, Denmark** **Dr. Pierre-Elouan Réthoré, DTU Wind Energy, Denmark**
5:00 pm to 5:15 pm	Closing Remarks **Dr. Paul Veers, NREL National Wind Technology Center**

Day 2: Opening Session

Wind Plant Cost of Energy: Past and Future

Abstract: This talk examines trends in wind plant cost of energy over the last several decades and discusses methods and examples of projections for future cost trends. Firstly, the talk will explore cost trends for wind energy from the 1980s where there has been an overall downward trend in wind plant energy costs. Underlying factors that influence these trends including turbine technology innovation for lower wind speed sites are explored.

Next, the talk looks at projections for the future development of wind energy costs. The talk discusses a variety of methods for establishing these projections including the use of learning curves, qualitative assessment using expert elicitation, and finally engineering-based analysis. A comparison of the methods is provided to explore their relative merits. Finally, a brief introduction is provided for the DOE program-wide shift towards an integrative use of qualitative and quantitative methods for assessing the potential impacts of wind plant technology innovations on reducing the wind plant cost of energy.

Biography: Dr. Maureen Hand leads a team of engineers and analysts at NREL exploring current and future costs of wind energy through market data analysis and modeling. She recently led NREL's Renewable Electricity Futures study, a collaborative effort among public and private organizations to investigate the potential for renewable electricity generation in the U.S. Maureen has a Ph.D. in Mechanical Engineering from the University of Colorado and has been at NREL since 1995.

Reducing Wind Plant Cost of Energy

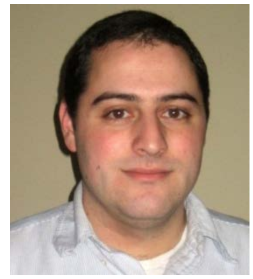
Abstract: A general formula for levelized cost of wind energy is used to describe the levers for reducing LCOE based on a typical cost breakdown. Important drivers for LCOE reduction are economies-of-scale (go bigger) and the learning effect (do better). Scenarios are presented to reduce the LCOE of both onshore and offshore wind, corresponding to subsidy-free onshore wind energy and 35% reduction in LCOE for offshore wind energy. Economies-of-scale triggers important savings for BOP and OPEX per megawatt, particularly for offshore. The learning effect relies on new technologies and more tailored loads design and turbine operation. Examples are the use of more experience-based load design leveraging data from GE's 20,000+ unit fleet and better accounting for climatological and real-time site-specific wind conditions.

A proposition is made that offshore wind energy is and will stay some two times more expensive than onshore wind energy but will continue to grow thanks to the commitment of developers and government to serve specific market characteristics, like strict rules on visual impact, support of offshore industry, or lack of land area. Essential non-tangible factors for wind energy are an affordable and sufficiently strong grid infrastructure, suitable financing schemes and a firm interest in the ownership of wind farms, together with a lasting growth in the demand for renewable energy.

Biography: Mr. Henk-Jan Kooijman has an MSc from Delft University in Aerospace Engineering and started his professional career at the Netherlands Energy Research Institute (ECN) - unit Wind in 1995. In 2003 he joined GE Wind Energy in Germany. At GE he worked as technical leader for Turbine Loads & Performance and as manager of the Systems Validation team. He currently is principal engineer of the Wind Farm Engineering team providing technical guidance and direction to promote new sales and services. His expertise entails integrated design assessment, turbine performance and loads, economics, and offshore application.

Session IV: Systems Engineering Methods Applied to Wind Energy III

This is the third session in a series focused on systems engineering methods applied to wind energy research, design and development. The talks in this third session provide examples of such analysis by focusing on the use of uncertainty quantification methods for the assessment of wind turbine performance.



Moderator Biography: Mr. Justin Gray holds a B.S. in Aerospace Engineering from the Georgia Institute of Technology and a Masters in Computer Science from Case Western Reserve University. He has worked in the NASA Glenn Research Center Multidisciplinary Design Analysis and Optimization Branch since 2004. He has a strong background in turbine engine systems analysis and MDAO applications for conceptual design of aerospace systems. Justin has been heavily involved in a number of engineering software development efforts from NASA, including the Numerical Propulsion Systems Simulation (NPSS) and the Object-oriented Turbomachinery Analysis Code (OTAC). He currently leads NASA OpenMDAO development project and open source MDAO framework project.

Computational Strategies for Aerodynamic Design and Analysis in the Presence of Uncertainties

Abstract: The quantification of the effect of uncertainties on the computational design and analysis of HAWT and VAWT is the objective of a collaborative project involving Stanford, Sandia and Purdue. We consider uncertainties related to operating conditions, manufacturing etc. and characterize them using probabilistic approaches. In addition, we investigate uncertainties connected to the choice of the physical models employed in the simulations such as the type of semi-empirical correlation chosen to represent laminar-to-turbulent transition on turbine blades. This presentation illustrates the computational multi-fidelity framework used to perform the analysis.

Biography: Dr. Gianluca Iaccarino holds an MS from the Aerospace Engineering Department at University of Naples and a PhD from the Mechanical Engineering from the School Polytechnic of Bari in Italy. He is an Assistant Professor in the Department of Mechanical Engineering at Stanford University. Since 2009, he has served as the director of the Thermal and Fluid Sciences Affiliate Program. In 2008 Dr. Iaccarino formed the Uncertainty Quantification Lab where the focus is research related to uncertainty quantification in Computational Fluid Dynamics. He received the PECASE award from DoE/NNSA in 2010.

Advances in UQ Algorithms for Wind Energy Applications

Abstract: In this presentation, I will discuss recent research in uncertainty quantification (UQ) algorithms, as motivated by wind energy applications within the Sandia/Stanford/Purdue ASCR UQ effort. Within this effort, we have initially investigated a set of adaptive collocation and sparsity detection methods and a framework for balancing discretization errors among deterministic and stochastic sources. These capabilities provide a core foundation that is now being leveraged for UQ studies that integrate multiple models of varying physics and fidelity.

Biography: Dr. Mike Eldred received his B.S. in Aerospace Engineering from Virginia Tech in 1989 and his M.S.E. and Ph.D. in Aerospace Engineering from the University of Michigan in 1990 and 1993 respectively. He is currently a Distinguished Member of the Technical Staff in the Optimization and Uncertainty Quantification Department within the Computation, Computers, Information, and Mathematics Center at Sandia National Laboratories. He led the DAKOTA project for 15 years (1994-2009) and now leads algorithm research and development activities related to DAKOTA.

Session V: Systems Engineering Application to Industry Wind Turbine Design

This panel is aimed at describing: 1) How specific components and turbine design relate to each other, 2) How the turbine architecture and wind plant design relate to each other, 3) How these relationships collectively dictate overall wind system design objectives, and 4) How these system design objectives are pursued through multidisciplinary design, analysis, and optimization (MDAO), with summaries of MDAO methodologies used.

Moderator Biography: Dr. Scott Schreck is a Principal Engineer at NREL's National Wind Technology Center. Scott Schreck joined NREL's National Wind Technology Center in 1998, and since then has served in various roles within the center, ranging from basic and applied research to utility scale technology development. At present, he leads various large-scale testing efforts in collaboration with industry partners, which are aimed at understanding turbine aerodynamics and atmospheric physics that govern energy production and machine structural loads. Early in his NREL career, Scott led the Aerodynamics and Aeroacoustics Team in applied research for discovering, characterizing, and modeling phenomena crucial to wind turbine efficiency and commercial viability. Subsequently, Scott managed the Low Wind Speed Technologies program, DOE's $40M multiyear effort for utility scale wind energy technology development. This effort consisted of a portfolio of industry-NREL subcontracts for developing wind turbine prototypes and components, and for conceptualizing long range technologies. Before coming to NREL, Scott was an Air Force officer and led a variety of defense science and engineering programs. These included the USAF Seiler Research Laboratory/Air Force Academy unsteady aerodynamics research program, a joint effort aimed at aircraft maneuverability enhancement, and an assignment was with the Air Force Office of Scientific Research Computational Mathematics Program.

GE Perspective on Wind Systems Engineering

Abstract: GE uses systems engineering tools and methods in many ways. Two important examples are evaluation of new technology and next-generation product designs. New technology is often component specific, but the impact of each technology travels throughout the entire wind turbine and often to the wind farm level. System engineering tools can be used to evaluate and optimize these new technologies, not just at a component level, but instead at a turbine or farm level. New technologies are often advertised with increased efficiency or reduced component mass, but one needs to consider the impact on revenue via AEP, overall wind turbine farm cost, and on operating costs to truly quantify the benefits. For example, the choice of drivetrain technology has a large effect not just on drivetrain cost, but also on AEP, and O&M costs. System engineering tools can also be used to develop next-generation product designs. This goes beyond optimizing the rotor diameter and rating, but also including what technology options for each component. Included in this analysis should be logistic costs and limitations, manufacturing limits, and targeted market conditions such as wind speed and tax benefits. Different market conditions will produce different optimal turbine architectures. Non-obvious interactions abound, such as with the choice of rotor diameter affecting BOP costs, wake losses, noise, and drivetrain torque. Both deep technical models are needed (such as to calculate aerodynamic efficiency or load impacts) as well as market specific economic models (to evaluate projected customer cash flow).

Biography: Dr. Charu Mehendale joined GE 8 years ago and is currently a Senior Product Manager in the GE Wind Product line team based in Schenectady, NY. In his current role, he leads the development and execution of the product technology strategy and ensures alignment with the GE Global Research Center and GE Wind Engineering teams. Prior to this role, Charu worked for 7 years at the GE Global Research Center focused on developing advanced control systems for wind turbines and Combined Cycle power plants. He led the development, implementation and field validation of model based controls and estimation algorithms for the GE 1.6MW, 100m wind turbine. He also led multi-disciplinary advanced technology programs on active aerodynamic loads control for Wind. Charu has a Ph.D in Mechanical Engineering and a MS in Applied Mathematics both from the University of Houston, a MS in Systems & Controls, from the Indian Institute of Technology in Mumbai, India and a BS in Electronics & Telecommunications, from the College of Engineering, Pune, India.

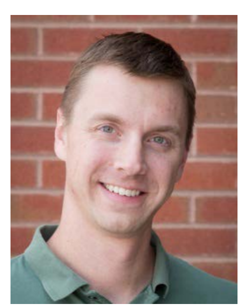
Applications of Concurrent Engineering in Wind Turbine Design

Abstract: This talk will highlight the advantages of Concurrent Engineering including improved product quality and reduced cost and explain how Concurrent Engineering relates to Systems Engineering, Multidisciplinary Design, Analysis and Optimization (MDAO) and other methodologies. After describing Concurrent Engineering, this presentation will make clear why wind industry companies should seriously consider deploying Concurrent Engineering methods into their current product development processes. Case studies with illustrative outcomes will be described and the advantages of Concurrent Engineering made clear. With this background, the bulk of the presentation will delineate how companies can make the most of any Concurrent Engineering implementation. Linking assorted computer aided engineering tools via MDAO is a step in the right direction but doesn't magically result in Concurrent Engineering. Diverse departments and personnel need to be "linked" as well. This requires that companies develop realistic Concurrent Engineering deployment goals, identify common obstacles to successful deployment, and plan and implement possible countermeasures or strategies to overcome these roadblocks; all of which requires a new emphasis on collaboration and communication. Finally, this presentation will highlight where to turn for additional resources for your Concurrent Engineering implementation.

Biography: Mr. John Leahey is an aerospace engineer with more than twenty years' experience designing and analyzing complex structures and mechanisms in industries including aerospace, consumer products, telecommunications hardware and renewable energy systems. John has also been actively involved in implementing Computer Aided Engineering (CAE) tools at numerous companies and industries throughout his career. Some of these experiences are neatly captured in his NAFEMS paper "Strategies for Implementing Finite Element Analysis (FEA) In Design: Adopt, Adapt and Retain." As part of a multi-disciplinary team, John is a composite design engineer at Vestas and is responsible for the structural design and analysis of new and existing rotor blades. John is actively involved in improving design methodologies at Vestas via CE principles.

Blade Design at Siemens Wind Power: Experiences from Industrial Application of MDO

Abstract: The creation of a modern wind turbine rotor is a complex multi-disciplinary multi-objective design problem. In the past each discipline could be treated independently and blades were designed manually in using a labour intensive iterative design by analysis method. Market pressure and the need for wind energy to become competitive independent of government subsidy has driven the need to further reduce cost of energy, increase design robustness/performance, and reduce design cycle time. Moreover, a general consequence of a cost of energy reduction and turbine scaling laws has meant that blade lengths have grown significantly over the last ten years and now include load alleviation technologies such as sweep and aero-elastic tailoring. The end result is a design problem that is substantially more complex, and one that has to be solved faster, better and cheaper than ever before. Automated design optimization and multi-disciplinary optimization techniques have been applied at Siemens Wind Power to help make this possible. A high-level description of the MDO framework at SWP is presented as well as some recent success stories. The challenges and benefits of using a 'multi-objective' mind-set as applied generally to technology evaluation and more specifically to blade design campaigns is discussed. This is followed with technical issues facing industrial MDO applications. The organizational experience of applying MDO within SWP is then covered in the context of lessons learned.



