

# Vertical-Axis Wind Turbines: a Solution for Floating Offshore Wind?

*PRESENTED BY*

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## 2 Floating Offshore Wind Energy

- Enables nearly unlimited development opportunities for wind energy in places with land constraints
- Not limited to shallow water depths and can be used to access better wind resources
- **Floating offshore wind is the most expensive form of wind energy installations**, around 3-4 times more expensive than land-based wind in the US



Block Island fixed-bottom wind plant being installed in Rhode Island, the only offshore wind plan in the US

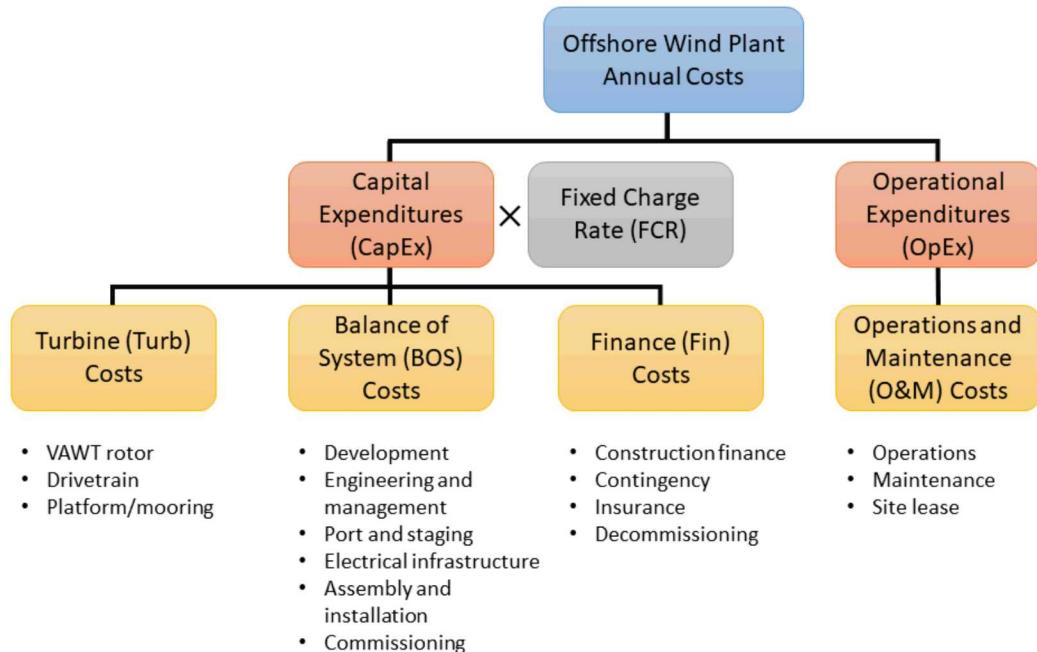
[www.dwwind.com](http://www.dwwind.com)



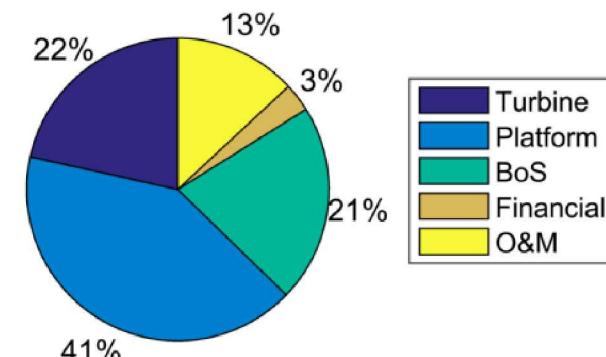
Hywind wind plant being installed in Scotland  
[www.independent.co.uk](http://www.independent.co.uk)

## Challenges with Floating Offshore Wind

- 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
- For floating offshore wind, the platform is the single largest contributor to the LCOE
- Operations and Maintenance costs are much higher than land-based wind due to costly and restricted accessibility

