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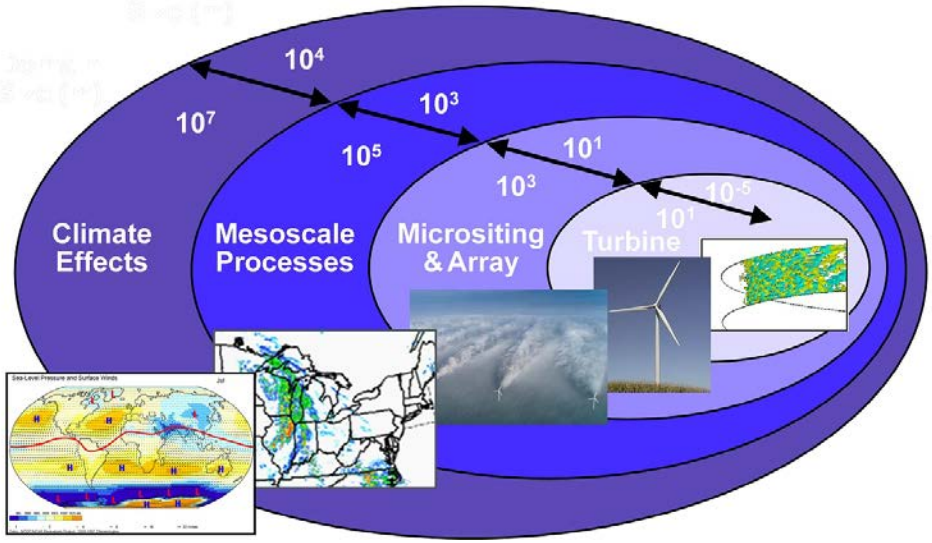
U.S. DEPARTMENT OF ENERGY

Atmosphere to Electrons (A2e) Initiative Overview

January 2014

DOE Wind and Water Power Technologies Office

Overview Agenda



- **Motivation for a new R&D framework**
- **A2e initiative overview**
  - Strategic planning framework
  - Management construct
  - Executive Management Committee (EMC)
  - National Laboratory Leadership
- **Strategic thrust area planning introduction**
- **Program objectives**
- **Open discussion of approach**

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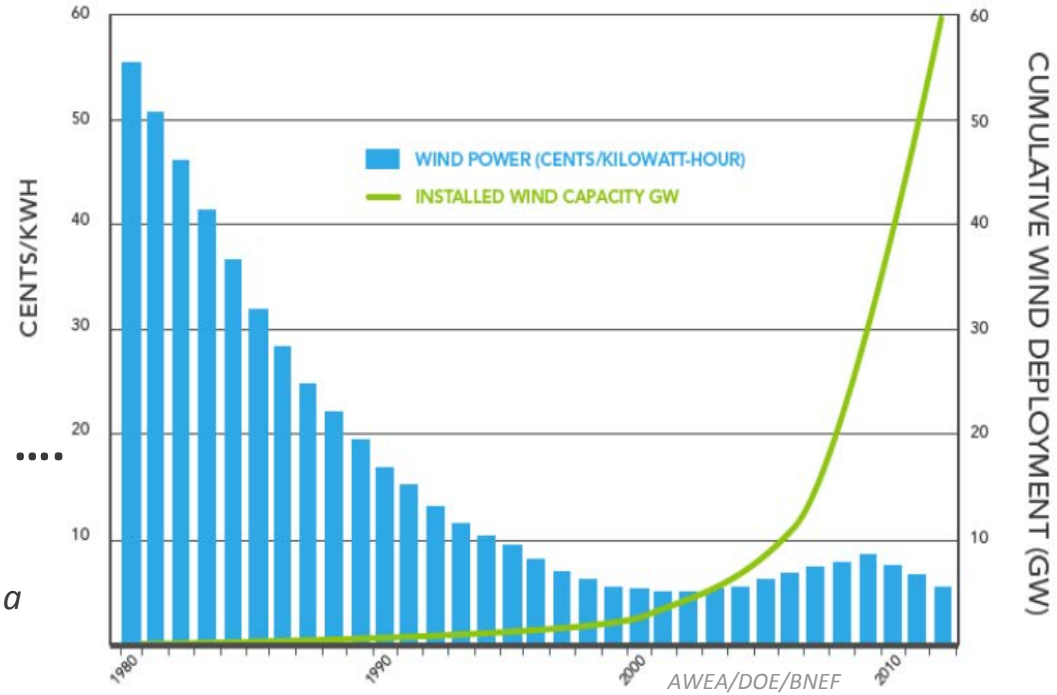
Wind Power Industry Overview

Wind energy today …..

