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# Global Wind Turbine Technology Trends

26 April 2017

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## Introduction

# A few words about MAKE

## Summary

- **MAKE is one of the global wind industry's premier strategic consulting and research firms, serving the world's leading wind companies from all parts of the value chain from raw material suppliers to IPPs and utilities.**
- MAKE is based in Aarhus (DK) and has offices in Hamburg (D), Chicago, Boston (U.S.) & Shanghai (China).
- Publish industry leading wind energy research reports, analysis and databases
- Consult on wind farm investments, market assessment, supply chain dynamics, technology, operations & maintenance, M&A advisory, business & market modelling and offshore wind
- Due-diligence partner for European and international PE and industrial investors



**Andy Li**  
Business Analyst

- *Leads the execution of MAKE's China advisory projects*
- *Solid background in the Chinese wind industry including product development at Envision Energy*
- *Extensive knowledge of wind turbine, wind farm solutions, and big data platform development*
- *B.Eng – Mechanical Engineering*
- *M.Eng – Industrial and Financial Engineering*

## Introduction

# A sample of our industrial clients



## Introduction

# A sample of our financial clients

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# Contents

- **Executive summary**
- **Global wind turbine technology trends**
- **Sources of innovation and 'breakthrough' technology**







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# Executive summary

24 April 2017

# Executive Summary

## 2016 saw increased focus in growing rotors and towers in the 3MW class

### Turbine Manufacturer (OEM) acquisitions present the biggest impact on global technology trends

- Siemens and Gamesa merger and resulting regional product strategy will shift global trends
- GE acquisition of LM may limit the world's largest blade supplier innovation footprint
- Integration efforts of GE/Alstom and Acciona/Nordex will influence regional product deployment

### Blades and MW ratings expected to continue growing in every global region

- Longer blades enabled by structural design, aerodynamics and material science
- Larger MW ratings in demand globally, N. America and China rapidly passing 2MW benchmark
- Logistics limitations continue to emerge as primary barrier to blade growth

### Many technologies continue evolutionary pace, while others experiencing innovation boom

- Converters, gearboxes and generators subject to slow evolutionary improvements
- Quest for 'intelligent' turbine has led to new technology for turbine loads monitoring and controls

Source: MAKE







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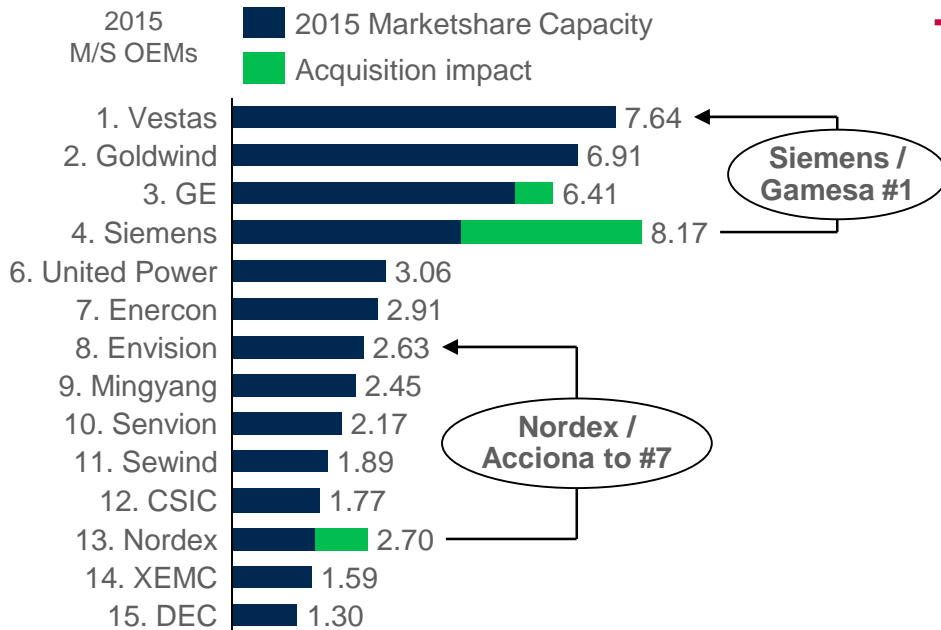
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# Global wind turbine technology trends



