Wind Technology Area

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Institute for ADVANCED Composites Manufacturing INNOVATION

Wind Technology Area

- Wind turbine blade and turbine component manufacturing
- Material, labor, cycle time, reliability, recycling, light weighting
- Wind industry / National Labs / Universities
- Wind industry metric: LCOE

$$\text{LCOE} = \frac{\text{sum of costs over lifetime}}{\text{sum of electrical energy produced over lifetime}} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Wind turbine manufacturing

MI

Integration:
- Thermoplastics
- RTM

Automation (Viper)

IN

Models for:
- Preforming
- Infusion
- RTM
- Pultrusion
- Cure kinetics
- Performance

OH

- Automation
- Fast resin infusion and curing
- Intermediate scale

TN

- Low-cost carbon fiber
- Pultrusion
- Nondestructive Evaluation
- Blade recyclability

State of Colorado Support

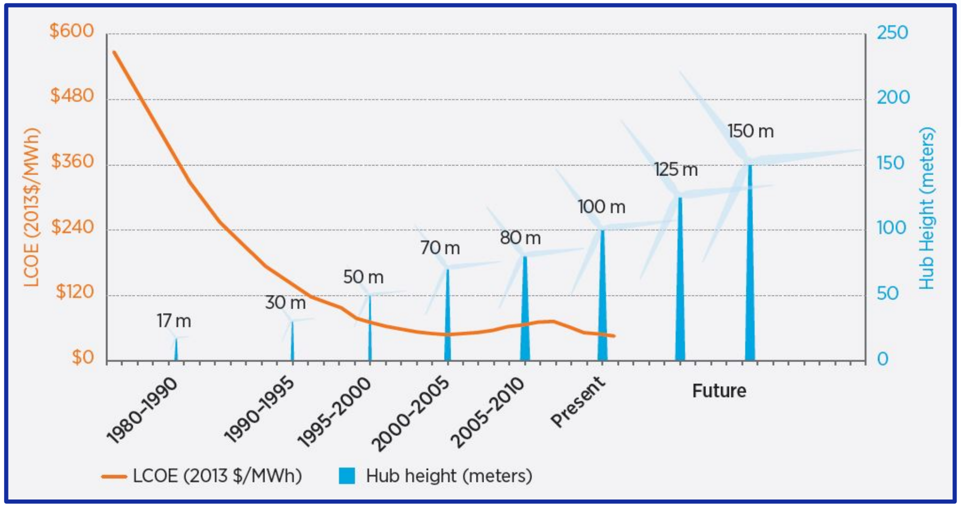
- Colorado Office of Economic Development and International Trade (OEDIT)
- Fully invested in composite manufacturing development
- $7M contribution
- Actively involved in oversight
- Workforce development
- Economic development
- Colorado industry

OEDIT CO COLORADO
Office of Economic Development & International Trade

State of Colorado - Investment

- Strong emphasis on workforce development for existing and potential Colorado wind manufacturing facilities
  - Vestas Wind (hiring 400+ composite technicians this year)
  - Bach Composites
- Local manufacturing innovation space for major wind OEMs in Colorado
  - Siemens (Boulder), Vestas (Windsor, Brighton and Pueblo)
- Economic development – state views the Wind TA as a potential regional hub for wind companies

Drivers of Wind Capacity Growth / Challenge



Average wind LCOE and wind technology scale-up trends

- Ability to scale wind turbine technology is a driving force in reducing the average wind LCOE in the United States

Challenges of blade transport (SSP Technology)

- Composite materials
- Composite manufacturing process innovation
- Large blade transportation logistics
- Blade reliability

Source: Wind Vision: A New Era for Wind Power in the United States, US Department of Energy 2015

Thermoplastic Composites Manufacturing

- Exploration of reactive infusion thermoplastic resins for improved cycle time, durability, recyclability
- Overcome concerns with fiber-matrix adhesion, high temperature processing and characterization
- Industrial partners: Johns Manville, TPI Composites, Arkema
- Technical Areas:
  - Techno-economic model
  - Develop spar cap baseline properties
  - Material development
  - Process development
  - Tooling development