Biography: Dr. Eddie Mayda is an R&D engineer with Siemens Wind Power in Boulder, Colorado. His primary responsibilities involve numerical design optimization of wind turbine airfoils and support of rotor design. Over his two years with Siemens, Eddie has played a critical role in co-developing multidisciplinary optimization tools which have already produced cost-of-energy improvements compared to existing design tools and processes. Eddie received his B.S., M.S. and Ph.D. degrees from the University of California, Davis, where he studied under the supervision of Prof. Case van Dam. His studies focused on automation methods and modeling enhancements of computational fluid dynamics solvers for use in the rotorcraft and wind energy industries.

Wind Turbine Drivetrain Development

Abstract: Wind turbine drivetrains typically consist of a main shaft, main bearings, gearbox, high speed coupling and generator. These parts are typically designed in isolation from each other with suppliers only having access to limited information. A more effective design may be achieved with a better understanding of how components interact in the system; in terms of loading, misalignments, dynamic responses and failure rates. Methods for physical modelling of the drivetrain system are discussed. The importance of understanding the effects of aerodynamic and electrical loads on the mechanical system is demonstrated. The reliability of a wind turbine drivetrain is critical to achieving a low overall turbine cost of energy. The drivetrain design with the lowest initial capital expenditure may not be the design with the lowest lifetime cost. To investigate the lifetime cost of different drivetrain designs a detailed capital expenditure model was combined with a detailed operations and maintenance model. The model shows that the cheapest cost of energy is achieved with a "medium-speed" drivetrain with one or two gear stages, significantly better than direct-drive (gear-less) turbines and typical 3-stage high-speed turbines. The drivetrain lifetime cost model for the drivetrain is then utilized to compare different cost-saving approaches.

Biography: Dr. Christopher Halse is Engineering Manager at Romax Technology Inc.'s Wind Technical Center in Boulder, Colorado. He has a PhD. in nonlinear dynamics from The University of Bristol, UK, 3 years of experience developing commercial software for simulation of rotating machines, and 5 years of experience in design and analysis of mechanical systems. He is particularly interested in wind turbine mechanical systems, and he has led projects in gear system optimization, failure investigations, drivetrain dynamics and gearbox refurbishment.

Day 2: Lunch Session Keynote

Offshore Wind System Design - Lessons Learned From the Oil & Gas industry

Abstract: The lunch talk, "Offshore Wind System Design - Lessons Learned From The Oil & Gas industry", will cover three areas. The first is a one page summary of the keynote talk the speaker gave to the DOI/DOE workshop in Washington DC last spring on offshore wind. That talk addressed lessons learned from the oil & gas Industry's general experience offshore. The second part of this current talk will go over Value Engineering process as used by the oil & Gas industry in improving offshore designs and work practices. The final part of the current talk will show the application to floating offshore wind power generation of one of the industries well tested tools for simulating the motions of floating structures, MLTSIM. That tool embodies over 20 years of industry operating experience and model testing, and can simulate time series motion of all of today's variety of floating structures. It has now been linked real time to the FAST program developed by NREL, using recent model test results from DOE funded DeepCwind program for validation. Brief results will be shown.

Biography: Mr. Jim O'Sullivan is Vice President of Technip USA and manages the Technology Services Department that supports all regional offshore projects and manages the company research regarding floating systems. Mr. O'Sullivan is responsible for the company's floating facility products that include developing and launching new technologies, along with supporting established products. He has 38 years of experience in the oil & gas industry, covering technology development, engineering, project management, commercial project development and multiple business related activities. He received a BS in Mechanical Engineering from North Carolina State University, a Masters in Ocean Engineering from MIT, a Professional Ocean Engineers Degree from MIT and Woods Hole Oceanographic Institution, and an MBA from Rice University's Jones Graduate School of Business.

Session VI: Wind Plant Design and Optimization I

This is the first panel in a series on wind plant design and optimization. From the last panel which focused on wind turbine design in the system context, we now move to a focus on wind plant design in the overall system context. This can potentially involve a large number of stakeholders and analysis steps. In this first talk, several aspects of the wind plant design and optimization process are highlighted including the development of software tools to aid in the design decision processes, simulation of wind plant dynamics including coupling of flow models with turbine dynamic models, and using risk assessment as a method in wind plant design.

Moderator Biography: Dr. Patrick Moriarty is the lead of the Aero and System Dynamics group and has been at NREL since 2001. Dr. Moriarty's research focuses are wind turbine design and systems engineering, statistical loads extrapolation, aerodynamics and aeroacoustics of wind turbines. He has developed design techniques that enable industry to more reliably predict loads and produce cheaper designs. He is involved in the development of advanced turbine noise measurement instrumentation and has developed aerodynamic and noise prediction models used in wind turbine simulation tools. Currently, he is working on computational models for wind turbine wakes and array effects using computational fluid dynamics. He leads an International Energy Agency Task on wind turbine wake model validation. He has published over 30 papers related to wind energy and also serves as associate editor for Wind Energy.

