Exhibit D

Research Project Requirement Template

Development of Biochar-Based Anti-Aging Agent for Carbon Neutral Durable Binder

Recipient/Grant (Contract) Number: 69A3552348306 (CY1-OU-05)

Center Name: Southern Plains Transportation Center (SPTC)

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

Principal Investigator(s): Baharak Sajjadi and Syed Ashik Ali, The University of Oklahoma.

Project Partners: University of Oklahoma

Research Project Funding: The University of Oklahoma: $48,951 (Federal) and $48,951 (Match)

Proposed Start and End Date: 10/01/2023 to 09/30/2024

Project Description: Bio-based energy production starts with pyrolysis, converting biomass to syngas, bio-oil, and biochar (BC). Carbon remains stable in BC's structure for thousands of years. Therefore, incorporating BC into asphalt binder reduces the carbon footprint of the construction industry by trapping carbon within the infrastructure. In addition, the nano-porous structure of BC allows for tailoring its surface with functional groups. The proposed project aims to develop and use the functionalized biochar to enhance the properties and performance of binder while concurrently reducing its carbon footprint. The specific objectives are to: (i) reduce the carbon footprint of binder using BCs of different properties; (ii) improve the UV and oxidative aging resistance of binder using nitrogen (N)- and phosphorous (P)-functionalized BC; and (iii) evaluate the rutting and cracking performances of asphalt mix incorporating biochar-modified binder.

The following four tasks will be pursued to achieve the objectives of this study. In Task 1, the production, characterization, and functionalization of biochar will be pursued. Also, the impact of BC on the rheological properties of asphalt binder will be evaluated. Two different biomass sources (Miscanthus and Switchgrass) will be used to produce biochar through pyrolysis. Pyrolysis will be conducted at three different temperatures (550, 650, and 750 °C) to obtain different physicochemical structures of biochar (pyrogenic, turbostratic char, and their composites). The physical structure and chemical characteristics of biochar will be examined through SEM, BET, and elemental analysis. These tests will provide essential insights into BC's porosity, surface area, carbon sequestration capability, and primary functional groups on the surface. Different blends of unaged binder and non-modified biochar will then be prepared and examined to develop a suitable mixing protocol. Different tests will be conducted at short- and long-term aged binder blends to determine rutting and cracking resistance. By analyzing the test results, the effect of the type, rate, particle size, and structure of biochar on the resistance to aging of the binders will be identified. In Task 2, the nitrogen (N) and phosphorous (P) containing functional groups will be introduced into the biochar surface and structure through a wet impregnation process. The N- and P-containing functional groups will be examined through elemental analysis. In addition, the rheological properties of the functionalized BC blended binders will be evaluated to determine their effectiveness. The chemical properties of the blends at different levels of aging will be investigated at the micro-level using an FTIR spectrometer in Task 3. The changes in carbonyl functional groups with different levels of aging will be monitored and used as a tool to evaluate the efficacy of biochar. In Task 4, laboratory testing will be conducted to evaluate biochar's influence on the performance of the asphalt mix. The

asphalt mix will be subjected to three periods of laboratory aging, namely short-, intermediate-, and long-term aging. The results from the asphalt mix tests will be compared with the binder tests to assess the efficacy of biochar as an anti-aging agent.

US DOT Priorities: Aligned with the US DOT's strategic goal to tackle the climate crisis, the use of 6% biochar in asphalt may result in sequestration of 67 mt C ~ 246 mt CO2e. Moreover, biochar and functionalization can reduce the emission of volatile organic compounds from asphalt by approximately 60%. Aligned with the US DOT's strategic goal of economic strength through increasing efficiency and reliability of transportation systems, the research team expects functionalized BC to delay the long-term aging of asphalt by 25-45%. In addition, the rutting resistance and fatigue cracking may also improve by 10 and 30%, respectively.

Outputs: The outputs of this project include the following: a final report, a 3- to 5-minute video, at least one publication in a reputed journal, at least one conference presentation, one technology transfer workshop, special provision per ODOT template for design of mixes containing biochar, and a technical note on using bio-based anti-aging agents. With respect to DEI, this project will train one graduate student to become STEM researchers in advanced technologies. Two female (PI and the graduate student) researchers will be involved for the successful completion of this project.

Outcomes/Impacts: This study is expected to open the window for collaboration with the industry and others. Considering the novelty and implementation potential of the idea, the PIs plan to leverage the SPTC support by submitting proposals to NSF, DOT, and FHWA, and seeking funding from the industry. If successful in the lab, the PIs will reach out to their industry partners to constructa field section in Oklahoma and monitor performance in the next phase of funding. Also, the product could be further improved and commercialized in collaboration with the asphalt industry. The PIs expect to develop special provisions for mix design using BC which could be used by the DOTs and asphalt industry.

Final Research Report: