Vision, Impact and Research Plan. The vision for ***Energize New Mexico*** is two-fold: first, to build and strengthen the scientific enterprise that will enable New Mexico to harness its abundant renewable energy resources (e.g. solar energy and biofuels) and sustainably capitalize on other resources such as geothermal and Uranium (U) reserves without adversely affecting the environment and water resources; and, second, to improve the state's STEM pipeline and R&D capacity, creating new businesses and industry that build upon the state's significant human and geographic diversity and intellectual capital. We propose to achieve this vision by investing in critical research equipment, facilities, and faculty hires that can transform our scientific enterprise, and by investing in cyberinfrastructure, external engagement, diversity, and workforce development programs that strategically enhance our human resources. We anticipate that these investments will strengthen our ability to compete for large, interdisciplinary grants; increase the size and diversity of the STEM workforce, emphasizing the role of our community colleges, Tribal colleges, and Hispanic-serving institutions; build new interdisciplinary and inter-institutional collaborations; and develop a sustainable culture of innovation and entrepreneurship.

Energize New Mexico is organized into three interrelated components: science, cyberinfrastructure (CI), and human resources. The science component focuses on one overarching question that has great potential to transform research in New Mexico and to promote sustainable development: **How can New Mexico realize its energy development potential in a sustainable manner?** This question encompasses two overlapping elements: (1) **How can the efficiency of resource utilization or extractive technologies be increased?** This question focuses on use-inspired fundamental research in the areas of bioalgal fuels, solar energy, and osmotic power production from oil and gas industry produced waters; and (2) **Can we sustain extractive energy development with minimal risk to water and environmental resources?** This question focuses on low-temperature geothermal energy development, U mining and environmental remediation, and the social/natural science nexus that includes dynamic systems modeling and understanding the factors that affect human choice and decision-making.

Proposed cutting-edge research equipment, facilities and activities will transform the capabilities of the six science teams to address these challenges:

(1) Bioalgal fuel development. New facilities including an outdoor large-scale integrated algal cultivation fuel processing facility and a small-scale experimental ecological design facility, as well as advanced instrumentation (e.g. online isotopic gas exchange system, membrane inlet mass spectrometer, ultra high pressure super critical fluid chromatography mass spectrometry, resonance Raman plate reader, and enhanced microscopy) will support research in next generation biofuel production in desert environments, pioneer the production of bio-crude oil from highly stable algal extremophiles with lower lipid contents, and provide new knowledge in algal ecology, physiology, agriculture and biomass process engineering.

(2) Solar energy. New electrochemical and optical spectroscopic methods and instrumentation will support the Solar Energy Research Team, in collaboration with New Mexico's Center for Integrated Nanotechnologies, in finding solutions to issues that prevent more widespread adoption of solar energy: the need for energy storage during dark periods, developing more effective and efficient solar energy processes and devices, and creating a transportable fuel alternative to fossil fuels.

(3) Osmotic power development. New equipment including a membrane osmometer, a high-pressure Pressure Reduced Osmosis system, and a new scanning electron microscope will enable the team to investigate membrane properties and module designs that maximize power generation (e.g. develop thin-film composite membranes using graphene-based support materials), as well as identify approaches that minimize membrane fouling and that regenerate membranes.

(4) U transport and site remediation. With EPSCoR infrastructure support for equipment that allows us to interface high-performance liquid chromatography (HPLC) to inductively coupled plasma mass spectrometry (ICP-MS) and to interface field flow fractionation to ICP-MS, university researchers in collaboration with Sandia National Laboratory and the Navajo Nation will improve laboratory capabilities to: enable faster, more sensitive analysis, including low-level speciation and isotopic measurements; conduct research to improve our understanding of U biogeochemistry and occurrence; and develop tools for predicting and controlling U mobility in the environment.

(5) Geothermal energy resources and sustainability. EPSCoR RII support for a Quantec Spartan MT Deep Resistivity Sounding System, two visualization workstations, ICP-MS, U-series and water and gas analysis, and autonomous sensors will enable researchers to understand the influence of fault-controlled plumbing systems, determine the extent of ground and surface water degradation that has already

occurred in these systems, compare the impacts of different types of geothermal production systems on both groundwater and energy sustainability, and determine the useful life span of geothermal systems. (6) Social and natural science nexus. RII support for developing a dynamic spatial database system, an integrated experimental infrastructure for human behavioral data, and a decision support system that includes a multidisciplinary system dynamics model will enable the multi-institutional team to develop a human-natural systems research framework to define energy resource pathways that are (or are not) sustainable when constraints and tradeoffs between system components are considered.

Seed funding will support New Mexico in filling critical gaps in expertise via four $150K startup packages for faculty hires, providing eight $50,000 seed awards to the regional universities and Tribal colleges, and supporting Interdisciplinary Innovation Working Groups.

Plans for Cyberinfrastructure. Support for new hardware, software and developer time will improve the New Mexico EPSCoR integrated data storage and modeling portal, expand interoperability with national and international data networks, and enhance statewide collaborations. The improvements will provide scientists, educators and decision-makers with easy access to data, information, models, and synthesized data products required by and derived from EPSCoR research and STEM activities (e.g. remote sensing and other geospatial data products, tabular data, and learning modules).

Development of Human Resources and Integration with Research. NM EPSCoR's Workforce Development, External Engagement, and Diversity Plans strategically target activities at all levels of the education continuum to build the human capacity needed to realize the state's potential in research, education and economic development.

Plans for workforce development include:
(1) Growing Up Thinking Computationally (GUTC) will engage 1,000 middle school students (ages 11-14) in an afterschool program focused on computational science, and 75 teachers in professional development workshops. GUTC will enable students to participate actively in scientific discovery using computer modeling and simulation, and through this activity, envision themselves as future scientists.
(2) STEM Advancement Program (STEMAP) will support the retention of 50 undergraduate STEM students from Primarily Undergraduate Institutions (PUI), including community colleges and Tribal colleges, by providing summer research experiences with EPSCoR researchers to gain first-hand experience with authentic scientific research as well as academic year mentoring and support.
(3) Graduate Student Externship Exchange encourages collaboration among graduate degree-granting institutions by enabling students to spend a semester at a different institution or national laboratory.
(4) Faculty Leadership and Professional Development Institute will enable 125 STEM faculty from community and Tribal Colleges and non-research universities to improve undergraduate STEM instruction for diverse student populations, contributing to the retention and success of underrepresented minorities (URM) students in STEM fields. The faculty will gain research-based pedagogical tools for today's adult learners, strategies for recruiting and retaining URM students in STEM fields, and create an online community of colleagues involved in professional development and research.
(5) Institute for Creative and Cultural Entrepreneurship (ICCE) will build New Mexico's workforce capacity for the emerging innovation economy in which entrepreneurship and creativity will be key drivers of economic success. The EI will provide 180-200 faculty members with skill development in key enterprise functions including opportunity analysis, marketing, finance, team building, and operations.

Plans for external engagement include:
(1) New Mexico Informal Science Education Network (NM ISE Net) will link research and informal science institutions with one another for the purpose of building and sharing capacity for informal science education, with a focus on acquiring and sharing knowledge about the research being performed by EPSCoR scientists. NM ISE Net partners will: build capacity around exhibit and program development; develop a workshop for EPSCoR researchers to develop skills as effective science communicators in informal environments; and develop programs to communicate EPSCoR-related science.
(2) Museum Exhibitions will be created at the New Mexico Museum of Natural History and Science, Explora!, and the National Museum of Nuclear Science and History that interpret EPSCoR research.
(3) A Town Hall Meeting will be held to provide a forum for scientists, educators, policy makers and business people to develop consensus on how to realize our energy development potential.
(4) Communication Activities and Technologies including the NM EPSCoR website, an electronic newsletter, social media, and the NM EPSCoR YouTube channel will communicate project activities, events, and discoveries to the public. We will also hold regular face-to-face meetings and

videoconferences for the various teams, and an annual workshop for all participants to coordinate work among institutions and investigators.

Plans for enhancing diversity include:
(1) creating a 0.5 FTE Diversity Coordinator to communicate and coordinate project diversity efforts and ensure, through institutional involvement and strategic recruitment, that diversity is a key component of all program activities. The Diversity Coordinator will be responsible for updating and disseminating the Faculty Diversity Plan and the Diversity Strategic Plan, and tracking progress on all diversity initiatives.
(2) convening Diversity IWGs to synthesize information and develop proposals or other concrete mechanisms that will enhance the diversity among STEM students and members of the workforce.
(3) strategically recruit students, faculty, and other participants to maximize geographic, ethnic, cultural, physical and gender diversity in all EPSCoR Programs.

Assessment and Evaluation (A&E). The success of the New Mexico RII programs will be measured using a comprehensive assessment model employing three components: two independent External Evaluators, an External Advisory Board (EAB) and the AAAS. Formative and summative evaluation strategies will be used throughout the project, and quantitative and qualitative data will be collected and reported to the State EPSCoR Committee, Management Team and NSF.

Sustainability. Sustainability was planned into this project by selecting the research, CI, and human resources improvement programs on the basis of their relevance to the State S&T Plan, defined university research and State economic development priorities, and current and anticipated elements of key NSF funding portfolios (SEES, Clean Energy, and CiF21). We will partner with informal science education institutions to support STEM Professional Development for 100 K-12 Teachers; host NSF Day to discuss relevant strategies for seeking funding from large Foundation-wide and cross-cutting programs; and fund Interdisciplinary Innovation Working Groups that stimulate new research activities.

Management Structure. We will use a broadly inclusive, team-based management approach that ensures engagement by and accountability to the state's research and STEM education enterprise via the Council of University Presidents and the State EPSCoR Committee. State Office activities are guided by the A&E Program.

Intellectual merit. Realizing New Mexico's potential for energy development requires an integration of basic and applied science and engineering that support fundamental understanding of processes and that enable technologies to be expanded to commercially viable enterprise scales. Resource utilization research focuses on: (1) generating new knowledge in algal ecology, physiology, agriculture and biomass process engineering that will support next generation biofuel production; (2) creating more efficient solar energy harvesting and photovoltaic devices, as well as developing methanol as a transportable fuel alternative to conventional fossil fuel derived hydrocarbons; and (3) solving scientific and engineering challenges related to membrane properties and fouling that currently prevent osmotic pressure systems from becoming commercially viable. Results will enable industry to make better use of New Mexico's abundant sunshine, large brackish water aquifers, and vast quantities of high salinity produced waters from the oil and gas industry. Achieving a sustainable energy future for New Mexico requires a complete and balanced suite of extractive and renewable energy sources that are socially adoptable, water resource achievable, and environmentally positive. Sustainability research focuses on: (1) developing a better fundamental understanding of U biogeochemistry and mobility in natural and contaminated environments, including new mechanisms that enable U transport to be controlled during and after mining; (2) analyzing the potential viability and impacts of expanded low-temperature geothermal energy development; and (3) supporting innovative research at the social and natural science nexus that includes dynamic systems modeling and developing an understanding of the factors that affect human choice and decision-making.

Broader impacts. *Energize New Mexico:* will support diverse, interdisciplinary, and inter-institutional partnerships that include the National Labs, business and industry, public and higher education, and other stakeholders; holistically address clean energy challenges; and communicate results via user-friendly cyberinfrastructure, innovative education and workforce development programs and broad-ranging stakeholder engagement activities (e.g. a focused state-wide Town Hall event) that lead to actionable results. Proposed activities are designed to engage new research and community college faculty, and support the STEM pipeline by training teachers, undergraduate and graduate students, and post-doctoral fellows. Research findings will be communicated broadly through new partnerships with New Mexico's museum network, a citizen-centric web portal, and vibrant, experiential programs targeting K-12 students.

4.1 Status and Overview

Status of the R&D Enterprise. New Mexico (NM) is known as the “Land of Enchantment” – a place of great beauty, abundant natural resources, and rich cultural diversity and traditions. These attributes attract both individuals and businesses to the state and have led to a growth rate of 14.5% from 2000 to 2011.[1] To serve its population, NM has built a geographically and culturally diverse higher education system featuring three public PhD-granting research universities, five regional universities and four-year colleges, and 21 community and Tribal colleges (Fig. 1). In addition, NM has two National Laboratories (SNL and LANL) with significant science and technology (S&T) resources that accounted for $2.1B in R&D funding in 2011; however, university R&D funding from NSF remains low, ranking 30th nationally.

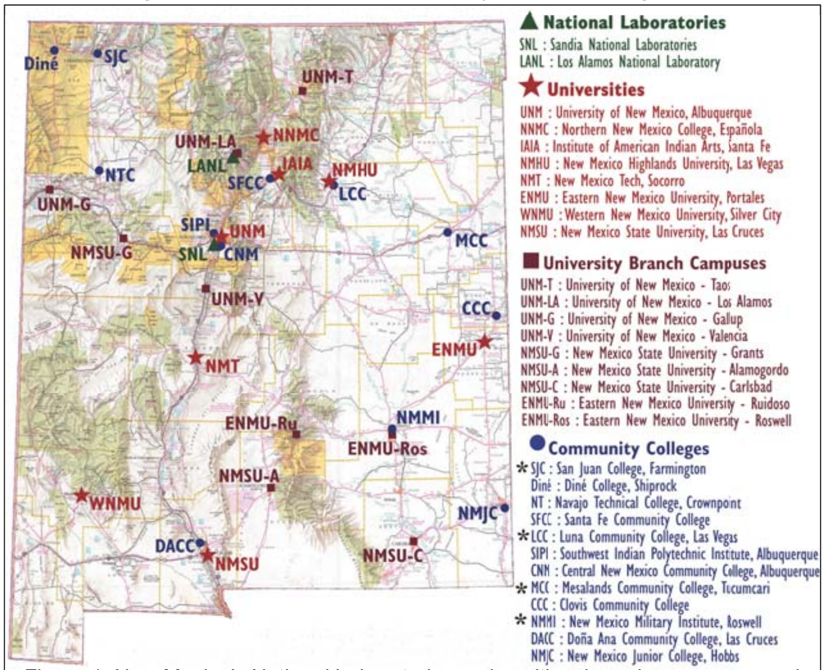

Figure 1. New Mexico's National Laboratories, universities, branch campuses, and community colleges; all except four colleges and universities (*) are designated as Minority-Serving or Hispanic-Serving Institutions by the US Department of Education.

Strengths, Barriers, and Opportunities. Significant barriers impede development of NM’s academic R&D enterprise. The state’s economy (47th in 2012) and near bottom ranking (43rd) in per capita income have seriously hampered the STEM pipeline and the R&D capacity of its universities. The geographic distance between higher education institutions, shortage of researchers in key areas, and lack of core multi-user research facilities and equipment hinder the state’s ability to engage in cutting-edge research. These problems are exacerbated by limited interdisciplinary and inter-institutional research collaborations. Limited statewide support for entrepreneurship means that innovative R&D activities do not translate into new businesses and jobs. A leaky STEM pipeline further undermines the state’s potential. For example, a recent study by the Corporation for Public Broadcasting ranked NM 6th in childhood poverty at 27.8%, while the overall high school graduation rate averaged less than 65%.[2]

NM’s future depends upon achieving success in two key areas. First, NM must harness its abundant renewable energy resources and sustainably capitalize on other resources such as geothermal and uranium reserves without adversely affecting the environment and water resources. Second, NM must improve its STEM pipeline and R&D capacity, creating new businesses and industries.

NM has unique opportunities for developing its academic institutions to support its R&D objectives. The state has immense, largely untapped energy reserves in the form of ample sunshine and wind, oil and natural gas reserves, extensive low-temperature geothermal energy sources, proven uranium deposits, and large brackish water aquifers with high total dissolved solids (i.e., supporting osmotic power development) that provide the potential for NM to be the first state to achieve energy self-sufficiency. NM also has a tremendous opportunity to strengthen its STEM pipeline by building capacity at the community colleges, developing better links between those schools and the research universities, and creating a new culture of entrepreneurship that leads to innovation and new business and economic development.[3]

Energize New Mexico. We will implement novel and transformational activities that will enable NM to capitalize on its human and natural resources. The ideas driving this proposal emerged over several years. NM EPSCoR played a key role in developing the State Science and Technology (S&T) Plan[4] by engaging Governor Bill Richardson’s Office and key stakeholders via statewide focus meetings that culminated in the publication of the first S&T Plan in 2009. The S&T Plan identified seven priority areas for NM: (1) energy, environment, and water; (2) aerospace; (3) bioscience; (4) nanotechnology; (5)

information technology; (6) education; and (7) economic development. The seven priority areas of the S&T Plan were updated and endorsed by Governor Susanna Martinez's administration in 2012.[4] Consistent with this plan, EPSCoR RII projects (1 and 2) focused on nanotechnology, biodiversity, and water, whereas RII3 focused on climate change impacts on mountain sources of water (Section 4.2.1).

A 2011 American Academy for the Advancement of Science (AAAS) Review Team assessed RII3 progress as well as statewide needs and opportunities, concluding that EPSCoR should build upon its enhanced research capabilities in water and the environment by transitioning to the broader energy, environment, and water area identified in the State S&T Plan. AAAS emphasized the opportunities for developing infrastructure that would enable NM to address fundamental basic and applied research questions related to improving energy extraction efficiencies (i.e., solar, geothermal, and bioalgal fuels) and promoting sustainable resource development (i.e., uranium, geothermal, and the social/natural science nexus). The State EPSCoR Committee unanimously endorsed the AAAS findings and chose the topic of energy as the focus of this proposal. The Project Director subsequently held a series of statewide meetings commencing in September 2011 to identify barriers and opportunities and to build the teams of investigators that collaboratively defined objectives and identified gaps in the research infrastructure, cyberinfrastructure (CI), and human resources necessary to improve the state's research competitiveness, STEM education pipeline, and workforce and economic development capacity.

Proposed S&T and STEM Improvements. Our goals are to improve the research, CI, and human resources required to enable NM to achieve its energy, education and workforce development potential. We will accomplish this by: (1) investing in critical equipment, facilities, and faculty hires; (2) increasing the size and diversity of the STEM workforce, emphasizing community and Tribal colleges, and Hispanic-serving institutions; (3) building new interdisciplinary and inter-institutional collaborations; and (4) developing a culture of innovation and entrepreneurship. Together, we will *Energize New Mexico*.

4.2. Results from Relevant Prior NSF Support

4.2.1 New Mexico EPSCoR RII3: Climate Change Impacts on New Mexico's Mountain Sources of Water (EPS-0814449; $15,000,000; 9/1/08-8/31/13). RII3 provided critical infrastructure, CI, and education and outreach opportunities that foster excellence in climate change research and education. RII3 was built upon improvements realized through previous EPSCoR awards. RII1 (EPS-0312632) developed the Institute for Natural Resource Analysis and Management (INRAM) to provide scientific information about NM natural resources. Resulting evapotranspiration (ET) maps based on models and satellite imagery formed the basis for the RII2 focus on regional hydrologic modeling and ET estimation in semiarid environments. RII2 (EPS-0447691) purchased computer clusters and storage for hydrology data storage, analysis, and modeling, and it improved the measurement of water and energy fluxes.

RII3 connected infrastructure designed to improve long-term, multi-scale monitoring of stream flows in high elevation watersheds to downstream flows that directly affect large populations and it expanded educational and outreach activities to provide a scientific underpinning to public policy discussions. RII3 filled instrumentation gaps in the NM climate observation network, including the Navajo Nation, and established an extensive array of surface water quality monitoring devices. The current proposal builds on the above results and on RII3 investments that:

- Installed hydro-meteorology equipment to characterize acequia (traditional irrigation) system flow distribution and conducted riparian health monitoring of watersheds used by acequia associations;
- Connected economic modeling components into the Systems Dynamics model for the middle Rio Grande and ran simulations to model impacts of population changes, use of pricing or conservation incentives, changes in attitude towards water scarcity, and changes in the timing of drought events;
- Supported numerous Innovation Working Groups that enabled development of conceptual frameworks that led to additional research opportunities, and a NM Diversity Strategic Plan;
- Contributed to improving the diversity of the STEM education and research enterprise through summer undergraduate research opportunities for students from non-research institutions;
- Developed the NM EPSCoR data portal for housing project data with metadata creation tools that support researcher data integration into the portal;
- Provided an annual weeklong faculty leadership workshop to enhance the communication, facilitation skills and productivity of junior faculty from around the state;
- Connected research activities with public outreach through a climate change exhibit at the NM Museum of Natural History, which brings EPSCoR-related science to over 250,000 visitors annually; and

- Hosted a Town Hall for nearly 100 New Mexicans to develop recommendations for mitigation and remediation of impacts of drought-enhanced wild fire on water quality and other NM resources.

4.2.2 Track 2 RII: Collaborative Research: Cyberinfrastructure Development in the Western Consortium of Idaho, Nevada, and New Mexico (EPS-0918635; $2,000,000; 9/1/09-8/31/13). This project developed a data repository built upon shared standards, allowing data sharing across the three jurisdictions and with national data systems. NM EPSCoR also developed climate-related instructional materials and supported the expansion of the Supercomputing Challenge and Project GUTS (Growing Up Thinking Scientifically), which brought additional science opportunities to school children across NM. In partnership with the Global Center for Cultural Entrepreneurship, we brought computer training to three rural NM communities, including over 400 members of the Navajo Nation.

4.2.3 C2: Improving Broadband Connectivity for Tribal and Regional Colleges in New Mexico (EPS-1005886; $1,176,470; 9/1/10-8/31/12). NM EPSCoR extended and enhanced the CI capabilities at WNMU, NNMC, and NTC. WNMU upgraded its outdated campus network and raised the bandwidth of the network backbone from 100MHz to 1GHz and the bandwidth of Internet access from 30Mbps to 40Mbps. NNMC significantly upgraded its wireless network, providing access to all campus areas. NTC extended its wireless network to better serve the Navajo Nation as well as connect to the UNM GigaPoP. These improvements increased student access to collaboration tools, on-line courses and research tools.

4.2.4 Valles Caldera, A Grand Land Experiment: Communicating Climate Change Research to Public Audiences (DRL-1038654; $150,000; 2/15/11-1/31/13). This Communicating Research to Public Audiences project created a one-hour film about EPSCoR research at the Valles Caldera National Preserve (VCNP). The film shows the effects of a devastating wildfire that burned a large portion of the VCNP in summer 2011. The documentary will be aired by PBS stations nationally, beginning in Fall 2012.

4.3 Research Program

In biophysical terms, humanity has never been moving faster nor further from sustainability.[5]

Biophysical sustainability is of acute importance in the western US where we have high population growth trajectories and associated increases in per capita needs for energy, freshwater and food—three requirements that are inextricably interrelated. As highlighted in the NM S&T Plan, the complex interdependencies are "*clearly demonstrated when you look at the production of fossil fuels, where more water is extracted from the ground than fuel and where the impact on our environment is significant. Renewable fuels also impact our flora and fauna as they often require enormous amounts of water.*"[4]

Scientists have long recognized many of the grand environmental challenges facing our planet and civilization.[6-8] Increasingly, research is leading to new understanding of natural resource limitations, feedback loops, thresholds, and tipping points—all of which affect the sustainability of coupled human-natural systems.[5,9-14] The question then is how can scientists and educators more effectively stimulate discovery and innovation, communicate that knowledge, and create incentives to change. *Energize New Mexico* will tackle this question by targeting investments in interdisciplinary and holistic approaches that transform science, integrate science and education, and benefit society. Specifically, we propose to:

- Support and grow diverse, interdisciplinary, and inter-institutional partnerships that include the National Labs, business and industry, public and higher education, and other stakeholders.
- Provide the infrastructure (e.g. equipment and faculty hires) that enables "use-inspired research" (i.e., the coupling of basic and applied research designed to holistically address particular problems).[5,15-16]
- Communicate results via user-friendly CI; innovative education, outreach, and workforce development programs; and stakeholder engagement activities that lead to actionable results.

New Mexico faces severe challenges as it tries to grow its economy and at the same time conserve its water resources and protect the environment—challenges that are exacerbated by climate change and population growth. *Energize New Mexico* focuses on one overarching question (Fig. 2) that has great potential to transform the research enterprise in NM and to promote sustainable development: **How can NM realize its energy development potential in a sustainable manner?** This question encompasses two interrelated components, each of which includes three primary foci: (1) **How can the efficiency of resource utilization or extractive technologies be increased?** This question focuses on use-inspired fundamental research in the areas of bioalgal fuels, solar energy, and osmotic power production from oil and gas industry produced waters. (2) **Can we sustain extractive energy development with no or minimal risk to water and environmental resources?** This question focuses on geothermal energy development, uranium mining and environmental remediation, and the social/science nexus that includes dynamic systems modeling and understanding factors that affect human choice and decision-making.

Proposed cutting-edge research facilities and activities will enhance strengths and resolve shortcomings identified in the NM S&T Plan.[4] These include purchasing much needed state-of-the-art equipment, filling critical gaps in expertise via faculty hires and by building new partnerships with the National Labs and industry, providing seed awards to the regional universities and Tribal colleges, and supporting Interdisciplinary Innovation Working Groups. The proposed infrastructure and activities are designed to support shared use equipment, engage new research and community college faculty, and support the STEM pipeline by training teachers, undergraduate and graduate students, and post-doctoral fellows. Research findings will be communicated broadly through new partnerships with NM's museum network, a citizen-centric designed web portal, and vibrant, experiential programs targeting K-12 students. The project will also enable our researchers to compete successfully for the array of new NSF programs included in the Clean Energy, CiF21, and SEES portfolios.