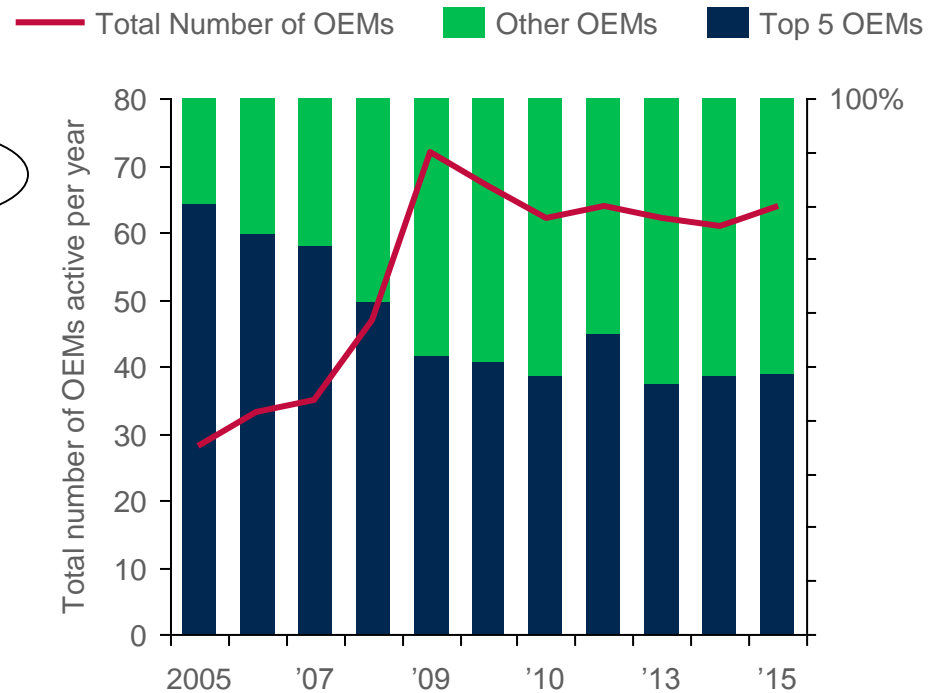
# Acquisitions and competition will re-shape technology trends

## Consolidation impact on OEM position



Note: Based on MAKE 2015 Marketshare positioning  
 Global Turbine OEM 2015 Marketshare Research Note  
 Source: MAKE

## Turbine OEM competition developments



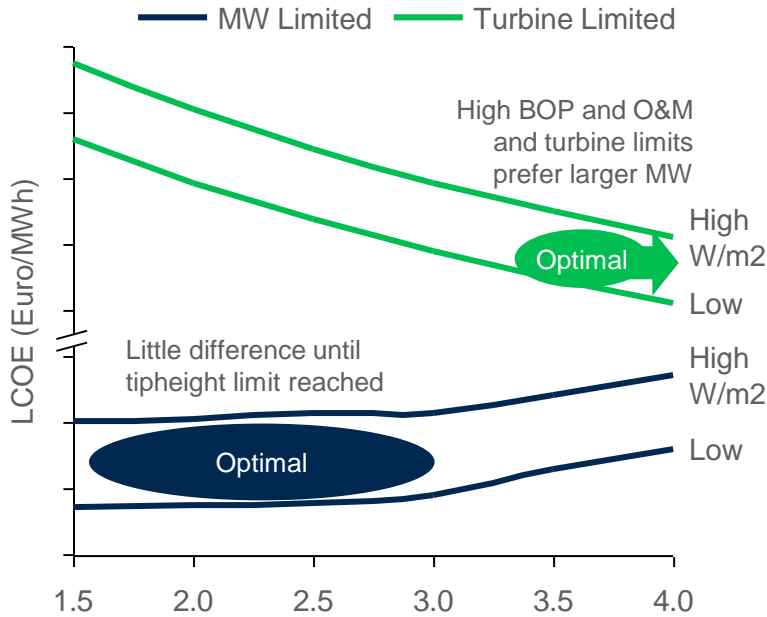
Note: Sub-MW turbine OEMs not included  
 Source: MAKE

Regional portfolio decisions made by Siemens/Gamesa will have lasting impacts

Consolidation is occurring but industry is still more intensely competitive than a decade ago

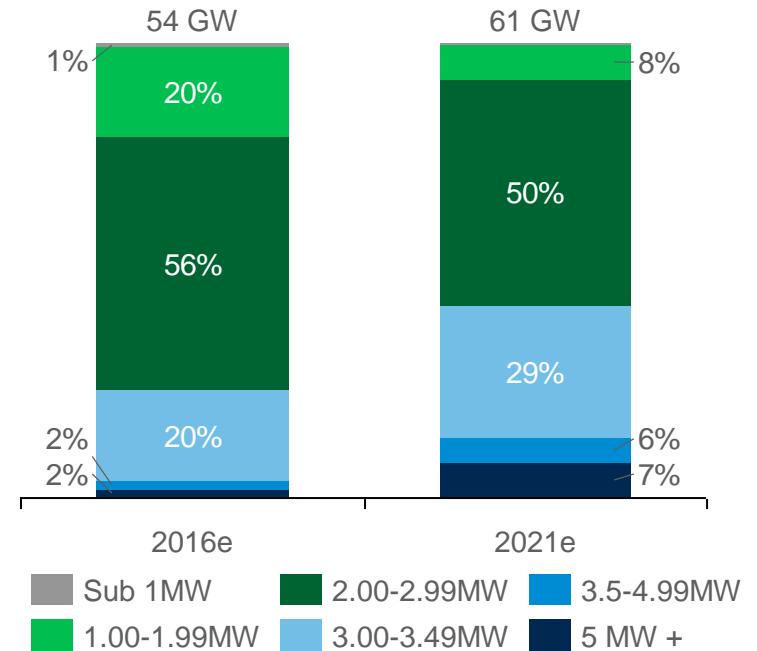
# 3MW class gaining ground in global markets

## LCOE optimization for MW rating



Note: High Specific Rating (W/m<sup>2</sup>) = 240. Low=200  
 Windspeed @ 80m = 8.0m/s  
 Tipheight limitation in MW limited markets = 152m  
 BOP % of CAPEX” MW Limited=23%, Turbine Limited =30%

## Global MW rating segmentation projections

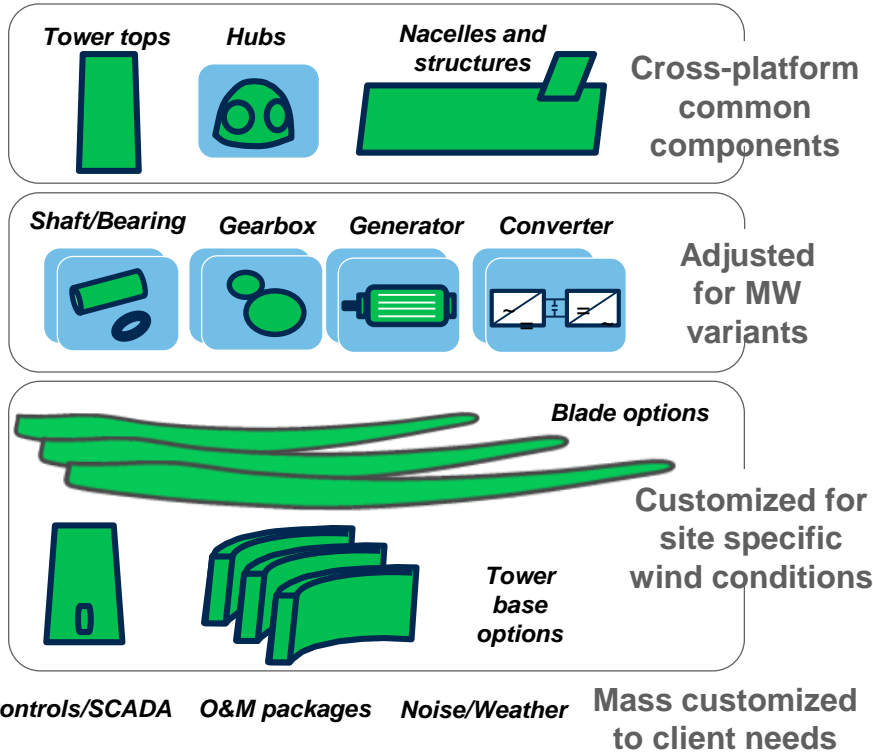


Note: 2016 and 2021 forecasted global annual installs shown  
 Source: MAKE

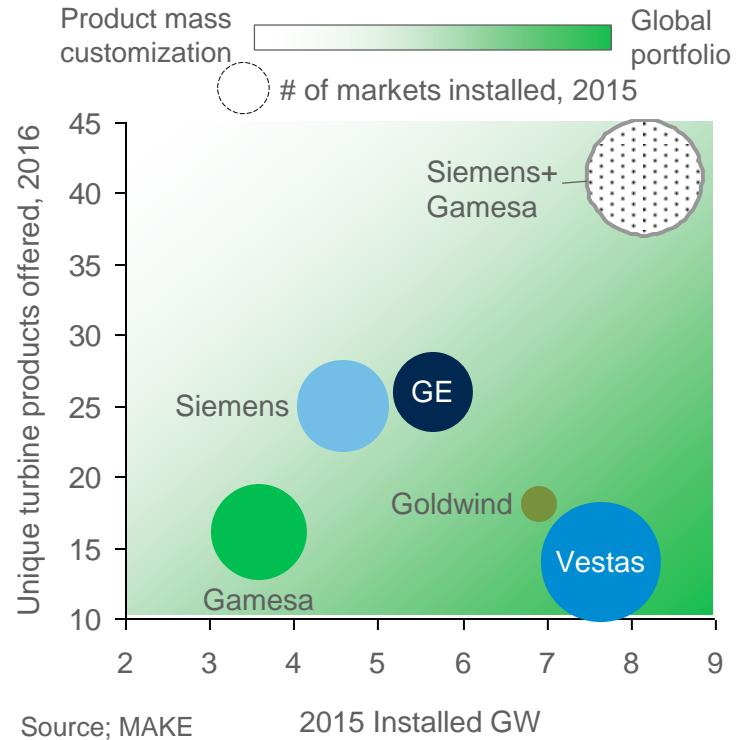
High cost of Balance of Plant (BOP) and performance gains makes 3MW more attractive  
 Lower than 2MW class due to drop substantially outside of select Asian markets

