Composites in the Energy Sector

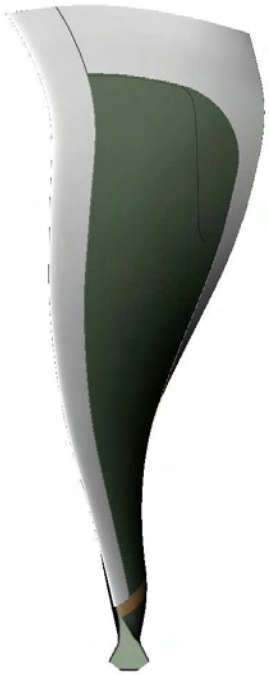
imagination at work

Scott Finn
General Electric
March 20, 2008

Some Composite Applications at GE

Propellers

Fan Case



Aircraft Engine Fan Blades

Wind Turbine Blades

Offshore Risers

McLaren Chassis

Military Engine Components

Nacelles

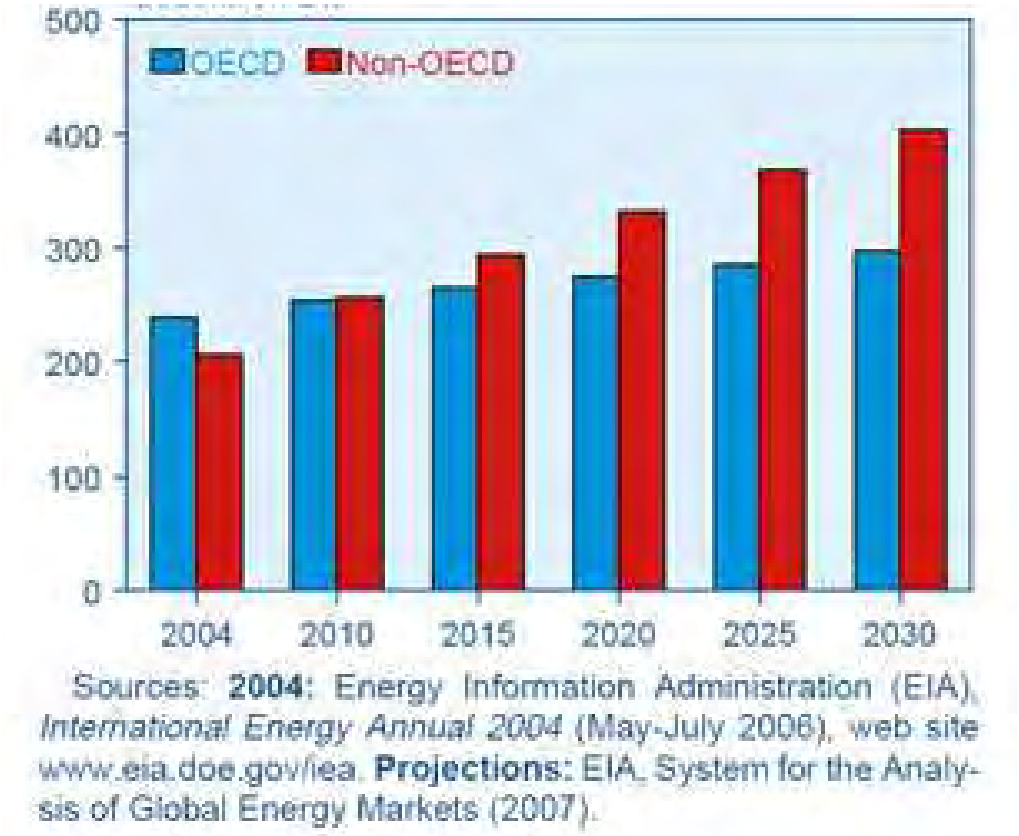
Thrust Reversers

Aircraft Components

MRI System Components

Projected World Energy Use

Energy Consumption (quadrillion BTU)

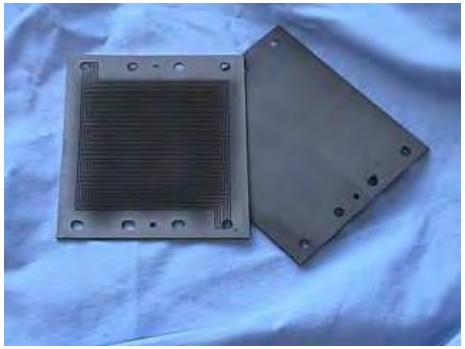


Sources: **2004:** Energy Information Administration (EIA), *International Energy Annual 2004* (May-July 2006), web site www.eia.doe.gov/iea. **Projections:** EIA, System for the Analysis of Global Energy Markets (2007).