Wind Turbine Layout and Performance Optimization – A Manufacturer's Perspective

Abstract: GE has developed system-level design/analysis tools to optimize the selection of a turbine model or multiple models and their placement for a particular site. These tools take advantage of design limits knowledge of OEMs, which enables the full utilization of the turbine potential. This presentation will give an overview of these tools and the important concept of application space as it relates to micrositing and post-construction performance optimization. Also highlighted in this presentation is how the controls strategy can be refined to maximize performance on a turbine and site specific basis. The use of design limits and controls knowledge to improve the economics of a wind plant is not without challenges, however, and the presentation will present some of them and seek to trigger dialogue on this topic during the panel discussion.

Biography: Mr. Philippe Giguère is a Sr. Engineer at GE Power & Water working on wind turbine systems integration and fleet support. Philippe has 18 years of wind energy experience with the last 12 years in industry. He has been with GE since the acquisition of Enron Wind in 2002 working in aerodynamic blade design and turbine performance until 2005 and then focusing on micrositing and turbine performance optimization for nearly 8 years. Prior to joining the wind industry, Philippe conducted blade design research sponsored by the National Renewable Energy laboratory at the University of Illinois at Urbana Champaign from 1994-1998 and at the National Wind Technology Center in 1998-1999. Philippe earned a Bachelor degree and Master degree in mechanical engineering from McGill University and Université Laval, respectively.

An Overview of SOWFA--The Simulator for Off/Onshore Wind Farm Applications

Abstract: The Simulator for Off/Onshore Wind Farm Applications (SOWFA) is a collection of tools for simulating wind farm aerodynamic and aeroelastic interactions. The vision is that SOWFA will be composed of high-fidelity computationally intensive computational fluid dynamics (CFD) based tools, reduced-order tools for wake modeling, aeroelastic tools, and means for coupling the wind plant calculation with mesoscale weather simulations. In its current form, it mainly consists of the high-fidelity CFD tools that can be used to perform atmospheric boundary layer large-eddy simulations (LES) coupled with an actuator line representation of turbines. The actuator line model is also coupled with NREL's FAST aeroelastics and system dynamics tool. The CFD and actuator line tools are based on the popular OpenFOAM CFD toolbox. Work is being done to understand how to couple this high fidelity set of tools with the Weather Research and Forecasting (WRF) mesoscale weather solver. Also, DTU Wind's reduced-order dynamic wake meandering (DWM) tool is currently being incorporated into FAST. This talk will provide a general overview of SOWFA along with some examples of how it is being applied to wind energy problems.

Biography: Dr. Matt Churchfield is a research engineer at the National Renewable Energy Laboratory (NREL). He works at the laboratory's National Wind Technology Center (NWTC), which is a 300+ acre site located just south of Boulder, Colorado near the foothills of the Front Range of the Rocky Mountains. Matt's expertise is in aerodynamics and computational fluid dynamics, and he studies wind plant aerodynamic effects, such as the way wind turbine wakes interact with one another, other turbines, and turbulence in the atmospheric boundary layer. He earned his masters and doctorate degrees in aeronautical engineering at Purdue University and his bachelors in mechanical engineering from the University of Nevada, Reno.

Layout optimization's influence on project risk

Abstract: DNV KEMA's team of over 150 wind energy professionals has been supporting and actively involved in the wind industry for more than 20 years. An important service DNV KEMA has performed over this period has been an independent review of developer, owner, and turbine manufacturer project designs, including optimization techniques and results. In DNV KEMA's opinion, project layout optimization involves maximizing long term project revenue while keeping technical risks at a tolerable level. As system engineering software becomes more sophisticated, long term project energy production should be increased through micrositing tools and new turbine designs and control methods. But such improvements should not increase the risks associated with the project or else a critical component of optimization is lost. System engineering tools used for layout optimization could benefit from recognition of input uncertainties as well as additional input parameters related to risk mitigation. New controls which monitor loads and/or allow automatic sector management, as well as future advances not yet developed, become part of the overall system but introduce added uncertainty and should be subject to quality assurance.

Biography: Mr. Jake Frye brings seven years of experience to his role as Senior Engineer at DNV KEMA Energy and Sustainability. Jake received his M.S. in mechanical engineering from the University of Canterbury in Christchurch, New Zealand. Prior to joining DNV KEMA, Jake was a member of the generation development team at MainPower New Zealand Ltd., a wind power project developer on the south island of New Zealand. At DNV KEMA, Jake's primary focus is independent due diligence of wind power project designs on behalf of project investors. Jake has specific experience with wind resource analysis, site suitability analysis, operation and maintenance cost modeling, construction monitoring, and evaluation of turbine technology and project financial performance.

Session VII: Wind Plant Design and Optimization II

This is the second session in a series on wind plant design and optimization. From the last panel which focused on wind turbine design in the system context, we now move to a focus on wind plant design in the overall system context. This can potentially involve a large number of stakeholders and analysis steps. In this second talk, several aspects of the wind plant design and optimization process are highlighted including resource assessment and wind flow modeling, development and land ownerships constraints, and optimization practices and constraints in lights of these variables.

Moderator Biography: Mr. Ryan King joined NREL's National Wind Technology Center in 2012 and works on drivetrain modeling for NREL's Systems Engineering efforts. Prior to joining NREL, Ryan worked as a Turbine Engineer and Energy Resource Engineer at RES Americas for three years. In those roles Ryan was involved in the layout optimization and construction of over 750 MW of now operational wind energy. Ryan holds a BS in Mechanical Engineering from MIT and is currently a PhD student in Mechanical Engineering at the University of Colorado, Boulder.

Layout Optimisation – What Are We Optimizing and How?

Abstract: We take a step back from focusing solely on computational layout optimization to consider what we are actually trying to optimize when designing a turbine layout for a wind farm project. Different variables in and sources of constraint to layout design are considered at a high level in light of these optimization goals, and practical approaches to each are discussed.

Biography: Mr. Matthew Lynn is in charge of GL Garrad Hassan's Online Data Management service and global energy analysis software tools, based in Portland Oregon. He has worked at GL Garrad Hassan since 2003, starting in Bristol, UK, moving to Vancouver BC to open an office there in 2008 and most recently out of the Portland office. He has extensive experience in wind farm resource measurement, energy assessment and layout design in areas as far east as Vietnam and as far west as Vancouver Island, and would thus like to hear from anyone with a project in Hawaii. Matthew holds Master's degrees in Physics with Study in Europe from the University of Manchester and Renewable Energy Systems Technology from the University of Loughborough in the UK. In a previous life he was a Software Developer.

Wind Project Design and Optimization: Introduction, Validation, and Applications of openWind

Abstract: Effective wind plant design and optimization require the successful synthesis of quality site information with potentially competing layout, technology, and construction requirements. Seeking a platform that would more intuitively integrate GIS-based site information and provide more transparency in project optimization, AWS Truepower developed the openWind software package. The founding premise of this effort, and openWind, is to foster industry collaboration and research with a flexible wind project design platform.

The open-source openWind tool, which includes current wake models and multiple optimization approaches, was intended to remove the barrier of proprietary software to developers, research entities, and other industry experts seeking to examine wind plant development. The commercial version of the tool enhances those capabilities by leveraging AWS Truepower's development efforts in wake modeling, layout design and cost of energy optimization, to design buildable, high-yield projects. Both packages are available for customization and integration into larger research and development efforts.

This discussion will present an overview of wind project design with openWind, including key input steps and their synthesis for cost of energy optimization. Specifically, it will summarize site selection and characterization via measurement and modeling. Second, it will provide an overview of openWind's development and validation as open-source and commercial wind energy calculation tools. Finally, it will present key applications of openWind, including current tools and new development plans.

Biography: Mr. Matthew Filippelli is Lead Engineer with AWS Truepower and has been engaged with wind development in the US since 2003. He applies his experience in aerodynamics, site characterization, and wind farm design to both internal research and to services for a diverse spectrum of clients. His efforts have supported nearly every phase of wind development, from siting through financial close, to operational analyses and forecasting. He has been involved in terrestrial and offshore wind projects located throughout North America, Asia, and Europe. He participates in a variety of offshore wind working groups as well as the IEA's Wind Energy Remote Sensing users group. Mr. Filippelli holds a dual degree in Mechanical and Aeronautical Engineering from Rensselaer Polytechnic Institute.

Wind Farm Design - A focus on real world development and constraints

Abstract: Wind farm (WF) design has traditionally been a qualitative iterative process with the goal being to maximize energy production within a set of development constraints. The approximate scale of temporal & spatial development constraints will be presented for an anonymous Iberdrola Renewables WF. Data from the FAA Obstruction Evaluation / Airport Airspace Analysis (OE/AAA) system will be analyzed to estimate design parameters used by the industry as a whole for a region roughly approximating TX. The analysis suggest that township section range (TSR) land ownership patterns are the primary driver behind WF design. Analysis of the OE/AAA data further suggest that WF developers could benefit financially from a systems engineering holistic approach that takes into consideration quantitatively, variables directly related to WF energy production in addition to property ownership.