# Modular product strategies have led to portfolio expansion

## Mass customization in wind energy



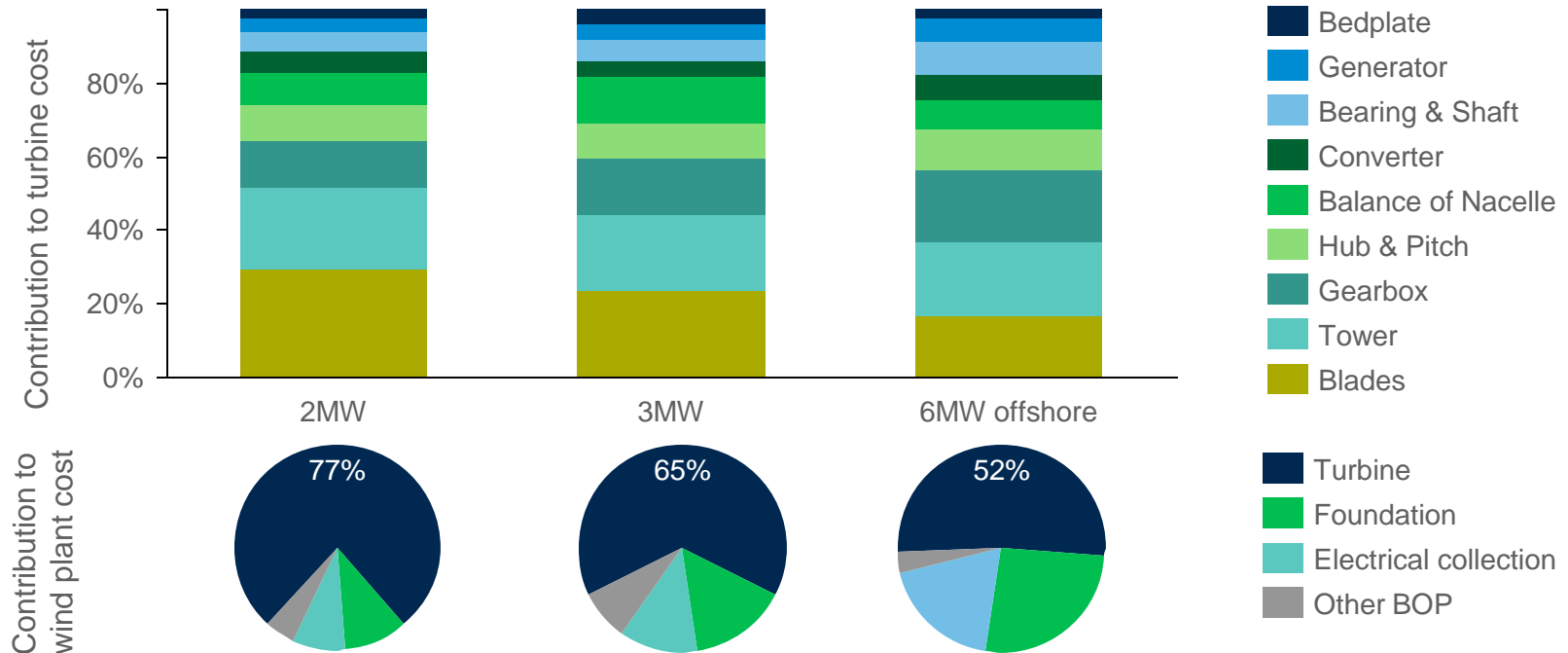
## OEM portfolio sizes and diversity



Modular product strategies have enabled strategic component re-use across products  
 Allows for streamlined mass customization to meet global needs and wind conditions

