## Panel Session 6 – *"Manufacturing"*

*Presented to Attendees of:*
University of Massachusetts Lowell

# *Wind Energy Research Workshop*

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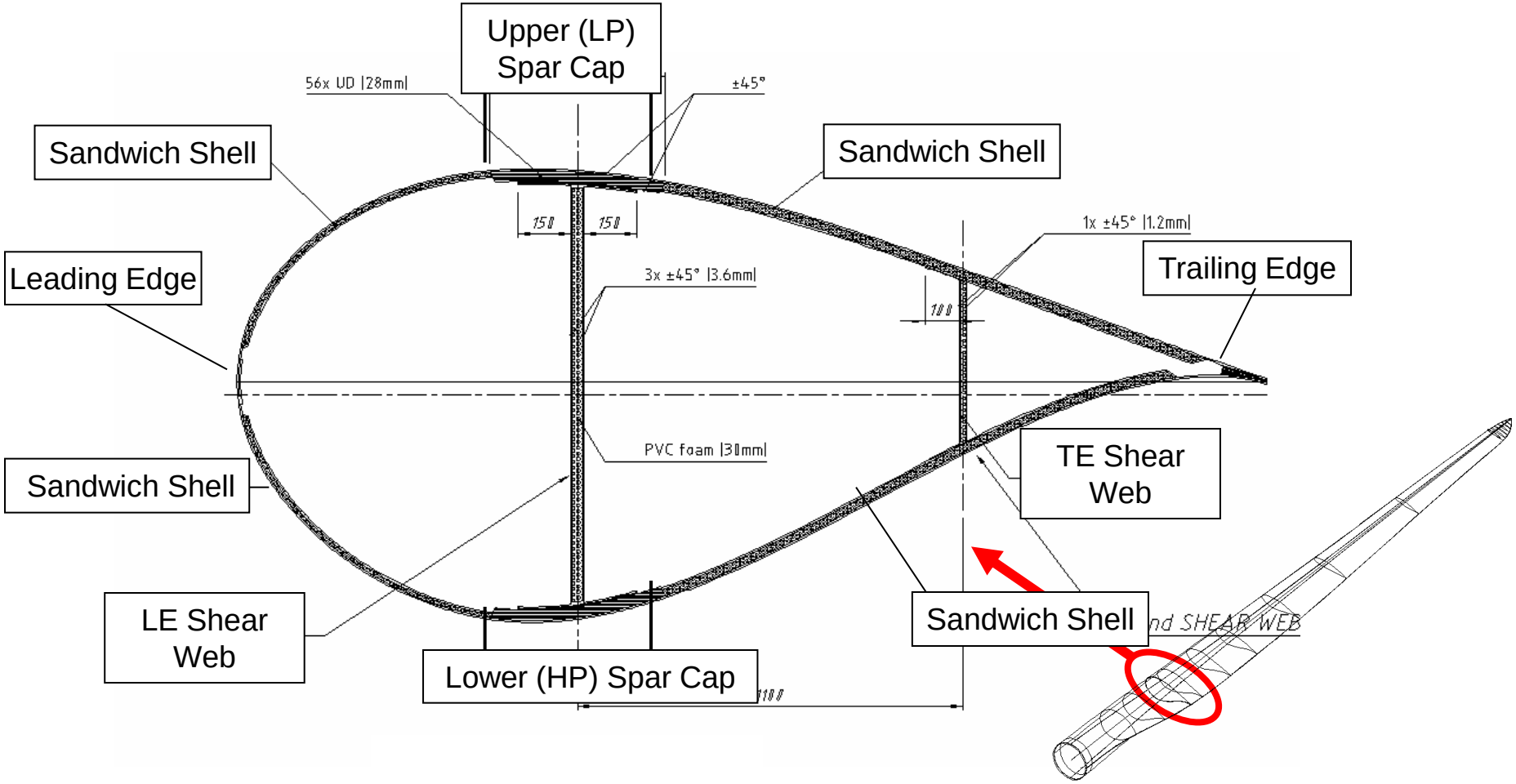
# Anatomy of a Wind Turbine Blade (near Max Chord)



# Blade Manufacturing – "What's it Take?"

- SPACE! - Physical Plant
  - Factory Space
  - Bridge Cranes/Heavy Lifting
  - Significant Consideration of Layout/Process Flow
    - Large Molding/Assembly Operations
    - Small Parts
    - Finishing Operations
    - Material Flow thru Plant

- Infrastructure
  - Systems
    - Resin Storage/Plumbing for delivery
    - Vacuum Lines/Compressed Air
    - Cure Ovens (if required)
    - Finishing Operations/Dust Control
    - Root Drill/Trim
    - Automation Equipment (if used)
  - Tooling/Assembly Fixtures
    - Heated vs. Ambient Cure Tools
    - Skin Molds
    - Shear Webs
    - Small Parts
      - Spar Caps, Root Preforms, balance boxes, etc.

# Blade Production Requires PEOPLE

- Materials & Materials Engineering
- Structural Design
- Process/Tool Engineering
- Quality Systems/Engineering
- Sensor Development and Technologies to Positively Impact R&M
  - NDI
  - Health Monitoring
  - Control/Load Mitigation
- Transportation/Logistics

# Automation for Blade Production – What's Coming up for AMII

# Automation of Blade Fabrication


- Automation of aerospace composite manufacturing is virtually routine with hundreds of prepreg tape machines operating across the globe.

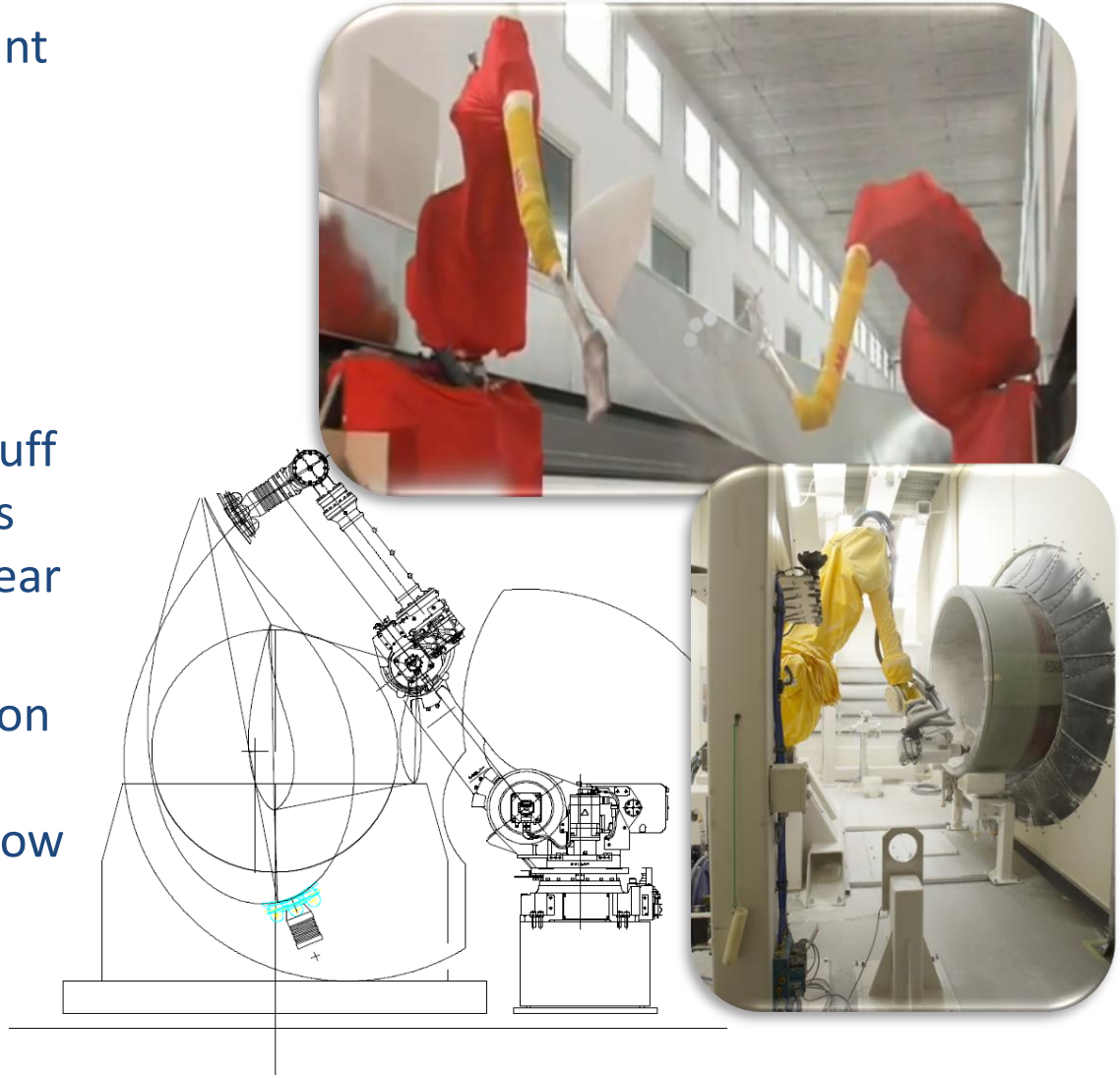
- Turbine blade manufacturing consists of a labor intensive set of highly distributed manual operations.
- From pattern cutting for material kits to layup to infusion and demolding of a multiplicity of sub assemblies over a vast area and distance, automation is a challenging and expensive endeavor.
- Return on CAPEX is rapid for structures with cost of finished goods from $200 to $700/lb as opposed to $5.00 to $10.00/lb required for the energy markets.

# Automation of Blade Fabrication

- Automation is at work in blade factories today:
  - Use of x-y ply cutting for material kits, automated ply nesting software, pick and place automation.
  - Limited use of material transfer systems into open molds, primarily with semi-automated or driven A-frames and gantries
  - Automated trimming and limited machine assisted surface grinding/finishing
  - Automated root trim, machine, and drill for T-Bolt installation.
  - Robotic application of coatings.

# Automation in Blade Finishing

- Blade molding operations account for less than 50% of total labor content.
- Finishing operations offer a brilliant opportunity for cost-effective CAPEX spending.
- Compliant grinding/finishing, scuff sanding and coating applications will become ubiquitous in the near term.
- Advances in vision systems and on the floor computational power coupled with the availability of low cost multi-axis robots makes automation of many tedious processes possible.



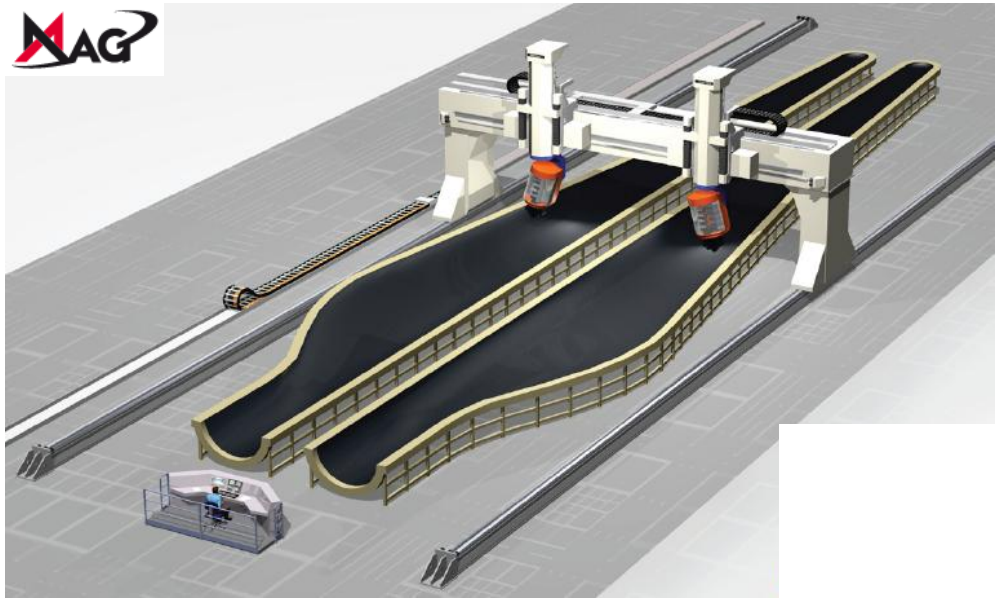
# Automation of Blade Components a First Step



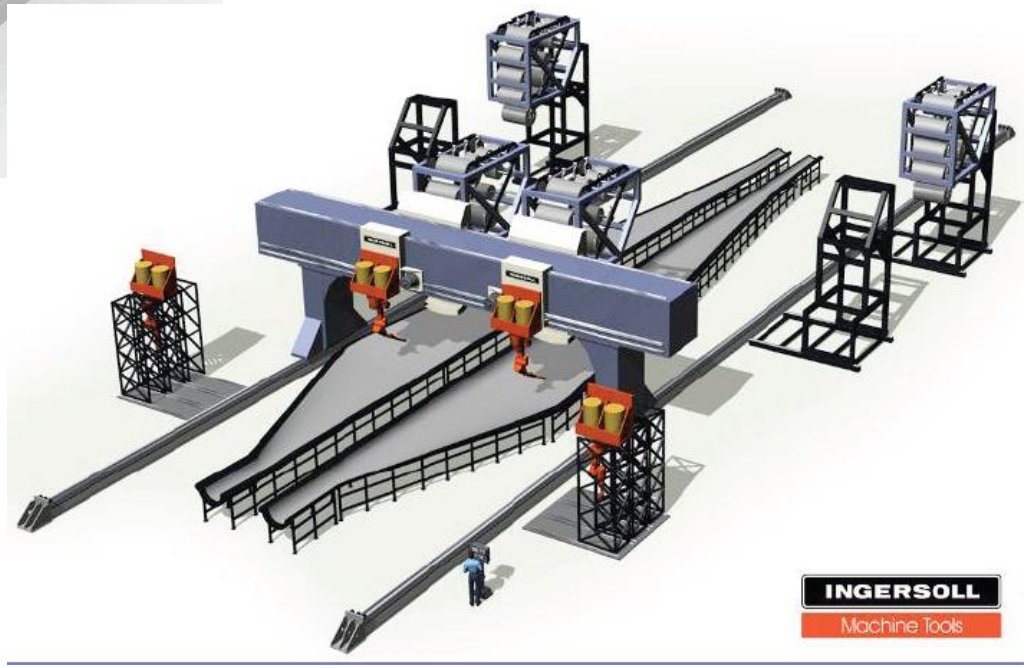
High Volume Machine for Spar Caps

- Spar Cap components are the logical first step with root preform parts a natural extension of capability.
  - Simple Geometry.
  - Uni-directional materials for lowest possible cost of prepreg/tow preg materials.
  - "Steerable" for curvilinear spar caps in swept blade design.
  - Performance critical.
- Assurance by major machine manufacturers that layup rates approaching 1,200 kg/hr in straight run spar caps possible

# Automation of Blade Manufacturing – Final Thoughts




- The jury is still out regarding the shape and form of future blade automation, but it is sure to come.
- Longer blades, use of carbon fiber and the need to ensure lower partial safety factors for manufacturing and material variance will expedite the drive for more automation in blade layup.

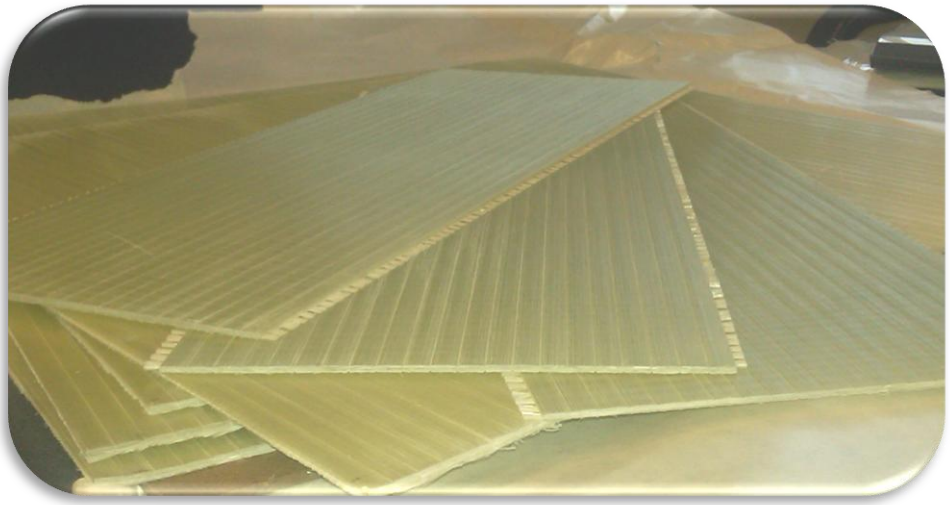


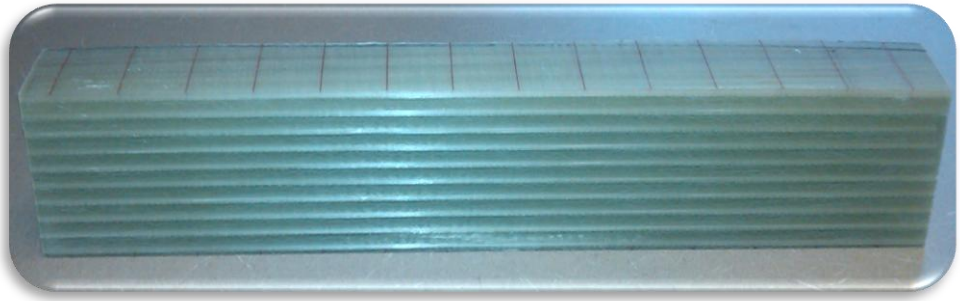

- Whether future automation is in the form of fiber/tow placement, prepreg or dry fabric robotic application, there are designs waiting in the wings.
- TPI is intimately involved in this process and helping to shape this future.


tpi
OVERSIZE LOAD

# Novel Materials for Spar Cap Assembly

- Pre-manufactured axial elements are bonded to a carrier to create a "ply-like" material for infusion.
- Used as an interleaving element in a stack of UD broad goods or as homogeneous laminating material in Spar Caps
  - Extremely high Fiber Volume Fraction
  - Eliminates potential for strength reducing waves/wrinkles
- Rapid infusion
  - Both as a "flow media"
  - And stand-alone as a homogeneous material.





In partnership with NEPTCO Incorporated — Premier Manufacturers of Tapes & Composites

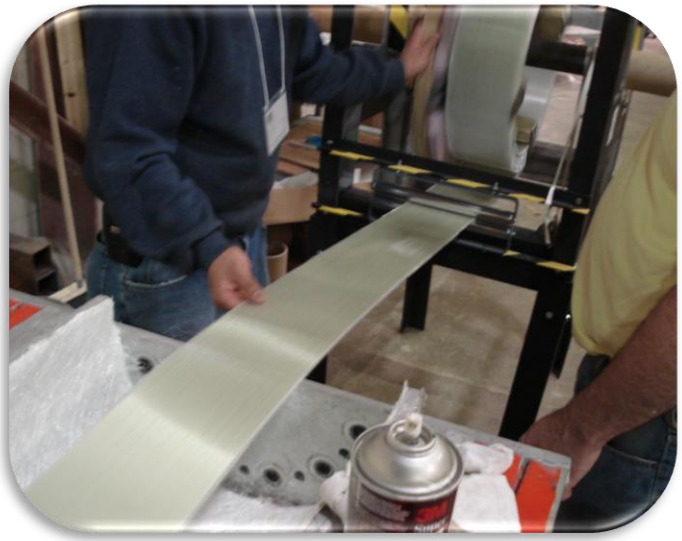
# …with Rather Amazing Properties

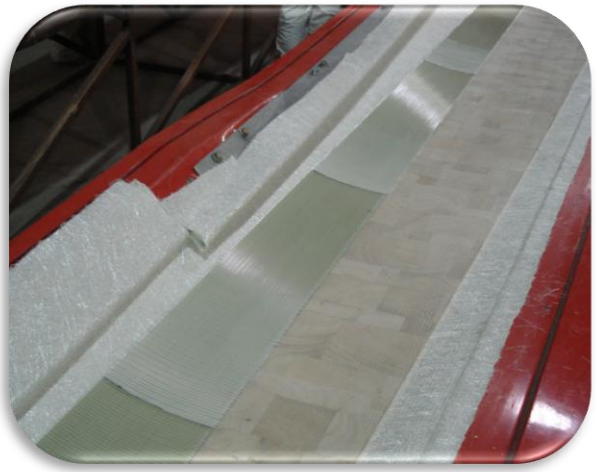
- Ultimate compressive strains of 2%.
- Ultimate tensile strains approaching theoretical limit of glass fiber.
- 45% higher design values for strength and 25% higher for modulus.
- Extremely low variance in results.

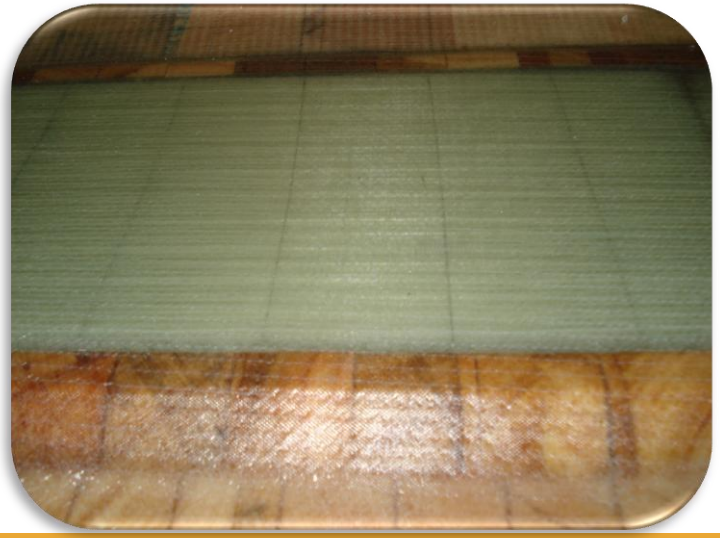

| Test Description | Mean Ult Strength (MPa) | Std Dev % | LCL (MPa) | Mean Max Strain (mm x $10^{-6}$) | Mean Modulus (MPa) | Std Dev % |
|---|---|---|---|---|---|---|
| Axial Tension (UD NCF) | 919 | 4.10% | 837 | 24,158 | 40,650 | 2.60% |
| Axial Tension (Pre-Manuf Elements) | 1,319 | 2.90% | 1,236 | 27,912 | 49,910 | 0.70% |
| Axial Compression (UD NCF) | 694 | 8.40% | 567 | 18,532 | 39,940 | 2.30% |
| Axial Compression (Pre-Manuf Elements) | 967 | 2.70% | 910 | 19,831 | 50,950 | 0.80% |

# First Up: 9m Blade Manufacture

- This past month TPI and NEPTCO built the first Composite Rod Spar Cap Blade.
- 9m 100kW NPS-100 blade.
- To be tested as part of AMII program.
- Ultimate benefit will be in large scale glass/carbon applications for highest translation of material properties.







# In the Works…..

- TPI and NEPTCO has built a full-scale (of limited length) Hybrid Spar Cap.
- Layup was 30% volume fraction Rod Packs and 70% 970gsm UD Fabric.
- Fabrication to develop infusion and cure cycle time… SHORTER and more robust.
- NO MORE WAVES.