4. Project Description

Delaware EPSCoR: Meeting Delaware's 21st Century Water and Energy Challenges through Research, Education, and Innovation

4.1 Status and Overview

Through the state EPSCoR steering committee, and with significant input from state government, academic, and private sector leaders, Delaware has generated a Science & Technology Plan (attached), a strategic roadmap to guide the development of the state's science, technology, and policy capabilities with the goal of strengthening Delaware's competitiveness and prosperity. This roadmap lays out research and development priorities for the state, which include the environment and energy as two of the six most critical scientific, economic, and educational thrusts. These two areas are the focus of Delaware's EPSCoR RII proposal.

Delaware RII Goals

- Grow a competitive science, technology, and policy community in the environment and energy
- Develop a new and diverse generation of experts
- Manage RII initiatives toward long-term sustainability

The development of the research themes for the RII proposal began in 2010 with a solicitation of white papers from faculty groups. Extensive discussions ensued with administrative leaders at the four partner institutions, faculty, private sector representatives, members of the state EPSCoR steering committee, and state government leaders. The steering committee gave major consideration to the challenges and opportunities facing the state and the areas with the greatest potential impact, both in terms of future research competitiveness and future economic and workforce development. Through this process, the themes were selected, and an overview of the RII proposal was reviewed and refined by the state EPSCoR steering committee before submission.

The four Delaware institutions of higher education that offer science degrees and are involved as partners in this proposal have been working together under the auspices of EPSCoR since 2003. Significant benefits have accrued from our partnership, as individual institutions and as a network of people and infrastructure. The four institutions each have their own unique character and mission: the University of Delaware (UD), a Carnegie research institution with very high research activity and 21,000 students; Delaware State University (DSU), an HBCU with 3,600 students that is actively transitioning from a primarily undergraduate institution to a graduate research institution; Delaware Technical Community College (DTCC), a primarily two-year institution with a focus on statewide workforce training and development with 15,000 students; and Wesley College (WC), a minority-serving liberal arts institution with 1,900 students and an objective to strengthen science and research in its undergraduate programs. Each institution in the Delaware partnership is participating in ways that adhere to their respective visions and implement their strategic priorities. (See letters from each institution's president.)

At UD, environment and energy have been selected as priority research and graduate education focal areas as part of the institutional strategic plan. New interdisciplinary research groups and facilities at UD will further energize this focus. Four of the seven colleges at UD have significant environmental programs under way, and the EPSCoR-catalyzed Delaware Environmental Institute (DENIN) serves as a hub for researchers from disparate academic homes to interact. Gaps in faculty expertise still exist (particularly in areas of geochemical, climate, and ecosystem services modeling) and will be addressed under this RII. Hiring in these areas will facilitate our ability to respond to funding initiatives in the areas of climate change, earth systems sustainability, and critical zone processes. While UD has managed to expand its research portfolio in recent years, the fierce competition for federal grants remains a constant challenge, and there is a need to be more competitive in winning large interdisciplinary and center grants.

At DSU, both research and the integration of research experiences in education are priorities. As a small, state-funded institution, careful planning of hires and focus on research options are essential to build both research and education capability. Retention of high-quality faculty is a challenge facing DSU that is being addressed by EPSCoR through the building of an institutional and statewide research community and infrastructure. The EPSCoR-launched Center for Integrated Biological and Environmental Research (CIBER) fills a similar role at DSU as DENIN does at UD and has also helped DSU establish a good track record in REU programs. DSU has also assembled and fostered research teams that are increasingly competitive for research and education grants in bioenergy and water. DSU will place significant focus on

strengthening these areas by hiring a new tenure-track faculty member in bioenergy and postdoctoral research support staff.

Wesley College is a small, private institution where student demographics have changed dramatically in the last few years, such that Wesley is now a minority-serving institution. At the same time, Wesley has experienced significant first-year student retention issues and, as a result, has developed a comprehensive retention strategy that includes undergraduate research for all Wesley students.

Delaware Tech engages a diverse population of STEM students, has a strong history of successfully bridging students to four-year institutions, and has exceptionally strong alignment with statewide and regional employers. At Delaware Tech, a new center for future-focused, data-driven workforce planning will help the partners and the state to train students in productive career directions. RII funds will also help Delaware Tech begin incorporating research, case studies, inquiry approaches, and internships into environment and energy degree programs, an integration of research and education that will serve students who enter the workforce immediately as well as those who transfer to baccalaureate programs.

Delaware's environmental focus stems from the widespread recognition in the state that a healthy environment supports significant ongoing economic activity, especially important in light of the recent closing or downsizing of major Delaware employers in chemical manufacturing, pharmaceuticals, automobile manufacturing, banking, and credit. The state's water resources provide a powerful economic engine, contributing up to $6.7 billion, including more than 70,000 jobs, and providing over $2 billion in wages (Narvaez and Kauffman, 2012). Tourism, including beach resorts, is the third largest private employer in the state and has grown to a $2.1-billion industry, employing 40,000 people and attracting more than 7 million visitors to Delaware each year. Agriculture, propelled by a vibrant poultry industry, provides a total economic contribution of nearly $8 billion to the state (Awokuse et al., 2010). Delaware's location and governmental policies offer potential for the development of environmentally friendly renewable energy, such as offshore wind and niche areas of plant-based bioenergy.

Delaware EPSCoR has built strong relationships with partners in the public and private sectors that will be expanded under the new proposal. Cooperation between academics and policy makers at the Delaware Department of Natural Resources and Environmental Control (DNREC) is very strong, providing ample opportunities to explore, discuss, and implement innovative policies going forward. DNREC Secretary Collin O'Mara will chair the Delaware EPSCoR steering committee, and a graduate student internship program at DNREC, piloted under the last RII, will continue to allow students to assist in the development of science-based environmental policy in the state. Collaborations have also been developed with the Delaware Nature Society and Stroud Water Research Center. Likewise, ties to partners in industry will be strengthened and formalized under this RII through the *Spin-In*^{TM} technology-transfer training program for students, managed by the Office of Economic Innovation and Partnerships (OEIP, the UD tech transfer office). We will also extend the UD/OEIP patent capability to all the EPSCoR partners by hiring an intellectual property licensing associate in UD's Technology Transfer Center.

4.2 Results from Relevant Prior NSF Support

The previous Delaware Research Infrastructure Improvement program, entitled *"Building Research and Education Infrastructure to Enhance Environmental Science and Its Application in Delaware"* (September 2008 – August 2013) was funded at $3 million per year over five years from NSF, with an additional $1 million per year provided by the state of Delaware. In the past four years, Delaware investigators have been awarded $24 million in new EPSCoR-related grants and have produced 207 peer-reviewed publications directly related to their EPSCoR-funded research in journals such as *PNAS, Science, Nature,* and *Environmental Science & Technology.*

Since EPSCoR status was obtained in 2003, Delaware investigators have generated more than $56 million from 150 EPSCoR-related grants. While many grants were led by UD faculty, major awards to other partner institutions were made during the grant period, including (1) a Department of Labor award to DTCC for $4.9 million to establish the Center for Industry Research and Workforce Alignment, (2) an NSF REU (Research Experiences for Undergraduates) award to DSU for $585,465, (3) an NSF ATE (Advanced Technological Education) award to DTCC for $500,000, (4) a USDA NRI (National Research Initiative) renewable energy education grant to DSU for $350,000, (5) an NSF ARI (Academic Research Infrastructure) award to Wesley for $282,000 and (6) an NSF DUE cyber-security education grant to UD and DTCC for $416,000. Delaware also secured one of six NSF Critical Zone Observatory (CZO) grants

for $4.3 million and two EPSCoR Track-2 awards for $2.2 million to implement key cyberinfrastructure improvements as part of a five-state North East Cyberinfrastructure Consortium (NECC). EPSCoR has proved to be a strong platform in Delaware to enhance the productivity of the state's research, education, and economic capability in environmental science.

Results
- $56 million in grants catalyzed by EPSCoR
- Institutionalized centers and institutes to drive research, education, and economic development
- Strong involvement of a diverse community, including minority-serving institutions

Research Infrastructure: EPSCoR has catalyzed institutes and centers that are driving research and education across the network. This infrastructure of people, programs, and facilities is the springboard for our new proposal. An important direct outcome of the EPSCoR project is the Delaware Environmental Institute (DENIN), established at UD in 2009 as a multidisciplinary, statewide initiative to conduct research and coordinate partnerships that integrate environmental science, engineering, and policy to address environmental challenges. DENIN was instrumental in the cluster hiring of four environmental faculty members at UD since 2010. DENIN also serves as a leader in the facilitation of a major UD investment, a new $132-million Interdisciplinary Science and Engineering (ISE) laboratory, which, in 2013, will become home to DENIN, the UD Energy Institute, 20 environmental and energy faculty laboratory groups, and shared core facilities.

DENIN has recruited senior professional staff with substantial grant writing, strategy, and program management experience who assemble faculty teams for large projects or work with individual early career faculty in grants development. Projects funded during the grant period with the assistance of the DENIN team include an NSF Water, Sustainability, and Climate award (Duke), two environment/water-related NSF CAREER awards (Chan, Michael), an NSF CZO (Sparks), an NSF ARI (D'Souza), an NSF DRMS/GEO award (Messer), and NSF EPSCoR Track-2 awards (Steiner). Thanks to these early successes, UD has committed recurring funding in partial support of DENIN's operating costs. (See UD president's letter of support.)

At DSU, the Center for Integrated Biological and Environmental Research (CIBER) was launched in 2009. CIBER has facilitated hiring two new tenure-track faculty in areas related to its mission; EPSCoR assisted with start-up for those faculty, who are now in hard-funded positions at DSU. Through CIBER, DSU has successfully assembled a multidisciplinary epigenomics team in bioinformatics, plant molecular biology, biotechnology, and soil science. CIBER is a partner with Cornell's USDA NRI project in bioenergy and bioproducts, and a pending biofuels research and education grant with Penn State has been recommended for funding. The team has laid out a future research strategy that will position them to contribute to the nation's plant-based bioenergy and environmental research agenda. DSU faculty and students are also engaged in water quality research and will be active collaborators in the network.

Core instrumentation centers located at UD are used by faculty and staff at all partner institutions. The previous RII provided (1) instrumentation upgrades and maintenance, (2) partial support for core center staff, and (3) fee waivers to allow EPSCoR researchers to obtain preliminary data. Key research instrumentation funded through the RIIs totals $1.34 million, significantly enhancing the research infrastructure available to investigators in the network. This successful core center strategy will strengthen our endeavor to build a new materials characterization core in UD's ISE Lab.

Education, Outreach, and External Engagement*:* The institutes and centers catalyzed by EPSCoR have also driven education, outreach, and external engagement initiatives. In 2011, DENIN was instrumental in developing UD's new interdisciplinary graduate program in water science and policy, involving four colleges and 30 faculty members, and was selected at UD to develop a (pending) NSF IGERT proposal focused on water sustainability. DENIN also launched new research and education interactions with DNREC, including graduate-level environmental science and policy internships and our EcoCafé workshop series involving UD faculty and DNREC staff. Our successful statewide undergraduate research internship program involves 30% underrepresented students. Our semiannual DENIN Dialogues featured high-profile speakers such as Rajendra Pachauri, chair of the IPCC.

At DSU, CIBER has been a coalescing force for undergraduate research and ethics training in central and southern Delaware. CIBER hosts an NSF REU in molecular genetics and genomics that involves students from around the nation and co-organizes DSU's university-wide, summer undergraduate

research symposium. In 2013, CIBER will launch research experiences for a total of 40 undergraduates over a five-year period in a bioenergy research and education project funded by USDA AFRI.

Catalyzed by EPSCoR, the Center for Science, Ethics, and Public Policy (CSEPP) was established at UD in 2012. Key outcomes include an NSF award for *"Research and Integrity in Science & Engineering (RAISE),"* which prepares science and engineering graduate students to train their peers in research ethics. CSEPP will be active in environmental justice research in the new RII program. Supported by EPSCoR, DTCC received a $4.9-million Department of Labor grant to establish the Center for Industry Research and Workforce Alignment (CIRWA), which will provide emerging education and career preparation data not available elsewhere, starting with a focus on energy and environmental jobs.