Biography: Mr. Scott Haynes is a Senior Meteorologist with Iberdrola Renewables. He has been employed in the wind industry since 2000 (excluding graduate school), holding a variety of positions including project developer, research scientist and meteorologist. He also briefly held an academic appointment as an Instructor of Physics at the University of Minnesota Duluth. Mr. Haynes earned a B.S. degree in Physics from the University of Wyoming in 2000 and an M.S. in Physics from the University of Minnesota Duluth in 2004.

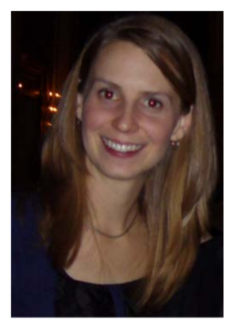
Session VIII: Integrated Wind Turbine and Plant Modeling

This final session presents a set of approaches for integrated wind turbine and plant modeling. Earlier sessions also provided several examples of integrated wind turbine and plant modeling from the view of a simple characterization of a wind turbine as a power curve and cost object in a layout optimization to the coupling of advanced models for flow and turbine dynamics. In this session, additional efforts will be highlighted including a systems engineering approach to wind plant analysis that includes models of various levels of fidelity connected together for overall cost of energy analysis, development of an optimized blade design for a very large-scale turbine, and a multi-fidelity approach to the analysis of wind plant performance and cost.

Moderator Biography: Dr. Peter Graf graduated from Stanford University in 1989. After several years working as a computer programmer, he entered graduate school and in 2003 received his Ph.D. in Mathematics from the University of California at Berkeley. His thesis involved optimization of model reduction for systems of ordinary differential equations, under advisor Alexandre Chorin. He is currently a senior scientist in NREL's Computational Science Center. Dr. Graf's research at NREL is primarily focused on bringing applied mathematics to bear on computational problems involving renewable energy, and to scale these solutions to utilize large parallel computational resources. In particular, he has helped develop simulation and optimization tools for problems including: inverse material design, systems biology parameter identification, atomistic to continuum simulation of organic photovoltaics devices, systems engineering for wind energy, and reduced order and multi-scale modeling of lithium-ion batteries.

Analysis of Wind Plant Cost with NREL's Wind Energy Systems Engineering Software

Abstract: This presentation introduces the development a new software tool for research, design, and development of wind energy systems which is meant to 1) represent a full wind plant including all components, turbines, and balance of system up to grid interconnection 2) allow use of interchangeable models of varying fidelity for different aspects of the system 3) support analyses ranging from sensitivity studies and parameter scans to optimization and uncertainty analysis. The architecture of the tool is presented and some analysis results from application of the tool are discussed.



Biography: Ms. Katherine Dykes joined NREL in 2011 to support an NWTC initiative for systems engineering methods applied to wind energy. The project is undergoing initial development and involves integrating engineering and cost-based analysis tools to analyze overall wind energy system performance. Katherine's PhD work in systems engineering involves understanding innovation and diffusion of wind energy technology. Her background in wind energy began while working as a wind program analyst for Green Energy Ohio in 2005 and as a data analyst for The Renaissance Group. In addition to wind energy, Katherine has worked as a system dynamics consultant to IBM's Smarter Cities Marketing Insights 2.0 initiative, a data quality analyst at EnerNOC for their demand management program, and as a controls engineer for GM's Hybrid Vehicle Program.

Towards an integrated design complex for wind turbines

Abstract: One of the main challenges to the continuous up-scaling of wind turbines is to maintain low weight while achieving high power efficiency and the necessary stiffness of the blade. An important parameter to achieve high stiffness is the relative thickness of the airfoils on the blade. Modern blade designs therefore move towards using thicker airfoils to maintain high stiffness while minimizing the weight.

This trend poses considerable challenges to the aerodynamic design, since thick airfoils in general are significantly less efficient than thinner ones. New solutions to both the structural and aerodynamic design of wind turbines are therefore needed in order to balance the structural constraints with the requirements of high aerodynamic efficiency. The Light Rotor project, which is a publicly funded project carried out by DTU Wind Energy in collaboration with Vestas Wind Systems, seeks to address these challenges for the next generation multi-mega-Watt wind turbines, through development of new design strategies and tools. In particular the project aims towards a more integrated approach to design, where a larger number of design variables and constraints can be taken into account in an integrated design process. Thus, the project ranges from design of optimal airfoil sections over aeroelasticly optimized blades to optimized blade structure.

