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Cost Reductions in Offshore Wind through Technology Innovation

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3rd NREL/DTU Wind Energy Systems Engineering Workshop

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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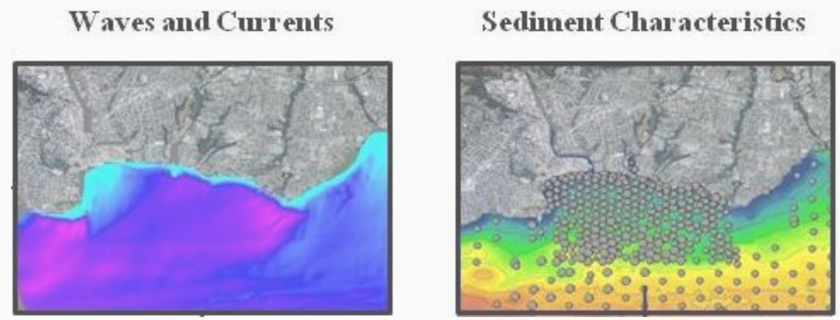
Characteristics of Offshore Wind

- Opportunities
  - Better winds
  - Vast resource
  - Proximity to load

- Challenges
  - High LCOE
  - High BOS costs
  - Accessibility
  - Inexperience, Immaturity

Offshore Wind @ Sandia

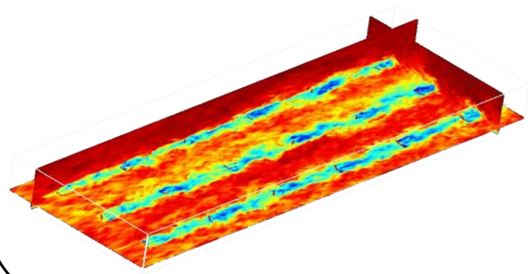
- **Vision**: Promote & accelerate the commercial OW industry and **reduce costs** through **technical innovation:**
  - Siting/Permitting: Sediment Transport & Radar
  - Large offshore HAWT rotors
  - Deepwater VAWT system
  - Structural health and prognostics management
  - Offshore wind farm modeling

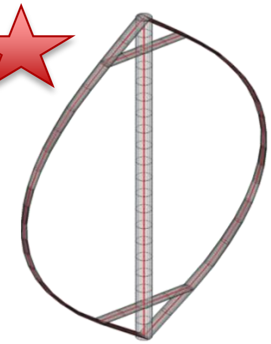


Offshore Siting Analysis

Sensing, Structural Health, and Prognostics

High-resolution Offshore Wind Farm Modeling





Deepwater Offshore VAWT

Large Offshore Rotors

Structural Health and Prognostics Management

Summary/LCOE Impact

- **Mitigate rising costs for offshore O&M** (estimated to be 2-5 times of land-based)
- **Maximize energy capture** by increasing availability

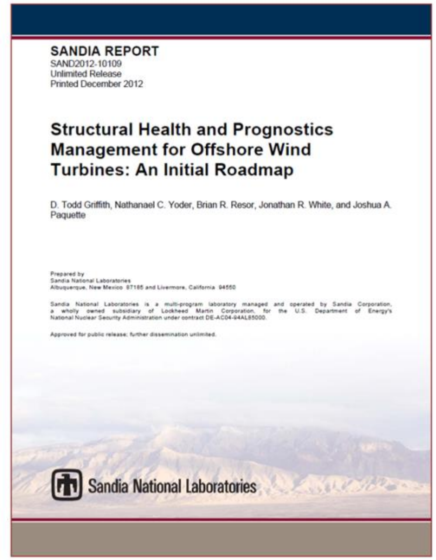
Focus Areas

Simulation of Damage:

1. Identify best operating signatures (sensors) : Damage Detection
2. Analyze effects of damage (state of health and remaining life): Prognostics

Key Blade Downtime Issues

- Rotor imbalance
- Trailing edge disbonds
- Leading edge cracks
- Edge-wise vibration
- Erosion
- Lighting
- Icing



SANDIA REPORT
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Structural Health and Prognostics Management for Offshore Wind Turbines: An Initial Roadmap

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Initial Roadmap Report

- Damage (Reliability) is a:
  - (1) Design issue?
  - (2) Monitoring and Inspection issue?
  - (3) Combination – tradeoffs in design cost versus operational costs

“Design with Inspection, Monitoring, and Maintenance”

