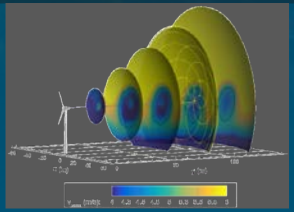
Sandia National Laboratories

Offshore Wind Energy Research Projects at Sandia

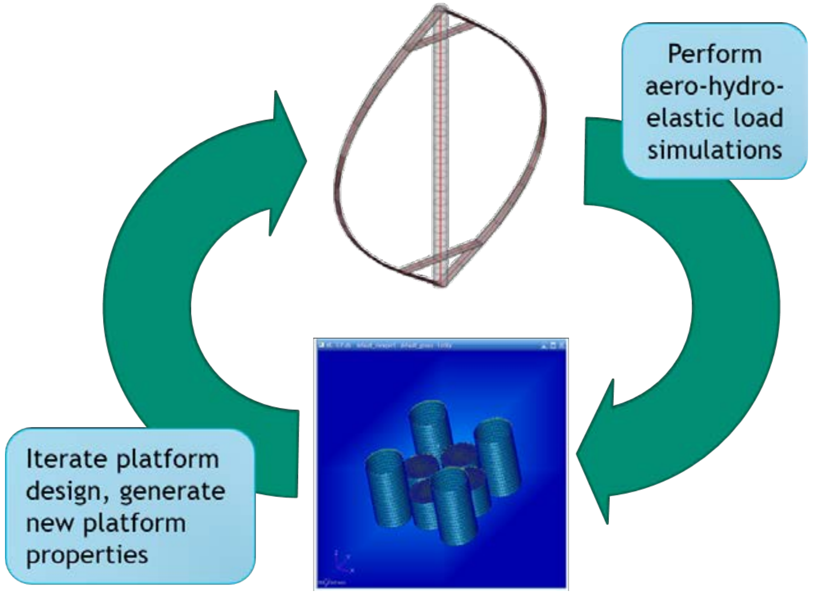


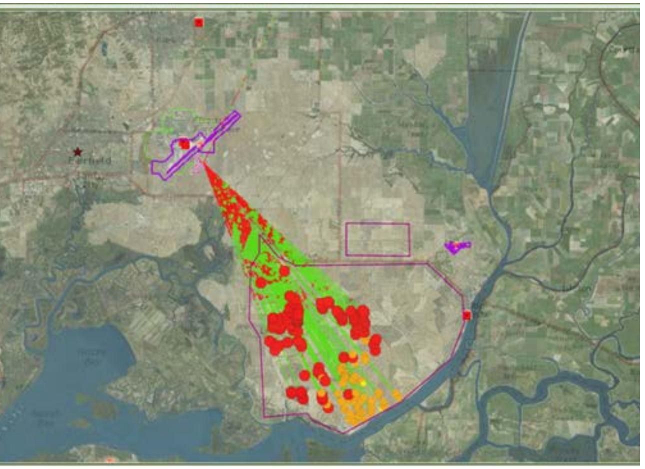
PRESENTED BY

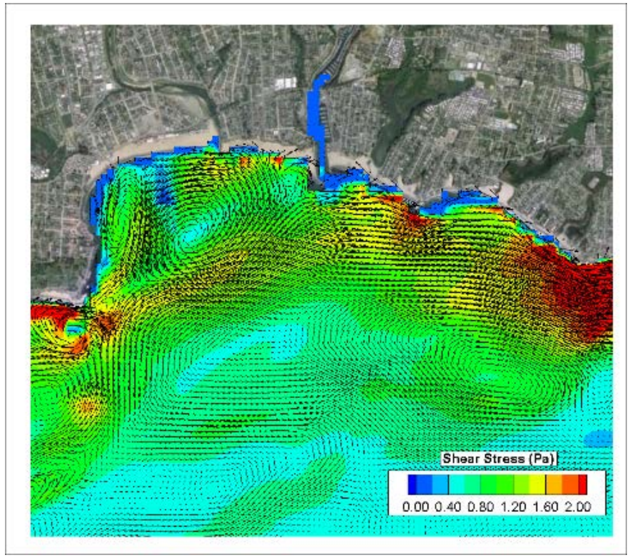
Jesse Roberts, Brandon Ennis

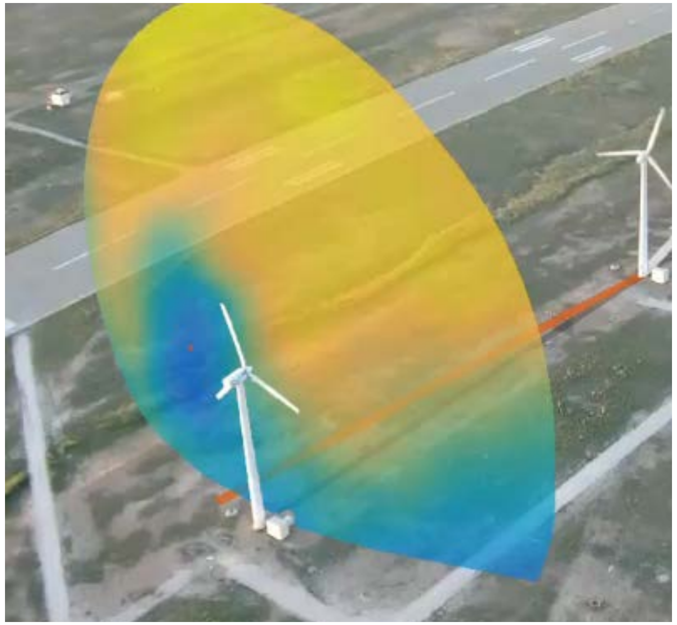
Sandia National Laboratories Offshore Wind R&D

- Floating Offshore Vertical-Axis Wind Turbine Project
- Structural Health Monitoring and Prognostics
- Wind Steering Experiment at the SWIFT Facility
- Radar Interference Mitigation
- Sediment Stability and Environmental Risk