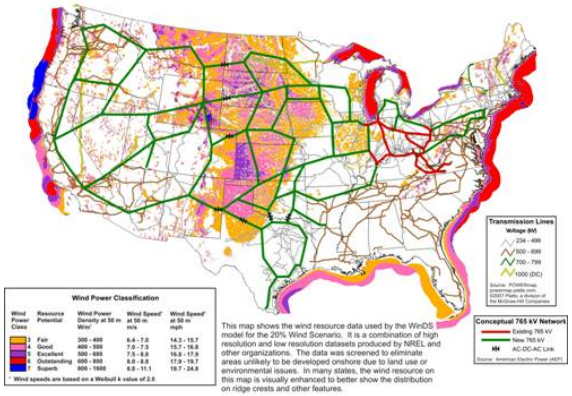
- *Multi-Billion dollar industry with involvement of multi-national corporations*
- *60+ GW Deployed (~5% of U.S. Electricity)*
- *Land-based wind: 7-8 ¢/kWh (beating coal)*
- *Competitive wind turbine technology at multi-megawatt scales*
- *Leads all renewable technology deployment*

Tremendous opportunity remains ….

- *Achieve parity with natural gas @5-6 ¢/kWh*
- *Establish offshore wind deployment*
- *Provide foundational R&D to facilitate wind as a principal technology in the RE 30-80% Vision*



Getting to future, high penetration scenarios will require:



- *Federal R&D and operational oversight to ensure power availability, reliability, and stability from weather driven resources*
- *Engagement & participation by multiple government agencies (e.g. DOE, DOC, DOI, DOD, NASA, NSF), university & private sector stakeholders*
- *Defining the operational wind plant environment driving future technology development & innovation*
- *New generation of advanced HPC tools to achieve high fidelity modeling of integrated renewable power systems at national scales*

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Motivation for a New Wind R&D Framework

Key Objectives:

I. Change the research paradigm from individual wind turbines to entire wind plant cost and performance optimization

II. Engage the national labs, universities, and industry in a collaborative consortia for the strategic planning and execution of comprehensive, high-value research initiatives

Strategic Approach:

I. Adopt an open "DOE/SC like" planning construct in establishing strategic goals, performance objectives and new initiatives

II. Lead the international research community in utilizing HPC to support the evolution and high penetration deployment of renewable technologies

A2e Initiative Considerations

1. Performance, Cost and Risk Factors

- Wind Plant Power Losses can be as high as 20-30% in modern wind farms*
- $100-300M in annual operating costs can be saved through forecasting accuracy improvements of 10-20%*
- Unplanned maintenance and long term O&M uncertainty are a significant risk factor driving discount rates and project financing*
- Although turbine technology is mature, optimal wind plant performance potential has not been established*

2. Complicating Factors

- Wind resource characteristics remain poorly resolved, modeled and observed at plant scales
- Wind plant performance is a multi-scale and physics problem spanning many technical disciplines
  - Atmospheric science phenomena and weather patterns
  - Wind plant aerodynamics, turbulence, complex terrain, and wake dynamics
  - Fluid structure interactions and structural dynamics
- Required research investment is substantial, requiring multi-national stakeholder collaboration
  - Supercomputing resources for multi-scale high fidelity modeling and coupled simulations
  - Large-scale field experiments at operating wind plants
  - Partnerships will be necessary to leverage enough resources to solve the problem
- No single national lab, university, or industry participant has ALL the necessary expertise

