formal training on climate change science and education as well as new tools for teachers to incorporate climate change into their classrooms. It is estimated that 800 middle school students are impacted annually via the teachers who participate in the program. As of June 2012, this project has resulted in 91 peer-reviewed publications, 18 conference proceedings, 32 funded projects totaling $12.8M, eight new faculty hires, eight postdoctoral fellows, 55 graduate students, and 128 undergraduate students.

DEB-0817073, 0816726; Collaborative Research: Root Induced Changes of Soil Physical Properties Using Synchrotron X-ray Microtomography (CMT) and Micromechanical Simulations. (PI: M. Berli [DRI], Co-PIs: T.A. Ghezzehei [LBNL], P. Nico [LBNL], M.H. Young [DRI], S.W. Tyler [UNR]); Award period: 09-01-08 to 08-31-11; $435,791 total. The project funded two Ph.D. students (one part-time), three full time M.S. students, and three undergraduate students. To date, the project yielded one peer-reviewed article, two peer-reviewed book chapters, and one dozen presentations.

4. Research Program

Background. In the U.S., on average 25 gallons of water are needed per kilowatt-hour (kWh) of electricity produced. This amount is expected to decline to 9.4–12 gallons per kWh by 2030 due to the enhanced use of dry cooling towers, which will replace many wet cooling systems [8]. The total amount of water used for energy generation in the U.S. has grown steadily, however, due to higher energy consumption; this energy consumption is expected to increase 30% by 2035 [8]. The interrelationship between water and energy is so strong that scientists have voiced concerns about the "water cost of electricity" and "virtual trade of water" when electricity is generated in one state and sold in others [9]. Solar-specific energy sources have a variety of water requirements, ranging from a high value of about 800–1000 gallons/MWh for a concentrating solar thermal plant with wet cooling and water for washing, to about 105 gallons/MWh for dry cooling; with some loss in plant efficiency. Photovoltaic plants have negligible needs for water compared to solar thermal plants [10]. Water requirements for solar power generation ultimately depend on the environmental conditions and the kind of technology being applied.

Nevada lies within the Great Basin and Mojave Desert, both of which are considered fragile ecosystems and easily altered by anthropogenic activities [11-12]. The Great Basin is considered to be one the most endangered eco-regions in the U.S. [11], and the Mojave Desert as one of the least fragmented and undisturbed eco-regions in the contiguous U.S. [13]. Only a few studies have attempted to project impacts to southwestern U.S. deserts from development, and solar projects were not anticipated as a major factor in these studies [14-17]. The need to establish baseline environmental assessments in these locations and the Great Basin is similarly recognized [18]. Desert landscapes in NV can be expected to change, perhaps dramatically in the near future, as the U.S. Bureau of Land Management is currently processing a large number of permits to build solar projects in the state. Even if only a small percentage of these permits are approved, significant alterations and disturbance to habitat will occur [19]. Solar facilities as large as one km^2 along with associated infrastructure have the potential to alter ecosystem processes, form, and function. Such impacts would arise by changing the landscape pattern (e.g., fragmentation, patch size, connectivity). Wu (2009) [20] states that "landscape fragmentation has profoundly transformed the spatial pattern of most if not all natural landscapes around the world and has become one of the greatest threats to biodiversity and ecosystem functioning." As such, long-term studies should be initiated to better understand desert ecosystems, especially habitat boundary responses and the range of ecological trajectories they may follow. Research on fragmentation of desert landscapes has received relatively little attention [12, 21], yet state and federal agencies must begin making and implementing land use management decisions that pertain to permitting solar and other energy projects.

Water and wastewater production – involving extraction, treatment, transmission, distribution, use, and disposal – require energy and impact the environment. The sustainability of water and wastewater systems is directly linked to a reduction in energy use [22-25]. Energy costs are the first or second highest operating cost for water and wastewater utilities [26, 8]. The water and wastewater industry is the third largest energy consumer [27-28] in the U.S. Energy savings and a reduced carbon footprint in drinking water and wastewater transport and treatment can be achieved by increasing water-use efficiency [29], introducing more efficient equipment [28], and generating renewable energy in water utility landholdings.

Some options being considered in NV to meet increasing water needs include water conveyance from the northern counties to southern NV (300 miles), water conservation, water reuse and reclamation, and seawater desalination [30-31]. All of these are associated with high-energy consumption. Currently, the Southern Nevada Water Authority (SNWA) requires more than one million megawatt-hours of energy per year to transport and treat water, the largest power user in Southern Nevada.

The Solar Energy-Water-Environment Nexus Challenge for Nevada. The nexus – or linkages – among solar power, water, and the environment is strong in Nevada because the state is deficient in water resources and is located in a sensitive desert environment. Yet, solar flux is abundant and exploration of this energy source has the potential to significantly diversify the economy of the state. It is therefore critical to understand the impacts of solar energy development on Nevada's limited water resources and the environment while achieving environmental benefits from renewable energy. Technology involved in improved power generation techniques, water use minimization, and protection of the environment can benefit all mankind, and these are objectives of this project. Three quarters of the electricity production in the U.S. are from fossil fuels, and this generates one third of total U.S. greenhouse gases [32] and increases dependency on global markets. Harnessing renewables such as solar could supply all the energy the U.S. needs, but there exist challenges, including high capital cost, need of transmission lines, remote location of high solar potential areas, intermittency of solar power, and permitting difficulties. The infrastructure and research proposed by our Track-1 project would contribute to meeting these challenges as well as having positive impacts on fundamental technical developments. Research on environmental impacts would generate data to improve plant and transmission siting and permit applications; development of better thermal power generation approaches and cooling systems would result in higher efficiencies and lower capital cost; understanding ambient dust accumulation has the potential to minimize water use; increased efficiency in water transport and treatment and development of water technologies that use solar power would result in less energy consumption from fossil fuels. The challenges to solar power development are not unique to the U.S. The proposed NEW-STAR facility will foster collaboration with researchers from other arid and sun-rich regions, including Southern Spain, Israel, Western China, North Africa, and Australia.

Goals and Objectives. The overarching goal of our proposed program is to advance new knowledge and discoveries in solar energy, water, and the environment. This research will be accelerated by developing new capabilities in cyberinfrastructure and will have far-reaching impacts on Nevada's economy, workforce, and STEM education. Many of these impacts will be addressed in the diversity, workforce development, external engagement, cyberinfrastructure, and sustainability plans that follow. It is anticipated that this work will have positive economic impacts on our region by: attracting companies that would take advantage of NEW-STAR's capabilities and expertise; training people in an environment related to and where the developed expertise exists will greatly enhance the ability of Nevada to meet the qualified staffing needs of companies; showing companies that NSHE is eager to collaborate and facilitate work on technical issues; demonstrating to companies that performance improvements to solar plants are possible with this message spreading through the industry; and assisting governmental agencies in better understanding the implications of the plant approval process, resulting in a more company-friendly environment for locating operational plants in Nevada. A significant outcome resulting from our proposed research can be less expensive – and thus more competitive – solar electricity. We propose five primary objectives in support of our overarching goal:

1. Minimize water use at solar energy facilities.
2. Decrease environmental impacts of solar energy projects.
3. Develop sustainable and advanced water/wastewater approaches to support water needs for solar energy development and related applications.
4. Improve reliability, economic modeling, and sunlight forecasting of solar energy supply.
5. Develop new and use existing cyberinfrastructure capabilities to accelerate the nexus research.

Each of these objectives has associated research tasks that will be performed using the proposed infrastructure improvements, including NEW-STAR and associated equipment, and the Nevada Research Data Center (NRDC). Descriptions of each research activity, including their intellectual merit and hypotheses to be tested, are provided below.

Objective 1: Minimize water use at solar energy facilities. The first research activity under this objective is to improve thermal cycles and power plant dry-cooling that will result in less water needed for cooling. Additional research activities propose to minimize water use in solar energy by understanding and controlling dust generation and soiling of panels and mirrors; using dust-repelling nanomaterials for application on panels and mirrors; understanding dust accumulation using remote sensing; and determining impacts of panel cleaning on soil and runoff. The proposed research activities are interdependent since knowledge of how dust soils panels and mirrors will provide insight into the type of materials that could be used to avoid soiling and lead to effective cleaning strategies. Development of effective thermal cycles would result directly in less water use and less land area needed for solar development, which would result in less environmental impact and better economics for the system.

Minimizing Water Use Through Improvements to the Power Plant – *We hypothesize that modifications to thermal energy conversion systems, both in terms of their basic efficiency and improvements in dry cooling approaches, can reduce water use in solar plants.*

Focus on the thermal energy conversion system**:** Improving dry cooling technology and developing more efficient thermo cycles can lead to less water use [33]. Dry cooling for thermal power plants saves considerable water in generating power but degrades plant efficiency and ideally can result in only a slight deficit in performance, much less than is commonly expected [33]. We propose to pursue methods of improving dry cooling performance. Investigation of more effective high temperature thermocycles could have an impact on identifying means to limit water use and reduce environmental impacts during energy generation. A variety of approaches have been proposed, including ultra-supercritical steam cycles [34] and supercriticial CO_2 (S-CO_2) cycles [35-36]. We propose to investigate high temperature approaches both experimentally and computationally, which will require filling a new faculty position in the Mechanical Engineering Department at UNLV, with expertise in high temperature materials, thermal storage, and cycle thermodynamics. ***Focus on high temperature nano-composite materials***: Thermo-electric (TE) materials, generally constructed from inorganic materials, can offer an opportunity to convert solar-driven heat to electricity, but common conversion efficiencies are low. Some advanced materials (i.e., nano-wires and super-lattices) can greatly improve the thermo-electric figure of merit but are difficult to manufacture in large scale [37-39]. Polymer-inorganic TE nano-composites offer attractive features such as low weight, low thermal conductivity, and easy processing [40-42]. The technical objective of this study will be to accumulate understanding of manufacturing polymer-inorganic TE nano-composite materials. ***Focus on cooling system:*** Solar cell cooling must be an integral part of the Concentrated Photovoltaic (CPV) design, since lower cell temperatures result in higher conversion efficiencies. We propose to investigate an advanced cooling design that uses a copper/water heat pipe with aluminum fins to cool a CPV cell by natural convection. We estimate that with a cell level waste heat flux of 40 W/cm^2, the heat pipe will transfer the heat to the environment with a total cell-to-ambient temperature rise of about 40°C. The heat pipe also can be used as a heat source to provide heat for water/wastewater membrane distillation (proposed below).

The intellectual merit and potentially transformative aspects of this research involves the application of the new proposed infrastructure to new low cost and, separately, high temperature devices and surfaces that could lead to a myriad of developments that impact many fields. The project's CI team will provide wireless connectivity of existing and new monitoring equipment initially to the UNLV GIS/Remote Sensing Laboratory and in year 2 to the NRDC. The NRDC will manage metadata and provide Web services and software tools for retrieval, analysis, and visualization. Because a huge amount of data will be collected, some from sensitive areas such as the water district and Nellis Air Force Base, data security and mining are paramount concerns that will be addressed by the CI team in Objective 5. **Team**: UNLV: Boehm; new faculty hire; 3 graduate students. **New equipment:** high temperature irradiation component and high temperature/high flow heat exchanger facility. **Facilities**: NEW-STAR; NRDC; UNLV: Science and Engineering Building, CER solar site, Nanotechnology Center, GIS/Remote Sensing Laboratory; Nellis Airforce Base solar plant; Sothern Nevada Water Authority (SNWA).

