Clarification to Address Reviewers' Comments
Project Proposal Submitted to the Renewable Energy Program
"Biocomposite Development for Industrial and Consumer Products"
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Rating Category 1:
In response to Reviewer 2C, the specific polymers and biomasses were not called out in the abstract or objectives to save space in the proposal. Biomasses to be used in this project are called out in "Anticipated Results", "Techniques to be Used, Their Availability, and Capability", and "Why this Project is Needed". The biomasses mentioned in the proposal include: sunflower hulls, flax shive, flax fiber, oat hulls, sugar beet pulp, dried distillers grains with solubles, soy bean hull, corn cob, etc. Specific polymers used or under consideration for the different proposed projects with the companies identified include: polypropylene (PP), polystyrene (PS), polycarbonate (PC), acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), etc. The technology we developed at NDSU over the past seven years of research was licensed by our company, c2renew corporation, and is based on a proprietary methodology of hybridizing (or mixing) multiple biomasses together with stabilization treatments for introduction into a multitude of different polymers.

Rating Category 2:
Reviewer 2A raised the question on the performance of current c2renew products compared to the specifications for the products listed in this proposal. Biocomposites by c2renew have been successfully formulated and produced for a belt guard application for Bobcat Co. and a lawn tractor handle for John Deere Co. Bobcat has since issued a purchase order for 350 lb to better evaluate our material for production purposes, and John Deere continues to work with us to evaluate the handles and develop other applications. Funding from this proposal through the REP would go towards developing other formulations and producing trial materials for the potential customers discussed in this proposal. Essentially, the purpose of this proposal is to fund research and development of new biocomposites to fit the specific needs of each application listed. The research backing the formulation and production of these biocomposites has been developed over the last seven years and the technology has been licensed by c2renew from NDSU.

The biocomposites are formulated to be lower in price than the neat polymers currently being used, giving the OEM an advantage of using a less expensive material, with similar or improved mechanical properties, and reducing the petroleum input with a more environmentally friendly product. In the case of previous work with Bobcat, the biocomposite developed was $0.05 per pound cheaper than the neat polymer. The economics for the 100% biocomposite Earth-Kind product are also appealing. The preliminary formulation consists of PLA with agricultural waste

filler. PLA is similar in cost to polypropylene or polystyrene, so it would not be more expensive than petroleum based analogs.

Admittedly, the rodent repellent holder timeframe is aggressive at 6 months. However, it is a relatively straightforward consumer product, and the preliminary design and material formulation have already been completed. For these reasons it is believed that the proposed timeframe is achievable. The main reason for the truncated timeline is to coincide with an anticipated product launch on Earth Day 2014.

Additionally Reviewer 2C requested polymer chemistry and processing details, which is a broad subject and was intentionally left out of the proposal to save space. When combining different hydrophobic polymers, such as PP, compatibilizers must be used to improve the bond with the hydrophilic biomass. The compatibilizer modifies the surface of the biomass such that the hydrophilic surface becomes hydrophobic, improving the bond with the base polymer. One common compatibilizer is Maleic Anhydride grafted Poly Propylene (MAPP), which has been shown to increase the strength of wood-PP biocomposites [1-5]. Another method of combining a hydrophilic polymer with hydrophobic biobased filler is a treatment called torrefaction. Torrefaction is the process of heating a material in the absence of oxygen (to prevent oxidation), and it breaks down undesirable constituents of lignocellulosic materials such as starches, fats, and proteins. Torrefaction can also be performed in such a way as to not degrade the cellulosic material, and it changes the surface chemistry of the material from hydrophilic to hydrophobic [6, 7]. In regards to processing of the biocomposite, the base polymer, biomass, and/or compatibilizer are combined using a twin screw extruder. This machine has a pair of intermeshing screws which are designed to convey and mix the material through a series of heated zones to melt the polymer and achieve a homogenous mixture [8]. This blended biocomposite material is then cut into pellets and cooled. One complexity of the compounding process is the effect of screw speed during extrusion [9]. At this point the biocomposite pellets are ready for injection molding into final parts.

Ultimately we decided not to divulge the specifics of any of the formulations for the proposed trial products under investigation. The description of each would have taken one to two pages and we wanted to protect the formulations in the most likely event they are commercialized.

Rating Category 3:

All reviewers identified the methodology as brief, and again, this was sacrificed to save space in the proposal. Reviewer 2A posed the question on testing required to meet the specifications of each product. Mechanical testing is required on the biocomposite material samples for each application. These tests include tensile, flexural, impact, and melt flow index (MFI) at a minimum. The results of these tests are then compared to the material properties of the polymer currently being used in each respective application. The material specifications for each

application are not disclosed in the proposal or this rebuttal since it is a public document, but are available upon request.