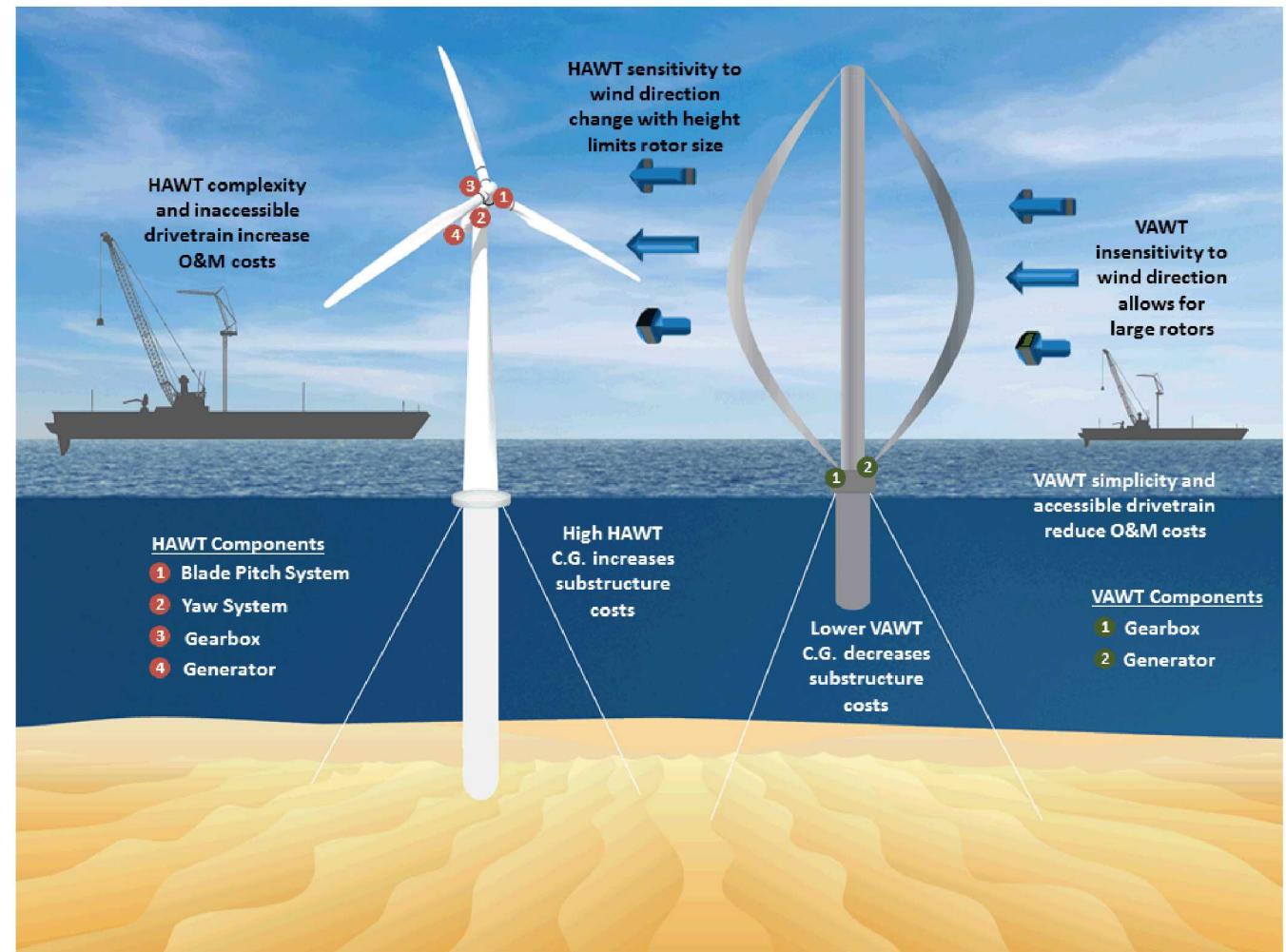


$$LCOE = \frac{(CapEx * FCR) + OpEx}{AEP_{net}}$$



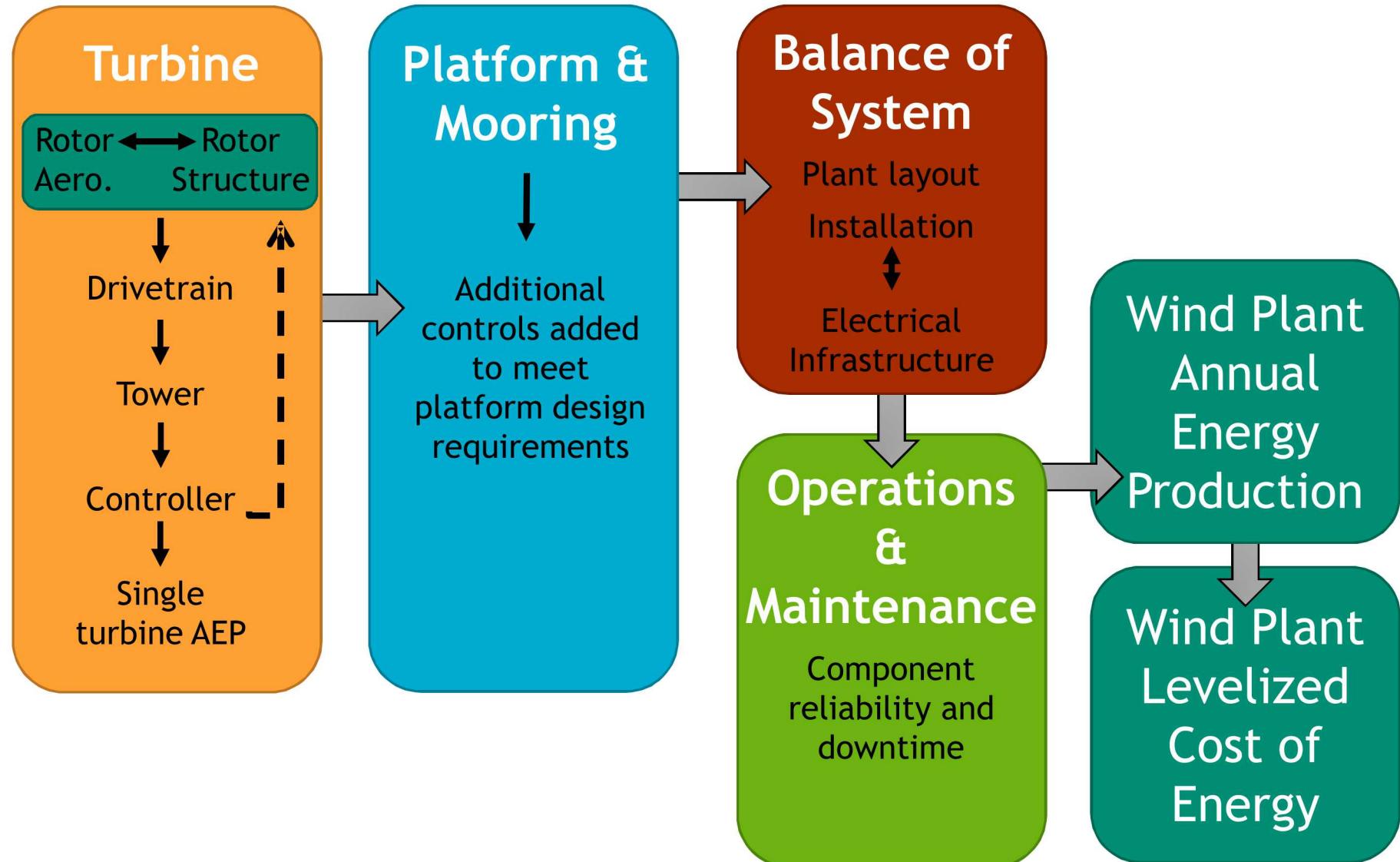
## Could VAWTs be a solution for floating offshore wind?

- Turbine costs represent 65% of wind plant costs for land-based sites compared to around 20% for floating offshore sites
- VAWTs are being studied as a potential solution for floating offshore wind energy **which have several benefits, including:**
  - (1) Lower center of gravity, which reduces topside moment of inertia and resulting platform costs
  - (2) Reduced O&M costs through removal of active components (yaw and pitch systems) and by platform-level placement of drivetrain
  - (3) Improved aerodynamic efficiency over HAWTs at multi-MW scales
  - (4) Insensitive to wind shear and veer
  - (5) Improved scaling compared to HAWTs



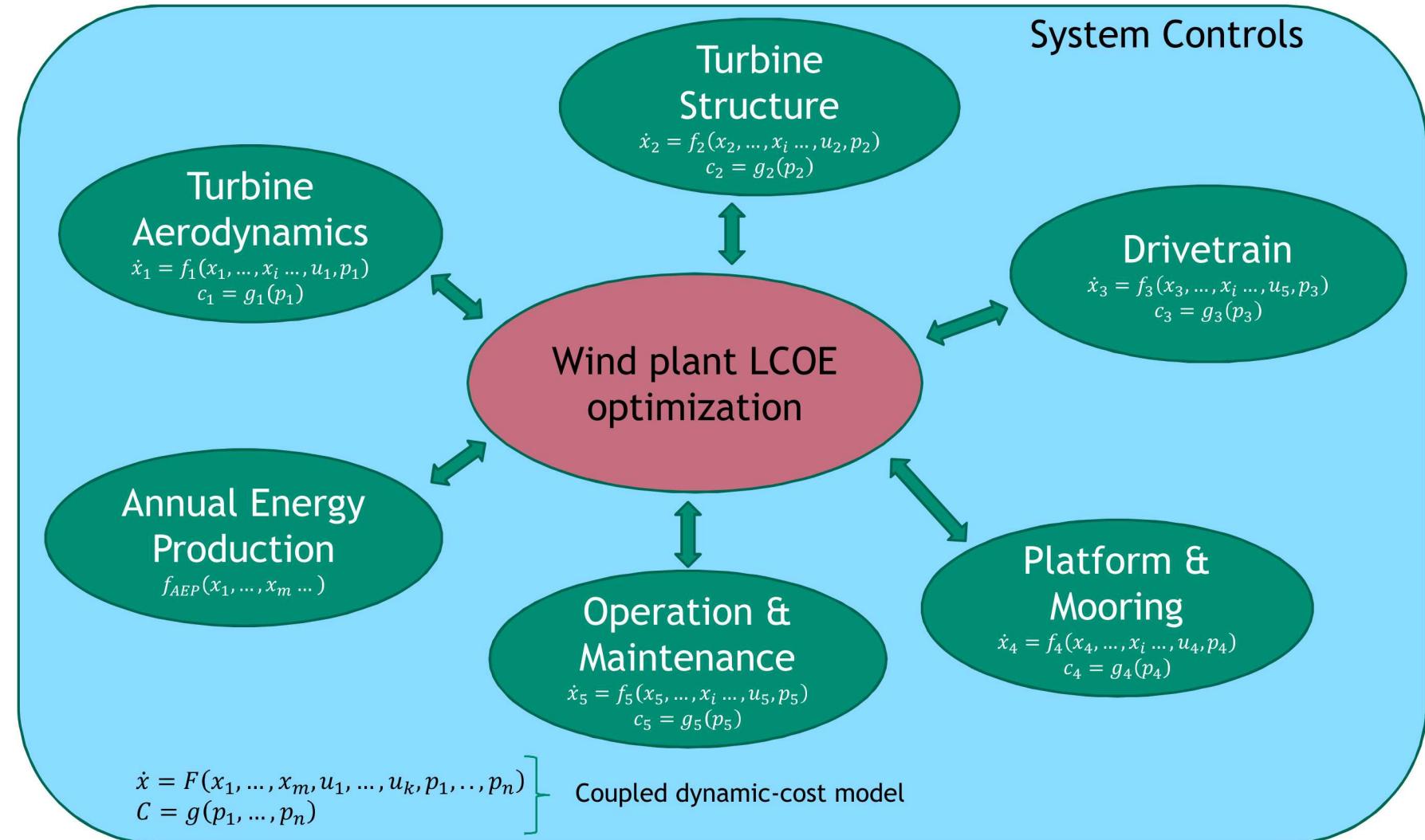
## 5 Traditional Offshore Wind System Design Process

- The current sequential design approach is suboptimal for floating offshore wind, and likely will not achieve the cost reductions needed to enable mass industry growth
- Relying on this approach will hinder identification of transformative solutions for floating offshore wind optimal system design



## 6 System Optimal Co-Design Process

- VAWTs can reduce LCOE for floating offshore wind by:
  - Reduced platform costs
  - Removal of active drive components (yaw and pitch) and improvements in O&M
  - Improved aerodynamic performance