Steady growth in already developed countries
Rapid growth in developing countries

Energy Sector Composite Products

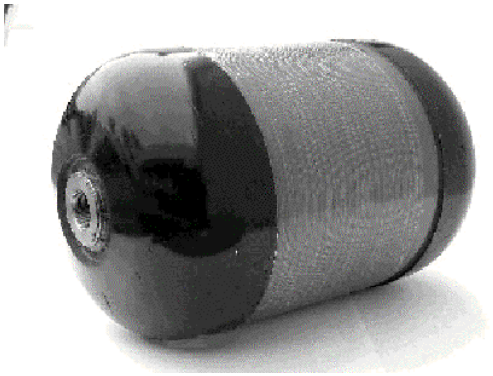
Flywheels



Fuel Cell
Bipolar Plates

Wind Turbine Blades

Marine Oil Risers



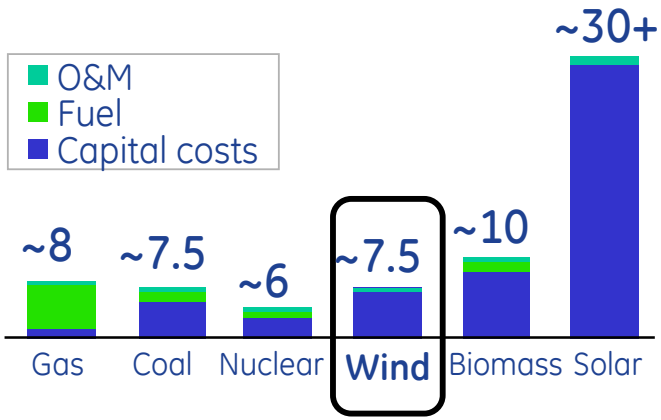
Fuel Storage

Wind Technology

Wind Energy Market

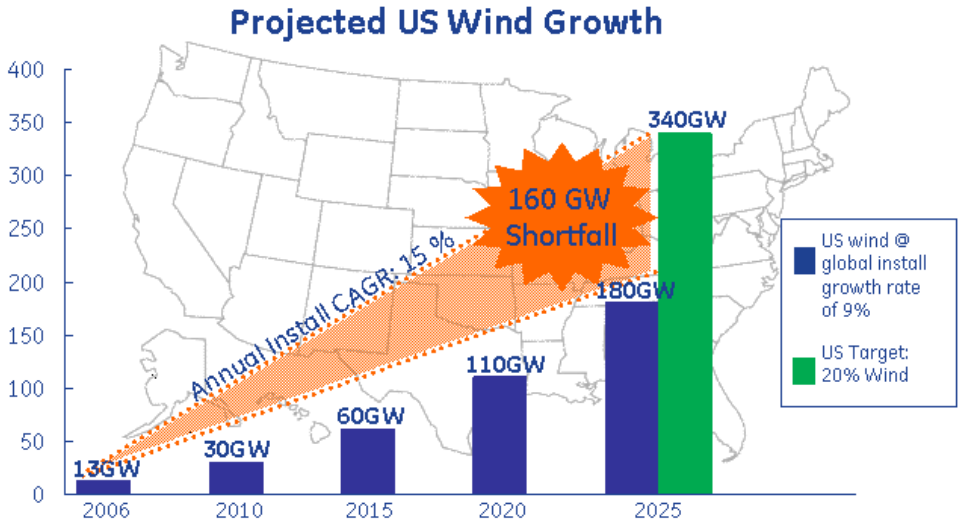
Cost of Electricity

¢ per kWhr



high capital costs puts premium on inexpensive materials and manufacturing

Forecast



- **Capacity Growth Needed:**

	2006	2025
• Wind Turbines	~2,500	~30,000
• **Wind Blades**	**~7,500**	**~90,000**

Wind Turbine Blades

ecomagination℠
a GE commitment

Key Facts

- Wind energy is greatly expanding market
  - 2006 US installed capacity 2400 MW
  - 2007 US installed capacity 4000 MW
  - Since 2004, 500% increase in GE turbine production
- GE is major supplier of turbines – over 8400 installations & 11,300 MW capacity
- Current blades are glass-reinforced composites
- Typical Blade Lengths
  - 1.5 MW – 37 m
  - 3.6 MW ~ 50 m
- Primary need: Reduce cost of energy
  - lower manufacturing & transportation cost
  - increased energy capture

Current Standard Technology

Design

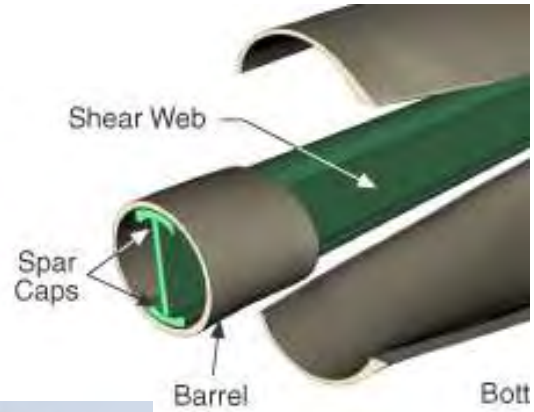
- Horizontal Axis
- Hollow Airfoil
- Semi-structural Skins
- Interior Spars Carry Most Load
- Bolted Hub Connection (e.g. barrel-nut)

Materials

- Glass fiber (limited carbon use)
- Epoxy, Polyester, or Vinylester Resin
- Foam or Balsa Core

Manufacturing Process

- Vacuum Infusion – one-sided tool
- Wet Laup
- Some Prepreg
- Fabricated in Halves and Bonded (usually)



Root Connection

Manufacturing cost is major constraint

- typical as-manufactured cost is much less than 10 dollars per pound
- can't sacrifice cost incremental cost to produce energy

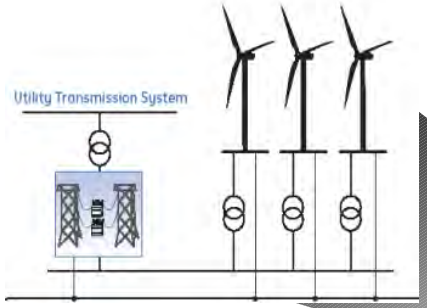
Special Design Considerations

- Loads Not Very Predictable
- High Fatigue Cycles (~1e9)
- Deflection Constraints (e.g. tower strikes)
- Noise Limitations (especially land-based)
- Prone to Lightning Strikes
- Must Be Compatible with Low Cost Manufacturing

People notice when something goes wrong

Capture the Wind Energy…

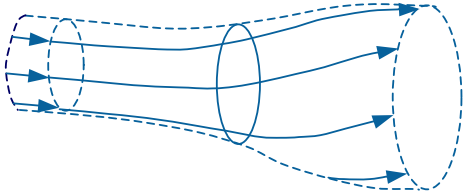
Energy Conversion

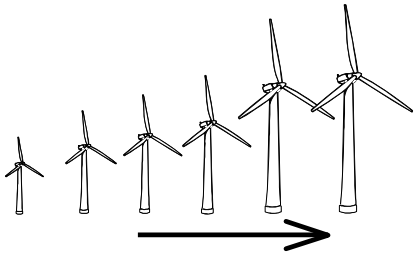


Technology to increase energy capture at the right COE

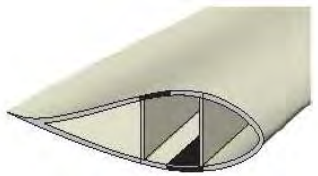
Light & Compact Drive-train

Energy Capture…Blades





Optimized Blades



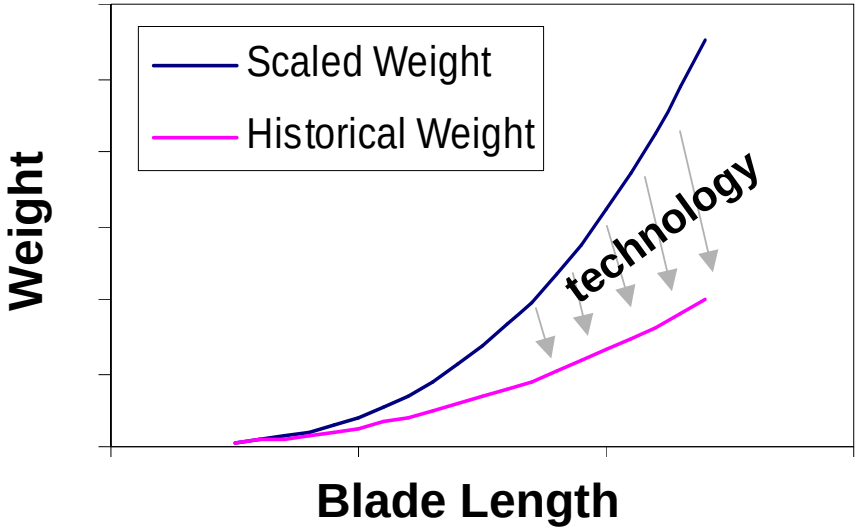
Control System

Support Structures

Blade Size – Factors Restricting Growth

Captured Power Increases with Square of Blade Length

Weight



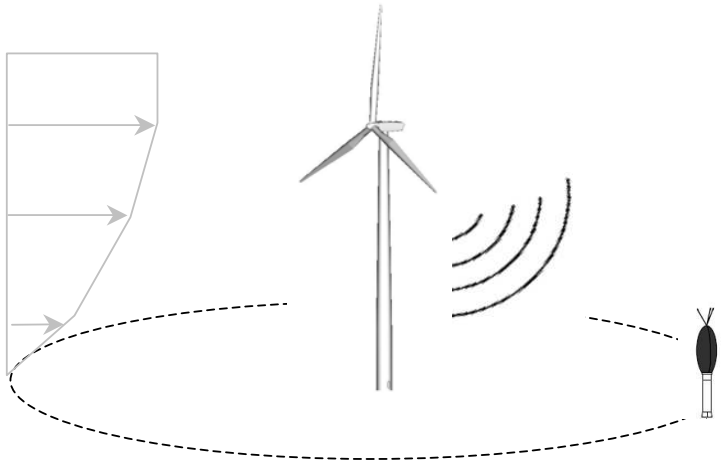
- New technology has been needed to allow growth in blade size without excessive weight
- Typical technological advances:
  - better materials
  - better designs
  - better manufacturing processes

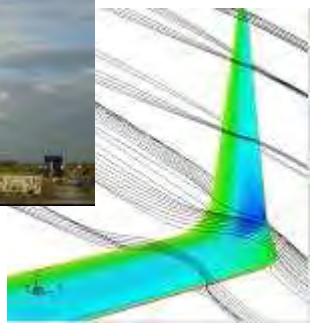
Industry has been looking at selective use of carbon, but cost/weight benefit still unclear

