Environment and Natural Resources Trust Fund
2019 Request for Proposals (RFP)

Project Title: **ENRTF ID: 177-E**

Plastics from Unused Lignin in Plants and Trees

Category: E. Air Quality, Climate Change, and Renewable Energy

Sub-Category:

Total Project Budget: $ 998,000

Proposed Project Time Period for the Funding Requested: June 30, 2022 (3 yrs)

Summary:

Profitable conversion of cellulose to fuels and chemicals has not been achieved from lignocellulose in forest and agricultural residues. Now, plastics composed almost entirely of lignin will provide necessary revenue.

Name: Simo Sarkanen

Sponsoring Organization: U of MN

Title: Professor

Department: Bioproducts & Biosystems Engineering

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Web Address

Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

Profitable conversion of cellulose to fuels and chemicals has not been achieved from lignocellulose in forest and agricultural residues. Now, plastics composed almost entirely of lignin will provide necessary revenue.

_____ Funding Priorities	_____ Multiple Benefits	_____ Outcomes	_____ Knowledge Base
_____ Extent of Impact	_____ Innovation	_____ Scientific/Tech Basis	_____ Urgency
_____ Capacity Readiness	_____ Leverage	_____ TOTAL	_____%
____ If under $200,000, waive presentation?			

PROJECT TITLE: Plastics from Unused Lignin in Plants and Trees

I. PROJECT STATEMENT

- **We will create useful plastics from the lignin** that makes up **15–30% of the dry material in** stems, stalks, trunks and limbs of **all plants and trees**. Our raw material will be the lignocellulose (lignin–cellulose composite) in agricultural residues and forest residuals.
- **We will bring profitability to processing plant materials and wood** in biorefineries. Other people will produce fuels and organic chemicals from the cellulose and hemicelluloses after separating them from the lignin. **We will produce plastics containing 90% levels or more of the unused lignin**.
- **Currently, we are the only research group with the necessary knowledge** for putting this into practice. Our lignin-based plastics are state-of-the-art materials that are dark in color. They will be suitable for automobile dashboards, stackable chairs, computer consoles, residential-insulation foams, and many other applications.
- **Our lignin-based plastics will match or surpass the mechanical behavior of polyethylene and polystyrene produced from petrochemical sources**. When discarded properly (with some carbohydrate) and ***only*** then, these new **lignin-based plastics** from plant materials and wood are **biodegradable**. On the other hand, polyethylene and polystyrene cause serious pollution because they are very resistant to biodegradation.
- **Minnesota's environmental heritage**. To minimize climate change, more liquid fuels, chemicals and plastics need to be produced from renewable sources. The lignocelluloses in plant materials and wood are promising options. We will bring profitability to processing lignocellulose: **we have overturned a serious mistake** (namely, the concept of lignin polymer-chain crosslinking) **made in lignin research 60 years ago**.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: Compositions for useful plastics containing 90–100% levels of lignin. Formulations for plastics with 90–100% lignin content will be created by solution-casting techniques. We will examine kraft lignin from a pulp mill; gamma-valerolactone (GVL) lignin from a biorefinery; wheat straw lignin from farms. Outcomes will be evaluated by standard mechanical tests, differential scanning calorimetry (DSC), dynamic mechanical analysis (DMTA), and X-ray powder diffraction. The results will pave the way to Activity 2.

Choice of lignins: Kraft lignins are co-products from the most common types of U.S. pulp mills that make paper from wood chips; GVL lignins will be co-products from the first biorefineries that convert corn stover, maple and pine ***profitably*** into liquid fuels and chemicals; wheat straw is one of the most abundant agricultural residues in the U.S. and Europe.

ENRTF BUDGET: $384,000

Outcome	Completion Date
1. Kraft lignin-based plastics matching polyethylene or polystyrene in mechanical behavior	*06/30/2020*
2. GVL lignin-based plastics matching polyethylene or polystyrene in mechanical behavior	*06/30/2020*
3. Wheat straw lignin plastics that match polyethylene or polystyrene mechanically	*06/30/2020*

Activity 2: Protocols for injection-molding lignin-based plastics. (***Importance***: injection-molding is one of the two most common methods for manufacturing plastic pieces and articles.) Compositions of plastics will be optimized with respect to the best injection-molding conditions. Outcomes will be evaluated by standard mechanical tests of plastic pieces, differential scanning calorimetry (DSC), dynamic mechanical analysis (DMTA), and X-ray powder diffraction. The outcomes will lead to formulations for toughening in Activity 3.

ENRTF BUDGET: $382,000

Outcome	Completion Date
1. Formulations for kraft lignin plastics that match polyethylene or polystyrene in mechanical behavior (work concurrent with activities leading to outcomes 2 and 3)	*06/30/2021*
2. Formulations for GVL lignin plastics that match polyethylene or polystyrene in mechanical behavior (work concurrent with activities leading to outcomes 1 and 3)	*06/30/2021*
3. Formulations for wheat straw lignin plastics that match polyethylene or polystyrene in mechanical behavior (work concurrent with activities leading to outcomes 1 and 2)	*06/30/2021*

Activity 3: Improvements in toughness of articles made from injection-molded plastics with very high lignin contents. In addition to evaluating results from standard mechanical tests, differential scanning calorimetry (DSC), dynamic mechanical analysis (DMTA), and X-ray powder diffraction, the impact resistance of polypropylene will be a benchmark of success in the overall project.

ENRTF BUDGET: $232,000

Outcome	Completion Date
1. Impact resistance of kraft lignin plastics matching that of polypropylene (work concurrent with activities leading to outcomes 2 and 3)	*06/30/2022*
2. Impact resistance of GVL lignin plastics matching that of polypropylene (work concurrent with activities leading to outcomes 1 and 3)	*06/30/2022*
3. Impact resistance of wheat straw lignin plastics matching that of polypropylene (work concurrent with activities leading to outcomes 1 and 2)	*06/30/2022*

III. PROJECT PARTNERS:

A. Partners receiving ENRTF funding

Name	Title	Affiliation	Role

B. Partners NOT receiving ENRTF funding

Name	Title	Affiliation	Role
George Huber	Professor	University of Wisconsin	Provider of GVL lignins

IV. LONG-TERM IMPLEMENTATION AND FUNDING:

As our project nears completion, our work will be sufficiently far advanced that the private sector (companies and/or entrepreneurs) will be taking an interest in bringing lignin plastics to the market place. Articles can take many forms, ranging from automobile dashboards through stackable auditorium chairs to garden furniture, etc. Consumers will find the "green" provenance of such items to be a particularly attractive feature. The equipment purchased with ENRTF funds will continue to be used intensively in developing lignin plastics formulations for a growing range of applications.

V. TIME LINE REQUIREMENTS: Each of the Activities 1, 2 and 3 consist of three concurrent sections of work focused on three contrasting lignin preparations. Although the means to the respective outcomes will be significantly different, the results from each will provide insights into solving problems encountered in the other two sections.

2019 Proposal Budget Spreadsheet

Project Title: Plastics from Unused Lignin in Plants and Trees

IV. TOTAL ENRTF REQUEST BUDGET: *3* years

BUDGET ITEM (See "Guidance on Allowable Expenses")	**AMOUNT**
Personnel: (other personnel categories may be used as needed)	**$ 609,000**
1 Researcher 6 (100% time for 3 years): development of plastics from kraft and GVL lignins; laboratory management; 74.9% toward salary, 25.1% toward benefits	$ 276,000.00
1 postdoc (100% time for 3 years): development of wheat straw lignin-based plastics; 82.4% toward salary, 17.6% toward benefits	$ 191,000.00
1 graduate research assistant (50% time for 3 years): development of plastics from biorefinery lignins; 58.4% toward salary, 41.6% toward benefits (including tuition)	$ 142,000.00
Professional/Technical/Service Contracts:	$ -
Equipment/Tools/Supplies:	**$ 369,000**
Supplies ($45,000) such as chemical reagents, solvents and laboratory consumables, etc.	$ 45,000.00
Haake MiniCTW Compounder ($111,514) to *produce plastics test pieces* ; Beckman Avanti JXN-26 centrifuge with rotors ($54,865) for *separating solids from solutions* ; Instron Model 5942 Testing System ($43,482) and Ceast 9050 Impact Test Machine ($36,955) *for plastics mechanical testing* ; TA Instruments Q850 Dynamic Mechanical Analyzer ($76,420) for *characterizing thermal response of plastics* ; desktop computer to operate mechanical testing equipment ($850)	$ 324,000.00
Acquisition (Fee Title or Permanent Easements):	$ -
Travel:	$ -
Additional Budget Items:	**$ 20,000**
Laboratory Services ($14,000) for plastic compostion optimization.	$ 14,000.00
Equipment repair and maintenance	$ 6,000.00
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	**$ 998,000**

V. OTHER FUNDS *(This entire section must be filled out. Do not delete rows. Indicate "N/A" if row is not applicable.)*

SOURCE OF FUNDS	**AMOUNT**	**Status**
Other Non-State $ To Be Applied To Project During Project Period:	$ -	
Other State $ To Be Applied To Project During Project Period:	$ -	
In-kind Services To Be Applied To Project During Project Period: Unrecovered F&A	$ 340,000	*secured*
Past and Current ENRTF Appropriation:	$ -	
Other Funding History:	$ -	

LIGNIN-BASED PLASTICS will lead to profitable conversion of residues from agriculture and forestry concurrently to materials, fuels & chemicals.

small logs & forest residuals

N.G. Lewis, Washington State University

wheat straw

www.ecn.nl/nl/nieuws/newsletter-en/

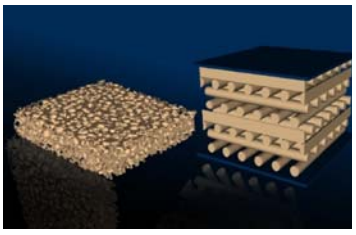
corn stover

Troy Walz, University of Nebraska-Lincoln

Lignin-based Plastics

Broad Range of Plastic Products

automobile dashboard; http://kinlane.com



3-D printed foam; doi:10.1038/srep24871

CD jewel case

insulation foam; www.foambymail.com

plastic chair, True Value

computer console, mainlinecomputer.com

Reduced Climate Change, Less Pollution from Plastics, Better Environmental Stewardship

SIMO SARKANEN

Professor, Bioproducts and Biosystems Engineering, University of Minnesota

Overview: As a faculty member at the University of Minnesota, Simo Sarkanen has over 30 years of research experience in lignin chemistry and biochemistry. With his coworkers, he has sought to: create the first thermoplastics in which simple lignin derivatives are the predominant active components; isolate the first enzyme that may qualify as a true lignin depolymerase; develop the first comprehensive working hypothesis for a mechanism through which lignin macromolecules could undergo replication as they are biosynthesized.

Patents:

Compositions Including Lignin and Methods for Making the Same: Chen, Y.-r.; Sarkanen, S. **2018**, U.S. Provisional Patent Application No. 62/645,940, filed March 21.

Compositions Including Lignin: Chen, Y.-r.; Sarkanen, S.; Wang, Y.-Y. **2015**, International Patent Application No. PCT/US2015/020599, filed March 13. U.S. National Stage Application No. 15/125,380 filed September 12, **2016**; assigned United States Patent Publication Number 2017/0166749 A1 June 15, **2017**.

Lignin Degrading Methods and Compositions: Chen, Y.-r.; Sarkanen, S.; Wang, Y.-Y. *U.S. Patent* **2017**, *No. 9,796,993* issued June 21**.**

Publications (Selected Publications Relevant to Proposed Research):

Wang, Y.-Y., Chen, Y.-r., Sarkanen, S., Blend configuration in functional polymeric materials with a high lignin content. *Faraday Discuss.* **2017**, *202*, 43-59.

Sarkanen, S.; Chen, Y.-r.; Wang, Y.-Y., Journey to polymeric materials composed exclusively of simple lignin derivatives. *ACS Sustainable Chem. Eng.* **2016**, *4*, 5223-5229.

Wang, Y.-Y., Chen, Y.-r., Sarkanen, S., Path to plastics composed of ligninsulphonates (lignosulfonates). *Green Chemistry* **2015**, *17*, 5069-5078.

Chen, Y.-r., Sarkanen, S., Wang, Y.-Y., Lignin-degrading enzyme activities, in *Methods in Molecular Biology: Biomass Conversion*, M.E. Himmel (ed.), Humana Press, New York, **2012**, pp. 251-268.

Chen, Y.-r., Sarkanen, S., Macromolecular replication during lignin biosynthesis. *Phytochemistry* **2010**, *71*, 453-462.

Chen, Y.-r., Sarkanen, S., From the macromolecular behavior of lignin components to the mechanical properties of lignin-based plastics. *Cellulose Chem. Technol.* **2006**, *40*(*3-4*), 149-163.

Li, Y., Sarkanen, S., Miscible blends of kraft lignin derivatives with low-T_g polymers. *Macromolecules* **2005**, *38*, 2296-2306.

Chen, Y.-r., Sarkanen, S., Macromolecular lignin replication—a mechanistic working hypothesis. *Phytochemistry Reviews* 2003, *2*, 235-255 ©**2004**.

Li, Y., Sarkanen, S., Biodegradable kraft lignin-based thermoplastics. In *Biodegradable Polymers and Plastics*, E. Chiellini, R. Solaro (eds.), Kluwer Academic/Plenum Publishers: New York, **2003**, pp 121-139.

Li, Y., Sarkanen, S., Alkylated kraft lignin based thermoplastic blends with aliphatic polyesters. *Macromolecules* **2002**, *35*, 9707-9715.

Nutsubidze, N.N., Sarkanen, S., Schmidt, E.L., Shashikanth, S., Consecutive polymerization and depolymerization of kraft lignin by *Trametes cingulate*. *Phytochemistry* **1998**, *49*, 1203-1212.

Li, Y., Mlynár, J., Sarkanen, S., The first 85% kraft lignin-based thermoplastics. *J. Polym. Sci. B: Polym. Phys.* **1997**, *35*, 1899-1910.