Economic Development: EPSCoR catalyzed the Office of Economic Innovation and Partnerships (OEIP), revitalizing the technology transfer process for UD and DSU, which has entered into a partnership with UD for the management of its patent portfolio. As a result, the value of IP-driven economic development has significantly increased among the EPSCoR faculty: over 30% have disclosed invention discoveries, filed provisional applications, or been awarded patents. Two license agreements and two research agreements totaling $1.7 million with private sector entities have been completed. For example, an EPSCoR-supported faculty team at UD disclosed an invention, filed a provisional patent application, received university proof-of-concept funding, reached a research agreement with a private sector company ($325,000 over three years), and are now in discussions with the company to license the technology. Three faculty-led start-up companies benefitted from EPSCoR funding; two have now been spun out. A proof-of-concept fund was established by OEIP to help bridge the "valley of death" for potential faculty-based start-ups; so far seven proposals have been funded of which four were from EPSCoR-funded faculty.

Management: Effective management that fosters productivity, innovation, and sustainability of the RII has been a priority. An inclusive EPSCoR leadership team, guided by a strategic plan, worked to integrate management and evaluation, which included an external scientific advisory board (EAB), a AAAS review panel, and an internal evaluator. The panels were composed of accomplished scientists and educators, who offered independent reviews of technical and scientific issues for Delaware EPSCoR, DENIN, and CIBER. A key component of effective management of the Delaware EPSCoR program is to ensure sustainability by growing and institutionalizing program initiatives.

4.3 Research Program

The overarching research question we seek to answer is, *"How do we sustain water and energy resources in changing and vulnerable coastal landscapes?"*

We approach the challenge of sustainable water and energy through four research foci: (1) the effect of sea-level rise on contaminant mobility and cycling, (2) coupled land use and climate change impacts on water and natural ecosystems, (3) development and deployment of environmental sensors at multiple spatial and temporal scales, and (4) innovations in environmentally sound renewable energy sources. Each theme is interdisciplinary, incorporates research in the natural and physical sciences, engineering, and social sciences, and is closely aligned with the state S&T Plan.

Research Themes

- Effect of sea-level rise on contaminant mobility and cycling
- Land use and climate change impacts on water and natural ecosystems
- Multiscale environmental sensing
- Innovations in renewable energy

Operationally, we have designed two approaches to catalyze research within the RII themes. As described below, cross-institutional, interdisciplinary research groups have formed and will hit the ground running when the RII launches. Teams will meet regularly to explore future research frontiers and funding opportunities and will be required to assemble new proposal-writing groups before the end of Year 1. We also list anticipated collaborators; only Delaware-based investigators will be supported with EPSCoR funds. In section 4.3.1, we describe our seed grant plan, designed to capitalize on new opportunities and to expand the network of investigators.

Theme 1: The Effect of Sea-Level Rise on Contaminant Mobility and Cycling *(Team Leaders: UD-Michael, Messer, Sparks)*

Sea-level rise (SLR) has been occurring since the late 19th century, and a recent USGS study found that sea level is rising faster in the mid-Atlantic region than elsewhere in the world and twice as fast as earlier estimates (Sallenger, 2012). The U.S. Climate Change Science Program's (CCSP) 2009 document, *Coastal Sensitivity to Sea Level Rise: A Focus on the Mid-Atlantic,* recommends that states prepare for a rise in sea level of at least 1m by 2100.

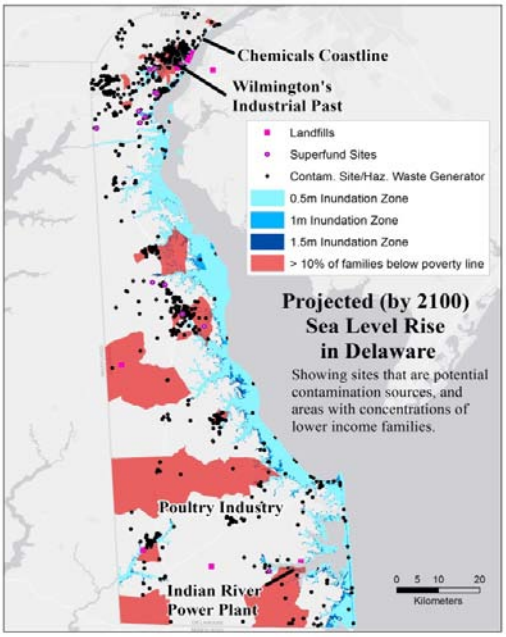

Figure 1. Map of Delaware, showing projected sea level rise, contaminated sites and low-income areas. (A. Homsey, Delaware Water Resources Agency)

Policy debates tend to focus on SLR risks that are most salient to people, such as inundation of coastal areas, damage from stochastic weather events, human and infrastructure adaptation, or the need to abandon low-lying coastal areas. However, concerns about climate change and SLR extend beyond these obvious issues of human adaptation. This theme seeks to understand the chemistry and hydrology of contaminant transport and cycling within the context of SLR and the way humans process the risks from both individual adaptation and public policy perspectives. The projected interaction of SLR and contaminated sites is a poorly understood problem, but a significant one, positioned at the interface of natural and social science. The scientific problem is complex, given factors such as the chemical effects of salinity, pH, and redox; the physical effects of changes in hydraulic gradients, rising water tables, and new areas inundated by storm surges; and the risk that currently immobilized constituents may be released. The human behavioral and policy responses are varied, including technological solutions for SLR prevention, remediation of contaminants, abandonment of affected areas, or even no change in behavior.

Research Questions: The proposed theme will examine the following scientific questions:

- How will SLR impact the hydrology and contaminant cycling in soils near tidal rivers and coastlines through both salinization and inundation processes?
- What will be the likely human response to a risk-mitigated situation compared to an unmitigated situation?
- How can feedbacks among natural systems, human behavior, and policy responses be incorporated into quantitative models that can be used to anticipate effects of SLR?

Industrial lands near the Delaware River and the Delaware Inland Bays provide ideal locations to study the threat of SLR on contaminant mobility and cycling and water sustainability. With climate change and the concomitant rise in sea level, there is concern about the cycling and transformations of soil contaminants such as metal(loids) and organic chemicals. Figure 1 shows Delaware's largest city, Wilmington, as well as a southern electricity generating plant located on the Indian River, which is also an area of intensive poultry operations and crop production. In addition, Figure 1 shows the clustered brownfield sites near tidal areas of Wilmington. As of July 2011, the state of Delaware had 159 certified brownfield sites, including 103 in the city of Wilmington (DNREC, 2011). These sites are now in use as both commercial and residential areas and are disproportionately populated by low-income and minority residents. These areas sometimes have unusually high levels of cancer and asthma that can be attributed to environmental pollution; thus, in addition to adaptation challenges, there are associated policy and environmental justice issues. Large population centers along much of the mid-Atlantic coast — and, indeed, urbanized coastal areas around the world — share this legacy of contaminated sites.

Research Approach: One cannot predict the fate of water, nutrients, and contaminants in coastal landscapes without anticipating and integrating human behavior. Complexities in physical environments affect the behavior of economic actors, and these economic decisions, in turn, affect the natural system.

This simultaneity allows for a better explanation of the possible feedback between complex and potentially stochastic systems than has been explored in the past. This theme will examine the feedback between human and natural systems through the combined use of field measurements, laboratory experiments, experimental and behavioral economics, and integrated modeling.

Geochemistry and Hydrogeology: We suggest two primary processes that could lead to the release of sediment-bound contaminants, greater solute mobility, and migration in response to SLR: (1) salinization and (2) rising water tables. First, salinity of soil and groundwater is likely to increase as saltwater fronts migrate inland, saltwater flooding becomes more widespread, and coastal storm surges increase in frequency and intensity (IPCC, 2007). This may lead to ion-exchange and sorption/desorption process alterations in contaminant speciation/form and changes in pH that can release contaminants and increase mobility by reducing retardation along flow paths.

Sodic soils can cause negative impacts on soil structure (e.g., dispersion) and the ability to support critical infrastructure (bridges, runways), native vegetation, and food production. Most of the data on sodic soils are derived from soils that are naturally high in Na-bearing parent material, and often the soils are located in arid and semi-arid regions. Little, if any, understanding exists on the development of sodic soils resulting from climate-change-induced SLR in temperate soils that are contaminated and acidic like those in the mid-Atlantic area. In fact, there is little in the scientific literature on the impacts of SLR on contaminant mobility, making this research highly novel. In more acid soils, decreases in soil pH can occur due to displacement of Al (III) and Fe (II) by basic cations such as Mg, Ca, and Na and subsequent hydrolysis (Wong et al., 2010). Lower pH also enhances the mobilization of metal cations such as Cd, Mn, Pb, and Zn (Charlatchka and Cambier, 2000).

Second, a rise in sea level will result in elevated water tables on land and more widespread occurrence of freshwater surface flooding. Beneath the water table, redox gradients often exist as conditions change from oxic in unsaturated soils to anoxic in saturated groundwater. Movement of this interface may mobilize chemicals by introducing reducing conditions to previously oxidizing soil zones. An example is dissolution of Fe and Mn (oxy)hydroxides under reducing conditions that results in release of surface-bound heavy metals and other constituents (Burton et al., 2008; Johnston et al., 2010a, b). Together, these processes will pose risks to both human water resources and ecosystems through release and rapid transport of harmful chemicals in the environment.

Hydrogeologic field investigations will be conducted on sites vulnerable to (1) salinization-induced contaminant release or (2) flooding- or water-table-induced contaminant release, such as the Indian River Power Plant and coastal brownfields in Wilmington (Figure 1). Site sampling will be conducted in collaboration with DNREC, using monitoring and measurement techniques, including in situ sensor technology. Monitored system response to tides and storms will be used to determine hydraulic connection to coastal waters and water table response to changes in hydrology. For salinization studies, we will identify likely pathways for contact between saltwater and contaminated sediments. These include surface flooding (dependent on topographic slope), vertical infiltration of saline surface water into unsaturated zones and the water table, and lateral intrusion of seawater into aquifers. For inland sites where water-table rise is the likely mobilizing agent, areas where redox gradients exist and where water-table changes or inundation are likely to occur will be identified. In both types of studies, site-specific groundwater flow and solute transport models (variable-density in the case of salinization studies) will be developed in order to test site-specific and general hypotheses about effects of rising sea level.

The physical, chemical, and mineralogical properties of soil samples from contaminated sites will be characterized, including speciation of contaminants using advanced synchrotron-based techniques. The soils will then be subjected to simulated salt waters (for salinization studies) and reducing conditions (for rising water table studies) for various periods of time, and changes in chemical and physical properties will be assessed, including pH, exchangeable bases, metal(loid) concentrations, sodium adsorption ratios, soil dispersibility in terms of exchangeable sodium percentage, and ion selectivity coefficients. Additionally, changes in metal(loid) speciation will be assessed using synchrotron-based X-ray absorption and X-ray fluorescence spectroscopy at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory and the Stanford Synchrotron Radiation Light (SSRL) source at Stanford University. Column studies with the contaminated soils will also be conducted to study how saltwater intrusion impacts various chemical and physical properties.

Site-scale numerical groundwater flow models can be extended to simulate reactive transport, parameterized by field and laboratory efforts. These models can then be coupled with decision-making and policy scenarios to determine feedbacks and interactions that produce natural and social outcomes.

Economics and Sociology: The research in this theme will explore the interaction of the above processes with human and societal behavior, leading to development of optimal mitigation-of-risk strategies for joint future impacts. Risk mitigation can be achieved through a variety of remediation alternatives, for which we propose to compare the corresponding benefits and costs, resulting in direct policy advice. Policy implications may include a different prioritization of technological solutions for remediation, including options for abandonment, containment, and human adaptation. This advice depends on the human psychological processing of perceived risks, the distributional patterns of received costs and benefits across different populations, and the political acceptability of these policies. Understanding individual and public response to risk from contaminants and SLR, including research on how responses vary when these risks are communicated in different ways, will provide insights into approaches that society can use to communicate about and prepare for important changes that arise in response to SLR. We will integrate experimental economic and sociology techniques to understand human behavioral responses to different contaminants and environmental risks and to explore potential policy solutions to these problems. The Laboratory for Experimental and Applied Economics at UD will be central to this research thrust.