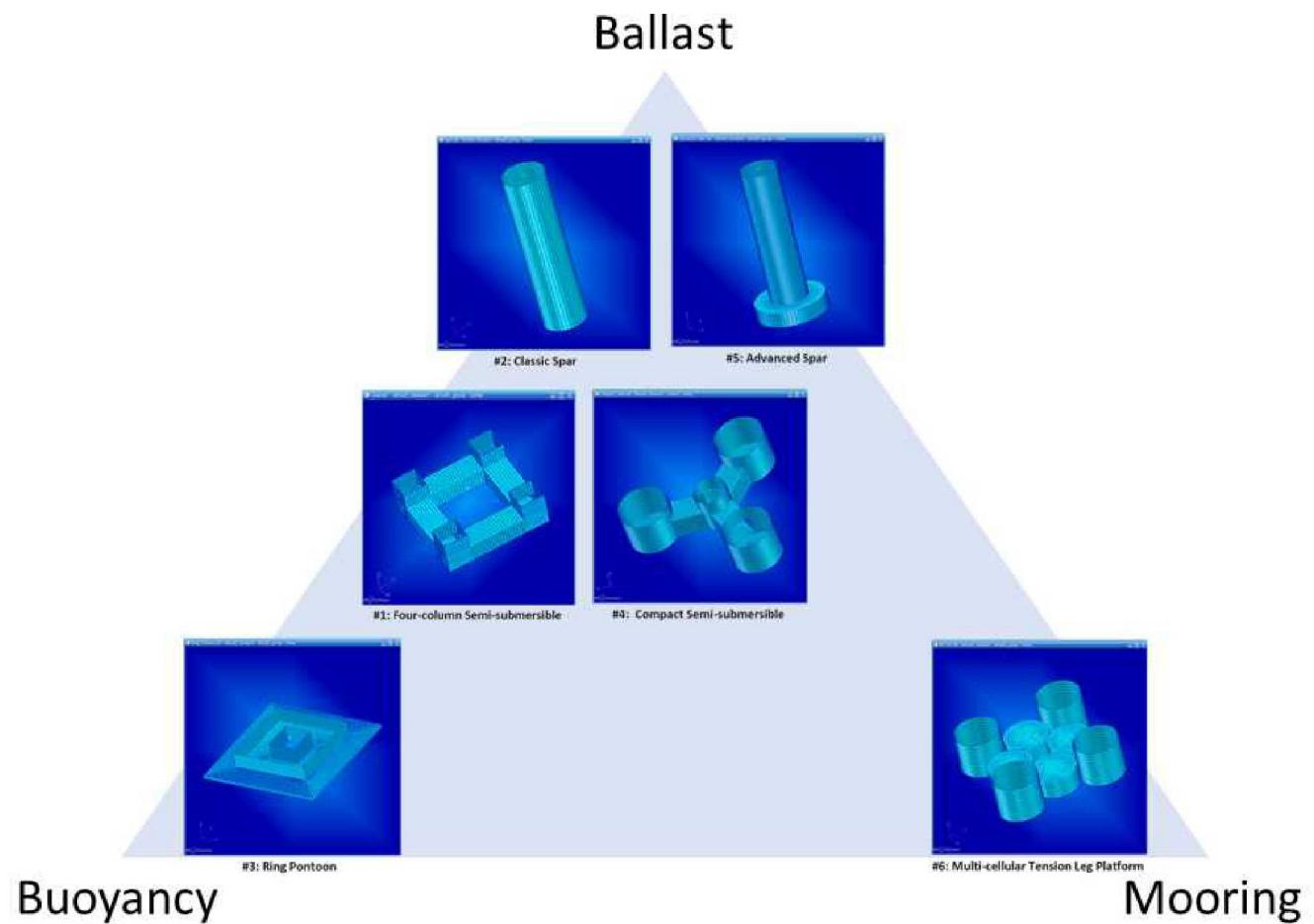


Optimal design  $(p_1, \dots, p_n)^* : \arg \min_{(p_1, \dots, p_n)} LCOE$

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

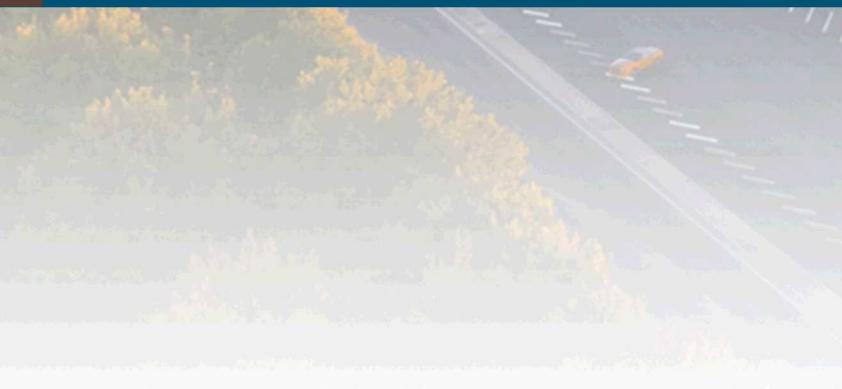
## 7 Challenges with Floating Offshore Wind

- VAWTs have much lower mass moments of inertia than HAWTs
- Previous VAWT study included floating platform design and analysis to determine the optimal floating platform architecture for LCOE and performance [1]
- 6 platforms covering the range of floating system stability mechanisms were studied
- A tension-leg platform with multiple columns was identified as the lowest cost option
- Performance benefits from the small roll/pitch motions include increased energy capture and reduced inertial loading on the turbine
- TLPs have been identified as a promising floating platform to reduce system LCOE [2]





If VAWTs are so great, then  
why don't you see... *any* of  
them... *anywhere*?



## 9 | VAWTs versus HAWTs

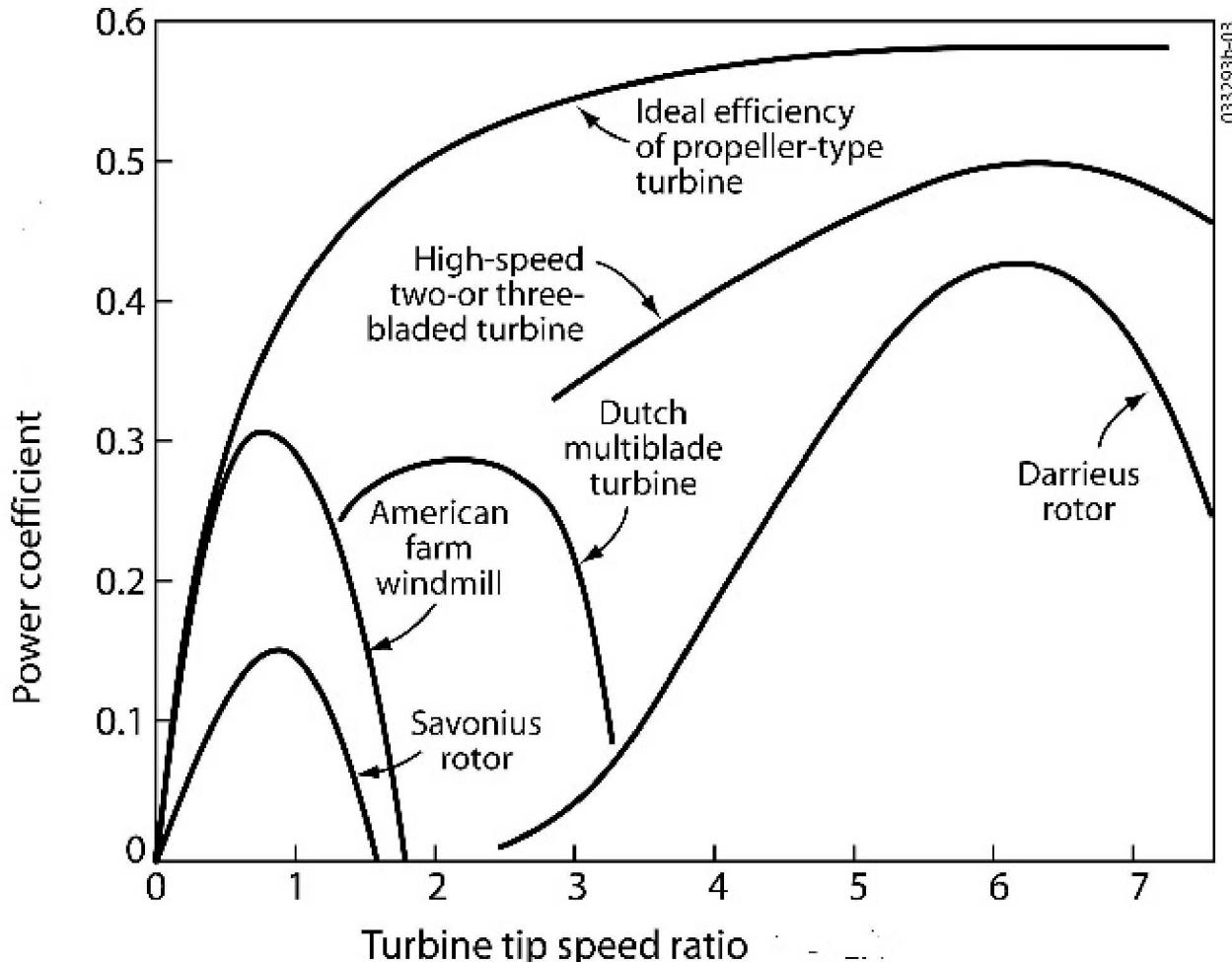
- HAWTs have been very successful, and are ideally suited for land-based installations
- The VAWT turbine might be more expensive than HAWTs, or at best comparable
- The benefit of utility-scale VAWTs arises strictly for floating offshore wind plants, where the platform and O&M costs dominate the LCOE

