Sustainability of the Wind Turbine Blade Manufacturing Process: A Bio-based Alternative

SEP Collaborative: Achieving a Sustainable Energy Pathway for Wind Turbine Blade Manufacturing

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Wind installed capacity will need to increase by an average of 15 GW annually to achieve the 20% wind production goal by 2030 (U.S. DOE, 2008).

Which we estimate could translate into the use of more than 150,000 tons of blade materials per year.

To meet the increasing demand, not only are more blades being manufactured, but also longer blades are being produced.
Context

- The current stock of blades and the actual manufacturing process use petroleum-based thermoset composites as the primary materials.

- Industry does not manufacture blades in a sustainable manner and has no optimal way to recycle them.

- Available technologies and key economic constraints result in some undesirable disposal methods as the only feasible options. All of them carry negative health, environmental and economic concerns.
The wind turbine blades are made from a combination of epoxy resin, glass fiber reinforcement and other fillers.

Once cured, thermoset composites cannot be melted and therefore cannot be reshaped. As a result, any attempt of reshaping the blades risks compromising the properties of the material through damage or destruction of the reinforcing fibers.

Moreover, petroleum-based Epoxy Resin is produced by a reaction of two potentially toxic components:
- Bisphenol-A (BPA)
- Epichlorohydrin (ECH)
Current findings indicate that the Epoxidized Linseed Oil (ELO) is a good prospect for the substitution of the petroleum-based resin in the manufacturing process of wind turbine blades.

The Anhydride ELO system has:
- Similar hardness
- Improved toughness
- Lower density vs. traditional amine-cured

It may be more amenable to being reworked due to their structure, though that remains to be proven.
Objective

The main objective of this project is to create an energy pathway for the sustainability of wind energy. Specifically, we want:

- To understand the economic, environmental and health implications of the bio-based alternative, compared to the conventional petroleum-based manufacturing process of the wind turbine blades.

- To assess the impact of switching to bio-based wind turbine blades manufacturing on job creation, education and skills requirements.

http://www.worldindustriareporter.com/bayer-polyurethane-infusion-resins-found-suitable-for-wind-turbine-rotor-blades/
Approach to Evaluation

Life Cycle Cost Analysis (LCCA)
- Assuming they (bio-based and conventional) have similar performance in terms of energy production, but differ in terms of the health, environmental and economic implications over their life cycle.
- A LCCA should tell us the least costly or most cost-effective manufacturing process of the wind turbine blades over their life cycle.

Toxic Use Reduction Analysis (TUR)
- Is it truly more environmentally friendly?
- We want to measure the impact of changes toward less toxic chemicals and resources conservation.
Preliminary Findings

- **Initial cost**
  - Switching cost (to a bio-based system) is very sensitive to curing temperature.
  - If the curing temperature is much higher, then new tooling, molds and materials would be needed.

- **Material costs**
  - Epoxidized linseed oil system seems to be slightly cheaper than conventional epoxy resins.
  - Petroleum-based epoxy resin raises concern about price volatility and declining supply

http://www.windpowermonthly.com/article/1109760/close---lms-735-metre-blade
Environmental and Health Aspects

- ELO is much safer than conventional: less reactive and more stable at room temperature

- Significant concerns about occupational exposure to Bisphenol-A and Epichlorohydrin in the manufacturing process of conventional epoxy resin.

- ELO production is a relatively clean, efficient process, with no highly toxic reagents or byproducts involved.

- Other materials found in the blades have not yet been found to be significantly different.
Recycling

Current disposal practices are suboptimal and carries negative health, environmental and economic concerns. See table in next slide:

A reworkable, bio-based alternative, would allow for optimal recycling, with an efficient recovery of all the materials in the fiber-reinforced plastic.

However, the development of a new recycling industry is challenging due to low value of end product.
## Existing Disposal Methods and Some of their Environment, Health and Economic Concerns

<table>
<thead>
<tr>
<th>Disposal method</th>
<th>Health and Environment</th>
<th>Economic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landfill</td>
<td>Organic components can release methane and other volatile organic compound that contribute to climate change</td>
<td>Opportunity cost of unrecovered material and concerns of long-term space availability</td>
</tr>
<tr>
<td>Thermal Recycling</td>
<td>Incineration with energy and/or material recovery</td>
<td>significant energy and machinery requirements to cut and transport the blades before the incineration process</td>
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<tr>
<td></td>
<td>Pollutant ash after the incineration process, possible emissions of hazardous flue gasses and other pollutant byproducts</td>
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<td></td>
<td>Emission of environmentally hazardous off-gases</td>
<td>Low market value of resulting fibers</td>
</tr>
<tr>
<td>Chemical Recycling</td>
<td>Environmental impact of using potentially hazardous chemicals</td>
<td>Unknown economic viability</td>
</tr>
<tr>
<td>Mechanical Recycling</td>
<td>Dust emission during the grinding process of glass and carbon fiber thermoset composites</td>
<td>Low market value of resulting fibers</td>
</tr>
</tbody>
</table>
Preliminary Findings

○ Workforce Education and Skills Requirement
  o Will the introduction of an ELO-based manufacturing process require training and skill development? What would the implication be in terms of job creation?

  o Preliminary findings suggest that workforce education and training will not change with the introduction of ELO into the blade manufacturing process.

  o Potential for a new recycling industry
    o Potential job creation at all levels
    o Education and skills for recycling composite thermoset
Main Challenge Bio-based System

- High curing temperature, which might substantially increase the cost in manufacturing process:
  - **Conventional**: 6 hours at 80°C
  - **Bio-based**: Two Step curing process ~4 hours at 90°C and ~4 hours at 180°C

- $35°C < T_c < 100°C$ (elevated temperature)
- $100°C < T_c < 135°C$ (high elevation)
- $135°C < T_c < 190°C$ (very high elevated)

Do not require different consumables and “low cost” materials to the ones being used actually.

A whole new set of plugs, molds, consumables and core materials would be needed.
Different Scenarios

Assuming different scenarios depending on the most critical variables gives us an idea for the comparison of the bio-based vs the conventional.

- **Worst Scenario**
  - High curing temperature in ELO (high costs)
  - Low residual value of end product

- **Good Scenario**
  - High curing temperature in ELO (high cost)
  - High residual value of end product

- **Better Scenario**
  - Low curing temperature in ELO (low cost)
  - Low residual value of end product

- **Best Scenario**
  - Low curing temperature in ELO (low cost)
  - High residual value of end product
Preliminary Conclusions

- Overall, findings suggest that petroleum-based epoxy system seems to have higher negative health and environmental impacts compared with the bio-based epoxy system.

- The bio-based system could be at least as competitive, economically, as the conventional petroleum-based system.

- The ELO system and reworkability property could potentially lead to job creation with a new recycling industry.

- Overall, findings indicate that a reworkable, high performance bio-based epoxy is a promising and more sustainable alternative to the current petroleum-based epoxy resins.
Thank you!

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