
http://canadianawareness.org/2014/01/metrolinx-wind-turbine-only-producing-9-of-projected-energy/

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

*SEP Collaborative: Achieving a Sustainable Energy Pathway for Wind Turbine Blade Manufacturing*[1]

University of Massachusetts Lowell

June 2015

[1]This project is funded by a grant from the National Science Foundation (NSF) Sustainable Energy Partnership Program

# Context

- 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.

http://plainswindeis.anl.gov/guide/basics/index.cfm

# 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.

# Context

## The Conventional Manufacturing Process

- 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)

# Context

## The Bio-based Alternative

- 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.

Linseed Oil and Flax Seeds
*http://www.shivorganics.com/castor-oil.html*

# 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.worldindustrialreporter.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.

http://www.windpowermonthly.com/article/1109760/close---lms-735-metre-blade

- **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

# Preliminary Findings

- **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.

http://www.thetimes.co.uk/tto/news/uk/scotland/article3975567.ece

# Preliminary Findings

- **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.

http://www.treehugger.com/urban-design/recycled-windmill-playground-2012-architecten.html

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

# Preliminary Findings

- **Workforce Education and Skills Requirement**
  - Will the introduction of an ELO-based manufacturing process require training and skill development? What would the implication be in terms of job creation?
  - Preliminary findings suggest that workforce education and training will not change with the introduction of ELO into the blade manufacturing process.
  - Potential for a new recycling industry
    - Potential job creation at all levels
    - 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 < Tc < 100°C (elevated temperature)**
- **100°C < Tc < 135°C (high elevation)**

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

- **135°C < Tc < 190°C (very high elevated)**

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!

**Contact Information:**

David Turcotte

David_Turcotte@uml.edu

Katerin Ramirez

Katerin_RamirezTejeda@student.ul.edu

**Center for Wind Energy**

**University of Massachusetts Lowell**