1) Proposed Research Focus:		Future Opportunities for Decarbonization with Climate-Smart Renewable Resources in Maine's Emerging Green Economy			
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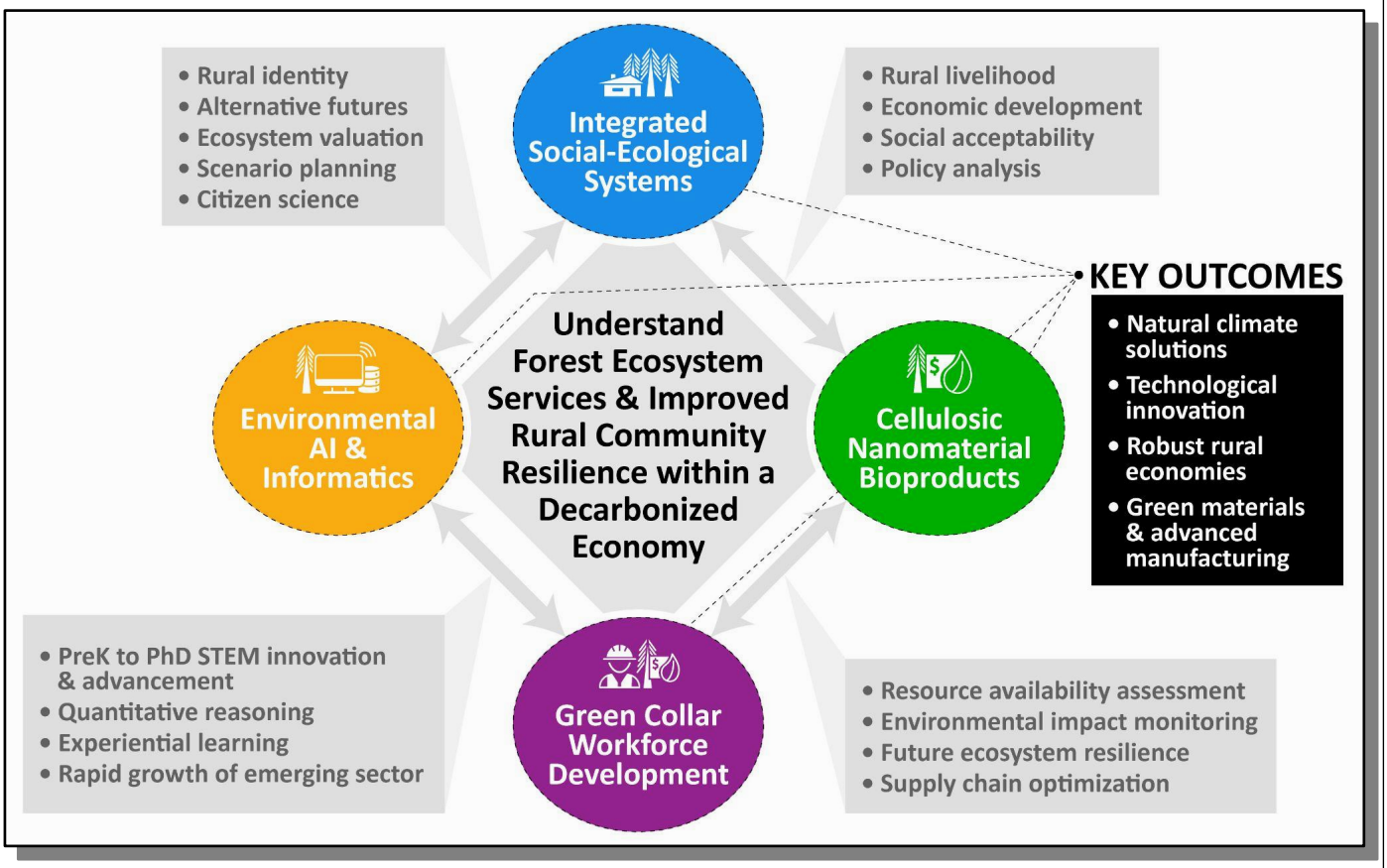
4) Intellectual Merit:

A. ***Need****:* Maine's forest-based economy and the rural communities it supports are rapidly changing because of a variety of complex and interactive factors. As a result, Maine was declared a Federal economic disaster zone in 2016 and has continued to struggle during the ongoing pandemic. Historically, Maine's forest products sector annually contributed $8-10 billion to the state's economy, which accounted for 5-7% of the state's GDP (one of the highest proportions in the US). In the last two years, there has been an estimated 30-40% decline in available wood markets, reduced harvesting, and a shift in the use of paper resulting in a 19% decrease in revenue for the remaining paper mills, which has negatively impacted rural communities that rely on a robust forest economy. In addition, a majority of Maine's forests have reached a critical biological tipping point related to decreased management due to this current lack of robust fiber markets, while being threatened by a potential spruce budworm outbreak occurring in Canada and the ongoing challenges created by climate change. As companies are now looking for renewable sources to replace fossil-fuel based components, Maine's forests can provide climate-smart products that support growth in these rural communities. Consequently, a new strategy is essential to sustainably and effectively manage resilient forests in the face of these threats, and grow a forest-based economy that enhances the utilization of renewable forest goods and services, particularly leveraging the growing advanced bioproducts sector in Maine. Recently, the University of Maine launched the FOREST initiative[1] to showcase its strength and the potential collaborative opportunities in this domain.

