Exhibit D

Research Project Requirement Template

Replacing Fossil Fuel-Based Asphalt Binder with Sustainable Lignin Binder from Wastes

Recipient/Grant (Contract) Number: 69A3552348306 (CY1-LTU-OU-LSU-01)

Center Name: Southern Plains Transportation Center (SPTC)

Research Priority: Improving the Durability and Extending the Life of Transportation Infrastructure

Principal Investigator(s): Joan Lynam, Louisiana Tech University; Syed Ashik Ali, University of Oklahoma; Mostafa Elseifi, Louisiana State University; Nazimuddin Wasiuddin, Louisiana Tech University; Kenneth Hobson, University of Oklahoma.

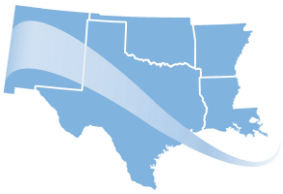
Project Partners: Louisiana Tech University (LTU), University of Oklahoma (OU) and Louisiana State University (LSU)

Research Project Funding: LTU: $48,000 (Federal) and $48,000 (Match); OU: $60,111 (Federal) and $60,111 (Match); LSU: $37,500 (Federal) and $39,322 (Match)

Proposed Start and End Date: 10/01/2023 to 9/30/2024

Project Description: With an increased focus on renewable energy nationally, the availability of fossil fuel-based asphalt binders will become an issue. Consequently, asphalt materials costs are expected to rise significantly in the future. Also, fossil fuel-based binders are detrimental to the environment. In this study, the multi-institutional research team will use an agricultural waste-based binder to partially replace fossil fuel-based binders. The PIs have recently found that a 6% replacement of fossil fuel-derived binder with a sustainably sourced binder can improve the high-temperature performance grade, long-term aging index, and resistance to rutting and cracking performance. In that study, lignin samples from local Louisiana sources, specifically lignin from a paper mill, sugar cane bagasse, and rice husks (hulls), were tested in asphalt binders up to a 6% replacement. However, that study did not include UV oxidation, low-temperature flexibility, and moisture sensitivity that are important to pavement performance. The goal of this study is to evaluate the effectiveness of using more than 6% lignin from different sources in asphalt binders as a sustainable and renewable paving material to partially replace (up to 30%) fossil fuel-based binders. Also, the performance of asphalt mixes with lignin-based binder and Reclaimed Asphalt Pavement (RAP) will be investigated using a balanced mix design (BMD) approach.

The proposed research will consist of six tasks split between the partner institutions. Task 1 (LTU lead) will examine the production of lignin from local waste sources for replacement of traditional asphalt binder. Task 2 (LTU lead) will involve incorporation of the derived lignin into binder blends at levels ranging from 8% to 35%. Task 3 (LTU lead) includes the evaluation of the rheological and chemical properties of binder blends. Task 4 (OU and LSU co-lead) will consist of the collection of aggregates and preparation of control mixes. The OU team will focus on developing BMD using the lignin binder blend and RAP. The LSU team will focus on the advanced characterization of mix fatigue and moisture-induced damage performance. Task 5 (OU lead) will include the evaluation of the performance of asphalt mixes with lignin binder blend and RAP relative to rutting, cracking, and moisture-induced damage. Task 6 (LSU lead) will include advanced laboratory characterization of asphalt mixes with the lignin binder blend to measure cracking behavior and moisture susceptibility.



US DOT Priorities: Results could facilitate additional options for binders in flexible pavements, allowing new local and sustainable materials in such mixes that are derived from waste. The lignin-modified binder is expected to improve the performance and service life of asphalt pavement. In addition, lignin-based binders will contribute to reducing environmental impacts and promoting sustainable construction practices. Through these outcomes the project will work toward supporting the USDOT goals for safer, more resilient, cost-effective transportation infrastructure. Also, graduate students will be trained in this project to become STEM researchers in advanced technologies.

Outputs: This project will help develop sustainable and renewable sources of paving materials that will provide stakeholders, including transportation agencies and manufacturers, knowledge and guidelines on using lignin-asphalt binder. The expected outputs include the following: Binder Specifications, a Balanced Mix Design from OU, and information on the sustainability of lignin-asphalt binder, as it can replace fossil fuel-based binders. This study has the potential for invention disclosure on the use of lignin-based binder as a replacement of petroleum-based binder. A final report and a 3-5-minute video containing the findings of this study will be prepared. The research team plans to conduct a workshop to share the findings with transportation agencies. Also, the findings of this study will be disseminated through international journals and conferences.

Outcomes/Impacts: If successful, this sustainable solution is expected to significantly reduce the construction cost of asphalt pavement. Also, the use of local materials is expected to enhance local economic development. In addition, this study will contribute to reducing environmental impacts from the construction industry with the use of bio/waste materials. Results from the proposed work should lead to funding from USDA since wastes originating from biomass will be sourced. Other potential sources of funding include the Louisiana Department of Transportation and Development (La DOTD) and the NSF, particularly the Division of Chemical, Bioengineering, Environmental and Transport Systems (ENG/CBET). In its Process Systems, Reaction Engineering, and Molecular Thermodynamics program, ENG/CBET is specifically interested in fundamental engineering research on the rates and mechanisms of chemical reactions as they apply to the production of specialized materials, such as this project will investigate. NSF's ENG/CBET also has an Environmental Sustainability program that funds research into sustainable engineered systems that support human well-being. The proposed project will generate preliminary data to support fundamental work in lignin chemistry, aging, and moisture sensitivity that will lead to proposal submissions to these NSF programs. Another potential funding source would be the Basic Research - Research Directorate of the Department of Defense.

Final Research Report: