Scope of Work

Project Name: Cellulose Nanocrystals as a Value-Based Additive for Low Carbon Footprint Concrete with Limestone

Principal Investigators:
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Project Abstract: This project utilizes cellulose nanocrystals (CNCs) as an additive that can aid in mixture modifications that reduce concrete's carbon footprint. The use of CNCs has been scaled for use in parking lots and a precast bridge. Laboratory tests have shown that CNCs can enhance placeability (reduce yield stress and viscosity), increase the rate and extent of reaction, and potentially improve concrete's tensile strength. The use of CNCs from woody forest material will aid in forest restoration and wildfire mitigation and offer rural economic development opportunities.

This project explores the use of CNCs (a rapidly emerging product) with Portland Limestone Cement (PLC meeting ASTM C595). It will explore the potential for even greater clinker replacement than is currently allowed by specification. Laboratory tests have shown enhanced hydration performance of the clinker occurs with CNCs. It is hypothesized that CNCs will allow greater replacement levels to further enable the concrete's embodied carbon footprint. Research will begin by evaluating the use of CNCs with ASTM C595 cements (up to 15% limestone). This work's stretch goal will be to determine if CNC can be used to design systems that reduce the embodied carbon content by 50% (from conventional ordinary Portland cement [OPC] using higher limestone content and supplementary cementitious materials like slag). The work will target a field trial to document these benefits.

Project Deliverables: During this project, the research team will characterize the raw materials and binder performance of OPC, PLC, and CNCs. Characterization will consist of chemical composition, particle size, heat of hydration, porosity, and flexural strength. This will, when possible, utilize a similar approach and materials to those used on a recent Caltrans project. The work will assess curing time and drying shrinkage using advanced techniques developed at OSU. A mixture proportioning methodology will be used that is based on thermodynamic modeling to determine the optimal properties of the mixture. An embodied carbon calculator will be used to evaluate the benefits of utilizing CNCs. Full scale field trials will be performed to assess the performance of concrete mixtures and slabs. Findings will be reported in a comprehensive report in addition to an ADA-compliant briefing document with photos (no more than 2 pages) and an ADA-compliant executive summary with major findings. Dissemination of project results will occur using appropriate wood and cement industry publications, media, and other information channels. The California Board of Forestry and Fire Protection Joint Institute for Wood Products Innovation shall be acknowledged in all information presented and/or distributed.

Budget Description: This agreement will utilize $200,000 to contract for the development and testing of CNCs as an additive for concrete. A complete budget is provided in the budget section of this report. The goal of this work is to build a body of knowledge of information that can demonstrate the role that CNCs can play in reducing the carbon footprint of PLC as compared to conventional materials. This will include the cost of the research as well as materials to fabricate, test, analyze, and disseminate results to appropriate audiences. Project findings will inform state highway agencies (such as Caltrans and other departments of transportation [DOT]) and support an expanded forest products sector in California. Costs associated with this agreement include raw materials, subject matter experts, slab placement, testing, sample disposal (as necessary), project management and coordination, and the production of a comprehensive report, an ADA-compliant briefing document with photos (no more than 2 pages), and an ADA-compliant executive summary.

Background and Justification: California has 33 million acres of forest which serves as a large carbon sink. Climate change and overstocked forests have resulted in increased wildfire size and intensity, leading to a need to increase the pace and scale of forest management and restoration activities. Cellulose nano materials (CNMs) are being developed for use in a variety of industries. The current market for CNM is estimated to be approximately 50,000 metric tons; however, less than 5% of this is CNC (i.e., 2,000 metric tons). Making a conservative estimation that CNCs could be used in 5% of the commercial, residential, and infrastructure applications of concrete, approximately 25,000 metric tons of CNC could be used annually (or nearly 10 times the annual production). Scaling up CNC production would require approximately 110,000 metric tons of woody materials. In addition to the use of forest woody materials to remove hazardous fuel sources from the forest, thereby improving forest health and wildfire resistance, this proposal can help create new markets for CNC products, promoting rural economic development.

The use of CNMs (consisting of CNCs and cellulose nano-fibrils) has been extensively studied for nearly decade. To date, the majority of the work has focused on laboratory studies with limited field test cases in concrete (sidewalk, parking lot, and bridge). This proposal outlines a plan to use CNMs in conjunction with PLCs to enable the mixtures to be redesigned to reduce the embodied carbon content of concrete. Experimental data will be developed at laboratory scale, models will be used, and full-scale elements will be evaluated.

What is being paid for, what determines the costs? Are there any outside cost factors? What are they?

This project consists of seven tasks as identified below. The work will focus on comparing three systems: OPC, PLC, and PLC + CNC. This work is described below.