Another powerful method of investigating human response to environmental and health risk is to involve the community as researchers. Community-based participatory research (CBPR) is a method that allows the community to work with scientists in formulating research questions and hypotheses that are based on the embodied experiences of the residents — that is, their local knowledge that informs their beliefs about the environmental causes of their ill health (Scott and Garner, 2013). In this way, CBPR allows scientists and community members to work collaboratively in studying the specific causes of environmentally induced ill health and work in tandem as agents of social justice in order to produce evidence and introduce social policy to address the health needs of polluted communities.

Students will have the opportunity to undertake community-based participatory research (CBPR) within this theme, to investigate human response to environmental and health risk. Two faculty, Victor Perez and Donald Sparks, a graduate student, and colleagues from the Bloomberg School of Public Health at The Johns Hopkins University are currently involved in a CBPR study with a low-income community living in a neighborhood with contaminated soils. This type of novel collaboration among a sociologist, an environmental chemist, public health experts, and community members offers students an exceptional opportunity to apply their expertise directly to help a local community.

Faculty Collaborators: This research theme will be led by H. Michael, a hydrologist with expertise in groundwater modeling; K. Messer, an environmental economist who focuses on environmental conservation and experimental economics; and D. Sparks, an expert in soil and environmental chemistry with emphasis on metal and nutrient kinetics and surface chemistry. Other investigators will include M. Greene, environmental ethicist; Y. Jin, an environmental soil physicist who specializes in contaminant transport and modeling; D. Leathers, a climatologist; G. Luther, an environmental chemist with expertise in redox chemistry; V. Perez, an environmental sociologist whose research deals with social movements and dynamics; T. Powers, an expert on environmental ethics and justice; and Q. Wang, an environmental chemist who focuses on organic chemical transport and reactivity. International collaborators will include L. de Jonge, J. Hering, F. Zhang, and Y. Zhu. The research will involve interactions with the Coastal Programs group of DNREC, national lab facilities, and EPA Region 3 (government); Delaware Nature Society (nonprofit); and the Institute of Urban Environment in Xiamen, China, and Swiss Federal Institute of Aquatic Science and Technology, Dubendorf, Switzerland (international).

Funding is requested for a postdoctoral associate, two graduate students, travel and supplies related to this research theme.

Theme 2: ***Coupled Land Use and Climate Change Impacts on Water and Natural Ecosystems***
(Team Leaders: UD-Inamdar, Dentel, Duke; DSU-Ozbay)

Our focus in this theme will be the mid-Atlantic's Delmarva Peninsula, located between two vulnerable aquatic ecosystems: the Chesapeake and Delaware Bays. The region has been subject to rapid urbanization and suburbanization of previously forested or agricultural landscapes. Urbanization has

already been shown to increase the intensity and magnitude of surface runoff and shorten the time it takes for water and nutrients to reach water bodies, effectively "short-circuiting" large portions of the landscape (Paul and Meyer, 2001). Further fragmentation of landscape parcels will likely result in severe repercussions for hydrology, water quality, and ecology of natural ecosystems.

These land use challenges are expected to intensify as future climate change spawns more extreme weather conditions (e.g., droughts, heat waves, and storm events). Long droughts may result in mineralization and release of nutrients from soils (such as dissolved organic carbon and nitrogen) that may then be flushed out in large quantities with extreme runoff events (Inamdar et al., 2011). Entry of these nutrients into water bodies results in drinking water challenges (Hrudley, 2009) and/or loss of recreational use due to pollution and eutrophication (Rabalais et al., 2009). Shifts in soil redox conditions associated with contrasting moisture conditions may also release sequestered contaminants and metals.

Our interest is in how the coupled influence of land use and climate change will impact the evolving health and integrity of complex terrestrial and aquatic ecosystems, and how we can employ empirical economics approaches to develop useful predictive models — with emphasis on understanding how these changes will alter water quantity and quality, especially through the fluxes and cycling of carbon, nitrogen, and phosphorus. We are not only interested in the physical, chemical, and biological processes and consequences of this coupled change, but also in understanding the social and economic drivers of land use change, the feedback effects on natural and human systems, and the critical (and possibly difficult) policy and management choices and adaptations that will have to be made to mitigate impacts.

Research Questions: The proposed theme will examine the following questions:

- How are land use and climate change altering the export and cycling of carbon, nitrogen, and phosphorus?
- How are land uses in the mid-Atlantic region changing in response to socioeconomic forces, and what are the long-term trends?
- What new policies and management strategies will have to be developed to address the environmental, economic, and social challenges raised by climate and land use change?

Research Approach*:* We bring together excellent faculty and research infrastructure to address these questions through a comprehensive, interdisciplinary approach that spans multiple spatial and temporal scales and couples the natural and human dimensions of the problem. Lessons and strategies developed for the mid-Atlantic region will be transferable to other coastal states and regions across the U.S. The project will leverage field sites and expertise in the community; UD is the home of one of six NSF-funded CZOs, the Christina River Basin CZO, where researchers are exploring how land use change (agriculture and urban practices) affects mineral weathering and transport, carbon-mineral complexation, long-term sequestration of carbon, and their consequences for the global carbon cycle. UD faculty are also working in the Delaware River Basin and have implemented experimental watersheds in forested (Inamdar et al., 2012, 2011), agricultural (Dutta et al., 2012a, b), and urban/suburban landscapes that can be used to evaluate impacts of land use on hydrology, water, socioeconomic, and policy issues.

Natural and Physical Sciences: A combination of methods including watershed monitoring and data collection, GIS analyses and spatial land use modeling, laboratory assays and analyses, numerical predictive modeling and scenario analyses, experimental economics, and community and stakeholder surveys to assess socioeconomic conditions and risks will be implemented. Watershed hydrologic responses (e.g., Claessens et al., 2006) will be characterized using data from weather stations, measurements from stream flow gauges, groundwater wells, soil moisture measurements, and evapotranspiration sensors. Water quality will be assessed using a combination of in situ, continuously logging, water quality sondes, automated runoff samplers, and manual sample collection. Potential phosphorus (P) sources such as agriculture, wastewater, and other geological origins and their $^{18}O_p$ isotope signatures will be investigated in the watersheds. This will include identification of spatially and temporally resolved variable P phases and their relationship with specific sources in the watersheds. Analyses of $^{18}O_p$ values of different P phases in the watersheds will help identify nutrient hotspots, nutrient transformation, and their cycling in the watersheds. A major thrust of the proposed research is identifying geochemical and nutrient-based sink-source switching processes. Trace and coexisting elements with specific P sources will be also used as proxies of nutrient cycling in the watershed.

Engineering: Many coastal environments also have several distinct features in common: shallow groundwater easily contaminated by land disposal of wastewater-produced biosolids and spray irrigation of treated wastewater; saltwater intrusion in drinking water aquifers; and the abundance of small, noncentralized, and poorly controlled wastewater treatment plants. In Kent County, Delaware, even though most biosolids are applied as limed pellets in a certified, award-winning program (Newton, 2008), it is not known how these “Class A” biosolids might react to flooding by saline waters. In Sussex County, the water table is so high that many rural sites can only use “mound systems” which essentially raise the septic field above ground level. These systems are notoriously poorly functioning under normal conditions and could desorb excess nutrients or contaminants upon exposure to saline conditions (DNREC, 2012). Thus, both exemplary *and* unsatisfactory wastewater and biosolids practices should be evaluated for their degree of resilience in the face of environmental change.

Technologies are needed that may mitigate adverse impacts of climate change in coastal regions. Two novel approaches will be examined. First, the use of a “breathable” or hydrophobic membrane, positioned to take advantage of solar warming, may improve the operation of septic fields and mounds by allowing only the release of pure water (driven by vapor diffusion and the temperature gradient); the concept is based on latrine-related research funded at UD by the Gates Foundation (Marzooghi, 2012). Second, the potential sequestration of biosolids and their associated organic carbon will be examined using deep subsurface injection into heavily saline aquifers far below the freshwater aquifers. This process is currently under evaluation in Los Angeles, and also takes advantage of high temperatures deep underground (>1600m) to produce concentrated methane as an energy source while capturing the remaining organic carbon and CO_2 underground (Bruno et al., 2005). To adapt this approach, the geology and also the microbial tolerance of salinity, high temperature, and high pressure must be better characterized. These research thrusts are relevant both to coastal areas and to a broader set of applications.

Economics, Sociology, and Policy: Research in this theme is novel in its integration of experimental economic and sociological techniques implemented to understand human behavioral responses to different contaminants and environmental risks. Interest in the efficiency properties of natural resources, public goods, and common pool resources has a long-standing history in the field of economics. In addition to theoretical and empirical studies, a number of experimental economics studies have been conducted (beginning with Ostrom et al., 1990) to explore the extent to which actual behavior matches theoretical predictions and to test potential policy solutions. Most of this research has assumed simple resource dynamics that do not capture heterogeneity of impacts across space, yet recent research suggests that neglecting the specific dynamics of the resource may lead to significant bias in the predicted behavior and social efficiency outcomes that result (Brozovic et al., 2010; Suter et al., 2012). On the other hand, natural science modeling, such as that done in hydrology, typically assumes constant use on the part of resource users (such as pumping water for irrigation) and ignores potential changes in human behavior. However, since human behavior changes due to natural resource dynamics, then natural resource modeling should also anticipate and account for this change in resource use by humans. In other words, while economists have often introduced bias into their policy recommendations by ignoring the specific hydrologic features of the aquifers that they study, natural scientists have often introduced bias by ignoring variable human behavioral responses.

The Laboratory for Experimental and Applied Economics at UD is on the forefront of social science research, integrating natural science understandings with human behavior. The lab has established a research environment appropriate for gauging individual and public responses to policies and for testing the efficacy and efficiency of potential policies. Fundamental to the success of this multidisciplinary research is that the collaborating researchers share the basic tenets of the research process, such as proposing hypotheses and testing them through a data-driven process that builds on the scientific approaches of experimental control and replicability. The integration of natural and social science research through the methods of experimental economics will be extended across RII research themes.

Economic models combined with community and stakeholder surveys will be conducted to evaluate policy and management strategies and their potential impacts on water quality. For example, this could include assessing nutrient-trading strategies for the Chesapeake Bay Program to limit the nutrient inputs from agriculture. Government regulations and policies will be evaluated to investigate if they account for the true costs (including environmental costs) associated with land use and management practices. Risk

analysis and experimental economics studies will be conducted to investigate how people respond to risk, such as risks from environmental contaminants (Messer et al., 2006), foodborne pathogens (Messer et al., 2011), and water pollution (Keisner et al., forthcoming). Federal, state, and local government agencies, nonprofit environmental organizations, and watershed communities and stakeholders will be closely involved in this research, in addition to faculty and students.

Faculty Collaborators: This research theme will be jointly led by researchers S. Inamdar, a hydrologist focused on watershed management, hydrology, and water quality; environmental engineer S. Dentel, who works on novel water treatment technologies; environmental economist J. Duke, an expert in land use and water policy economics; and G. Ozbay, a water quality and nutrient cycling researcher. Other faculty in this research theme include L. Claessens, climate and nutrient cycling; G. Kauffman, watershed policy; A. Sarzynski, environmental policy; M. Guo, water quality and nutrient management; D. Jaisi, phosphorus isotope biogeochemistry; and P. Imhoff, groundwater contamination and mathematical modeling. The research will involve close interactions with DNREC, the Delaware Department of Agriculture, the NSF-supported Christina River Basin CZO, and the nonprofit Delaware Wild Lands. International collaborators include the Indian Institute of Science in Bangalore and China Agriculture University in Beijing.

Funding is requested for a postdoctoral researcher, two graduate students, four undergraduate researchers, supplies and travel related to the research.

Theme 3: Developing and Deploying Multiple Spatial and Temporal Scale Environmental Sensors
(Team Leaders: UD-Leathers, Ni, Rabolt, Xiao)

"Observing and accurately predicting Earth's environment are critical for the health, safety, and prosperity of the nation" (NAS, 2003). The environmental issues facing Delaware — including variations and changes in the climate system, sea level, water quality and quantity, land cover and land use, and ecosystem health — warrant an environmental sensing and monitoring capability at multiple spatial and temporal scales (Klemas et al., 2000; Hansager et al., 2008). Delaware currently boasts one of the nation's highest-resolution environmental observing networks. More than 250 observing platforms across the Delmarva region track macroscale environmental data such as meteorological variables, stream flow, tide levels, water quality, well levels, and snow depth. However, these independent data streams are often not suitable on their own to provide solutions to complex environmental problems; more integration, analysis, and visualization of environmental data are needed (Brock et al., 1995; Czajkowski et al., 2000). Moreover, the lack of nanoscale sensing capabilities to identify trace amounts of nutrient elements and metal(loid)s limit the research questions we can pose and the development of operational monitoring systems that could provide critical information to policy makers across the region. Therefore, we propose to establish a molecular- to macro-scale sensing and monitoring capability to address the multiscale environmental issues endemic to Delaware and much of the United States.

Research Questions: The following questions will be addressed to provide the data needed for research and operational monitoring:

- What novel nanoscale sensors can be developed to detect nutrient elements and metal(loids) in natural environments?
- How can we incorporate nanoscale sensors and the data that they generate into a macroscale environmental sensor network?
- How do individuals and public policy makers understand, respond to, and integrate environmental data into the policy process to lead to more sustainable outcomes?

Research Approach: Integrating data from the molecular- to the macro-scale has already begun through the Delaware Environmental Monitoring and Analysis Center (DEMAC) supported by EPSCoR Track-2 C2 funding. Integration comprises ingesting diverse data streams; developing appropriate database structures to store, analyze, and disseminate the data streams; and making the databases available in a common format to researchers, government agencies, and educators throughout the state. An environmental informatics specialist leads this effort. DEMAC is currently developing several new environmental monitoring systems including a water-quality monitoring portal for Delaware's Inland Bays and a statewide drought advisory system with special applications to agriculture. This multiscale integration of data is unique in the solution of the region's environmental issues, and we propose to continue to develop and expand this system, particularly through additional nanoscale sensors and data.

We propose to develop a fast and ultrasensitive attenuated total reflection (ATR) sensing setup, which, when coupled with a cylindrical ATR element, can be used to study adsorption on high-surface-area solids with a time resolution of 10 milliseconds. For high surface areas, we will use electrospun polymer nanofibers as the platform technology for adsorption and sensing substrates.

Although electrospun fibrous membranes can be used for detecting contaminants in water and air directly, one area where we will focus our future efforts is detecting metal(loids) (e.g., As, Pb, Ni, Mn, Zn, Cu, Cr) and nutrient elements (e.g., N, P) in the environment. This will be done via two approaches. The first uses electrospun membranes composed of nanofibers that have been functionalized with chemical groups targeted to “capture” As or Cu compounds, for example, followed by real-time analysis using the PA-IR ATR technique, which will allow the spatial detection of contaminants on inhomogeneous “capture” membranes. The second approach integrates electrospun fiber and gold nanorod detection using surface-enhanced Raman spectroscopy (SERS).

Gold nanorods (AuNRs) have intriguing, fine-tunable optoelectronic properties and have become a promising building block in the fabrication of surface-enhanced Raman scattering (SERS) substrates. In future research under the RII, we will attempt to immobilize AuNRs on electrospun polycaprolactone (PCL) fibers using polyelectrolyte (PE) decoration. In general, charges are deposited on the PCL fibers during the electrospinning process, and the AuNRs will be adhered to these fibers by PE multilayer deposition. This multistage process will be investigated by PA-IR and X-ray photoelectron spectroscopy (XPS). In addition, AuNR/PCL substrates with varied AuNR densities will be fabricated and characterized by scanning electron microscopy (SEM). The high sensitivity makes the substrate a promising candidate for the detection of trace amounts of toxic substances in the environment. Specifically, we plan to chemically modify the AuNRs with thiol-derived compounds that contain functional groups that will interact chemically or physically with heavy metal(loids) and, as a result, change their vibrational frequencies and/or intensities to make their presence detectable. The SERS enhancement of multiple orders of magnitude will help considerably in detecting trace quantities of heavy metals in the environment.

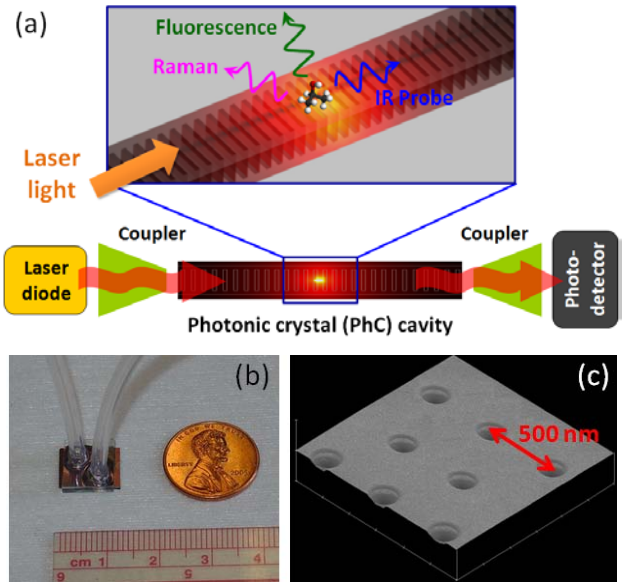

Figure 2. (a) Operating mechanism of the sensor chip: laser light is tightly confined in a photonic crystal (PhC) cavity to induce strong interactions such as Raman/fluorescence emission and IR absorption. (b) Photo of a sensor device the UD group demonstrated which integrates a micro-sensor optical chip with microfluidics for analyte transport; (c) Surface morphology of PhCs measured by AFM.

For chip-scale photonic sensors, we will develop an integrated spectroscopic sensor for real-time monitoring of organophosphate, nitrate, and trace metal(lloids) in water, air, and soil. The device will overcome the specificity bottleneck of current on-chip sensors by combining several complementary detection mechanisms to achieve superior specificity. All of these techniques capitalize on strong light-molecule interactions in dual-wavelength-resonance photonic crystal (PhC) cavities to achieve detection sensitivity down to a single molecule, since such interactions are amplified at both pump and probe (or emission) wavelengths. We will aim at integrating this chip-scale sensor with commercial laser diodes and detectors to demonstrate a sensor for field-deployable applications. A diagram of the operating mechanism is shown in Figure 2.

We have analyzed Raman and IR photothermal sensors using PhC cavities (Hu, 2010; Lin, 2012). The IR sensor predicts a limit of detection down to the sub-ppb level, and the Raman sensor will be capable of single-molecule detection. The unique double resonance mechanism leads to more than four orders of magnitude sensitivity improvement compared to state-of-the-art on-chip sensors for both Raman and IR detection.

In this project, we will first investigate novel double resonance photonic sensing mechanisms and sensor platforms and will explore a novel nanofabrication technique. A new Zeiss Auriga 60 CrossBeam™ FIB nanofabrication and nano-prototyping workstation at UD's W.M. Keck Electron Microscopy Facility will be used in the PhC device fabrication. Optical and sensing performance of the sensor chip will be quantified using a home-built nanophotonic device testing setup at the NanoPhotonic Glass Lab at UD. Fluid samples will be delivered to the sensor using microfluidic channels and the optical response of the device will be monitored in situ. Secondly, we will demonstrate a standalone sensor device by exploring integration with diode lasers and detectors, using a commercial butterfly fiber-coupled diode laser, and the sensor chip will be bonded to a printed circuit board. A pre-etched V-groove on the sensor chip offers a robust mechanical alignment mechanism to ensure reproducible coupling between the laser and the sensor cavity (Sun, 2007). A photodetector can be integrated with the PhC sensor using an evanescent coupling design we previously established (Hu, 2012).

Magnetic nanoparticle-magnetoresistive (MNP-MR) biochips use highly sensitive MR sensors to detect the field from, potentially, a single MNP bonded to a molecule to be detected. In past years, we have systematically investigated the fabrication of MNPS and MR sensors in UD's Center for Spintronics and Biodetection. Magnetic sensors typically show a magnetoresistive ratio of more than 300%. In this project, we will develop MNP-MR sensors to detect trace metalloids in the environment. The sensor is portable in chip-scale, analyte-specific, and quantitative. We will first demonstrate the detection of trace Hg and then extend the technology to other metalloids such as As, Pb, Ni, Mn, Zn, Cu, Cr, etc.

***Faculty Collaborators**:* The macrosensing portion of this research theme will be led by D. Leathers, a climatologist and director of DEMAC. The microsensing efforts will be led by C. Ni, a materials scientist/engineer who is an expert in microscopy and functionalized nanostructures and mesophases; J. Xiao, a physicist who specializes in synthesis, characterization, and applications of nanostructured materials; and J. Rabolt, a materials scientist/engineer whose specialty is infrared and Raman spectroscopy. Other collaborators include J. J. Hu, a materials scientist/engineer who focuses on biomolecular sensing. External collaborators include S. Sun, Brown University, and X. F. Han, Institute of Physics, Chinese Academy of Sciences, Beijing.

Funding is requested for a postdoctoral associate, two graduate students, travel and supplies related to this research theme.

***Theme 4: Innovations in Renewable Energy** (Team Leaders: UD-Madsen; DSU-Kalavacharla)*

In this research theme, we seek to support new, high-potential teams in renewable energy; we believe these teams have excellent prospects as part of future energy research in our jurisdiction. Delaware has long been a national and international powerhouse in solar energy research, particularly through the Institute for Energy Conversion at UD. However, two additional forms of renewable energy — offshore wind and plant-based biofuels — are emerging areas of interest and research in the state. Delaware's coastal location promises advantages to researchers in either area, including suitable shoreline and potential nonfood sources of biomass in the form of perennial grasses. Initial research in these areas will focus on assessing and overcoming barriers to the further development of these resources.

Research Questions: This theme will examine the following questions:

- Where along the mid-Atlantic coast in general, and the offshore Wind Energy Areas (WEAs) in particular, are the most preferable sites for locating gigawatt-scale wind energy projects?
- What risks and benefits must be known to adequately inform a decision framework relating to offshore wind deployments along our coasts?
- What are the effects of biotic and abiotic stresses such as fungal rust, drought, and salinity on bioenergy crops, and what effects do these stresses have on the epigenome?
- Can selections be made for traits that would help in the establishment of successful biofuel crops that have a low environmental impact but can withstand abiotic and biotic stresses?
- What would the economic impact be on Delaware's coastal communities and tourism from offshore wind farms? What factors (e.g., educational, technological, risk) are most pertinent to farmers in making the decision to invest in biofuel crops?

Research to Reduce Costs and Analyze Risks of Offshore Wind Development: U.S. development of offshore wind energy is in its initial stages. One of the key barriers to implementation is the relatively high costs associated with these projects resulting from the technical and logistical challenges of installing and operating large wind turbines in open-sea environments and connecting their output to the on-land electrical grid. A substantial portion of these costs, estimated at up to 30%, are associated with offshore wind turbine foundations and the electrical cabling between turbines and offshore substations and between substations and onshore grid interconnections. Beyond the technical and cost challenges of this relatively new energy technology, unfamiliar risks and benefits to the community and regulators inevitably arise. These risks have already led to expensive and broad-based studies in the European Union — where gigawatt-scale installations are taking place — as well as delays in U.S. permitting approvals in state and federal waters and the Great Lakes. For example, large risks and uncertainties are presented by various species, such as the North Atlantic right whale and the Atlantic sturgeon, regulated by the Endangered Species Act.

One component of this research project seeks to better understand how to assess the potential environmental and human effects of deploying renewable energy, particularly offshore wind facilities, along our coastlines. The assessment requires a robust and systematic risk paradigm. Evaluating potential risks requires a consistent program of research over time that collects relevant data for each sectoral area, such as bat and bird collisions with wind turbines, fragmentation of marine habitats, seismic hazard potential, structural security of turbines, safety of shipping lanes, and economic impacts on coastal communities and tourism. As the regulatory community and other stakeholders are well aware, data collection alone will not lead to better decision making (NRC, 2009). Thus, a risk-informed decision framework will contribute significantly to a better understanding of renewable energy deployments.

There are many potential risks and benefits associated with deployment of offshore wind plants in the Atlantic. This research effort will have two parts. Year 1 will investigate existing studies — some of which are already summarized in work by project investigator Bonnie Ram (Musial and Ram, 2010) and additional domestic and international resources. An annotated bibliography will be compiled and an analysis conducted of potential effects. This research will characterize the potential adverse effects and estimate the probability of occurrence and the extent of the consequence. These effects will be compared to other “stressors” in the marine environment, a fundamental principle of risk analysis (NRC, 2009). The concept is not to address every sector, but to summarize the information we have now to better inform decision makers with this risk-informed approach. Water resource issues are included in this cross-sectoral approach and, in this case, comparative water use across energy supplies would be a considered factor (NRC, 2010; UCS, 2012). Year 2 of the investigation would identify significant gaps in the knowledge base compiled in Year 1 that would inform R&D priorities in the near term and elucidate where research can close the gap in knowledge or reduce the potential risks posed. In addition, Year 2 research would begin to address the more complex questions of cumulative risks and life cycle effects, where limited R&D has been conducted to date.

To address ways in which the costs of offshore wind projects can be lowered, the second component of this research project will review the geological framework of the continental shelf of the Mid-Atlantic Bight (MAB), extending from eastern Long Island to North Carolina, for the purpose of identifying preferred locations for offshore wind projects. Given their differing geotechnical properties, the MAB bottom and subsurface sediments and/or bedrock are critical in the design and installation of offshore wind turbine foundations, the placement of transmission cables, and the degree of scouring in the vicinity of cables and foundations. If sites for projects, and even the location of individual foundations within project areas, can be selected based on preferred geological/geotechnical conditions that enable more economical solutions to foundation design, cable installation, and response to scouring, there is an opportunity to reduce the overall costs of offshore wind projects. The outcomes of this research can be used to aid individual offshore wind projects along the MAB and serve as a model for how this geological/ geotechnical approach can be used in future projects devoted to planning offshore wind development in coastal areas around the globe.

Research on Plant-Based Biofuels: Bioenergy production through various cellulosic feed stocks has emerged as a promising alternative to fossil-fuel derived energy sources. Steady progress has been made in bioenergy research at Delaware State University, including (1) exploring biofuel production from cassava, various oil seeds, and organic residues; (2) epigenomic mechanisms of abiotic and biotic

stresses; (3) assessing potential environmental and economic impacts of different biofuel systems; and (4) preparing educators with knowledge about the science and technology of bioenergy and bioproducts.

However, little is known about the interaction of environment and epigenome in the physiological development of perennial grasses that are now being assessed nationwide as bioenergy crops. In the RII, DSU's interest in plant-based renewable bioenergy will be directed toward studying the impact of abiotic and biotic stresses on two dedicated bioenergy grasses, switchgrass and prairie cordgrass (PCG), and the epigenomics of these stresses on the grasses. An additional interest that ties into the other major research components of this RII is that these bioenergy crops, especially PCG, can be grown on marginal lands and under conditions of high salinity. We will leverage existing resources while developing a niche area that will be useful for the research and training of Delaware students and scientists in the area of plant-based, renewable bioenergy.

We plan to develop reference epigenomes of selected switchgrass and PCG genotypes through methods developed and adapted at DSU. We will then evaluate the effect of one biotic stress (rust fungal infection) and two abiotic stresses (drought and salinity) on the transcriptome and epigenome of the two grasses. This will include determining genome-wide distribution of selected histone modification marks using chromatin immunoprecipitation sequencing (ChIP-seq); understanding histone deacetylase and DNA methylase activities and developing perennial grass lines deficient in key genes in these pathways; and profiling of genomewide transcription through small RNA-seq and mRNA-seq during and after stress.

PCG is among the most salt tolerant dry-land plants and is thus an excellent reference species for understanding salt adaptation mechanisms. It can grow optimally even at salt concentrations equivalent to seawater. Multiple mechanisms of salt tolerance that act in parallel have been identified in PCG, making it a unique source of genes that might confer salt tolerance traits to other plant species. Saltmarsh grass (*S. alterniflora*), a relative of PCG, is native to Delaware and grows well in brackish water. Therefore, understanding the epigenetic mechanisms underlying salt tolerance in PCG and comparing them with those in saltmarsh grass would be useful and applicable to the broader range of biofuel crops. In addition, these studies will improve our understanding of plant responses to drought and resultant salinity due to climate change and sea-level rise. Finally, by these comparisons, we hope to understand the formation, impact, and transmission of stress-induced epigenetic variation. We will also evaluate the inheritance of these epigenomic marks in subsequent generations, to evaluate their heritability and to determine whether these marks are transient or permanent. Results of these investigations will be made available to the broader plant epigenetics and perennial grass genetics and breeding communities through appropriate websites and databases.

Faculty Collaborators: The geological portion of this theme will be led by coastal geologist J. Madsen, a scientist in UD's Center for Carbon-Free Power Integration (CCPI). The risk portion will be led by B. Ram, associate director and senior research scientist at CCPI. Additional wind energy collaborators include J. Firestone, wind energy policy; D. Fox, an expert on Atlantic sturgeon, and K. Vulinec, an expert on bats. The biofuel subtheme will be led by RII co-PI V. Kalavacharla, a plant scientist specializing in molecular genetics and genomics and director of the Center for Integrated Biological and Environmental Research (CIBER) at DSU. Additional investigators in this area include B. Hankoua, an expert in developing bioenergy crop lines; M. Guo, a soil scientist with expertise in drought and salinity; S. Elavarthi, a plant physiologist with expertise in physiological effects of stress; and T. Smolinski, a bioinformatician. We will also collaborate with two EPSCoR jurisdictions: M. Saha of the Noble Foundation in Oklahoma and J. Gonzalez of South Dakota, who are breeders of switchgrass and PCG respectively.

Funding requested to support one postdoctoral researcher and two undergraduates for wind research. To support DSU bioenergy and water research, support for one tenure-track assistant professor, three postdocs, two research technicians, and one research scientist is requested.

4.3.1 Seed Funding and Emerging Areas. The program will fund about 34 seed grants at $1.2 million to catalyze multidisciplinary and cross-institutional collaboration and enhance competitiveness for extramural funding. Grants can include graduate student stipends, supplies, travel expenses, and instrument fee waivers. This mechanism was extremely successful in prior RIIs in developing a base of collaborating researchers and faculty across institutional and disciplinary boundaries. Seed grants will require a future funding plan; formal faculty mentoring plan; a state agency, academic institution, or private industry partner; and participation in some aspect of EOD programming. All four EPSCoR

institutions including DTCC will participate. A segment of the EPSCoR faculty leadership team will issue an RFP, arrange external peer review, and select proposals for funding.

Fill Faculty Expertise Gaps with New Hires: The RII will provide assistance in hiring five new faculty members-one full professor and four junior-level faculty, to fill gaps in expertise and enhance our ability to respond to funding initiatives in the areas of climate change, earth systems sustainability, critical zone processes, and bioenergy. Faculty positions in the following areas have been committed by UD: (1) Howard E. Cosgrove Chair in the Environment, a position for a renowned scholar in environmental science, engineering, policy, or economics to further enhance the prominence of UD's environmental teaching and research programs and to assist in building the Delaware Environmental Institute (DENIN) to a position of national and international prominence; (2) a top climatologist investigating the key lingering uncertainties in climate modeling and forecasting including the roles played by clouds, the cryosphere, the oceans, land use, and couplings between climate and biogeochemical cycles; (3) a low-temperature geochemist whose research could include aqueous and/or mineral chemistry applied to weathering reactions, nutrient and metal cycling, or carbon cycling, including natural and anthropogenic processes and carbon sequestration; and (4) an ecosystems services modeler who is able to capture the broad physical, biological, and chemical dynamics of ecosystems and the effects of land use, population, and climate variability and their feedbacks on biodiversity, biogeochemical cycles, and ecosystem services. The fifth faculty hire will be at DSU, which has created a tenure-track faculty position in bioenergy, to strengthen their research capabilities in this area.

Partner to Fill Remaining Gap: Partnering outside Delaware will play an important role in filling resource gaps and providing access to state-of-the-art spectroscopic and microscopic instrumentation. We will partner with national labs and colleagues at other universities around the world to enhance our ability to answer our research questions. Many of these have been named in the above research theme descriptions; letters of support from these institutions are included in the Supplementary Documents.

4.4 Diversity Plan

The Delaware EPSCoR RII aims to increase the diversity of students, faculty, and staff in our network in environmentally relevant research and education in science, engineering, technology, and policy.

Institutional Diversity in STEM: Delaware EPSCoR includes a diverse partnership of institutions: a research-intensive university (UD), an HBCU (DSU), a minority-serving liberal arts institution (Wesley College), and a community college with urban and rural campuses (DTCC). The Delaware EPSCoR diversity plan is closely aligned with our workforce development and external engagement plans, as described in Sections 4.5 and 4.7. We have also engaged a diverse set of partners in the public and private sectors who are committed to preparing students for careers at every educational level. (See letters of support in Supplementary Documents.)

National Data: The National Science Board reported that in 2008, with 3.5 million workers in S&E occupations, whites made up over 70% of U.S. scientists and engineers. Whites are highly concentrated in areas focused on macrophysical systems, including forestry and conservation science (91%) and earth, atmospheric, and ocean science (86%) (NSB, 2012). While the scientific focus of Delaware EPSCoR will involve macrophysical systems, our participants will be much more diverse, as described below.

Diversity Milestones: Delaware EPSCoR plans 13 new hires including four faculty at UD (Years 2-4), a new tenure-track faculty member in bioenergy and six research staff at DSU (Years 1-5), a director of student success at Wesley (Year 1), a statewide intellectual property licensing associate (Year 1), program manager at DTCC (Year 1), and a student success liaison at UD (Year 1). We are committed to hiring at least 50% women and members of underrepresented groups, including minorities and people with disabilities, for these new hires.

Diversity

- Diverse institutions, reflecting the state and the nation
- 13 new hires will be at least 50% women and members of UR groups
- Graduate students will be 50% women and members of UR groups
- EPSCoR Scholars will be 50% women and 25% members of UR groups

Among undergraduate EPSCoR scholars, we plan to involve at least 50% women and 30% students from underrepresented groups, including first-generation and students with disabilities, and at least 50% women and members of underrepresented groups at the graduate level. We have also arranged to invite undergraduates from HBCUs with water quality programs to take part in undergraduate research in Delaware

(see Taylor letter of support). In some cases, partner institutions have set diversity goals for enrollment in specific programs. For example, DTCC aims to increase the number of women in its environment and energy programs, which currently have predominantly male students. Among K-12 students in our Stem Workforce Outreach program (Section 4.7), we will involve participants that reflect the demographics of Delaware, with at least 30% underrepresented students and 50% females.