Johns Manville

tpi DELIVERING COMPOSITE SOLUTIONS

ARKEMA INNOVATIVE CHEMISTRY

SCHOOL OF MINES COLORADO 1874

NREL NATIONAL RENEWABLE ENERGY LABORATORY

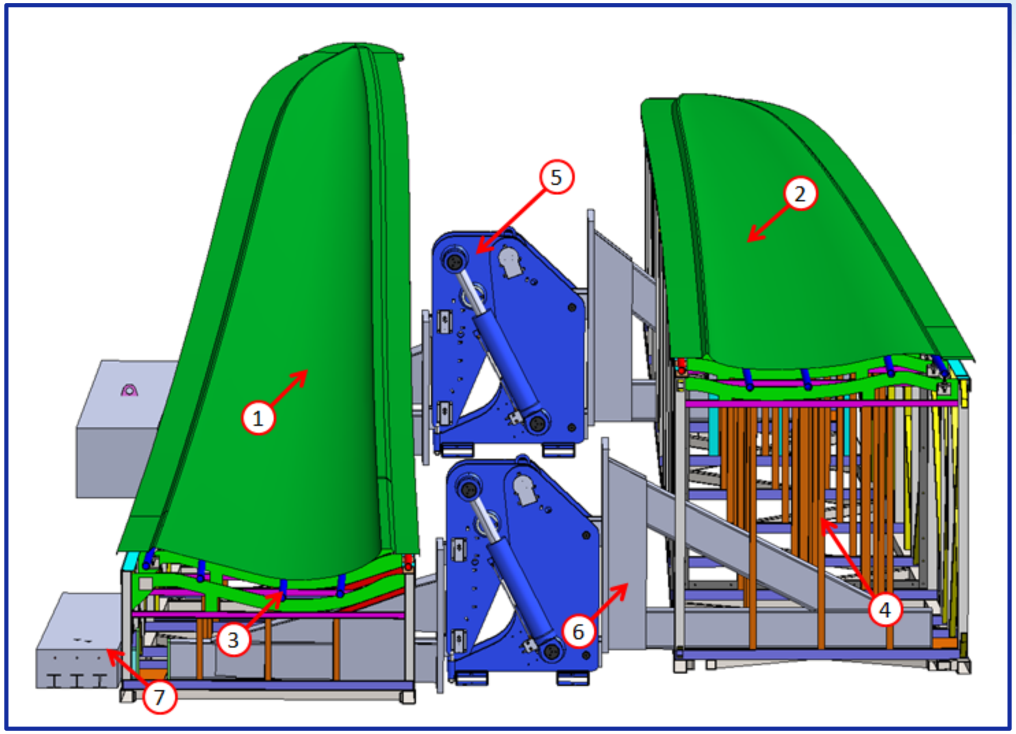
Thermoplastic Project: BP1 Work

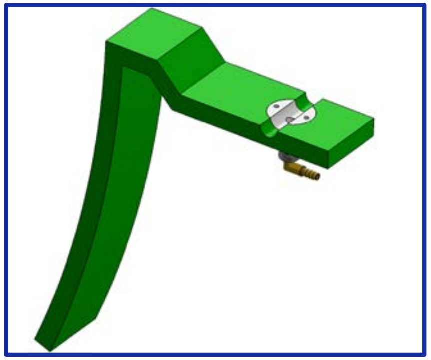
Criteria	TP-VARTM	TP-RTM	TP-RIM	TP Pultrusion	TP-Prepreg
Design freedom	o Same as thermoset process today	+ As today, but better flow length	+ As today, but better flow length	-- Fixed cross section	+ Fabric design and fiber content adjustable Lamination process
Ease of production	o	+	- Potential fiber misalignments, potential resin degradation due to high pressure	-	++ Decoupling of polymerization and part production
Production costs	o	+ Only due to infusion and polymerization	+ Only due to infusion and polymerization	+ Continuous process	++ Continuous prepreg process
Equipment and mold costs / component	o/+ potential higher molding costs	- Higher costs for equipment and potential mold	- Higher costs for equipment and potential mold	+ Costs reduced due to continuous process	++ Mainly depreciation for the continuous process
Available know how and training requirements	o Knowhow available, training required	o Knowhow available, training required	o Knowhow available, training required	-- Very limited know how available	+ Know how available, training required
Production Scrap	o as today	o as today	o as today	+ continuous process, mainly during start up	++ continuous process, easy to recycle

