NDSU | RESEARCH FOUNDATION

Green Technologies Available for Licensing

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'Green'

NDSU/RF uses the term "Green" to refer to a technology that results in a positive impact, to any degree, on the environment.

Clean

G r e e n

Environmentally Friendly

Green Technologies by Application

Tech No.	Green Paints and Coatings Titles
RFT-499	Polymers Derived from Bio-Diesel Waste for Road Dust Control
RFT-490	Acetoacetylated Lignin Thermosets
RFT-488	Bio-based Cyclic Carbonate Functional Resins and Polyurethane Thermosets
RFT-462	Acrylic Monomers Derived from Plant Oils—Synthesis and Use in High Value Polymers
RFT-438	Plant Oil-Based Reactive Diluents for Coating and Composite Applications
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Tech No.	Green Electronics and Sensors Technology Titles
RFT-530	Photoinitiators that Trigger Extremely Rapid and Efficient Polymer Synthesis Using UV or Visible Light
RFT-529	Renewable and Sustainable Biomass Derived Photodegradable Polymers
RFT-428	Biodegradable Soil Sensors that can be “Planted” with a Seed Mixture
RFT-311	Unique Electrospinning Process and Compositions for High Volume Silicon Nanowire Production
RFT-161	Chromophore and Polymer Capable of Detecting the Presence of Various Neurotoxins

Tech No.	Green Nanotechnology Titles
RFT-413	Vegetable Oil-Based Polymers for Nanoparticle Surface Modification
RFT-311	Unique Electrospinning Process and Compositions for High Volume Silicon Nanowire Production

Green Technologies by Application, continued

Tech No.	Green Chemistry and Materials
RFT-530	Photoinitiators that Trigger Extremely Rapid and Efficient Polymer Synthesis Using UV or Visible Light
RFT-529	Renewable and Sustainable Biomass Derived Photodegradable Polymers
RFT-514	Metal-Free Synthesis of N-Containing Compounds Using Stabilized Photoreactive Hydrazide Scaffolds
RFT-512, RFT-513	Modified Soybean Oil Derivatives as Processing Oils for Rubber Compounds
RFT-499	Polymers Derived from Bio-Diesel Waste for Road Dust Control
RFT-490	Acetoacetylated Lignin Thermosets
RFT-488	Bio-based Cyclic Carbonate Functional Resins and Polyurethane Thermosets
RFT-478	Novel Monomers from Biomass
RFT-462	Acrylic Monomers Derived from Plant Oils—Synthesis and Use in High Value Polymers
RFT-438	Plant Oil-Based Reactive Diluents for Coating and Composite Applications
RFT-430/431	Removal and Recovery of Phosphate, Selenium, and Arsenic from Water, w/potential Reuse as Fertilizers
RFT-423	Novel Polymers and Polymeric Materials Based on the Renewable Compounds, Eugenol and Iso-Eugenol
RFT-419	Removal and Recovery of Phosphate from Water Bodies and Reuse as a Fertilizer
RFT-413	Vegetable Oil-Based Polymers for Nanoparticle Surface Modification
RFT-368,452	High Performance, Bio-based Polyamides for Injection Moldable Products
RFT-311	Unique Electrospinning Process and Compositions for High-Volume Silicon Nanowire Production
RFT-318	Polymers Derived from Vegetable Oils Exhibit Increased Crosslink Density, Superior Properties
RFT-161	Chromophore and Polymer Capable of Detecting the Presence of Various Neurotoxins
Tech No.	**Green Pharmaceutical**
RFT-21	Prophylactic, Therapeutic, and Diagnostic Remedy for Treatment of Colibacillosis Infection

Tech. No.	Technology Title	Category(ies)
RFT-530	**Photoinitiators that Trigger Extremely Rapid and Efficient Polymer Synthesis Using UV or Visible Light** NDSU researchers have developed a range of Type I, Type II, and acidic photoinitiators, which provide polymerization of polyacrylate with good efficiency at low concentrations. The synthesis of photoinitiators is efficient using routine chemistry, and their structures are easily manipulated to tune for low energy (including visible) light wavelengths. These photoinitiators are each triggered by a very narrow and easily defined wavelength, making timing of polymerization easy to control (and avoiding inadvertent triggering of the reaction). The photoinitiators may be produced from either bio-based or petroleum-based starting materials, including such readily available materials as vanillin.	General Chemistry and Materials Green
RFT-529	**Renewable and Sustainable Biomass Derived Photodegradable Polymers** Worldwide efforts have been devoted to converting biomass into chemicals due to the high abundance, low cost, and renewability. Carbohydrates are of particular interest as one of its derivatives, FDCA, is one of the top 14 bio-based chemicals that can be used as a replacement in the synthesis of polyethylene terephthalate (PET). Though made from renewable resources, recyclability of the polymers has remained an issue. Sivaguru et al addressed this through the use of a nitrobenzyl phototrigger unit backbone which allows for controlled photodegradation, via UV irradiation, of biomass-derived polymers.	General Chemistry and Materials Green
RFT-514	**Metal-Free Synthesis of N-Containing Compounds Using Stabilized Photoreactive Hydrazide Scaffolds** NDSU Scientists have developed highly stable hydrazide-based scaffolds that use visible light and a metal-free process to produce molecules and polymers that contain nitrogen (positioned singly or as a pair of adjacent nitrogen atoms). This scaffold begins with a N-N bond that can be used as a catalyst to make anything from drug and specialty molecules to complex polymers. The N-N moiety allows creation of unique N-containing molecules, using visible light rather than higher energy UV. The unique approach is possible because the NDSU team as developed handling procedures that stabilize the hydrazide scaffold until a light sensitizer (such as thioxanthone) is added. The scaffold utilizes photoinduced excited state chemistry rather than ground state redox chemistry, providing substantially different end products and performance attributes as compared with compounds derived from redox chemistry.	General Chemistry and Materials Green
RFT-512 RFT-513	**Modified Soybean Oil Derivatives as Processing Oils for Rubber Compounds** There has been growing commercial and industrial interest in biodegradable and renewable materials over petroleum-based materials. Particularly, soybean oil is widely used due to its availability and low cost. Chisholm et al have determined that appropriate modification of soybean oil results in materials for use as a processing oil for rubber compounds. They show, through numerous examples, that the use of unmodified soybean oil reduces key mechanical properties, such as moduli and tensile strength when compared to conventional petroleum-based processing oils. However, rheological and mechanical properties can be substantially improved by 1) styrenating the soybean oil or 2) producing a higher molecular weight liquid from soybean oil (ex: sucrose soyate and soy-based oligomer). Thus, soybean oil can be used as the basis for a bio-based and green alternative to petroleum-based oils for rubber compounds	General Chemistry and Materials Green
RFT-499	**Polymers Derived from Bio-Diesel Waste for Road Dust Control** Scientists at NDSU have developed a new material that can be applied to gravel roads for suppression of road dust. The material is made from the huge waste stream that is generated during the production of biodiesel which is primarily glycerol and biodegradable or bio-derived fatty acid esters. The new material is made up of mono- and di-gylcerides that are synthesized from a combination of waste glycerol and soybean oil triglycerides. Upon application to the road surface, the glycerides undergo crosslinking reactions to form a larger, more stable molecule.	General Chemistry and Materials Green