The quality control of the incoming biofeedstock is a good point, and will require sourcing quality material in small quantities to allow minimal inventory for storage indoors to limit environmental degradation. This will require the implementation of LEAN manufacturing processes, leading to minimal inventory and avoiding wasting of feedstock. These types of high quality agricultural waste materials are available through Red River Commodities, FlaxStalk, American Crystal Sugar, Emerson Milling, Tharaldson Ethanol, etc. Additionally, following the introduction of the biomass to the polymer, as well as any pretreatment or compatibilizer, the biomass becomes stable and better resists environmental degradation.

Once again, the technology we developed at NDSU over the past seven years of research was licensed by our company, c2renew corporation, and is based on a proprietary methodology of hybridizing (or mixing) multiple biomasses together with stabilization treatments for introduction into a multitude of different polymers. We would not have pursued spinning off a startup business based on this technology and backed by several investors if volume manufacturing, feedstock management, and profitability were not well understood. I hope that the council recognizes that for the success of the business we cannot reveal all of our strategies in such details that the reviewers requested.

An additional question was raised by Reviewer 2C regarding the production of the Rodent Repellent holder by the injection molding process. This statement was merely intended to illustrate the intended manufacturing method for the product. The injection molding would be completed by a molding company, and any machine settings for the injection molder would be dependent on material properties, part geometry, and mold design. None of which are not yet determined.

Rating Category 4:
Reviewer 2C stated that it seemed like in certain parts of the proposal the NDIC goals were merely a second thought, and then went on to identify “the invention of the biocomposites would spur more biocomposite creation, which was not substantiated by further evidence in the paper.” We feel that this is within the NDIC goals and the invention of biocomposites would spur more biocomposite creation. Growth in biocomposite development and use would lead to additional use of North Dakota agricultural by-product, creating more value for agricultural producers and farmers. Additional biocomposite creation through the invention of biocomposites can be illustrated by our relationship with both Bobcat and John Deere. Through the process of working with both of these companies in the past, previously trialing of our biocomposites in specific applications has led to additional applications being requested in this proposal.

Rating Category 5:
All reviewers identified a lack of literature review, and again, this was sacrificed to save space in the proposal. The use of biomass as a filler in plastics is not new or unique to NDSU or c2renew. One common use of lignocellulosic material as a filler in thermoplastics is the use of wood flour and wood fiber as a filler in PP. Applications for this material include decking, fencing, moldings, and trim [1]. Additional research in this area has been done using other lignocellulosic materials including rice husk flour [10], rye husk [11], wheat straw [12], sugarcane bagasse [13], and corn derived filler [14]. What makes our projects and company unique is our significant research background in the area of hybridizing and stabilizing lignocellulosic fillers and our experience to develop formulations which achieve specific material properties in specific applications for our customers.

Currently the IP strategy for the technology is that of trade secret. This technology was developed over the period of seven years through research completed in the Mechanical Engineering Department at NDSU. This technology was then licensed by NDSU to c2renew. c2renew was then able to develop a business from this technology, and with this IP strategy has attracted outside investors to fund the company.

Rating Category 7:
We are in constant contact with the OEMs for each of the defined projects. They have all expressed interest in replacing their current polymer with a biocomposite produced by c2renew. Specifically with Bobcat, John Deere, and Toshiba, we are in contact with both the plastic part designers and engineers working at the OEM level, as well as the injection molding companies who produce the final parts for these companies. The names and contact information for these individuals are available to the council upon request.

The Rodent Repellent Holder schedule is aggressive, but this is offset by the relative simplicity of the consumer product and a preliminary formulation is already chosen. Additionally, it is understood that accelerated work on the Rodent Repellent Holder will take time away from the other projects, and it is accounted for in the timeline.

Rating Category 9:
Again, the quality control of the incoming biofeedstock is a good point, and will require sourcing quality material in limited quantities to allow for storage indoors to minimize environmental degradation. In addition, our company's philosophy of utilizing lean manufacturing practices will ensure a steady supply of new biomass.

The concern was raised regarding access to mechanical testing capabilities; this was addressed in the proposal by the NDSU Mechanical Engineering laboratory's full suite of composite testing equipment. This includes a lab scale twin screw extruder for testing small scale formulations, an

injection molder for the production of mechanical testing samples, a load frame for tensile and flexural testing, impact testing, Dynamic Mechanical Analyser (DMA), and Melt Flow Indexer (MFI). All of these facilities are available to us by entering an engineering services contract with the university when needed.

References:

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