**There is also some legacy misinformation that has hindered their acceptance for future floating wind development:**

- VAWT power performance
- VAWT fatigue
- Lack of development and proven performance at scale

## VAWTs... “their power performance is inferior”...

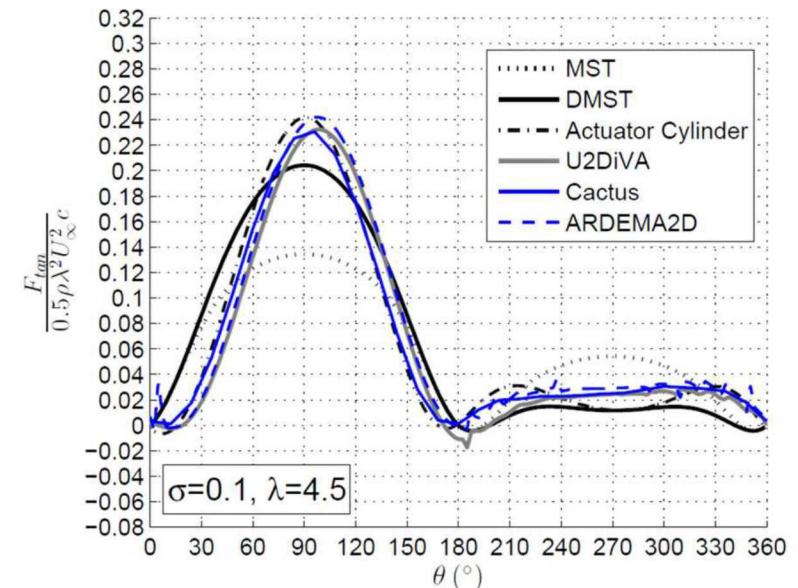
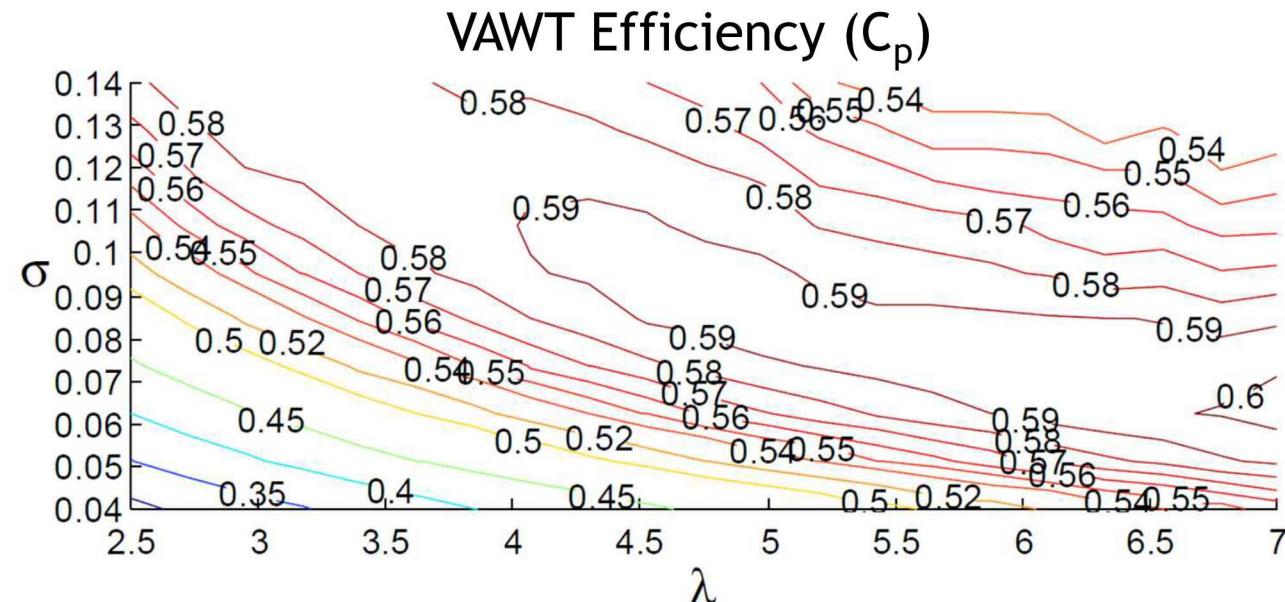
- VAWTs actually have a 4-8% higher aerodynamic power conversion efficiency than the Betz limit (for HAWTs) [3-5]
- Large VAWTs can have a sufficiently high tip speed ratio and low solidity to achieve high aerodynamic efficiency (power coefficients)



This graphic has been used for a long time as support for the relatively poor power performance of VAWTs, it appears to have been generated based on limited data, not theory [7].

## VAWTs... “their power performance is inferior”...

VAWTs operate through  $360^\circ$  relative to the incoming wind and in their own wake. For large VAWTs this effect on angle of attack is minimized while the effective double passage through the wind can actually produce higher aerodynamic efficiencies than HAWTs.



Sandia’s free wake vortex code CACTUS shows high VAWT efficiencies, comparing well to full CFD results at a fraction of the computational cost.

## VAWTs... “they have fatigue problems”...

- VAWTs do have inherent loading fluctuations due to their vertical rotation
- Large VAWTs with high tip speed ratios reduce the cyclical loading
- However, previous VAWTs had fatigue issues due to material and design choices which do not represent the industry today:
  - VAWTs in the 70s and 80s were manufactured using extruded aluminum blade sections, as composite materials were not prominent
  - Large VAWT blades had bolted connections which created stress concentrations, increasing the fatigue damage
  - Lifetime loading conditions for wind turbines were not as well known (design standards)



# VAWTs... “they haven’t been developed at scale”...



FloWind installed over 500 turbines (>95 MW) in California’s Altamont and Tehachapi passes, which operated for over a decade (prior to fatigue issues).