3. The Atmosphere to Electrons Collaborative Approach Solution

- Seven (7) year “hub like” initiative, targeting specific wind plant cost and performance improvement objectives
- DOE/FFRDC led consortia leveraging national and international experts actively engaged in the planning process
- Formation of international science panels and external workshops in developing plans and approach
- Flexible funding framework inclusive of multiple execution methods (e.g. FOAs, AOPs, IAAs, International Agreements, etc.)
- Retain DOE oversight and control through active program management, project reviews

*For references, please see Appendix

Introducing Atmosphere to Electrons (A2e)

A2e is a new, multi-year, multi-stakeholder DOE R&D initiative tasked with improving wind plant performance and mitigating risk and uncertainty to achieve substantial reductions in the cost of wind energy.

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Need for a New Collaborative R&D Framework

Goals and Objectives for a lower cost, higher performance wind power plant paradigm …

1. **Optimized Performance of Existing Wind Plants**
   - Increase Power Production
   - LCOE Reduction
   - Predicted Power Performance Probability Variance (P50/P99)
2. **Wind Plant / Grid Interface**
   - Improve 24 Hour Ahead Forecasted Power Production Accuracy
   - Reduce Annual Curtailment
   - Prediction Certainty of Anomalous Ramping Events
3. **Next Generation Wind Plant Technology Development**
   - CapEx Reduction
   - Increase Capacity Factory (C_F)
   - O&M Reduction
   - Reduced Acoustic Emissions
   - Reduce Discount Rate

… Require the following R&D cross cutting activities …

a. Quantify contributing factors to underperformance
b. Minimize array loss effect
c. Improve performance prediction confidence
d. Improve reliability and reduce major component failure rates
e. Improve production through flow resource active monitoring & control
f. Characterize physical atmospheric phenomena
g. Quantify gaps in boundary layer physics models
h. Improve high fidelity atmospheric models
i. Assess inter- and intra-array effects on macro and micro climatology
j. Integrate real-time forecast models into dispatch & operational control strategies
k. Explore optimal wind plant configurations
l. Incorporation of wake and flow control
m. Optimize turbine systems for next generation wind plant designs
n. Active incorporation of flow monitoring and resource characterization
o. Develop scaled prototypes of new technology
p. Develop pre-commercial prototypes at full scale
q. Full system integration and modeling

… Which require the following activities and capabilities:

- **Cross cutting and synergistic science & technology initiatives**
  - HPC, small- & large-scale experiments, field tests, design tools, etc.
- **Long-term integrated planning and execution**
  - Requires centralized planning and execution consisting of technical experts from multiple disciplines
  - Requires flexible, multi-year funding decisions
- **Multi-stakeholder engagement**
  - Must engage national labs, industry, international experts, & universities
- **Public dissemination of results**
  - Results must benefit the entire U.S. wind industry

Atmosphere to Electrons (A2e)

- ✓ Seven year strategic initiative managed as a "hub like" consortia in a DOE lead partnership with National Laboratories
- ✓ Integrated strategic research planning lead by National Labs & DOE engaging multiple domestic and international stakeholders
- ✓ Planning separated from research implementation
- ✓ Research activities conducted by most appropriate stakeholder using the most expeditious contract mechanism

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WWPTO Addresses these 3 R&D Topics in 2 Sub-Programs

WWPTO Director's Office and Operations
(WWPTO Director: Jose Zayas)

Wind Power R&D
Cost Reduction & Deployment
(Mike Derby)

Resource Characterization
(Joel Cline)

- Forecasting
- Complex terrain
- Meso-scale to LES coupling
- Long-term measurement
- Coupled wind/wave simulation

Wind Plant Technology
(Mike Derby)

- Wind plant and array aerodynamics
- Fluid structure interaction
- Advanced controls
- Component R&D
- Wind plant reliability
- Design & systems engineering tools

A2e Initiative
- Optimize Wind Plant Performance

Grid Integration
(Charlton Clark)

Market Barriers
(Patrick Gilman)

Water Power R&D
Cost Reduction & Deployment

R.C. | Tech | Grid | M.B.

- **A2e Combines These Two Sub-Programs into a jointly-planned Initiative.**
- **Currently, Grid Integration & Market Barriers Not Included in Scope**
  - Focus on wind plant performance, not full system performance
  - Limit planning impact on existing program
  - Have received some pushback

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A2e Executive Management Committee

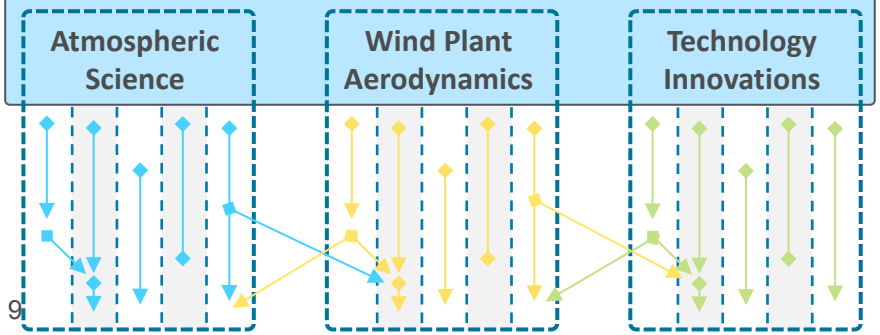
Wind Power R&D
A2e Fiscal and Planning Oversight and Approval
(Mike Derby)

A2e Initiative
(Director: Mike Robinson, acting)

Strategy Management Office
(John Meissner, Samantha Rooney, & Noel Bakhtian)

Executive Management Committee (EMC)
- A2e Director
- DOE Technology Feds (Derby, Cline, Ananthan)
- National Lab Subject Matter Experts (Veers, Shaw, Laird)

R&D Implementation Organizations
- EMC plan the R&D, does not execute
- Research conducted by best entity for the job



External Merit Review Board
- External assessment of program performance and assessment of program impact on industry
- Chaired by Sandy Butterfield, CTO Boulder Wind Power, AWEA Board Liaison with R&D committee, Former Chief Engineer of the National Wind Technology Center
- Board constituency reflecting sector representation from industry, national laboratories, academia, government agencies, and international stakeholders

- The **EMC** provides A2e with vision & direction and coordinates the integrated program planning activities
- External Merit Review Board convenes on an annual basis
- EMC holds formal reviews of all R&D progress on a quarterly basis, with meetings rotating between DOE HQ, NREL, PNNL, and SNL

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EMC Membership Aligns with Technical Areas

Executive Management Committee (EMC)

Director: Mike Robinson (*acting, pending IPA approval*)

Joel Cline (DOE)

PNNL

- Field campaign testing experience
- Atmospheric science leadership
- Relationships with NOAA, NCAR, NSF, OS
- High performance computing expertise
- Reference Facility for Offshore Renewable Energy (RFORE)

Lab Rep: Will Shaw

Shreyas Ananthan (DOE)

SNL

- Field campaign testing experience
- Scaled Wind Farm Facility (SWiFT)
- Performance & reliability leadership
- Instrumentation/sensor package dev.
- Wind Plant CFD (HPC simulations)
- U.S. fleet data collection relationships