Task 1: Constituent Material and Initial Mixture Characterization The first task of this project will take place over the first eight months of the project and will consist of performing testing to characterize the raw materials. Specifically, this will consist of performing calorimetery testing to assess the reacted products, rheology to characterize the impact of the PLC/CNC blends, desorption and drying studies, and B3B flexural strength testing. This work will require approximately eight months to complete and will be useful for determination of the final mixture designs for the field trial site (Task 4).

Task 2: Computational Simulation During Task 2, the research team will build on the previously developed coupled thermodynamic/kinetic modeling framework. Specifically, the research team will begin to explore the implementation of a series of papers to better understand the impact of mixture design on reducing the carbon content. The experimental results will be able to be used to extend the model to include the role of CNMs. The second task of this project will consist of performing computational modeling using thermodynamic mixture proportioning using previously developed approaches to identify the most optimal mixtures for field testing (Task 5). It is anticipated that this work will be compared, as appropriate, with results from Task 1 (during months 6 - 8). It is anticipated that this portion of the work will occur during months 6 - 8. This work will also utilize information from the embodied carbon results obtained from Task 4 to update the model during the months 12-14. The work will also investigate whether the reduction in the pore solution pH can have benefits on the CNC performance.

Task 3: Advanced Materials Performance Assessment This task will utilize a combination of drying shrinkage, desorption, and neutron radiography to assess the potential benefits of CNCs in enhancing the curing, especially in PLC mixtures which rely on the increased hydration of the clinker. This work will occur during months 9 - 14. This work will also determine whether CNCs may help to reduce drying shrinkage as a potential value-added product.

Task 4: Study of Greenhouse Gas Emission Reductions The fourth task of this work will expand upon a greenhouse gas emissions tool that was previously developed for a Caltrans funded project to now also incorporate the use of CNCs (months 9 - 14). While it will be helpful to update the model for CNCs, additional values used as inputs will be obtained when this is integrated with the mixture proportioning method in Task 2 and Task 6 to enable mixtures to be designed to reduce greenhouse gas emissions from concrete production.

Task 5: Field Planning/Placement/Monitoring The fifth task of this research will focus on developing full scale pavement slabs of sizes typically used for thin concrete overlays on asphalt using three mixture proportions (OPC, PLC, PLC+CNCs) that target the reduction of the carbon footprint. The slabs will be formed, screeded, and finished. The mixtures will be assessed through standard testing (slump, strength, finishability, hygrothermal compliance, and transport properties) as well as maturity testing. The slabs will be instrumented with sensors to measure the structural and hygrothermal response under the ambient environment actions and the cement hydration process. This will occur in months 3 - 16.

Task 6: Model Update and Comparison with Data The sixth task will focus on coordinating the results of the modeling predictions with the carbon calculator and the measured laboratory and field performance. Specifically, this work will attempt to correlate the findings with the modeling predictions. It should be noted that the software will be used to produce representative graphs that will be used in a mixture design methodology (i.e., the software itself is not a deliverable as this was developed outside this project). This will occur from months 14 - 16.

Task 7: Final Deliverables and Review A comprehensive report will be produced in addition to an ADA-compliant briefing document with photos (no more than 2 pages), and an ADA-compliant executive summary with major findings. In addition, ADA-compliant papers will be developed to document the experimental techniques and experimental results obtained as a part of this project. The results will be contextualized to share the benefits of the CNM in a manner that can be published in the open, referred literature. It is anticipated that these results will be able to be utilized to make a case for the CNM to be added to a DOT's approved material list. The work will be presented to the Joint Institute and Board per the timeline below.

Project findings are expected to inform the use of CNCs in concrete for use in California and other states, increasing the potential use of CNCs. Project outreach results will occur using appropriate wood and cement publications, media, and other information channels. The California Board of Forestry and Fire Protection Joint Institute for Wood Products Innovation shall be acknowledged in all information presented and/or distributed.

Personnel. What type and how many staff are to be utilized? What specific licenses, certifications, etc. are required?

OSU is the academic institution with whom the Board will contract for this agreement. This will require 2 PIs at OSU.

Coordination responsibilities. Who is doing what and who is responsible for what?

Board staff will oversee and support this agreement, assuring all Board responsibilities and requirements are met and that OSU receives payments and is assisted when in need of agreement support. OSU will meet all requirements and timelines set forth in this agreement.

What are the deliverables? Any reports required? What result is sought by contracting this service?

Deliverables:

- Chemical Composition and particle size for the cement used in the study.
- Quarterly progress reports.
- Calorimetry curves for OPC, PLC and PLC + CNC mixtures for use in calculation of the degree of hydration.
- Measured paste properties including B3B flexural strength, porosity, shrinkage and curing data. The goal will be to determine the influence of CNC on the properties and generate data for consideration by the Caltrans materials specification committee.
- Thermodynamic modeling data that provides constituent materials as well as reacted products for a range of mixture proportions with and without limestone addition. Work is developing outside of this project to determine what changes are needed for CNC materials in the modeling approach.