# Blades, tower and gearbox are majority of turbine cost

## Cost distribution in typical turbine technologies



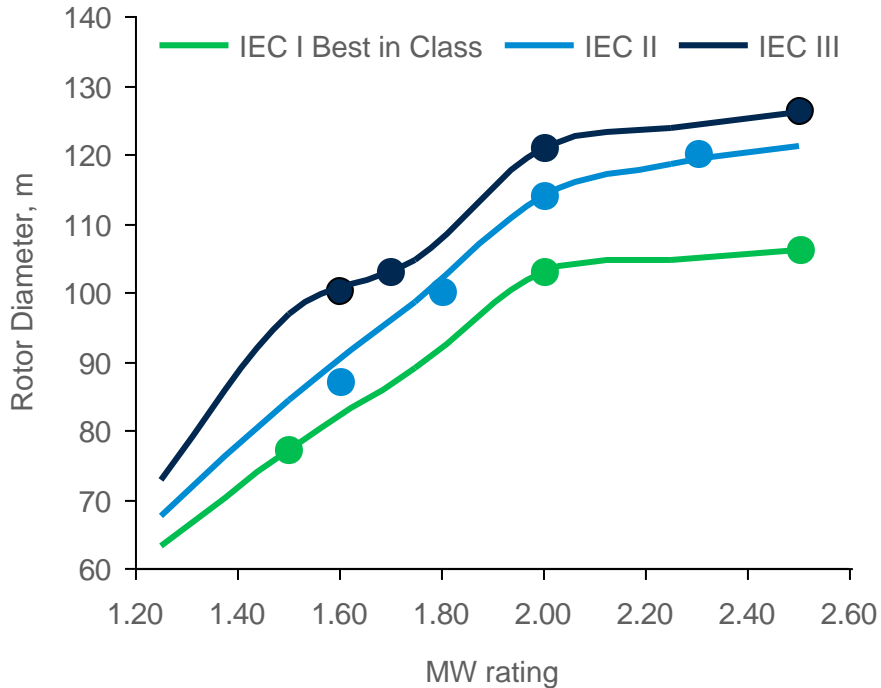
Note: Representative of mainstream high speed geared drivetrain technologies and wind plant characteristics in each market segment. 2MW class is representative of US, 3MW class representative of Northern Europe, Offshore representative of Northern Europe offshore  
 Source: MAKE

Increased cost of Balance of Plant is driving preference for larger turbines in EU and offshore  
 Cost-out focus will remain on blades and towers in order to reduce LCOE