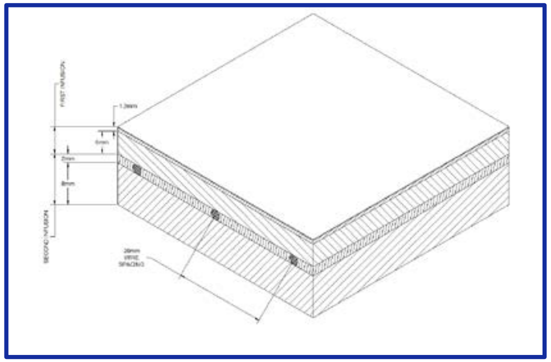
Thermoplastic Manufacturing Process Evaluation

Thermoplastic Project: BP1 Work

- Definition of baseline tooling specifications
- Master plug
- Standard production tooling
  - Design
  - Laminate
  - Heating system
  - Vacuum system
  - Mold framework
  - Bonding operation equipment
  - Staging
- Mold qualification
- Design tolerances
- Mold maintenance

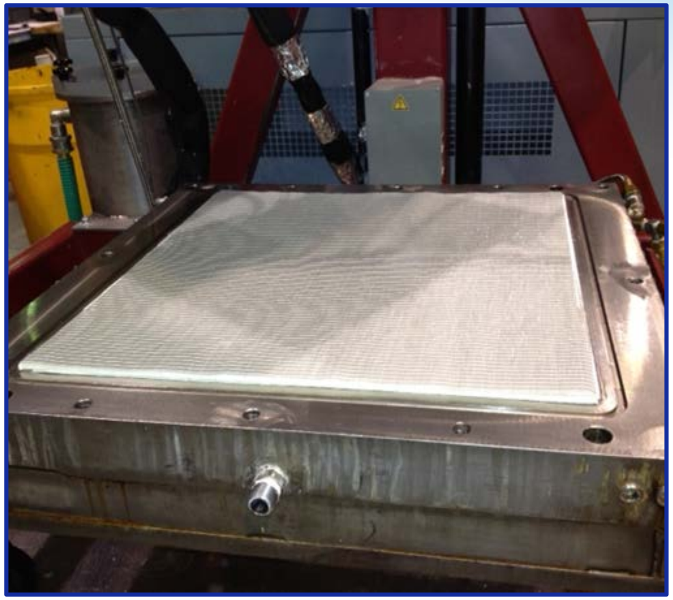


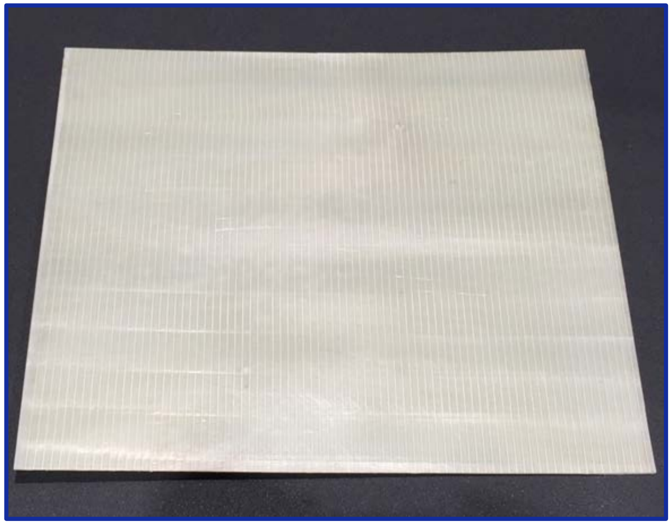




Thermoplastic Project: BP1 Work

- Constructed backbone of techno-economic model
- Defined baseline structural properties for wind blade spar caps
- Evaluated thermoplastic matrix choices:
  - Caprolactam-based nylon-6
  - Acrylic (Arkema Elium)
- Evaluated manufacturing methods:
  - Infusion, pultrusion, pre-preg and RTM
- Detailed potential tooling challenges for thermoplastic resin processing
- Manufactured four thermoplastic panels
  - Panel 1,2: Nylon-6 using RTM
  - Panel 3,4: Arkema Elium using infusion





Nylon-6 Panel Fabrication at Johns Manville

Thermoplastic Project: BP2 Plans

- Continued evolution of techno-economic model
- Commission laboratory scale VARTM facility at CSM
- Produce panels for each chosen combination of thermoplastic resin and manufacturing method
- Use panels to produce test coupons to determine the material properties of each combination
- Design and fabricate blade component tool to be used with thermoplastic resin composites
- Integration with the Modeling & Simulation TA and the Materials & Processing TA
  - Process parameter modeling
  - In-process non-destructive evaluation (NDE)

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