ATMOSPHERE TO ELECTRONS

U.S. DEPARTMENT OF ENERGY

Atmosphere to electrons (A2e) Overview

Wind & Water Power Technologies Office

Shreyas Ananthan

What is A2e?

1 ***A Research Initiative targeting Wind Plant Optimization*** *to enable low cost wind energy*

2 ***A Novel DOE Management Construct*** to engage diverse expertise and stakeholder groups

Motivation for A2e

> **The largest remaining opportunities to reduce LCOE** will come from advances in total wind-plant system design & operation.

Consider the following challenges facing modern wind power plants:

- Wind plant energy losses of 20% or higher.[1,2,3]
- Major components not meeting 20-year design life.[4,5]
- Investment risk has inflated the cost of capital.[6]
- Inaccurate forecasts cost industry $300M+/year.[7]

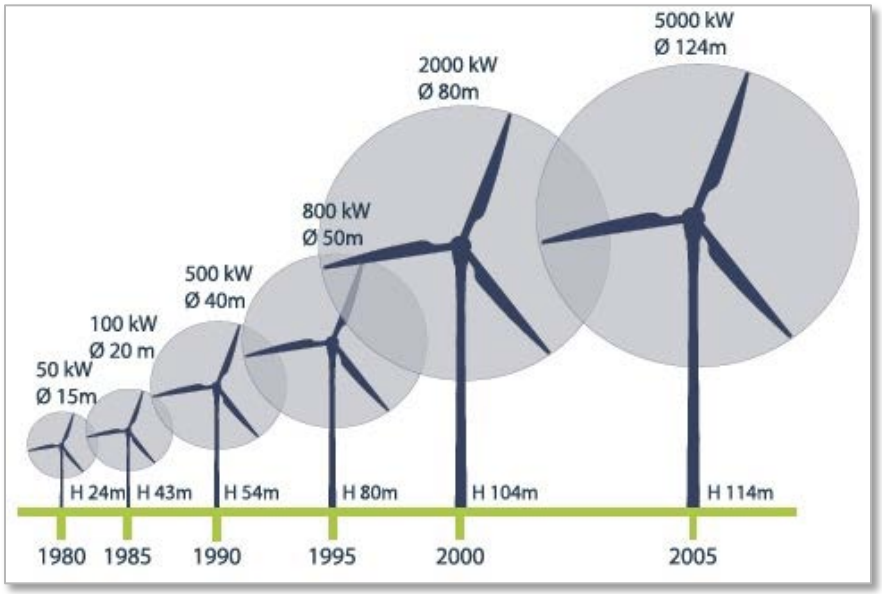
Desired Goals and Objectives

Challenges	Plant Optimization Objectives[10,11]	A2e LCOE Impact[10,11]
Wind plant energy losses of 20% or higher	✓ Increase Plant capacity factors from 0.39 to 0.50 ✓ Reduce losses from 20% to 12%	$65/MWh to $42/MWh[9,10] (39% reduction from 2014 to 2030)
Major components not meeting 20-year design life	✓ Extend component/system design life from 20 to 30 years	
Investment risk has inflated the cost of capital	✓ Reduce installed capital costs from 1615 to 1454 $/kW ✓ Reduce cost of capital (WACC) from 8.5% to 7.5% for land (larger opportunity for OSW)	
Inaccurate forecasts cost industry $300M+/year	✓ Improve day- and hour-ahead forecast accuracy by 10-20%	

Note: Starting points and trajectories (2014-2030) for A2e objectives and LCOE targets are from the 2014 NREL LCOE Memo to WWPTO, which builds from the Wind Vision study, the 2013 Wind Market Report, and WWPTO LCOE analysis

Attaining these objectives will require a shift in R&D focus

Yesterday
(Individual Turbines)



2015-2021 (and beyond)
(Smart Wind Plants)

Individual wind turbine R&D

- Turbine and rotor scaling driving LCOE reductions
- Well defined design process and value engineering
- Mature wind turbine industry

Wind plant optimization R&D

- Design for operation at optimal project profitability and Internal Rate of Return (IRR)
- Develop new technologies that exploit interactions among turbines, resource, & operating environment

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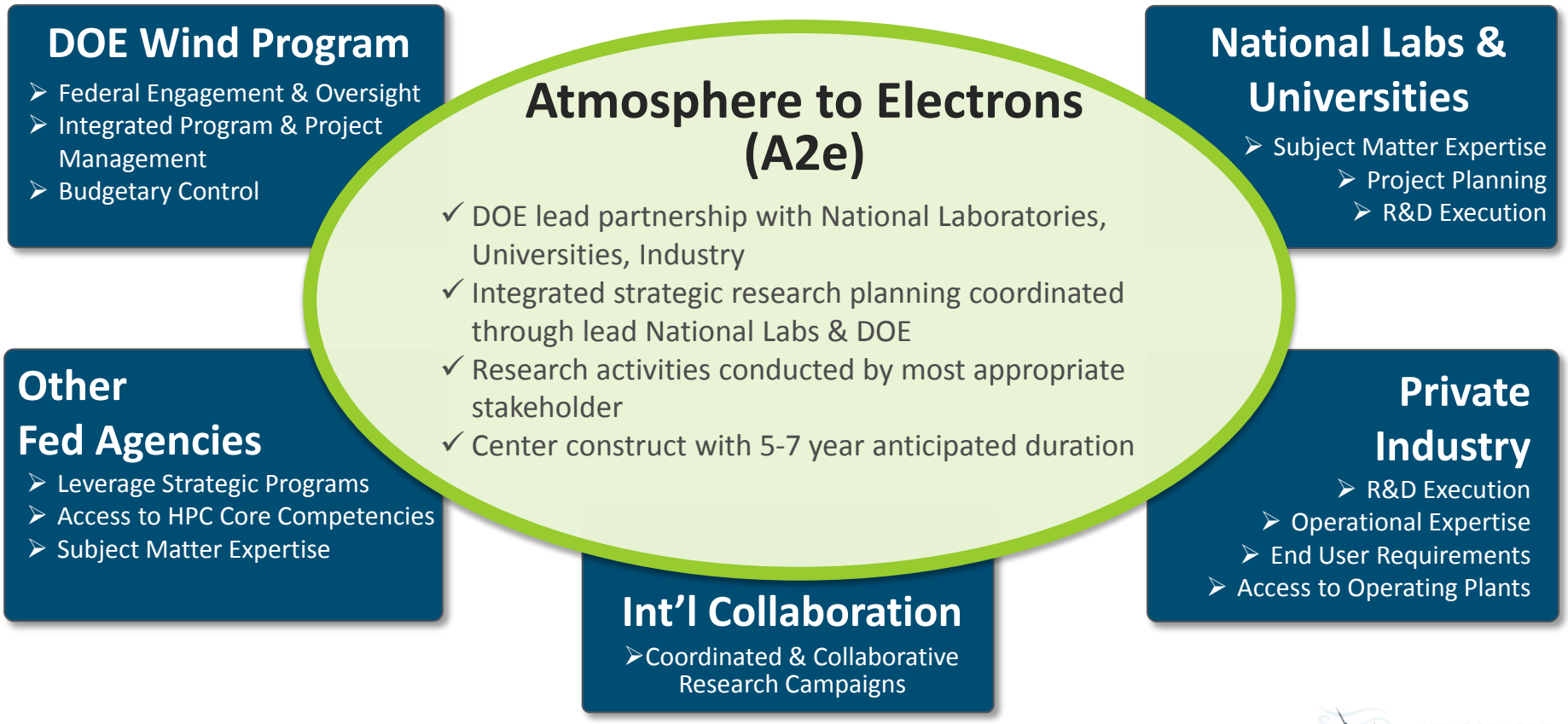
A shift in R&D focus requires a *Novel DOE Management Construct*

Implementing A2e will require a focused, multi-year, multi-stakeholder, R&D effort lead and supported by DOE.



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A2e management construct

Executive Management Committee (EMC)

Director: *Mike Robinson, DOE IPA*
DOE Reps*: Mike Derby, Joel Cline, Shreyas Ananthan*
National Lab*: Veers (NREL), Shaw (PNNL), Laird (SNL)*

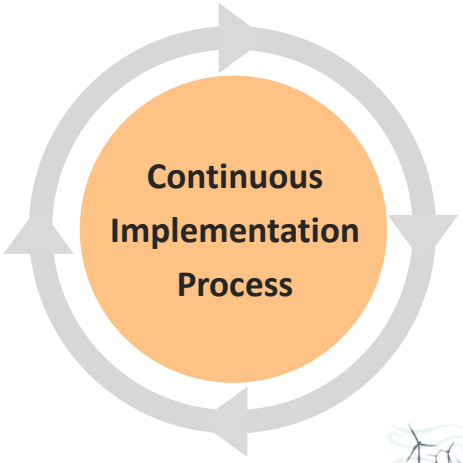
- Provides vision & direction and coordinates integrated program planning activities
- Develops and "owns" A2e integrated, multi-year strategic plan
- Conducts formal quarterly reviews of all R&D planning and project performance
- EMC members assigned to each A2e focus area

R&D Implementation Organizations

- EMC plans and coordinates R&D, does not execute
- R&D organized around Strategic Focus Areas
- Research conducted by domain experts and expected to include a diverse group of industry stakeholders and research organizations

External Merit Review Board

- External assessment of A2e performance and impact on industry
- Constituency includes senior representatives from industry, national laboratories, academia, government agencies, and international stakeholders
- Members meet with A2e leadership on an annual basis to provide an outside perspective on strategic priorities



Scope of Work and Timeline

Near Term (2015) Lay Groundwork

I. Implement Formal Verification & Validation Framework (V&V)

- Must start with a systematic approach to ID physics gaps, uncertainties, and instrumentation requirements

II. Kick-off high fidelity physics modeling activities

- ID starting point, personnel, and availability of HPC resources
- Develop open HFM architecture that is scalable and relevant
- Benchmark state-of-the-art high fidelity modeling approaches
- Preliminary code comparison & validation efforts.

III. Conduct initial field experiments and instrumentation assessment

- LIDAR and instrumentation capabilities assessment project
- Launch Wind Forecasting Improvement Project II (WFIP II)

Mid Term (2016-2019) Investigate the Physics

I. Conduct detailed field measurement campaigns

- Conduct experiments at SWIFT, beginning with a detailed investigation of the near-wake region and proceeding to more complex physics
- Begin data collection for WFIP2
- Continue instrumentation development and assessment

II. High fidelity modeling utilizing high performance computing

- Multi-lab, multi-stakeholder code development and model comparison
- Evaluate control strategies that enhance wind plant performance
- Evaluate plant designs and layouts

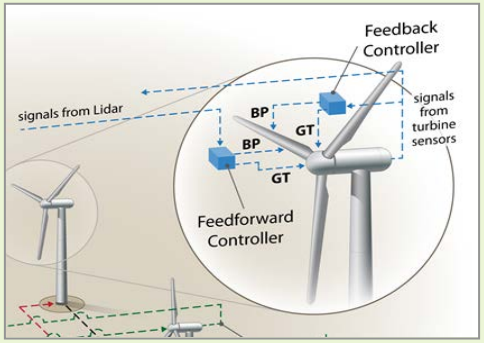
III. Define path from new physics to technology innovations

- Define linkages between model results and technology pathways for reducing LCOE

Long Term (2017-2021) Develop Technology

I. Partner With Industry to Develop New Technology

- Integrated wind plant level control systems with sophisticated dispatch strategies
- Advanced sensing technologies and real-time flow monitoring
- Adaptive rotor technology that mitigates loads and extends design life while reducing failure rates
- Short-term forecasting tools that ensure high reliability dispatch.



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A2e Perspective on Systems Engineering

What should the SE community start thinking about in coming years?

- **A validated hierarchy of models that captures critical system-level interactions for the desired application**
  - A2e is not just building models, but wants to back everything with confidence levels and validation
- **Development of methodologies and best practices to assess uncertainty, as well as the impact of uncertainty on design and operational decisions**
  - Turbine design, plant siting, and operational processes
  - Impact of plant level objectives/constraints on turbine design process
- **The appropriate role of SE for plant operations and reliability improvements**
  - Potential upgrades to existing plants
  - Plant control strategies to address siting issues or resource variability
- **Integrating Wind into the Grid in the most effective manner**
  - Grid integration and improving the overall value of wind to the grid

Appendix

References

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7. Lew, D.; Milligan, M.; Jordan, G.; Piwko, R. (2011). Value of Wind Power Forecasting. 13 pp.; *NREL Report No. CP-5500-50814*.
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9. Zayas, et al; DOE Wind Vision Report (unpublished), 2014.
10. Internal Wind Program Analysis, DOE and NREL, 2014.
11. 2014 NREL LCOE Memo to the DOE Wind Power Program, October, 2014.