Table 1: Demographics of the State of Delaware and RII Academic Partners (2011-2012)

Delaware	**Total Number**	**% Female**	**% African-American, Hispanic and Native American**
State of Delaware, 2011	907,135	52%	31%
STEM Student Demographics by Institution**	**Total**	**Female**	**% African-American, Hispanic and Native American**
University of Delaware (STEM grad. students)	2,100	47%	10% (210)
Delaware State Univ. (STEM grad. students)	111	68%	38% (42)
University of Delaware (STEM undergraduates)	7,871	57%	8% (630)
Delaware State Univ. (STEM undergraduates)	1048	58%	81% (845)
Wesley College (STEM undergraduates)	138	60%	56% (77)
Delaware Tech (STEM undergraduates)	1,844	24%	29% (535)
Total STEM Graduate Students	**2,211**	**48%**	**11% (252)**
Total STEM Undergraduates	**10,901**	**52%**	**25% (2,732)**
Faculty Demographics	**Total**	**Female**	**% African-American, Hispanic and Native American**
University of Delaware (Faculty)	**1,172**	**40%**	**19% (222)**
Delaware State University (Faculty)	**211**	**40%**	**36% (76)**
Wesley College (Faculty)	**155**	**50%**	**10% (15)**
Delaware Tech (Faculty)	**1,149**	**63%**	**11% (128)**
Total Delaware Faculty	**2,687**	**50%**	**16% (441)**

** STEM populations here include some human health-related majors.

4.5 Workforce Development Plan

Delaware EPSCoR has designed a workforce development plan that bridges students' exposure to science and research from middle school to graduate school, with a particular focus on minority-serving and two-year and four-year institutions. We maintain that degree completion is a prerequisite to STEM career success, and we seek to increase retention and degree completion across institutions. We will track retention and degree completion using the National Student Clearinghouse (NSC) database, which is updated every 30-40 days and thus provides virtually real-time data on progress. Our goal is a combined ongoing enrollment and degree completion target of at least 90% among students supported directly by the RII.

Workforce
- Center for Industry Research and Workforce Alignment
- UG student research experiences and career support
- New graduate program in environmental biogeochemistry
- Real-world intellectual property training
- Applied environment/policy research with government, nonprofits, private sector

Data-driven Workforce Preparation: A transformative element of the Delaware EPSCoR workforce development plan is the newly formed Center for Industry Research and Workforce Alignment (CIRWA) housed at Delaware Tech. CIRWA will research labor market data, emerging trends, new technology, and external events to project the impact on new and existing jobs related to energy and the environment, especially water, including factors such as climate change, sea-level rise, and water quality and scarcity. CIRWA is modeled upon the successful California Community College System *Centers of Excellence* program, which has provided future-focused

workforce research customized for regional decision-making. CIRWA will provide relevant data to serve the pipeline of projected job opportunities and associated educational requirements. Beginning with a focus on energy and environmental careers, CIRWA will connect with local businesses, government leaders, and academic institutions to identify education and skill gaps within the environment and energy sectors that are emerging and to inform the design of new educational programs, courses, and/or experiential learning opportunities. CIRWA will provide workshops and webinars to inform stakeholders of the latest data, beginning with an analysis of the clean energy job pipeline, to be completed in fall 2013.

Career Tools to Guide Students in Decision-making: Through our evaluation process among undergraduates, we know that students are deeply concerned about career decision-making and that it is challenging for all institutions to provide customized, personalized support to each undergraduate. To support students in their career exploration process, Delaware EPSCoR will pilot use of career support software beginning in Year 1 through Focus2 Careers, a web-based career exploration software tool that helps students to assess their work interests, skills, personality, and values profiles, and which offers suggested career directions, along with educational requirements/majors and salary expectations. All undergraduate students supported through the grant will be required to complete a profile and to develop a personal education and career plan. We will evaluate the software during the program and work with our career services offices toward adoption. Additionally, as a result of CIRWA's research, DTCC will map the pipeline of Delaware's STEM jobs at the associate degree, bachelor's, and graduate levels to provide current information to students and parents. This will be a model that other states can replicate.

***Undergraduate Research Experiences*:** Our second major thrust in workforce development is our undergraduate research program, EPSCoR Scholars, which will provide students from all partner institutions the opportunity to carry out full-time summer and part-time academic-year research. Our goal is to attract, engage, and retain a diverse group of students in science and engineering majors and to encourage degree completion consistent with students' career objectives. Benefits to students associated with undergraduate research are documented in studies and include significant influence on educational and career outcomes of *students from underrepresented groups* (Alexander et al., 1998; Hathaway et al., 2002; Thiry and Laursen, 2009), and *higher GPA* (Fechheimer, 2011). Studies also support the value of academic-year research experiences, through on-campus research courses associated with *advanced degree completion* (Carter, 2009). We have observed that students involved in undergraduate research through previous Delaware EPSCoR programs complete degrees and persist in degree programs at high levels. For example, for the period 2007-2011, more than 92% of Delaware EPSCoR undergraduates involved in research had completed degrees or were still enrolled and on track as undergraduates.

Delaware EPSCoR will support 30 students per year in mentored undergraduate research. We have secured commitments to host undergraduate interns across Delaware's academic, industry, and nonprofit sectors, ensuring that we can match a student's career interests and skills with an appropriate internship opportunity. During the summer program, we will provide an offsite retreat featuring career roundtables, research presentations, science communication training, and outdoor environmental activities. Summer field and lab visits with RII researchers and DNREC personnel will provide students with a broad perspective on emerging issues in the environment and energy. Students will present research findings at a summer research symposium and regional/national meetings. Supported by the literature on undergraduate STEM education, our goals encompass engagement and retention, integrating inquiry-based learning (NRC, 2000), developing understanding of the scientific process, and the growth of critical thinking skills (Bauer and Bennett, 2003; Merkel, 2001; Osborn, 2009), by preparing students to carry out research as EPSCoR Scholars in academic labs, government agencies, or the private sector.

Students across the Delaware network also participate through an NSF REU at DSU, led by RII co-PI V. Kalavacharla. We will track enrollment and degree completion through the NSC database and job placement through student and faculty surveys. The successes of our undergraduate research and statewide partnerships are also documented in recent publications from Wesley College (D'Souza et al., 2012; D'Souza et al., 2011). On an ongoing basis, we will connect two- and four-year institution faculty with investigators who are pursuing NSF research grants, such as CAREER awards, who wish to design powerful *broader impacts* partnerships. Finally, participation of community college research participants is noteworthy because it is unusual in associate degree education. In this project, community college students involved include majors in environmental and other engineering technologies, energy management, water quality, and life sciences, to be further developed as described below.

Embedding Research into Community College Courses: As a sustainable approach to engaging more students in the high-impact practice of undergraduate research, DTCC will (1) develop and implement a train-the-trainer program to prepare community college faculty to embed research concepts and experiences into associate degree curriculum; (2) include research content and experience into three associate degree programs that currently do not have this content — environmental engineering technology, water quality, and energy management; and (3) offer a multidisciplinary research course, developed through an ATE grant, for associate's degree students appropriate for a variety of STEM majors. We will also encourage students to consider continued education at a four-year institution and plan regular professional development and release time for community college faculty who will incorporate research experiences into curricula, building institutional capacity. On an ongoing basis, we will connect DTCC and partner institution faculty for integrated research and education opportunities.

College-wide Undergraduate Research: Catalyzed by the success of EPSCoR undergraduate interns, Wesley College, a minority-serving institution, approved an initiative in 2012 to involve every undergraduate in research as one element of a plan to increase student retention. In tandem, a newly reorganized Career Services Department is focused on job and career readiness for students. A director of student success will be partially supported by EPSCoR; multiple initiatives are supported through Wesley institutional funds, and best practices will be shared across the network.

New Graduate Program in Environmental Biogeochemistry: Interdisciplinary graduate programs are important both for students and in attracting excellent faculty. In Year 1 of the EPSCoR project, planning will begin on a new graduate program in environmental biogeochemistry at UD, to prepare students for careers in academia, government, and the private sector. The program's interdisciplinary environmental research focus will tap areas of significant expertise in environmental chemistry and geochemistry, geostatistics, hydrology, microbiology and life sciences, numerical modeling, and soil science. New facilities on campus will support faculty and student interaction in the new degree program. The new $132-million Interdisciplinary Science and Engineering (ISE) Laboratory will house 20 environmental and energy science faculty labs, DENIN, energy and environmental policy research centers, state-of-the-art core facilities, graduate student office space, and PBL classrooms.

Spin-In™ Technology Transfer Training for Students: We seek to further prepare students for the workforce by providing intellectual property experience. *Spin-In™* will be an annual independent study course, managed by the Office of Economic Innovation and Partnerships (the UD tech transfer office), in which entrepreneurial companies spin into UD their developing intellectual property or product ideas that have not yet reached the commercialization level. Teams of students will be assigned to develop the ideas, which are then spun back out to the company for commercialization. In this small group learning environment, students will develop the ideas, present a package to the client company, and learn the process of taking a discovery toward commercialization. Students with a particular interest in the innovation process will have the option of a summer internship at OEIP.

Graduate Internships at DNREC and Industry: To synergize university expertise and the environmental needs of the state of Delaware, we will support annual graduate student internships with DNREC. Research questions will be designed by DNREC; graduate students seeking an applied research experience will be invited to apply. Students will make a presentation to DNREC senior leadership and write a paper with findings and recommendations. Each year, DNREC will evaluate student projects and will note how the findings were used. In collaboration with the business community, we have also planned graduate internships in Delaware environmental businesses. (See letters of support.)

4.6 Cyberinfrastructure Plan

Over the past five years, with financial support provided by NSF EPSCoR RII, Track-2 and Track-2 C2, and NIH-INBRE Supplement funding, Delaware's academic institutions have significantly enhanced their cyberinfrastructure. For the next five years of RII support, we will take advantage of these upgrades and focus on key areas of need to create a sustainable community of natural and social scientists and engineers who contribute fully to the national research agenda, seamlessly using cyber-technologies.

Objectives: Delaware EPSCoR has three main cyberinfrastructure objectives: (1) strengthen Delaware's cyberinfrastructure to support natural and social science collaboration in the four RII research themes;

(2) create a statewide, multispatial and multitemporal environmental sensing capability; and (3) enhance collaborative research capabilities among partner institutions in Delaware and with other EPSCoR states.

Status: Since the launch of the current RII program in 2008, Delaware's EPSCoR partners have hired eight new bioinformatics faculty (six at UD and two at DSU); launched the Center for Bioinformatics and Computational Biology; enhanced bandwidth and redundancy at each of the RII partner institutions; established a state-of-the-art Sequencing and Genotyping Center; initiated the Laboratory for Experimental and Applied Economics; implemented a multiplatform CISCO video bridge to facilitate face-to-face collaboration; launched the Delaware Environmental Monitoring and Analysis Center (DEMAC); and led an initiative with four other EPSCoR states (NH, ME, RI, VT) to launch the successful Northeast Cyberinfrastructure Consortium (NECC). NECC filled the "black hole of connectivity" in the northeastern U.S. by providing broadband access to the New England states, created a first-generation set of regionally distributed data centers in Maine and Delaware, and sequenced the little skate (*Leucoraja erinacea*) genome and algal bloom metagenomes. The Delaware Cyberinfrastructure Task Force, comprised of chief information officers at the partner institutions, meets regularly to assess the status and adjust plans to provide a fast, affordable, and reliable cyberinfrastructure.

Activities: Delaware's cyber-activities will concentrate on the three objectives outlined above:

Strengthening Delaware's Cyberinfrastructure to Support Key RII Research Themes: The next stage of cyber-enhancements has been designed to support the broader scientific goals of the RII. Within this framework, Delaware will continue to enhance the capabilities of cyber-savvy scientific staff, invest in distributed data storage and computational servers, and upgrade its broadband capacity with the overall goal of supporting the RII environmental research mission. In 2011, UD installed a new, high-performance computer cluster, featuring over 200 computer nodes, 5,000+ processor cores, and 200 terabytes of disk space. UD offers EPSCoR partner institutions both access to and opportunity to become stakeholders in this cluster, providing considerable leverage to enhance the purchasing power of their institutional research budgets. UD also provides first-tier GIS and geospatial analysis software to researchers in energy and environmental sciences at significantly reduced costs, along with training and research-level consulting. These capabilities are carefully integrated to support the current RII research activities. We now request funds for an additional 50 terabytes of storage that will be connected to this cluster, as part of Delaware's commitment to provide a regional data server for our partners within Delaware and among the NECC partner states. The Laboratory for Experimental and Applied Economics has mobile computer equipment that supports research related to all four of the RII themes.