# New products announced in 2016 shifted competitive benchmarks

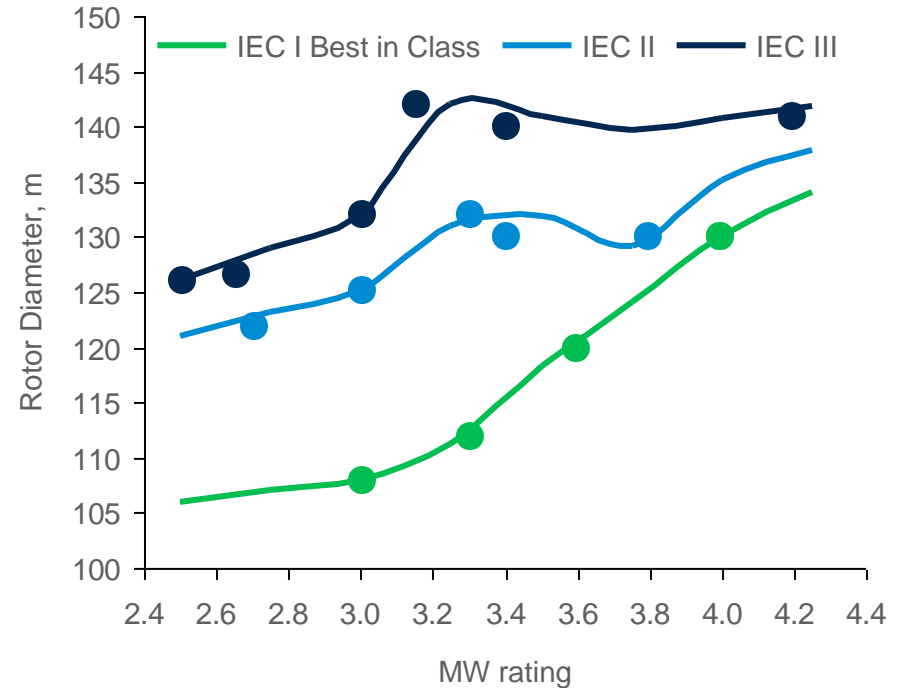
## Capacity constrained leaders, 2016



Note: If turbine is an S-class, IEC defined by certified Vavg

Source: MAKE

## Turbine constrained leaders, 2016



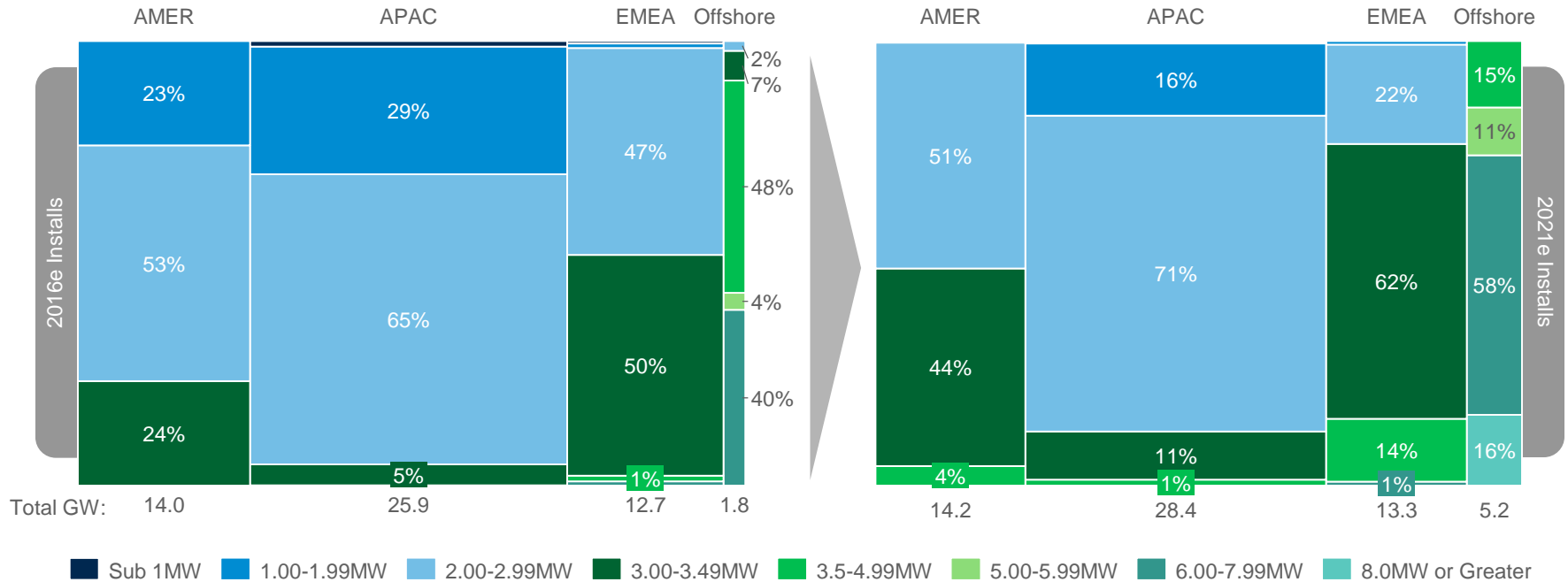
After years of rotor growth in 2MW class, many OEMs shift focus to 3MW giants  
 New products announced by Siemens and Senvion shift 3MW class landscape



## Global wind turbine technology trends

# <2MW turbines to disappear globally as 3MW class grows

## Global MW rating and segmentation, 2016e and 2021e



Note: Segmentation performed by total GW installed

Source: MAKE

Asia Pacific remains the last stronghold for the 1.5MW class, despite 2MW gains  
Europe and the Americas to see substantial growth in 3MW class installations