- Development of carbon footprint calculations for CNC mixtures that can be added to a recently developed approach at UC Davis.
- Arrange for samples to be cast. Monitoring the performance of the samples in terms of typical concrete properties. Documentation of results of the study include strength, porosity, transport, and carbon footprint properties.
- Presentations to the Joint Institute and Board of Forestry and Fire Protection.
- The final report will consist of an approximately 20-30 page ADA-complaint executive summary with major findings as well as an ADA-compliant briefing document with photos (no more than 2 pages), and a comprehensive report with project details that will be submitted through the OSU Kiewit Center for digital repository with a DOI. The California Board of Forestry and Fire Protection Joint Institute for Wood Products Innovation shall be acknowledged in all information presented and/or distributed. Project outreach results will occur using appropriate wood and cement publications, media, and other information channels.

How did you determine that these services cannot be performed within state service resources? Whom have you contacted?

OSU possesses unique facilities and expertise currently not available within California and whose mandate is to assist the forest products sector regionally to innovate and grow. OSU is geographically close to California and has lab space and personnel availability to be able to carry out the project within the timeframes necessary.

Timelines. What is to be done by when? Be specific. Are progress reports needed?

A Gannt chart is provided in Table 1. This research is to begin July 1, 2021. Quarterly research updates will be provided to Board staff and the Institute beginning at the end of December 2021. An initial draft of the comprehensive report, a draft briefing document with photos (no more than 2 pages), and the draft executive summary will be submitted to the Institute by November 1, 2022. The Institute-approved comprehensive draft report, executive summary, and briefing document with photos (no more than 2 pages) will be presented in person (or virtually if in-person meetings are not occurring) to the Board at their January 2023 meeting (date pending Board calendar update for 2023), with all 3 document drafts due to Board staff the Wednesday prior to the January Board meeting date for Board binder inclusion and review time. The final draft comprehensive report, draft ADA-compliant briefing document with photos (no more than 2 pages), and draft ADA-compliant executive summary will be presented to the Board for final approval at their March 2023 meeting (date pending Board calendar update for 2023), with all three final draft documents due to Board staff the Wednesday prior to the March Board meeting date. The final comprehensive report, final ADA-compliant briefing document with photos (no more than 2 pages), and final ADA-compliant executive summary shall be completed no later than March 31, 2023, with all invoices submitted no later than May 15, 2023.

Table 1: GANNT Chart Showing the Project Timeline

	2021						2022												2023					
Month	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M			
Task 1: Constituent Material/Binder Characterization	■	■	■	■	■	■	■	■																
Task 2: Computational Simulation of Mixture Design						■	■	■				■	■	■										
Task 3: Advanced Materials Performance Assessment									■	■	■	■	■	■										
Task 4: Carbon Calculator Imput Assessment									■	■	■	■	■	■										
Task 5: Field Planning/Placement/Monitoring			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						
Task 6: Model Update/Data Comparison														■	■	■	■	■						
Task 7: Final Report and Summaries Development																	■	■	■	■	■			
Submission of Draft Report and Summaries to Advisory Council						■											* 11/1	■	■	■	■			
Submission of Draft Report and Summaries to Board																			*1/10 @mtg	■	■	■	■	■
Submission of Final Draft Report and Summaries for Board Approval																					*2/24 @mtg	■	■	■
Project Deadline																					* 3/31/23	■	■	■

Evaluation. How will the contractor be evaluated and performance accepted?

Evaluation will be based on the required final comprehensive report, ADA-compliant briefing document with photos (no more than 2 pages), and ADA-compliant executive summary being delivered by the Board March 2023 meeting, with all 3 final documents approved and completed by March 31, 2023 and findings for all 7 tasks addressed as outlined in the agreement.

BUDGET

The budget for this project is $200,000. Dr. Jason Weiss will serve as principal investigator with 1.25 months of effort. He will be primarily responsible for overseeing the project, performing outreach, providing direction and feedback for the research tasks, and preparing deliverables. Dr. Burkan Isgor will serve as co-principal investigator. $50,745 will be set aside for the research and field samples in California. Materials, supplies, and/or minor equipment are budgeted for $19,555 for the life of the project. Laboratory testing will be performed that will require consumables, cement, and aggregate (CNC will be donated by the US Endowment/FPL/Blue Goose Industries etc.), cylinder molds, and formwork as well as shipping.

Table 2: Project Budget

Task	Cost
Task 1: Constituent Material/Binder Characterization	$ 18,086
Task 2: Computational Simulation of Mixture Design	$ 21,988
Task 3: Advanced Materials Performance Assessment	$ 23,320
Task 4: Carbon Calculator Imput Assessment	$ 23,099
Task 5: Field Planning/Placement/Monitoring	$ 52,908
Task 6: Model Update/Data Comparison	$ 17,809
Task 7: Final Report and Review	$ 20,061
Subtotal	$ 177,271
Overhead	$ 22,729
Total	$ 200,000