Research Stage 1 Problem Statement

PROPOSED TITLE: ***BIO-CEMENTATION AS A NATURE-BASED SOLUTION TO PREVENT COASTAL EROSION***

1. Concisely describe the transportation issue (including problems, improvements, or untested solutions) that Oregon needs to research.

Oregon's coastline is vulnerable to erosion, leading to loss of right-of-way and damage to coastal transportation infrastructure (e.g., roadways). Various armoring approaches are used to mitigate erosion. Armoring approaches may be considered "soft", such as planted grass, revetments or strategic placement of foredunes, or "hard", such as riprap or heavily-engineered structures. These soft armoring approaches are favored and more likely to have broader acceptance because they are non-intrusive to the natural scenery, however, the high wave energy environment along Oregon's coastline, particularly at Oregon's highest priority location, greatly limits their efficacy. Hard armoring approaches are effective against erosion, however, they may displace the erosion, interrupt natural sediment transport, and are potentially intrusive, both environmentally and aesthetically. Bio-cementation, specifically microbially induced calcite precipitation (MICP) or enzymatic-induced carbonate precipitation (EICP), can be deployed as a means of cementing in-place dunes and natural sands, potentially protecting against coastal erosion as a method that is more effective than soft-armoring solutions and maintains the natural coastline appearance. Essentially, bio-cementation can be an armoring approach that falls between "soft" and "hard" armoring. Research is required to investigate and, eventually, deploy bio-cementation as an erosion mitigation tool for ODOT along Oregon's coastline.

2. What final product or information needs to be produced to enable this research to be implemented?

This research will investigate bio-cementation as an erosion mitigation method for areas of Oregon's coastline. Over the last 20 years, bio-cementation has advanced from laboratory studies to field trial applications. The engineering applications investigated for bio-cementation include liquefaction ground improvement, dust mitigation, and erosion and scour protection. Bio-cementation for soils is performed by introducing a treatment solution of calcium and urea into the soil, either through surface application, trenching or subsurface injection. The treatment solution stimulates native microbes to metabolize the treatment solution and precipitate calcium carbonate that cements soil particles together. The presence of the cement between particles increases the soil's resistance to erosion and shear strength. Field trials of bio-cementation for coastal erosion have demonstrated its efficacy when deployed under field conditions for dunes and moderate slopes. Laboratory and medium-scale research indicates that bio-cementation can be effective to mitigate coastal erosion in moderate environments where a solution between "soft" and "hard" armoring is desired.

To deploy bio-cementation, research involving laboratory studies, field application, and monitoring will be required. The following information will need to be produced to implement bio-cementation against coastal erosion:

(1) Laboratory testing: A laboratory study to develop a "recipe" for the treatment solution given the specific properties of Oregon's coastal sand (e.g., grain size distribution, mineralogy) and water

chemistry (e.g., use of seawater or freshwater). The laboratory study will determine an appropriate treatment solution recipes to yield sufficiently high levels of bio-cementation.

(2) Field trial: Pending ODOT and other expert guidance, field trials at one or more sites along the Oregon coast will be a "proof-of-concept" application, as well as provide practical information on bio-cementation deployment under Oregon's field conditions. The field trials will use the recipe developed in the lab. If multiple field trials are performed, they may investigate application of bio-cementation in different coastal settings (e.g., slope steepness, slope height, wave energy), and/or with different application methods. Documented field trials generally apply the treatment solution over about 10 to 14 days, suggesting that summer or fall deployment will be optimal.

(3) Monitoring: Longevity and effectiveness of the bio-cementation will be monitored after the field trials. Monitoring will be performed with various methods, such as laser scanning to compare erosion at treated and untreated areas, physical sampling to measure depth and amount of cementation, or penetrometer resistance testing.

(4) Recommendations for Implementation: Synthesize field trials and provide guidance for implementation of bio-cemented sand as an erosion mitigation technique in context of other armoring solutions. Provide examples of applications where bio-cementation would be effective, either standalone or in combination with other mitigation techniques.

3. (Optional) Are there any individuals in Oregon who will be instrumental to the success of implementing any solution that is identified by this research? If so, please list them below.

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T. Matt Evans	Professor	matt.evans@oregonstate.edu	
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4. Other comments:

In 2019, near-prototype scale sand dunes were constructed in the Large Wave Flume at the O.H. Hinsdale Wave Research Laboratory (HWRL) on the OSU campus. Two experiments were performed. In the first, one-third of the dune was stabilized through surface application of bio-cementation (MICP), one-third was stabilized through vertical injection (MICP), and one third was untreated. The second experiment was similar, but the surface application was EICP rather than MICP. In both cases, the dunes were then subjected to scaled Hurricane Sandy wave conditions consisting of 19 sets of approximately 300 waves each with a total wave loading time of over 11 hours. Laser scans between sets and in-situ sensors indicated in all cases that the bio-cemented dunes far outperformed the untreated dunes in terms of the amount of material eroded and the persistence of elevated pore water pressures. The mass stabilization through vertical injection approach implied great promise for co-deployment with dune grass to provide a natural rather than "armored" appearance, although this was not tested explicitly.

Bio-cementation as an approach to mitigate coastal erosion has also been applied in several field trials, including in North Carolina (Ghasemi & Montoya 2022), China (Li et al 2024), Singapore (Wu et al. 2024). Notably, it was studied in North Carolina for NCDOT (Montoya 2021). These field trials showed reduced erosion rates in areas treated with bio-cementation. With successful application, a cemented crust

forms on the surface of the soil that is resistant to erosion. However, development of this crust and the crust's longevity depends on several treatment variables, including treatment solution application method and treatment solution chemistry.

This research should examine the following variables, among others, to inform future application of bio-cementation along Oregon's coast:

Application method. Various treatment application methods have been examined in past studies, including surface application, vertical drains, or trenches. The application method affects the distribution and depth of calcite precipitation of the treated soil. For example, with surficial application, the precipitated crust forms early in treatment and may prevent the treatment solution from reaching deeper soils, resulting in a shallower treatment depth compared to other application methods.

Treatment Solution. A significant aspect of the cost of bio-cementation treatment is chemicals for the treatment solution. The required treatment solution can depend on soil properties and environment. Therefore, laboratory studies can be used to investigate effective and efficient treatment solutions for application in Oregon.

Combined armoring approaches. Bio-cementation has potential to be combined with other coastal armoring approaches. For example, foredune construction could be combined with bio-cementation to increase the resilience of the foredune to erosion. Another example may be armoring slopes by placing cobbles and sand, with the sand further armored with bio-cementation. This research would result in a treatment process that is complementary to other standard erosion mitigation techniques.

Additional Applications. As a form of ground Improvement, bio-cementation could be applicable to other significant geotechnical problems such as liquefaction mitigation, subgrade stabilization, slope stabilization, and erosion control. This research would be beneficial to finding lower-cost solutions to these ongoing, expensive problems.

Relevant references:

Ghasemi, P., B. M. Montoya, T. M. Evans, and M. E. Wengrove. 2024. "Geotechnical Properties and Performance of Large-Scale Coastal Dunes Reinforced by Biocementation under Hurricane Wave Conditions." *J. Geotech. Geoenviron. Eng.*, 150 (10): 04024103. https://doi.org/10.1061/JGGEFK.GTENG-12483.

Yazdani, E., B. M. Montoya, M. Wengrove, and T. M. Evans. 2024. "Effect of Bio-Cementation on Wave-Induced Pore Water Pressure in Sand." *Geo-Congress 2024*, 20–29. Vancouver, British Columbia, Canada: American Society of Civil Engineers.

Yazdani, E., B. Montoya, M. Wengrove, and T. Evans. 2022. "Bio-Cementation for Protection of Coastal Dunes: Physical Models and Element Tests." *Geo-Congress 2022*, 406–416.

Ghasemi, P., & Montoya, B. M. (2022). "Field implementation of microbially induced calcium carbonate precipitation for surface erosion reduction of a coastal plain sandy slope." *Journal of Geotechnical and Geoenvironmental Engineering*, *148*(9), 04022071. https://doi.org/10.1061/(ASCE)GT.1943-5606.0002836

Li, Y., Guo, Z., Wang, L., Zhu, Y., & Rui, S. (2024). Field implementation to resist coastal erosion of sandy slope by eco-friendly methods. *Coastal Engineering*, *189*, 104489.

Montoya, B. M. (2021). *Reducing Erosion Susceptibility of Coastal Highways using Biologically-Based Methods* (No. 2018-18). North Carolina. Dept. of Transportation.

Wu, S., Wang, W., Zhang, A., Chu, J., and Lam, K.P. (2024). Field trial of EICP reinforced beach slope against coastal erosion. Proceedings of GeoCongress 2024, Vancouver, British Columbia.

5. State of Oregon Decision Making Lenses

State decision making lenses are a part of the state of Oregon's policy structure. State policy and federal policy are not always aligned. The state will prioritize research according to state policy, however ODOT may be required to skip prioritized proposals based on constraints placed on the use of federal funds. If state funds are available ODOT will attempt to fund prioritized research that is deemed ineligible for federal funding.

Please complete the following three sections. Your answers to these questions will be applied on a programmatic basis to support agency decisions. Answering yes to the questions below is not required. Resolving a narrowly focused technical research problem may meet agency needs without answering yes to any of the following questions. The ODOT Research Section will seek a balanced portfolio some projects will answer yes to one of the three categories below (e.g. climate, equity, and/ or safety) and other projects in a different category.

We are looking for an overall program balance and no one project is expected to balance all categories. Generally, a research problem statement is expected to be able to answer yes with clear and verifiable information in only one of the three categories below, some projects may be able to answer yes in two or even three categories. Some projects (i.e. needs focused on specific elements of infrastructure design), may have no 'yes' answers but may still be a high value research need.