Understanding dust depositing and removal from panels and mirrors – *There exists a critical need to quantify mechanisms of interaction between atmospheric aerosol deposition and solar power generation. We hypothesize that mitigation methods depend on type and size of aerosol found at a chosen location.*

Dust accumulation can degrade solar plant output by as much as 40% with a sand dust concentration of 1 gm/m^2 [43-47]. Long-term costs for cleaning and prevention of dust accumulation are not well quantified due to uncertainty in the magnitude of dust fouling effects [48]. The connection of physical and chemical characteristics of dust/atmospheric aerosols to fouling of solar energy panel and mirror surfaces is largely unknown. The interaction between light and particles is strongly influenced by the size of the particles, their chemical and mineral composition, their morphology, and light wavelength [49]. We propose to measure degradation of solar power production in situ across the light spectrum and relate it to specific particle properties. The intellectual merit will be to advance understanding of the interaction of deposited dust particles with surfaces used in power generation and the transformative outcome will be predictions of resources needed to clean equipment for optimal power production, which can then be balanced with the need for conservation of other resources such as water. The project's CI team will provide connectivity from existing weather and solar intensity stations, as well as data loggers collecting dust data, initially to the UNLV GIS/Remote Sensing Laboratory and later to the proposed NRDC. Data collected will also be used for data security research described in Objective 5 as well as data mining to assure the data is searchable as it accumulates through time. **Team**: DRI: Etyemezian; UNLV: Steinberg; 2 graduate students. **New equipment:** JAZ-ULM-200 Spectrometer; Reninshaw Fourier Transform Infrared Spectroscopy (FTIR)/Raman system for field and laboratory measurements and develop models for mechanistic understanding of dust deposition and soiling effects. **Facilities**: NEW-STAR; NRDC; UNLV GIS/Remote Sensing Laboratory; Sempra Energy plant.

Use of nanotechnology in mitigating dust accumulation – *We hypothesize that advanced nanotechnology methods can minimize dust accumulation on solar panels and create cost effective dust removal solutions.*

Micro- and nanotechnologies can provide significant enhancement for dust control on solar panels [50-51]. Low-cost processes for fabrication of large arrays of nanostructures [51-52] can be modified to create inexpensive dust control systems. Nanoscale surface texturing can significantly reduce dust accumulation by reducing contact angle while some low cost non-lithographic techniques have also been investigated [53]. Enhanced panel cleaning can take advantage of natural mechanisms that prevent water droplets from wetting a surface [54-59] and as well as inducing water to roll off surfaces [60]. We propose to develop a process to modify the electrical properties of dust particles through use of transparent nano-wires and nano-pyramids to provide focused electric fields by modifying low cost non-lithographic techniques [61]. Electrical characterization of dust particles will be accomplished using established techniques [62]. Objectives include determining the feasibility of using transparent graphene nanocomposites; providing a fundamental understanding of interfacial phenomenon on heterogeneous surfaces; and examining durability of graphene nanocomposites for dust removal applications. We will also investigate the use of polymer-filled nano-porous surfaces for promoting a super-hydrophobic surface. A polymer material of interest is polyphenylene sulfide, a thermoplastic polymer that has attracted interest due to its thermal stability, thermal conductivity, and outstanding high-temperature stability. The intellectual merit of the proposed study is to gain new knowledge on how dusts can be transported on solar panel surface through surface-modifications affecting electrical properties of dust particles and associated contact angle hysteresis. The optically transparent materials of interest include surface-structured ZnO, ITO, pyramids, and graphene-nanocomposite that can be tunable in micro- and nanoscale. The dust particles can be electro-actively removed from the panels by fine-tuning the surface properties, which we believe will be a transformative technology. The project's CI team will establish connectivity between the remote data collection devices at the Nanotechnology Center and the NRDC; generated data products and publications will be made available via the NRDC. **Team**: UNLV: Das, Kim;

2 graduate students. **New equipment:** spray-coating apparatus, differential scanning colorimeter, high precision oscilloscope, high temperature oven and furnace. **Facilities**: NEW-STAR; NRDC; UNLV: Nevada Nanotechnology Center, Engineering Building, Center for Energy Research solar site.

Use of remote sensing to detect particle deposition on panels and mirrors – *We hypothesize that cameras can be used to detect, characterize, and quantify dust deposition based on absorption of each of the channels (R, G, and B) due to the presence of dust particles.*

The frequency components of white light as it passes through the atmosphere are attenuated. Depending on the particles introduced in the atmosphere, correlations between red and green, red and blue, and green and blue change, the covariance matrix changes, and the mean of the trivariate probability distribution function of the (R, G, B) vector changes. Therefore, the eigenvectors and corresponding eigenvalues change. We propose that high-resolution images of dust accumulated onto solar panels can be used to optimize cleaning cycles based on intensity of dust accumulation, thereby saving water. Cameras will be installed at NEW-STAR and existing solar facilities and connected remotely to the UNLV and UNR campuses to enable detection of particle deposition onto panels and mirrors. An algorithm will be developed using a classification vector that includes the trivariate probability density function of the (R, G, B) vector, the autocorrelation function for a number of lags for each of the (R, G, B) channels, the cross correlation function between channels, the eigenvectors and eigenvalues of the variance covariance matrix of the (R, G, B) channels, the frequency spectrum of each of the eigenvectors, the phase spectrum, and wavelet components of the principal components. The classifier will be able to decide if there is dust on the panels above a minimum threshold that reduces voltage production of the panel. This research will result in a database of spectral signatures of the dust accumulated on solar panels and will provide mathematical relations between interplaying variables such as energy produced, depth of dust layer, constituents of dust, and their temporal behavior. This information can be used to improve design of dust repellent pane surfaces/coatings and efficient dust removal mechanisms. The project's CI team will provide storage and network security for data/imagery at the research sites, as well as connectivity from the site to the UNLV GIS/Remote Sensing Laboratory. CI research on data processing, analysis, management, and security in Objective 5 will facilitate algorithm development, data mining, and visualization. Generated data products and publications will be disseminated via the NRDC. **Team**: UNLV: Yfantis, Stephen; 2 graduate students. **New equipment:** multichannel high-resolution cameras, Compute Unified Device Architecture (CUDA) for video processing. **Facilities**: NEW-STAR; NRDC; UNLV: Environmental Engineering Laboratory and Engineering Building, GIS/Remote Sensing Laboratory; (SNWA); Sun Edison Apex solar site; Nellis Air Force Base solar plant.