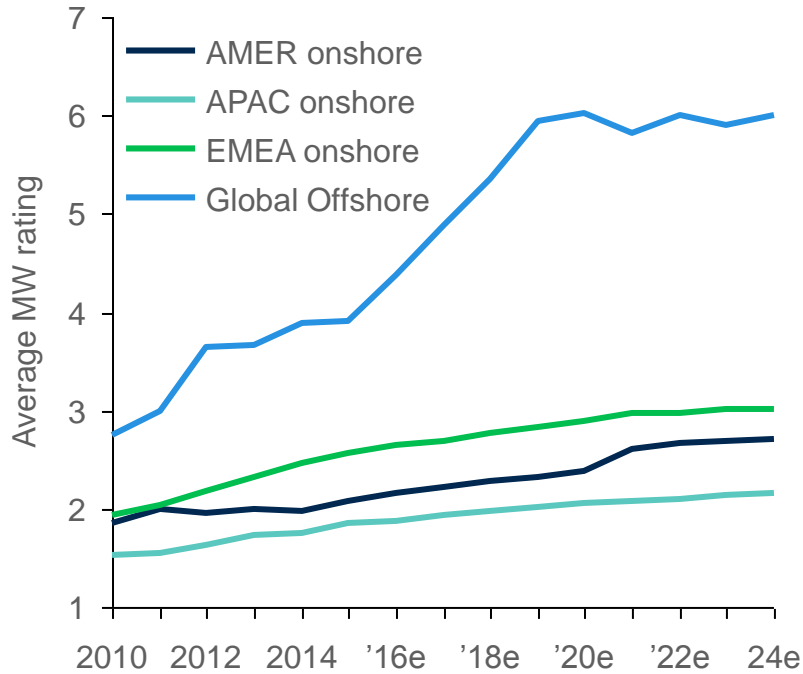


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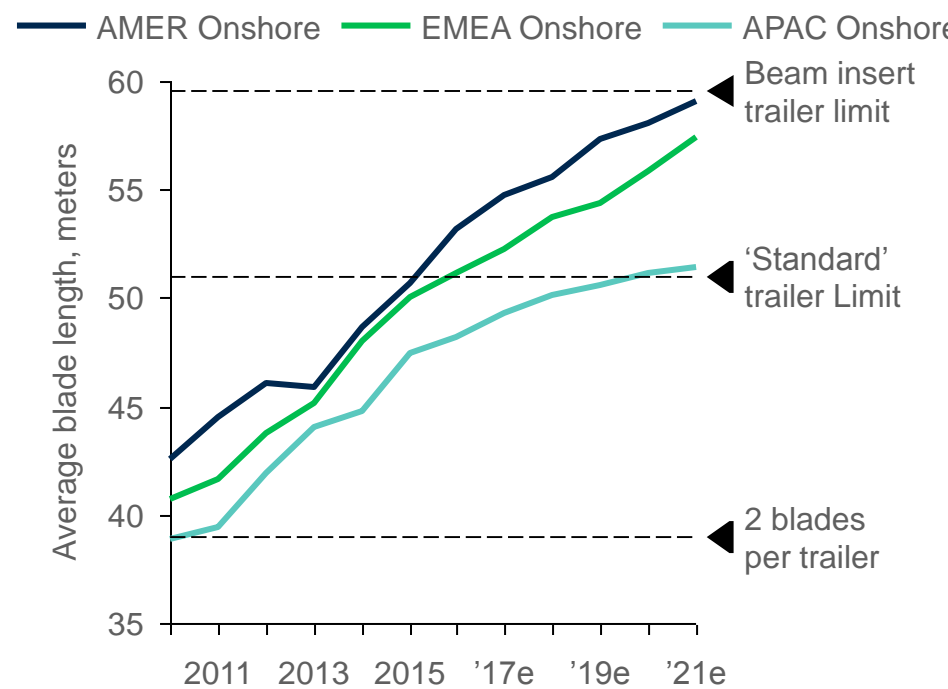
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# Average turbine sizes to grow in all regions

Average MW rating growth per region



Average Rotor diameter growth per region



Source: MAKE

Economies of scale of larger turbines improve with volume and BOP cost escalation  
 Longer blades are continually stressing logistics limits in all regions



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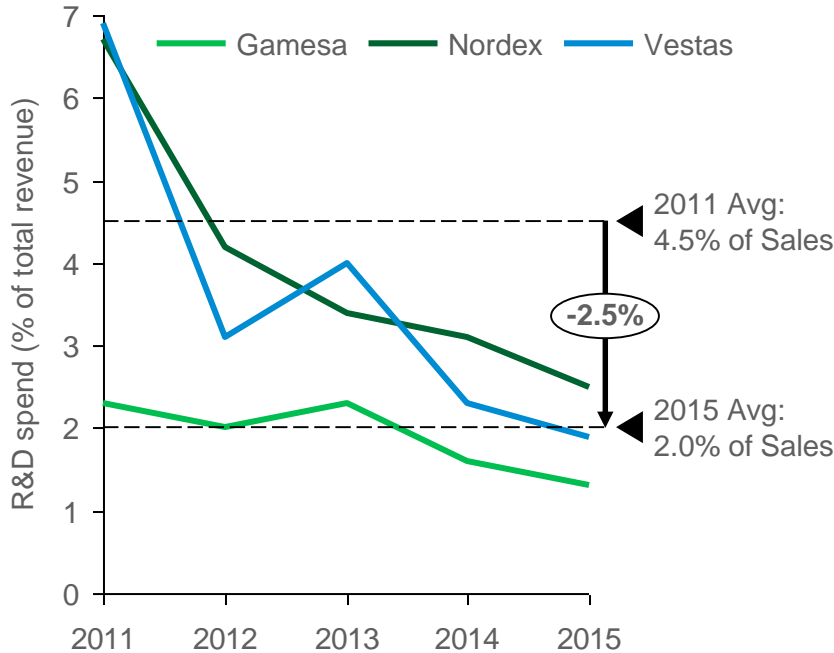
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Sources of innovation  
and ‘breakthrough’  
technology



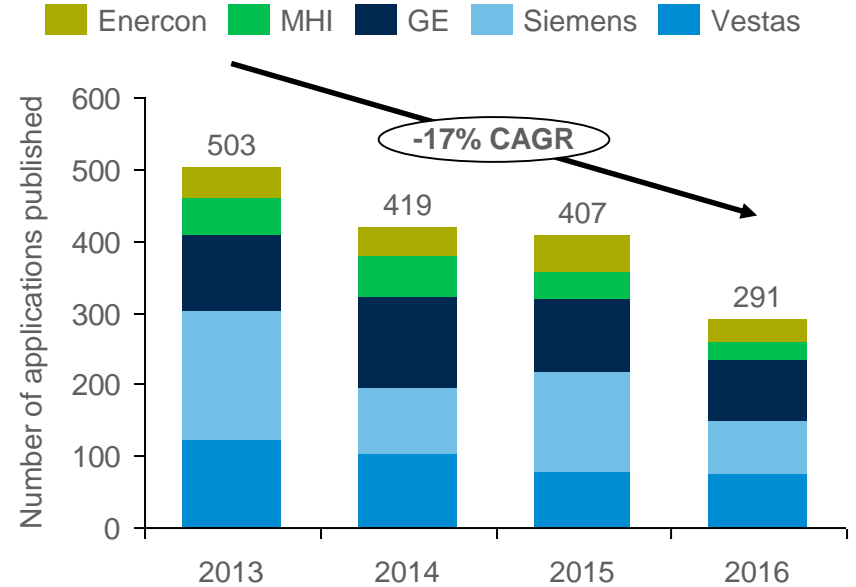
# OEM's reduce R&D spending to focus on product evolution