Figure 2. *Energize New Mexico* foci.

Below, we describe the six research foci, the challenges being addressed, the infrastructure and activities that will enable innovative research, and how this enhanced research capacity will contribute to new scientific knowledge and NM's strategy for future research, innovation, and national and international competitiveness. Note that each of the six research teams represents collaboration among several institutions with co-leaders from two separate institutions (highlighted in bold).

Component 1: Resource Utilization. How can the efficiency of resource utilization or extractive technologies be increased? Realizing NM's potential for renewable energy development requires an integration of basic and applied science and engineering that supports fundamental understanding of processes and that enables technologies to be expanded to commercially viable enterprise scales. Resource utilization focuses on: (1) generating new knowledge in algal ecology, physiology, agriculture and biomass process engineering that will support next generation biofuel production; (2) creating more effective and efficient solar energy harvesting and photovoltaic devices, as well as developing methanol as a transportable fuel alternative to conventional fossil fuel derived hydrocarbons; and (3) solving scientific and engineering challenges related to membrane properties and fouling that currently prevent osmotic pressure systems from becoming commercially viable. Results will also contribute to Component 2 (i.e., sustainability) by enabling industry to make better use of NM's sunshine, brackish water aquifers, and high salinity produced waters from the oil and gas industry.

Focus 1 – Bioalgal Energy Development. Team: ENMU: Manuel Varela, Juchao Yan; NMSU: Wiebke Boeing, Shuguang Deng, Robert Hagevoort, C. Meghan Starbuck-Downs, Omar Holguin, Shanna Ivey, Nirmal Khandan, **Peter Lammers,** Tanner Schaub**,** Adrian Unc; UNM: Becky Bixby, Ramesh Giri, **David Hanson,** Keith Lidke, Richard Sayre (NMC), Andrew Schuler, Andrew Shreve, Olga Pontes, Christina Takacs-Vesbach, Jerilyn A. Timlin (SNL); 2 technicians; 16 graduate students; 2 undergraduate students

Objectives. The objective of the bioalgal team is to generate fundamental knowledge about algal biology and scaling algal biofuels production from cells and populations to large reactors. The long-term objective is to craft solutions to techno-economic problems that uniquely impact the nascent bio-algae industry in the desert Southwest. We will invest in large- and small-scale facilities and critical instrumentation for algal cultivation and processing. We will support collaborations in NM among groups working on algal cultivation and wastewater management and provide training to graduate students using new infrastructure and by partnering with the NMSU Chemical Analysis and Instrumentation Laboratory.

Background and Proposed Research. Algal biomass has the potential to contribute significantly to meeting the U.S. Renewable Fuel Standard by 2022[17] if solutions can be found for several biological and techno-economic problems. Scaling up from the lab to large-scale, outdoor production requires a re-thinking of fundamental algae-environment interactions with respect to productivity. At large scales, supplying light, CO_2, and nutrients (especially the macronutrients N, P, and K) each introduce new problems that have not been well addressed. Sunlight brings oxidative stress and heat, especially when closing algal cultures to prevent water loss. Winter brings radiant heat losses that decrease growth rate. Supplemental CO_2 acidifies cultures and often contains toxic chemicals, as is the case for CO_2 from stack gasses that are one of the most promising sources. Industrial, agricultural, and municipal wastewaters are often nutrient-replete and available at large scales, but they can contain toxins and hormones with unknown effects on algal physiology. Solutions that make use of non-arable land and non-potable water will be key to avoiding resource competition and food-versus-fuel conflicts. Importantly, the solution to these formidable problems will minimally require understanding how species in traditional and moderately studied genera, such as *Nannochloropsis* respond to the new conditions and will also require engineering of novel culture environments to reduce the energy and material inputs without disrupting biological function. We believe that process logistics for economic viability may ultimately require use of non-traditional organisms, such as species in the thermophilic and acidophilic genus *Galdieria*, whose mixotrophic biology is very promising for wastewater processing but still poorly understood.[18] We will investigate three overarching questions through the component activities described below.

(1) Can inexpensive, scalable, closed bioreactor designs maximize biomass productivities with heat-tolerant algae in summer and cold-tolerant strains in winter with minimal water consumption and cultivation costs while achieving a net positive energy balance?

(2) What species/community characteristics and cultivation conditions best promote stable, reproducible, large-scale production of algal biomass and also harmonize with (i) design specifications for algal cultivation, (ii) extraction and conversion processes for high-, mid- and low-value products and (iii) QA/QC specifications for fuels and co-products?

(3) Can wastewater sources safely offset nutrient requirements at large scales, and how do associated scale up logistics, reactor design and operation affect output water quality to meet process recycling and discharge requirements?

Outdoor Large-scale Integrated Algal Cultivation Fuel Processing Facility. We will demonstrate a novel integrated set of processes linking cultivation, biomass processing, and recycling systems that will yield dramatic water savings. The efficacy and scalability of this system depends on two critical enabling technologies: outdoor closed cultivation photobioreactors (PBRs) and hydrothermal biomass processing. For large scale, highly productive algal cultivation in desert environments, we will develop inexpensive plastic PBRs that eliminate prohibitive evaporative water losses in summer and reduce radiative heat losses in winter via solar heat gain. We will evaluate four thermo-tolerant strains (55 °C) that grow at pH 1-4 from the genus *Galdieria* strains. Prototype outdoor bioreactors at the NMSU test bed exhibit a diurnal temperature range of 28-50°C outdoors in August. Test strains currently in development include a photoautotropic Yellowstone Type 1A, two mixotrophic Yellowstone Type II, and one mixotrophic New Zealand Type IV strain.[19] We will analyze *Nannochloropsis* (CCMP1776) and a fast-growing *Chlorella* strain from the DOE-NAABB consortium (DOE-2412) for winter growth in the solar-heating PBRs. *Nannochloropsis* is largely unaffected by predators and invasive algal species when grown outdoors in closed PBRs.[20-21] We will evaluate hydrothermal, microwave-assisted, and supercritical processing concepts for chemical extraction and fuel conversion[22-26] as well as for easy nutrient recycling from process waste streams and inorganic carbon.[27] Of critical importance, hydrothermal processing allows bio-crude oil recovery at 5-25% higher than lipid content.[28] For example, *Cyanidium* has 61% protein, 18% lipid and 21% carbohydrate[29] which could yield 23-43% liquefaction oil by weight. We will test hydrothermal processing technology on *Nannochloropsis, Chlorella, Galdieria* and also ecologically stable strain mixtures shown recently by the NMSU group to enhance algal biomass productivity.[30] We will investigate transition-metal catalyzed decarboxylation processes tailored to de-oxygenation of bio-crude oils in order to meet ASTM fuel standards.[31-32] Finally, continuous growth at large scale is expected to select for fast-growing weedy variants at the expense of lipid content.[33] To test this hypothesis, we will periodically reassess lipid content phenotypes strains in continuous cultivation during the operations of our large-scale cultivation facilities.

Team members will evaluate the potential for using nutrient-rich municipal and agricultural wastewaters and other non-potable water sources in the closed PBR systems, and we will test the hypothesis that low pH cultivation of *Galdieria* strains will dramatically reduce the titer of pathogenic bacteria present in municipal and dairy waste waters. This waste-to-energy theme will include efforts to adapt the Algal Turf Scrubber® (ATS™) to remove N and P from dairy effluents, nutrient contaminated groundwater, and storm-water runoff from dairy operations, and it will include efforts to produce algal biomass for biofuel conversion. ENMU and NMSU will collaborate on chemical and microbial composition analysis and evaluation of 16S/18S rRNA metagenomic analysis in samples undergoing adaptive management on the Turf Scrubber system at the ENMU agricultural research facilities in Portales.

Small-scale Experimental Ecological Design (SEED) Facility. We propose to create a unique small-scale facility to develop three concepts for testing at large-scales.

(1) *Selection System for High Lipid Producers.* We will apply ecological principles to develop a multi-stage cultivation system that self-selects for high lipid production. Under conditions that simulate large-scale wastewater processing facilities, we will evaluate the effects of lipids on biomass density as a potential selectable characteristic, develop agent-based models of microbes with storage products in reactor systems,[34-35] study the physiological responses of algae through time and physical location including stable isotope methods for real-time monitoring of photosynthetic physiology,[36-37] and monitor media and microalgal chemical compositions in each stage to understand nutrient dynamics and how industrial, municipal, and agricultural wastewater as a nutrient substrate affects system function.

(2) Microalgal Encapsulation Technology. We will design novel μ-photobioreactors (μPBR) systems using hydrogels to encapsulate very high density microalgal cells[38] along with solid-state devices and/or fluorescent proteins that will frequency-shift non-photosynthetically active green photons to red photons to increase the number of useable photons by up to 30%.[39] This will require engineering self-modulating antennae via shifts in chlorophyll a/b ratios to down-regulate light absorption at the surface of uPBRs and up-regulate it in the interior. To generate additional efficiencies, we will incorporate engineered human carbonic anhydrases with K_{cats} approaching theoretical maximum to enhance bicarbonate uptake and reduce photorespiratory losses (~35%). The uPBRs also encapsulate nutrients and reagents to sequester growth of inhibitory waste products. Genetic engineering will initially focus on a rapid-growing *Chlorella sorokiniana* strain for which a complete molecular toolbox/vector system (Phycal Inc.) has been made available in the Sayre laboratory at the New Mexico Consortium.

(3) *Sustainability from Ecological Robustness of Communities.* We will experimentally evaluate how diversity and trophic interactions influence lipid production in algae and related species by tracking the total biomass, population sizes, C and N metabolism, and lipid fluxes of multispecies cultures. This will require rapid screening of culture dynamics through time, flow cytometry, and enhanced mass spectrometry. It will involve membrane inlet mass spectrometry (MIMS) to assess complex photosynthetic dynamics[40-41] as well as nitrogen fixation and cycling dynamics[42-43] to compare the efficacy of (a) incorporating nitrogen fixing micro-organisms into a culturing system to (b) providing nitrogen from municipal or agricultural wastewater or from recycled products from hydrothermal biomass processing. We will collaborate with physicists and engineers at UNM to develop and apply novel methods for assessing variability of physiological function between cells within single and multi-species cultures through hyperspectral confocal fluorescence microscopy (HCFM) and multivariate curve resolution.[44-48]

Infrastructure and Activities Supported. EPSCoR support will enable new research efforts in large and small-scale facilities and the acquisition of needed instrumentation, including: (1) scalable PBRs for outdoor algal cultivation without evaporative water loss; (2) a continuous flow hydrothermal liquefaction system for bio-crude oil generation from algal biomass with variable lipid/protein contents; (3) a photochemical reactor to develop a catalyst to deoxygenate bio-crude oil; (4) the ATS™ cultivation system at ENMU; (5) SEED Facility infrastructure − (a) small-scale bioreactors for flexible control of environmental conditions during experiments, (b) online isotopic gas exchange system to monitor photosynthetic efficiency in real-time, (c) membrane inlet mass spectrometer (MIMS) for detailed algal physiology, (d) ultra high pressure super critical fluid chromatography mass spectrometry (UPSFC/MS) for rapid pigment profiling, (e) GC/MS system to understand nutrient dynamics, (f) resonance Raman plate reader to screen productivity; (6) enhanced microscopy at UNM − (a) HCFM camera for assessing cell-cell variation in function within cultures, and (b) digital microscope for monitoring species composition and morphology in algal cultures.

Our research will support collaborations between groups in the state working on multiple scales of algal culture (NMSU, SNL, New Mexico Consortium (NMC)-LANL, UNM) and groups working to manage wastewater streams from dairy (ENMU, NMSU), oil and gas (NMT, UNM), municipalities (UNM, NMSU), and managed systems (NMSU, UNM, NMT, Valles Caldera). We will encourage interaction and integration through joint training of graduate students and by using the NMSU Chemical Analysis and Instrumentation Laboratory (CAIL) to provide centralized analytical processing and additional training of faculty and students around the state.

Transformative Nature of Research and Activities. The proposed infrastructure will support innovative new technologies that will minimize the disadvantages of algal cultivation in desert environments. The new testing facilities will support next generation biofuel production, pioneer the production of bio-crude oil from highly stable algal extremophiles with lower-lipid contents, and provide new knowledge in algal ecology, physiology, agriculture and biomass process engineering. The team and infrastructure will enable interdisciplinary training for graduate and undergraduate students statewide and support new interactions among universities, national laboratories, and industry in the state.