Motivations for a Structural Health and Prognostics Management System

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A SHPM system that can be used to:

1. Ensure operations in a desired safe state of health
2. Avoid catastrophic failures through advanced warning
3. Aid in planning of maintenance processes versus more costly unplanned servicing
4. Improve energy capture by avoiding unnecessary shutdown

COE affected in 3 areas

$$COE = \frac{ICC*FCR + LRC}{AEP_{net}} + O\&M$$

COE- Cost of Energy ($/kWh)
ICC- Initial Capital Cost ($)
FCR- Fixed Charge Rate (%/yr)
LRC- Levelized Replacement Cost ($/year)
O&M- Operations and Maintenance Costs($/kWh)
AEP- Annual Energy Production (kWh/yr)

ICC ↑
O&M ↓↓
AEP ↑↑↑

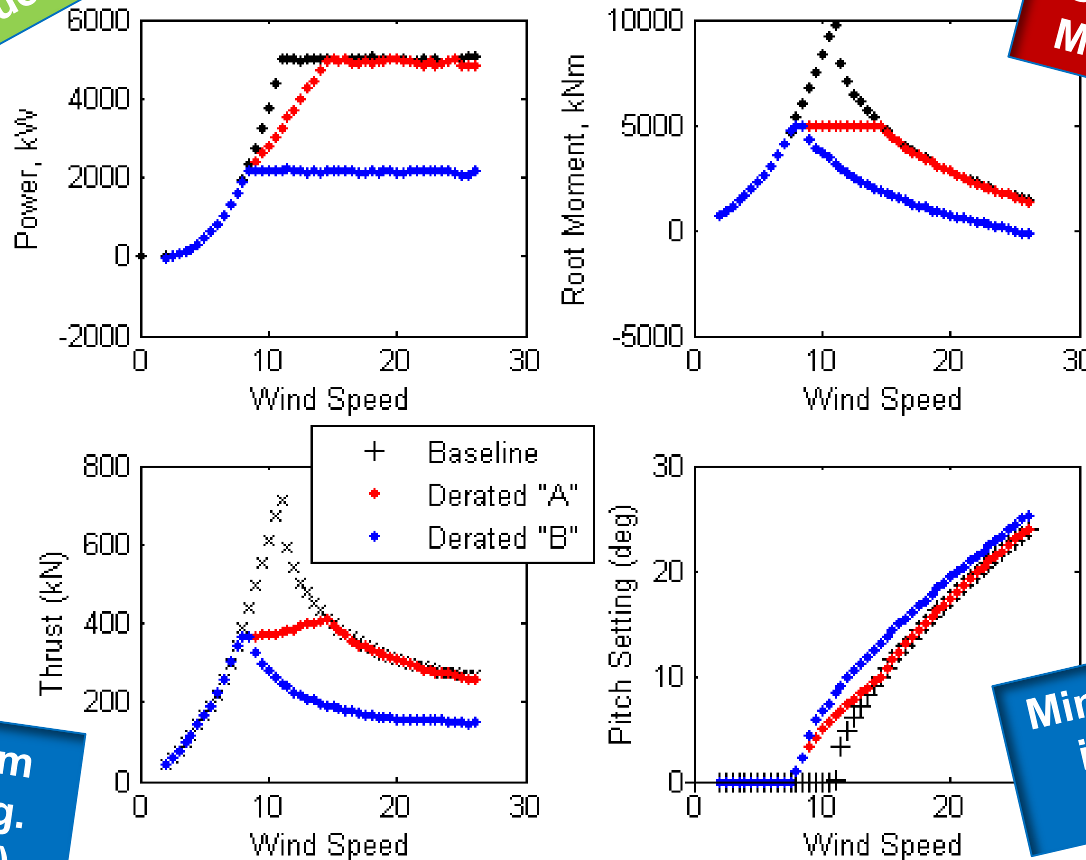
Greater motivation offshore with accessibility issues.
Reduce O&M costs and Maximize Energy Capture

Smart Loads Management

“derating”, “prognostic control”

Revenue

Smart Loads Management

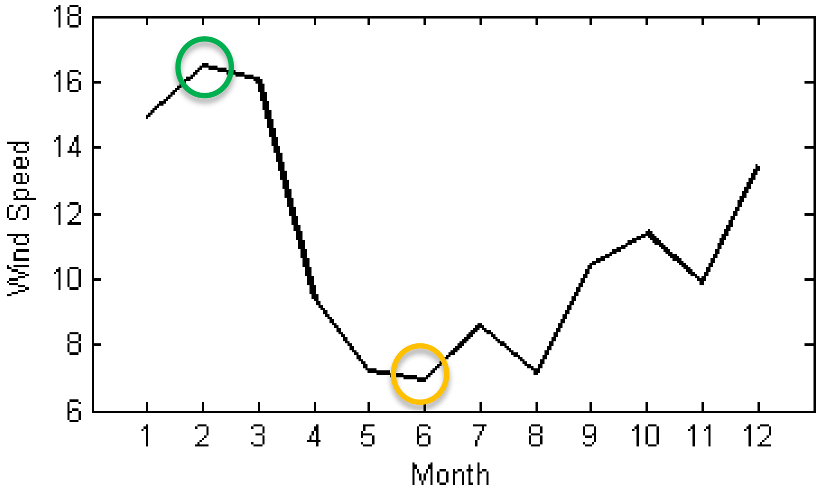


Secondary, System Level Benefits (e.g. support structure)

Minor Change in Control Strategy

Increase energy capture and reduce O&M costs with planned maintenance

SHPM Economics: *Effects of Monthly Wind Resource Variation and level of derating*



The increased energy capture of derating ranges from 1.5% to 10.7% depending on level of derating and monthly variation in the wind resource,

Strong opportunity for return on investment of monitoring system

Derated in Month 6

Derated in Month 2

Table 2: Variations due to monthly wind speed variation in possible revenue increases (using 5 c/kWh), when derating for 1 month instead of shutdown.

Derating Level	Low Speed (7 m/s)	High Speed (16.5 m/s)
75% (A)	+\$63,800 (+4.9%)	+\$140,000 (+10.7%)
75% (B)	+\$53,400 (+4.1%)	+\$99,100 (+7.6%)
50% (A)	+\$55,800 (+4.3%)	+\$131,000 (+10.0%)
50% (B)	+\$44,500 (+3.4%)	+\$73,800 (+5.6%)
25% (A)	+\$35,300 (+2.7%)	+\$96,800 (+7.4%)
25% (B)	+\$19,200 (+1.5%)	+\$23,900 (+1.8%)

Results for a single 5MW turbine

- Is a “Baby Boomer” generation of aging turbines coming?

  - 71% of worldwide installations are less than 6 years old
  - Varies by region
    - 54% European Market
    - 74% North American Market
    - 87% Asian Market

- Current maturity of SHPM technology?

Inflow Variability Study

- **Goal: Quantify effect of variable wind inflow on robustness of damage detection with a POD simulations campaign**

Table 3: FAST Simulation Matrix for Each Blade Damage Type.

	Healthy	1m Dis-bond	2m Dis-bond	3m Dis-bond	4m Dis-bond	5m Dis-bond	10m Dis-bond
Wind Speed (3 - 25 m/s)	101	101	101	101	101	101	101
Horizontal Shear (30%, 60%, 90%)	303	303	303	303	303	303	303
Turbulence (A, B, KHTEST)	303	303	303	303	303	303	303

- >16,000 simulations with varied extent of damage and varied inflow
- Sensitivities to varying inflow:
  - Wind speed, horizontal shear, and turbulence
- Effect on POD
  - POD improved in certain wind speed ranges (SHM optimization!)

- **Waked flow is a subset of the varied inflow conditions: increased turbulence, horizontal shear, and velocity deficit**

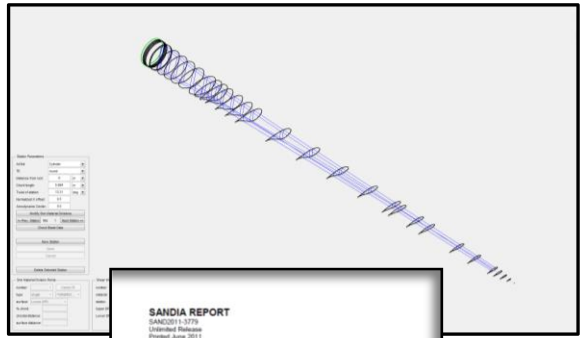
POD = Probability of Detection

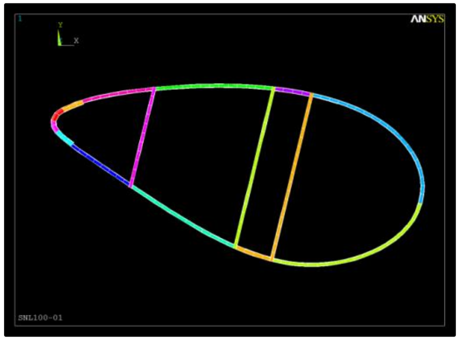
Large Offshore Rotor Development (100-meter Blade Project)

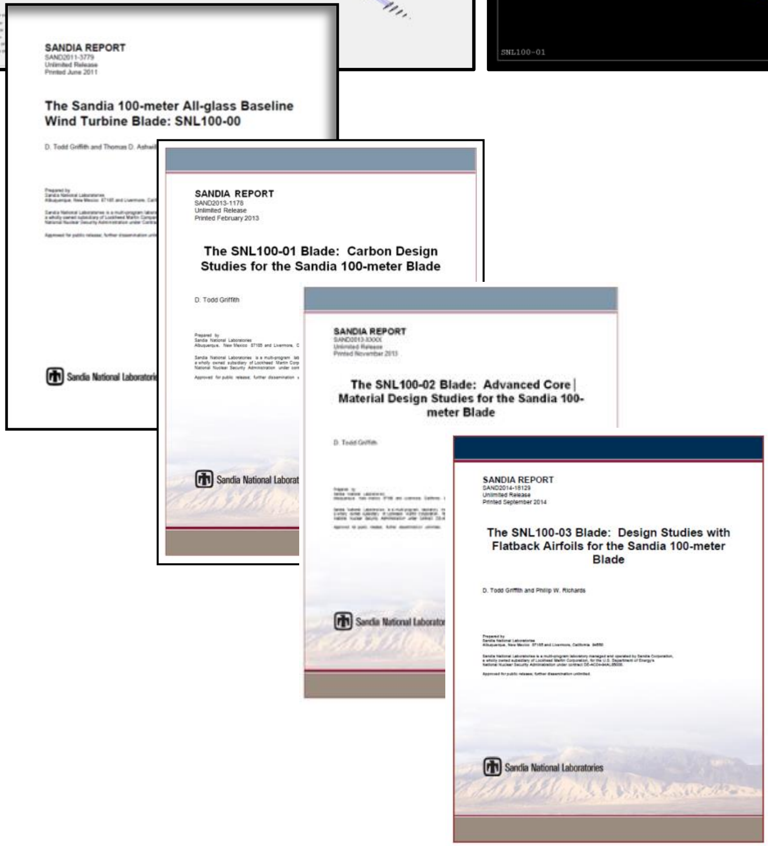
- **Summary**
  - Large blade design studies
  - **Public domain blade project**
  - **Reference Models**
- **Objectives/Focus Areas**
  - Identify trends and challenges
  - **Detailed 100-meter reference designs**
  - **Targeted follow-on studies**: **advanced concepts, materials**, flutter, manufacturing cost trends, **thick airfoils**, CFD, optimization
- **Products**
  - Design reports
  - 100-m blade and 13.2 MW turbine reference models

http://largeoffshorerotor.sandia.gov

- **Partners:**
  - **None funded, In-kind**
  - **70+ users**







Sandia Blade Manufacturing Cost Model: Approach

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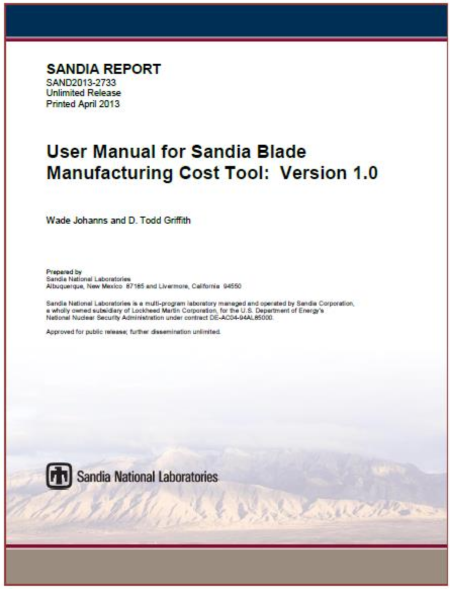
- Components of the Model:
  - Materials, Labor, Capital Equipment
  - Reports: SAND2013-2733 & SAND2013-2734
- Input the design characteristics
  - Geometry and BOM from blade design software (NuMAD)
  - Materials cost based on weight or area
  - Labor scaled based on geometry associated with the subtask
  - Capital equipment scaled from typical on-shore blades


SANDIA REPORT
SAND2013-2733
Unlimited Release
Printed April 2013

User Manual for Sandia Blade Manufacturing Cost Tool: Version 1.0

Wade Johanns and D. Todd Griffith

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Two principal questions:

Trends in principal cost components for larger blades?
Cost trade-offs for SNL100 meter design variants?

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Innovative Offshore Vertical-Axis Wind Turbine Rotors Project

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A VAWT in deep-water has several inherent advantages.
Large reduction in offshore costs requires non-incremental solutions.

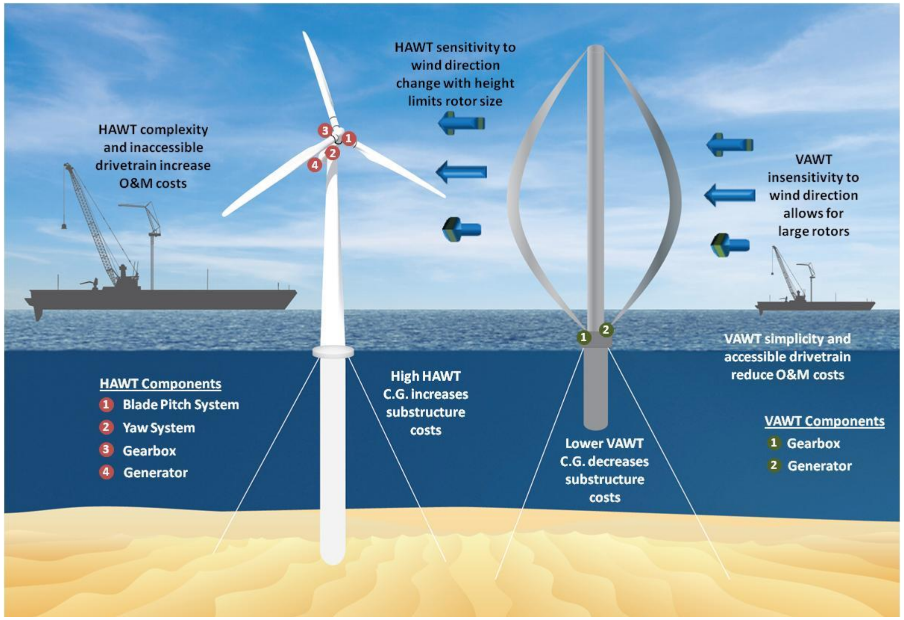


Figure 1 - Comparison of HAWT and VAWT Machines for Offshore Deployment

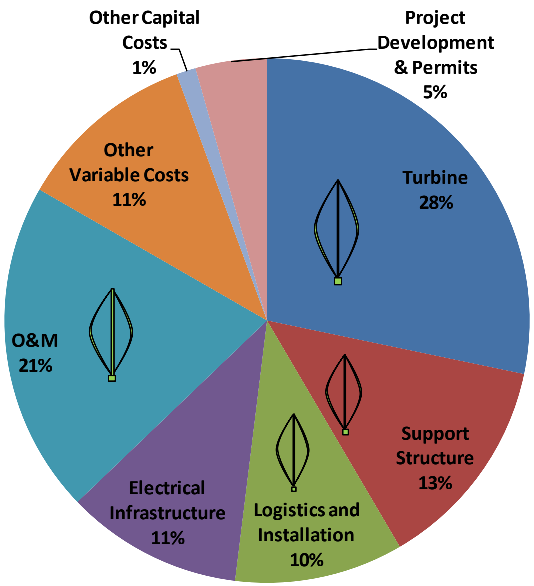
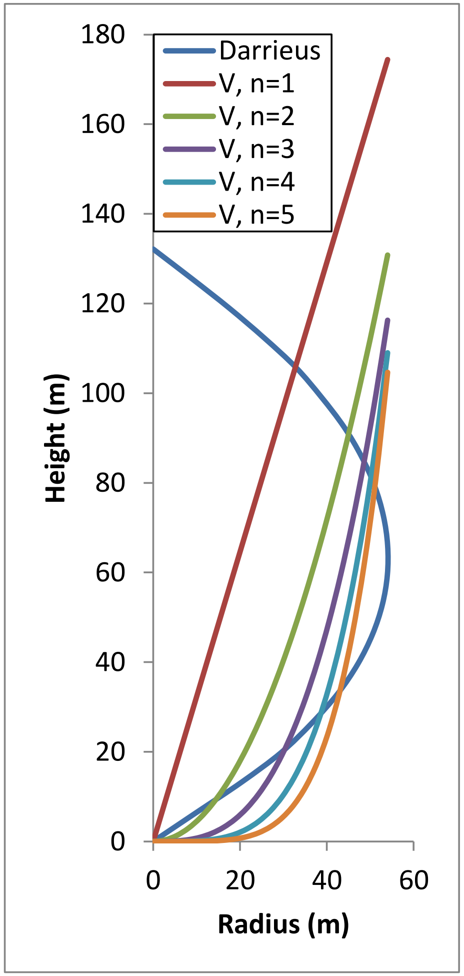