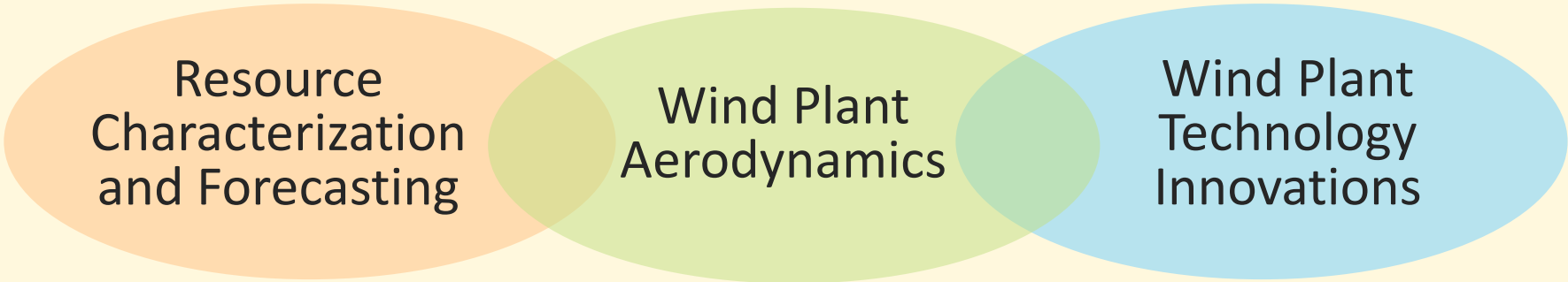
Lab Rep: Daniel Laird

Mike Derby (DOE)

NREL

- Field campaign testing experience
- System design, standards, and analysis
- Utility-scale turbine testing facilities
- Turbine component test facilities
- NASA Wind tunnel test experience
- ESIF facility

Lab Rep: Paul Veers



External Merit Review Board Membership

Reviewer Name	Organization	Industry Role
Sandy Butterfield (Chair)	BWP / AWEA	OEM, standards, AWEA
Mark Jonkhoff	GE	OEM
Henrik Stiesdal*	Siemens	OEM
Dan Brake	NextEra	Owner/operator
Jim Lyons	NOVUS	Investor
Erik White	JPMorgan	Investor
Robert Poore	DNV	Service provider (Due diligence)
Bruce Bailey	AWS TruePower	Service provider (Forecasting)
Charlie Smith	UVIG	Utility integration
Peter Hauge Madsen*	DTU	Academic R&D (Wind Energy R&D)
Bill Mahoney	NCAR	Academic R&D (Atmospheric Science)
Steve Binkley**	Office of Science	ASCR

* International R&D community

** Involvement pending formal discussions

Initial, High Priority Strategic Planning Areas

Strategic Planning Areas

1. Financial Risk, Uncertainty, and Portfolio Analysis
   - John Meissner (DOE Contractor)
2. High Fidelity Modeling
   - Dr. David Womble (SNL), Dr. Steve Hammond (NREL)
3. Experimental Measurement Campaigns
   - Dr. Scott Schreck (NREL), Dr. Jon White (SNL)
   - Dr. Jim Wilczak (NOAA)
4. Data Archive and Portal
   - Chitra Sivaraman (PNNL)
5. Integrated Wind Plant Control
   - Dr. Kathryn Johnson (Colorado School of Mines/NREL)
   - Dr. Dave Wilson (SNL)
6. Wind Plant Reliability
   - Dr. Carsten Westergaard (SNL Contractor)
   - Dr. Jonathan Keller (NREL)
7. Aeroacoustics and Propagation
   - Dr. Pat Moriarty (NREL)
8. Integrated Wind Plant Design and Analysis
   - Acting Lead, Dr. Shreyas Ananthan (DOE)

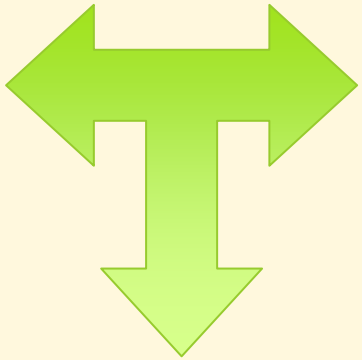
- **High priority R&D areas that need accelerated planning to align with A2e objectives**
- **Each area has an external topical expert planning group chaired by internationally recognized national lab experts**
  - Committees include expert stakeholder community
  - Working groups identify technology gaps and challenges
  - Recommended program plans vetted through open symposiums and workshops
- **Areas maintain a "wind plant performance centric" activity scope**
- **Cross-cutting activity planning is the key benefit of a consortia "wind plant systems" approach**

Prioritizing the Research Portfolio

Financial Risk, Uncertainty, and Portfolio Analysis

Validate System Plant Cost & Performance

- Identify & benchmark key system LCOE drivers
  - Knockdown Factors
  - Operational Availability
  - Downtime Statistics
  - Site Specific Power Curve
  - Plant and turbine energy production
  - O&M operation & balance of station
  - Component & system level cost ….
- Assessment methodologies & best practices
- Established Relationships with Owner / Operators
- Independent 3rd Party Protected Data & Statistics Repository