In this presentation an overview of the newly developed DTU 10 MW Reference Wind Turbine will be given. As this is the first comprehensive design of a wind turbine carried out in the department, where aerodynamic, aeroelastic and structural experts are involved at the same time, this presentation also seeks to provide some perspectives on the lessons learned and future directions for the development of design tools for wind turbines at DTU Wind Energy.

Biography: Dr. Frederik Zahle completed his masters in Aeronautical Engineering at Imperial College, London in 2003, and carried out a PhD jointly between Imperial College and Risø DTU in the field of computational fluid dynamics (CFD) of wind turbines which he completed in 2007. He is currenty holding a position as a senior scientist in the aeroelastic design section (AED) at DTU WInd Energy, Risø Campus. His current research activities are within aerodynamics of airfoils and rotors, computational fluid dynamics, and development of multi-disciplinary design tools for wind turbines and airfoils.

Integrated design of wind farms with TOPFARM and EERA-DTOC: the presentation of two design tools for wind farms that take various aspects of the wind energy system into account.

Abstract: Two European funded projects, TOPFARM (Topology OPtimization of windFARMs, EU-FP6 2006-2009) and EERA-DTOC (European Energy Research Alliance - Design Tool for Offshore Clusters, EU-FP7 2012-2014) have both the intent to create a design tool for wind farms. The TOPFARM project focused on creating a multi-fidelity framework to optimize onshore and offshore wind farms based on the financial balance seen from a wind farm developer perspective. The tool included cost functions for the annual energy production, wind turbine degradation and maintenance due to wake induced fatigue loads, electrical infrastructure and offshore foundation costs. The next generation of the tool, based on openMDAO, is under development. EERA-DTOC is itself focusing on the mesoscale wake effect of neighboring wind farms on the target wind farm, the inter-wind farm electrical connection design, and taking also into account uncertainties, and mesoscale wind variabilities.

Biography: Dr. Pierre-Elouan Réthoré is a Senior Researcher at DTU Wind Energy in the Aero-Elastic Design section. He holds a PhD from Aalborg University and Risø DTU National Laboratory in computational fluid mechanics on the topic of wind farm wake aerodynamics. He has been working during the past 7 years on various wind farm and wind turbine integrated design topics.

Workshop Follow-On Meetings Agenda

Thursday, January 31st, 2013 (At NREL NWTC)	
8:00 am to 12:00 pm	**DAKOTA Tutorial: Basics** In this introduction to DAKOTA, we will tour DAKOTA's capabilities and learn how to create simple DAKOTA studies. Format will be mixed lecture and demonstration including: ➢ DAKOTA Overview: orientation, how to get started, JAGUAR DAKOTA GUI, workflows. ➢ Sensitivity Analysis: identifying the most important input factors. ➢ Uncertainty Quantification: performing statistical analysis of response quantities. ➢ Optimization: finding the best designs. ➢ Calibration: using data to estimate model parameters.
12:00 pm to 1:00 pm	**NREL NWTC Tour** Walking tour of the NREL NWTC facilities.
1:00 pm to 5:00 pm	**OpenMDAO Tutorial: Basics** The OpenMDAO Training session will cover installation, basic component definitions, GUI usage, MetaModeling and Optimization Processes.
Friday, February 1st, 2013 (At NREL NWTC)	
8:00 am to 10:00 am	**Working Group Session on Standard Software Interfaces for OpenMDAO Wind Applications** The NREL NTWC and DTU-Wind are working together to establish a unified framework for interoperability of wind turbine and plant software in OpenMDAO. This workgroup will discuss the status of the framework development and seek to engage other parties to join in the framework development process.
10:00 am to 1:00 pm	**DAKOTA Tutorial: Advanced Topics** In this follow-on DAKOTA tutorial, we will tour more advanced DAKOTA capabilities and learn how to interface with engineering simulations. Format will be mixed lecture and demonstration. Modules will include: ➢ Simulation interfacing: an introduction to interfacing DAKOTA to your model. ➢ Parallel computing: asynchronous local, MPI, and hybrid modes. ➢ Multi-component studies with multiple methods and models. ➢ Other research topics of interest: e.g., surrogate-based and adaptive methods.
1:00 pm to 3:00 pm	**NREL TWISTER Tutorial: Demonstration and Tutorial** This tutorial is a mixed lecture and interactive demonstration of the new NREL TWISTER model for wind plant systems engineering. NREL seeks to establish a Beta-user community for the new integrated software tool.
3:00 pm to 5:00 pm	**FAST Modularization Framework Presentation** Presentation on the new FAST modularization framework and programming guidelines.