Objective 2: Investigate environmental impacts of solar energy projects. An interdisciplinary team of biologists, engineers, water, and remote sensing scientists will determine the effects of solar energy production facilities and associated infrastructure development on desert ecosystems. The proposed infrastructure will enable the environmental component of this multi-institutional team to better understand desert ecosystem responses at multiple scales to perturbations associated with development of solar energy facilities. The proposed research will result in science-based information that agencies can use for designing effective ways to manage and mitigate these environmental issues. We propose to test six hypotheses, described below.

Population dynamics of organisms influenced by solar energy plants – *We hypothesize that the footprint of a solar energy operation will alter population (e.g., demographic and genetic connectivity) and community structure (e.g., interspecific relative abundances and ecological interactions), with consequences for long-term population and community viability, as a function of both direct habitat loss at the local scale as well as alterations of the larger habitat mosaic at the regional scale.*

The population dynamics of organisms influenced by solar energy facilities will be assessed using genetic information obtained by means of "next generation" sequencing technologies in order to assay genomes at thousands of loci and millions of base pairs. We will rely on the project's CI expertise, research, and equipment to store, manage, and disseminate these large molecular data sets efficiently. Data security and processing (in particular, data mining and visualization), enhanced by the proposed CI research in network connectivity and data management, will be of paramount importance for this task. This approach will open new opportunities to address population and community genomics on non-model organisms [63]. This research will benefit from new CI software tools described in Objective 5. **Team**: UNLV: Riddle; 1 graduate student. **New equipment:** none. **Facilities**: NEW-STAR; NRDC; UNLV Center for Genomics; Nellis Air Force Base solar plant; Sun-Edison Apex solar site; Southern Nevada River Mountain Solar Facility.

Microclimate change on desert plant communities – *We hypothesize that construction of solar energy facilities will cause significant disturbance, alter microclimates, thereby creating an environmental footprint on adjacent plant communities.*

Construction of solar energy collection facilities will lead to fragmentation of the landscape and alteration of energy balances and microclimates within the operational grounds of the facility, impacting wind and thermal patterns in adjacent plant communities. Fragmentation has been shown to alter fluxes of radiation, momentum, water, and nutrients across the landscape [64]. Such changes will, in turn, alter evapotranspiration and erosion-dust generation (impacting water use for dust removal from panels and mirrors), water availability, as well as overall health and productivity at the plant and community levels. We propose to assess the extent of microclimate change on desert plant communities [65] adjacent to solar production facilities by establishing monitoring stations within and outside existing solar facilities. This network of sensors will allow assessment of environmental gradients to determine how altered microclimates influence the size and direction of the larger footprint on adjacent plant communities [66]. The proposed research will advance our knowledge and understanding of landscape fragmentation in arid environments associated with solar energy development. The project's CI team will establish network connectivity with the monitoring equipment, and incorporate results of CI research on secure wireless communication networks and remote sensing. Data collected from the equipment will be stored and accessed from the NRDC, benefiting from CI data processing, mining, and visualization efforts in Objective 5. **Team**: UNLV: Devitt; 1 graduate student. **New equipment:** scintillometer and three monitoring stations to investigate microclimate changes at solar installations. **Facilities**: NEW-STAR; NRDC; Nellis Air Force Base solar plant; Sun Edison Apex solar site.

Impact of solar arrays on the water balance of arid soils – *We hypothesize that solar panel arrays can be a way to harvest rainwater effectively.*

Arid areas of the southwestern U.S. are characterized by low precipitation and high evapo-transpiration, leading to limited plant available water and groundwater recharge. Water infiltration depth and storage depend on how "concentrated" water is applied to the soil surface [67]. In a solar array, panels and mirrors can be considered rainwater collectors, guiding and concentrating precipitation on areas between the panels from which it is more likely to infiltrate into deeper parts of the soil leading to increasing soil water content through time and eventually groundwater recharge. The goal of this activity is to explore whether solar arrays are devices that harvest energy and also could be considered "rainwater harvesters." We propose to study the effects of solar arrays on the water balance of the underlying soil using the proposed NEW-STAR in conjunction with experiments at the existing weighing lysimeters facility. The research will involve infiltration experiments at the lysimeters and numerical modeling using HYDRUS 2D [68]. The potentially transformative aspect lies in using infrastructure designed for solar energy generation to harvest rainwater and increase water availability for arid environments. The project's CI team, in collaboration with DRI, will establish network connectivity from the lysimeter facility to the NRDC for the collection and dissemination of measurements. CI research on data processing, database optimization, and data management in Objective 5 will benefit this scientific task. **Team**: DRI: Berli; 1 graduate student. **New equipment:** scintillometer and three monitoring stations to investigate microclimate changes in and around solar installations. **Facilities**: NEW-STAR; NRDC; DRI: Weighing lysimeter facility; SNWA solar site.