Align R&D portfolio to address greatest potential return on investment

Correlation of Project Financing to Modeling & Performance Uncertainty

- Dissect current project finance modeling approaches
- Identify key component drivers and assumptions
- Correlation of risk and reliability to performance confidence levels
- Identify and implement R&D initiatives to reduce discount rate drivers
- Requires building a much closer relationship with finance community

The cost of sub-optimal performance

$$LCOE = \frac{FCR \times CC + (O\&M + LRC)}{AEP}$$

Project Financing Terms and Structure

- **Financing structures and discount rates**: FCR includes the discount rate for loans as well as project equity structure. Risk mitigation activities can improve financing terms for future wind energy projects.

Capital Cost of Turbine and Components

- **Wind plant and wind turbine design**: Technology improvements may result in longer, lighter blades, more efficient, lighter drivetrains, novel offshore platform designs, or other changes to existing designs that may remove cost from the system.

Operations, Maintenance, and Replacements

- **Wind Plant Reliability and Profitability**: O&M costs and component replacements can have a huge impact on project profitability. Technology and monitoring improvements can improve component reliability and mitigate O&M variability.

Annual Energy Production (AEP)

- **Wind Plant Losses and Rotor Scaling:** Complex terrain, wind turbine wake interactions, siting issues, availability, and other phenomena can lead to energy losses as high as 20%. Advanced controls , next gen design and forecasting tools, and component innovations can mitigate these losses.

Definitions: FCR=Fixed Charge Rate; CC=Capital Cost; O&M=Operations & Maintenance; LRC=Levelized Replacement Cost (of major components); AEP=Annual Energy Production.

The cost of uncertainty

Cost of Uncertainty

Long-term Wind Forecast Uncertainty +

- **Higher Discount Rate & Financing Costs**
  - Project risk for financiers (plant efficiency and climate change).

Day/Hour-Ahead Wind Forecast Uncertainty +

- **Reduced Project Profitability**
  - Interconnection fees require larger cash reserves.
- **Reduced Plant Reliability**
  - Unexpected extreme events and ramp events reduce component lifetimes

Wind Plant Inflow Uncertainty +

- **Energy Losses**
  - Inaccurate inflow simulations of terrain interaction, atmospheric conditions, etc.
- **Reduced Reliability & Premature Failures**
  - Unknown inflow and loading conditions lead to sub-optimal plant and turbine design