FY14 and FY15 Activities

FY14 Emphasis – Stakeholder Engagement and Strategic Plan Development

- **Focus Area Workshops**
  - High-Fidelity Modeling, Experimental Measurement Campaigns, Verification & Validation
  - Advanced Controls, Plant Reliability, & Aeroacoustics
  - Performance Risk, Uncertainty, and Finance (PRUF)
  - Data Archival and Portal

FY15 emphasis on V&V framework, initial experiments and modeling

- **V&V Framework Development**
- **Wind Forecasting Improvement Project (WFIP) II**
- **Experimental PBL Instrumentation Assessment (XPIA)**
- **Code Comparison for Meso-Micro Coupling Approaches**
- **Near-Wake Experimental Campaigns – Wind Tunnel and SWiFT Scale**
- **Upcoming Workshops**
  - Integrated Wind Plant Design & Analysis (Jan. 16)
  - High-Fidelity Modeling Simulation Environment Workshop (Jan. 27-28)
  - High-Fidelity Modeling Needs Workshop (Feb. 24-26)

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 has external Planning Group, with appointed Chair
- Cross-cutting activity planning is the key benefit of a consortia "wind plant systems" approach
- In the completed integrated strategic plan, must directly link these initial R&D thrust areas to LCOE-driven objectives and desired outcomes.

Input from Senior Industry Leaders

External Merit Review Board

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

A2e – Integrated Execution Framework

Wind Technology Program Manager

Mike Derby, DOE HQ

- EERE Senior & Executive Management Reporting
- Strategic planning and fiduciary responsibility

A2e Executive Management Committee

Director: Mike Robinson (DOE IPA)

Atmospheric Science: Joel Cline & Will Shaw

Wind Plant Aerodynamics: Shreyas Ananthan & Daniel Laird

Technology Development: Mike Derby & Paul Veers

- Multi-year strategic program planning
- Establish R&D priorities and implementation strategy
- Stakeholder coordination & leveraging
- Coordination of multiple research initiatives
- Continuous oversight and integrated management to achieve programmatic goals and objectives

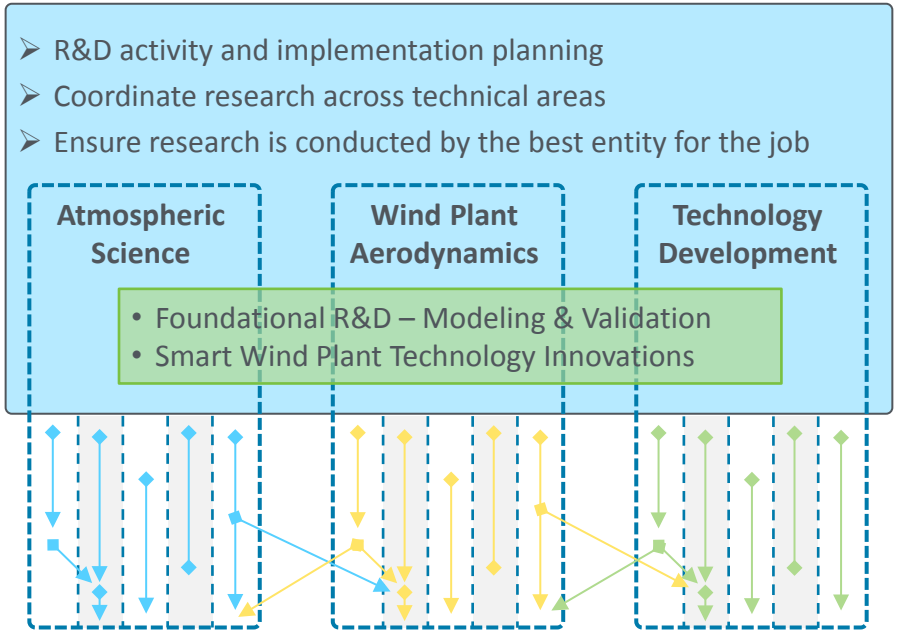
Lead Laboratories

Atmospheric Science: PNNL (Will Shaw)

Wind Plant Aerodynamics: SNL (Daniel Laird)

Technology Development: NREL (Paul Veers)

- R&D activity and implementation planning
- Coordinate research across technical areas
- Ensure research is conducted by the best entity for the job



R&D Execution

Lead Labs coordinate the R&D, but the actual research will be conducted by appropriate stakeholders including national Labs, universities, manufacturers, gov't agencies, owners, operators, international entities, etc.

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