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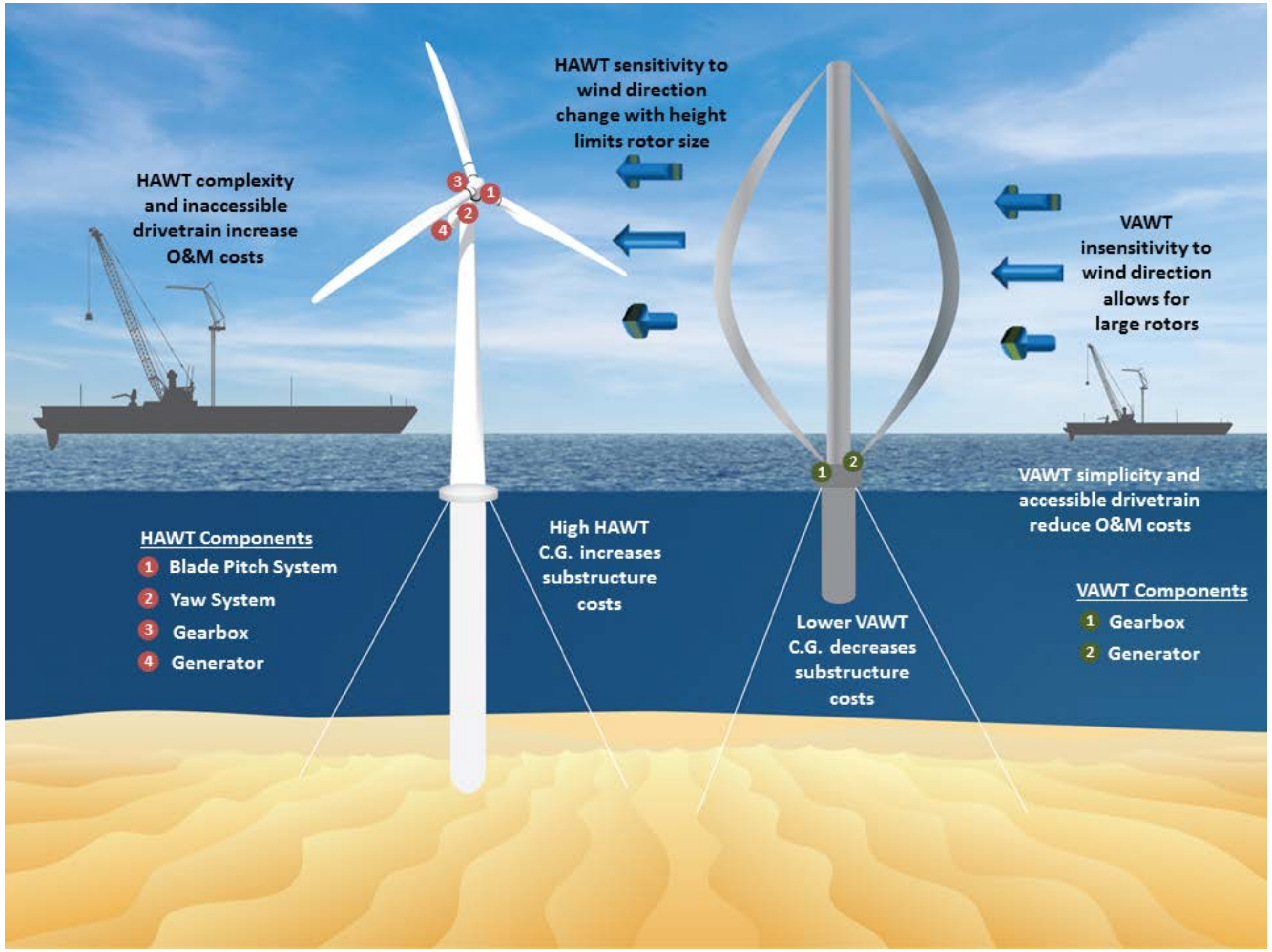
Floating Offshore Wind Energy

- Floating offshore wind plants have more components than land-based machines
- Turbine costs represent 65% of wind plant costs for land-based sites compared to around 20% for floating offshore sites
- Platform costs now represent the largest single contributor to LCOE
- Vertical-axis wind turbines have been studied as a potential solution for floating offshore wind energy which have several benefits, including:
  - Lower center of gravity, reducing platform costs
  - Improved efficiency over HAWTs at multi-MW scales
  - Reduced O&M costs through removal of active components and platform-level placement of drivetrain



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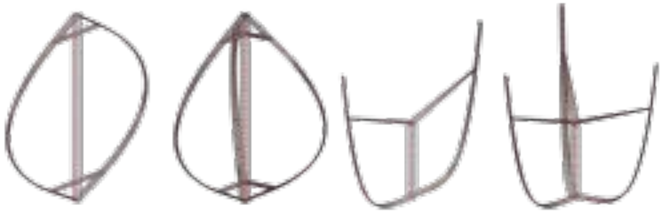
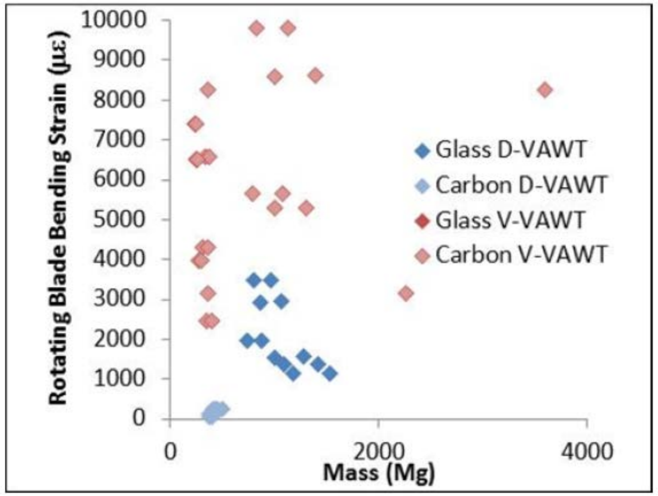
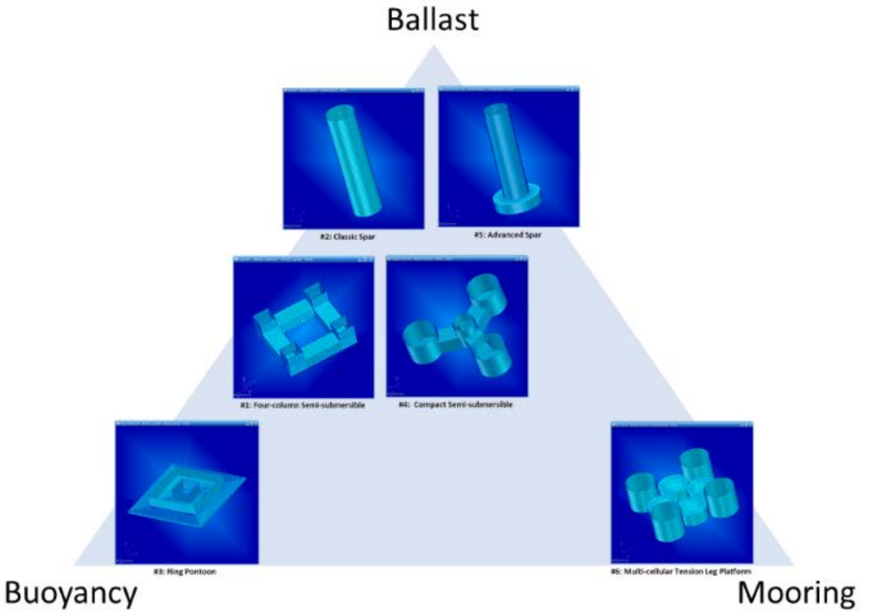
Floating Offshore Vertical-Axis Wind Turbine Project

