American Superconductor®

Drivetrains

Direct Drive Generators

High Temperature Superconductor Based Machines

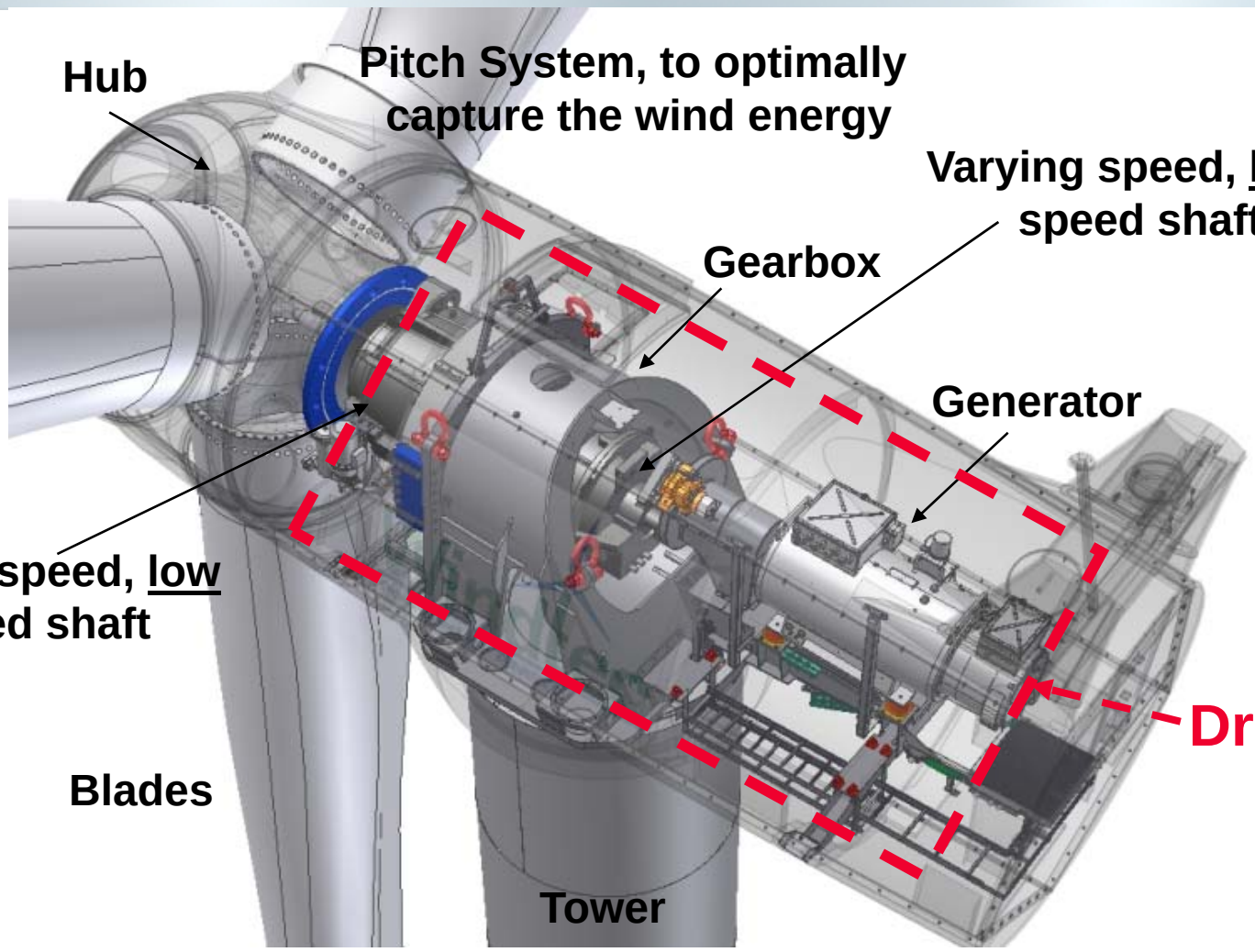
Daniel McGahn – Senior Vice President

Powered by AMSC®

AGENDA

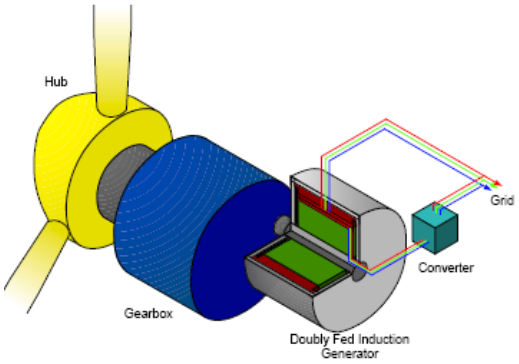
- Wind turbine power conversion
- Drivetrain evolution
- Market Driver: Cost of Electricity
- Superconductor Generators

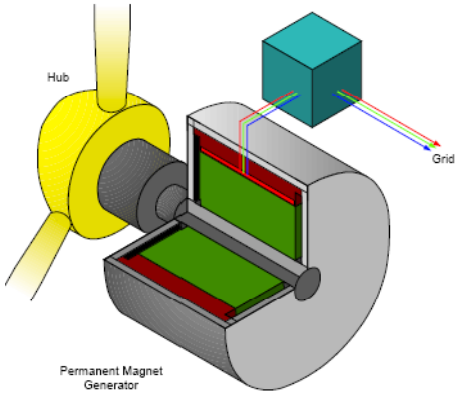
Wind Turbines: "Wind Energy Converters" Classical Turbine