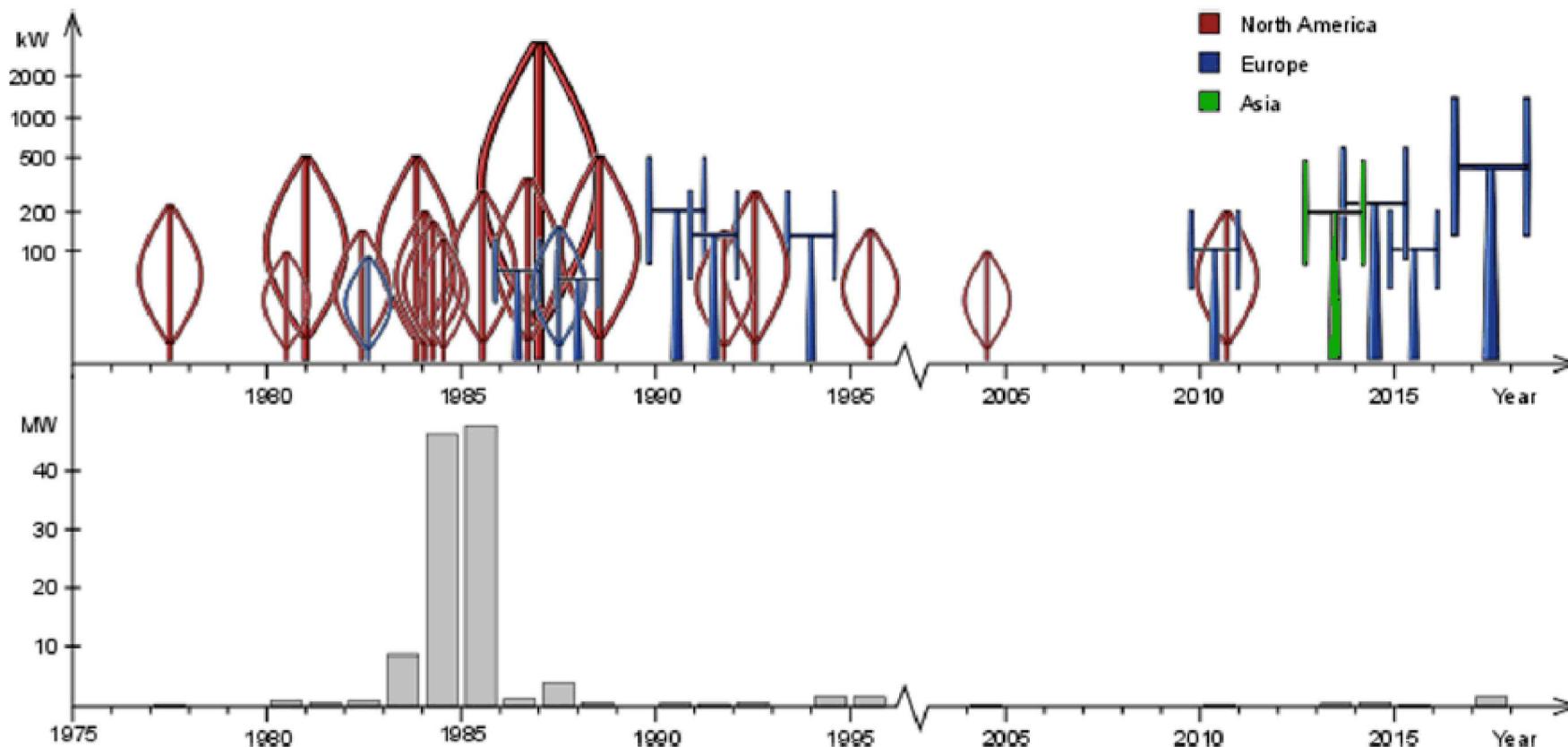
[www.wind-works.org](http://www.wind-works.org)



Eole was built in 1984 and had a rotor area equivalent to a 71m diameter HAWT. Eole was operated for 6 years in Quebec with a maximum power of 3.4 MW and was decommissioned due to bearing damage.

[www.wind-works.org](http://www.wind-works.org)

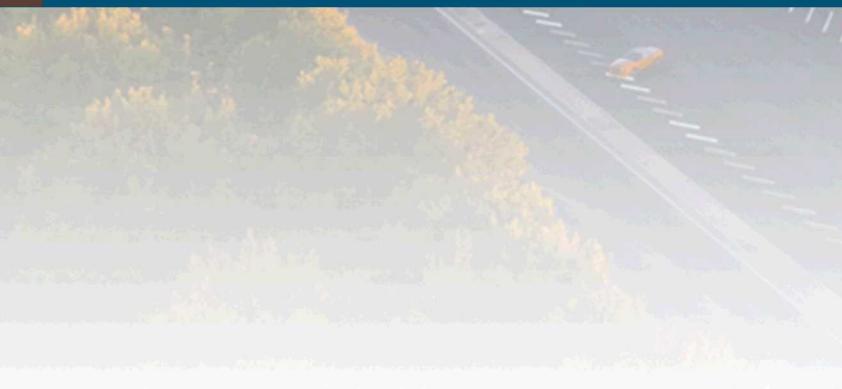
## VAWTs... “they haven’t been developed at scale”...



Early research of VAWTs included numerous developmental turbines (>100 kW) with somewhat successful commercialization efforts. When composite materials became common in the 90s, HAWTs began to dominate both research and commercialization [6].

