Center for Bioplastics and Biocomposites

Project Accomplishments and Outcomes

Iowa State University  NSF  Washington State University
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With a steadily increasing number of companies and institutions setting sustainability goals for their operations, CB² (Center for Bioplastics and Biocomposites) is well-positioned to support these efforts. CB² is a collaborative effort by the Biopolymers & Biocomposites Research Team at Iowa State University, the Composite Materials and Engineering Center at Washington State University, and industry members to conduct commercially relevant research. As a National Science Foundation (NSF) Industry/University Cooperative Research Center (I/UCRC) we connect a broad spectrum of industry members with university experts. This allows industry to leverage their individual resources to develop new materials, processes, knowledge, and intellectual property, giving them a competitive edge and grow their profitability. While the center creates an environment that fosters partnerships between industry and leading experts from universities, its research focus and the allocation of resources are determined by industry partners. The center’s operation is designed to encourage technology transfer between universities and industry through monthly mentoring meetings, internships, and bi-annual meetings.

The novel technologies and materials resulting from CB² efforts allow industry to quickly and confidently adopt new and demanding sustainable materials and processes and integrate them seamlessly in their existing operations. The new materials not only meet consumer demands, but also government regulations while supporting corporate goals of environmental stewardship. CB²’s member companies are leading the industry in sustainable materials through their engagement in the renown I/UCRC NSF Center for Bioplastics and Biocomposites.
Introduction

The Center for Bioplastics and Biocomposites (CB\textsuperscript{2}) is a National Science Foundation Industry & University Cooperative Research Center (I/UCRC) that focuses on developing high-value biobased products from agricultural and forestry feedstocks.

The goals of this center are threefold: (1) to improve the basic understanding of the synthesis, processing, properties, and compounding of bioplastic and biocomposite materials; (2) to develop reliable material characteristics data for industrial partners; and (3) to support large-scale implementation of renewable materials. In order to achieve these goals, the activities will be:

- Collaboration with industry to develop fundamental knowledge of bioplastics and biocomposites
- Dissemination of this knowledge through publications, workshops, and tradeshows
- Education of future researchers, engineers, and scientists

Our center’s operational costs are covered by the National Science Foundation (NSF) while the research is funded by our industry partners. The partners start project selection through a well-documented and effective process, including development of seed concepts to serve as topics for a call for proposals from our university partners. The university researchers and their teams submit proposals to address the seed concepts within well-defined thrust areas. Through a multi-step system, our industry partners select the projects for funding based on a vote. Once the projects are funded, they are mentored by the industry partners on a monthly basis. Any intellectual property that is developed in the course of a CB\textsuperscript{2} project belongs to the industry partners that fund the execution of the patent royalty free.

While the thrust areas represent general technological and scientific topics where CB\textsuperscript{2} has unique strengths compared to other research institutes, other technologies outside these thrust areas are also continuously developed to meet the expressed goals of our industry partners. Our goal is to develop viable, science-based, and economically feasible solutions that meet our partners’ needs for a sustainable future.

The vision of the center is to develop the knowledge that will allow the production of an array of high-value products, including plastics, coatings, adhesives, and composites from agricultural and forest-based resources that are compatible with current industrial manufacturing systems and thereby promote domestic development.
**Institution Partners**
1. Iowa State University
2. Washington State University
3. University of Georgia
   *a potential partner in planning stage*

**Industry Partners†**
1. 3M
2. ADM
3. Berry Plastics Corporation
4. Boeing
5. Branson Ultrasonics
6. Byogy Renewables, Inc.
7. CycleWood Solutions Inc.
8. Diageo
9. Dixie Chemical Company
10. Dukane Ultrasonics
11. EcoProducts
12. EVOLVE GOLF
13. Ford
14. Hyundai
15. Idaho Forest Group, LLC
16. Inland Packaging
17. John Deer
18. Laurel Biocomposite
19. Minnesota Corn Research
20. Myriant/PTTGC
21. Natural Soy Products
22. Northwest Green Chemistry
23. Powder Coating Research
24. Renewable Energy Group
25. RheTech
26. Rubbermaid
27. SelfEco
28. Siegwerk USA
29. SuGanit BioRenewables
30. Sunstrand
31. Swamp Fox Chemical LLC
32. Taylor Technologies
33. USDA-ARS-NCAUR
34. Viskase Companies Inc.

†All previous and current industry partners are listed.

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**Collaboration**

- **Faculty Members:**
  The NSF Industry & University Cooperative Research Center program is a vehicle for encouraging formal, topical relationships between academic institutions and industry collaborators.

- **Industry Members:**
  Companies and organizations interested in bioplastics and biocomposites are invited to join CB². Becoming a member has many advantages including leveraging research and development efforts through the center’s projects, receiving access to technologies developed by the center and having access to scientists and undergraduate and graduate students for future employment.

- **Affiliate Members:**
  In addition to its core funding from the National Science Foundation and industry members, CB² is supported by affiliate members.
Center Organization

Timeline for project selection

MAY
- Call for seed concepts from IAB
- Seed concepts due, prepared by IAB

JUL
- Proposals due, PIs (ISU, WSU)
- Call for proposals, PIs (ISU, WSU)
- IAB vote of proposals

SEP
- Revised final proposals due, PIs (ISU, WSU)
- Final proposals for podium announced

OCT
- EARLY NOVEMBER
- IAB meeting
- Podium presentations
- Selected projects start

NOV
- MID-NOVEMBER
- Final proposals selected for funding by IAB

JAN
- Selected projects start
Research

CB² focuses on five research thrust areas that promote industry-wide acceptance of bioplastics and biocomposites and increase the use of sustainable materials. Each thrust area is listed below.

**BIOBASED PRODUCTS**
- Zero VOC powder coatings
- Greenhouse potting systems
- Starch-based packaging products
- Chitin-based coatings and films
- Biobased insecticide garments
- Consumer-safe bioplastic blister packs
- Vitrimerizing ester bond-containing thermoplastics for property improvement

**SYNTHESIS AND COMPOUNDING**
- Starch-based packaging
- Biobased PET
- Biobased thermoplastics elastomers
- Starch-based plastics with polyacrylated glycerol
- Biobased methacrylates
- Pressure sensitive adhesives
- Sugar-based PP
- Toward biobased ABS
- Biobased transparent waterborne UV absorbing coating
- PEN polymers—next generation bottles and packaging materials

**BIOCOMPOSITES**
- Bio-oil based carbon fibers
- Lignin composites
- Lignin composites
- Biorefinery-based carbon fibers
- Biorefinery-based carbon fibers
- Increasing interfacial bonding in agave fiber-polypropylene biocomposites for enhanced properties
- Production of low-cost lignin composite materials using biorefinery lignin

**PROCESSING**
- Processing of chitin-based plastics
- Odor control of natural fibers
- Processing of starch and polyacrylated glycerol

**MODELING**
- LCA of bioplastics
- Interfacial healing
- Interfacial healing
- Consumer-safe bioplastics blister packs
SYNTHESIS AND COMPOUNDING
This thrust area develops fundamental understanding of bioplastic synthesis and compounding, including fermentation and polymerization. This includes vegetable oil-based plastics, coatings and adhesives, biobased waxes, monomers, elastomers, poly(ester-amides), protein-based plastics, sustainable approaches to advanced functional materials and polymer additives, and feedstock preparation.

BIOMATERIALS
Knowledge of biocomposites, including fiber synthesis, biobased resin systems, and biobased fiber systems, is developed in this thrust. These areas include self-healing composites, fiber production from lignin, nanotechnologies as well as biobased composites.

PROCESSING
This thrust focuses on the specific requirements of biobased polymers and composites during vital processing operations. This includes melt processing, extrusion, and molding, as well as secondary operations such as cutting, welding, and coating.

BIOMATERIALS
This thrust focuses on developing biobased products, such as plastics or composite products, that are drop-in substitutes for petroleum-based products currently in the market. It also includes determining sustainability metrics such as environmental impact. Part of the center’s already existing system is a web-based interactive life cycle assessment software that allows users to easily analyze their current and future products.

MODELING
This thrust studies energy and mass transfer for typical processing techniques such as extrusion and injection molding. The long-term goal is to develop models based on fundamental principles that can be used across a wide range of applications.

COMMERCIALIZATION
The center affiliates have a proven track record of working with member companies to successfully commercialize biobased products. Because the center offers member companies royalty-free access to intellectual property resulting from center projects, the center is well positioned for direct technology transfer from academia to industry. The center supports the development of Small Business Innovation Research (SBIR) proposals and business plans, facilitates networking, and identifies markets and potential market penetration. This allows member companies to leverage their resources and increase their profits.
Thrust 1

SYNTHESIS AND COMPOUNDING

This thrust area develops fundamental understanding of bioplastic synthesis and compounding, including fermentation and polymerization. This includes vegetable oil-based plastics, coatings and adhesives, biobased waxes, monomers, elastomers, poly(ester-amides), protein based plastics, sustainable approaches to advanced functional materials and polymer additives, and feedstock preparation.
The objective of this project was to develop low-cost biobased reactive diluents suitable for vinyl ester and vegetable oil-based composites that decrease concentrations of volatile organic compounds (VOC) including styrene, reducing emissions throughout the composite life cycle. We synthesized a range of biobased methacrylates, including methacrylated vanillin (MV), methacrylated vanillyl alcohol (MVA), and methacrylated eugenol (ME), through the reaction between methacrylic anhydride with hydroxyl groups on the biobased precursors. These reactive diluents were blended with high-viscosity thermosetting resins (both vinyl ester and vegetable oil-based resins) and cured via free radical polymerization.

**Outcomes**

1. Successfully synthesized biobased MV, MVA, and ME.

2. Evaluated reactive diluents with CB² member company’s maleinated acrylated epoxidized soybean oil (MAESO) resin and commercially important vinyl ester resins.

3. Characterized the volatility, viscosity, cure kinetics (gel time and curing extent), thermos-mechanical properties, mechanical properties, and thermal stability as a function of diluent content.

**Accomplishments**

1. Significant reduction of system viscosity (over an order of magnitude) was achieved when 30 wt% of MVA was used.

2. Biobased methacrylates were shown to have great potential to serve as combined reactive diluents for MAESO and vinyl ester resins with decreased viscosity and improved thermal-mechanical properties while maintaining low VOC emission compared to that of commercial styrene resins.
Polypropylene (PP) is the second largest polymer produced by volume, used in a wide variety of applications. At present, most of propylene is still obtained from the refining gasoline or produced by splitting, cracking, and reforming hydrocarbon mixtures. However, these processes are still based on petroleum-based feedstock, are performed at high temperatures, and require expensive noble metal catalysts. With the finite stocks of fossil resources and the growing market demand for propylene, development of alternative feedstocks for the production of propylene is an attractive solution. In this work, we developed new and more economic production methods for biobased propylene using sugar-derived 1,2-propanediol (1,2-PDO) and glycerol as feedstocks, respectively.

**Outcomes**
1. Three-step and two-step conversion processes have been designed and fully investigated.

2. Efficient catalysts for each step within the whole transformation process were identified and the optimized reaction conditions have been determined, which will be the fundamental data for future scale-up processes.

**Accomplishments**
1. Highly pure propylene was produced with yields higher than 90% based on the whole conversion process.

2. Technical economic analysis (TEA) was initially conducted to predict the production costs of these two conversion processes. The price of renewable propylene produced using our processes is comparable with that of petroleum-based propylene in the marketplace.
Glycerol-Based Thermoplastic Elastomers

Lead: Eric Cochran, Iowa State University

Our group is interested in the synthesis and characterization of heterogeneous block copolymers and polymer nanocomposites for applications ranging from asphalt modification to adhesives to improved performance biomaterials. Our research team discovered synthetic routes to non-cross linked thermoplastics and thermoplastic elastomers derived from vegetable oils.

We are currently investigating the use of other renewable feedstocks, such as glycerol, as potential replacements for petrochemically derived monomers in specialty polymers, for example biobased, pressure-sensitive adhesives.

Outcomes
1. Synthesis of glycerol-based, non-cross linked thermoplastic elastomers.

2. Formulations to produce tackifier-less, pressure sensitive adhesives from renewable feedstocks.

Accomplishments
1. Production of glycerol-based, pressure sensitive adhesives with mechanical properties comparable to petroleum-based adhesives.

2. Synthesis of novel transfer agents facilitating the polymerization of triblock copolymers that will improve the mechanical properties of the biobased adhesives.
Thrust 2

BIOCOMPOSITES

Knowledge of biocomposites, including fiber synthesis, biobased resin systems, and biobased fiber systems, is developed in this thrust. These areas include self-healing composites, fiber production from lignin, nano-technologies as well as biobased composites.
Mechanochemically Activated and/or Functionalized Cellulose Powders and Their Reinforced Plastic Composites for Higher Demanding Applications

**Lead:** Michael Wolcott, Washington State University  
**Postdoctoral Fellow:** Mohammadali Azadfar, Washington State University  
**Students:** Lang Huang and Max Graham, Washington State University

Cellulose fiber and nanocellulose have the potential for a variety of new applications. However, difficulties in achieving a proper dispersion and a strong interface with the matrix polymer prohibit the realization of this potential. In this research, we hypothesize that wood pulps, composed primarily of cellulose, can be subjected to mechanochemical activation with selected chemicals to prepare surface activated and/or functionalized cellulose powders for reinforcements.

**Outcomes**

This project evaluated the activation of hydroxyl groups and reducing-end groups on cellulose powder surfaces through the use of a lab-scale planetary ball mill in dry media chemical reaction systems to demonstrate functionalization of cellulose powder.

1. Preparation of size-reduced and activated cellulose powders.

2. Formulations to improve the interfacial adhesion between filling cellulose powders and polypropylene matrices.

3. Development of techniques and tools for analysis, visualization, and dissemination of different aspects of the research project.

**Accomplishments**

1. Development of solvent-free chemomechanical processes to simultaneously pulverize, activate, and functionalize wood pulp, producing property-tuned meterable cellulose powders.

2. Production of cellulose powders-reinforced polypropylene composites with improved physico-mechanical features.
Production of Low-Cost Carbon Fiber from Heavy Fraction of Fast Pyrolysis Bio-Oil

Lead: Xianglan Bai, Iowa State University

Lignin is a promising precursor of low-cost carbon fibers. However, the mechanical properties of carbon fibers produced from melt-spinning of raw lignin are poor, restricted by the randomly cross-linked polymer structures of lignin. In this project, pyrolytic lignin, which is a depolymerized lignin that consists of phenolic monomers and oligomers, was used as the starting material to produce carbon fiber. By repolymerizing the pyrolytic lignin, the modified precursor with improved quality can be obtained.

Outcomes
1. Pretreated pyrolytic lignin is turned into a melt-spinnable carbon fiber precursor with lower glass transition temperature.

2. Carbon fibers with maximum tensile strength of 1040 MPa and modulus of 112 GPa are obtained.

Accomplishments
1. Production of carbon fiber from low-cost biorenewable feedstock.

2. A new approach to modify the intrinsic molecular structure of lignin to improve the quality of carbon fibers.
Carbon fibers form an essential component in automobiles and airplanes, increasing fuel efficiencies and mechanical strength. The increased cost of carbon fibers, however, significantly affects the final product. Our group focuses on research related to the sustainable conversion of lignocellulosic biomass to biofuels and bioproducts and we have been working on modifying the biorefinery lignin stream as a low-cost compound for in-mixing with polyacrylonitrile (PAN). This will reduce the cost of carbon fibers with minimal impact on strength. We use biorefinery lignin, which is highly methoxylated during the upfront pretreatment process that is used to remove carbohydrates from the lignin. These changes make it a better substrate for in-mixing with PAN when compared to commonly available lignins such as Kraft lignin. In this process, the modified lignin (using esterification to increase hydrophobicity) was chemically fused with the PAN through melt spinning to produce carbon fibers with minimal reduction in mechanical characteristics.

