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Summary Statement: Ragauskas' Governor's Chair in Biorefining

Ragauskas heads a multifaceted program to understand and exploit the fundamental structure of municipal waste and bioresources to develop new and improved conversion pathways for sustainable fuels, power, materials, and chemicals within the circular economy while educating the next generation of leaders. The program leverages the unique research infrastructure and expertise located on the campuses of the Oak Ridge National Laboratory (ORNL), University of Tennessee, Knoxville (UTK), and the University of Tennessee Institute of Agriculture (UTIA). Ragauskas' research thrusts focus on four central overlapping focus areas:

- Fundamental investigation of the structure of lignocellulosics and their relationship to biological biorefining of biomass to biofuels
- Valorization of biomass components for bio-derived materials
- Development of new tools and methodologies for biomass characterization
- Upcycling of societal waste streams.

Ragauskas assumed the ORNL-UTK Governor's Chair in Biorefining in June 2014 and was renewed in October 2019. This UTK faculty position, jointly funded by UTK and ORNL, was envisaged to develop a fundamental research and academic program for sustainable biomass biorefining. His research-educational thrusts are pursued and developed within the boundaries of a circular economy.

Figure 1: Overview of Ragauskas' ORNL, UTK, and UTIA Governor Chair in Biorefining.

Historically, the bio-economy was frequently viewed from the "lens of biorefining bioresources from forest and agricultural resources" to serve society's needs, which by default are centered in major metropolitan centers. Over the last decade, this vision of producers and consumers has evolved, as captured by the circular economy (see **Fig. 1**), in which products are manufactured to be used, recycled, and reused. Thus, the bio-economy and Ragauskas' studies have been broadened to utilize virgin biomass resources and waste streams from industry and the general population. The outcomes of Ragauskas studies over the past 4.5 years have been documented in +239 publications, three patent filings, +60 conference presentations, and the graduation of four UTK Ph.D. students. Reflective of these studies, Ragauskas has a Google H-Index of 129 and was the 2022 awardee of the *RSC Environment, Sustainability, and Energy Division open award: Environment Prize.*

Significant Research Contributions: To address evolving research and educational challenges in biorefining-circular economy, Dr. Ragauskas has developed a dynamic, internationally recognized ORNL-UTK-UTIA research team in the field of fundamental (i) biorefining of lignocellulosics, (ii) green chemistry/engineering, (iii) material science of bio-derived materials, and (iv) valorization of modern societal waste streams.

Figure 2 provides a descriptive breakdown of Ragauskas' publication portfolio as determined by the Web of Science. This analysis provides a quantitative description of the breadth of Dr. Ragauskas' research portfolio. These results reflect the multidisciplinary nature of his research program as a Governor's Chair. **Figure 3** provides an analysis of Ragauskas' UTIA-UTK collaborative publications via UTK Elements and a publication network analysis for 2020-2024. These results demonstrate a strong publication partnership between UTIA and UTK researchers (**Figure 3a**), and **Figure 3b** highlights the integration of our research studies with the BSD/ORNL research mission. (NB: BSD/ORNL mission focuses on advancing science and technology to better understand complex biological systems and their relationship with the environment. The division has expertise and special facilities in genomics, computational biology, microbiology, microbial ecology, biophysics, structural biology, and plant sciences. This collective expertise includes collaborations within and outside ORNL and focuses on scientific challenges in biology for Department of Energy (DOE) missions in energy and the environment.)

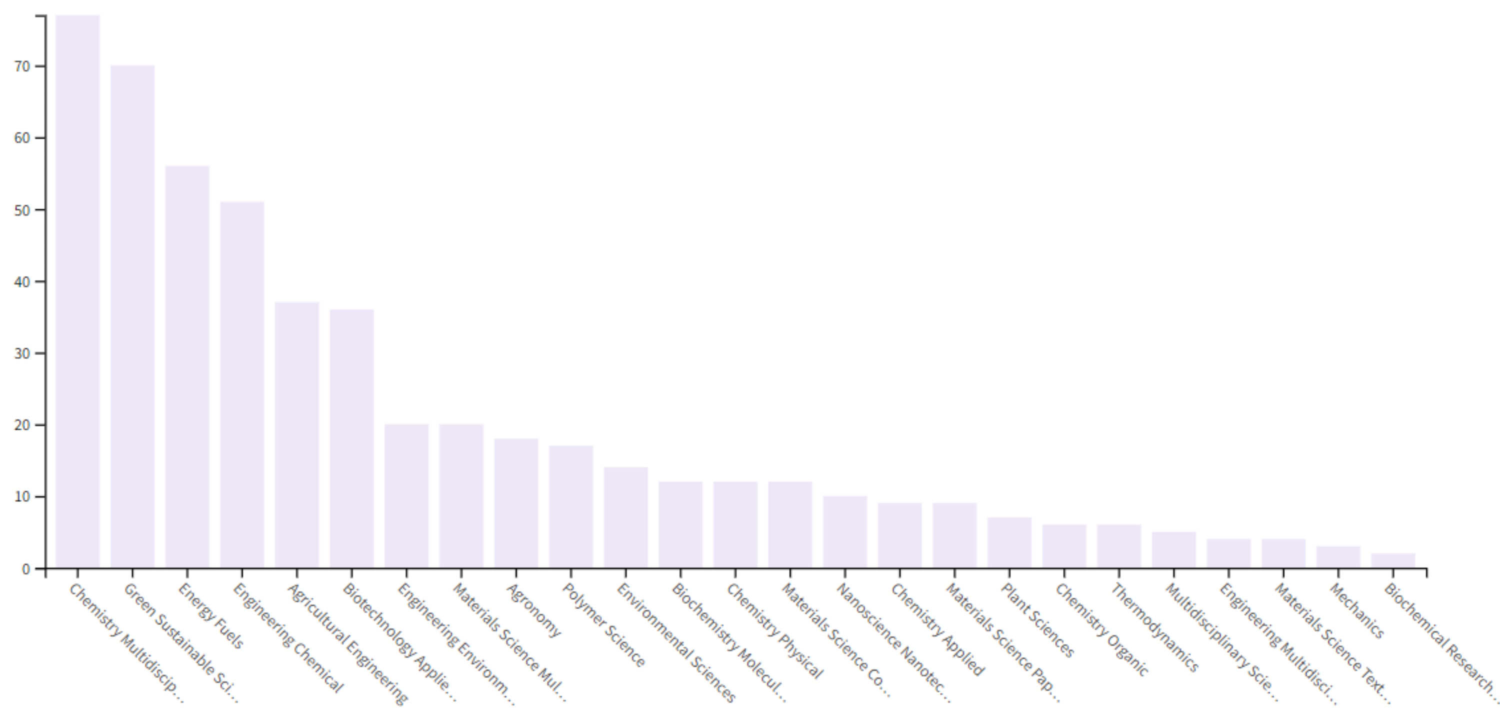

Figure 2: (a) Description of Ragauskas' publication disciplinarity distribution as determined by Web of Science for 2020-2024.

Figure 4 summarizes Ragauskas' biorefining research focus. **Figure 5** illustrates his circular economy research focus, which covers the spectrum of utilizing virgin bioresources and waste products for sustainable generation of fuels, chemicals, and materials.

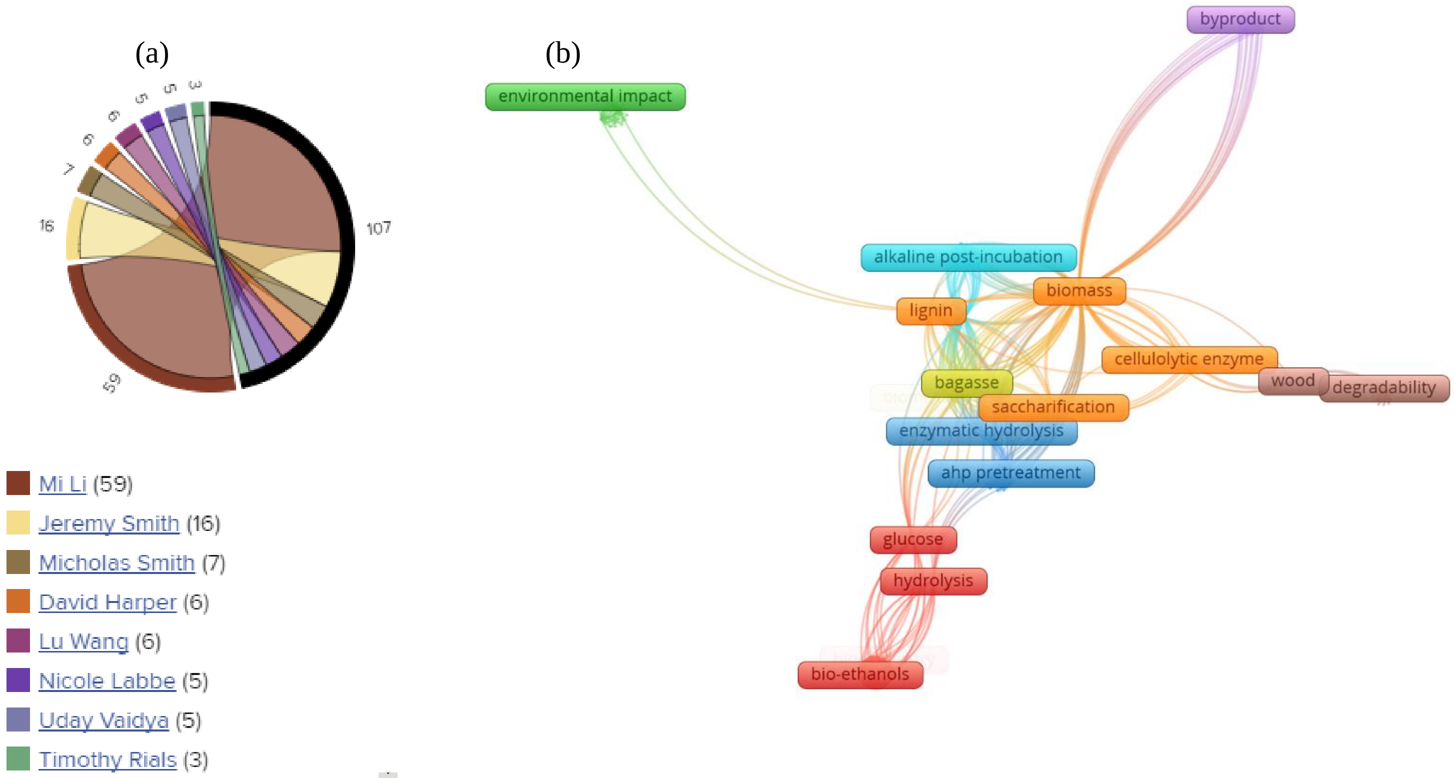

Figure 3: (a) Element analysis of Ragauskas UTK-UTIA publication interactions and (b) network analysis of 2020-2024 Ragauskas publications.

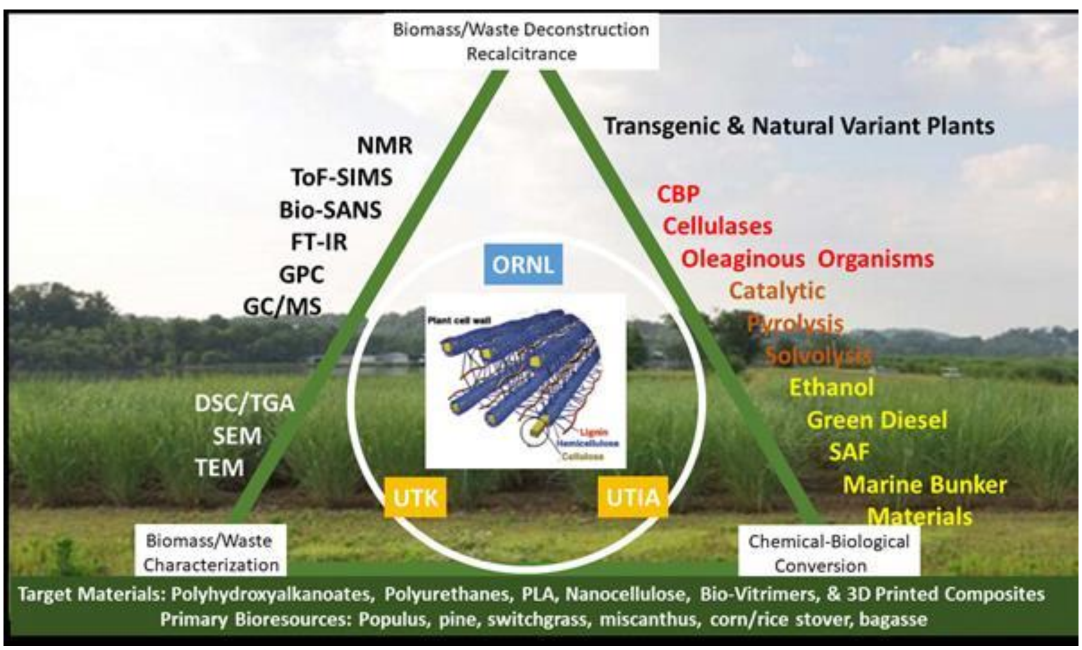

Figure 4: Ragauskas' biorefining studies.

Figure 4 demonstrates a strong emphasis on advanced analytics and biofuel research, which is consistent with Ragauskas' contributions to the Center of Bioenergy Innovation (CBI) and Science Focus Area (SFA, titled' Visualization of Solvent Disruption of Biomass and Biomembrane Structures in the Production of Advanced Biofuels and Bioproducts') DOE-funded programs centered at ORNL. As shown in **Figure 5**, our circular economy studies are primarily directed at upcycling waste streams for sustainable generation of chemicals, fuels, and materials. Both focus areas leverage ORNL, UTK, and UTIA research infrastructure and expertise. (NB: our coal material studies are directed at providing value-added alternatives to the combustion of coal)

Figure 5: Ragauskas' circular economy studies.

***ORNL Focused Activities**:* Five selected publications representing Ragauskas' 2020-2024 Governor's Chair research efforts at ORNL are summarized below:

1. Economics and global warming potential of a *commercial*-scale delignifying biorefinery based on cosolvent-enhanced lignocellulosic fractionation to produce alcohols, sustainable aviation fuels, and biomass co-products. Klein, Bruno Colling; Scheidemantle, Brent; Hanes, Rebecca J.; Bartling, Andrew W.; Grundl, Nicholas J.; Clark, Robin J.; Biddy, Mary J.; Tao, Ling; Trinh, Cong T.; Guss, Adam M.; Wayman, Charles E.; Ragauskas, Arthur J.; Webb, Erin G.; Davison, Brian H.; Cai, Charles M., *Energy & Environmental Science* (2024), 17(3), 1202-1215.
2. Characterization and molecular simulation of lignin in cyrene pretreatment of switchgrass. Wang, Yun-Yan; Wang, Yunxuan; Liang, Luna; Smith, Micholas Dean; Meng, Xianzhi; Pu, Yunqiao; Mazarei, Mitra; Agarwal, Rupesh; Rukmani, Shalini J.; Davison, Brian H.; Ragauskas, Arthur J. *Green Chemistry* (2024), 26(6), 3170-3182
3. Novel candidate genes for lignin structure identified through genome-wide association study of naturally varying *Populus trichocarpa*. Bryant, Nathan; Zhang, Jin; Feng, Kai; Shu, Mengjun; Ployet, Raphael; Chen, Jin-Gui; Muchero, Wellington; Yoo, Chang Geun; Tschaplinski, Timothy J; Pu, Yunqiao; Ragauskas, Arthur J. *Frontiers in Plant Science* (2023), 14, 1153113.
4. Deconstruction of biomass enabled by local demixing of cosolvents at cellulose and lignin surfaces. Pingali, Sai Venkatesh; Smith, Micholas Dean; Liu, Shih-Hsien; Rawal, Takat B.; Pu, Yunqiao; Shah, Riddhi; Evans, Barbara R.; Urban, Volker S.; Davison, Brian H.; Cai, Charles M.; Ragauskas, Arthur J.; O'Neill, Hugh, M.; Smith, Jeremy; Petridis, Loukas. *Proceedings of the National Academy of Sciences of the United States of America* (2020), 117(29), 16776-16781.
5. Tensile properties of 3D-printed wood-filled PLA materials using poplar trees. Bhagia S; Lowden RR; Erdman D; Rodriguez M; Haga BA; Solano IRM; Gallego NC; Pu Y; Muchero W; Kunc, V; Ragauskas AJ. *Applied Materials Today* (2020) 21, 100832.

Publications 1 and 3 represent Ragauskas' collaborative efforts within the BioEnergy Science Center (BESC) and Center of Bioenergy Innovation (CBI). Publication 1 presents a techno-economic and life cycle analysis of a hybrid biorefinery strategy that integrates several leading biochemical and catalytic processes to maximize the utilization of lignocellulosic biomass and produce commercially relevant biofuels and bioproducts. High-fidelity computer models were assembled to evaluate the impact of feedstock and co-product selection on the biorefinery's overall economics and global warming potential. Central to this biorefinery model is the application of a mild co-solvent enhanced lignocellulosic fractionation (CELF) pretreatment as the first step to non-destructively fractionate biomass into clean hemicellulose sugars, cellulose, and lignin intermediates which are funneled to a suite of downstream conversion technologies to yield alcohols, esters, carboxylic acids, and hydrocarbons as co-products.

The results provide in-depth work aimed at providing feedback to different R&D teams to guide further experimental development, for which TEA/LCA can inform minimum performance thresholds to be attained at the laboratory scale in a circular workflow model. (NB: We have published extensively on CELF chemistry, for example, co-solvent-enhanced lignocellulosic fractionation tailoring lignin chemistry and enhancing lignin bioconversion.[1]

To investigate the variability and underlying genetic basis of the complex structure of lignin (Publication 3), a population of 409 three-year-old, naturally varying unique *Populus trichocarpa* genotypes which were characterized by heteronuclear single quantum coherence (HSQC) nuclear magnetic resonance (NMR). A subsequent genome-wide association study (GWAS) was conducted using approximately 8.3 million single nucleotide polymorphisms (SNPs), which identified 756 genes that were significantly associated with at least one lignin phenotype. Several promising candidate genes have been identified, many of which have not been previously reported to be associated with lignin or cell wall biosynthesis. These results provide a resource for gaining insights into the molecular mechanisms of lignin biosynthesis and new targets for future genetic improvement in poplar, and demonstrate a new methodology to integrate NMR lignin analysis with plant genetics.