***Soil crust disturbance and dust generation** – We hypothesize that (1) solar facility installation and maintenance activities negatively affect crust health and dust emissions compared to undisturbed soils; and (2) disturbed crust recovery can be facilitated through deliberate intervention.*

A large percentage of soil surface in arid southwestern U.S. is covered by cryptogamic crusts formed by cyanobacteria, lichens, or mosses [69]. In addition to contributing organic carbon and nitrogen to soil [70-71], these microbial mats help stabilize soil and prevent dust emission [72-73]. Cryptogamic crusts are extremely fragile and vulnerable to physical disturbance caused by solar farm installations and maintenance activities [74]. We propose to develop a crust reclamation process based in part on recent research demonstrating the benefits of cyanobacterium-based biofilms when they are applied to agricultural soils [75]. Native cryptogamic crust material will be analyzed to determine the organic and microbial composition of the gel matrix that holds the crust together [76-77]. A simulated crust matrix will be created and applied to disturbed surfaces to determine dust suppression with and without irrigation. We also propose to evaluate the addition of native crust organisms for accelerating crust development on disturbed soil surfaces [69]. This research will improve our understanding of the impacts that large scale solar farms will have on a fragile desert ecosystem and to the development of mitigation strategies. A new faculty position in restoration ecology, to be housed in the UNLV College of Sciences, is required to conduct this research. The project's CI team will establish network connectivity between observational measurement systems and the NRDC, which will store, manage, curate, and disseminate the collected measurements. Further, the CI team will host all data products and publications created by the researchers on the NRDC, enabling sharing across the scientific community. **Team**: DRI: Sun, new faculty hire; 1 graduate student. **New equipment:** elemental analyzer to determine carbon and nitrogen in crusts. **Facilities**: NEW-STAR; NRDC; SNWA solar site.

***Remote sensing investigation for pre-, syn-, and post-installation of solar energy plants** – We hypothesize that investigation of pre-, syn-, and post-installation conditions of proposed solar energy facilities can help in the recognition of environmental impacts on habitat, plants, animals, soil, and in the identification of necessary management approaches and remedial measures to implement.*

The scale of environmental impacts associated with solar energy facilities varies with the facility size and management strategies [78]. Assessing related landscape impacts requires spatial analysis based on remotely sensed data and geographic information systems (GIS). These well-established tools for environmental impact assessment [79-82] have not been applied previously to investigate the environmental impact of solar energy facilities in arid regions. Changes in habitat structure, connectivity, productivity, plant water stress, soil crust damage, and restoration success can be quantified using a remote sensing approach that includes both satellite imagery and land-based high resolution cameras [83-87]. We propose to conduct change analyses at a landscape level based on projections of solar energy facility placement including infrastructure, with the goal of assessing environmental degradation and recovery through time. We will utilize existing archived remote sensing data sets along with new acquisition data to assess quantitative landscape metrics which indicate fragmentation as well as restoration success. The research will create a blueprint that may guide development of solar energy facilities with minimal environmental impact, assist agencies in developing guidelines for review of license applications, and inform management and policy decisions for Nevada to become a model for other states. The project's CI team will help deploy and configure sensors and cameras on three transects around the solar power plants. The CI team will also provide network connectivity to these devices, streaming collected data to the NRDC via Web services and software tools. **Team**: DRI: Cablk; UNLV: Stephen; 2 graduate students. **New equipment:** none. **Facilities**: NEW-STAR; NRDC; UNLV: GIS/Remote Sensing Lab; SNWA solar site; Nellis Air Force Base solar plant; Sun Edison solar site.

***Reduced environmental footprint** – We hypothesize that landscape fragmentation and habitat destruction will occur with construction of solar energy facilities but can be remediated through restoration efforts.*

Ecological restoration of desert habitats is costly, difficult, and prone to failure [88]. The feasibility and trade-offs for minimizing the "footprint" of development and the compatibility with maintaining vegetation has been insufficiently evaluated. Strategies for restoration can be developed to minimize the environmental footprint of solar energy facilities [19]. We propose to identify specific techniques that can establish vegetation on disturbed sites as well as help protect soils, build plant biomass, and provide cover and food for wildlife. Effective techniques for seeding are desirable, because seeding has potential to be less costly and covers larger areas than planting [89]. Such techniques have the potential to promote self-seeding of surviving plants and the effectiveness of restoration of land disturbed by a variety of anthropogenic activities, including renewable energy development. **Team**: new UNLV hire in restoration ecology; 1 graduate student. **New equipment:** none. **Facilities**: NEW-STAR; SNWA solar site; Nellis Air Force solar plant; Sun Edison Apex solar site.

Objective 3: Develop sustainable and advanced water/wastewater approaches to support water needs for solar energy development. Sustainable and advanced water/wastewater treatment technologies are part of the solution to issues relating to the water-energy-environment nexus. Development of water technologies that can use renewable energy, such as solar, would represent a significant advancement in energy savings. During the last few decades, attempts have been made to introduce solar-based technologies to processes in water/wastewater treatment [90-95]. Much remains to be investigated, and the need for such research has become more critical as the link between water and energy is recognized. Solar energy production and water resources are interdependent, as water is needed to produce solar energy and, in turn, solar energy can be used to process water. The proposed research will result in advances in water and wastewater treatment leading to improved environmental sustainability through reducing discharge by-products into the environment, limiting chemical and material consumption for treatment, minimizing energy for water treatment and transport, and infrastructure footprints.