- The optimal VAWT rotor architecture was unknown at the beginning of the project
- The rotor with the greatest potential to reduce turbine-platform LCOE was determined to be the Darrieus design due to loads being carried mostly axially

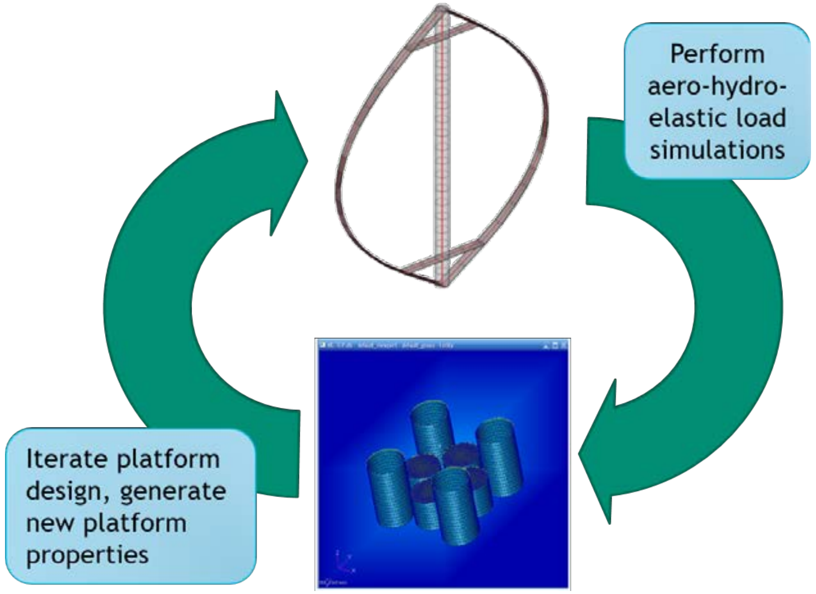




- Floating platform design and analysis was performed to determine the optimal floating platform architecture for LCOE and performance
- 6 platforms covering the range of floating system stability mechanisms were studied and compared
- A tension-leg platform was optimal