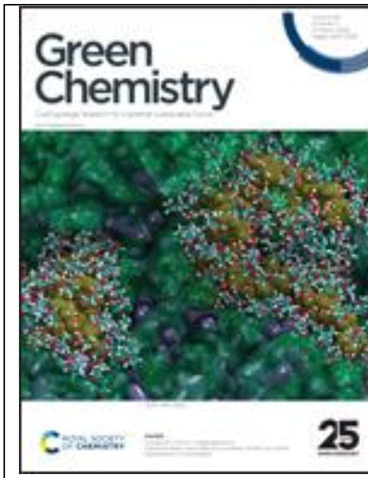

Figure 6: Molecular simulation of switchgrass lignin with Cyrene.

Publications 2 and 4 are representative of our SFA studies directed at determining the fundamental interactions between the pretreatment solvent and plant cell wall structures at elevated temperatures. Our studies highlighted the unique benefits of Cyrene for pretreatment, which indicated correlations between pretreatment conditions,recovery and structural modification of lignin. Switchgrass lignin extracted by Cyrene pretreatment possessed high preservation of β-O-4 ether inter-unit linkages, which could provide versatility in integrating downstream lignin valorization into modern biorefinery industries.

Molecular modeling examined the solvation of switchgrass lignin and the disaggregation of low-molecular-weight lignin aggregates under pretreatment conditions, indicating that a preferential interaction exists between Cyrene and lignin, which likely drives lignin release and that the disruption of inter-lignin contacts can be modulated as a non-monotonic function of Cyrene:water ratio. Furthermore, while Cyrene–lignin interactions permit lignin solubilization, simulations with proxy reactive species reveal that changes to the diffusion of these reactive proxies and their localization near linkage sites under Cyrene conditions may inhibit chemical processes. Our journal coversheet invitation highlights these findings, as summarized in **Figure 6**

Publication 4 extends this research approach to integrate neutron scattering data and molecular dynamics simulations to reveal temperature-dependent morphological changes in poplar wood biomass during tetrahydrofuran(THF):water pretreatment and provides a mechanism by which the solvent components drive efficient biomass breakdown. Although lignin dissociates over a wide temperature range (>25 °C), cellulose disruption only occurs above 150 °C. Neutron scattering with contrast variation provides direct evidence of the formation of THF-rich nanoclusters on nonpolar cellulose surfaces, hydrophobic lignin, and equivalent water-rich nanoclusters on polar cellulose surfaces. The disassembly of amphiphilic biomass is thus enabled through the local demixing of highly functional cosolvents, THF, and water, which preferentially solvate specific biomass surfaces to match the local solute polarity. A multiscale description of the efficiency of THF water pretreatment is provided, and matching polarity at the atomic scale prevents lignin aggregation and disrupts cellulose, leading to improvements in deconstruction at the macroscopic scale and establishing a unique insight that can be garnered by neutron analysis coupled with molecular modeling.

Finally, publication 5 represents a new research thrust directed at linking unique genotypic variations among Populus trichocarpa and PLA/Populus composite tensile properties. Through the use of seventy unique poplar samples in 3D printing, physical testing indicated median values of 50 MPa tensile strength at yield, 48 MPa tensile strength at break, 1.6% strain% at yield, 2.1% strain% at the break, and 3.65 GPa Young's modulus were observed. Statistical analysis showed the significant effects of natural diversity among the poplar structural properties on the tensile strength and Young's modulus of the 3D-printed PLA poplar materials. These findings provide a new methodology for genetically tailoring plant cell-wall properties for composite applications. Historically, research efforts in this field have mainly been Edisonian in nature, screening hundreds of biomass samples, isolated by numerous separation technologies, and incorporated into composites using extrusion, compression molding, injection molding, sheet extrusion, film blowing, and more recently, 3-D printing techniques. Our results developed a novel approach for selecting specific genotypes for specific composite phenotypes.

These key discoveries were made possible by collaboration between researchers from (1) the Center for Molecular Biophysics, BioSciences Division, and Neutron Scattering Division at ORNL, (2) the Chemical and Biomolecular Engineering Department/UTK and Center for Renewable Carbon/UTIA; and (3) Ragauskas team members. These findings provide a valuable tool for researchers to tune the structures of lignin, cellulose, and hemicellulose for a variety of chemical, biological, and material applications. We highlight these opportunities in several reviews.[2,3,4]

UTK/UTIA Focused Activities: In addition to these activities, Ragauskas has developed several UTK-UTIA research thrusts leveraging ORNL capabilities, as summarized in five representative publications presented below:

1. 3D printed lignin/polymer composite with enhanced mechanical and anti-thermal-aging performance. Zhang, Shuyang; Meng, Xianzhi; Bhagia, Samarthya; Ji, Anqi; Dean Smith, Micholas; Wang, Yun-yan; Liu, Bo; Yoo, Chang Geun; Harper, David P.; Ragauskas, Arthur J. *Chemical Engineering Journal* (2024), 481, 148449.
2. Catalytic cascade upcycling single-use natural rubber glove wastes into fuels via a two-stage pressurized fixed-bed reactor. Wang, Jia; Jiang, Jianchun; Meng, Xianzhi; Lam, Su Shiung; Ragauskas, Arthur J.; Wang, Yanqin. *Fuel Processing Technology* (2022), 238, 107490.
3. Upcycling disposable face masks into fuel range iso-alkanes through hydropyrolysis coupled with vapor-phase hydrocracking. Wang, Jia; Jiang, Jianchun; Zhang, Yiyun; Meng, Xianzhi; Ragauskas, Arthur J. *Energy* (2023), 263(Part_B), 125843.
4. A facile strategy to fabricate a lignin-based thermoset alternative to formaldehyde-based wood adhesives. Shi, Xiaoyu; Gao, Shishuai; Jin, Can; Zhang, Daihui; Lai, Chenhuan; Wang, Chunpeng; Chu, Fuxiang; Ragauskas, Arthur J.; Li, Mi. *Green Chemistry* (2023), 25(15), 5907-5915.
5. Influence of plasticizers on thermal and mechanical properties of biocomposite filaments made from lignin and polylactic acid for 3D printing. Wasti, Sanjita; Triggs, Eldon; Farag, Ramsis; Auad, Maria; Adhikari, Sushil; Bajwa, Dilpreet; Li, Mi; Ragauskas, Arthur J. *Composites, Part B: Engineering* (2021), 205, 108483.

Publication 1 is representative of our studies to advance bio-derived 3D printed composites by tailoring the structure of lignin to enhance compatibility with copolymers. In this study, demethylated hardwood lignin was used to introduce more phenolic hydroxyl groups to improve interfacial interactions. Research studies on rheological behavior and molecular simulations have demonstrated that an increased phenolic hydroxyl content could improve the adhesion between the modified lignin and the polymer matrix at the interface. Hence, the tensile performance of the samples from the fused depositional modeling 3D printing technique was improved owing to the improved interfacial adhesion between the lignin and nylon. This publication is one of the first to show that the addition of lignin significantly enhances the physical strength performance of lignin composites. As documented in publication 5, we can further improve the interfacial lignin-polymer interactions by introducing plasticizers. Although commonly used in modern plastics, this additive effect has been overlooked in lignin-based composites. Along with our 3D printing studies, we are actively investigating other lignin-based materials, given their carbon negativity, abundance, and low cost. In terms of thermosets, we are actively pursuing the development of lignin vitrimers and crosslinked lignin materials. Publication 4 examined thermosets composed of alkali lignin and poly(propylene glycol) bis(2-aminopropyl ether) (D2000) to prepare particleboards. During hot-pressing, lignin and D2000 formed crosslinked networks containing ionic and covalent bonds, leading to particleboards with high internal bonding strength, high biomass content, and low toxicity. Previous studies using bio-based adhesives have faced challenges in achieving high biomass content and IB strength; however, this study outperforms many of the reported results.

Publications 2 and 3 are indicative of our research efforts to utilize plastic waste streams to generate fuel and chemicals. To generate fuel-range cycloalkanes and isoalkanes from natural rubber glove wastes (NRGWs), rubber depolymerization was performed by integrating hydropyrolysis with vapor-phase hydrogenation over a bifunctional Ni/Al_2O_3-SiO_2 catalyst. Isoprene and limonene were the primary alkenes obtained from the non-catalytic hydropyrolysis of NRGWs, and these intermediates were vapor-phase hydrotreated over Ni/Al_2O_3-SiO_2, producing C10 cycloalkanes as the dominant species. These results demonstrate that upcycling polymer waste by cascade hydropyrolysis-hydrogenation is promising for the delivery of alternative fuels with improved properties. Using the same approach, hydropyrolysis coupled with vapor-phase hydrocracking was utilized to convert disposable face masks to iso-alkanes with gasoline selectivity, as summarized in Publication 3. These studies demonstrate a unique catalytic pyrolysis conversion process involving cascade hydropyrolysis and hydrocracking, which exhibits high adaptability and flexibility in upcycling single-use syringes, food packaging, and plastic bags, generating fuel range iso/n-alkanes.