Focus 2 - Solar Energy Development. Team: NMHU: Tatiana Timofeeva; NMSU: Jeremy Smith; NMT: **Michael Heagy; UNM:** John Grey, **Marty Kirk,** Yang Qin; 8 graduate students; 5 undergraduates

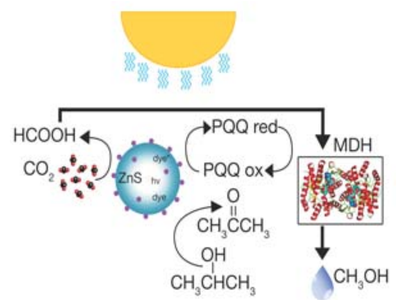

Figure 3. Catalytic cycle involving photodriven excitation of ZnS by chromophore dye absorbed onto ZnS surface.[56] The ZnS valence band resides at the appropriate energy to be involved in both CO_2 reduction and the reduction of enzyme cofactor PQQ.[57] PQQ regenerates methanol dehydrogenase (MDH), for final conversion of formic acid (HCOOH) to methanol.[58]

Objectives. The objective of the Solar Energy Research (SER) Team is to help NM transition from fossil fuels to renewable energy by improving the state's ability to use solar energy. We will forge a research collaboratory and invest in spectroscopic instrumentation that will enable us to: (1) explore the potential of solar energy in reducing atmospheric CO_2 to methanol, an alternative transportable fuel; (2) develop a solar-driven water oxidation process that uses inexpensive catalysts to generate H_2, a high-energy fuel that does not emit C; and (3) design more efficient organic solar photovoltaic cells.

Background and Proposed Research. In 2011[49] NM ranked 1st for solar power utilization per resident, yet today there remain several challenges to widespread adoption of solar energy. There is a need for energy storage during dark periods, for more effective and efficient solar energy processes and devices, and for a transportable fuel alternative to fossil fuels. The SER Team will conduct research in three areas.

(1) Nanoscience and technology can unlock the potential of solar energy to convert atmospheric CO_2, which is linked to global climate change, to formate, a key intermediate step toward the methanol economy. The NMT and UNM teams led by Heagy and Kirk have developed an approach to reducing atmospheric CO_2 that focuses on its conversion to formate by solar mediated photoreduction (Fig. 3).[50-51] This approach has been referred to as "chemical carbon mitigation,[52-53] and can lead to methanol, an important chemical fuel in the "methanol economy" as championed by Chemistry Nobel Laureate, George A. Olah.[54] Specifically, we will: (1) use nanoparticle ZnS semiconductor materials to catalyze the reduction of CO_2; and (2) develop new organic dyes that efficiently augment ZnS performance by lowering the semiconductor band-gap to use the visible solar spectrum.[55] Working in collaboration with Sandia's Center for Integrated Nanotechnologies (CINT), we will investigate the excited-state dynamics of the charge-transfer dyes using femtosecond transient absorption spectroscopy to develop insight into the degree of singlet vs. triplet character of these photochemical processes and the degree of electron-transfer into the nanoparticle material. Elucidating which excited state pathway occurs is key to using these dyes in solar absorption and to their subsequent electron injection into the conduction band involved in the photochemical process.

(2) Inexpensive, earth-abundant, and well-defined metal complexes will facilitate solar-driven catalytic water oxidation to generate oxygen. The need for storage remains a major barrier to widespread use of solar energy when cloudy weather and nighttime darkness interrupt its availability. In response to this problem, Smith and Kirk will lead a team effort to develop an artificial photosynthetic process for production of H_2, a high-energy fuel that does not produce CO_2. The process will convert solar energy into electrical energy that can power the electrochemical splitting of water, oxidizing it to O_2 at the anode and reducing it to H_2 at the cathode.[59] We will use well-defined manganese complexes as catalysts for the electrolytic water oxidation. In contrast to the majority of homogenous water oxidation catalysts, the proposed catalysts come from an earth-abundant and inexpensive metal.[60] Readily prepared and easily modified pyridinophane macrocycles, $Py_2(NR)_2$, will support the complexes. Much like complexes of related open-chain aminopyridine ligands, electrochemical oxidation of $[Py_2(NR)_2]MnII(H_2O)_2^{2+}$ complexes in saline solutions will afford higher valent manganese oxo intermediates that are precursors to oxygen

formation.[61] The flexible molecular design is compatible with the long-term goal of incorporating the catalysts into photochemical devices for solar harvesting. We will facilitate catalyst design and improvement by developing a detailed understanding of how the catalyst electronic structure contributes to reactivity. We will determine catalyst electronic structure by coupling electronic structure calculations with a combined spectroscopic approach involving magnetic circular dichroism (MCD), Raman, electronic absorption, and multifrequency electron paramagnetic resonance (EPR) spectroscopies.

(3) We will develop solar photovoltaic power to generate energy directly from sunlight to compete with water-intensive concentrated solar power systems (CSPs). The solar photovoltaic teams at UNM (Grey, Qin, Kirk) will lead our effort on bulk heterojunction (BHJ) organic photovoltaics (OPVs), which represent the most successful class of molecular solar cells obtained through blending electron donating and accepting materials.[62] Current BHJs operate at an efficiency plateau despite widespread belief that further improvement is possible.[63] BHJ morphologies result from uncontrolled random phase separation and are thermodynamically unstable; to improve OPV performance will depend on achieving a stable and precisely controlled morphology.[64] We will develop ordered and thermodynamically stable BHJs from a single polymer system using self-assembly strategies (Fig. 4). Our goal is to understand the emergent properties and assemblies of these novel molecules.

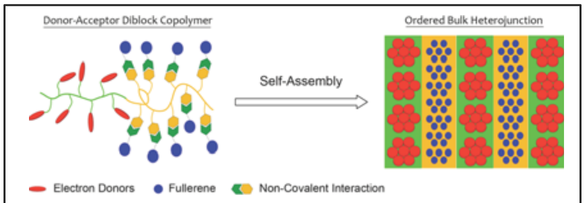

Figure 4. Diblock copolymers possessing disk-like liquid crystalline (LC) electron donors (i.e. metallophthalocyanines) attached to one block (i.e. polystyrenes) and fullerene electron acceptors to the other (i.e. polyacrylates).[65]

To achieve this goal, we must determine the electronic properties of bulk heterojunction materials, and this will require the use of electrochemical and optical spectroscopic methods that can link molecular structure and device performance with the underpinning electronic structure. Spectroscopic measurements will be important for determining bandgap energies as a function of the donor and acceptor. We will determine the charge transfer character using photoluminescence, Raman, and EPR spectroscopies. Multifrequency EPR will be very useful in understanding the mobility and nature of free charge carriers (polarons), anion radicals, and polaron-radical pairs, etc. generated under variable-temperature photoillumination conditions. The use of paramagnetic phthalocyanine metal complexes as donors will be advantageous due to their planar structure and extensive π-delocalization. VTVH and NIR-UV-VIS MCD spectroscopies will probe the electronic structure of the metallophthalocyanine donor in these copolymer bulk heterojunction materials.

Infrastructure and Activities Supported. Although UNM and the Center for Integrated Nanotechnologies (CINT) possess world-class capabilities in spectroscopy, the SER team lacks specific spectroscopic instrumentation required to conduct the proposed research. With EPSCoR support we will acquire new spectroscopic instrumentation and forge a "collaboratory" that will enable and educate students in advanced spectroscopic techniques. The proposed instrumentation will be centrally located at UNM and NMT in order to exploit current expertise and maximize access. To carry out ultrafast time dependent absorption spectroscopy, we will have collaborative support from CINT. Data gathered from this center will allow characterization of singlet and triplet components to various dye-doped nanoparticulate systems under investigation. We will use Cryogen Free Magnetic Circular Dichroism to collect key high-resolution data for all consortium researchers who require magneto-optical experiments on paramagnetic catalysts, nano-materials, and bulk heterojunction components. Raman spectroscopy will provide key electronic and geometric structural information on the catalysts, semiconductor materials, BHJ OVPs, under study. We will use a Raman system (Rennishaw inVia) coupled to an optical microscope in order to achieve high spatial resolution under a variety of conditions. This system is ideal for studying semiconductor nanoparticles, polymers, and photovoltaic cells at the sub-micron level. When coupled with a scanning probe microscope, the instrument can provide resolution on the nanoscale.

Transformative Nature of the Research and Activities. The SER Team will develop new scientific knowledge and transformative technologies that will: (1) enable the wider use of inexpensive, earth-abundant catalysts in solar-driven processes; (2) accelerate the transition from silicon-based solar cell technology to OPV-based solar energy; and (3) contribute to the development of methanol as a transportable fuel alternative to conventional fossil fuel derived hydrocarbons.

Focus 3 – Osmotic Power Development. Team: ENMU: Juchao Yan; LANL: Jeri Sullivan; NMT: **Frank Huang,** Corey Leclerc, Mike Riley, Snezna Rogelj; NMSU: Tanner Schaub; SNL: Pat Brady; UNM: David

Hanson, Cristina Takacs-Vesbach, **Bruce Thomson**; 1 chemist; 2 post doctoral fellows; 2 graduate students; 8 undergraduates

Objective. The objective of the osmotic power team is to investigate issues related to membrane properties and fouling that prevent osmotic pressure systems from becoming commercially viable sources of power. To accomplish this objective, we will invest in critical instrumentation (a membrane osmometer, a pressure retarded osmosis system, and a SEM-EDS and provide support for students, specialized post-docs, and a research chemist with expertise relevant to the proposed research. Our work will be collaborative among the participating institutions and employees of the oil and gas industry and it will leverage resources located in the Cancer Research Facility at UNM.

Background and Proposed Research. In 2007, oil and gas production in the US generated around 880 billion gallons of produced water, much of it considered to be waste; NM alone generates about 28 billion gallons of produced water annually, with 22 billion gallons coming from the oil rich Permian Basin in the southeastern corner of the state. More than half (56%) of this produced water was injected to enhance oil recovery while the remainder was disposed of via salt-water disposal (SWD) wells.[66] With a scarcity of freshwater in NM, there have been attempts to desalinize the produced water using reverse osmosis,[67-68] but energy requirements and membrane fouling resulting from high total dissolved solid (TDS) concentrations render the approach cost-prohibitive.[69] Although high TDS presents a challenge for desalinization, it provides a unique opportunity for osmotic power generation.

Osmotic pressure generated from salinity gradients can be a renewable and sustainable source of power in the future. Previously, the concept of osmotic power has been explored using fresh river water and seawater (TDS: 3.5%) as the water sources for pressure retarded osmosis (PRO).[70-74] These efforts demonstrated a power density up to 3~4 W/m^2 for this salinity gradient (osmotic pressure differential, $\Delta\pi$ ~ 26 atm)[75-80] and suggested 5 W/m^2 as the threshold for commercialization.[77] In southeastern NM, there are approximately 630 permitted SWD wells, each handling produced water from 40 oil wells with a mix of salinity. TDS in produced water available at a SWD well can span from less than 1% to 40%.[81] Calculations using produced water with TDS of 1.2% and 21% ($\Delta\pi$ ~ 160 atm) suggest that PRO could achieve a power density of 17 W/m^2 – more than three times the threshold for commercialization. However, further development of PRO using produced water will require research on two key questions:
(1) Which membrane properties and module designs will maximize power generation? For asymmetric membranes, the main factors affecting the performance of PRO are internal concentration polarization (ICP), reverse salt diffusion, dilution of the draw solution, and external concentration polarization (ECP)[75] The membrane module configuration (e.g., spiral wound, flat sheet, etc.) can also affect the achievable power density.[79] Our research will use commercially-available membranes and modules (e.g., Hydration Technology Innovations, HTI) to establish experimental baseline data (peak power density, burst hydraulic pressure, effect of ICP, etc.) and model predictions using produced water as feed and draw solutions. Then, we will develop thin-film composite (TFC) membranes tailored to reduce the effect of ICP and provide strength for hydraulic pressures when high TDS produced waters are used as the draw solutions. Membranes with thinner, less tortuous and more porous support layers to reduce ICP may be a key factor in successful osmotic power development.[75] HTI developed the Hydrowell membrane with an ultra-thin polyester support.[79] We propose to develop TFC membranes using graphene-based support materials. Graphene is one of the strongest materials known[82], and graphene-based materials (e.g., graphene oxide) have been suggested as membrane support for water purification.[83-85] We will investigate how key manufacturing parameters (carbon source, temperature, concentrations, templating materials, other additives, etc.) affect membrane structure, properties, and performance. Cellulose triacetate (CTA) has been the main choice of active-layer material for salt rejection due to its hydrophilicity; however, a membrane with more hydrophobic polyamide as the active layer was developed recently and possesses a good power density.[80] We will focus on polyamide and other materials that have a better oxidant tolerance than CTA to compensate for the high fouling potential of produced water. Finally, we will study the design of the membrane module to maximize fluid circulation on both sides of the membrane and reduce ECP.[75,79]
(2) Could membrane fouling be controlled to minimize the impact on PRO? Membrane is an essential component for PRO and is highly susceptible to constituents in produced water. Membrane fouling can severely hinder membrane water flux and lead to lower energy generation. We will set up our experimental PRO system at a SWD site for several reasons: it minimizes transportation costs by using produced water already delivered to the SWD for disposal; it reduces the cost of pre-treating the produced water for power generation since the SWD operators already treat the water to prevent

clogging; and it uses the existing SWD to dispose of the brine produced during osmotic energy extraction. Since the magnitude of power generation at a particular SWD site is positively correlated to the rate of produced water processed through the PRO system, we will select a SWD site with a capacity of more than 10,000 barrels per day. Our research will focus on the occurrence, prevention, and mitigation of fouling caused by precipitates (e.g., $CaCO_3$, $CaSO_4$), organics (e.g., residual oil, fatty acids) and microorganisms, with a particular interest in organic and biofouling that are more difficult to prevent and mitigate than other types of fouling. Our work will: identify dominant organic materials that accumulate on the membranes and may, in addition to direct clogging, also serve as nutrients for biofilm-forming bacteria;[86] identify bacterial species that accumulate on the membranes using 16S ribosomal DNA analysis;[87] explore physical (e.g. collapsing microbubbles), chemical (e.g. deep eutectic solvents, D-amino acids), and biochemical (e.g. enzymes) approaches to regenerate the membranes.[88-90]