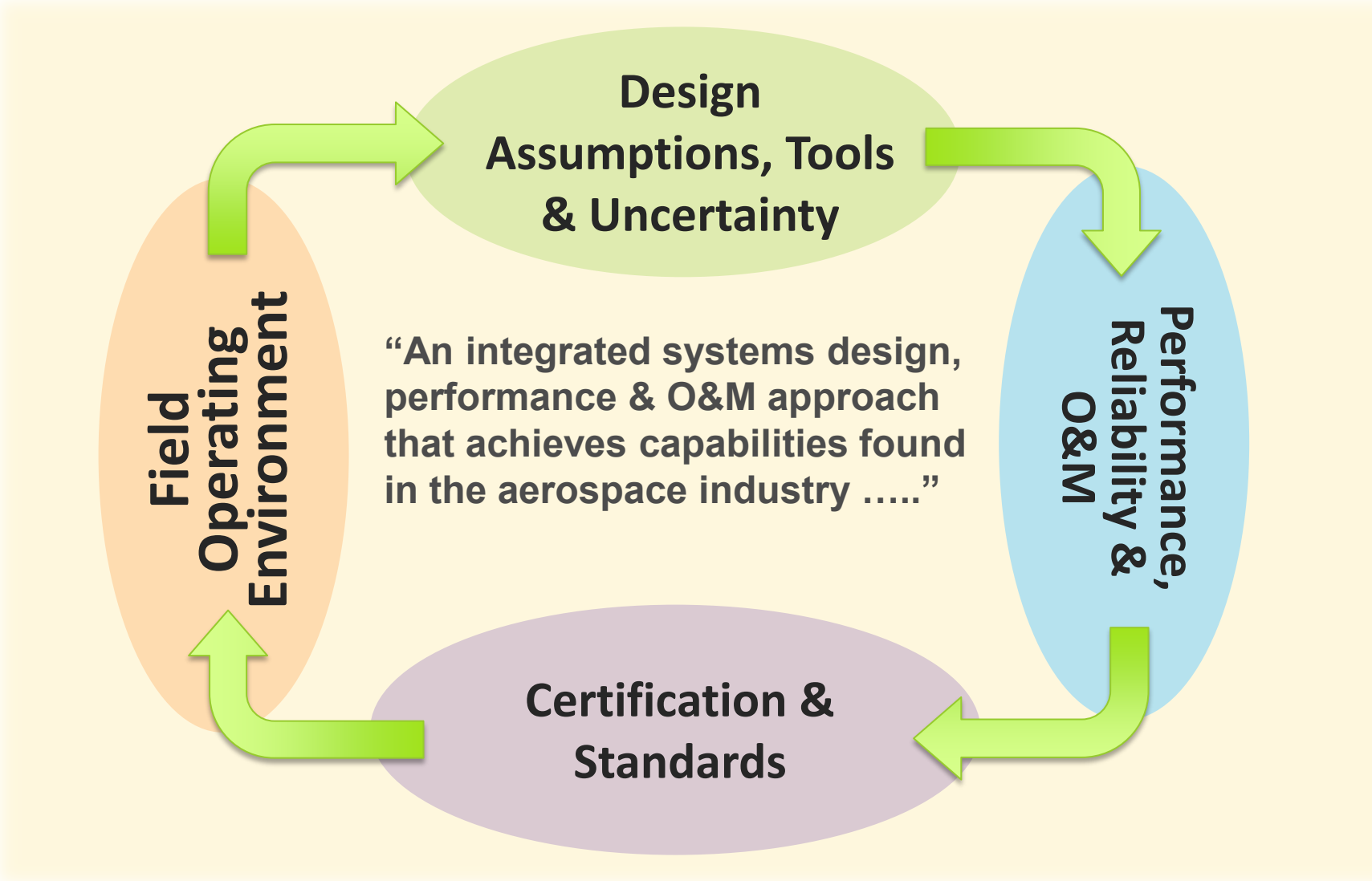
Intra-Plant flow Uncertainty +

- **Energy Losses**
  - Inaccurate inflow simulations of wakes, complex terrain, and turbulence
- **Reduced Reliability & Premature Failures**
  - Unknown wake interactions and loading conditions lead to over- or under-designed components

Other Uncertainties

- **O&M Uncertainty**
  - Variable maintenance costs and timelines
- **Project Development**
  - Uncertain project timelines and costs
- **Policy & Regulation**
  - Esp. Offshore
- **Others…**

What are the Possibilities?



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Key Milestones Achieved

- ✓ **A2e Approved by EERE Assistant Secretary June 2013**
- ✓ **Formed Executive Management Committee (EMC)**
  - Convened three in-person meetings and many phone calls
  - Visited or invited to DOE a large swath of the international wind stakeholder community to establish support and solicit ideas. Organizations visited include Boulder Wind Power, GE, GH-GL, DNV-GL, AWS TruePower, Risoe/DTU, TU Delft, ECN, DOE/SC/ASCR, et.al.
- ✓ **Recruited Twelve (12) Member External Merit Review Committee**
  - External Merit Review planned for February 4-5 in Washington, DC
- ✓ **Defined Key R&D Priorities & Planning Areas**
  - Developed R&D Matrix and initial thrust areas
- ✓ **Established Eight (8) R&D Planning Groups with Chairs and co-Chairs**
  - Modeling & Analysis: High Fidelity Modeling, Experimental Measurement Campaigns, Data Archival and Dissemination, Performance Uncertainty Analysis
  - Four Technical: Wind Plant Reliability, Design Tools and Methodologies, Wind Plant Aeroacoustics, Wind Plant Controls
  - Active Strategic Planning by seven of the eight groups underway
- ✓ **Completed an initial FY14 Crosswalk of Existing Activities**
  - Developed R&D Matrix and initial thrust
- ✓ **First Merit Review of Strategic Planning Scheduled February 4th, 2014**

A2e Initiative Objectives

Where do we want to be by 2020?