One important potential direction and solution is through effective statewide decarbonization with the sustainable management and utilization of climate-smart renewable resources provided by the forest. Currently, the forest and associated products it generates offset 60-75% of Maine's greenhouse gas emissions[2], with a potential to offset significantly more through improved management and innovative products[3]. However, addressing this opportunity and associated uncertainty requires a comprehensively integrated research, education, and outreach program that examines and strengthens rural community resilience by focusing on developing new applications for low-value wood fiber, quantifying ecosystem service values via emerging technologies & methods, promoting individual and community equity & health, and fostering diversified & robust forest-based economies. Here, resilience is conceptualized as the ability of a system to absorb and effectively respond to change, and our theory of change stipulates that we can improve system resilience by working at the intersection of science, technological innovation, economic diversification, workforce development, and public policy. First, we seek to understand how contrasting rural communities have responded to and recovered from past as well as current economic crises. Second, through

1 https://umaine.edu/forest/
2 https://crsf.umaine.edu/forest-climate-change-initiative/carbon-budget
3 https://crsf.umaine.edu/forest-climate-change-initiative/ncs/



the development and use of emerging research areas as well as STEM education and citizen science engagement/outreach, we intend to build capacities to detect past, current, and future social-ecological changes while developing new and diversified economic opportunities, such as carbon sequestration, sustainable bioproducts, and nature-based tourism, that can further support the socio-technical infrastructure to spur further innovation and resilience in forest-based economies. To succeed, this program will require a comprehensive, integrated, transdisciplinary, and statewide effort across multiple institutions with a goal of advancing research, STEM education, and policy in ways that will build rural forest-based communities and economies that are able to detect, withstand, and recover from current/future shocks.

B. ***Research Goal & Objectives:*** To address the state's strategic scientific and technological needs, this project seeks to build a comprehensive program that would address four primary themes: (1) Forest-based Cellulosic Nanomaterials; (2) Environmental Artificial Intelligence (AI) and Informatics; (3) Integrated Social-Ecological Systems (SES) Participatory Modeling; and (4) Green Collar STEM Workforce Development. The primary project objectives of this effort are: (1) accelerate the utilization of advanced manufacturing of forest-based nanomaterials to reduce energy requirements for production and develop novel, climate-smart alternatives for fossil-fuel based components; (2) application of environmental AI and informatics to better understand trends in forest ecosystem service value, production, and use to grow the economic and social opportunities they create; (3) utilization of SES participatory frameworks to engage stakeholders and assess relationships among innovation, policy planning processes, and adaptive outcomes as it relates to rural community resilience and economic diversification; and (4) increased awareness among Maine youth, parents, and education professionals of the scope, breadth, and availability of Maine's "green collar" careers while creating sector-based career pathways for high school students to transition to a career by leveraging available resources and facilities to deliver educational opportunities throughout the state. In addition, significant program efforts will be made to educate and train individuals on the developed technologies, AI/informatics, and linked SES frameworks to foster an improved understanding of forest ecosystem service values and community resilience for better decision-making, particularly for the intersections of forest and tourism economies. In addition, this effort would strengthen foundational PreK-12 STEM education to build awareness and understanding of these potential Green Collar careers, which would be supported through additional undergraduate- and graduate-level opportunities.

C. ***Research Actions:*** This project would require a comprehensive, integrated, transdisciplinary, statewide effort across multiple institutions with strategic engagement of key stakeholders and rural communities throughout the state. In particular, the project would involve expertise in forestry, wood products, landscape ecology, remote sensing, AI, rural economics, communications, business, computer science, engineering, spatial information, wildlife, hydrology, data informatics, advanced manufacturing, outdoor recreation and tourism, anthropology, business, and Native American studies. Currently, Maine lacks the necessary human capital as well as physical- and cyber-infrastructure needed to address and integrate each of these four themes. Because of its transdisciplinary nature,