Infrastructure and Activities Supported. EPSCoR will enable this project to attract talented students, a post-doc who specializes in membrane synthesis, another post-doc who specializes in foulant characterization, and a research chemist who specializes in chemical characterization of produced water. It will enable acquisition of: a membrane osmometer to facilitate the measurement of osmotic pressure generated by high TDS produced water; a high-pressure PRO system to explore the feasibility of utilizing high TDS produced water for energy production; and a SEM-EDS (to supplement the aging and cumbersome SEM at NMT) for characterizing membranes and foulants. We will analyze samples on the Confocal Laser Scanning Microscopes (CLSM)[91-93] at the Cancer Research Facility at UNM to characterize the major biological components in extracellular polymeric substances (EPS) of biofouling and to design subsequent mitigation studies.

The proposed research is a collaborative effort among researchers at different institutions and employees of the oil and gas industry. The research chemist and a researcher will characterize the produced water at the NMSU Chemical Analysis and Instrumentation Lab and at ENMU, respectively. Researchers from NMT and UNM will collaborate on membrane development and testing of the PRO system, and researchers at NMT, UNM, SNL, and ENMU will investigate fouling issues. Apache, a major oil corporation, and Nasus Water Technologies, a water treatment company, have both shown interest in the developing PRO using produced water to reduce the disposal cost, and we will collaborate with them.

Transformative Nature of the Research and Activities. Although osmotic pressure has been observed for centuries, it was never used to harness energy with produced waters from oil and gas as the source. New Mexico generates a significant amount of produced water that is disposed via underground injection at an estimated annual cost of $780 million.[94-94] The proposed research will further develop osmotic power, and, if viable, will extract clean energy from "waste products," thereby off-setting the disposal cost and lowering the carbon footprint of the oil and gas industry. Our conservative estimate indicates that the electricity generated from the PRO systems could offset about 5-10% of the disposal cost, resulting in initial cost savings of $3-6 million per year. We further estimate that the clean energy generated from the PRO systems could lead to a reduction of 21,000 to 42,000 metric tons of CO_2 equivalent emitted per year from burning fuels for oil exploration and production. Thus, this research will generate new knowledge and increase NM's research competitiveness in osmotic power, a clean energy source that has a global potential of 2,000 TWh per year.[76]

Component 2: Sustainability. Can we sustain extractive energy development with no or minimal risk to water and environmental resources? Achieving a sustainable energy future for NM requires a complete and balanced suite of extractive and renewable energy sources that is socially adoptable, water resource achievable, and environmentally positive. The sustainability component focuses on: (1) developing a better fundamental understanding of uranium (U) biogeochemistry and mobility in natural and contaminated environments, including new mechanisms that enable U transport to be controlled during and after mining; (2) analyzing the potential viability and impacts of expanded low-temperature geothermal energy development; and (3) supporting innovative research at the social and natural science nexus that includes dynamic systems modeling and developing an understanding of the factors that affect human choice and decision-making The sustainability research foci, especially the social and natural science nexus, complement and incorporate the knowledge generated in Component 1 (i.e., increasing the extractive efficiencies of energy development).

Focus 4 – Uranium Transport and Site Remediation. Team: NMT: Bonnie Frey, Mike Pullin, Mike Timmons, **Dana Ulmer-Scholle**; SNL**:** Patrick Brady; UNM: Abdul-Mehdi Ali, **Steve Cabaniss** Bruce Thomson, Gary Weissman; 7 graduate students; 5 undergraduate students

Objective. Inadequate understanding of uranium (U) biogeochemistry and mobility in natural and contaminated environments and our consequent inability to control transport of U during and after mining is a critical roadblock to its sustainable utilization in NM. The objective of the U transport and site remediation team is to improve laboratory capabilities to: enable faster, more sensitive analyses, including low-level speciation and isotopic measurements; conduct research to improve our understanding of U biogeochemistry and occurrence; and develop tools for predicting and controlling U mobility in the environment. We will accomplish this objective by investing in critically needed equipment and by implementing the six research components described below.

Background and Proposed Research. While nuclear power generation can reduce carbon emissions, sustainable use of NM's prolific U resources will depend on developing methods for extraction, processing, and remediation that do not impair the limited water supplies in this arid region and do not leave behind a legacy of contamination harmful to ecosystem or human health. More specifically, environmentally responsible development and remediation of U requires better understanding of its speciation and mobility. Since the 1990's, the dominant paradigm for U speciation in high-pH western environments has held that U exists principally as soluble U(VI)-carbonato complexes, insoluble U(IV) oxides (uraninite) and adsorbed U(VI) species.[96] Consequently, remediation of the numerous abandoned mine and milling sites has focused on U immobilization through stimulated bioreduction of soluble U(VI) to insoluble U(IV).[97-98] Field trials showed lower-than-predicted immobilization,[99] and subsequent laboratory studies of bioreduction showed that in the presence of organic molecules, U(IV) can remain in a soluble, mobile form.[100-102] X-ray spectroscopy indicates that U(IV) does not completely precipitate as uraninite in the field, but can remain as mono-nuclear U(IV) for months or years.[103-104]

These results require a refinement of the U speciation paradigm and new approaches to remediating contaminated sites. Kinetic and thermodynamic studies of U(IV) speciation to determine its expected behavior in the environment may help to design more effective strategies for bioreduction in low-oxygen groundwaters. Where bioreduction is not a viable strategy, for example in drier well-oxygenated sites dotting the Navajo Nation lands, remediation methods based on precipitation of U(VI) phosphate minerals offer a promising alternative.[105-106] However, these methods require more extensive lab testing before they are ready for field trials. Finally, novel ablation technologies from the mining industry have been proposed, but not field-tested, for remediation purposes.

Our research will address questions related to natural and engineered U mobilization and transport. What dissolved and colloidal U species exist in contaminated subsurface sites? Can U mobility in groundwaters be predicted quantitatively? How can U be quickly and economically extracted from deep and/or low-grade ore deposits without danger of long-term contamination? How can U be immobilized to prevent contamination of water sources? Can *in situ* recovery technologies be applied to impaired water supplies to restore aquifer quality? Can mine and mill tailings be "mined" economically to partially offset remediation costs? How has U been transported from scattered point sources to other locations in an arid environment? We will divide our research on these questions into six major components.

(1) *Development of methodologies for rapid, sensitive measurement of environmental U speciation.* By interfacing high-performance liquid chromatography (HPLC) to inductively coupled plasma mass spectrometry (ICP-MS) detection, we will be able to make speciation measurements based on molecular size and polarity. This technique will enable us to devise new methods of U(IV) speciation in environmental matrices. Similarly, by interfacing field-flow fractionation (FFF) to ICP-MS detection, we can make separate measurements of colloidal and dissolved U, a crucial distinction for subsurface transport.

(2) *Biogeochemistry of U in reducing environments.* Using HPLC-MS, we will examine the kinetic stability of bio-reduced monomeric and colloidal U(IV) species in solution under anoxic and sub-oxic conditions. By combining microbiological and geochemical experiments with speciation modeling, we plan to produce quantitative predictions of soluble U(IV) lifetimes in the aqueous subsurface environment. These projections will in turn be used to devise possible mobilization and demobilization strategies.

(3) *Development and testing of novel technologies for U de/mobilization*. We will test proposed methods of U(VI) immobilization and removal that could be applied directly to oxic systems such as the abandoned mining and milling sites found across the Colorado Plateau. One potentially cost-effective treatment is the immobilization of U(VI) by application of phosphate bearing minerals to oxic, arid surface deposits. A second proposed method to be tested has the potential to convert mine wastes and tailings into usable 'yellowcake' uranium by enhanced extraction. We will also test alternative lixiviant (the oxidizing extractive solution pumped into the U-bearing units) formulations for *in situ* recovery, with the goal of minimizing

residual oxidizing potential after removal has been completed, thus facilitating the process of returning dissolved U to pre-extraction levels.

(4) *Hydrogeology of U transport*. We will collect geochemical data (general chemistry, chemical tracers, isotopes, ages, etc.) and hydrologic data (conductivity, mineralogy, etc.) to characterize the flow paths and apparent age of a regional groundwater system in the Grants Mineral Belt. Using stochastic modeling of fluid movement based upon estimates of aquifer heterogeneity, we will assess output variability and model reliability. We will employ these assessments to delineate and predict potential *in situ* mining impacts as well as contaminant plumes from legacy mining operations.

(5) *Field-scale mapping and modeling of subsurface U mobility.* We will construct U resource and contamination maps by combining digitized U resource and mining information with industrial data and new measurements, including water chemistry. These maps will in turn become the basis for more sophisticated and complete subsurface hydrogeochemical models of U sources in water supplies in the Grants Mineral Belt especially where remobilized U is impacting the water supply for the area.

(6) *Uranium transport and transformations in arid ecosystems.* To evaluate the potential roles of wind-born dust and animal (or human) vectors in the arid lands of the Diné reservation, we will work with UNM investigators (J. Lewis and collaborators) in acquiring samples on the reservation for exposure assessment. We will use the combined data to map surface contamination and couple this with aeolian transport and network modeling of vehicle and organismal transport. The fieldwork will rely upon undergraduates familiar with the area (essential when working on Navajo lands). Model implementation will combine existing aeolian transport with vector codes to simulate other modes of transport.

Infrastructure and Activities Supported. We will conduct the proposed U research at NMT and UNM, collaborating with SNL and the Navajo Nation (NN). EPSCoR will support our critical major equipment needs: an ICP-MS, microwave digestion and FFF for NMT, and HPLC for UNM. UNM will perform the biogeochemical studies and the technology development and testing, while NMT will perform the database development and associated field sampling, analyses and modeling. Ulmer-Scholle, Cabaniss and Thomson will be responsible for the mapping/database development, biogeochemistry and engineering research areas, respectively.

Transformative Nature of the Research and Activities. The proposed activities will enable researchers to push the knowledge boundaries of both fundamental and applied topics. The proposed work will promote collaborations between university scientists concerned with fundamental U biogeochemistry and engineers and applied geologists concerned with mineral resources, contamination, and remediation – two groups that often act independently. Work on Navajo lands will bring scientists, engineers and CDC-funded health researchers together with Tribal resource managers and regulators and Native American citizens, with Native American students being the links between these often disparate groups.

Focus 5 – Geothermal Energy Resources and Sustainability. Team: NMT: Shari Kelly; **Mark Person,** Fred Phillips, Glenn Spinelli; UNM: **Laura Crossey,** Karl Karlstrom; VCNP: Robert Parmenter; 7 graduate students; 1 undergraduate student

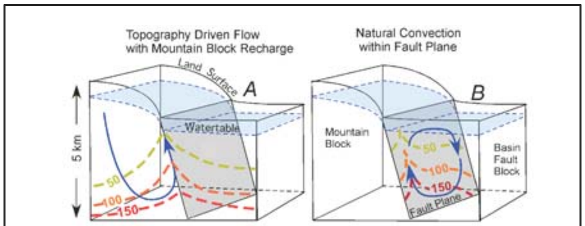

Figure 5. Schematic diagram illustrating differences between (A) forced convection systems and (B) fault controlled free convection systems in New Mexico.

Objective. The geothermal energy team will develop a better understanding of factors that affect the viability and sustainability of NM's underlying natural hydrothermal systems. The team will develop a statewide collaborative research program and purchase instruments for sensing, measuring and visualizing hydrothermal systems.