Tech. No.	Technology Title	Category(ies)
RFT-490	**Acetoacetylated Lignin Thermosets** Lignin is a key component of woody plants, the most abundant aromatic bio-polymer in nature, and is made up of a mixture of aromatic alcohols, the monolignols, as opposed to carbohydrate monomers. Commercially, lignin is sourced from wood products and is a direct byproduct of the pulping process to convert wood into wood pulp and extract cellulose. However, it is currently treated as a waste product which limits its use. Webster et al have identified another use through the acetoacetylation of lignin to develop bio-based resins. The lignin can be used directly from the pulping process or be depolymerized first and is an excellent source of terrestrial carbon that can be developed into thermoplastic and thermo-setting polymers. Acetoacetylation of lignin results in a resinous liquid.	General Chemistry and Materials Green
RFT-488	**Bio-based Cyclic Carbonate Functional Resins and Polyurethane Thermosets** There has been growing interest in bio-based resins due to the foreseeable limit of fossil feedstocks and increasing environmental concern. Additionally, polyurethanes are widely used commercially but rely on petroleum-based materials and utilize isocyanate, which is hazardous. Webster et al. have developed a novel bio-based material that can be reacted with amines to form polyurethanes using a non-isocyanate route, and thus are safer than current systems. Specifically, the resins contain a high number of cyclic carbonate groups synthesized from the reaction of epoxidized sucrose fatty acid ester resin with carbon dioxide. Further, these resins are prepared from epoxidized sucrose fatty acid esters from different vege-table oils and can be fully or partially carbonylated.	General Chemistry and Materials Green
RFT-478	**Novel Monomers from Biomass** The majority of biomass polymers, when broken down into their constituents, consist of cellulose derived sugars of 5 or 6 carbon atoms and lignin-derived aromatic building blocks. These building blocks are relatively highly oxidized and thus, without further chemical conversion, are not well-suited for fuels and chemicals. Scientists at NDSU have recently invented novel methods for the conversion of renewable resources to feedstock chemicals. The lignin and cellulose degradation products are converted to higher quality monomers through certain chemical reactions for use in polymer synthesis.	Chemistry and Materials
RFT-462	**Acrylic Monomers Derived from Plant Oils - Synthesis and Use in High Value Polymers** Scientists at NDSU have developed a one-step method to convert plant oil into acrylic monomers that substitute for petroleum-based monomers in the production of acrylic polymers. This method can use essentially any plant oil, animal fat, or other fatty esters as the raw material. The output is a combination of (meth) acrylic fatty monomers that can be used directly in the production of latexes, adhesives, surfac-tants, sizing agents, resins, binders, and other products that utilize acrylic polymers. Additionally, the NDSU monomers contain two types of double bonds. The one within the acrylic group is reactive in con-ventional addition free radical polymerization, which allows formation of linear polymers. The double bonds within the fatty chain remain unaffected during free radical polymerization, so remain available for oxidative cross-linking and additional tuning of the polymer performance characteristics. This is in con-trast to existing plant oil based monomers, which produce non-linear branched and cross-linked poly-mers (because their fatty chain double bonds participate in the polymerization).	Chemistry and Materials
RFT-438	**Plant Oil-Based Reactive Diluents for Coating and Composite Applications** NDSU scientists have developed plant oil-based reactive diluents for coating and composite applications that possess both low viscosity and high reactive functionality. With these improved characteristics, these plant oil-based materials eliminate or reduce the need to be blended with petrochemicals thereby increasing the bio-based content of the product, which is environmentally more desirable. The funda-mental aspect of the invention involves transesterification of a plant oil triglyceride with an alcohol that also contains at least one double bond. By completely replacing the glycerol component of the plant oil triglyceride with three equivalents of the unsaturated alcohol, fatty acids esters are produced containing at least one double bond that is not derived from the parent plant oil. Depending on the application re-quirements, a low-cost, bio-based unsaturated alcohol can be used to produce the reactive diluents of the invention.	General UV Curable Bio-Based Green

