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

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

Integration:
- Thermoplastics
- RTM
- Automation (Viper)

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

- Automation
- Fast resin infusion and curing
- Intermediate scale

- 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
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

- 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

Average wind LCOE and wind technology scale-up trends

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
<table>
<thead>
<tr>
<th>Criteria</th>
<th>TP-VARTM</th>
<th>TP-RTM</th>
<th>TP-RIM</th>
<th>TP Pultrusion</th>
<th>TP-Prepreg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design freedom</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>--</td>
<td>+</td>
</tr>
<tr>
<td>Same as thermoset process today</td>
<td>As today, but better flow length</td>
<td>As today, but better flow length</td>
<td>Fixed cross section</td>
<td>Fabric design and fiber content adjustable</td>
<td></td>
</tr>
<tr>
<td>Ease of production</td>
<td>0</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>++</td>
</tr>
<tr>
<td>Potential fiber misalignments, potential resin degradation due to high pressure</td>
<td>Potential fiber misalignments, potential resin degradation due to high pressure</td>
<td></td>
<td></td>
<td>Decoupling of polymerization and part production</td>
<td></td>
</tr>
<tr>
<td>Production costs</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Only due to infusion and polymerization</td>
<td>Only due to infusion and polymerization</td>
<td>Only due to infusion and polymerization</td>
<td>Continuous process</td>
<td>Continuous prepreg process</td>
<td></td>
</tr>
<tr>
<td>Equipment and mold costs / component</td>
<td>0/+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>++</td>
</tr>
<tr>
<td>potential higher molding costs</td>
<td>Higher costs for equipment and potential mold</td>
<td>Higher costs for equipment and potential mold</td>
<td>Costs reduced due to continuous process</td>
<td>Mainly depreciation for the continuous process</td>
<td></td>
</tr>
<tr>
<td>Available know how and training requirements</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>--</td>
<td>+</td>
</tr>
<tr>
<td>Knowhow available, training required</td>
<td>Knowhow available, training required</td>
<td>Knowhow available, training required</td>
<td>Very limited know how available</td>
<td>Know how available, training required</td>
<td></td>
</tr>
<tr>
<td>Production Scrap</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>as today</td>
<td>as today</td>
<td>as today</td>
<td>continuous process, mainly during start up</td>
<td>continuous process, easy to recycle</td>
<td></td>
</tr>
</tbody>
</table>

Thermoplastic Manufacturing Process Evaluation

The Institute for Advanced Composites Manufacturing Innovation
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
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
  o Process parameter modeling
  o In-process non-destructive evaluation (NDE)
IACMI Wind TA Personnel

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