Background and Proposed Research. New Mexico is endowed with relatively high background heat flow[107] and permeable, fractured bedrock.[108] These conditions have given rise to numerous low-temperature (< 80^{o} C) geothermal systems[109]) and to economically viable greenhouse-aquaculture industries.[110] Some systems (e.g. Socorro Springs[111] and Truth or Consequences(TorC)[112-113]) are driven by regional water table gradients (forced convection systems) (Fig. 5-A) and others (e.g. Valles Caldera and Lightning Dock) are fault controlled, driven by natural (free) convection[114] with discharge that is episodic in nature (Fig. 5-B). Other systems may reflect a combination of these processes (e.g., Soda Dam, San Ysidro, La Madera).

Hydrothermal energy exploration and utilization has the potential to become increasingly important to NM's energy future.[107] Developing geothermal energy as a viable and sustainable resource in NM, however, will require a better understanding of the underlying natural hydrothermal systems and of the practical limitations and human technologies involved in its application. Science has incomplete knowledge about depth and drivers of fluid flow, longevity and episodicity of vent systems, fluid conduits, and mixing of meteoric with endogenic fluids in hydrothermal systems. When human technologies are applied to these natural systems for geothermal energy production, they can cause profound changes to surface hydrologic features (e.g. cessation of the Beowawe geyser field[115]) that can lead to net loss of groundwater (e.g. Coso and the Geysers, California) potentially requiring groundwater replacement using make-up fluids.[116]

Developing a fundamental understanding of the magnitude and sustainability of geothermal resources also has direct implications for NM economic development. For instance, in the spa town of TorC, over-pumping has resulted in net declines of artesian heads in wells and reduced hot spring discharge by as much as 50%. The city council has placed a one-year ban on new drilling and expressed great interest in working with us to develop a geothermal sustainability plan for their city. Similarly, within the Lighting Dock geothermal system near Animas in southwestern NM, geothermal companies interested in installing a 1.5 MW binary geothermal power plant (Raser, Cyrq Energy, Ormat) have been at odds with existing shallow claims by Burgett Geothermal Greenhouse and Americulture Tilapia farms.

To better understand the impact of hot spring discharge on surface water quality and the potential viability and impact of expanded geothermal energy use in NM, our research will focus on two questions: *(1) How long-lived are fault controlled and topography-driven geothermal systems within New Mexico? Is the development of geothermal systems associated with discharge areas of regional, topography-driven flow systems more sustainable than the development of fault controlled systems driven by natural convection?* Our investigations will begin by dating hot spring deposits and fault surfaces associated with fault-controlled natural-convection (e.g. Soda Dam system) and topography-driven flow systems (e.g. Socorro Springs, TorC) as a means of determining their longevity and episodicity.[117] To obtain data on the periodicity of NM geothermal systems, we will apply U-series geochronology on carbonate spring deposits.[118-120] Using a magnetotelluric (MT) exploration system acquired as part of this project, we will assess the resistivity structure of several fault- and topography-controlled geothermal systems (including Socorro Springs, Valles Caldera and Lighting Dock). Since pilot studies have shown that brackish-saline geothermal waters have relatively low resistivity,[121] we expect to be able to determine salinity footprints and relate them to shallow heat flow data. To quantify the plumbing, longevity, and sustainability of NM geothermal resources, we will develop novel high performance computer models of groundwater flow, heat, and solute mass transport using the computer simulation code *PGEOFE* developed by co-Lead Person and his colleagues.[122-123] These hydrothermal models will incorporate groundwater residence time,[124] fluid-rock isotope exchange, and transport systematics[125] to improve model calibration to observed conditions. We will construct georeferenced grids using LaGrit[126] developed at LANL and we will use high performance visualization workstations (acquired as part of this project) combined with parallel visualization software (Paraview, SNL) to interrogate model results. After calibrating our models to thermal, isotopic, and geochemical tracer data (including published ^{14}C and ^{4}He measurements), we will explore the sustainability of geothermal energy production over time scales of 50 to 100 years adding historical and projected production rates.

(2) What is the extent of degradation of groundwater and surface water quality from hydrothermal systems in NM? Our research will build on and extend published hydrochemical sampling and modeling[127-129] by applying campaign-style hydrochemical analysis of NM groundwaters and surface waters. We will extend major, trace, and gas analyses (including noble gases) to major hydrothermal areas and travertine-depositing regions in the state. For real-time monitoring of selected sites, we will use the NM autonomous sensor facility at UNM. We will evaluate the extent to which hydrothermal waters carry trace metals and salts that significantly degrade water quality, which has important implications for NM's aquifer systems and surface water hydrology. For example, pilot work on the Jemez River system,[129] using combined geochemical and hydrologic studies, documents water degradation at surface springs and provides a pathway for mitigation of point source degradations via characterizing, isolating, and treating springs and wells that tap into endogenic waters. By evaluating fluid flux along faults and fluid mixing at various scales, this research links to the other hydrothermal goals of this project.[130]

Infrastructure and Activities Supported. EPSCoR support will enable our team to acquire a Phoenix-Geophysics magnetotelluric (MT) System (NMT); visualization workstations (2, NMT), U-series and water and gas analysis (UNM), and autonomous sensors (UNM) to address the above research questions.

Transformative Nature of the Research and Activities. This research will allow us to test the idea that geothermal vents reflect complex mixing (along faults) of epigenic and endogenic fluid sources and may reveal that deep crustal fluids are an important factor in surface water quality degradation along the Rio Grande and Jemez Rivers. In microbiology, the "continental smokers" (analogous to mid ocean ridge black and white smokers) concept identifies these vents as potentially unique niches for ecological communities. These unique niches and the important hydrological phenomena they encode, are not well protected in NM. We use the term "vents" as analogous to magmatism in the view that hydrothermal regions are important areas for neotectonic research as well as for quantifying deep earth CO_2 degassing and natural analogs for carbon sequestration storage/leakage. In addition, we are not aware of any hydrothermal models that incorporate isotope systematics and groundwater residence times as a means of constraining the depth of circulation and longevity of geothermal systems. Incorporation of these tracers in our computer code *PGEOFE* combined with the ability to constrain model results using MT resistivity imaging will provide us with a competitive advantage in applying for future research funding.

Focus 6 – The Social and Natural Science Nexus. Team: Navajo Nation Environmental Protection Agency: Steve Austin; NMSU: **Sam Fernald,** Steve Guldan, Carlos Ochoa, Ursula Smedly, Caiti Steele; NMT: Mike Pullin, SNL: Vince Tidwell; UNM: **Janie Chermak,** Jennifer Thacher, Bruce Thomson; VCNP: Bob Parmenter; 1 post-doc; 8 graduate students; 6 undergraduate students.

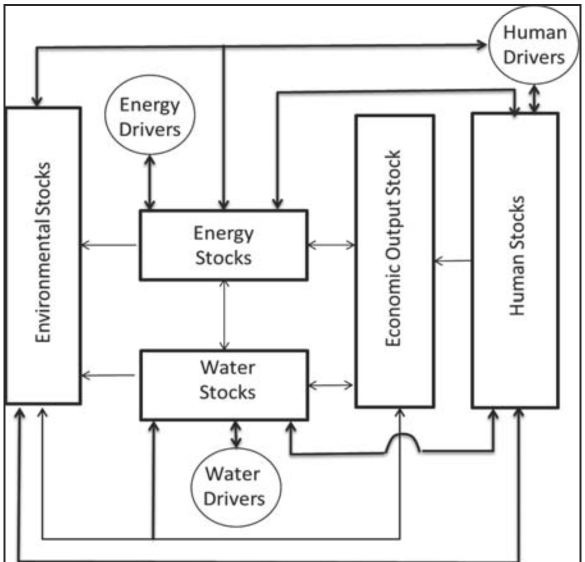

Fig.6. A simple schematic of the potential interactions between the elements of a System Dynamics model that considers the physical (environmental, energy, and water) stocks and the socio-economic (economic and human) stocks. The natural and human stocks provide the resources to produce goods that are economic output. Depending on the system, the impacts between stocks can occur in either direction, and feedback loops are determined by the specific system. The figure also shows potential drivers that can impact the stocks or vice versa. For example, drivers such as the tastes and preferences or the legal and regulatory framework may impact the human stock and its impact on economic output. Water stocks may be impacted by drivers of climate (temperature and precipitation) and by biogeophysical processes (within soil, vegetation and other organisms). Likewise, energy resources would have a broad set of drivers that impact energy development and use. In this compact representation, we illustrate a separate set of drivers for each area, though in reality there is likely overlap across elements.

Objective: The objective of the social and natural science team is to better understand the trade-offs that occur between different energy and economic development choices while considering the potential for sustainable socio-economics, environment, and water use. To accomplish this objective, the team will develop a cutting-edge multidisciplinary model that links natural and human systems. This effort will require investing primarily in the people who will develop a systems dynamics (SD) modeling framework and detailed water, energy, environment, and socio-economic budgets.

Background and Proposed Research. The modeling effort builds on complexity science and previous water resource models. The hydrology and coupled water resource management elements of the SD model have been developed for part of the Rio Grande Basin.[131] Previous efforts used SD to go beyond physical hydrology to incorporate economic and environmental variables based on expert and collaborator opinion.[132] Recent efforts funded by RII3 built on this functioning SD toolbox to include linked socio-cultural and hydrologic subsystems.[133] The proposed research adds energy, environmental and socio-economic human systems as the next step in SD science that will use quantified spatially variable dynamic budgets to link multiple physical systems as well as human socio-economic systems (Fig 6.).

The need for this proposed model derives from the state's energy industries that are important to the economy yet constrained by environmental impacts and water resources. For example, the oil and natural gas industry contributes more than 90,000 jobs to the state (over 8% of total employment) and more than $8.2 billion (12.2%) of the state's domestic product.[134] Yet the industry contributes more than one million metric tons (mmt) of CO_2, methane and nitrous oxide.[135] For every one-barrel of oil produced, between two and eight barrels of water are also produced, often with high salinity, organics, and naturally occurring radionuclides.[136] Hydraulic-fracturing of a natural gas well, used in the San Juan Basin and increasingly in shale gas plays in the Permian Basin of Texas and NM, can use in excess of 3 million gallons of water per well, depending on the location and well type.[137] Similar trade-offs occur with coal-fired power generation, algal biofuel production, and U mining. To evaluate energy development and source viability as these relate to water, environment, and socio-economic considerations, more powerful, integrative modeling tools are needed.

The social and natural systems team will build an SD infrastructure to integrate social and natural sciences by developing three dynamic budgets that provide the relationships between inputs and outputs of a resource over time: (1) the energy budget based largely on parallel work in this overall RII proposal, (2) socio-economic budgets incorporating a newly developed data gathering mechanism for human perceptions; and (3) a statewide water budget adding other river basins and groundwater basins to the Rio Grande database already incorporated into the existing SD toolbox.

By combining newly acquired attitude data with other available data, we will establish the basis for agent-based behavioral models and for the human budget components in the SD model. We will create an infrastructure to collect and use human perceptions data including: platforms for surveys[138] and field experiments[139] as well as CI for data utilization. Our efforts will include developing data to fill data gaps on human perceptions and attitudes.[140] We will develop and administer an initial statewide survey to provide baseline data on attitudes about energy/water issues that are the focus of this RII proposal.[141]

We will develop a statewide dynamic water budget that is linkable through the SD model to other science and social data models.[142] Our effort will build on the NM EPSCoR hydrology infrastructure, including the Hydrologic Information System database populated as part of the EPSCoR CI component. We will merge existing and new water resource data to establish dynamic water budgets that researchers and policy makers can access when they need integrated current status water budgets.[143] The statewide dynamic water budget will use (i) data from cooperators (USGS, NRCS, US BOR); (ii) data from ongoing studies, (iii) live data streams from sensors including previous EPSCoR funded infrastructure[144] and (iv) remotely sensed products (precipitation, snow cover, soil moisture, ET and vegetation cover) derived from Earth observation missions. A SD subsystems model will define physical hydrology processes. The water budget will use datasets to define the broader context of water in NM for boundary conditions and state conditions at the core of sustainability research.

We will use broad scale integrative modeling that crosses disciplines, incorporating modeling modules from disparate fields into a decision support system designed with flexible scale and focus. Our models will be dynamic and will add human behavior data parallel to the physical science data used or developed in other sections of this proposal. To enable simultaneous rather than sequential modeling of the integrated components, our model will be interdisciplinary, operate at the state level, and converge varying time and spatial scales.[145] These innovations will produce CI that incorporates an interdisciplinary and theoretically-driven framework for investigating and integrating economic and behavioral responses with near real-time natural science data and process representations.

Infrastructure and Activities Supported. EPSCoR will support the team's postdoctoral fellow and students and enhance the team's capacity for modeling coupled natural and human systems (NMSU, UNM, and SNL), experimental design and economics (UNM), hydrology and water resources management (NMSU), SD modeling (SNL), energy and engineering (UNM), developing educational linkages (NM Tech), linking to previous NSF hydrology through CZO and EPSCoR (VCNP and NMSU), and encouraging stakeholder participation (NMSU). EPSCoR travel support will bring the team together for data integration and modeling workshops with the CI team and for research team meetings and visits to data repositories. EPSCoR support will enhance collaboration with policymakers and stakeholders from the community at large and it will enable the team to reach out to state agencies (e.g., Office of the State Engineer, NM Environment Department, and Taxation and Revenue) that can contribute to our model's relevance, the utilization of our products, and future research.