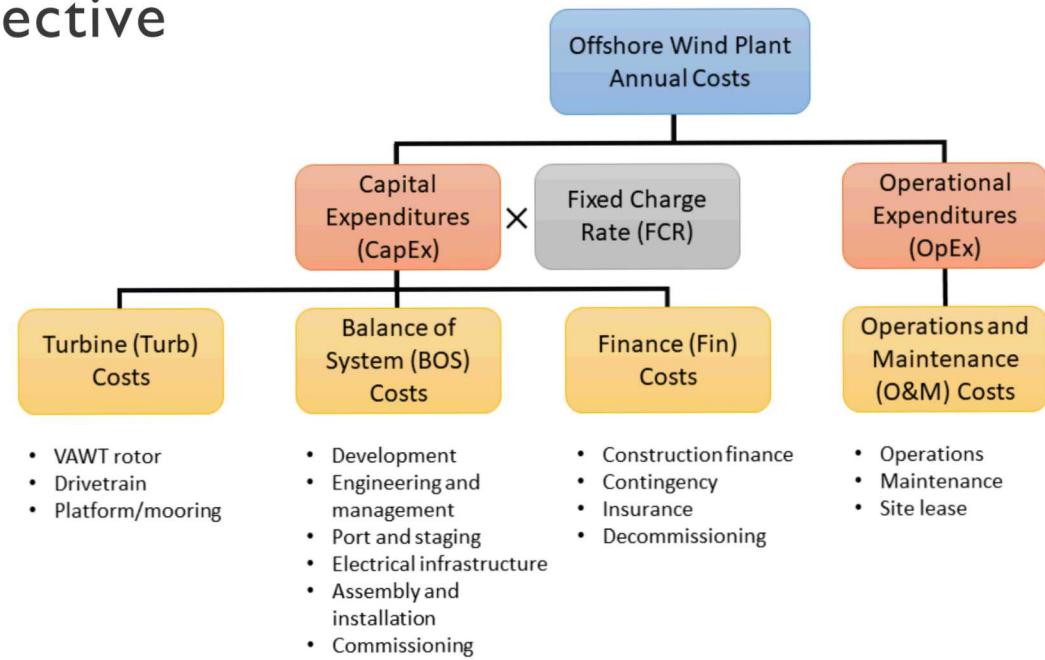


Additional benefits of VAWTs  
for floating offshore wind

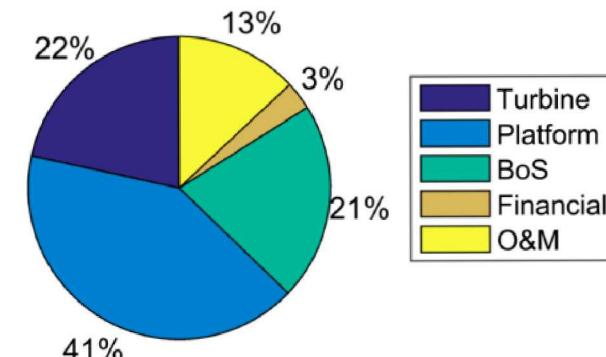


## VAWTs can reduce the LCOE design objective

- The solution for LCOE minimization is to reduce the system costs and increase energy capture
- The ideal wind energy system would eliminate all mass and cost that is not directly capturing energy from the wind
- This objective is even more significant for floating offshore sites where increased mass above the water level must be supported by larger and more expensive floating platforms

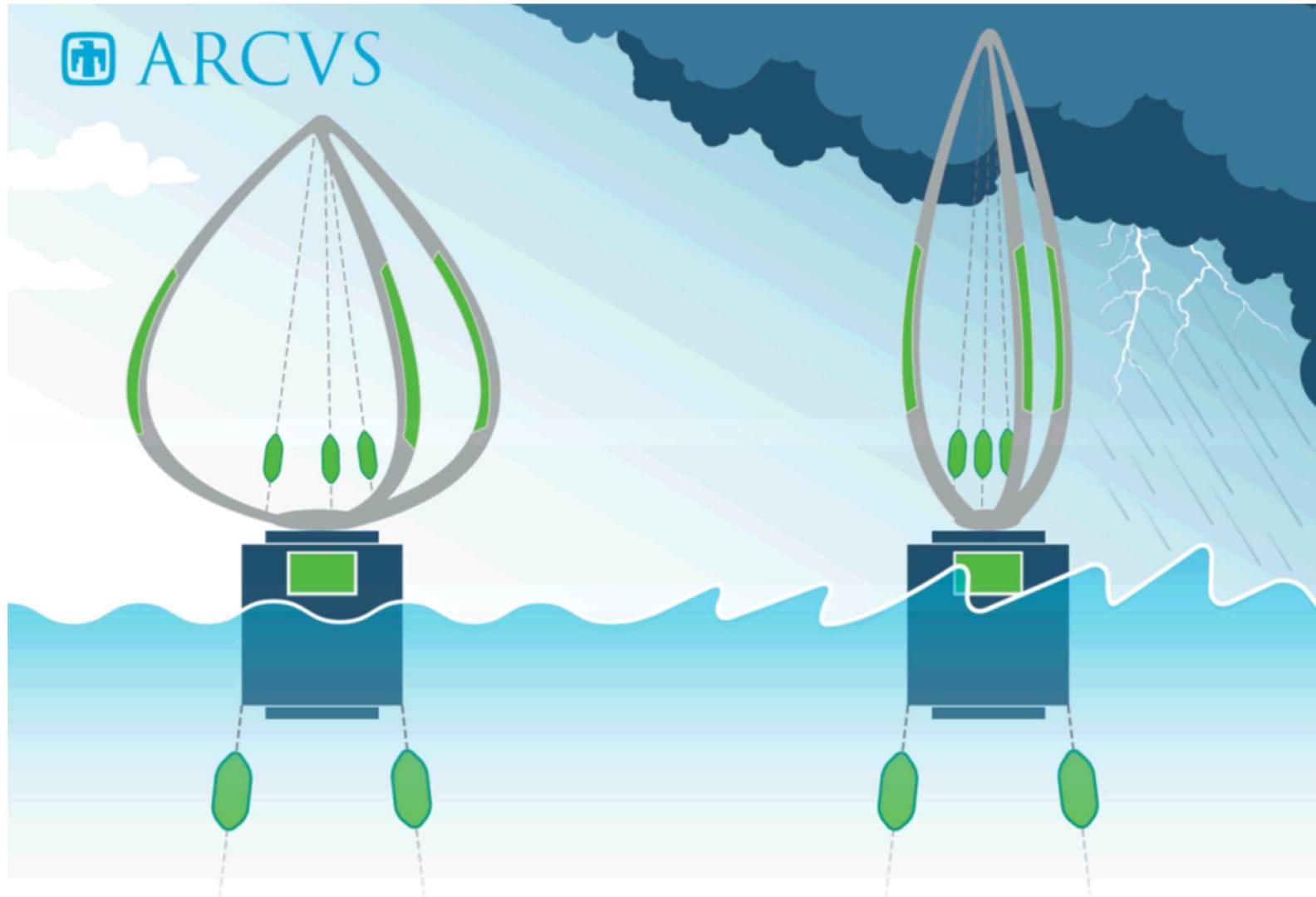


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## A VAWT designed for floating offshore sites