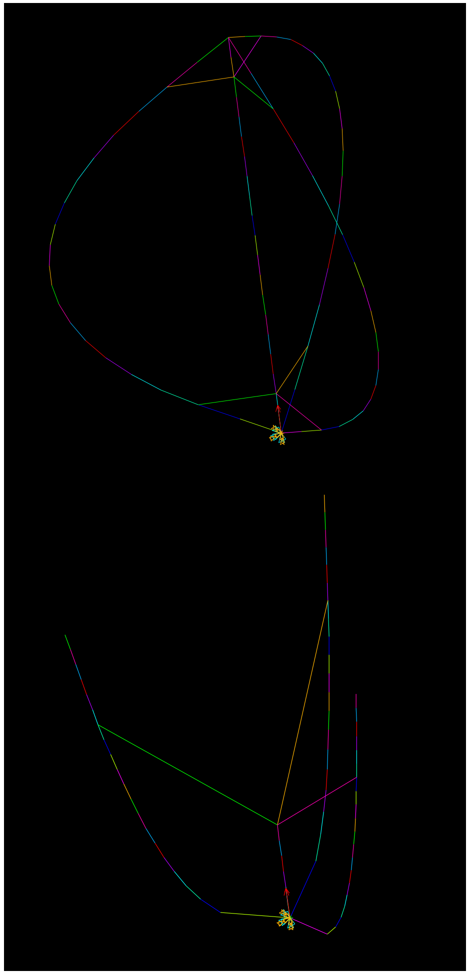
Figure 2 - Estimated Life-Cycle Cost Breakdown for an Offshore Wind Project, and Areas that VAWTs Improve

Rotor Structural Design Configurations

Parameter	Values Considered
Architecture	Darrieus, V
Number of Blades	2, 3
Tip Chord Length	2m, 3m
Composite Material:	Glass/Epoxy, Carbon/Epoxy
Tapering Scheme (Darrieus only, V-VAWTS used Single Taper)	No Taper, Single Taper, Double Taper
Curvature or Power Law Exponent (V-VAWT)	n=1, n=3, n=5



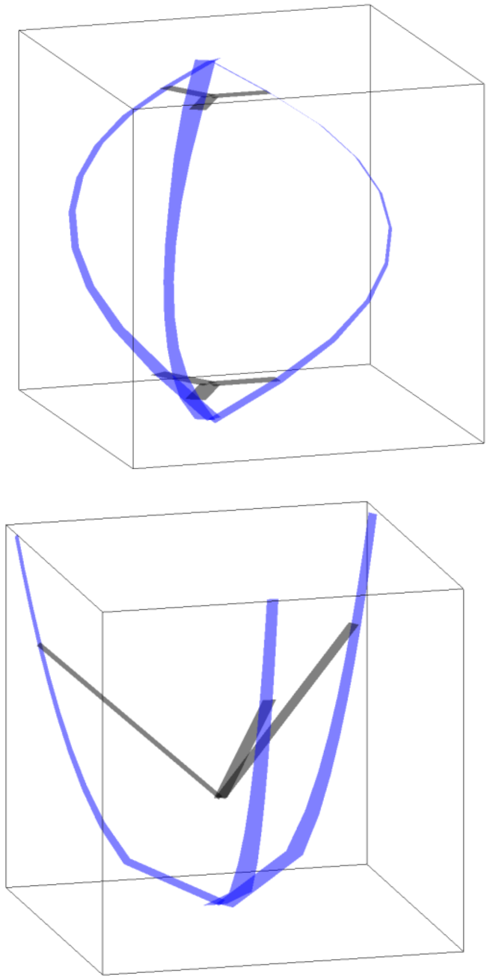
D and V VAWT Shapes



ANSYS Beam Models of D and V VAWTS

Rotor Aero Design Population

- 24 Candidate Rotor Design **External Shapes**
  - 12 Darrieus :
    - large/small chord
    - single/double/no blade taper
    - two/three blades
  - 12 "V"-Rotors :
    - large/small chord
    - power law shape exponent = 1/3/5
    - two/three blades
- Constraints
  - Max radius = 54 m
  - Same capture area
  - NACA 0021 airfoil section