Cyberinfrastructure
- Support RII research themes
- Support environmental informatics for multiscale sensing
- Expand cyber-savvy personnel resources
- Increase bandwidth at partners
- Expand distributed data center

DSU will further enhance its campus wide cyberinfrastructure by providing redundant connections to key buildings directly involved in RII research and educational activities. Future improvements at DSU will strengthen bioinformatics infrastructure to analyze sequencing data that will be generated in support of DSU's RII research theme in epigenetics of biofuel crops. This will include additional data storage servers and increased computing capabilities for research and training in bioinformatics and experimental economics at DSU. Wesley will upgrade its GIS Computer Lab with updated software, data storage, and GIS interfaces. The lab provides training facilities for students in environmental studies, and the GIS course is available to all majors across campus to broaden their cyber skills.

Creating a Statewide, Multispatial and Multitemporal Environmental Sensing Capability: Delaware EPSCoR will acquire technologies and expand personnel to integrate temporally and spatially diverse sets of environmental data into meaningful applications to support research, interface with statewide emergency responders, and, ultimately, benefit the citizens of Delaware. The coordinating entity for this plan is DEMAC, initially launched with EPSCoR Track-2 C2 funding, which has already secured additional external support. DEMAC applies spatial mapping technologies to create value-added applications that provide improved, integrative approaches to understanding the dynamics of Delaware's environment.

As DEMAC continues to mature, enhancements to current systems and additional space for storage of several high-bandwidth data streams is a priority. In 2011, DEMAC hired an environmental informatics specialist, Tina Callahan, M.S., who collaborates with state and local agencies and with regional and national research groups. This position provides data manipulation and analysis skills, data visualization using modern online mapping technologies, a strong GIS background, database management, and web design and development to governmental agencies, K-12 education, and the public.

Enhancing Collaborative Research Capabilities: In 2012, UD installed a CISCO TelePresence server, (funded by NSF EPSCoR RII and NIH-INBRE) to support multisite videoconferencing among the Delaware partners and national/international collaborators. The server allows partners to schedule and control high-quality multisite discussions directly, thus reducing barriers to its use. Under the RII, we will build on this capability to engage student groups for joint research activities, workshops, and symposia and expand capacity for external engagement by providing online access to workshops on such topics as environmental sensing and the integration of social and natural sciences. A new Polycom video system will be installed in the future home of the EPSCoR and DENIN offices and research labs within UD's Interdisciplinary Science and Engineering Laboratory.

This proposal will support the enhancement of experimental economics laboratories at UD, DSU, DTCC and Wesley that will aid in the integration of social and natural science research related to all four research themes. Workshops will be provided on how to use the laboratories in integrated research. In addition to supporting experimental economics research, the laboratories will support multidisciplinary research that uses stated-preference surveys, mathematical programming, and virtual-reality simulations for economic valuation and policy analysis.

4.7 External Engagement Plan

Our outreach, communication, and dissemination strategies combine technology, formal and informal education, and special events focused on developing a diverse, well-prepared, globally engaged STEM workforce and scientifically literate public.

Engagement
- New multimedia streams to communicate science and train communicators
- Outreach to schools and hands-on science
- Inclusive and interesting public events statewide
- NSF outreach to build grants competitiveness

***Multimedia Initiatives*:** Delaware EPSCoR will launch a new science communication project with WDDE, the state's first NPR station, based in Dover and a joint project between DSU and UD. WDDE went on air in summer 2012 and offers the opportunity to showcase local science stories of interest to the Delaware community and for Delaware faculty and students to gain experience in communicating science to the public. WDDE's online presence is Delaware First Media, which offers an outlet for digital student productions, described below.

Delaware EPSCoR will maintain several content-rich websites among the partnership to ensure that the public and NSF have easy access to project news, results, and publication information. We will use an array of digital communication tools (electronic newsletters, blogs, email marketing services, Facebook) to reach broader and more diverse audiences, including other EPSCoR jurisdictions. Video conferencing among the Delaware EPSCoR group will be supported on a CISCO platform (described in section 4.6).

***Digital Storytelling Initiative*.** RII funds are requested to initiate a new communication project in digital storytelling that will benefit the statewide network. We propose to support part-time staff and equipment that will enable the journalism minor program at UD to enhance its offerings in digital media production. A suite of courses will train undergraduate and graduate students in digital media, audio and video production, and oral and written communication. Products of these courses will include professional quality videos, radio programs, digital magazines and other web content, and educational apps featuring Delaware EPSCoR-sponsored research. This approach will provide cost-effective media content about accomplishments and will prepare our students to communicate their work effectively using what are fast becoming essential 21st century job skills. Students at all institutions in the Delaware network benefit from the program through opportunities to master digital storytelling skills in productions on their research.

***STEM Career Workforce Outreach*:** Led by DTCC, and supported by Wesley College, DSU, and UD faculty and students, we plan an experiential science program through nearly 50 on-site visits to K-12 schools that serve geographically and socioeconomically diverse students. K-12 students will engage in hands-on science activities related to our theme areas, learn about STEM career and educational options through planned mapping of the job pipeline, and will be invited to take part in summer science opportunities described below. As part of our on-site visits, we will collaborate with Delaware's business community through the Committee of 100, a business group focused on economic development and good governance (see letter of support). Our plan for outreach to schools is supported by studies of STEM classroom experiences that influenced students' decisions to continue in science. Woolnough (1994) found that discussion about careers and issues in science was one of several influential classroom

experiences. Oakes (1990) found that group work and active learning were especially influential for female and minority students. Maltese and Tai (2011) found that 12th graders who reported plans to major in a STEM field were more than three times as likely to earn a STEM degree as those who reported plans for a different major *(underscoring the importance of this period in engaging future STEM degree earners).* School science visits will include information about college requirements and the application process and will involve 125 unique students in Year 1, increasing to 300 unique students in Year 5. Through this initiative, DTCC aims to expand enrollment and diversity in programs linked to the EPSCoR theme: environmental engineering, water quality, and energy management. DSU will host an annual RET for K-12 teachers, providing hands-on kits and laboratory supplies for teachers to use in the classroom. Programming for K-12 students is aligned with the objectives and work of the Governor's STEM Council, established in 2011 as a collaboration among PK-12 education, higher education, and business (Delaware STEM Council, 2012).

***Summer Science Camps*:** To engage middle and high school students in the excitement of science, we plan 11 one-week summer camps focused on water/environment or energy. Studies have found that involvement in informal science education programs are associated with significant gains on standardized science tests and positive perceptions of science careers (Tyler-Wood et al., 2012). Many engaging, age-appropriate models exist, such as three-day "mini-research projects" for high school students (Hammond, 2010). Led by faculty at Wesley College and experienced program managers at DTCC, in conjunction with EPSCoR investigators and students, the tuition-free camps will involve low-income students through the TRIO programs, as well as students recruited through school visits described above. In the current Delaware EPSCoR program, science camps involved underrepresented and low-income students; 90% of students graduated from high school and entered postsecondary education. We will also provide environmental science camp scholarships for students in Delaware's urban and rural 4-H camps.

Events to Build an Informed Community: Delaware EPSCoR will host events to strengthen the scientific network and build scientific literacy for public audiences. Through the *EcoCafé* series, we will bring together university researchers in environmental areas with DNREC staff; a pilot of the EcoCafé helped us to identify important research topics for this proposal, as well as for key focal areas for graduate intern research with the agency. Through our public *DENIN Dialogues,* we will invite distinguished environmental speakers to Delaware, twice annually, with live-streaming and podcasts for later viewing. Pilots of the *Dialogues* have attracted audiences of several hundred. Through our ethics programs, we will host science roundtables for the public on issues of importance. The Center for Science, Ethics, and Public Policy, will host its popular *Science Café* series statewide. In conjunction with the DSU Ethics Resource Site, we will host annual events for state legislators in Delaware's capital. Delaware EPSCoR will host an annual Research Symposium, open to all faculty, students, and partners in the private and public sectors. For all events, we will advertise broadly to ensure a diverse audience.

***NSF Outreach*:** We plan to engage NSF program officers with visits at least annually, for the Delaware EPSCoR Research Symposium, and also timed to assist teams as they plan new grant submissions.

4.8 Evaluation and Assessment Plan

Evaluation
- Strategic plan
- Internal evaluation team
- External evaluation with AAAS and external advisory board

To insure all programmatic elements undergo formative and summative evaluation throughout the life of the grant, the evaluation and assessment plan engages two groups to conduct the external evaluation and a third to conduct the internal evaluation and reporting. The underlying evaluation framework aligns with Patton's utilization-focused approach (Patton, 2008) intended to insure that the needs of critical stakeholders (e.g., Delaware EPSCoR leadership and NSF) are met through the evaluation process and that results are useful and timely. In addition, the *American Evaluation Association Guiding Principles for Evaluation* (AEA, 2004) will be followed to guide the professional practice of all evaluation personnel. Quantitative and qualitative methods will be used for ongoing evaluation, external program review, and annual reporting to NSF.

Strategic Plan Development: To facilitate immediate implementation, in the summer preceding the grant award, Delaware EPSCoR will develop a comprehensive strategic plan for all program elements to serve as the basis for evaluating progress toward programmatic goals.

External Evaluation: A panel from the AAAS Research Competitiveness Program, to include three to four members (with expertise in undergraduate research integration and economic development training, sustainability, and overall program) and one senior staff member, will meet in Years 1 and 4. In Year 1, the panel will review the overall program and strategic plan. In year 4 the panel will review the complete program as well as progress toward objectives and milestones in specific programmatic areas.

The Delaware EPSCoR external advisory board (EAB), with expertise in science and administration related to our discovery research themes, will meet annually to review the progress being made in scientific productivity and network development. The EAB will also review program progress and outcomes related to economic development initiatives, with specific attention to scientific innovation.

Both external evaluation bodies will (1) use information provided by the internal evaluation team and program leadership, along with stakeholder interviews during a site visit, to provide guidance on achieving benchmarks; (2) assess progress as it relates to the relevant program elements and goals; and (3) offer perspectives on the local, state, and national impacts of programmatic elements. External reviews will conclude with a brief presentation to the Delaware EPSCoR leadership summarizing strengths, challenges, and recommendations. A more detailed written report will be provided within one month of the meeting, serving as a tool for program management. These reports will be provided to NSF, and details of how recommendations were addressed will be included in our annual report.

Internal Evaluation: The internal evaluation team is led by Dr. Cheryl M. Ackerman, the current associate director of evaluation for Delaware EPSCoR. Dr. Amy Slocum, Delaware EPSCoR associate director; Ms. Kelly Doremus, accountant; and two part-time graduate research assistants complete the internal evaluation team, who, in collaboration with administrative support at partner institutions, will:

- Design and implement a system for ongoing formative evaluation to provide timely feedback to the Delaware EPSCoR leadership, including the management team and steering committee;
- Ensure all IRB protocols are followed as required, unless exempt under 45CFR46.101b (1) or (2);
- Coordinate external evaluation meetings, clarify the charge to and prepare advance briefing materials for external evaluation groups, in collaboration with program leaders;
- Facilitate Delaware EPSCoR leadership discussions of how external and internal evaluation feedback will be used to improve programmatic elements; and gather information to complete required reports.

Table 2. Evaluation and Assessment Plan Summary
*Numbers refer to data sources: 1-Student survey; 2-NSC data; 3-Online system; 4-Faculty survey; 5-Faculty interviews; 6-Key informant interviews; 7-OEIP data; 8-SNA; 9-Usage data; 10-EAB; 11-AAAS.