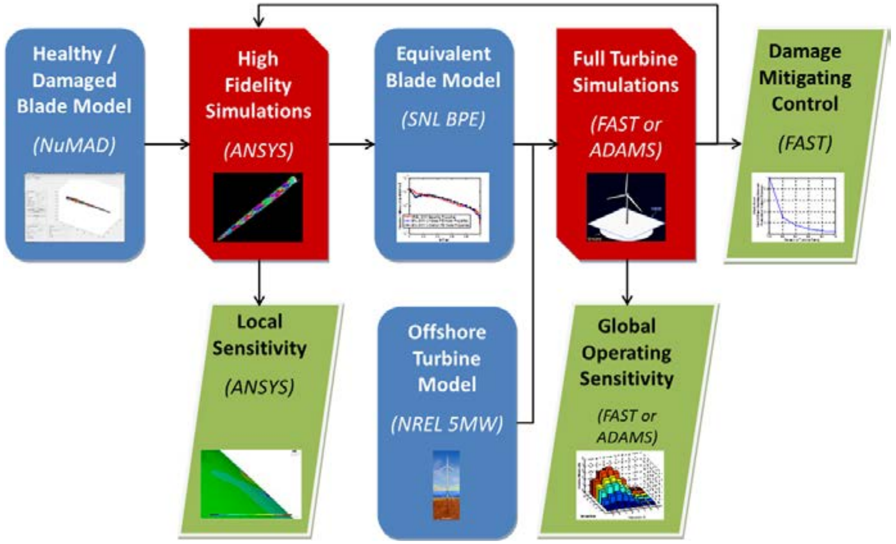


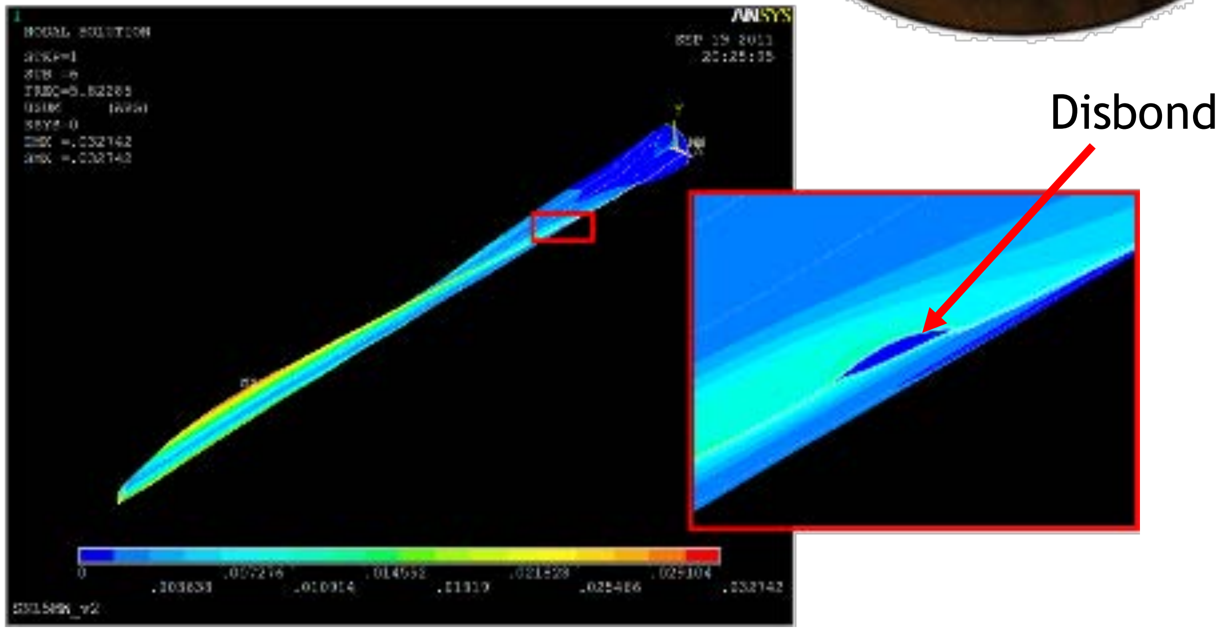
- The final platform design was determined through coupled aero-hydro-elastic simulations of the VAWT-TLP system performed at Sandia
- The platform would be redesigned by Stress Engineering Services (SES) in response to the dynamic loads and cost estimated using industrial cost data



Structural Health Monitoring and Prognostics

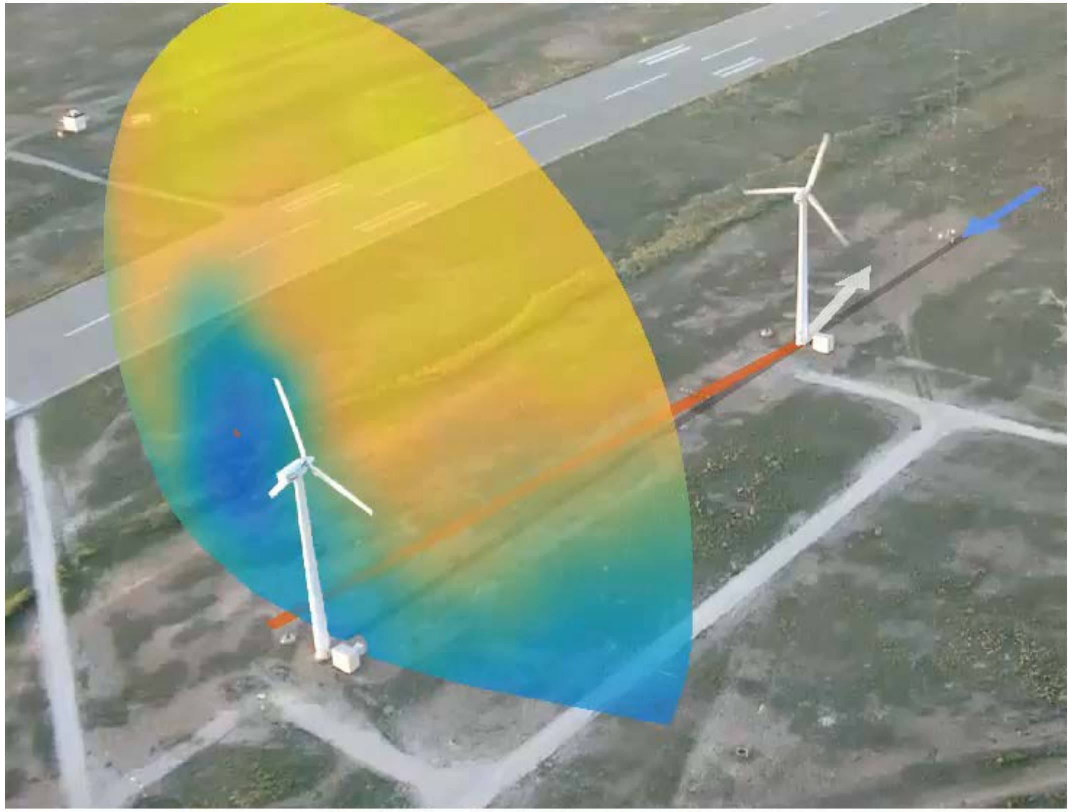
- O&M costs are over 25% of the annual costs for a mature offshore industry
- Project developed a multiscale modeling approach to identify how the blade response is affected by the presence of damage
- Trailing edge disbond can be detected in the blade's torsional response, and derating the turbine by as little as 5% could extend the blade fatigue life by as much as a factor of 3

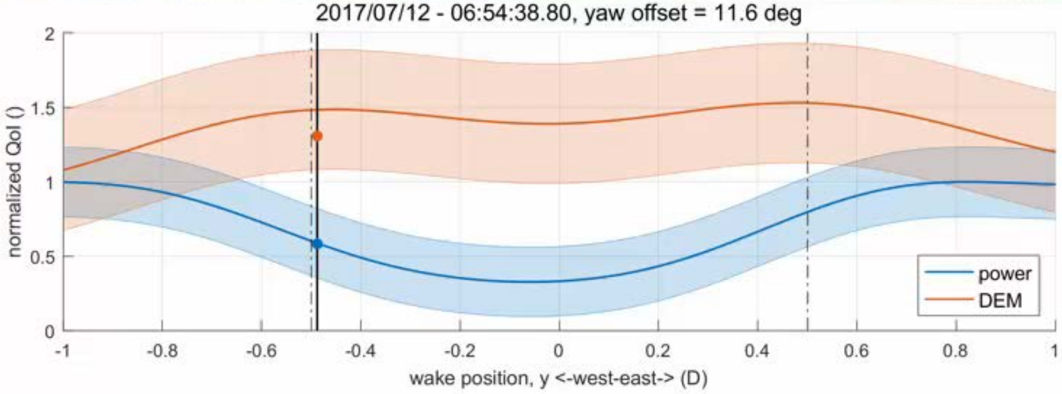


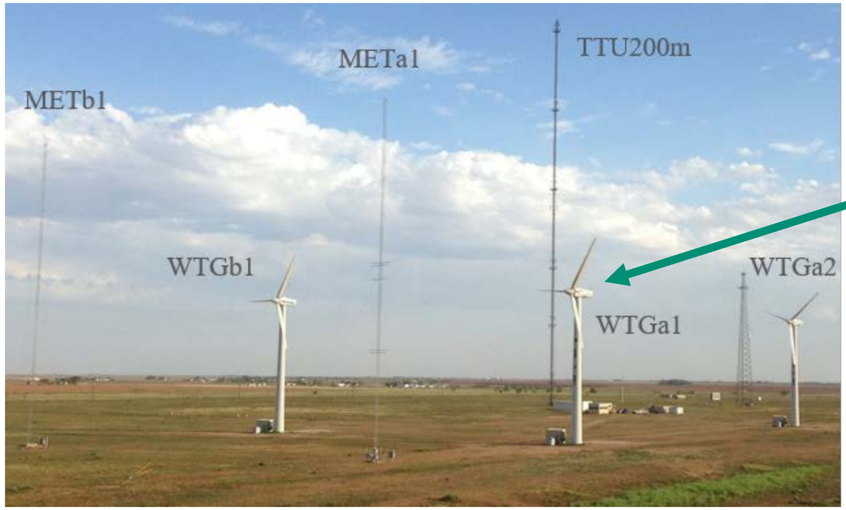


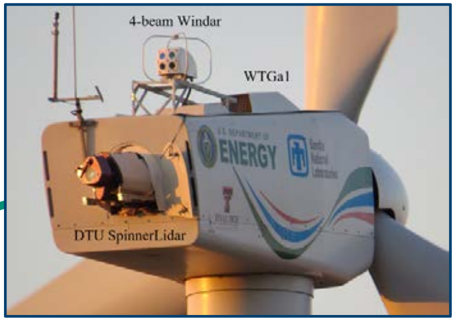
Wake Steering Experiment at the SWiFT Facility

- A wind plant controls strategy was tested at the DOE/SNL Scaled Wind Farm Technology (SWiFT) facility
  - Project looked at the effect of intentionally yawing an upstream wind turbine out of the wind to move the wake off of a downstream turbine, in partnership with NREL
- Scanning lidar mounted on the upstream wind turbine measured wake position, and turbine loads were measured with blade structural sensors
- Optimal control decisions were determined from the study which increase AEP and decrease fatigue loads









Sediment Stability and Environmental Risk

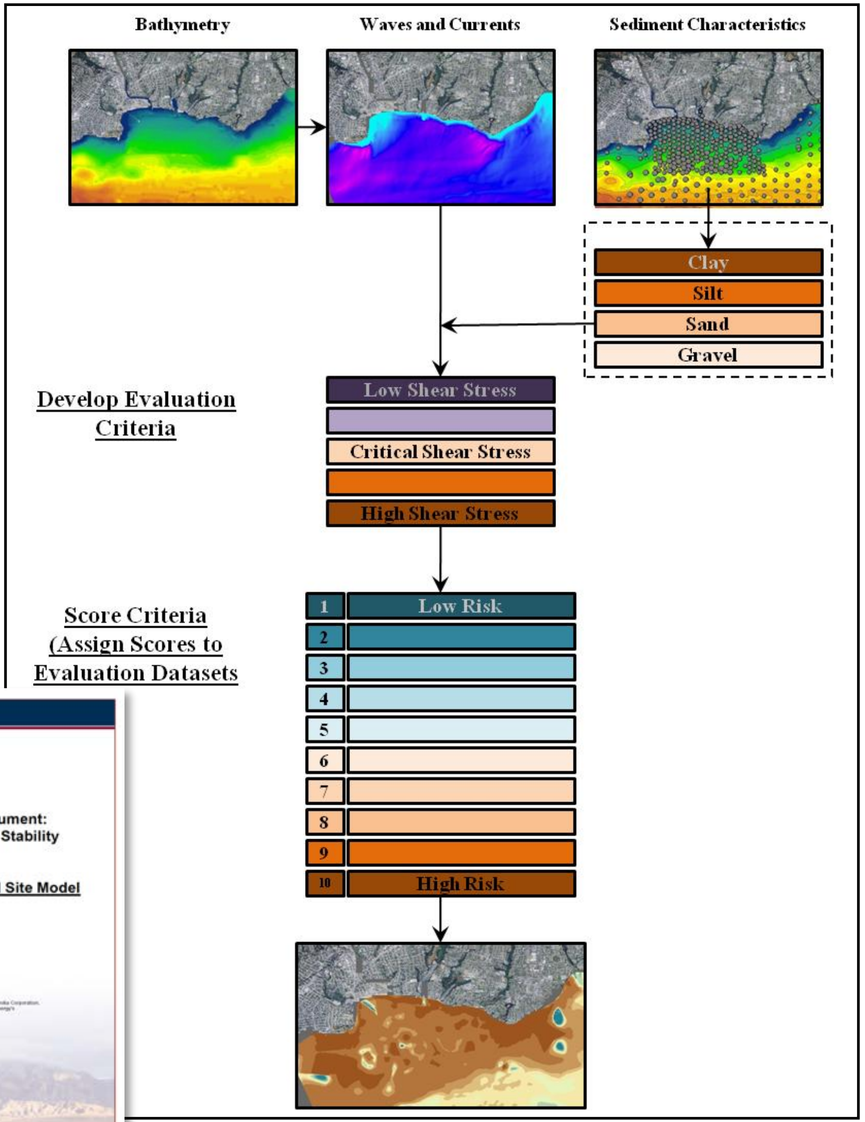
Risk: Harmful interaction between OW sub-structures/cables and the seafloor & unwanted environmental change.

Approach: Use coupled hydrodynamic and sediment transport models to assess spatial patterns of likely erosion, transport, and deposition.

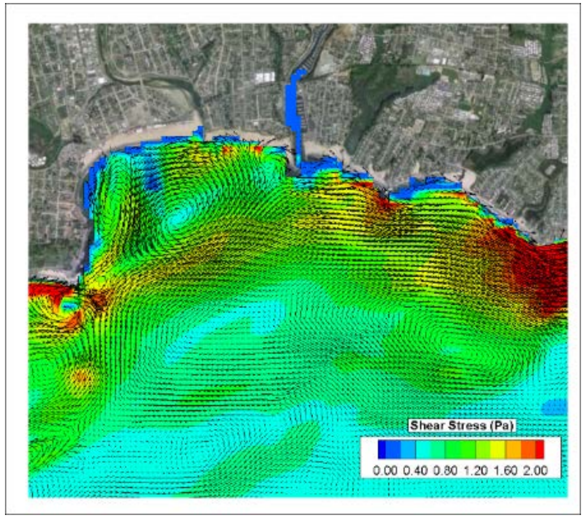
Purpose: Provide tools and guidance to quantify seafloor processes

- Mitigate infrastructure scour risk
- Retire/mitigate environmental risk

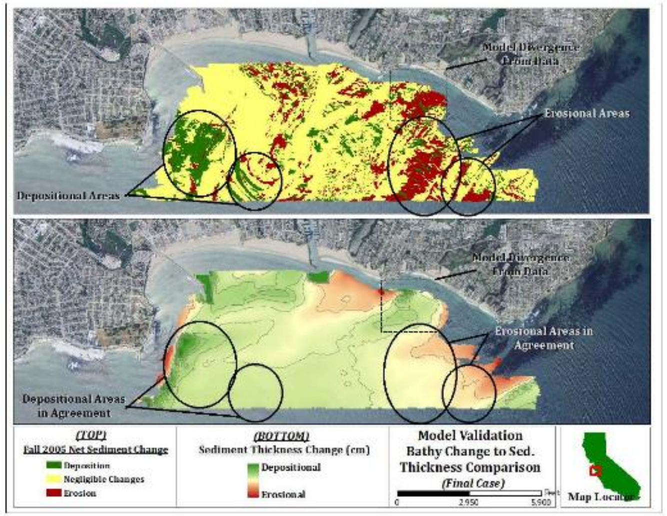
Sediment Stability Risk Framework

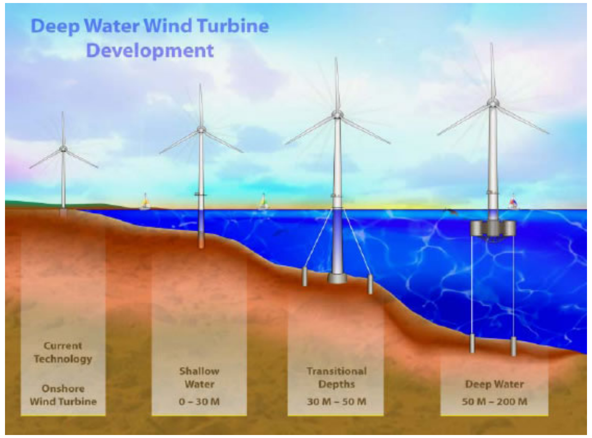


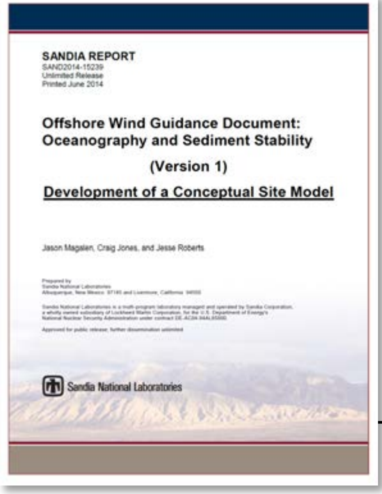
Bed Shear Stress and Velocity Vectors



Site Data (top) vs. Model Prediction (bottom)







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Wind Turbine-Radar Interference Mitigation

Wind turbines can interfere with radar systems

- Increase clutter, reduce detection sensitivity, obscure potential radar targets
- Inhibit target detection, generate false targets, interfere with target tracking, & impede weather forecasts

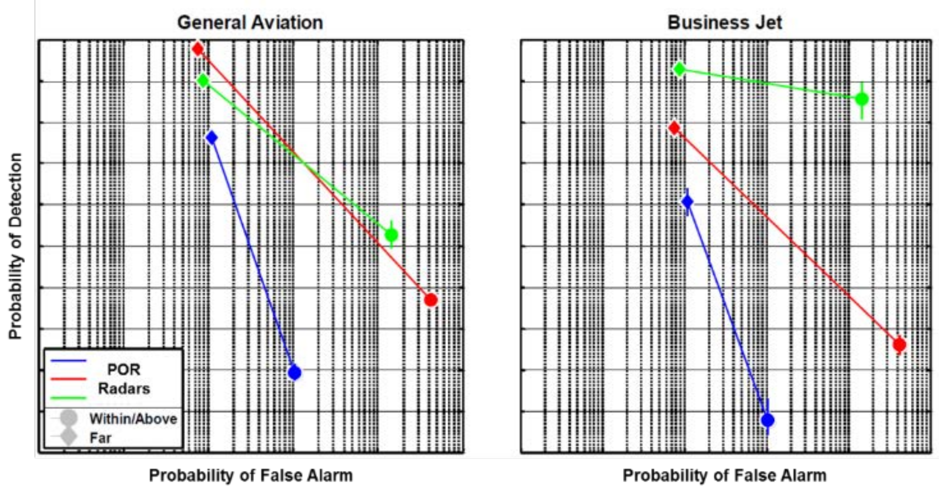
Rapidly Deploying & Testing Near-Term Mitigation Solutions

Travis Air Force Base Pilot Mitigation Project

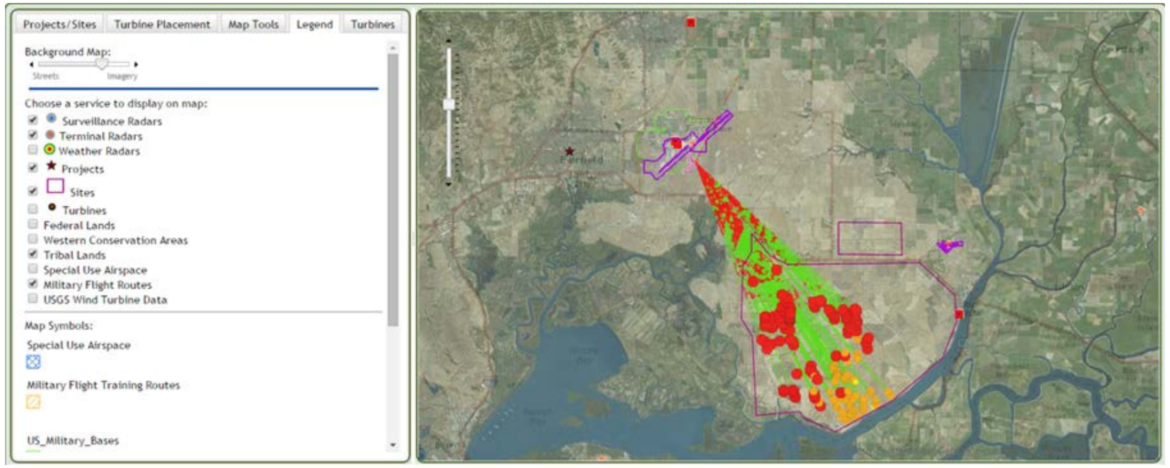
- FAA STARS Infill Radar Integration Project is seeking to test the feasibility of smaller infill radar system to restore the air surveillance picture of current radar that is experiencing wind turbine interference.