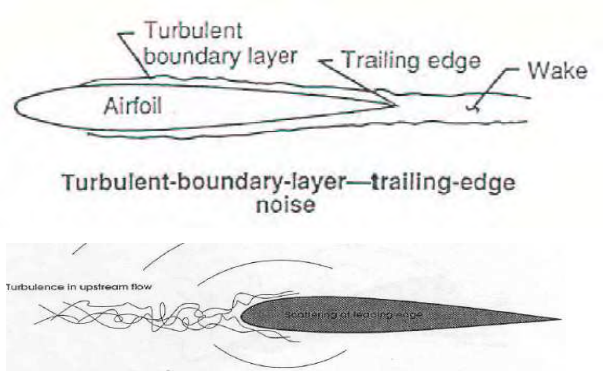
Transportation

- Current blade sizes becoming very difficult to transport – especially by road
  - chord widths particularly limiting
- Offshore still a small percentage of total
- Possible solutions
  - Multi-piece blades assembled at site
  - On-site or near-site manufacturing
  - Innovative transportation

Dance with the Wind Energy…

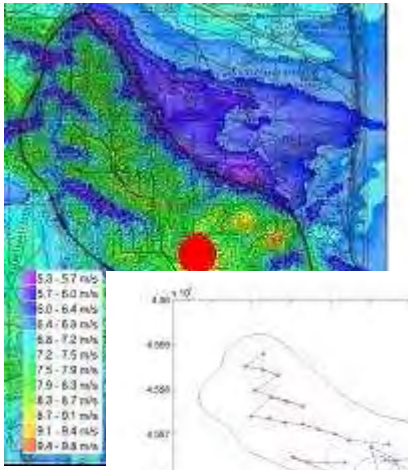


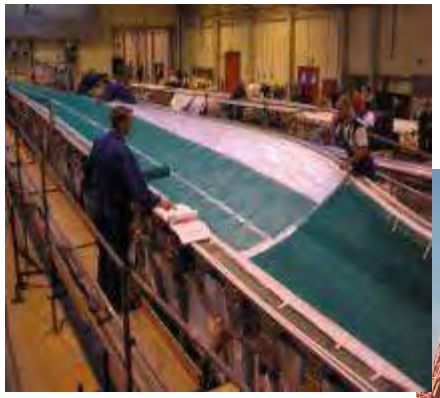


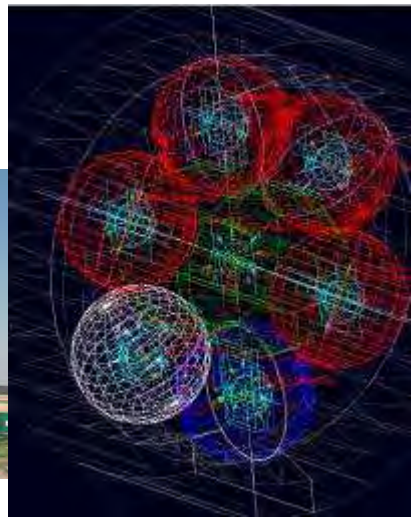


Create new airfoils to balance noise and performance

Reach the Wind Energy…

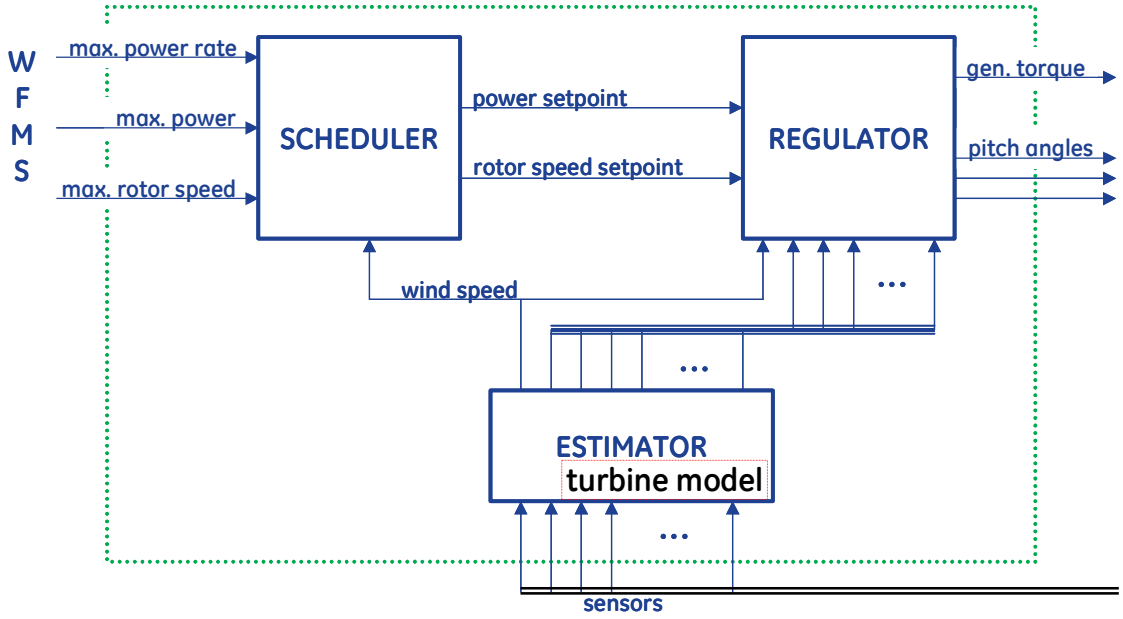


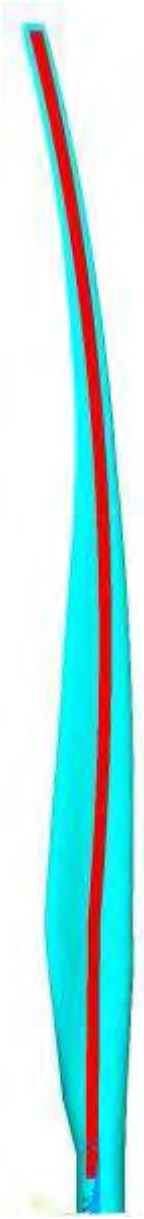




Technology to deliver turbines where they want to be

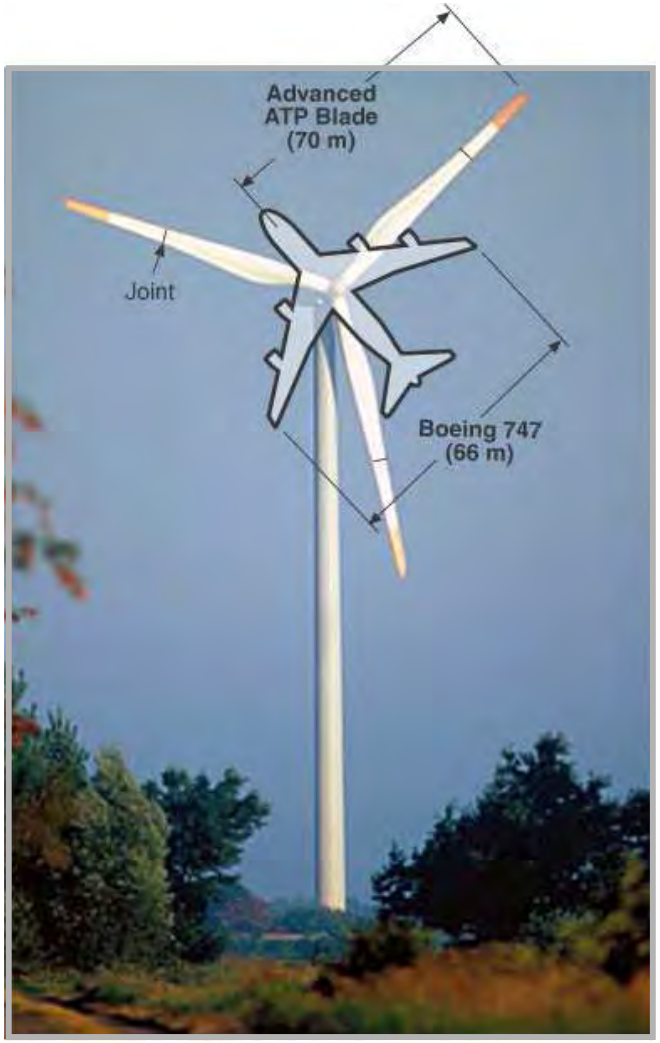
Negotiate with the Wind Energy…





- **Business objectives captured at the turbine le**
  - Annual energy production
  - Trade life and production rate
  - Trade noise and performance
  - Adapt to the wind, the grid to fulfill needs

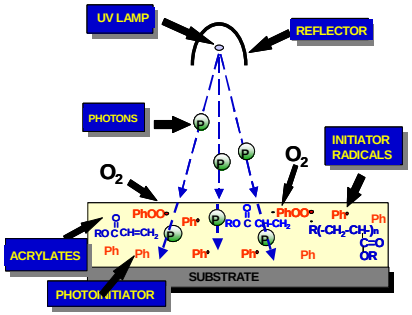
Making it happen… fast



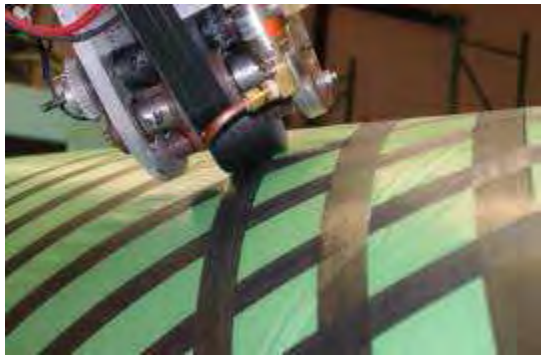
Rapid Prototyping

Cost & Cycle Time for Tooling Often Controls Development Cycle

New Materials

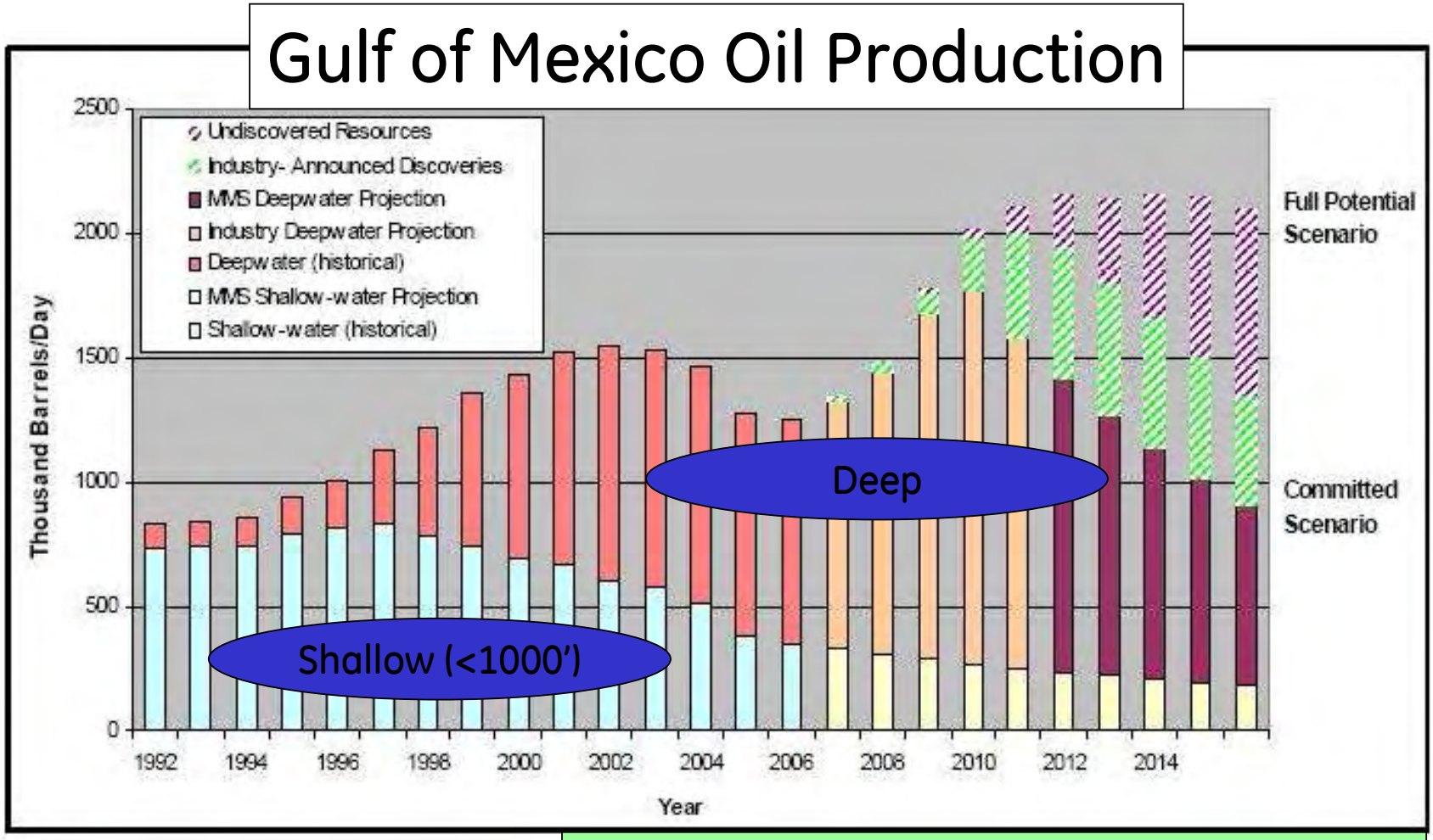


Automation



Offshore Oil & Gas

Importance of Deep Water Solutions



60% of world production is offshore

53 million bbl/day

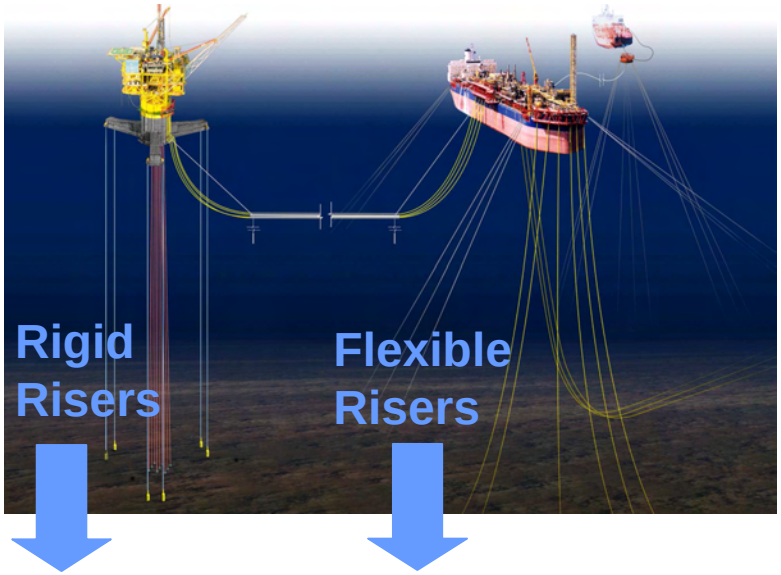
$200B annual expense

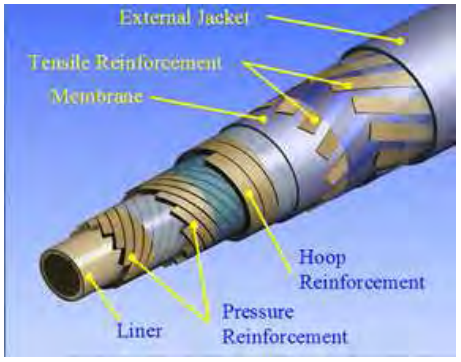
Composites for Offshore Oil

- Composites Currently Used in Subsea Installations as Protective Structures

- **Composite Rigid Risers** Have Been Subject of Numerous Development Programs
  - available offshore resources moving to deeper and deeper water
  - lighter weight could enable top-side development to depths > 10,000 ft
  - each riser segment 70-90 ft. long
  - *currently one unit in field*

- **Composite Flexible Production Risers** May be Nearing Product Introduction
  - industry standard is non-bonded, layered metallic





Fuel Cell Bipolar Plates

Function

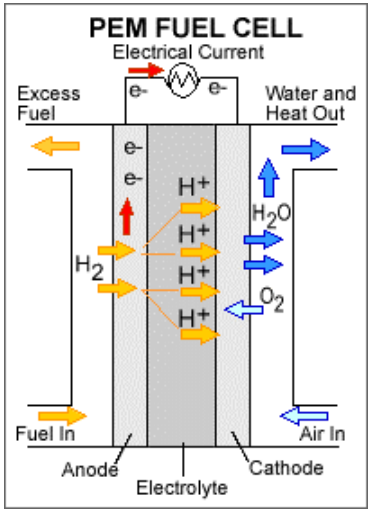
- Distribute the fuel gas and air uniformly over the active areas
- Remove heat from active area
- Conduct current from cell to cell
- Prevent leakage of gasses

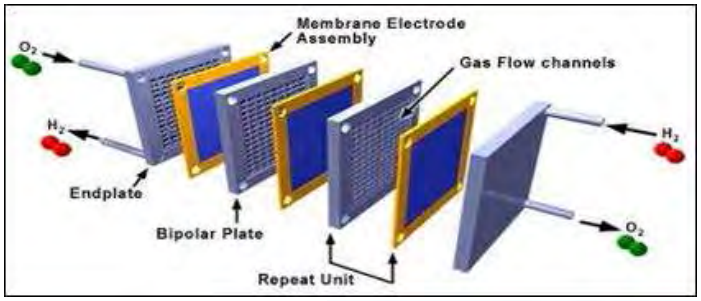
Requirements

- High electrical conductivity
- Lightweight
- Costs (plates are significant fraction of total)
- Corrosion Resistance