	the project would build important and necessary synergies across a variety of organizations. This proposed effort would specifically leverage several ongoing large NSF projects, particularly those currently being led by PI Weiskittel, including a RII Track-2 FEC (Award #1920908) focused on big data and a national IUCRC on technological advances in forestry (Award #1915078) as well as a recent NRT (Award #1828466) on resilient conservation systems and a pending NSF AI research institute pre-proposal with Weiskittel as Co-PI. Forest-based nanomaterials, geospatial technologies, environmental AI & informatics, computational infrastructure, ecosystem services valuation, and coupled SES frameworks are the future for a decarbonized world. However, Maine currently has limited capacity in each of these areas. In addition, there is currently no fully integrated program in the state that effectively links emerging wood products with the available/future forest resource coupled to human dimensions.
D.	***Priority:*** The uniqueness of Maine's forest SES and current/future markets requires a large-scale, transdisciplinary, collaborative research initiative that is comprehensive and integrated. The scope and required infrastructure is beyond other existing Federal agencies' research programs and would address several current NSF FY22 budget request priorities, including advanced technologies like wireless and manufacturing, K-12 STEM education, and climate science as well as sustainability research. The effort also aligns well with the priorities of Maine's 10-year economic opportunities like bio-based alternatives, climate change, and AI.
5)	**Broader Impacts:**
E.	***In-state Collaborations****:* This proposal would have involvement of numerous departments and institutions across the state, including University of Maine, University of Southern Maine, University of Maine Fort Kent, and University of Maine Presque Isle as well as several industry/community partners, like forest landowners (e.g., JD Irving, Seven Islands, Weyerhaeuser), manufacturing industry (e.g., SAPPI), geospatial technology companies (e.g,. Quantum Spatial), state agencies (e.g., Maine Forest Service, Maine Office of GIS, Maine Department of Inland Fisheries and Wildlife, Maine Department of Agriculture, Conservation and Forestry), and several nonprofit organizations (e.g., Maine Development Foundation, Maine TREE Foundation, Schoodic Institute, and The Nature Conservancy).
F.	***Regional/National Collaborations****:* This effort would leverage existing connections to other EPSCoR jurisdictions, NSF research centers, and Federal national laboratories. The NSF Track II effort (INSPIRES) being led by Weiskittel has provided critical connections to other EPSCoR jurisdictions, including New Hampshire, Vermont, and most recently, Alabama. The NSF IUCRC (Center for Advanced Forestry Systems) also led by Weiskittel is a national organization that provides strong connections to 6 other universities and over 80 unique forestry sector organizations across the US and is currently in Year 3 of Phase 3 while seeking successful graduation in 2024. In recent years, the University of Maine has developed strong working relationships with numerous Federal national laboratories, such as the US Forest Service Forest Products Laboratory, DOE's Argonne, Los Alamos, & Oak Ridge National Laboratories, and NASA's Jet Propulsion Laboratory & Goddard Space Flight Center.
G.	***Economic Development****:* Maine is highly dependent on the health and sustainable management of its terrestrial ecosystems while supporting robust rural economies. Given the uncertain future of the current forest economy and challenges created by the pandemic, a new direction is needed. The technology and information provided by this project would significantly improve management as well as provide valuation of other key ecosystem services beyond fiber. There is significant and growing capital interest in these ecosystem services, particularly carbon sequestration. In addition, this project has direct linkage to Maine's small and highly rural communities to help foster more robust and diversified economies, and broaden stakeholder participation from diverse socio-demographic backgrounds.
H.	***Workforce Development****:* A workforce that understands new technology, products, and data science as well as ecosystem management is in strong demand, particularly in a state like Maine, where the economy is heavily dependent on natural resources. This project would provide a broad array of opportunities for undergraduate, graduate, post-doctoral, faculty, and professional workforce development. Currently, there are limited and poorly integrated training opportunities for some emerging fields like geospatial technologies, AI, systems analysis of both forest resources and supply chains, nanotechnology, and participatory models for broad stakeholder engagement. In particular, this effort supports workforce development with a specific focus on making Maine youth and parents aware of the potential and diversity of "green collar" careers**.** This would be accomplished through foundational PreK-12 STEM curriculum development, undergraduate- & graduate-level microcredentialing, and professional outreach & development opportunities. An especially important aspect of workforce development in this effort is spanning the rural to urban divide that bisects Maine, particularly engaging under-represented minorities.
I.	***Infrastructure****:* This project has significant potential to provide critical infrastructure to Maine that grows the state's flagship university in terms of academic research, education, and outreach capacity. In particular, this would build essential critical mass in faculty expertise for emerging fields with relevance to the state's economic needs, including environmental life cycle analysis, renewable bioproduct development, and landscape geoinformatics & AI. Critical equipment and space upgrades would also be completed to further support the University of Maine's growing capacity. This is especially true for the production, characterization and use of cellulose nanomaterials upgrades critically needed to work at various scales that range from the lab bench to pilot plant capacities.