## R&D as percent of revenue trends



Note: R&D expense as identified on income statements  
Source: MAKE, Company financials

## Patent application filing trends

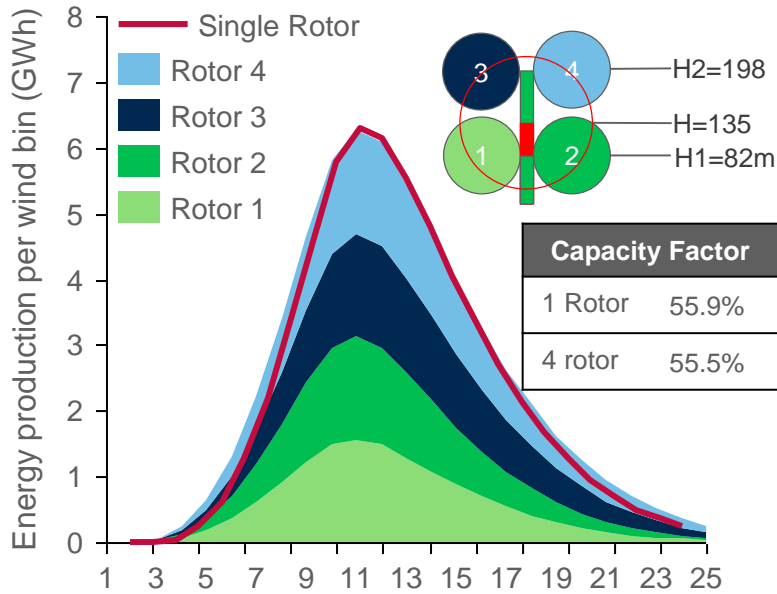


Note: Only patent applications in the European Patent (EP) database  
Vestas includes MHI Vestas patent applications  
GE includes Alstom, Blade Dynamics and LM  
Source: MAKE

Product introductions accelerating, despite slowdown in IP filings and R&D spending  
R&D spend expected to stabilize following years of solid profit gains

# Radically different technology still being pursued by large companies

## Vestas Quad rotor energy comparisons



Note: Vavg @ 80m=9.0 m/s. Shear = 0.15. Max Cp = 45.5%  
 Assuming 2% losses due to inter-array aerodynamics in Quad rotor  
 Source: MAKE

## Aerial wind turbine state of the art

Company	Investors	Technology	Status
Makani	Google	Airborne generators	Commercial offering
Altaeros	MHI	Airborne ducted turbine	Sub-scale prototype
Kite Power Systems	Shell, E.On Schlumberger	Kites powering ground generator	Sub-scale prototype
Ampyx Power	Crowd funding (EUR 2 Million)	Tethered planes ground generator	Sub-scale prototype
SkySails	Venture capital	Kites powering ground generator	Laboratory prototypes
Kitegen	Venture capital	Kites powering ground generator	Laboratory prototypes



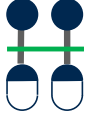


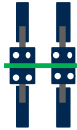































Hypothetical	Laboratory prototypes	Sub-scale prototype	Full scale prototypes	Commercial offering

Although the industry has largely consolidated on a few turbine architectures, some long-term technology investment persists for radically different wind turbine architectures



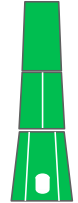


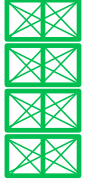































## Sources of innovation and 'breakthrough' technology

# Nabrawind looks to solve 2 critical technology scaling issues

### Blade joint options being researched

	 Not feasible					
	 Optimal	Bonded	T-Bolt	Double fitting	Tension fitting	nabrajoint
Strength / bolt sizing						
Mass and cost						
Field assembly						
Maintenance needs						
Reliability/inspectability						

### Taller tower options available

	 Not desirable					
	 Optimal	Tubular steel	Segment steel	Precast concrete	Lattice/Spaceframe	Nabralift
Tower material cost						
Logistics cost and time						
Assembly and erection						
Modal coupling						
Specialized large crane						

Source: MAKE, Nabrawind

Segmented blades and cost effective taller towers are critical to onshore turbine growth  
 Nabrawind focusing on developing both technologies to solve scaling constraints

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