Program Element	Evaluation Questions	Output & Outcome Metrics	YEAR, Data Sources*				
			1	2	3	4	5
External Review	To what degree is Delaware EPSCoR making progress toward meeting its program goals?	Strategic plan finalization. External review and feedback.	10, 11	10	10	10,11	10
Benchmark Attainment	Have benchmarks for each program element been attained?	Diverse data sources.	x	x	x	x	x
Discovery Research	What is the level of EPSCoR researcher productivity and how does it change over time?	Grant applications and awards, publications, presentations	3	3	3	3	3
	How interdisciplinary is research across the program? Are researchers integrating in meaningful and productive ways?	Development of inter-disciplinary teams. Academic productivity, expanded EPSCoR network.	3, 6	3, 8	3, 6	3, 8	3
	To what degree do support mechanisms facilitate productivity, collaboration, access to opportunity?	Faculty leadership team efforts. Faculty evidence of assistance provided.	6	4	6	4	
Education, Outreach & Diversity	What benefits are students gaining through their EPSCoR experience?	Student academic products. STEM career, education plans. Retention, degree completion.	1,2,3	1,2,3	1,2,3	1,2,3	1,2,3

	How successful has program been in involving diverse faculty, students?	Demographics of faculty, students, other participants.	3	3	3	3	3
	How successful have outreach activities been at bringing information to the public?	Breadth of outreach activities. Utility to the public.	3	3,6	3	3,6	3
Economic Dev. & Innovation	How are supports for economic development and innovation improving marketable outputs?	Inventions, patents, royalties. Change over time in outputs.	7	7	7	7	7
	To what extent has EPSCoR catalyzed a culture change in converting research into social and economic development?	Use of OEIP services across partners. Increased connectivity with external partners.	7	6, 7	7	6, 7	7
Cyber	How has cyberinfrastructure use changed?	Usage data.	9	9	9	9	9
	How have discovery, EOD, and economic development activities been enhanced by cyber?	Enhanced data mgt., access to online community, improved instruction, communications.	6		6		6
Sustaina-bility	To what degree are EPSCoR sustainability efforts materializing?	Significant and novel science; Faculty integration and productivity.		5,6,8		5,6,8	
	To what degree are targeted multi-investigator grants submitted?	Grant submissions and awards.	3	3	3	3	3
	What EPSCoR investments are leading to job creation & prosperity? Are businesses tech. advances being developed, sustained?	New start-ups. Spin-In outcomes.		7	6	7	6

To improve the efficiency of data collection required for reporting to NSF, and to provide Delaware leadership prompt access to this data, we will collaborate with a group of jurisdictions developing an online data collection and management system: the *NSF EPSCoR Drupal System Collaboration*.

4.9 Sustainability Plan

The prospects for success are high. The RII clearly reflects the state S&T plan, and NSF and national priorities. Novel, interdisciplinary, and significant research directions are proposed; educational programs will strengthen our institutions and the STEM pipeline. Personnel are in place to manage the program expertly, to support new grant submissions, and to institutionalize programs.

Sustainability
- Significant and novel science
- Strategic new hires
- Effective and sustainable training plans
- Solid grants plan; experienced proposal team in place

4.9.1 Education and Human Resource Development. This award will provide partial support for five new tenure-track faculty positions related to the project's research and education goals. New faculty will be integrated into the research program and will be mentored by faculty already engaged in the proposed research, education, and economic development initiatives. A new graduate program in environmental biogeochemistry will be launched at UD, with development to begin in Year 1. The Laboratory for Experimental and Applied Economics will be developed into a formal Center at UD. DSU and Wesley will launch a green chemistry collaboration, which will enable students to take courses and carry out research at either campus. DTCC will launch faculty professional development and mentoring to incorporate research into community college courses, with embedded research modules and a stand-alone research course to begin by Year 3. Wesley College will launch a college-wide requirement for an undergraduate research experience, as part of a broader retention and engagement strategy. A new statewide licensing associate will ensure linkage between research and economic development.

4.9.2 Post-RII Extramural Funding. Initiatives catalyzed by the EPSCoR RII will be the focus of external funding targets, to build upon research findings, physical infrastructure (e.g., cyberinfrastructure, core

centers), and personnel investments. The team will seek to develop the following: Year 1: NSF SEES (UD); NSF MRI to support core instrumentation (UD); USDA NRI on biochar use for greenhouse gas mitigation (DSU and UD); NSF STEP (Wesley); NSF DEB Ecology (UD); NSF PGRP in epigenomics (DSU). Year 2: NSF Science and Technology Center (UD); NSF Molecular/Cellular Biology in epigenomics (DSU); and USDA NIFA to support bioenergy research (DSU); Year 3: NSF TUES (Wesley, DTCC); NSF Chemistry and the Environment (UD). Year 4: NSF ATE (DTCC). Throughout the project, we will work collaboratively on submissions and mentor faculty applying for CAREER awards as well as students applying for NSF Graduate Research and EPA STAR Fellowships. Other programs to be monitored include the Army's DURIP program, DOE, EPA, and foundation and philanthropic funding.

4.10 Management Plan

Strategic Plan: Program management is driven by a strategic plan, which will serve as a "living document" that aligns project goals, objectives, activities, milestones, short-term outputs, and long-term outcomes. The plan will be used as an organizational, evaluation, and management tool to be routinely revisited to make course corrections as needed. To develop and implement the strategic plan, the RII Management Plan has three components: (1) management, faculty leadership, and EOD teams; (2) an evaluation and assessment plan with both internal and external components; and (3) a sustainability plan. Our teams include 48% women and members of underrepresented groups, as detailed below.

Management Team: The management team of Delaware's RII program includes both program veterans and new faculty, responsible for setting goals, objectives, activities, and milestones for the program. The team has a record of successfully developing and managing large interdisciplinary grants and is well qualified to lead the EPSCoR RII program (50% F; 19% UR groups).

Management
- Inclusive and experienced management team
- Solid strategic plan
- Internal and external evaluation
- Steering committee of statewide leaders

The team includes **Donald L. Sparks**, Ph.D., S. Hallock du Pont Chair of Plant and Soil Sciences at UD and director of DENIN, who serves as principal investigator and project director. He has over 30 years of academic research experience, guiding the research of 75 students and postdocs and serving as a department chair for 20 years. He is the PI of the Christina River Basin CZO and will provide oversight to the thematic research programs. He will have overall program responsibility and will conduct annual program performance and financial reviews. Co-PI **Venugopal Kalavacharla**, Ph.D., is associate professor of molecular genetics and genomics at DSU and director of CIBER. He will oversee research and education activities at DSU. Co-PI **Kent Messer,** Ph.D., is associate professor in applied economics and statistics and director of the Laboratory for Experimental and Applied Economics at UD. He will oversee the development of interdisciplinary research between social and natural scientists. Co-PI **Stephanie Smith,** M.S.S., vice president for academic affairs at DTCC, brings 23 years of experience leading education initiatives and building institutional effectiveness. She is leading a student success initiative to increase student engagement and graduation rates and will oversee education initiatives at DTCC. Co-PI **Karl V. Steiner**, Ph.D., senior associate provost for research development and professor of electrical and computer engineering at UD, brings 20 years of experience in leading academic research centers and externally funded research projects. He will oversee cyberinfrastructure activities, core instrumentation centers and will provide operational leadership. **Malcolm D'Souza**, Ph.D., professor of chemistry and director of sponsored research at Wesley College, will oversee research and education activities at Wesley. **Dyremple Marsh**, Ph.D., dean of the College of Agriculture and Related Sciences at DSU, will provide institutional leadership. **Stephen Taylor**, Ph.D., associate professor of philosophy, DSU, will oversee ethics education and outreach in central and southern Delaware. **Thomas Powers**, Ph.D., assistant professor of philosophy, will oversee ethics training and environmental justice research. **Clytrice Watson**, Ph.D., associate professor, will oversee internships at DSU. **David S. Weir**, Ph.D., will lead statewide economic development initiatives through OEIP. **Amy Slocum**, Ed.D., EPSCoR associate director and assistant director of DENIN, brings 14 years of experience in grants management. She will coordinate the state EPSCoR office, including DOE, DoD, and EPA EPSCoR programs, provide overall financial oversight of the EPSCoR/DENIN grants portfolio, work closely with partner institutions and with the AAAS external assessment team and external advisory boards. **Jeanette L. Miller**, M.Ed., associate director of DENIN and EPSCoR EOD, brings 20 years of teaching, program management, and grants development experience. She was instrumental in the development of the Delaware Biotechnology

Institute at UD and serves in a leadership role at DENIN. Miller will oversee the grants strategy and EOD activities. **Elizabeth Chajes,** M.S., communications manager, has degrees in environmental science and communications. With 20 years of public relations, media, and communications experience, Chajes will oversee the RII external engagement strategy to enhance public understanding of EPSCoR science and related programs. **Cheryl Ackerman**, Ph.D., is responsible for the internal evaluation process. She has been working with the EPSCoR program since 2011 and with NIH-INBRE since 2007. She has broad experience managing all phases of evaluation. Administrative staff (two FTE) include an EPSCoR/DENIN staff assistant (**Kathy Fleischut**) and an accountant (**Kelly Doremus,** M.B.A).

Succession Plan: This management team will remain in place throughout the course of the program. Donald L. Sparks, the PI of the RII, works closely with the other PIs on the project, Stephanie Smith, Karl Steiner, Venugopal Kalavacharla, and Kent Messer. One of them could assume the role of PI. There is a strong team of scientists who will help lead the research portion of the project. Any one or two of them could assume overall leadership for the research. In the event of departures by other personnel, such as the associate director or the EOD director, the missing staff member could be temporarily replaced with other members of the Delaware EPSCoR team until permanent replacements were found. In the case of illness of the PI/PD, Slocum and Miller could assume the PD's responsibilities.

Faculty Leadership Team: Faculty from all partner institutions — Sparks, Inamdar, Duke, Michael, Messer, Dentel, Imhoff, Leathers, Luther, Xiao, Rabolt, and Madsen (UD); Kalavacharla and Ozbay (DSU), Allison and D'Souza (Wesley), and DTCC science faculty — will form the RII faculty leadership team. The group will catalyze new initiatives and enhance external partnerships. To ensure good communication among research, education, and program management, Miller (EOD, grants strategy) and Slocum (associate director, financials) will also participate as members of the team. (22% F; 5% UR)

Education, Outreach and Diversity Team: Faculty and professionals from all four partner institutions — Miller, Chajes, Slocum, Sparks, Messer (UD), Watson, Kalavacharla, Melmaiee (DSU), Allison, D'Souza (Wesley), and Program Manger (DTCC) — will oversee EOD activities and new grants. (50% F; 20% UR)

The ***EPSCoR Steering Committee*** includes leaders from academia, government, and the private sector, and provides advice to the PI and leadership to guide the progress of the RII, assure alignment with institutional and state priorities, and identify R&D opportunities to increase research capabilities within the state. The group will meet annually. Members include Chair Collin O'Mara, Secretary of DNREC; Michael Bowman, President, Delaware Technology Park; Jeff Bross, Chair, Duffield Assoc.; Patricia Dwyer, V.P. Academic Affairs, Wesley College; John S. Riley, V.P., Ashland, Inc.; Stephanie Smith, V.P. Academic Affairs, DTCC; Donald Sparks, Director, DENIN; Alton Thompson, Provost and V.P. Academic Affairs, DSU; and David Weir, Director, OEIP. (22% F; 11% UR)

The ***EPSCoR External Advisory Board*** includes Phillip Cherry, DNREC; George Hornberger, Vanderbilt University; Katherine Miller, National Center for Atmospheric Research; Ramesh Reddy, University of Florida; Lori Palmer, Ashland, Inc.; and Robert Taylor, Florida A&M University. (33% F; 17% UR)

4.10.1 Jurisdictional and Other Support. The state of Delaware has provided $4 million in matching funds in direct support of the EPSCoR RII initiatives. (See letter from Governor Jack Markell.)

4.10.2 Summary Table of Requested NSF Support

Budget Table A - Research Support Levels ($K)						
Awardee	Year 1 ($K)	Year 2 ($K)	Year 3 ($K)	Year 4 ($K)	Year 5 ($K)	%
University of Delaware	2,536	2,311	1,993	2,082	2,440	57%
Delaware State University	907	1197	1483	1388	1035	30%
Wesley College	206	206	219	224	221	5%
Delaware Technical Community College	351	286	305	306	304	8%
Total	4,000	4,000	4,000	4,000	4,000	100%