**Outcomes**
1. Production of PAN-lignin blends using melt spinning process for further conversion to carbon fibers.

2. Increased in-mixing of PAN-lignin at melt spinning conditions through modification of lignin (by esterification) and using plasticizers without significant impact on mechanical strength.

**Accomplishments**
1. Production of PAN-lignin blends up to 30 wt% in-mixing with mechanical properties similar to those of pure PAN used in carbon fiber production.

2. Melt spinning of PAN-lignin blends using ionic liquid as plasticizer that will facilitate chemical interaction between PAN and lignin, resulting in better lignin-based carbon fibers than currently reported in the literature.
Biobased composites with mechanical and chemical properties comparable to those of petroleum-based counterparts have considerable economic and environmental advantages. This project investigated the use of a wide range of bio-fillers in combination with petroleum-based matrix polymers to explore the potential of biobased composites that can serve as a one-to-one drop-in for traditional plastics at industrial scale.

Outcomes
1. Established the limits of bio-filler content in polymer matrices.

2. Gained an understanding of filler-matrix chemical bonding.

3. Determined mechanical and thermal properties of the resultant biobased composites.

4. Proven economic advantages of the biobased composites using cost analyses.

Accomplishments
1. Developed decision-making tools to determine filler type, filler content, and type of polymer matrix to obtain target mechanical properties.

2. The developed knowledge platform facilitates design and manufacturing of parts with biobased composites.
Thrust 3

PROCESSING

This thrust focuses on the specific requirements of biobased polymers and composites during vital processing operations. This includes melt processing, extrusion, and molding, as well as secondary operations such as cutting, welding, and coating.
While biobased plastics provide an environmentally friendly and cost-effective alternative to petroleum-based plastics and are establishing a new consumer-driven market, some challenges still exist in realizing their full integration with consumer goods. One major challenge is the odor of biobased materials. The odor, typically caused by impurities and not inherent to the biomaterials, is conveyed to biocomposites containing bio-fillers and consequently makes them unsuitable for many applications. This project focused on the development of a low-cost and scalable process and formulation for mitigating and eliminating such odors in agave fiber-based composites.

**Outcomes**
1. Developed a scalable process for mitigation of odors in agave fiber composites.
2. Measured the impact of pre-processing conditions of mechanical properties of the biobased composites.

**Accomplishments**
1. Fabricated agave fiber-based polymer composites with no noticeable odor and improved mechanical properties.
2. Developed complete set of preprocessing conditions and formulation for odor-free agave-fiber polymer composites.
3. This is a process that can be adopted for other bio-fillers.
Chitin is an abundant biopolymer in nature and can be extracted economically from leftover shells from lobsters, crabs, and shrimp consumed by humans. Chitin in commercially available powder form does not dissolve in water and most common organic solvents, making it difficult to be processed into products industrially. Making chitin dispersible or soluble can increase the scope and value of its applications leading to value-added products and additional revenues for the fishing industry, which in turn decreases the cost of crustacean products.

**Outcomes**
1. Developed mechanochemical methods to convert chitin into chitin nanofibers that can be dispersed uniformly and stably into water and water-based coating systems.
2. Developed methods to convert chitin into chitin esters that can be dissolved in several commercially important organic solvents.
3. Characterized chitin nanofibers and chitin esters as well as their coating formulations and films.

**Accomplishments**
1. Demonstrated the potential of chitin nanofibers and chitin esters in applications ranging from inks and films to composites.
2. Used as rheological modifiers or reinforcing additives in water-based or solvent-based ink or coating systems, or as oxygen barrier layer in packaging films.
Few biobased thermoplastic materials can successfully compete with their petroleum counterparts, in large part because of a lack in understanding of the fundamental properties of the materials. The use of thermoplastic starches (TPS) has suffered from their inability to maintain thermoplasticity as the material ages. As they age, TPS undergo retrogradation where the starch recrystallizes and the water molecules and other plasticizers are pushed out, making the material harder and less flexible. If TPS retrogradation can be controlled, many commercial applications will become available. In particular, our interest is focused on the creation of “green” films with controlled oxygen and water permeability for use in food applications. Also desirable is the ability for the material to accept dye, e.g., from printing processes.

**Outcomes**
1. Developed thermoplastic starch formulations to make films suitable for packaging materials.
2. Improved the water resistance of thermoplastic starch by functionalizing starch.

**Accomplishments**
1. PAG copolymer had 2,000x the ductility of unmodified TPS.
2. Developed functionalized thermoplastic starch resulting in increased moisture resistance.

**Lead:** Nacu Hernandez, Iowa State University
Thrust 4

BIOBASED PRODUCTS

This thrust focuses on developing biobased products, such as plastics or composite products, that are drop-in substitutes for petroleum-based products currently in the market. It also includes determining sustainability metrics such as environmental impact. Part of the center's already existing system is a web-based interactive life cycle assessment software that allows users to easily analyze their current and future products.
Powder coating has attracted increasing attention in recent years, as it is environmentally friendly and virtually pollution-free. Powder coatings represent more than 15% of the industrial coatings market and is predicted to continue to grow. Current powder coatings, like many other polymer materials, are entirely based on petrochemical feedstocks. We have made a significant effort to develop alternative biobased powder coatings using renewable chemical feedstocks such as rosin acid and dipentene.

**Outcomes**
1. Understanding the design space and limitation of some renewable feedstock for powder coating applications.
2. Introducing promising biobased powder coatings and potential applications.

**Accomplishments**
1. Developed chemical structures and synthesis methods of rosin-derived epoxy powder coatings and rosin-derived curing agents for polyester powder coatings.
2. Determined curing behavior and fundamental performance.
Improving Thermoplastic Properties of Starch

Lead: Buddhi Lamsal, Iowa State University

Utilizing starch for bioplastic-related applications, i.e., films, adhesives, and molded products among others, requires understanding of the factors that turn it into thermoplastic polymer during extrusion. Factors such as starch composition and structure, plasticizer, temperature of extrusion, moisture content, and nature of blending materials affect resulting starch and film properties. This study investigated those factors, understanding of which allows scientists, designers, engineers, and manufacturers to consider starch for various biobased applications.

Outcomes
1. Starch-based cast films were prepared to optimize film formulations and ingredient interactions for desirable film properties.

2. Optimized film formulations were extruded in a twin-screw extruder at various processing conditions for sheet films and pertinent properties of resulting films, e.g., strength, barrier properties, hydrophobicity, glass-transition, and thermal degradation, were compared.

Accomplishments
1. The outcomes allowed stakeholders to produce starch-based films with specific properties.

2. Adding nanomaterials, including biodegradable nano-biofibers, was shown to increase mechanical and barrier properties of starch films.
Effectiveness and Nutrient Tracking of Biopolymer Horticultural Systems

Lead: James Schrader, Iowa State University

The extensive use of petroleum-based plastic pots (containers) and synthetic fertilizers in horticulture provides unparalleled effectiveness, but this effectiveness is achieved through heavy consumption of finite fossil resources and with a disproportionate impact on the environment. We evaluated the effectiveness and nutrient efficiency of emerging biopolymer horticultural systems that utilize containers made of biorenewable polymers that provide nutrients to plants by using protein-based biopolymers without synthetic fertilizer.

Outcomes
1. Biopolymer horticultural systems were found to be effective and suitable for providing fertilizer nutrients to plants grown in containers and in garden soil.

2. The nutrient efficiency of biopolymer horticultural systems equaled or exceeded the efficiency of synthetic controlled-release fertilizer.

Accomplishments
1. Biopolymer horticultural systems are a promising alternative to petroleum-based plastic containers and synthetic fertilizers.

2. Our results demonstrate that they can provide similar functionality, with greatly improved sustainability.
Our research team is interested in developing biobased, degradable materials that exhibit the intrinsic function of insecticides and/or insect repellents and can be used in protective garments for public health and environmental safety providers. In addition these materials can be used as protective tree coating/sleeves, and for the production of pellets that can help reduce the effects of the spread of mosquito larvae in standing water. One of the key finds was the development of the knowledge on how to manufacture these materials without denaturing their chemical structures in order to retain their functionality.

**Outcomes**
1. The project measured the materials' thermal-mechanical properties to provide insight into the compounding of biobased and degradable materials with natural insect repellents without thermal degradation of the various components.

2. Processing conditions and formulations were investigated to produce fibers with insecticide functionality; the insect repellent efficacy was determined with contract irritancy assay to repel Yellow Fever mosquitoes (Aedes aegypti adult females).

**Accomplishments**
1. The biobased and degradable fibers with intrinsic insecticide functionality can be used in producing a range of disposable garments to protect environmental and health protection staff.

2. The materials' thermal-mechanical properties match standardized material characteristics for product design.
Thrust 5

MODELING

This thrust studies energy and mass transfer for typical processing techniques such as extrusion and injection molding. The long-term goal is to develop models based on fundamental principles that can be used across a wide range of applications.
Interfacial healing of bioplastics is critical in primary processing, such as weld line (net line) formation in injection molding or in secondary operations such as welding and sealing of bioplastic components. Understanding how these novel materials join together provides designers, engineers, and manufacturers with the fundamental knowledge they need to produce biobased, sustainable materials with high quality and consistency that meet the demands of industry.

**Outcomes**
1. This project measured the activation energy of auto-adhesion of several grades of Polylactic acid (PLA) to allow the prediction of healing of PLA interfaces.

2. Transient models based on first order principles were used to predict heat generation in welding and, coupled with finite element models, temperature fields in various welding processes.

**Accomplishments**
1. The outcomes allow designers, engineers, and manufacturers to predict healing of bioplastic interfaces for the sustainable manufacture of plastic products.

2. The coupled models facilitate the production of parts via primary and secondary processes with enhanced quality and consistency. This knowledge gives manufacturers the confidence to utilize novel sustainable materials.
Costs and environmental performance of plastics continue to be topics important to both industry and consumers. Our research has focused on life-cycle assessments (LCA) and techno-economic analyses (TEA) in order to understand material and processing costs and environmental impacts of using various fillers in polylactic acid (PLA) composites. We have examined organic fillers such as DDGS, flax, hemp, rice husks, and wood, and compared these against common inorganic fillers such as glass and talc.

Outcomes
1. Our work has quantified costs, emissions, and energy intensities associated with raw materials acquisition, processing, transport, and end-of-life treatments.

2. Environmental impacts have included global warming potential, air acidification, air eutrophication, water eutrophication, ozone layer depletion, air smog, carcinogens, and non-carcinogens.

Accomplishments
1. Overall we found that use of organic fillers results in lower costs and environmental impacts compared to use of inorganic fillers.

2. This research has shown that utilizing landfill as end-of-life treatment for glass-filled components can be the most environmentally harmful option and resulted in the highest cost.

3. Alternatively, both DDGS and wood filler composites paired with recycling end-of-life treatment were shown to have the lowest environmental impacts and the lowest cost of all PLA composites considered.
Outcomes

Publications


• CB² and Bioplastics in Cropping Systems, D. Grewell, Agricultural Film 2015 International Industry Conference on Silage, Mulch, Greenhouse and Tunnel Films Used in Agriculture 29 September – 1 October 2015, Barcelona, Spain.

• Bioplastics and Biocomposites and Applications, D. Grewell, North Dakota State University, Fargo, ND, May 2015.

• Extrusion Processing and Characterization of Hydroxypropylated Corn Starch Films, H. Kim, J. Jane, B. Lamsal, Corn Utilization and Technology Conference, June 6–8, 2016, St. Louis, MO.


• Center for Bioplastics and Biocomposites: Bringing Industry and Universities Together to Develop New Biobased Products and Technologies, M. R. Kessler, Composites at Lake Louise, November 8–12, 2015, Alberta, Canada.