I. An integrated strategic program foundation to guide the development of new technologies optimizing wind plant performance

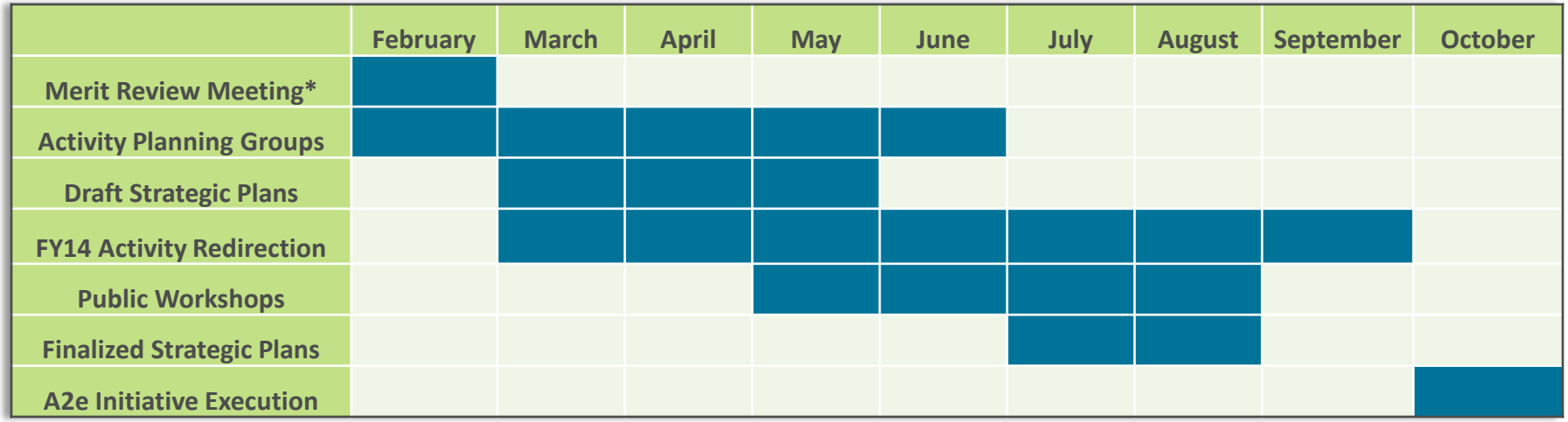
II. Much better understanding of the underlying physical processes and causal effects driving wind plant underperformance

III. Next generation of high fidelity, multi-scale, multi-physics modeling and simulation tools that incorporate the underlying physics & phenomenology of large multi-array wind plants

IV. Identify and assess technology innovations and opportunities to maximize performance, minimize cost and mitigate risk from an integrated wind plant systems perspective

V. Provide industry with the validated tools and demonstrated concepts for developing the next generation technology that can achieve high penetration wind plant deployment

Key Activities Timeline



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Summary

- **DOE Program Refocusing R&D to Address Wind Plant Performance:**
  - Established the A2e multiyear initiative based on an open DOE/SC approach
  - National Laboratories leading the strategic planning process
  - Engaging industry, academia, and other agencies in an open planning process
  - Redirect FY14 projects to align with new strategic program priorities
  - Integrated A2e program execution to begin in FY15

- **Focus Questions for the Merit Panel:**
  - Does the proposed program RD&D transition (Turbine to Plant) reflect industry needs?
  - Are the proposed strategic thrust areas the highest priority?
  - What potential outcomes would be most impactful?
  - What is the most effective way of communicating results?
  - What are the prospects for future technology innovation if successful?
  - What additional near term high priority thrust areas are we missing?

Questions?

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