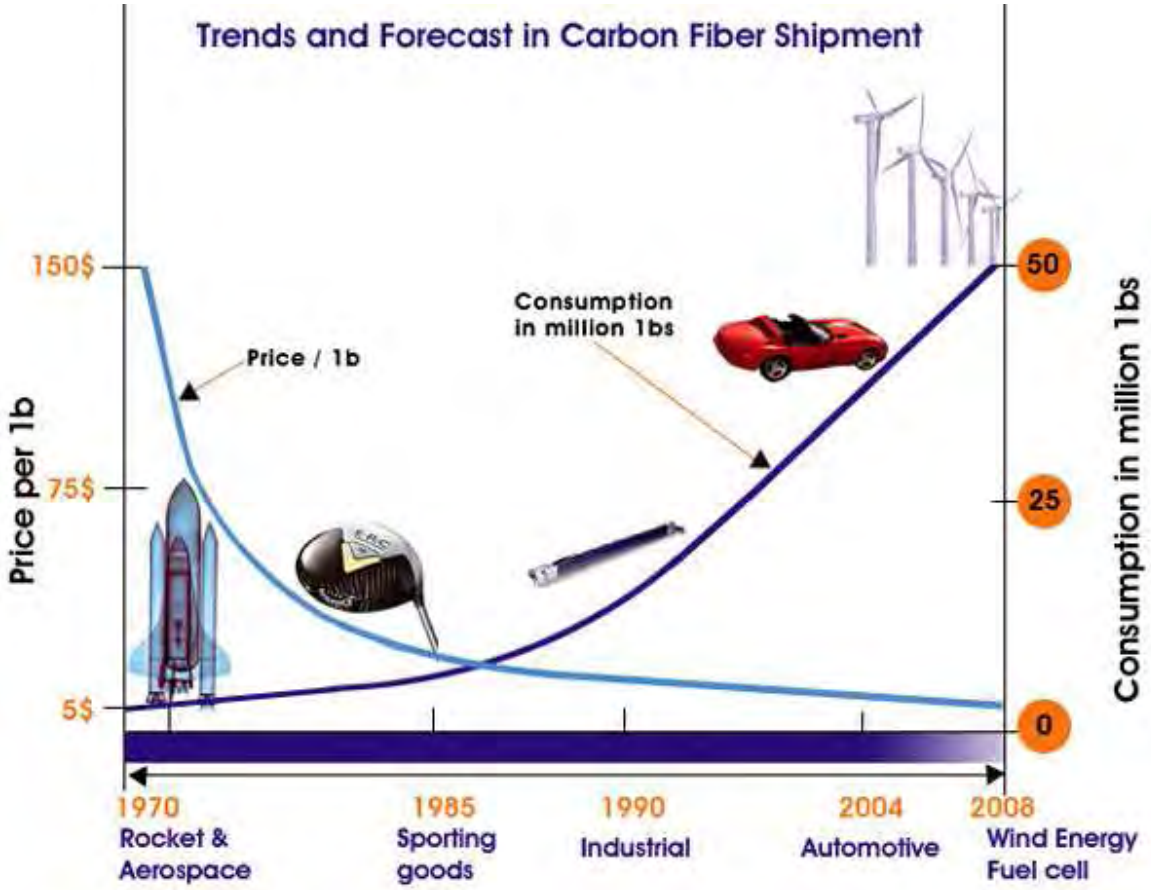
Common Materials

- Electro graphite (high cost)
- Carbon-carbon composite (high cost)
- Sheet metal (low cost; corrosion resistant varieties have high electrical contact resistance)
- Graphite foil (repeatability
- Carbon fiber reinforced composites (intermediate cost, light weight)





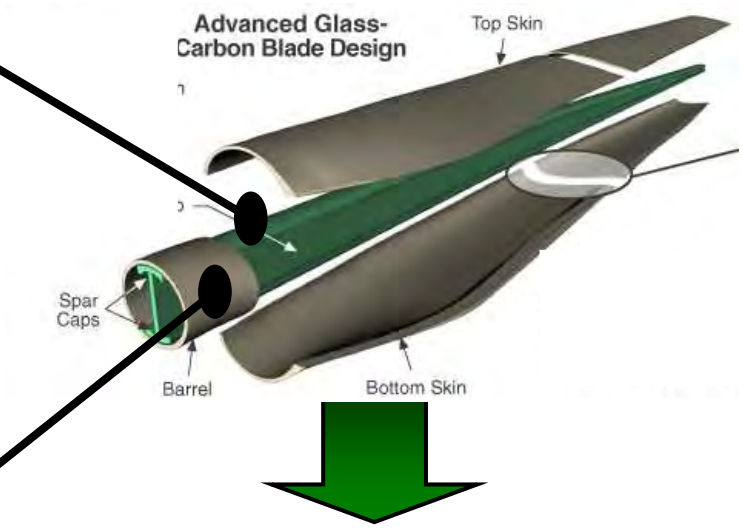
Backup



From “Growth Opportunities in the Carbon Fiber Market 2004-2010”

- Enercon (Germany)
- Gamesa (Spain)
- General Electric (USA)
- Vestas (Denmark), the world's largest manufacturer of wind turbines

Composites – Fibe-X Manufactured Wind Blades

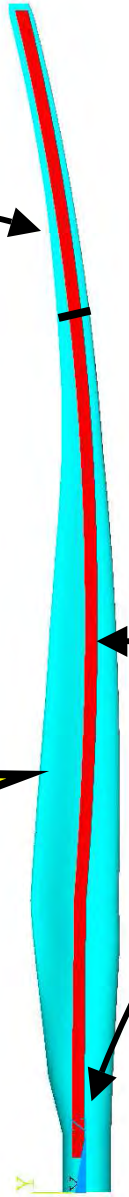


Hybrid Blade Construction (VARTM + Pre-cured Components)

Key Concepts

- Modular Construction
- Automated Manufacturing (Quality)
- Regional Manufacturing
- Dimensional Stability
- Shipping & Handling
- Cost Control

Next Generation Wind Blade



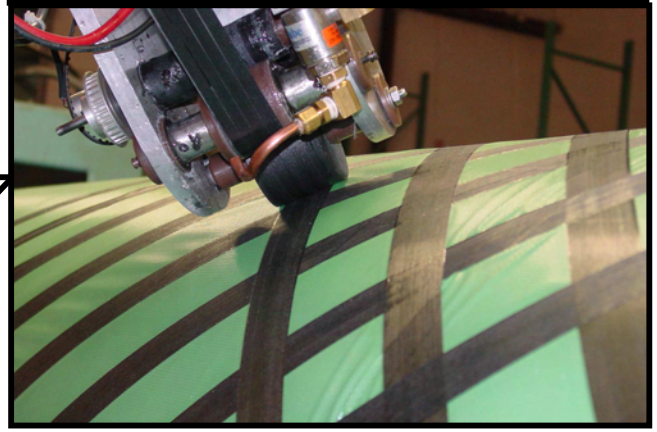
17 Tons

6-Megawatt Turbine
70-Meter Blade (25 Tons)

Design CTQ's

- High Efficiency + Low Noise
- Swept Airfoil Design
- Hybrid Carbon and Fiberglass
- Jointed Construction

Fibe-X™ Automated Manufacturing



Manufacturing

- Automated Manufacturing
- Logistics
- Low Temperature Cure Resin


WIND TURBINE FAILS
9 abc
11:07 38°