• Sustainable Plastics and the Center for Bioplastics and Biocomposites, D. Grewell, M. R. Kessler, International Conference and Exposition on Biopolymers and Bioplastics, August 10–12, 2015, San Francisco, CA.


• Bioadvantaged Thermoplastic Elastomers at Iowa State University, Bioplastics and Biocomposites, E. Cochran, San Francisco, August 10–12, 2015.

• Corn Starch Film Properties as Affected by Plasticizers and Amylose Contents, H. Kim, J. Jane, D. Grewell, B. Lamsal, Biopolymers and Bioplastics Conference August 10–12, 2015, San Francisco.
Outcomes

Patents/Patent Applications

• Thermal Compounding of Fully Biobased Degradable Plastic with Natural Insecticide Functionality, Disclosure November 2017, ISURF 04719, D. Grewell, C. Xiang, C. Annandarajah

• Special Die Design: 3D Printed Fiber Extrusion Die with Special Opening Shapes with Minimal Die Swell, Disclosure November 2017, ISURF 04720, D. Grewell, C. Xiang, C. Annandarajah


• Methods and Processes of Catalytic Conversion of Lignocellulosic Sugar Derived 1,2-Propanediol into Different Monomers, Disclosure October 2016, C. Liu, J. Xin, J. Zhang, M. R. Kessler

Products

• Agave Fiber Composites

The team worked with Ford Motor Company, Hyundai Motor Group, Diageo, and ARaymond to develop a biobased composite that had superior strength, weight properties, and LCA benefit compared to traditional composites, allowing the automotive industry to manufacture more efficient vehicles and upvaluing coproducts (agave fibers) from the adult beverage industry.
• **Multifunctional Biobased Pots**

CB² related projects were instrumental in developing and commercializing a novel pot design for growers. The pots are:

1. Fully biobased
2. Degradable
3. Self-fertilizing with no petrochemical fertilizer additions
4. Able to increase vegetable yield by 100% because of enhanced root ball morphology (stops root circling)

The team included center researchers, Laurel Biocomposites, and SelfEco which now sells the product through Walmart and Amazon. The project was leveraged with a USDA, Specialty Crops Research Initiative (award # 2011-51181-30735) grant.
Appendix

What Are Bioplastics?

Bioplastics come in many flavors. They can be designed to be as durable as many petrochemical plastics or to degrade under certain environmental conditions. This makes them very versatile and able to meet a wide range of industry needs.
Common Bioplastics and Biobased Content

The biobased content for various bioplastics can vary depending on the type of plastic as well as the source/manufacturer. The table below summarizes the common bioplastics and their typical biobased content.

Research Experience for Undergraduates (REU)

Each year, 10 students (recruited primarily from academic institutions with limited STEM research programs) work on research conducted by the CB², with 5 students conducting their research at Washington State University and 5 students doing their research projects at Iowa State University.

During the program, the students participate in a series of bioplastics short courses, take on responsibility for an independent research project performed with state-of-the-art equipment and facilities, and engage with leading industry experts from the Industrial Advisory Board of the CB².
2017 Research Experience Undergraduate (REU) students

1- Nathan Glandon
2- Jacob Bowen
3- Aleesha Slattengren
4- Daniel Fortino
5- Daniel Vincent
6- Amelia Cantwell
7- Samantha Trimble
8- Anna Treppa
9- Ryan Funk
10- Nicholas Van Nest
11- Mason Moeller
Current Industry Members

3M
ADM
Bioplastics Magazine.com
Branson
Department of Ecology State of Washington
Diageo
Dukane
Evolvegolf
Ford
Hyundai Motor Group
Idaho Forest Group
Inland
We power great packaging
John Deere
Myriant
PCR
Ptt Global Chemical
Reg
Siegwerk
USDA
Affiliate Members

- Department of Agricultural and Biosystems Engineering
- College of Agriculture and Life Sciences
- Center for Crops Utilization Research
- College of Engineering
- Bioeconomy Institute

- Voiland College of Engineering and Architecture
- Composite Materials & Engineering Center
- New Materials Institute