

MOU Number: NREL MOU-17-488

MEMORANDUM OF UNDERSTANDING

Between

National Renewable Energy Laboratory

and

National Technology & Engineering Solutions of Sandia, LLC

and

Technical University of Denmark
Department of Wind Energy
Anker Engelundsvej 1, Bygning 101A
Bygning 101A
2800 Lyngby
Denmark

Subject: Coordination of activities to promote the development of publicly available High Fidelity Modeling (HFM) simulation and analysis software, experimental validation data, science and engineering methods used for optimizing wind plant cost and performance.

INTRODUCTION

The **National Renewable Energy Laboratory (NREL)** is a national laboratory managed and operated by the Alliance for Sustainable Energy, LLC for the United States Department of Energy (DOE) under Contract No. DE-AC36-08GO28308.

National Technology & Engineering Solutions of Sandia, LLC ("Sandia"), manager and operator of Sandia National Laboratories for the DOE/National Nuclear Security Administration (NNSA) under contract DE-NA0003525 ("Prime Contract"), a limited liability company formed under the laws of the State of Delaware whose principal place of business is located in Albuquerque, New Mexico.

Integral to their mission for the U.S. Department of Energy (DOE), NREL and Sandia conduct integrated systems & innovation analysis within the DOE Wind Energy Technology Office (WETO) research and development focus area on wind plant optimization and performance.

The **Technical University of Denmark (DTU)** includes a Wind Energy Department that constitutes a large research center conducting research within ten research programs which are organized into three main topics: wind energy systems, wind turbine technology, and basis for wind energy.

NREL, Sandia or DTU are separately referred to as a "Participant" and collectively as "Participants."

The purpose of this MOU is to encourage coordination in areas of mutual interest and benefit to all three Participants. Based on the principles of equality and reciprocity, this MOU is intended to

serve as a general framework for planned coordination between the three Participants and is intended to facilitate discussions for the development of a more specific planned program of research and development collaboration. Any specific program of collaboration or sharing of confidential information is to be implemented through an appropriate written contract between the Participants.

DTU Wind Energy, Sandia and NREL have conducted renewable energy research with a focus on wind energy for many years. They have cooperated informally by exchanging professionals and invitations to hosted events of mutual interest. The Participant's goals historically overlapped in areas such as rotor aerodynamics, structural dynamics, power conversion technology and atmospheric fluid mechanics.

In recent years, the Participants have focused on wind plant flow modeling and validation. DTU has developed a variety of wind plant design capabilities derived from their Ellipsys Computational Fluid Dynamics (CFD) software package. NREL has used OpenFOAM, a public domain CFD solver, coupled with NREL's FAST turbine aeroelastic modeling tool to create a wind plant modeling capability called SOWFA. Sandia has created Nalu, a high performance CFD capability that extends scalability to the next generation of exascale computer architectures. NREL and Sandia are already engaged in a joint effort funded by DOE WETO and the Office of Science to transition the SOWFA capability to Nalu in order to achieve the comprehensive scalability necessary to fully resolve complex wind plant flow fields. FAST has also been transformed into OpenFAST to parallel that exascale development in a developer community format.

The existing capabilities of each Participant in this Memorandum of Understanding (MOU) bring unique strengths to the joint effort for advancing exascale wind plant flow modeling capabilities. All Participants are concurrently engaged in technology innovation activities that derive their understanding of the physics of wind plant flows from the high fidelity computational models. All Participants are also engaged in experimental campaigns that validate the models for the purpose of wind plant technology advancement. Through these efforts, the development of wind plant design and optimization technologies and methods will be accelerated to make wind the lowest cost electricity source in the world. This MOU between DTU Wind Energy, Sandia and NREL formalizes the intent to coordinate their respective research activities to maximize the benefit of each Partner's respective research contributions in advancing High Fidelity Modeling (HFM) and analysis methods in support of industry to more rapidly advance wind plant technology development.

The Participants express their non-binding intent to coordinate their respective research activities around the development of HFM computational capabilities and analysis methods for wind plant flow modeling and validation.