Transformative Nature of the Research and Activities. This research considers interactions and feedbacks between the social and natural sciences in order to determine the sustainability and acceptability of energy production and use. The resulting database, models, and DSS will help inform policy and enable researchers to compare and/or integrate information across research endeavors by seeking to answer key research questions that are integrative in nature and reach beyond the viability and acceptability of a single energy production process. What are tipping points for sustainability? How do changing social and economic value of water, energy, and the environment constrain or encourage energy production? What are the social, cultural, and political constraints linked to energy, water, and the environment? How do societal or physical world boundaries impact energy sustainability? How might changes in climate propagated through natural and social systems impact energy development? In this way, this research will help NM to develop its energy resources in a sustainable way.

4.3.1 Seed Funding and Emerging Areas

Support for seed funding and emerging areas is provided through three separate competitive programs based on need, innovation, diversity, and institutional support:

The Faculty Start-up Package Program allows NM to attract new faculty to its academic institutions by providing four $150,000 start-up packages that support equipment needs (to at least be matched equally by the home institution).

The Seed Award Program provides up to eight $50,000 awards for critical laboratory and field instrumentation that will support innovative research, education and workforce development capabilities at community colleges, Tribal colleges, and regional universities (i.e., non-PhD granting institutions).

Interdisciplinary Innovation Working Groups (I-IWG) Program, done in conjunction with our Track II Western Consortium partners (Idaho, Nevada) supports week-long working group activities for 8-12 participants who will work collaboratively to integrate and synthesize data, information, and knowledge on challenging interdisciplinary problems that can transform science and education. Expected outcomes include synthesis papers and proposals that target disciplinary and crosscutting programs.

4.4 Diversity Plan. Team: ENMU: Juchao Yan; Global Center for Cultural Entrepreneurship: **Alice Loy**; NMEPSCoR: Mary Jo Daniel, Bennie Francisco; NM Consortium: Steve Buelow; NMT: Michael Pullin; SFCC: **Phyllis Baca**, Dana MacArthur; Santa Fe Institute: Irene Lee; UNM: Laura Crossey

NM EPSCoR will actively seek and welcome people with diverse backgrounds to join our multidisciplinary, multicultural, and multigenerational team in an inclusive environment where ideas are freely exchanged, cultures and traditions are respected, and personal and professional growth are encouraged. We will use guidelines from the faculty diversity plan written in RII3 to inform the recruiting and hiring of new faculty during NM EPSCoR RII4. The Tri-State Diversity Strategic Plan developed in 2010 through a Track 2 IWG will provide a road map for activities that will enhance the diversity of NM EPSCoR participants at all levels and will serve as a starting point for our current Diversity Plan. The activities in our Workforce Development and External Engagement Plans (Sections 4.5 and 4.7) will also enhance diversity in STEM and are key components of our Diversity Plan.

	UNM	NMT	NMSU	NMHU	ENMU	NNMC	WNMU
Enrollment	28,688	1,775	18,600	3,750	5,075	2,179	3,506
Race / ethnicity							
American Indian or Alaska Native	6%	2%	3%	7%	2%	8%	2%
Asian	3%	3%	2%	0%	1%	1%	1%
Black or African American	3%	1%	3%	6%	4%	1%	3%
Hispanic/Latino	39%	26%	48%	55%	33%	68%	55%
White	42%	63%	34%	21%	52%	15%	27%
Unknown	3%	0%	7%	2%	3%	5%	10%

Table A. Demographics at public four-year instititions.

4.4.1 Current State of Diversity. New Mexico is a "minority majority" state with a richly diverse population: 46.7% Hispanic, 10.1% Native American, 2.5% Black, and 40.2% White (non-Hispanic). Student populations at NM universities are also very diverse (Table A), and in most cases, white students represent significantly less than half of the total student body. Still, as is true nationally, non-white students remain underrepresented in STEM fields.

4.4.2 Programs

Diversity Coordinator. The State Office will create a 0.5 FTE position (Bennie Francisco, Diné) to coordinate efforts and to ensure, through institutional involvement and strategic recruitment, that diversity is a key component of all program activities; our target is to have 50% representation by women and underrepresented minorities in all EPSCoR-supported programs. The Diversity Coordinator will update and disseminate the Faculty Diversity plan and Diversity Strategic Plan, as well as track progress on all diversity initiatives. The Diversity Coordinator will network with existing programs focused on diversity (e.g., LSAMP, AISES, HACU) to expand our knowledge of and disseminate information about strategies that are successful with diverse populations.

Embedded Focus on Diversity in Research. Each research team is geographically diverse, engaging researchers from different institutions, disciplines and levels of experience. Senior research faculty members will mentor junior faculty and post-docs. The research teams will mentor students at all academic levels in a multi-institutional multi-tiered instructional cadre where more advanced students mentor upcoming students, and where NM's underrepresented groups are involved in projects of direct interest to their communities. The Seed Award Program (Section 4.3.1) is designed to increase the research capacity of the regional colleges and state and Tribal community colleges, most of which are Hispanic or Native American serving institutions.

Diversity Innovation Working Group (IWG). Diversity IWGs (with Idaho and Nevada) will bring in additional expertise to gather/synthesize information that can lead to proposals or other concrete mechanisms that will enhance the diversity among STEM students and members of the workforce.

Strategic Recruitment of Students for Research Opportunities. The STEM Advancement Program (STEMAP) (see Section 4.5) will select qualified student applicants who maximize geographic, ethnic, cultural, physical and gender diversity. Students will be involved in research experiences, encouraged to pursue an advanced STEM degree, linked to faculty and support mentors and given financial support through stipends. This program provides all of the ingredients for minority success in STEM.[146]

Diversity through Workforce Development. All activities in the Workforce Development Plan (WFD) (Section 4.5) include a focus on reaching and supporting individuals underrepresented in STEM.

4.5 Workforce Development Plan. Team: Global Center for Cultural Entrepreneurship: **Alice Loy**; NMEPSCoR: Selena Connealy; Mary Jo Daniel; NM Consortium: Steve Buelow; NMT: Michael Pullin; SFCC: **Phyllis Baca**, Dana MacArthur; Santa Fe Institute: Irene Lee

Each interdisciplinary research team (Section 4.3) will train undergraduate, graduate students and post-doctoral fellows in the use of equipment and applicable research and visualization techniques. The WFD Plan addresses other levels of STEM education through activities that build the human capacity NM needs to realize its research, education, and economic development potential. The plan will help New Mexicans achieve greater educational success in STEM fields, which will open opportunities for their employment in well-paid jobs and increase the state's research competitiveness. By developing entrepreneurship, the plan will create new, innovative business ventures that contribute to NM's economic base. To multiply benefits, we will implement the WFD Plan in synergy with the Diversity Plan (Section 4.4) to engage and support individuals underrepresented in STEM.

4.5.1 Current Status. K-12 students in NM fall well below the national average in science and math achievement, with NM ranking 44th in the nation in eighth grade science and 48th in eighth grade math[147]. Assessment data show a persistent gap between white students and their minority peers in science and math achievement[148]. High school graduation rates (2011) across the state are low, averaging 63%, and even lower for minority students (Hispanic 59.3%, Native American 56%, and African American 60%)[148]. Of those students who graduate from NM high schools, over 50% enroll in remedial math courses when they enter college. The three NM research universities have six-year graduation rates of 43-45%[149].

Since many NM students, including those from groups underrepresented in STEM, begin their post-secondary education at community and Tribal colleges, improving undergraduate STEM courses at these institutions will have a significant positive impact on increasing the diversity of our STEM workforce. Our plan to increase student access to and engagement in research at the K-12, undergraduate and graduate levels, improve post-doc and STEM faculty effectiveness, and equip faculty with tools and skills to become creative entrepreneurs will contribute to the development of NM's STEM workforce.

4.5.2 Workforce Development Activities

Growing Up Thinking Computationally (GUTC) (Lee). We will engage 1,000 middle school students (ages 11-14) in an afterschool program focused on computational science, and 75 teachers in professional development workshops. GUTC's primary strategy, designed to increase the number of students interested in and prepared for high school STEM classes and interdisciplinary computational science research projects, is to explore science topics relevant to local communities, through the lens of complex adaptive systems and computational modeling and simulation. Research shows that students who have a science career interest at age 13 are two to three times more likely to graduate from college with a degree in science.[150] GUTC will enable students to participate in scientific discovery using computer modeling and simulation,[151] and through this activity, learn to envision themselves as future scientists. GUTC curricular units will align with practices outlined in the Common Core State Standards[152]

(Standards for Mathematical Practice) and the Framework for K-12 Science Education[153] (Scientific and Engineering Practices), and they will address areas that may be unfamiliar to many teachers, e.g., computational thinking, developing and using models, systems and systems models. By expanding the successful model developed by Project GUTS: Growing Up Thinking Scientifically (NSF award #0639637, PI Lee), GUTC annual professional development workshops will provide teachers with skills needed to lead weekly two-hour club meetings at local schools. GUTC curricular units (e.g., energy, environment, water) will form the basis for instruction, concluding in student-driven computational modeling project work.

STEM Advancement Program (STEMAP) (Pullin, Connealy). EPSCoR will provide summer research experiences for 50 undergraduate STEM students from Primarily Undergraduate Institutions (PUI). Students will gain experience in scientific research by working with faculty on the research teams. Students will receive fellowships for an academic year during which they will work with a sponsoring faculty member to develop individual objectives that extend their experiences in STEM research. The EPSCoR Education Coordinator will provide workshops (face to face and virtual) for students in topics such as applying for an NSF Graduate Research Fellowship, developing effective science posters, and using strategies for student success. STEMAP aligns with recommendations in a recent report[146] for increasing the completion rate of underrepresented students by providing strong academic, social, and financial support through programs that integrate academic, social, and professional development and also facilitate the transition from the undergraduate to the next academic level.

Graduate Student Externship Exchange (Daniel, Buelow). Five NM EPSCoR graduate students will receive support in Years 3-5 to spend a semester at a different institution or national laboratory. At the host institution, the students will take courses and participate in research related to the research they are conducting at their home institution. Faculty at the host and home institutions will co-mentor the students and serve on their degree committees. NM EPSCoR will fund the exchange students' housing, travel and subsistence; the applicable EPSCoR research component will provide their assistantships.

Postdoctoral Fellowship Leadership Workshops (Daniel, Buelow). We will develop a week-long Postdoctoral Fellow Leadership Training workshop to be held in early January in Years 2 and 4 supporting fellows from Idaho, Nevada, and New Mexico. See the Post Doc Mentoring Plan for details.

Faculty Leadership and Professional Development Institute (Baca, McArthur). We will develop an Institute for 125 STEM faculty from NM community and Tribal colleges and non-research universities to improve undergraduate STEM instruction for diverse student populations. Each year, 25 faculty from 10 institutions will participate in a one-day workshop with subsequent on-line training. The faculty will acquire research-based pedagogical tools for today's adult learners and strategies for recruiting and retaining URM's in STEM fields, and they will create an online community of colleagues involved in professional development and research. NM EPSCoR research faculty will work with participating community college faculty to identify research projects that can be scaled to a community or Tribal college, and each year, they will form four Colleague Research teams to build the community colleges' capacity to offer authentic research experiences for their students. The WFD Team will facilitate connecting this effort with the STEMAP program. The ten institutions will each identify a faculty institutional coordinator to receive additional training; the coordinators will participate in the professional development workshop, develop a STEM Recruiting and Retention Plan for their campus, coordinate their institution's STEM professional development and research collaborations, and track STEM student retention.

Institute for Creative and Cultural Entrepreneurship (ICCE) (Loy, Montoya). We will build NM's workforce capacity for the emerging innovation economy in which entrepreneurship and creativity will be key drivers of economic success. Recent reports indicate a decline in entrepreneurial activity in the US[154] with NM falling into 35th place. Skill development is a key to entrepreneurial success[155] while access to social networks and technical resources increase entrepreneurial activity.[156-157] The ICCE will provide NM faculty (primarily URM) with skill development in key enterprise functions including opportunity analysis, marketing, finance, team building, and operations. ICCE events will cultivate a strong entrepreneurship network among attendees, faculty, mentors, and resource partners. ICCE will host five Institutes, training 180-200 entrepreneurs; selected Fellows will be matched with mentors for a 12-month period. Mentors and resource partners will include experienced entrepreneurs, financiers, market leaders, and scholars.