Energy intensity and carbon footprint for transport and treatment of drinking water and wastewater – *We hypothesize that energy consumption can be reduced by assessing and modeling water/wastewater transport and treatment systems to flag areas of high consumption for energy efficiencies. As a result, power consumption and the associated carbon footprint could be decreased.*

In the urban centers of Nevada, Las Vegas and Reno, water and wastewater treatment plants use large amounts of energy to transport and treat water. Electric loads at these plants consist primarily of pump motors, which consume the most power. Efficiency improvements that would save energy and water are possible by evaluating the performance of existing variable frequency drives, motor efficiency, pumping algorithms, and shifting to off-peak periods [96]. We propose to identify processes with potential for energy savings, and feasibility and extent of reduction of energy using energy recovery techniques by developing a decision support system (DSS) using a system dynamics (SD) modeling approach [97]. The underlying difference between SD and other modeling approaches is the study of a system in terms of stocks and flows, which interact through feedback loops. DSS models have been developed for some aspects of water use and energy consumption in Las Vegas Valley [25, 98-101]. The methodology developed in this research can be used in water/wastewater infrastructure to reduce energy consumption. The project's CI team will provide connectivity to Phasor Measurement Units (PMUs), Supervisory Control and Data Acquisition (SCADA) system, and valve sensors for researchers at UNR. Related CI data mining and computer security studies will be performed as described in Objective 5. **Team**: UNLV: Ahmad, Batista; UNR: Etezadi; 3 graduate students. **New equipment:** 2 PMUs, 1 SCADA, energy recovery pressure valve. **Facilities**: NEW-STAR; NRDC; UNLV: Water Resources Laboratory; SNWA facility; Clark County Sanitation District facility; Truckee Meadows Wastewater Treatment Plant.

Membrane distillation of solar facility cooling waters – *We hypothesize that it is feasible to treat cooling waters from solar plants and other high TDS waters with membrane distillation.*

We propose to evaluate the technical and economic feasibility of membrane distillation (MD) to treat cooling waters at solar energy facilities. The desired outcome is increased efficiency and productivity of the solar facility through on-site water reuse. Another objective will be to evaluate MD to treat groundwater with high total dissolved solids (TDS) that can then be made available for use at the solar energy facility or for local potable water needs (drinking or irrigation). We propose to build on current collaborations and private industry (e.g., oil/gas fracking water treatment) interactions to study water treatment and wastewater reclamation needs associated with solar energy systems. Our focus will be on minimization of fossil fuel usage (for a low carbon footprint) and systems with minimum consumption and disposal (for improved environmental sustainability), including an MD system. Direct Contact Membrane Distillation (DCMD) is one of the simplest configurations of MD; it requires only a membrane module and two low-pressure pumps to move liquids across the membrane. This configuration makes it suitable for implementation in large-scale applications. MD potentially has substantial advantages compared to MD reverse osmosis (RO): it requires only small temperature differences achievable through use of low-grade heat/renewable energy; the driving force in MD operates at hydrostatic pressure and can be used to treat high salinity solutions or provide enhanced recovery through brine desalination; and MD produces higher quality water. We will construct a small-scale, pilot, integrated MD system consisting of a membrane module, heat exchanger, plus instrumentation and control system. The system will be equipped with electronic sensors (e.g., pressure and temperature transducers, flow meters, controls, pH and conductivity probes) that will be connected to a LabVIEW control system for automated operation, process control, and data collection. The longevity of commercially available membranes will be evaluated using actual or synthetic challenge waters. Results will reveal the need for pretreatment processes. This research will potentially result in increased efficiency and productivity of the solar facility through on-site water reuse, a breakthrough in the nexus between water and solar power with significant improvement benefits. Treatment of high TDS water is a challenge and a global need as fresh water resources become more scarce, therefore the MD research proposed can significantly impact technology development for high TDS waters, which are cost effective. The project's CI team will provide wireless connectivity from the pilot plant to the UNR campus, streaming observational measurements to the NRDC for use by researchers. **Team**: UNR: Childress, Park; UNLV: Batista; DRI: new faculty hire in water treatment; 2 graduate students. **New equipment:** pilot membrane plant, optical tensiometer. **Facilities**: NEW-STAR; NRDC; UNR: Environmental Engineering Laboratory.

Objective 4. Improve reliability, economic modeling, and sunlight forecasting for renewable/solar energy supply. Four research activities are proposed to improve the development and reliability of renewable and solar energy supply: generation of renewable energy from utility landholdings; solar irradiance forecasting; use of groundwater for renewable energy; and economic analysis of solar/renewable energy projects.

Energy generation on landholdings. *We hypothesize that landholdings from utilities can be used to generate some of their own energy from renewable sources.*

The State of Nevada's Renewable Portfolio Standard [102] calls for 25% energy generation from renewable sources by 2025. To test the hypothesis, we will investigate the renewable resources that are accessible to Nevada utilities, identify areas where their expansion can be achieved economically, and operate the utilities independently from the power grid during power outages. This research could potentially transform the operation of utilities throughout the nation with potentially huge energy savings. In Southern Nevada, water utilities have installed more than 3.6 MW of PV power generation systems, on top of water reservoirs and parking structures. In-conduit hydroelectric energy recovery projects also can be exploited for the large pipes transporting water in Nevada. A small micro-grid will be constructed to supply electrical power to the proposed research site using two distributed generation resources, a diesel engine generator, and a photovoltaic. New control strategies will be developed to achieve high reliability and quality of power. The project's CI team will establish connectivity for the micro-grid, enabling remote control by researchers, streaming observational measurements to the NRDC, and facilitating related data processing activities. **Team**: UNLV: Baghzouz; UNR: Etezadi; 1 graduate student. **New equipment:** 2 distributed generation resources, 1 diesel engine generator, 1 photovoltaic array. **Facilities**: NEW-STAR; UNLV/UNR campus facilities.

Solar irradiance forecasting. *We hypothesize that solar irradiance forecasting can improve solar power generation, and management and planning of solar energy resources.*

One of the major issues with the reliability of solar energy is uncertainty in sunlight availability due to clouds, wildfires, dust storms, and aerosols [103-104]. We propose to develop a short-term nowcasting and forecasting model of solar irradiance, meteorological parameters, and aerosol impacts using high resolution atmospheric [105] and Lagrangian stochastic dispersion [106] models in an ensemble mode

[107]. We will use a novel approach of coupling solar irradiance forecasting with aerosol modeling and apply principles of artificial intelligence to transform the research for application and educational use. The NRDC will have a dedicated solar forecasting Web site that will access solar forecast results obtained on DRI's computer cluster. Solar monitoring, dust, and power generation data will be made available via NRDC Web services for model evaluation and forecasting efforts at DRI. **Team**: DRI: Koracin; 1 graduate student. **New equipment:** none. **Facilities**: DRI computer cluster.

Groundwater for renewable energy – *We hypothesize that development of shallow groundwater maps coupled with use of lesser quality waters for solar energy will support solar energy development.*

Since water is limited in Nevada, it is important to explore reuse water and low quality groundwater for use at solar energy plants. Southern Nevada shallow groundwater has high TDS [108] and may promote scales on panels when used in solar plants. Reuse water typically has moderate TDS and is likely to promote fouling of the solar surfaces. We propose to investigate effects of using water of lesser quality on cleaning solar panels and mirrors. We will also use a groundwater flow model (e.g., MODFLOW) to estimate aquifer storage and safe yield in shallow aquifers. Information on the quantity and quality of available groundwater – along with other information such as distance from the grid station, road networks, dust storm tracks, and ecologically sensitive areas – will be valuable for identifying suitable locations for new solar facilities. This research will require a new faculty position in water technology at DRI. The project's CI team will provide for dissemination of the post-processed MODFLOW models via the NRDC and will ensure secure data sharing of generated groundwater maps with the water community. **Team**: UNLV: Batista, Ahmad, Stephen; DRI: new faculty hire; 2 graduate students. **New equipment:** none. **Facilities**: NRDC; SNWA solar plant; City of Las Vegas systems.

Economic analysis of solar/renewable energy projects *– We hypothesize that estimation of economic feasibility of solar power investments must include assessment of risk to identify all management alternatives. Water footprints must be evaluated to derive water demand for solar power investments.*

Economic analysis of solar energy generation and water linkages will be at the firm and regional economic level. Usual investment analysis is completed under deterministic assumptions that often ignore price and cost variability and do not incorporate risk [109-111]. Monte Carlo simulation provides decision-makers with extreme values of KOVs and their probabilities. Pouliquen (1970) [109] suggests that a complete feasibility simulation can be used for analyzing alternative management plans if a solar energy investment project is to be undertaken. Regional analysis will incorporate aspects of analyzing the solar investment by way of water footprints. Using published procedures [112-117], indirect water use can be calculated for solar energy investments. A water footprint analysis will provide an estimate of total water use in a potential solar energy investment that decision-makers can use in evaluating energy versus water tradeoffs. Accomplishment of this task will require a new faculty position at UNR in the Department of Economics, with expertise in clean energy and specifically solar power. The project's CI team will provide for dissemination of generated visualizations and data generated by the resultant economic models. **Team**: UNR: T. Harris, new faculty hire in clean energy/solar power economics; 2 graduate students. **New equipment:** none. **Facilities**: NRDC; UNR Center for Economic Development.

Objective 5: Develop new and use existing cyberinfrastructure capabilities to accelerate the nexus research. The proposed nexus research will be accelerated by enhancing Nevada's CI capabilities for data communication, processing, and management while establishing a new archetype for CI research and development. Infrastructure improvements are planned that will expand the capabilities and scope of the existing SENSOR and NCCP systems [118-121] into the proposed NRDC and an extended sensor network, including additional communication links, servers, and databases. Proposed CI research includes four main focus areas: (1) data processing and analysis; (2) software engineering and human-computer interaction; (3) communication networks; and (4) database architecture and data management. Talented CI personnel from UNR, UNLV and DRI will be required to accomplish this research, including existing and new CI faculty, technicians, graduate students (5), and undergraduate students (4).

Data processing and analysis *- We propose that new handling, processing, and analysis methods and tools created by CI will facilitate and accelerate research and education in Nevada.*

The process of handling and processing research data involves many common activities; different research areas may perform similar analyses or manipulations of data that require various computer resources. Identification of these common, cross-discipline needs stands to enhance data processing by leading to new techniques and tools for data handling and analysis [122] that can significantly increase the efficiency of scientific data exploration [123-124]. We propose to identify ways in which data can be handled, examined, and used with the goal of creating artifacts that can be incorporated into CI systems for the benefit of various project stakeholders. This includes core CI processes – such as analyzing raw data files for errors or integrating data collections – as well as new tools that support scientists, such as data services for efficient data selection, visualization, or format conversion [125]. CI research will include development of advanced data services [126-128], design of real-time data streaming and visualization [129-130], data mining and analysis [131-132], and image processing. The outcome will be a series of new techniques and tools (e.g., mixed data mining methods, new Web data services, new visualizations) that will aid the proposed nexus research and education. Accomplishment of this research will require hiring a new faculty member with expertise in intelligent data mining in the College of Engineering at UNR. **Team**: UNR: F. Harris (lead), Louis, Varol, new faculty hire; UNLV: Jo, Yang, Jiang; DRI: Jackman; 2 graduate students. **New equipment:** computing equipment to enhance existing hardware and software resources for the NRDC. **Facilities**: NRDC.

Software engineering and human-computer interactions *– We propose that new software practices and tools can streamline CI engineering and facilitate scientific and education work; we will define a process model to guide future CI developments that support data-intensive research.*

Ensuring that research data and information are accessible to both researchers and educational audiences is key to sustainability and long-term support of diverse research efforts. Used directly by stakeholders, well-designed software tools and user interfaces positively impact data accessibility, utility, and system acceptance [133-134]. In the broader scope of developing these CI capabilities for interdisciplinary research and education, focused process models are notoriously lacking, although they are key instruments in the construction of all well-planned software engineering applications [135-136]. To fill this gap, we propose to identify and apply techniques, practices, and tools that streamline CI engineering while facilitating scientific and education efforts. We will create user-friendly interactive software tools that aid scientific exploration and education, leading to new capabilities for model and data interoperability [137-139] as well as to software applications with educational content for mobile devices such as iPads. We will define a process model that integrates sound system and software engineering practices with Human Computer Interaction tools and methods, which can be applied in the research and other complex data-intensive interdisciplinary projects. The proposed nexus research activities that will use the new CI capabilities include population dynamics of organisms influenced by solar energy plants, assessment of energy intensity and carbon footprint for transport and treatment of drinking water and wastewater, and solar irradiance forecasting. The work will enable the project's workforce development component to increase public understanding of on-line learning opportunities available through the NRDC. **Team**: UNR: Dascalu, Louis (leads); 1 graduate student. **New equipment:** software design and implementation tools. **Facilities**: NRDC.

Communication networks – *We propose that advances in long-term remote data collection require Nevada to expand and enhance a reusable, extensible high-speed, secure communication network.*

Lossless, high-speed, secure communication systems are a core component in observational research, especially involving remote locations [140-141]. We propose to address important challenges in data transmission, by leveraging and expanding an existing multi-use, scalable, high-speed, lossless, managed, secure wireless communication network developed by the UNR Nevada Seismology Lab (NSL). This work will include optimal network connectivity deployments to facilitate remote research efforts [142], cloud computing research [143-144], development of security and privacy enhancing mechanisms [145], study of congestion and traffic control to improve network performance [146], and investigation of vulnerabilities in communication protocols for control systems [147]. Further research will focus on complex network analysis [148-149] of energy-environment-water interactions, which will lead to the identification of small and large-scale interaction patterns in the proposed program. The proposed CI research will benefit all proposed nexus research sites and activities by providing improved network security, bandwidth, and reliability, which ultimately will allow the scientists to probe ever-increasing data-intensive topics. **Team**: UNR: Kent, Smith (leads), Gunes; UNLV: Latifi, Jiang, Jo, Yang; 1 graduate student. **New equipment:** Connectivity equipment. **Facilities**: NRDC; UNR NSL.

Database architecture and data management research *– We propose that performance, extensibility, and sustainability of computing infrastructure need to be optimally designed, configured, and managed.*

We propose to address issues pertaining to database and system performance optimization; development of automated quality assurance/quality control (QA/QC) processes for imported data [150]; extension of data curation [151] activities and facilities; and application of artificial intelligence techniques, such as cognitive methods [152-153], to enhance access to the databases. Sound data curation and management practices are key to preserving quality data, which rely upon optimized database architecture and implementation. We propose to focus on creating advanced tools and techniques – executing on cloud-level computing resources [154-155] – that can be deployed into CI systems to benefit all observational research and workforce development activities that require storing and accessing data and information on the NRDC. **Team**: UNR: Dascalu (lead), Smith, Varol, new UNR faculty hire in data mining; UNLV: Latifi; 1 graduate student. **New equipment:** connectivity equipment. **Facilities**: NRDC.

Seed Funding and Emerging Areas. We propose to offer two competitive seed funding programs: a research and educational seed grant program and a interdisciplinary-innovation working group program.

Research and Educational Seed Grant Program. We propose one-year competitive seed grants in years 2 and 3 of the project ($30,000 each; 10 total) to encourage scientists and engineers from NSHE institutions to participate in research and educational components related to the solar energy-water-environment nexus. The program will be publicized through webinars that will acquaint NSHE faculty with the goals of the overall program and available facilities and through the NV EPSCoR Web site and announcements, and various institutional research offices. A peer-review committee consisting of faculty from throughout the three institutions will select the best proposals to assure new ideas with potential for follow-on external funding. Although the seed grants will be open to any NSHE faculty, including faculty from community colleges, some preference will be given to junior faculty members. In accepting the grants, awardees will agree to submit a proposal to a funding agency, a peer-reviewed publication, or develop an end product that can be used as an educational tool.

Interdisciplinary Innovation Working Groups. In conjunction with our Western Tri-State Consortium partners (Idaho and New Mexico), we propose to support competitive, interdisciplinary-innovation working groups (I-IWGs) that build on our existing Tri-State IWG program, which was modeled after those hosted by the National Center for Ecological Analysis and Synthesis (NCEAS). I-IWGs will support week-long working group activities for 8-12 participants who will work collaboratively to integrate and synthesize data, information, and knowledge on interdisciplinary issues that can transform science and education. Expected outcomes include peer-reviewed synthesis papers and proposals that target disciplinary and crosscutting programs. Two to three I-IWG's ($10,000 to $15,000 each depending on scope) will be supported each year in years 2-5.

5. Diversity Plan

The goal of the Diversity Plan is to develop a comprehensive approach that leads to an increase in the number of underrepresented students who graduate from STEM degree-granting programs. The diversity team will work collaboratively with the research group to build a sustainable, integrated program through enhancing knowledge and participation, and increasing aptitude and advancement and diversification of STEM enterprises for individuals, institutions, and geographic regions. The percent of underrepresented minorities (URM) at NSHE campuses ranges from 16% to 42%, with Hispanics being the largest minority group (Table 2). Nevada has demonstrated an increase in degrees conferred in science, technology, engineering, and mathematics (STEM) for minority students from 2001 to 2009.