Tech. No.	Technology Title	Category(ies)
RFT-430/431	**Removal and Recovery of Phosphate, Selenium, and Arsenic from Water, w/ Potential Reuse as Fertilizers** Scientists at NDSU have developed a technology that removes selenium, arsenic, trichloroethylene and phosphorus from water using beads containing reactive nano zero valent iron (nZVI) particles encapsulated in calcium alginate beads. When charged with phosphorus or selenium, these beads can be beneficially reused to provide phosphate and/or micronutrient fertilization. Therefore, the technology provides dual benefits of cleaning eutrophic and contaminated water bodies and waste streams, while collecting some of the contaminants (selenium and phosphate) with the potential of reuse in a form that facilitates this reuse.	**Chemistry and Materials**
RFT-428	**Biodegradable Soil Sensors that can be "Planted" with a Seed Mixture** Scientists working at NDSU are developing biodegradable sensors capable of directly monitoring and reporting the soil environment in which they are placed. The sensors are constructed by using NDSU's patent-pending "direct write" electronic printing techniques to print circuit and antenna patterns directly onto renewable, bio-based materials. The circuit patterns are printed with trace amounts of metallic materials such as aluminum that are safe for the soil when the sensors naturally biodegrade over time. The Sensing Earth Environment Directly (SEED) sensors are self-contained and could be deployed directly into the soil during the seeding process by mixing the sensors in with the seed mix being planted. A reading device mounted beneath an agricultural vehicle would interact with the SEED sensors embedded in the soil and provide direct measurements of soil conditions, moisture, and chemical content in real time. **Licensed Exclusively in all Fields of Use and in all Territories**	**Agriculture** **Electronics and Sensors** **Bio-Based**
RFT-423	**Novel Polymers and Polymeric Materials Based on the Renewable Compounds, Eugenol and Iso-Eugenol** Due to the finite supply of fossil resources and the growing environmental concern, there is a major need for chemicals and materials derived from renewable resources. Aromatic building blocks, such as phenols, are particularly important and can be derived from renewable sources. Chisholm et al are the first to convert eugenol and iso-eugenol into vinyl ether monomers via reaction of the hydroxyl group. The result is soluble, processable linear polymers that retain the allyl group for crosslinking reactions and incorporation of other functional groups.	**General** **Chemistry and Materials**
RFT-422	**Blocked Bio-Based Carboxylic Acids and Their Use in Thermosetting Materials** Scientists working at NDSU have discovered a way to make vinyl-block bio-based carboxylic acid crosslinkers for epoxy resins that are particularly useful for vegetable oil based epoxy resins. The resulting coatings have an excellent combination of hardness, flexibility, adhesion, and solvent resistance.	**General** **Bio-Based**
RFT-419	**Removal and Recovery of Phosphate from Water Bodies and Reuse as a Fertiziler** Scientists at NDSU have developed biodegradable iron-containing alginate beads that remove phosphorus from water, and can then be beneficially reused to provide Phosphate fertilization. As a result, this dual-use technology can be used to clean water bodies that are eutrophic due to excess phosphorous, then use the phosphorous for fertilization in agricultural, nursery, and greenhouse settings where phosphorus is a limiting nutrient.	**Chemistry and Materials**

Tech. No.	Technology Title	Category(ies)
RFT-413	**Vegetable Oil-Based Polymers for Nanoparticle Surface Modification** Researchers at NDSU have developed a new plant-oil-based polymer technology focused on the application of nanoparticle suspension in water. One primary example of this technology's application is its use as a protectant, while dispersing and suspending FeNPs in decontamination efforts involving chlorinated hydrocarbons, such as tetrachloroethylene. The copolymers described herein are not only high effective with respect to suspending nanoparticles in water, but also exhibit high biodegradability. Biodegradability is important for environmental applications because the polymer is typically not recovered after treatment of a ground water contaminant plume. In addition, compared to other approaches, this copolymer technology enables compositions to be highly tailored or optimized for a given nanoparticle and application.	Chemistry and Materials Nanotechnology Green
RFT-368 RFT-452	**High Performance, Bio-based Polyamides for Injection Moldable Products** Scientists working at NDSU have discovered a method for making thermoplastics for injection molding that are based, in part, on renewable resources. Unlike other bio-based polyamides, these possess the high melting temperatures, fast crystallization rates, low moisture uptake, and good mechanical properties associated with engineering thermoplastics. These polymers can be used to replace the petroleum-based nylon 6,6 and nylon 6 for high end injection molding applications such as the electronic and automotive parts.	Chemistry and Materials
RFT-365	**Bio-Based Toughening Agent for UV-Curable Coatings and Thermoset Polymers** Scientists working at NDSU have developed branched and hyperbranched oligomers derived from a combination of soybean and cashew nutshell oils (CNSL). These oligomers can be either UV-cured (for coatings) or thermally cured (to produce thermoset polymers). Coatings incorporating this hyperbranched material had improved adhesion and impact resistance, because the coatings were both strong and flexible. This material can be used in anti-corrosion coatings and sealants, composites, inks, and adhesives, as well as directly in thermoset polymers. These oligomers impart improved material properties compared to current bio-based materials, and in some cases exhibit properties superior to even their petroleum-based counterparts.	Coatings: Architectural UV-Curable Bio-Based
RFT-349	**Fast UV-Curing of Anti-Corrosion and Anti-Stain Coatings with High Bio-Based Content** NDSU Scientists have developed a UV-curable anti-corrosion coating for metal and wood substrates. The coating is curable in 30 to 60 seconds at room temperature under UV light. Coating components include well-known materials, including a UV-responsive photoinitiators, acrylated plant oil (providing hydrophobicity and contributing to physical barrier), and hyperbranched polyester (providing physical barrier to moisture). Variations on this basic formula can be developed and optimized for specific substrates and environmental conditions to create highly functional anti-corrosion coatings with a high bio-based content.	Coatings: UV-Curable Bio-Based Anti-Corrosion
RFT-335	**Bio-Based Coatings Based on Monomer-Grafted Alkyd Ester Resins** Scientists at NDSU have synthesized monomer-grafted sucrose ester resins by polymerizing styrene in the presence of the sucrose ester resins. At a composition of 50% styrene-50% sucrose ester, coatings had extremely fast track free drying times, similar to a commercial styrenated alkyd resin. However, the styrenated sucrose ester resin had a much lower viscosity than the commercial resin, meaning that higher solids coatings can be prepared. In addition, water dispersible resins were prepared by grafting a mixture of styrene and acrylic acid with the sucrose ester resin. These could be cross-linked with a melamine-formaldehyde resin to yield coatings that had good hardness, adhesion, and flexibility.	Coatings: Architectural UV-Curable Bio-Based

Tech. No.	Technology Title	Category(ies)
RFT-318	**Polymers Derived from Vegetable Oils Exhibit Increased Crosslink Density, Superior Properties** NDSU Scientists have invented a novel soybean based polymer polyVESFA (vinylether of soybean oil fatty acids) that has been shown to exhibit several superior properties from conversional soybean oil. polyVESFA has many more fatty ester branches per molecule than soybean oil that can be used to great advantage for many applications such as coatings and composites. PolyVESFA has been shown to exhibit superior mechanical properties, modulus, hardness, chemical resistance, corrosion resistance and stain resistance. Besides these characteristics, polyVESFA exhibits reduced shrinkage upon cure and enhanced adhesion capabilities due to its higher molecular weight and higher number of fatty ester branches. Additionally, polyVESFA offers tremendous potential for desirable tailoring of the polymer as it can be copolymerized with other vinyl ether monomers.	**Coatings:** **Architectural** **Bio-Based** **Chemistry and Materials**
RFT-314	**Bio-Based Functional Resins and Thermoset Materials with Excellent Mechanical Properties** NDSU Scientists have synthesized highly functional epoxy resins from the epoxidation of vegetable oil esters of polyols having 4 hydroxyl groups per molecule. These epoxy resins can be cured using UV photo-initiators into hard coatings. The novel epoxy resins can also be incorporated into formulations containing oxetanes, cycloaliphatic epoxies, and polyols. The photo-polymerization rate is significant-ly higher for these novel epoxy resins when compared to conventional epoxidized vegetable oil.	**Coatings:** **Architectural** **UV-Curable** **Bio-Based**
RFT-311	**Unique Electrospinning Process and Compositions for High-Volume Silicon Nanowire Production** This is a unique synthetic routes to a novel liquid silicon precursor, cyclohexasilane (Si6H12), which is converted to silicon nanowires by electrospinning. Readily purified by distillation, the liquid nature of Si6H12 allows the development of a high-volume electrospinning route for silicon nanowire produc-tion. Because the spun wires convert to amorphous silicon at relatively low temperatures, formation of excessive surface oxide and carbide phases can be avoided which would otherwise negatively affect capacity and rate capabilities. The technology can be used in the development of anodes for use in next-generation lithium ion batteries, in which the traditional carbon-based anode is replaced with a silicon-based anode for a dramatic increase in capacity (theoretically over 1100% increase in capacity).	**Electronics** **Nanotechnology** **Chemistry and Materials**
RFT-179	**Novel Environment Friendly Coatings for Bio-Medical Applications** This invention pertains to the synthesis of a formulation that has combined biocidal and foul release activities in a single polymeric compound. The formulation is a unique environmentally friendly coating that holds promise in both marine and medical applications. It consists of biocidal moieties that are tethered to its polymer matrix, which in turn prevent them from leaching into the environment. The mechanical properties of these coatings are similar to silicone elastomers, yet the coating con-tains biocidal moieties to deter settlement of organisms. To inhibit leaching of toxic components into the water, biocide moieties are tethered to the polymer matrix.	**Coatings:** **Marine** **Biomedical**
RFT-161	**Chromophore and Polymer Capable of Detecting the Presence of Various Neurotox-ins** This NDSU-developed invention is a dual-use technology that was initially reported under the spin electronics program funded by Department of Defense. The "spintronics" polymer is being tested for use in applications such as increased electronic or computer memory. However, this same material was also used by NDSU in sensor tests. The material provides an optical alert when it comes in contact with metallic poison such as insecticides that are in the same family as nerve gas and neurotoxins.	**Electronics/ Sensors** **Chemistry and Materials**