Platform Options

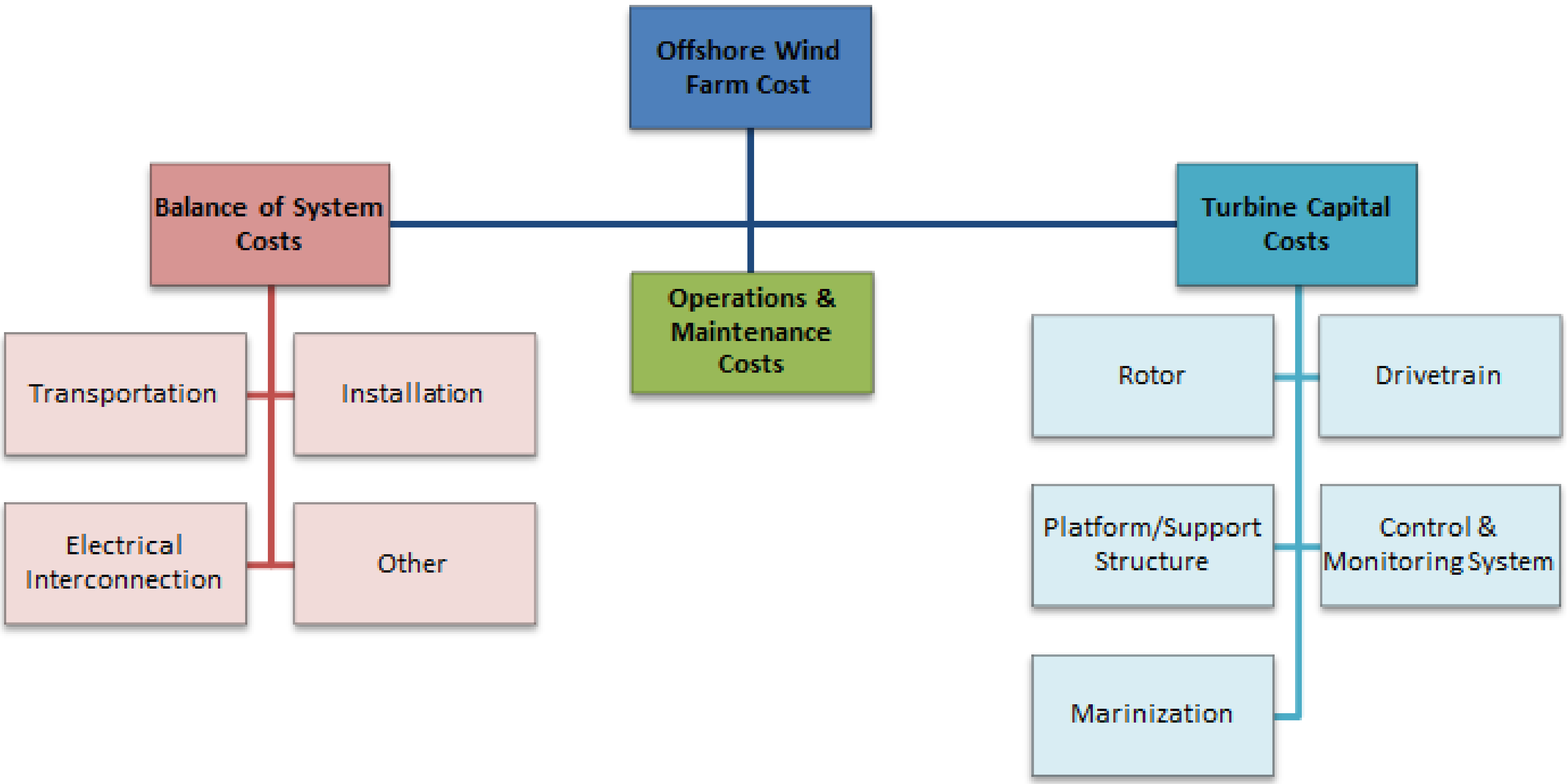
- Evaluate two main platform designs:

WindFloat Semi-Submersible

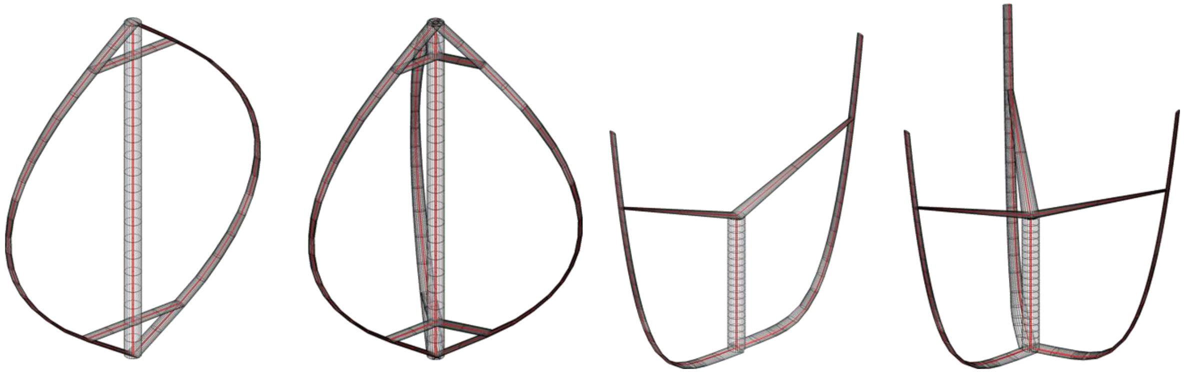
Hywind Spar

- Alter size as a function of the VAWT topside input.

Cost Analysis Components



- Total of 31 offshore VAWT rotors analyzed



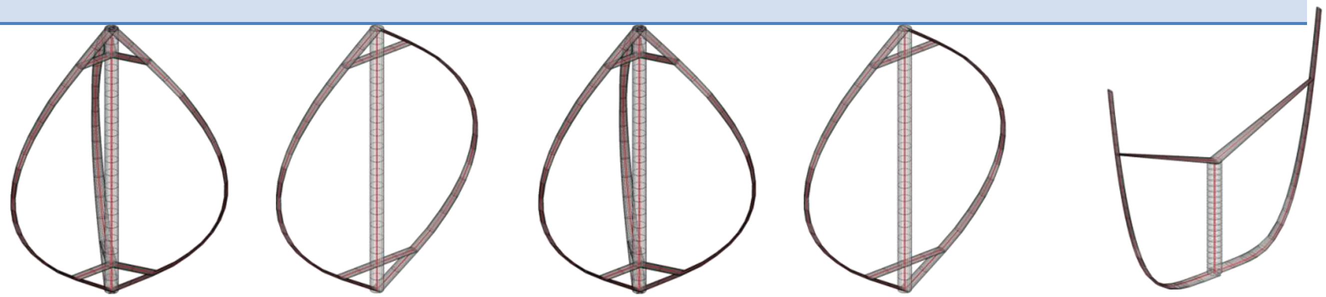
- A number of turbine, platform, drive-train configurations were considered (5 MW rotors)
  - Rotor mass a critical parameter for rotor and platform costs
  - Rotor RPM another key parameter

System Trade-offs:

AEP, RPM, Drivetrain

Rotor vs Platform

Parameter	DC_3B_LCDT	DC_2B_LCDT	DG_3B_SCDT	DG_2B_SCDT	VC_2B_LCN5
	Carbon 3 blades Large chord	Carbon 2 blades Large chord	Glass 3 blades Small chord	Glass 2 blades Small chord	Carbon 2 blades Large chord
Turbine AEP (MW-hr)	20069	18443	18880	17004	18992
Rotor Speed (RPM)	6.30	7.20	7.20	8.25	7.40
Drive-train Cost (M USD)	3.7	3.2	3.2	2.8	3.1
Rotor Cost (M USD)	++	++	+	+	+++
Spar Platform Cost (M USD)	+	+	++	++	++



Concluding Remarks

- Cost reductions are needed to unlock vast potential for offshore wind.
- Sandia performing R&D in targeted technology areas.
- A systems approach to integrating technology solutions would be beneficial to explore the lowest cost area of the (offshore) wind design space.
- “System” not only the capital equipment but also ***include the important decisions and costs of the operating system during their lifetime***.