Climate

Oregon recognizes the climate crisis and makes systemic changes to reduce emissions caused by travel. To that end, we seek research that reduces carbon emissions from construction activities and materials, and from maintenance equipment and operations. Oregon envisions a transportation system that is resilient, this means a system that is durable in the face of seismic events and extreme weather to avoid negative impacts, withstand them or bounce back quickly to resume system function. We seek research that improves the ability of the transportation system to adapt or cope with more frequent and extreme weather events. This may include innovations in data and data sharing, construction materials and project design, communication, emergency planning and response, and more. Similarly, we seek research that avoids negative impacts on key habitats and ecosystems that can buffer or reduce damage to infrastructure and improve environmental conditions for wildlife and native vegetation. For definitions and details please review the equity vision, goals, and objectives of the ODOT Strategic Action Plan and Oregon Transportation Plan.

5a. Will addressing the transportation issue identified as a need in Question 1 develop, or **validate methods for the estimation, measurement, or monitoring** of transportation generated greenhouse gases (GHG)?

☐Yes ☒No ☐Unsure

5b. If climate or GHG is not the focus of this **transportation issue** identified in this problem statement, will the research apply a GHG analysis to transportation infrastructure, planning, operations, maintenance, or materials?

☐Yes ☒No ☐Unsure

5c. Will addressing the **transportation issue** include development or testing of construction practices, methods, or materials to establish potential reductions in greenhouse gas emissions?

☐Yes ☒No ☐Unsure

5d. Will solving the **transportation issue** in question 1 study or support the reduction of vehicle miles traveled and single occupancy vehicle travel or support transition to electric vehicles (or other types of zero emission vehicles) or low-carbon alternative fuels?

☐Yes ☒No ☐Unsure

5e. Will the solving the **transportation issue** in question 1 lead to work that will support, measure, or monitor, transportation system resilience in response to expected climate events, effects, or natural disasters in general?

☒Yes ☐No ☐Unsure

5f. Will solving the **transportation issue** in question 1 lead to work that may result in better environmental conditions for wildlife and native vegetation?

☐Yes ☒No ☐Unsure

5g. If you answered yes to any of the climate questions above or can provide alternative details related to climate, please provide additional information:

Rising sea levels and more frequent severe storm events from climate change accelerate coastal erosion. The proposed coastal armoring technique can be a low-impact solution to mitigate increasing coastal erosion using less invasive techniques.

Equity

Equity can have many dimensions and impacts relating to communities and transportation. It is important that problem statement proposals clearly explain the equity dimensions or impacts being examined. Oregon commits to social equity in the OTP, specifically to *improve access to safe and affordable transportation for all, recognizing the unmet mobility needs of people who have been systemically excluded and underserved. Create an equitable and transparent engagement and communications decision-making structure that builds public trust*. We seek research that studies elements of this goal or applies analysis to specific transportation topics to ensure the resulting research recommendation is consistent with agency equity goals. For definitions and details please review the equity vision, goals, and objectives of the ODOT Strategic Action Plan and Oregon Transportation Plan.

5h. Is the **transportation issue** identified as a need in Question 1 specifically focused on transportation equity?

☐Yes ☒No ☐Unsure

5i. If the **transportation issue** is not focused on transportation equity, will the primary topic be assessed for equity benefits or impacts within the research project?

☐Yes ☒No ☐Unsure

5j. Is the implementation of potential findings from this research likely to directly involve participation from an identified group that would benefit from an equitable process or outcome?

☐Yes ☒No ☐Unsure

5k. Is the intended final product or information expected to support ODOT's equity efforts (Including but not limited to supporting one of the equity related objectives of the ODOT's Strategic Action Plan or Oregon Transportation Plan) ?

☐Yes ☒No ☐Unsure

5l. If you answered yes to any of the equity questions above or can provide alternative details related to equity, please provide additional information:

Safety

Research outcomes may include interventions and countermeasures to prevent or reduce the frequency of crashes or other causes of transportation-related injury or death; or may include measures to reduce severity of injury (including prevention of death) after a crash or other injurious event. For definitions and details please review the equity vision, goals, and objectives of the ODOT Strategic Action Plan, Oregon Transportation Safety Action Plan and Oregon Transportation Plan.

5m. Will solving the **transportation issue** in question 1 support improving **safety culture** for either transportation workers or the traveling public?

☐Yes ☒No ☐Unsure

5n. Will the solving the **transportation issue** support improving safety through **healthy and livable communities**?

☐Yes ☒No ☐Unsure

5o. Will solving the **transportation issue** support improving safety through using **best available technologies**?

☐Yes ☒No ☐Unsure

5p. Will solving the **transportation issue** support improving safety through **communication and collaboration**?

☐Yes ☒No ☐Unsure

5q. Will solving the **transportation issue** support improving safety through **investing strategically**? 5r. If you answered yes to any of the safety questions above or can provide alternative details related to safety, please provide additional information:

6. Corresponding Submitter's Contact Information:

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7. ODOT Sponsor Contact Information (Required if Submitter is not an ODOT employee)

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This form is not a grant application or contract document. Please do not include proprietary information on this form. Once this form is received ODOT may revise and publish the problem statement. If selected, ODOT will assign investigator(s) of the department's choosing to conduct research.