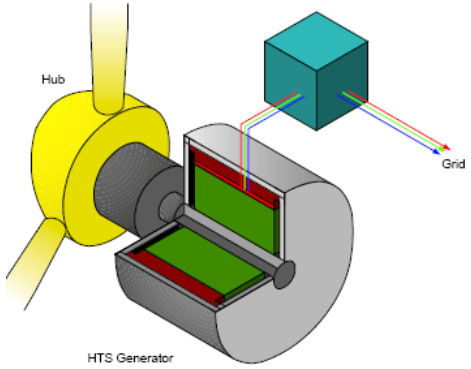


From Variable Wind Power to Mechanical Varying Speed to Fixed Frequency Electrical Power to the Grid

Drive Train Comparison





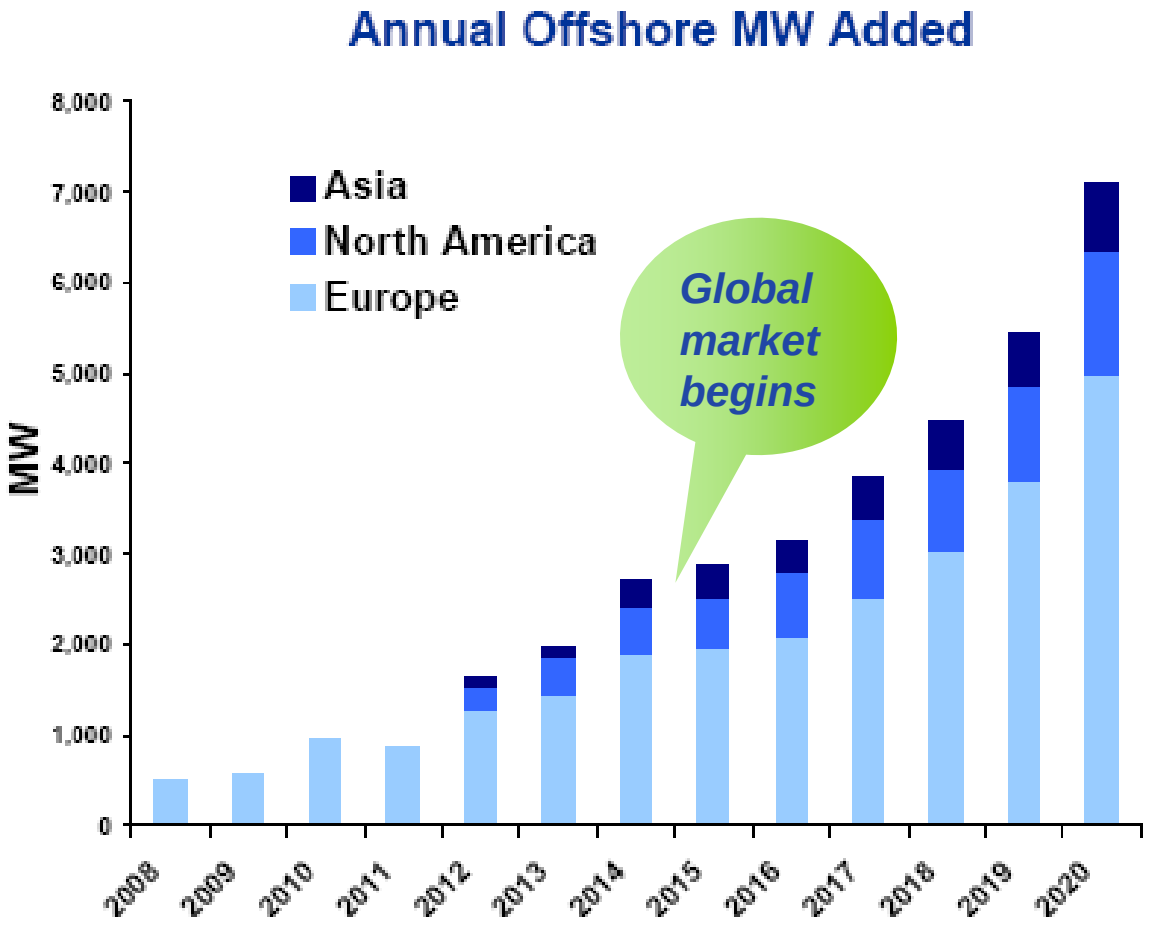


	Doubly Fed Induction (Geared)	Full Conversion PM (Geared or no Gear)	Full Conversion HTS (Direct Drive)
History:	~1990	~2000	~2010
Usage:	1.5 to 3MW	2 to 4MW	5 to +10MW
Benefits:	Low Cost Mature Technology	Good Power Quality, possibility of no gear	Great power quality, efficient at all loads, small, light, no gear
Drawback:	Poor Power Quality, Gear Failures	Large/Heavy - difficult to transport	In Development
Cost Energy*:	1.0	.9	.8

*relative; onshore about 5¢/kwh, offshore about 10¢/kwh

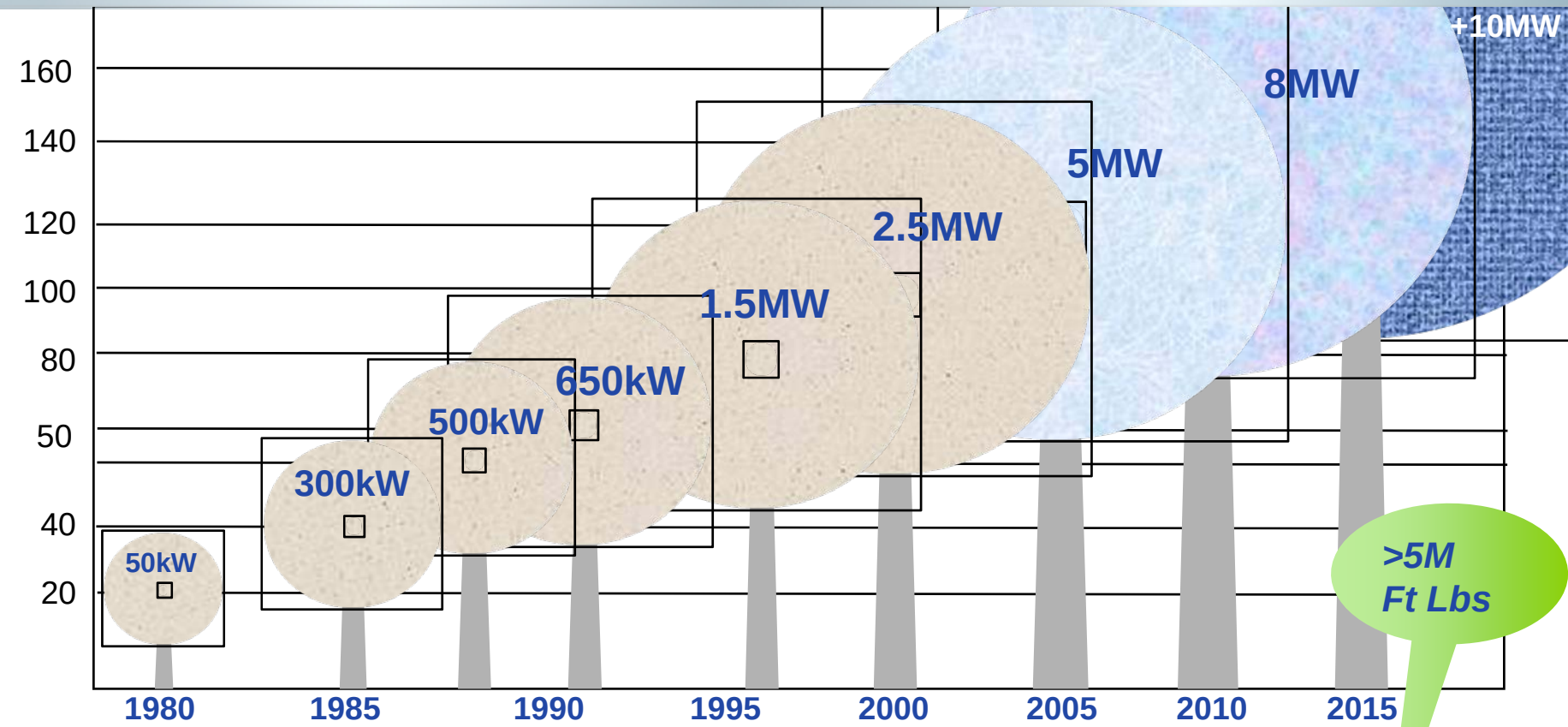
HTS Enables OffShore and Scaling Enables Lowest Cost of Energy

Offshore: Lowered Cost of Energy Reduction through Technology: Large HTS Direct Drive



HTS Based Direct Drive Turbines Needed to Reach Low Cost of Energy

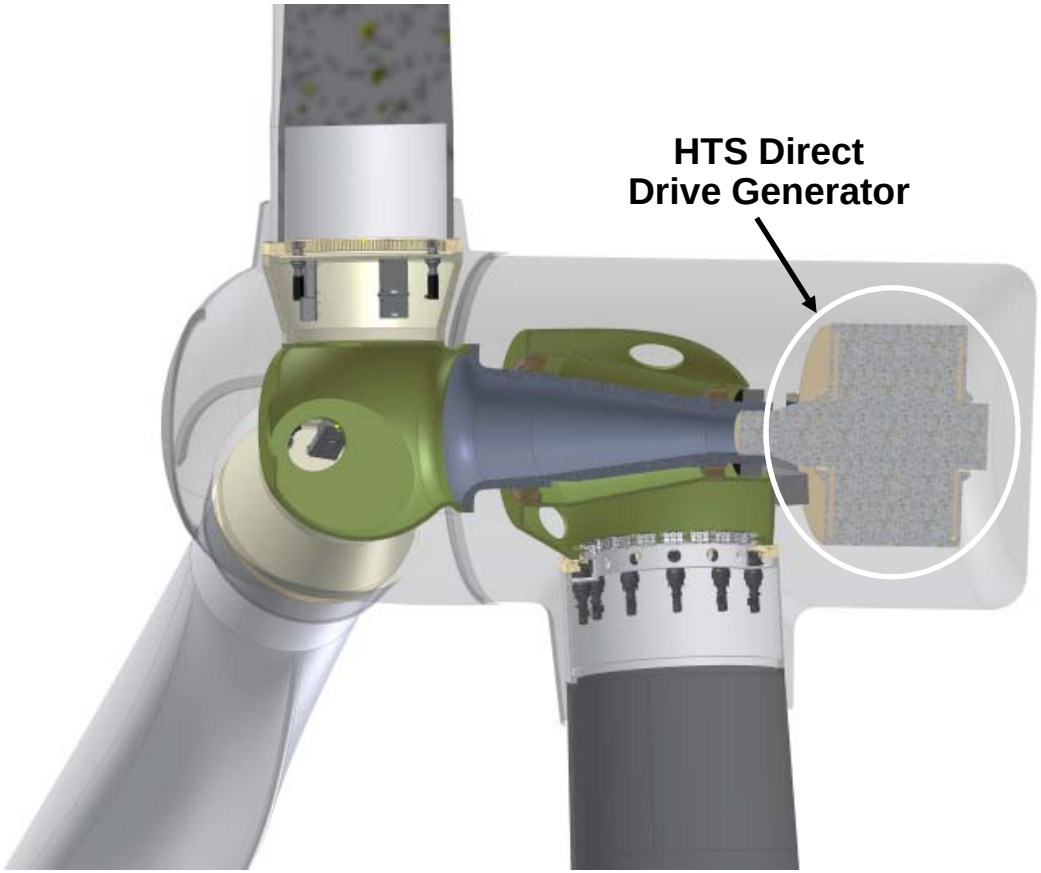
The Growth in Turbine Size is Predictable



Drive Train	Induction	DFIG	DFIG	DFIG	Full Conv.	PM	FC HTS
Tower Height (m)	60	70	75	80	100	120	140
Torque Produced (ft-lb)	19k	124K	218K	754K	353K	2932K	5118K
Top Weight (Metric Tons)	50	100		200		400	450

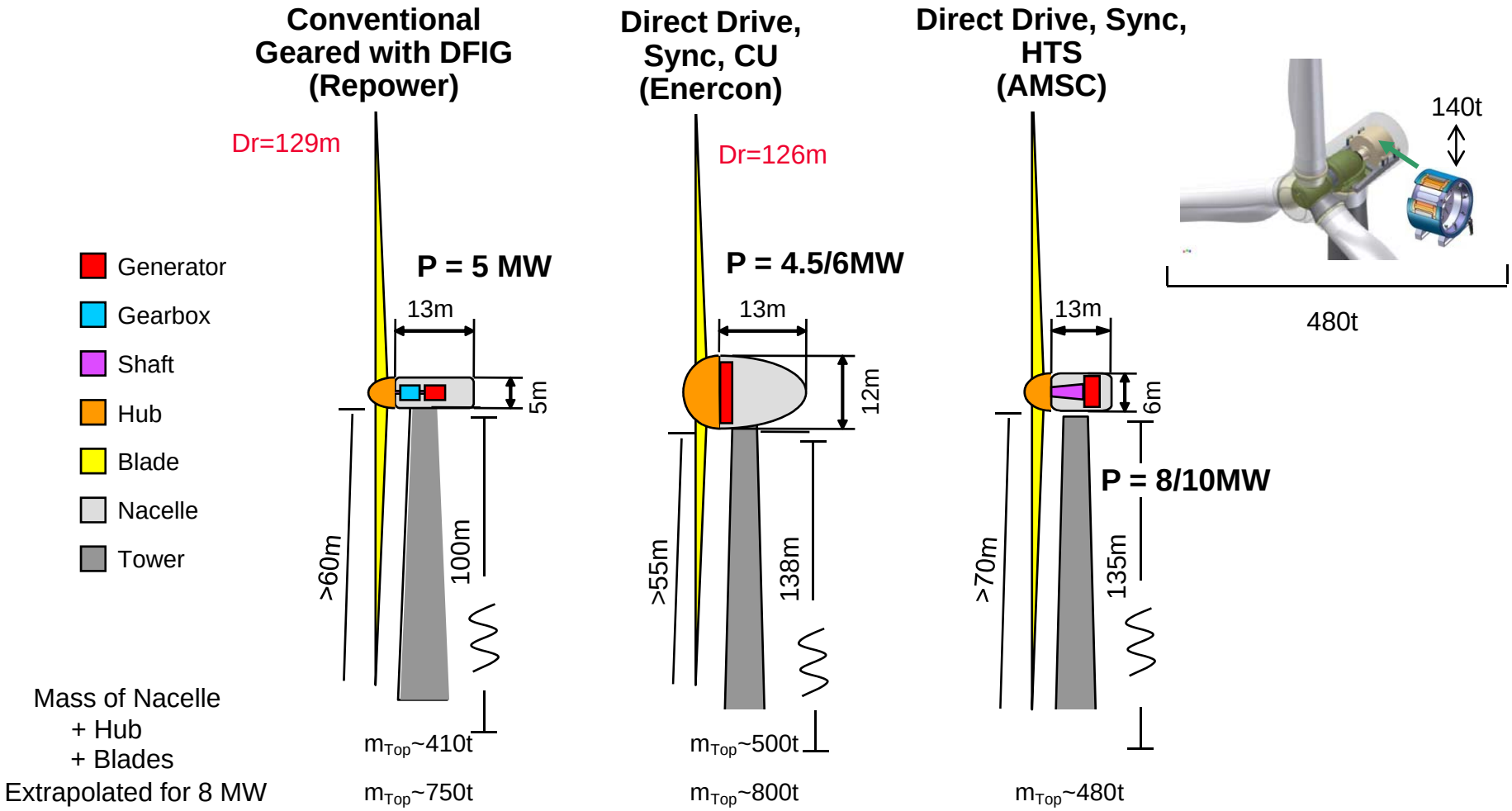
HTS Enables Large Turbines, Nothing else can Convert the Torque to Power

Performance and Profitability Solution: Direct Drive Superconductor Wind Turbines



Superconductor wind generators are a key enabler of 10 MW-class wind turbines

10 MW Class, Direct Drive HTS Wind Turbine Size Comparison



Power density of HTS generators allows for 8/10MW in a 5MW top head weight

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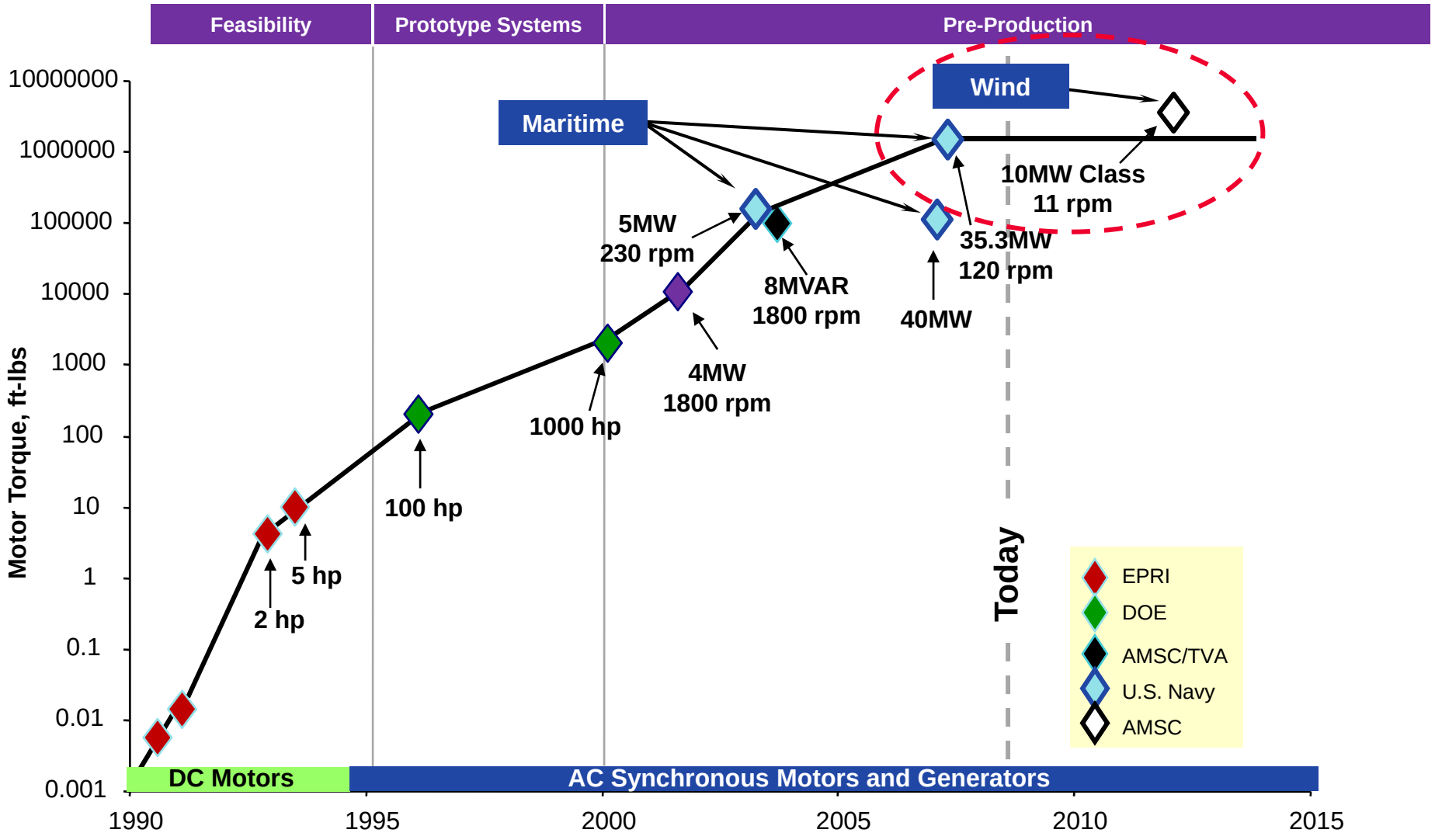
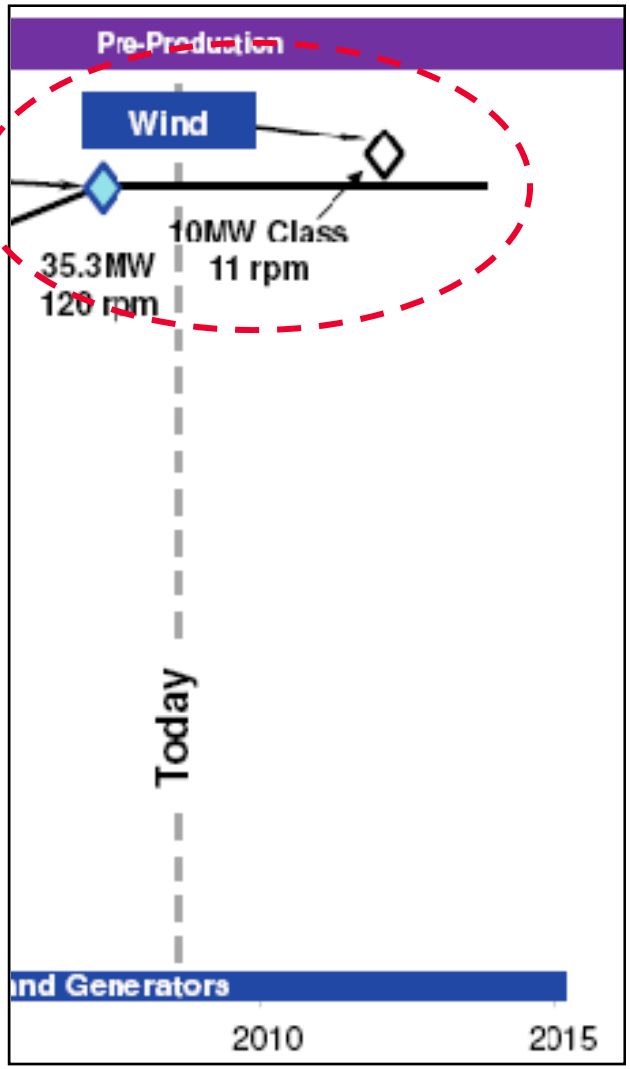
AMSC's HTS Machine Development History



Over 18 years of HTS machine development has validated HTS benefits…
New opportunity emerging with large scale wind generation

Partners for The Development of the HTS Wind Generator



PARTNERS

American Superconductor®

TECO

NIST

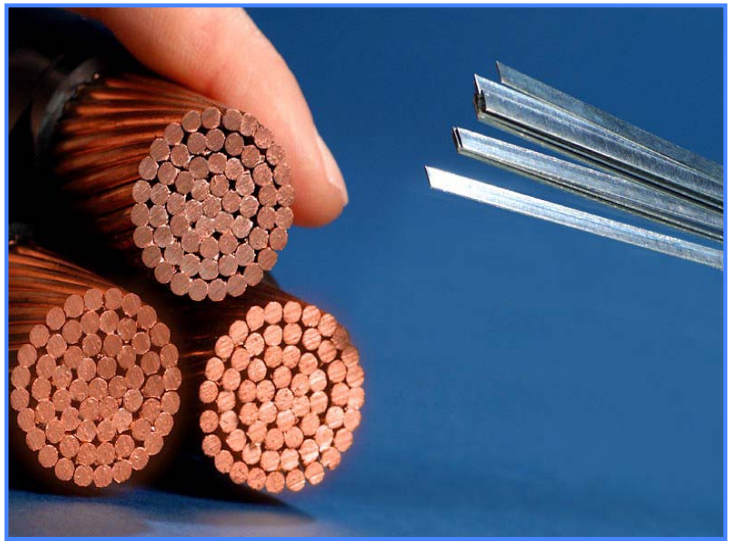
ADVANCED TECHNOLOGY PROGRAM

U.S. DEPARTMENT OF ENERGY

NREL

Superconductor Facts: Wind Turbine Generators

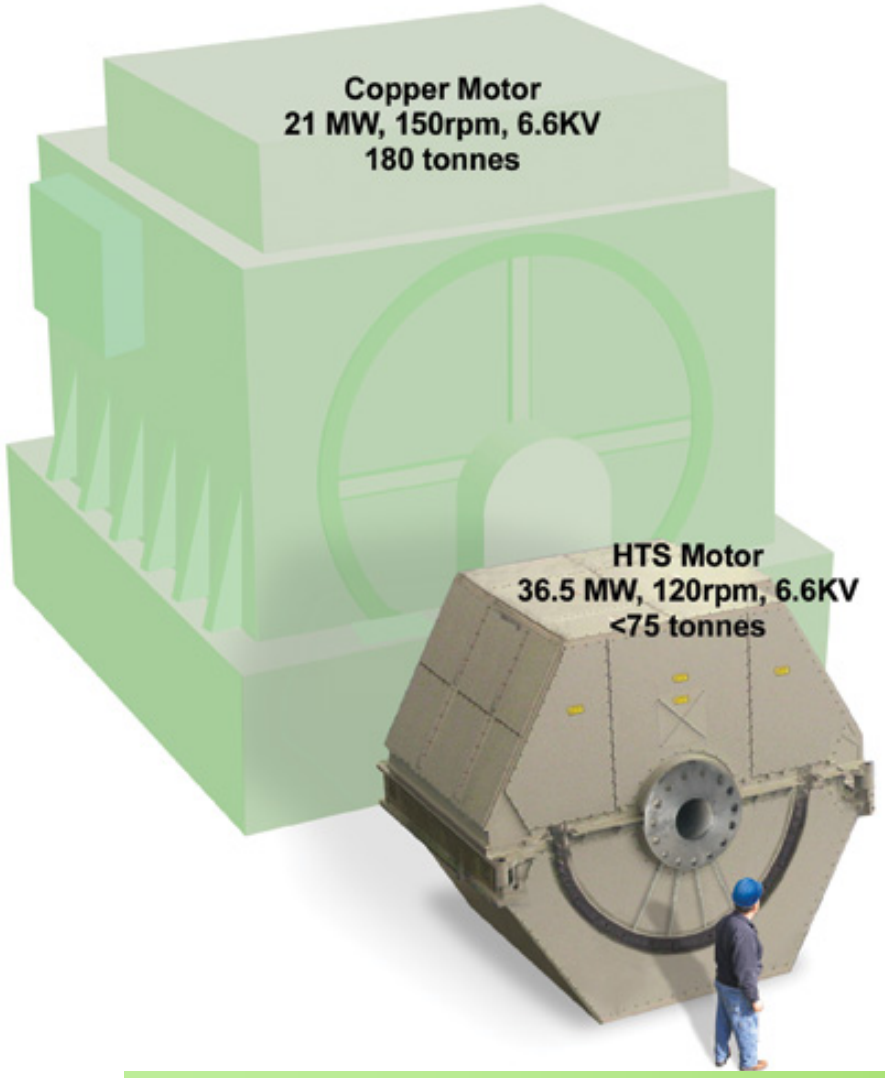
- **Zero DC electrical resistance**
- **Metallic superconductors were discovered in 1911**
  - **Require cooling to 4K; Hospital MRIs are the best example**
- **Ceramic High temperature Superconductors (HTS) were discovered by IBM in 1986**
  - **Much higher temperature**
  - **Less cooling required, enables ultra low speed (10rpm), power dense, synchronous generators**
- **Over 100 times more power than copper wire of the same dimensions**