Enhancing Modeling & Simulation Capabilities

- Mitigating the interference that wind turbines have on radar systems begins with modeling proposed wind turbines and simulating the impact they may have on radar systems.
- Sandia has developed a public NOAA NEXRAD Radar Screening Tool to address the potential impacts on weather forecasts.
- The Tool for Siting, Planning, and Encroachment Analysis for Renewables (TSPEAR) was developed to model the potential impact proposed wind turbines may have on existing radar systems.



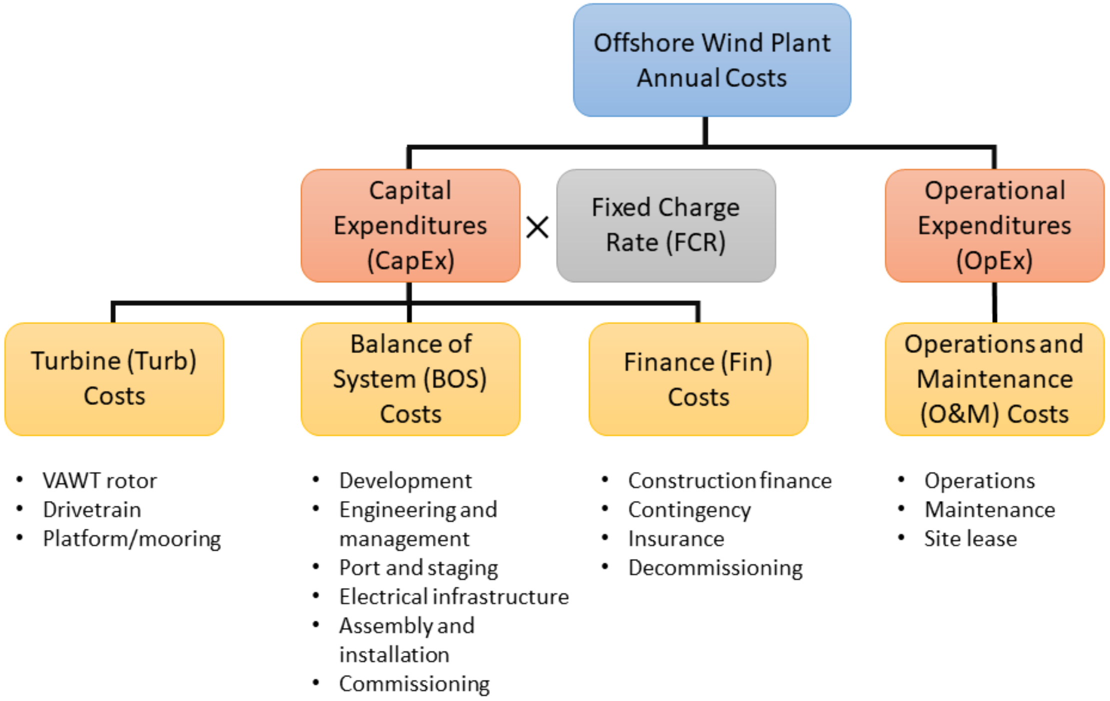
SOURCE: IFT&E Industry Report: Wind Turbine – Radar Interference Test Summary, SAND2014-19003, Sep 2014
http://energy.gov/eere/wind/downloads/interagency-field-test-evaluation-wind-turbine-radar-interference-mitigation

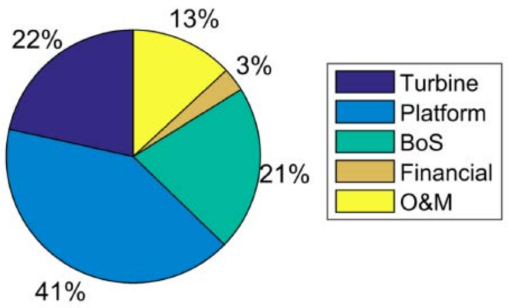


BACKUP SLIDES

Floating Offshore Wind Energy

- Energy generation sources have traditionally been selected based on an LCOE comparison with alternative sources
- Annual expenses include capital costs and operational expenses, which become significant for offshore systems
  - The relatively low cost of the turbine suggests that a more expensive turbine system than would be considered for land-based applications might be optimal for a system LCOE by reductions in the platform costs
- Energy production divides the entire cost formula, however a larger rotor also results in a larger drivetrain, tower, and platform which increases the system capital expenditures
  - The sensitivities of the sub-component relationships with cost must be understood to produce the optimal system