Section 1: Areas of Coordination

Coordination of the Participants' research activities under this MOU will focus on the development and validation of HFM capabilities and analysis methods to advance wind plant technology. Wind plant modeling is a complex problem requiring resolution of the atmospheric inflow physics and the intra plant flow field dynamics driven by complex terrain and megawatt scale turbine wake interactions within. The complexities and processes involved represent a multi-scale and multi-physics problem, deemed a "Grand Challenge" by the DOE Office of Science, requiring HFM and exascale computational capabilities for full resolution. Participants will use their best efforts to coordinate the high fidelity modeling research needed to resolve fully

integrated wind plants containing multiple turbines and capable of resolving the unique and site specific mesoscale atmospheric conditions driving plant performance.

The coordination activities planned under this MOU, and the programs of collaboration contemplated in furtherance of, are focused on cooperation to maximize the benefit to their respective institutional interests, which may include the following selected topics:

1. Wall models
2. Numerical Solvers
3. Scalability to Exascale
4. Complex Terrain
5. Treating surfaces (Ocean, Airfoil, Ground, etc.)
6. Uncertainty Quantification
7. Embedded models for turbines (actuator line and other approaches)
8. Hybrid RANS/LES approaches
9. Meso to Micro scale coupling
10. Verification and Validation

Section 2: Forms of Coordination

Planned coordination under this MOU may include, but is not limited to:

1. Exchange of published scientific and technical information, publications, and reports;
2. Meetings organized to discuss specific topics identified in Section 1, including conferences, seminars, and workshops;
3. Exchange of scientists, engineers, and other specialists for participation in workshops, conferences, seminars, working sessions, and coordination of research activities. Each Participant is to abide by the health, safety, and environmental requirements of the host institution when on an exchange assignment at the host institution's facility.

Section 3: Funding

1. The scope of planned activities under this MOU should be mutually determined in light of time, resources and/or funds available at both institutions for the types of coordination undertaken and by such other financial assistance as may be obtained by either Participant from external sources.
2. Unless the Participants otherwise determine in a separate written agreement, each Participant is to be responsible for the costs it incurs in participating in the coordination contemplated by this MOU, including all administrative costs, overhead expenses, labor costs, insurance costs, travel expenses and similar costs.

Section 4: Researcher Exchanges

1. Each Participant retains responsibility for its own personnel in relation to researcher exchanges to carry out the coordination under this MOU.
2. Each Participant's personnel are to abide by the regulations, policies, and procedures of the host Participant in carrying out activities under this MOU. Such separate written agreements for the exchange of personnel may include clarification regarding one or more of the following:

1. Protection of business proprietary information, protection of intellectual property, compliance with export control laws and regulations, conditions of coordination and decorum, health, safety, and security requirements, and all other terms under which personnel are authorized to participate in researcher exchanges at the host Participant's facility. Such activities may require entry into separate written agreements.
2. Each Participant is to be solely responsible for its own personnel in relation to matters such as visa and travel formalities, appropriate insurance (medical insurance and medical evacuation and repatriation insurance), travel expenses, and suitable living accommodation and expenses.
3. To the extent possible, the host Participant should assist in facilitating travel arrangements of the other Participant's personnel in relation to researcher exchanges in accordance with its applicable procedures governing foreign national access to the host Participant's facility.

Section 5: Dissemination of Information

Each Participant intends to participate in the coordination in a manner that facilitates exchanges of publicly available, non-proprietary business information. Subject to applicable laws and regulations of its country, each Participant may disseminate information, data, and reports of the coordination carried out under this MOU.

Section 6: Use of Information

Any information transmitted by one Participant to the other Participant under this MOU should be accurate to the best knowledge and belief of the transmitting Participant.

Section 7: Intellectual Property

The Participants do not anticipate the transfer of rights in intellectual property or the sharing of confidential information to occur under any planned coordination activity under this MOU.

Section 8: Future Collaborations

In the event that the transfer or commitment of funds is to be implemented, it will be performed through an appropriate written contract between the Participants. Any such contract should include a work plan, staffing requirements, cost estimates, funding sources, the adequate and effective protection and allocation of intellectual property rights, and other arrangements or conditions; and must be authorized under the appropriate contracting vehicle for each Participant.

Section 9: Review of Coordination

The Participants intend to review the coordination undertaken under this MOU as a means to ascertain its effectiveness, document achievements and lessons learned, recognize technical personnel, and identify and plan areas for potential future collaboration that involves the conduct of research and development. This review should take the form of periodic meetings of representatives of each Participant to discuss ongoing coordination and to identify and plan future collaboration that involves the conduct of research and development activities.

Section 10: Contacts

1. One or more designated representatives from each Participant should oversee, manage and facilitate implementation of this MOU in cooperation with each other on behalf of their respective institutions. All notices, communications and coordination should involve, at a minimum, the following individuals, their successors and/or designees as follows:

- (a) For the National Renewable Energy Laboratory:

Daniel Laird, Director of the NWTCL
Alliance for Sustainable Energy, LLC
National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
Daniel.laird@nrel.gov

- (a) For Sandia:

Geoffrey Klise, Manager, Wind Energy Technologies Department
National Technology & Engineering Solutions of Sandia (NTESS)
Sandia National Laboratories
PO Box 5800
Albuquerque, NM 87185
g.klise@sandia.gov

- (b) For Technical University of Denmark - DTU

Peter Hauge Madsen, Department Head of DTU Wind Energy
Technical University of Denmark
Frederiksborgvej 399
Building 125, room S30-36
4000 Roskilde
Denmark
npha@dtu.dk

Section 11: General Considerations

1. This MOU is not intended to create any legally binding obligations between the Participants.
2. Each Participant should conduct the coordination contemplated by this MOU in accordance with applicable laws and regulations to which it is subject and international agreements to which its government is party. NTESS must also conduct its participation in accordance with the terms and conditions of its Prime Contract with DOE/NNSA.

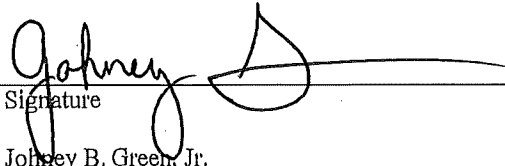
Section 12: Commencement, Modification and Discontinuation

1. Coordination under this MOU may commence upon signature, and may continue for a period of five (5) years, unless discontinued in accordance with paragraph 3 of this section.
2. The Participants may modify this MOU at any time by mutual consent in writing.

3. The Participants may discontinue coordination under this MOU at any time by mutual consent in writing. Alternatively, a Participant that desires to discontinue its participation in this MOU should endeavor to provide the other Participant at least 90 days advance written notice.

Signed in triplicate

For the
National Renewable Energy Laboratory


Signature

John B. Green, Jr.
Associate Laboratory Director, Mechanical &
Thermal Engineering Sciences

19 March 2019
Date

SUBJECT TO DOE APPROVAL

For
National Technology & Engineering Solutions of
Sandia, LLC

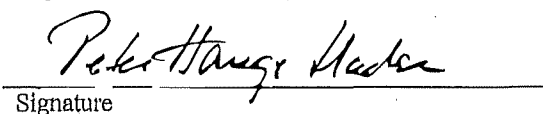
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Signature

Doris E. Ellis
Associate Labs Director, Research & Development

Date
SUBJECT TO DOE APPROVAL

For the
Technical University of Denmark
Department of Wind Energy


Signature

Peter Hauge Madsen
Department Head of DTU Wind Energy

28/2 - 2019
Date

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Signed in triplicate

For the
National Renewable Energy Laboratory

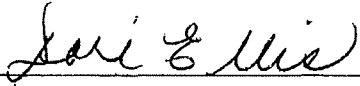
Signature

Johney Green
Associate Laboratory Director, Mechanical and
Thermal Engineering

Date

SUBJECT TO DOE APPROVAL

For
National Technology & Engineering Solutions of
Sandia, LLC



Signature

Doris E. Ellis
Associate Labs Director, Research & Development

Date

SUBJECT TO DOE APPROVAL

For the
Technical University of Denmark
Department of Wind Energy

Signature

Peter Hauge Madsen
Department Head of DTU Wind Energy

Date