Research Projects and Five-Year Plan: Our research activities are supported by research funding from DOE, ARPA-E, DARPA, SERDP, ORNL, USDA NIFA, and Sun grant. They are forward-looking and directed at developing fundamental science and engineering to advance next-generation biorefining operations that address circular economy challenges. We have leveraged critical assets on the ORNL, UTK, and UTIA campuses to develop unique solutions and understanding of biomass and its conversion to biofuels, bio-based chemicals, and materials. These advances have come due to our partnerships with researchers from several departments, including:

- ORNL: Neutron Sciences, Chemical Sciences, BioSciences Division, Computational Systems Biology, and Manufacturing Demonstration Facility
- UTK: Chemical Biomolecular Engineering, Department of Plant Sciences
- UTIA: Center for Renewable Carbon

We remain one of the leading groups in biomass characterization and valorization of cellulose and lignin, both nationally and internationally. Based on our past accomplishments and ongoing research efforts, two Center proposals have been submitted to (1) NSF: Global Center for Sustainable Bioproducts (NB: Selected for funding) and (2) DOE: Assessment of CORE-CM Resources in Eastern Coastal U.S. Waste Streams. We have been and will continue to strongly support ORNL's SFA and CBI's research mission, working with plant scientists and deconstruction teams to characterize and understand the key plant cell wall features that contribute to recalcitrance. In addition, as our nanocellulose/lignin and related material studies at UTK/UTIA mature, we anticipate leveraging ORNL's SNS, computational science, and plant science expertise in joint proposals.

Integration: Ragauskas' research activities at ORNL, UTK, and UTIA are seamlessly integrated, as our learnings of the plant cell wall in CBI/ORNL guide our material research studies at UTK/UTIA. Likewise, our SFA/ORNL studies are directed at advanced biomass pretreatments, which guide our efforts on lignin valorization, which is also critical for our material research at UTK/UTIA. Our material studies are also being used to guide next-generation plants for biomass valorization at the ORNL. Ragauskas' students and postdoctoral fellows benefit from these interactions, as they have gained experience with unique ORNL analytical tools that represent state-of-the-art research capabilities. In addition, they gain experience working in large intradisciplinary national research teams, which several Ragauskas team members have highlighted as a competitive advantage after graduation and entering the labor market. As Governor's Chair and Acting Head of CBE, Ragauskas has championed cross-collaboration between ORNL and UTK/UTIA; these accomplishments include Dr. B. Davison/ORNL delivering a seminar to CBE (2023), Assistant Professor R. Corder/CBE utilization of SNS facilities, Prof. C. Trinh continued partnership with CBI, serving on Circular Bioeconomy Systems UTORII assistant professor search committee, and encouraging CBE faculty to submit proposals to UTORII rfp.

Educational Mission

Although Ragauskas' current position does not require a teaching component, a core value of his academic mission is that a professor can only be as successful as the students he educates, mentors, and graduates. As such, Ragauskas' academic mission has been and remains a cornerstone of his career objectives. These career objectives include the following.

- Develop a challenging and enriching educational and research experience that facilitates the intellectual development of UTK/UTIA students and postdoctoral fellows and supports the mission of the Department of Chemical and Biomolecular Engineering and the Center for Renewable Carbon.

- Recruit, educate, and develop the next generation of scientists who will be nationally and internationally recognized leaders in biorefining, green chemistry/engineering of biofuels, bio-derived materials, chemicals, and circular economy chemical processes.

As such, Dr. Ragauskas presented a graduate 600 course to CBE graduate students (2024) titled 'Best practices and strategies to employed for publishing high impact scientific papers.' The course covered an advanced understanding of the technical approaches used to (1) identify a target manuscript, literature searching, (2) writing a research manuscript and/or review manuscript, and (3) understanding the journal submission processes, and responding to reviewers.

In Ragauskas' course and graduate mentoring programs, he strives to develop a teaching/learning format tailored to students' needs and to engage them to achieve intellectual excellence and growth. This goal is pursued by an integrated constellation of activities, including critical thinking, analysis of the literature, innovation, constructive support and feedback, teaching and research skills, research integrity, and professional and long-term career development skills.

Although postdoctoral research fellows supervised by Ragauskas are at different stages in their academic careers, he continues to provide a supportive and stimulating environment, enabling the researcher to learn the essential methodologies, concepts, and culture of chemical engineering while performing high-quality research. Postdoctoral research fellows are introduced into the broader context of biorefining, and the relevant communities of scholars learn how to prepare conference presentations, manuscripts, and technical reports, engage with research funding sponsors, and, most importantly, have a strong sense of research integrity. These efforts are directed at helping position researchers for future careers, both within and outside academia. For instance, Dr. C.G. Yoo, his former ORNL postdoctoral research fellow (2015-2018), published 32 peer-reviewed journal articles and 1 book chapter during his ORNL postdoctoral training under Ragauskas. He received the Supplementary Performance Award at ORNL in 2016 and was selected as an honoree in the 2017 UT-Battelle Award Night Program as a result of research supported by Ragauskas. Dr. Yoo is currently an Associate Professor at the State University of New York Syracuse - College of Environmental Science and Forestry. Dr. M. Li, former Ragauskas postdoctoral fellow, is currently an Assistant professor at CRC/UTIA. Dr. Bhagia, a graduate student from UCR, was a research postdoctoral fellow in the Ragauskas group, transitioned to an ORNL research scientist, and recently transitioned (2024) to PlantSwitch, a leading company renowned for his profound contributions to bioprocess technologies and biomass conversion to bio-derived materials.

Similarly, other postdoctoral fellows also successfully secured positions at different research institutes, colleges, and industries after training with Ragauskas (see CV for post-career outcomes after UTK/ORNL postdoctoral research fellow experience).

Summary of post-doc, graduate student, and undergraduate mentoring/support: During the research period 2020-2024, Ragauskas' program involved:

- Eight Ph.D. and two undergraduate students in the Department of Chemical & Biomolecular Engineering, UTK
- Four postdoctoral research fellows, eight visiting research scientists, and students
- Three research scientists at ORNL and UTK.

In addition, Ragauskas has acted as an external Ph.D. Thesis opponent for:

- Invited by Prof. S. Jayalalitha to review the Ph. D. thesis of Ms. Bhuvaneswari, SASTRA Deemed University, Thanjavur-613 401, India (2023)
- Invited by Prof. David Lokhat to review Student Adeolu Abiodun Awoyale's thesis titled "Bioethanol Production from Excess Food Crops in Nigeria: Process Design, Optimization, and Techno-Economic Analysis." School of Chemical Engineering University of KwaZulu-Natal (2021)
- Invited by Prof. Dr. Magda Ali Akl, Analytical Chemistry, Student name Wael Ibrahim, Thesis title "Studies on Modifications of Some Selected Natural Fibers for the Removal of Some Environmental Pollutants." Chemistry Department, Faculty of Science, Mansoura University, Mansoura, Egypt (2020)
- Invited by Professor M. Monier, Student name: Wael Mohamed Ibrahim Ali, Thesis title: "Studies on Modifications of Some Selected Natural Fibers for the Removal of Some Environmental Pollutants." Chemistry Department, Faculty of Science, Mansoura University, Mansoura, Egypt (2020).

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[1] Cosolvent enhanced lignocellulosic fractionation tailoring lignin chemistry and enhancing lignin bioconversion. Zhao, Zhi-Min; Meng, Xianzhi; Scheidemantle, Brent; Pu, Yunqiao; Liu, Zhi-Hua; Li, Bing-Zhi; Wyman, Charles E.; Cai, Charles M.; Ragauskas, Arthur J. Bioresource Technology (2022), 347, 126367).

[2] Applications of biomass-derived solvents in biomass pretreatment - Strategies, challenges, and prospects. Meng, Xianzhi; Wang, Yunxuan; Conte, Austin J.; Zhang, Shuyang; Ryu, Jiae; Wie, Jeong Jae; Pu, Yunqiao; Davison, Brian H.; Yoo, Chang Geun; Ragauskas, Arthur J. Bioresource Technology (2023), 368, 128280.

[3] Emerging Strategies for Modifying Lignin Chemistry to Enhance Biological Lignin Valorization. Zhao, Zhi-Min; Liu, Zhi-Hua; Pu, Yunqiao; Meng, Xianzhi; Xu, Jifei; Yuan, Joshua S.; Ragauskas, Arthur J. ChemSusChem (2020), 13(20), 5423-5432.

[4] Transgenic Poplar Designed for Biofuels. Bryant, Nathan D.; Pu, Yunqiao; Tschaplinski, Timothy J.; Tuskan, Gerald A.; Muchero, Wellington; Kalluri, Udaya C.; Yoo, Chang Geun; Ragauskas, Arthur J. Trends in Plant Science (2020), 25(9), 881-896