Tech. No.	Technology Title	Category(ies)
RFT-140	**Total Chromium-Free Primer Coating for Corrosion Protection** Since the early 1980's, the use of chromates and other chromium-containing compounds have been subject to stringent regulations due to their recognized carcinogenic properties. In an attempt to find a substitute for widely used chromium-based primer coating products, scientists at North Dakota State University have invented a novel, chrome–free primer coating with proven anti -corrosive properties on metal substrates The use of this primer eliminates risks associated with handling toxic and carcinogenic chromium metallic compounds, and alleviates waste disposal hazards. This invention has been proven to be the only technology that protects high strength Aluminum alloys from corrosion, without the need of any chromate pretreatment or pigmentation.	**Architectural** **Anti-corrosion**
RFT-133	**Novel Environment Friendly Coatings for Marine Applications** Proprietary and novel, silicone-based compounds (and methods for synthesis), some of which incorporate tethered biocide moieties (for marine applications), have been developed that can be used in coating formulations to prevent or reduce fouling by marine life and related substances on ship surfaces.	**Coatings:** **Marine**
RFT-26	**Novel Environmentally Safe Coatings for Ceramer Films Based on Unsaturated Oil** This NDSU invention is a ceramer precursor coating composition which can be used to form ceramer coatings having high tensile modulus and tensile strength while exhibiting a relatively moderate strain-at-break value. The coating composition includes an unsaturated oil stock and a sol-gel precursor which includes a mixture of at least two different sol-gel precursor species. The use of two sol -gel precursors has resulted in superior film properties over the use of a single sol-gel precursor. Examples of suitable mixed metal sol-gel precursors include mixtures which contain at least one titanium and one zirconium sol-gel precursors. Examples of unsaturated oil stock suitable for use in forming the coating composition are linseed oil, tung oil, perilla oil, sunflower oil, soybean oil, fish oil, and dehydrated castor oil, as well as mixtures of these components.	**Coatings:** **Architectural**
RFT-21	**Prophylactic, Therapeutic, and Diagnostic Remedy for Treatment of Colibacillosis Infection** Scientists at North Dakota State University have cloned and sequenced the iss (increased serum survival) gene from virulent avian Escherichia coli strains and expressed its encoded ISS polypeptide sequence. This has enabled them to conduct studies in understanding the gene's potential and devise strategies to detect and control the colibacillosis infection that the gene is believed to cause. This invention pertains to the application of this study in formulating DNA vaccines and immunogenic compositions for providing adequate prophylactic, therapeutic and diagnostic remedies against the colibacillosis infection in humans and avian organisms. Applications of this invention could be in: Veterinary: Avian DNA vaccine for colibacillosis (in chickens, turkeys, waterfowl) and potential diagnostics. Human: Potential human vaccine against urinary tract infections caused by E. coli.	**Pharmaceutical**

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