Power density allows efficient, maintenance free, direct drive generators

Revolutionizing the wind turbine generator industry

Superconductor Synchronous Machines: HTS Compared to Copper



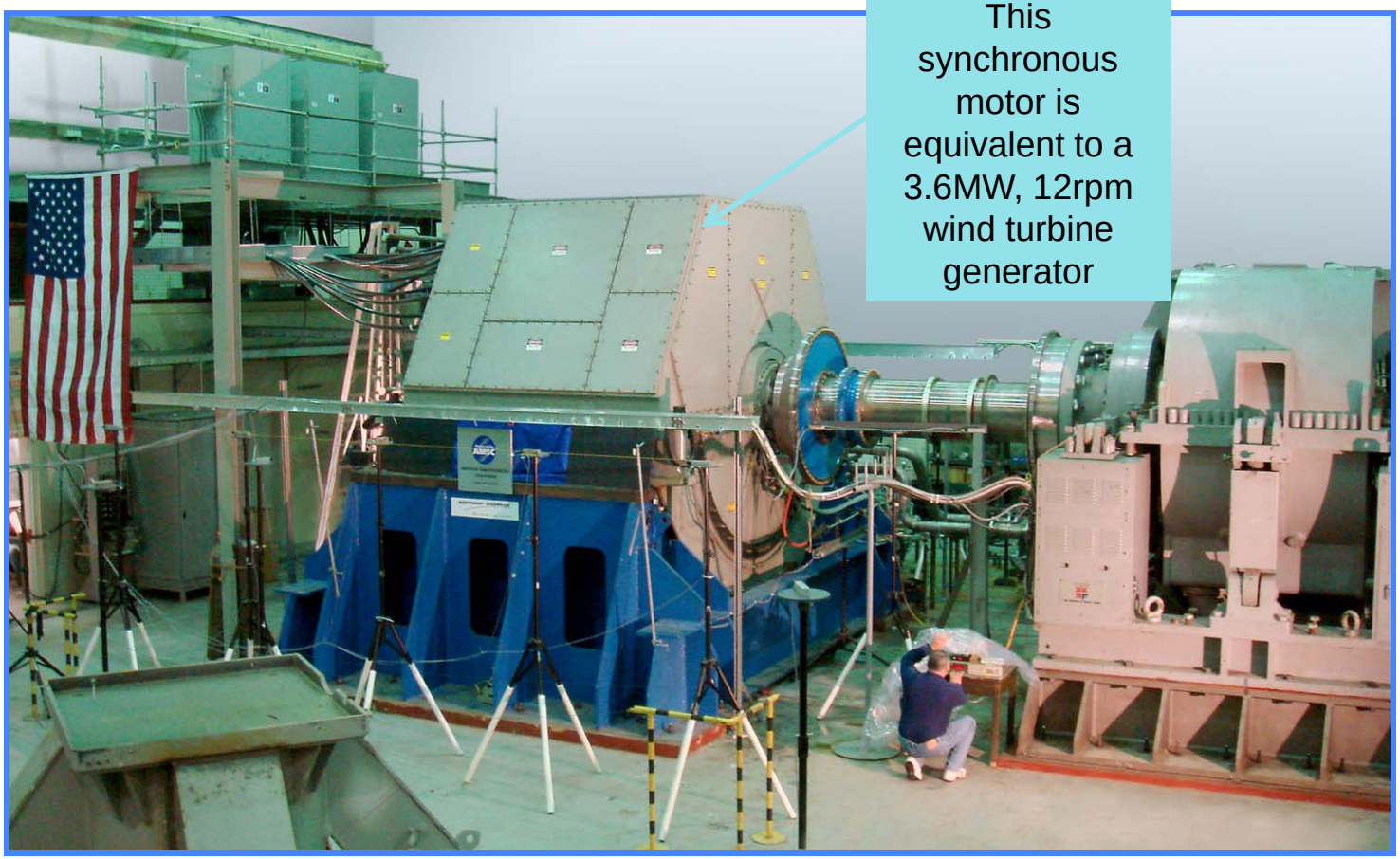
- **Less than half the size**
- **Less than a third the weight**
- **High Efficiency**
- **Controllable field**
- **Low noise**

HTS enables slow speed machines with very high field synchronous rotor without iron

5MW, 230RPM
HTS POD Motor, Powered by AMSC

The Florida State University and the FAMU-FSU College of Engineering in cooperation with the National High Magnetic Field Laboratory have established the ***Center for Advanced Power Systems (CAPS)***. Also in association with CAPS is the Electric Ship Research and Development Consortium.

36.5MW, 120rpm, Superconductor Motor



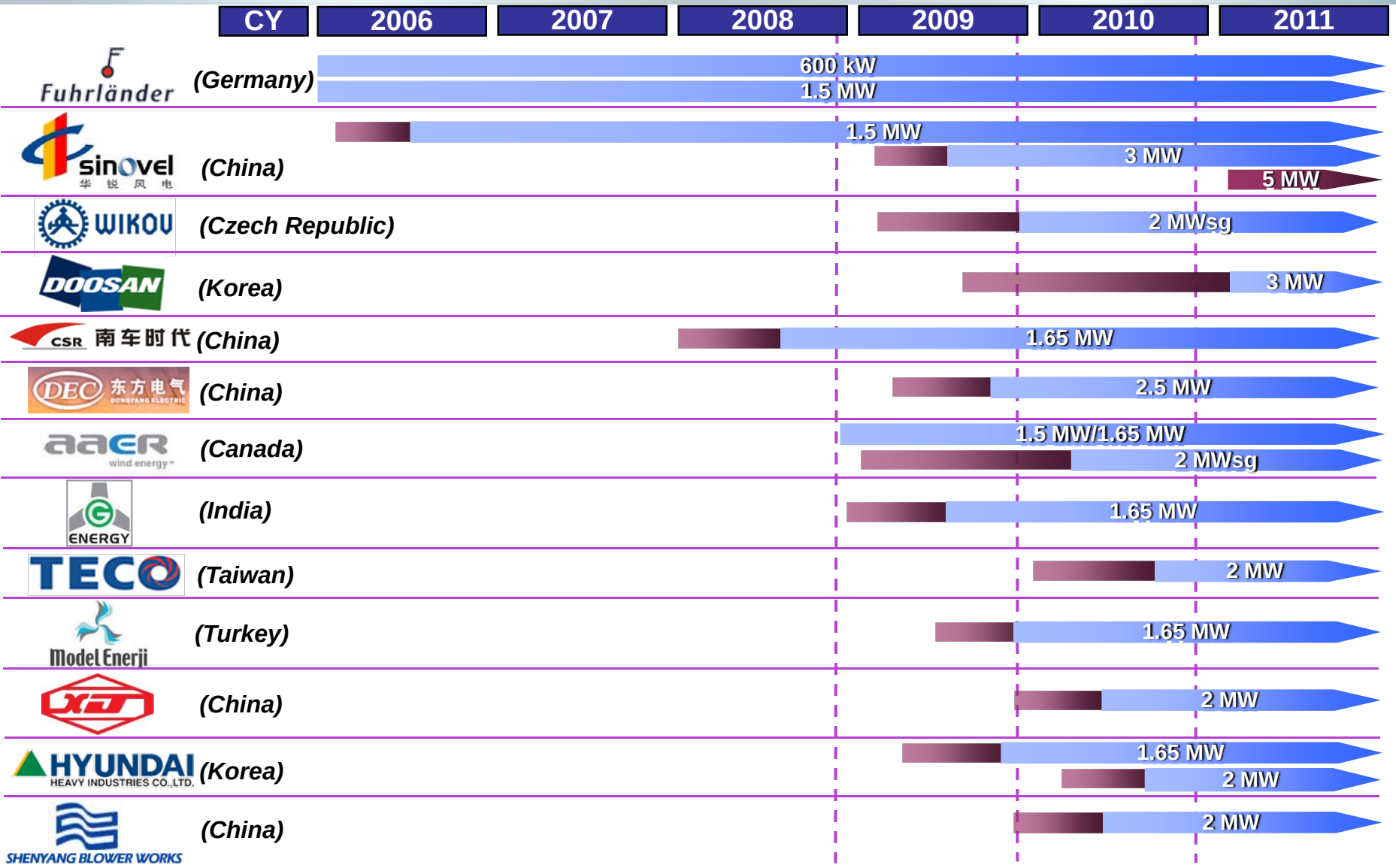
More than $150 million invested in slow-speed HTS machines at AMSC

AMSC Windtec
Approach to the Wind Energy Market

- Design and license wind turbines
- Develop customized wind turbines
- Sell turbine electrical systems
- Localization and supply chain support
- Develop superconductor wind generators

Fully engaged in all aspects of the wind "value chain"

AMSC Windtec Customer Timelines



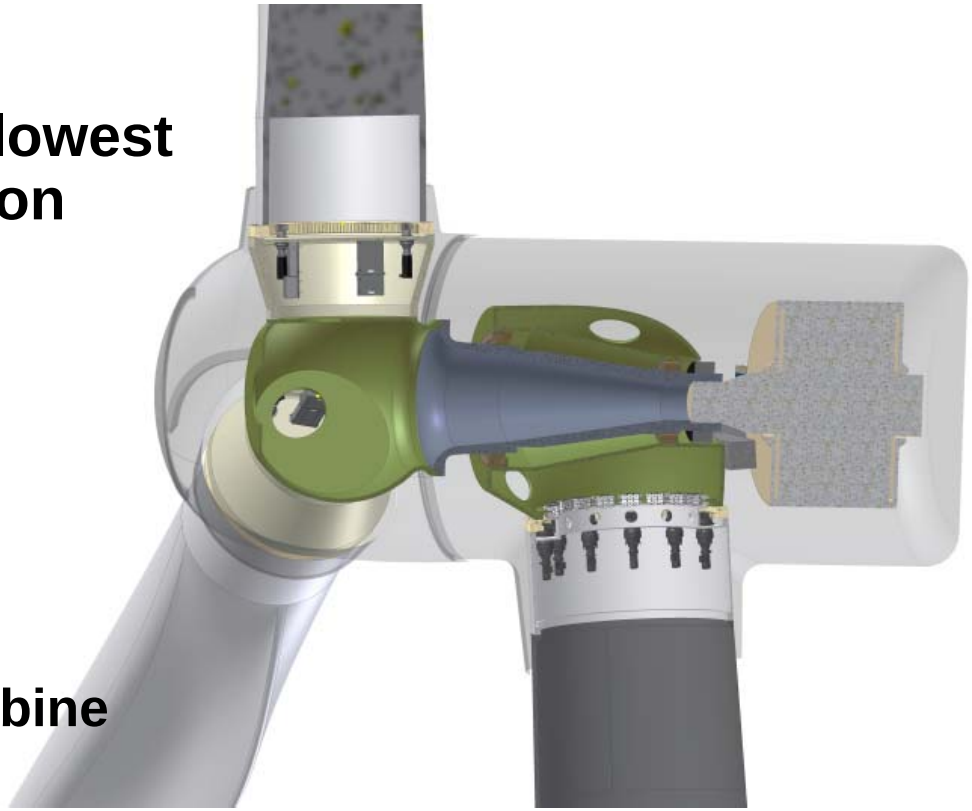
10MW Class Direct Drive Superconductor Wind Turbine

Benefits…

In a multi-turbine windfarm the lowest Cost of Energy of *any* solution

- High revenue and profit

- **Lowest installed cost:**
  - **10MW vs Multiple 5MWs or 3.6MWs or 2MWs**
- **Lowest operating cost:**
  - **Highest efficiency of any turbine**
  - **Availability exceeding 98%**
  - **Maintenance interval >2 years**



10MW Direct Drive Superconductor Wind Turbines promise highly profitable wind energy generation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