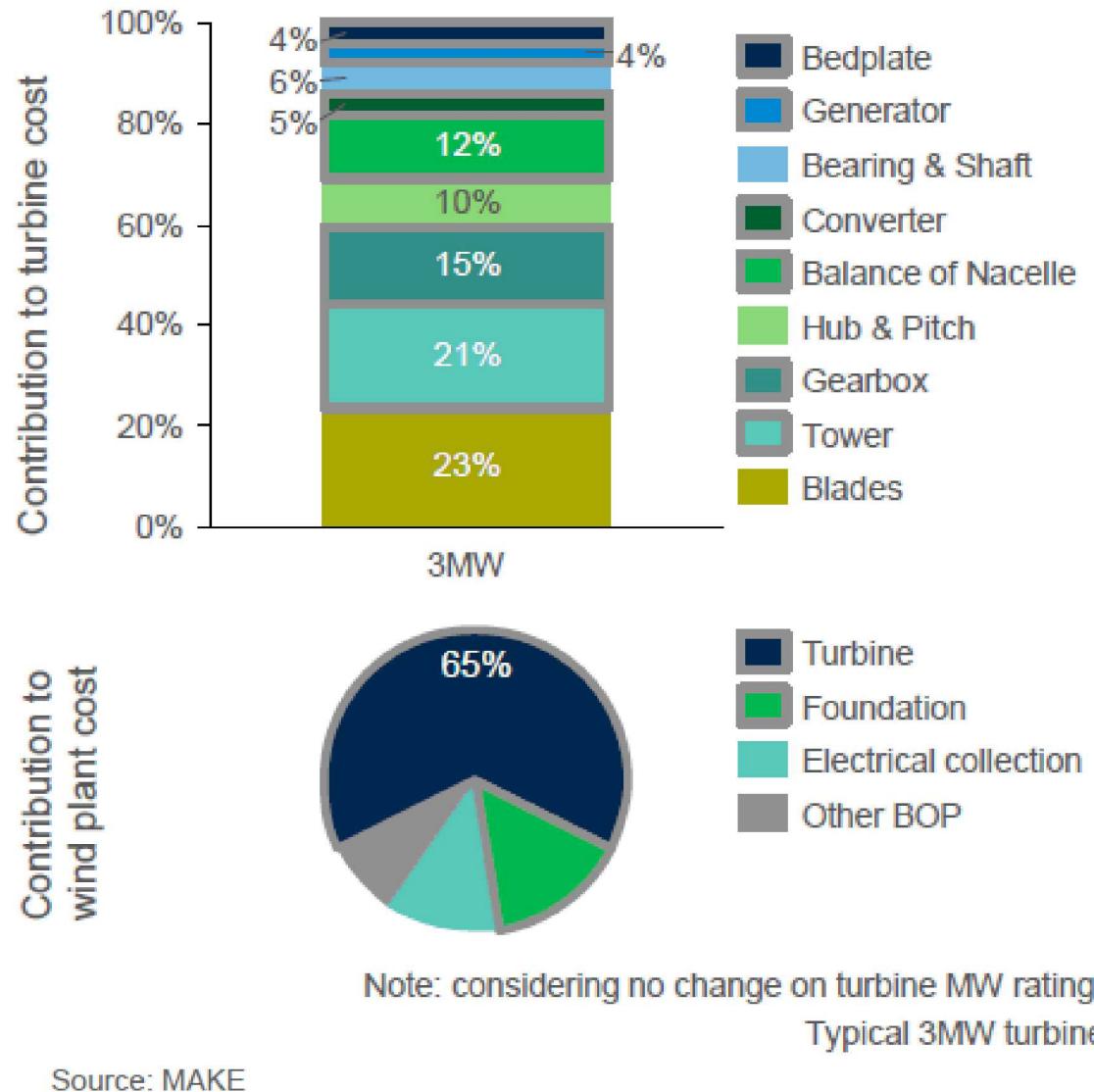
- The ARCUS Darrieus VAWT replaces the rigid tower with tensioned center supports and pre-stressed blades
- In previous Sandia studies, the tower represented 80% of the rotor mass
- ARCUS may enable a 50% rotor mass reduction, being studied through the ARPA-e ATLANTIS program



The ARCUS Darrieus VAWT has been designed by Sandia to address the high costs of floating offshore wind; patent-pending.

## A VAWT designed for floating offshore sites

- By eliminating the tower, the total rotor mass may be reduced, which has a cascading effect on platform costs
- The ARCUS blades will be more expensive than traditional Darrieus blades, but the net result should be reduced turbine costs and, more substantially, system LCOE
- VAWTs generally have longer, more expensive blades than HAWTs, but this is only 23% of the turbine capital cost
- VAWTs eliminate the hub and pitch systems, the nacelle structural system and bedplate, and the ARCUS VAWT eliminates the rigid tower which total to 47% of the capital costs



## A HAWT Equivalent of the ARCUS VAWT

VAWTs offer some unique design advantages for floating sites that simply cannot be replicated by HAWTs.



## References

- [1] Ennis, B. L. and Griffith, D. T., “*System Levelized Cost of Energy Analysis for Floating Offshore Vertical-Axis Wind Turbines*,” Tech. Rep. SAND2018-9131, Sandia National Laboratories, 2018.
- [2] Myhr, A., Bjerkseter, C., Agotnes, A. and Nygaard, T. A., “Levelised cost of energy for offshore floating wind turbines in a life cycle perspective,” *Renewable Energy*, Vol. 66, 2014, pp. 714-728.
- [3] B. G. Newman. Actuator-disc theory for vertical-axis wind turbines. *Journal of Wind Engineering and Industrial Aerodynamics*, 15:347–355, 1983.
- [4] J. L. Loth and H. McCoy. Optimization of darrieus turbines with an upwind and downwind momentum model. *Journal of Energy*, 7:313–318, 1983.
- [5] H. A. Madsen, U. S. Paulsen, and L. Vitae. Analysis of VAWT aerodynamics and design using the Actuator Cylinder flow model. *Journal of Physics: Conference Series*, 555(1), 2014.
- [6] Mollerstrom, E., Gipe, P., Beurskens, J. and Ottermo, F., “A historical review of vertical axis wind turbines rated 100 kW and above,” *Renewable and Sustainable Energy Reviews*. 105:1-13. 2019.
- [7] <https://facts.net/science/technology/wind-energy-facts>. Accessed 10/11/2020.