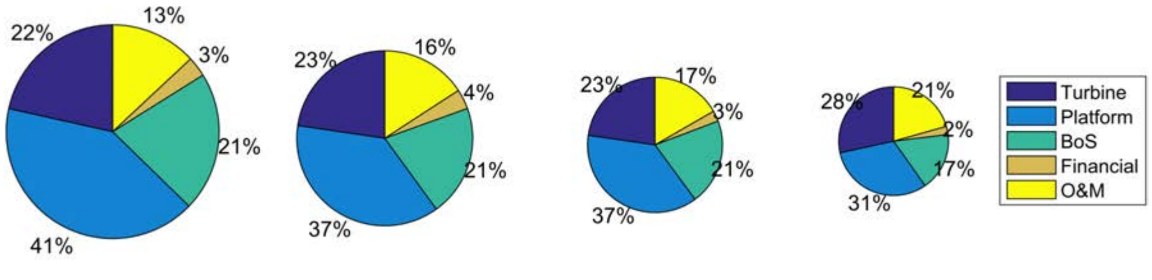




$$LCOE = \frac{(CapEx * FCR) + OpEx}{AEP_{net}}$$

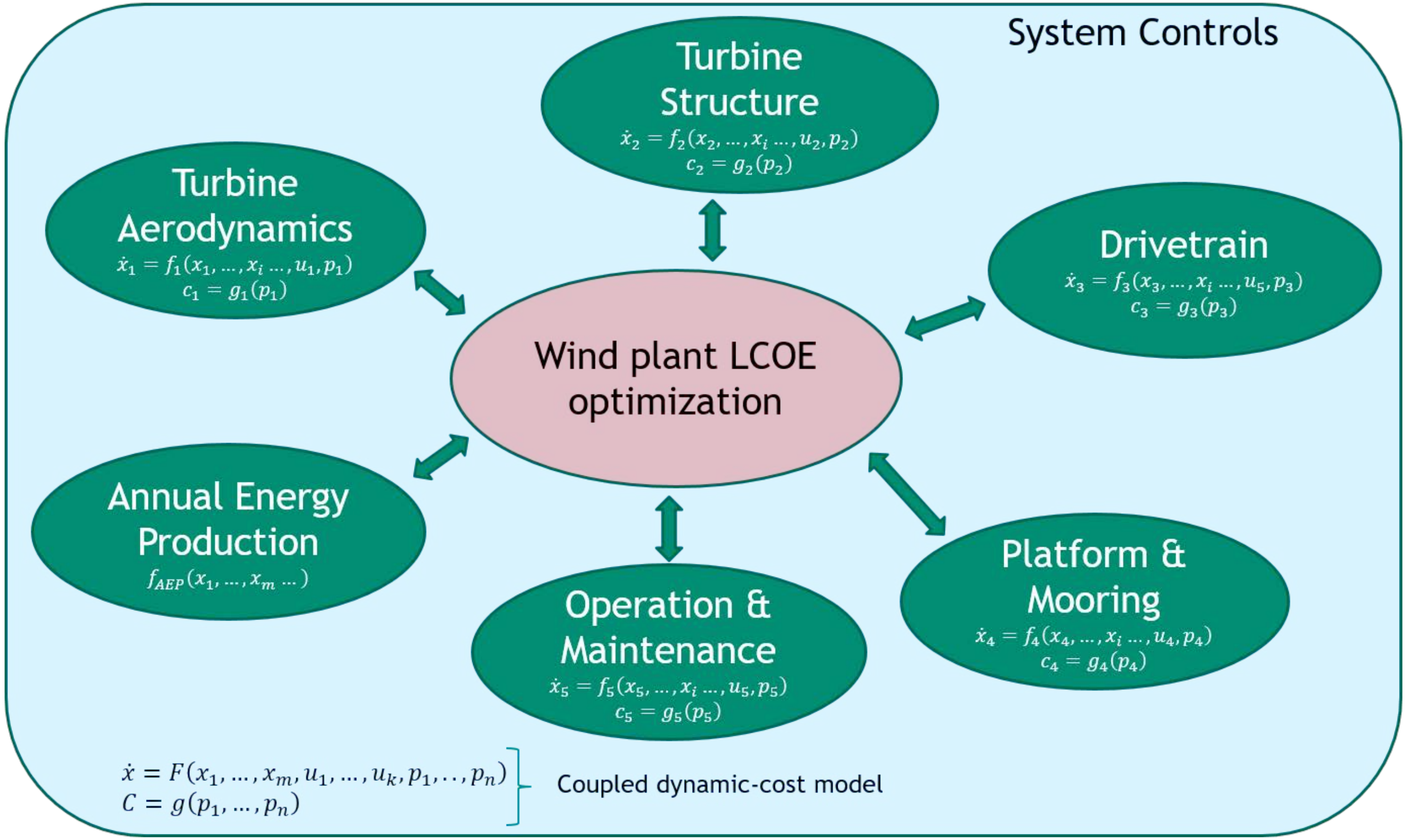
VAWT Costs

	Baseline LCOE	Upper-bound LCOE	Projected near-term LCOE	Project mid-term LCOE	Projected longer-term LCOE
AEP	Baseline	Baseline	16.1% increase from advanced controls	Advanced controls	47% increase in energy capture
Rotor costs	Baseline	Baseline	Rotor material optimization	Reduction from low-cost carbon fiber	78.2% increase in rotor cost
Platform and mooring	Most-likely value	Upper-bound estimate	13.6% reduction for optimal system platform	25% reduction for mid-term optimization	Mid-term optimization
Installation	Most-likely value	Upper-bound estimate	15.3% reduction for the improved installation procedure	25% reduction for mid-term optimization	Mid-term optimization
O&M direct costs	Baseline	Baseline	Baseline	19% reduction by eliminating jack-up vessel charters	Elimination of jack-up vessel charters
Levelized cost of energy (USD/MWh)	274	323	213	176 (FCR=10.3%) 135 (FCR=7.9%)	110 (FCR=7.9%)



LCOE = $213/MWh   LCOE = $176/MWh   LCOE = $135/MWh   LCOE = $110/MWh

Offshore Wind Farm LCOE Optimization



$f_i(\dots)$: dynamic model of i-th subsystem
$g_i(p_i)$: cost model of i-th subsystem, as function of the set of parameters p_i

Optimal design $(p_1, \dots, p_n)^*: \underset{(p_1, \dots, p_n)}{\arg\min} \, LCOE$

OW Strategy: Themes and Action Areas

Table 3.1. National Offshore Wind Strategy Strategic Themes and Action Areas

Strategic Themes	Action Areas
1. Reducing Costs and Technology Risks	1. Offshore Wind Power Resources and Site Characterization 2. Offshore Wind Plant Technology Advancement 3. Installation, Operation and Maintenance, and Supply Chain Solutions
2. Supporting Effective Stewardship	1. Ensuring Efficiency, Consistency, and Clarity in the Regulatory Process 2. Managing Key Environmental and Human-Use Concerns
3. Increasing Understanding of the Benefits and Costs of Offshore Wind	1. Offshore Wind Electricity Delivery and Grid Integration 2. Quantifying and Communicating the Benefits and Costs of Offshore Wind