4.6 Cyberinfrastructure (CI) Plan. Team: NMEPSCoR: Mary Jo Daniel; NMSU: Sam Fernald, Caiti Steele; NMT: Michael Heagy, Frank Huang, Dana Ulmer-Scholle; UNM: **Karl Benedict**, Becky Bixby, **Julie Coonrod**; 5 graduate students.

Objectives. New Mexico's S&T Plan[4] calls for expansion of the state's knowledge economy through development of broadly accessible and usable data and information. Accordingly, we will develop CI that: (1) provides scientists, educators, and decision-makers with easy access to data, information, models, and synthetic data products required by and derived from EPSCoR research and STEM activities (e.g. remote sensing and other geospatial data products, tabular data, maps, analytic and visualization tools, and learning modules); (2) promotes broad discovery and use of EPSCoR data and information; and (3) supports improved statewide data and data visualization through virtual collaboration tools.

Background and Proposed Activities. Our plan builds on CI that was developed jointly with the New Mexico Resource Geographic Information System (housed at UNM) and supported by NM EPSCoR and state resources. Current CI capabilities include a tiered, services oriented architecture (left region of Fig. 7) with data management, processing, and client tiers designed for maximum flexibility and scalability. The CI plan focuses on: (1) improving the integrated data storage and modeling portal; (2) expanding our interoperability with national and international data networks; and (3) enhancing tools for collaboration.

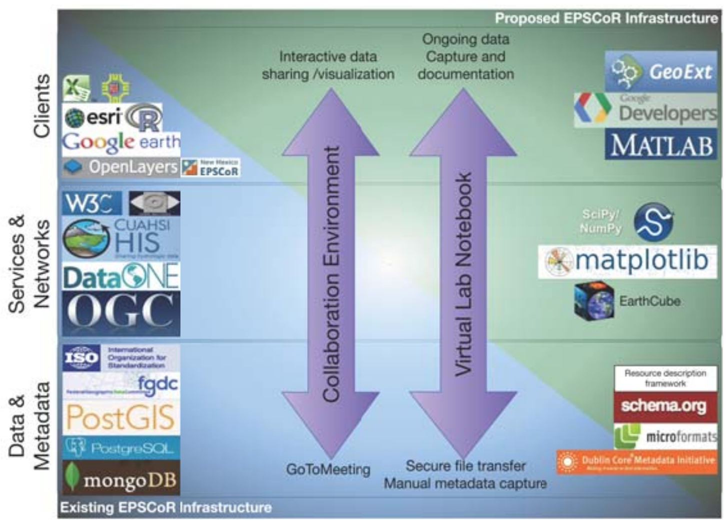

Figure 7. Existing CI (blue) provides the underlying framework for data storage, interoperability with select national networks, manual metadata capture and secure file transfer, analysis using tools like R and Google Earth, and collaboration via GoToMeeting. Proposed CI (green) adds new storage capacity, metadata management and semantic tools, interoperability solutions, and analytical tools that will enhance our capacity to share and support discovery of data and information, and collaborate more effectively via new interactive data sharing/visualization capabilities and a virtual lab notebook that will be used by science teams for data capture, documentation and sharing. The architecture is based on community and open visualization[158], data access[159], and metadata[160] standards and web service protocols[161] and can support a wide range of commercial and open source client applications that use these standards and protocols.

(1) Integrated Data Storage and Modeling Portal. We will enhance the Portal by enhancing the capacity and capabilities in all three tiers (right region of Fig. 7). This effort will include developing analytic services and client interfaces in close consultation with the research and education teams that will use them. We will also provide new capabilities for socio-economic modeling and analysis on the data platform of the Portal by deploying service interfaces that support interaction with dynamic system models (Section 4.3, Focus 6). In addition, we will acquire data to support the research in this proposal (i.e. spatially enabled socio-economic, energy use, and infrastructure data; environmental data; and geologic data). We will integrate these data into the project's data discovery and access system to improve research productivity, and we will document data products of the research teams and integrate them into the Portal. The Portal will include an education resources section that enables educators to easily upload, discover, and download learning modules and other resources.

To make our project data easier to extract, index, manage, and discover on the web, not only through interfaces such as the Google and Bing search engines but also through custom applications that are based upon semantic web[162] and similar technologies (e.g. the Schema.org[163]and other microformats[164]), we will evolve the current XML document-based data documentation model to include more information about data content. We will modify component services that deliver ISO metadata to enable delivery and assimilation of RDF[165] compatible content used in these linked data applications. We will expand the system's analytic capabilities to include server-side and client-side capabilities tools and services, the locus (server or client-side) depending up the computational and data requirements of a specific analysis.

(2) Interoperability with National and International Partners. We will maintain the strong interoperability capabilities of the current system by (i) continuing the Western Consortium (ID, NV, NM) CI Working

Group that identifies and promotes interoperability, visualization, provenance, and other standards, and (ii) expanding it by including additional support for web service protocols used by networks (e.g. DataONE, CUAHSI HIS), connecting to external geospatial server platforms (e.g. the NM Bureau of Geology at NMT, NMSU), and registering project data products with national (e.g. http://geo.data.gov) and international (e.g. GEOSS) component/service registries. For long-term archival storage and preservation, we will add project data products to LoboVault (UNM's Institutional Repository).
(3) Connectivity and Collaboration. We will build upon the current EPSCoR CI web meeting software (GoToMeeting) by developing complementary next generation data-centered collaboration capabilities, including an online analytic and visualization interface that enables distributed users to view a common collection of hosted data through a coupled interface. The collaboration system will complement an online lab notebook system in which preliminary data products and their associated metadata can be captured and shared within research teams, streamlining data ingest and publication through the data portal.

Infrastructure and Activities Supported. EPSCoR will provide critical storage capacity, software (i.e., an online lab notebook system, enhanced web meeting software), and software developer time.
Transformative Nature of CI Activities. The new Portal, expanded interoperability, analytical capabilities, and collaboration tools will make it easier for scientists, educators and the public to discover, acquire, and use data, information and learning modules developed and acquired by NM EPSCoR. These capabilities and our commitment to open source software and data sharing and to support knowledge transfer and discovery will position us to contribute to and benefit from future CI development.

4.7 External Engagement Plan

EPSCoR seeks to increase public understanding of NM's potential for sustainable energy development, engage more New Mexicans in STEM-related activities and education, and disseminate EPSCoR results.

4.7.1 Informal Science Education (ISE) Network (Walter, NM Museum of Natural History and Science (NMMNHS))**.** We will establish the NM ISE Network (NM ISE Net) to link research and informal education institutions (e.g., museums, professional associations, public media, cultural centers) with one another to build capacity for informal science education, with a focus on acquiring and sharing knowledge about the research being performed by EPSCoR scientists. Several NSF funded projects have shown networks are effective in building the capacity of their member institutions to develop programs for diverse communities to increase their understanding of research and science learning. One NSF network project, Portal to the Public (NSF-063921) included Explora!, a NM Science museum that will be a key partner in NM ISE Net. The NM ISE Net will build on a foundation established through an RII3 ISE IWG. In Years 1-4 of this proposal, NM ISE Net partners will meet three times per year to build capacity around exhibit and program development. In Year 3, the project will draw upon experience gained through Explora!'s participation in the Portal to the Public to develop a workshop for EPSCoR researchers to develop skills as effective science communicators and to build relationships between researchers and ISE Net members that will facilitate future work. In Years 3–5, the project will award grants to NM ISE Net members to develop programs to communicate EPSCoR science to the public.

4.7.2 Museum Exhibitions (Walter, NMMNHS; Walther, National Museum of Nuclear Science and History; Lopez, Explora!). The three museums will work together to create three distinctive exhibitions that interpret NM EPSCoR research, in Years 3 and 5. Exhibits will be complementary and will be designed so components of them can travel to NM ISE Net members across NM. Museums will utilize outcomes from the Exploratorium's "Best Practices in Science Exhibition Development" (NSF-0227627) to inform their process and will be supported by on-going evaluation.

4.7.3 Town Hall Meeting (Daniel and Michener, EPSCoR State Office). In Year 5, NM EPSCoR, in collaboration with New Mexico First, will organize a two-day Town Hall meeting to provide a forum for scientists, educators, policy makers and business people to discuss outcomes of NM EPSCoR research. The meeting organizers will collaborate with NM EPSCoR researchers to develop a Background Research Paper for participants who will use it as a reference guide and learning tool. Participants from the public, the corps of NM EPSCoR scientists and economists, government, and business leaders will engage in highly structured small group discussions as well as plenary sessions to develop recommendations for how NM can realize its potential for sustainable energy development. After the meeting, New Mexico First will produce a final report to use in presentations to community leaders, to advise policy-makers, and to inform the broader public of the Town Hall results, collaboratively developing actionable recommendations with stakeholders who represent diverse perspectives.

4.7.4 Communication Activities and Technologies (Daniel and Michener, EPSCoR State Office)**.** The EPSCoR website (http://nmepscor.org) and an electronic newsletter will communicate project activities, events, and discoveries to the public and among project personnel. The communications coordinator will also use social media (e.g. Facebook, Twitter) to communicate project activities and will create project videos for the NM EPSCoR YouTube channel (http://www.youtube.com/user/NewMexicoEPSCoR). She will work with public media outlets including newspapers, radio, and NM PBS to develop opportunities to share information about EPSCoR research. We will also hold regular (i.e., monthly to quarterly) face-to-face visits and videoconferences for the various teams, and an annual workshop for all participants (including industry and regulatory agencies) to coordinate work among institutions and investigators.

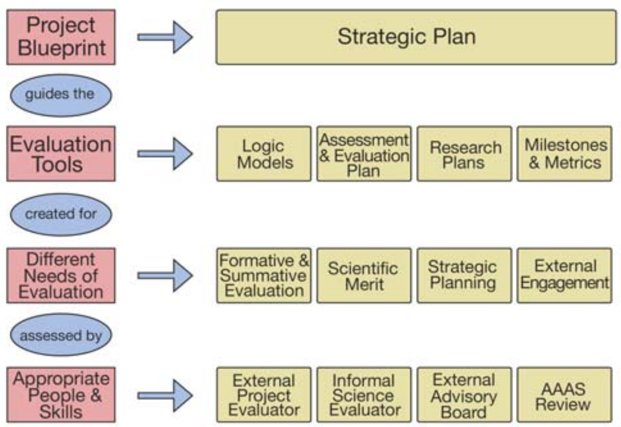

Figure 8. The assessment and evaluation (A&E) process. Within 90 days of the award, a 1-2 day facilitated workshop will lead to a Strategic Plan that is based on project objectives and activities. The Strategic Plan serves as the Project Blueprint and guides the development of evaluation tools including: a project logic model that starts with inputs such as funding for facilities, equipment, and human resources as well as contributions from our affiliated universities, colleges, business and industry partners, and governmental and non-governmental organizations; a detailed A&E plan; research plans; and milestones and metrics for all components of the project. The evaluation tools are created to provide the basis for the different needs for evaluation including: formative and summative evaluation, scientific merit, annual strategic planning, and external engagement. A&E activities are performed by: the external project evaluator, the informal science evaluator, the External Advisory Board, and the AAAS review team.

4.8. Assessment and Evaluation Plan

Success of NM EPSCoR programs will be evaluated using a comprehensive assessment plan with both quantitative and qualitative methods (Fig. 8). The plan includes independent external experts who will monitor progress and regularly review and report on each of the programs to the State Director. The NM EPSCoR Management Team (MT) will ensure the program components are collecting the data needed by EPSCoR and the external experts to assess and evaluate the impacts and achievements of the award. Report recommendations will be used by the MT during their annual review of the strategic plan.

The overarching goal of RII4 is to create sustainable improvements in the research infrastructure that leads to R&D national competitiveness. *Energize New Mexico* proposes to achieve this goal through programs in research, workforce development, informal science and external engagement. To assess how, and to what extent, each of these programs, and the intersection of these programs, is moving NM towards this overarching goal, the team of experts will assess key evaluation questions, such as: Are NM researchers becoming more competitive for R&D funding?; Is the research generating knowledge that is being disseminated and applied for the good of NM?; Are collaborations being fostered that advance research, innovation and benefit society?; Is the program broadening participation of people, institutions and organizations in STEM?; Does the state R&D community capitalize on EPSCoR to further develop experimental programs?; and Are the programs expanding the scientific literacy of all New Mexicans and informing them of the importance of STEM research and education?

The evaluation and assessment plan includes four external evaluation efforts covering the: Research Program (External Advisory Board (EAB)); Strategic Planning (AAAS Research Competiveness Program); Informal Science (Dr. Elsa Bailey); and the External Project Evaluator (Kirk Minnick) who will focus on assessing progress of the award towards meeting External Engagement, Workforce Development and intra- and inter-jurisdictional collaboration goals.

4.8.1 External Advisory Board. The EAB (Section 4.10) will meet annually for 1.5-2 days to advise the Project Director and MT on recommendations for improving all EPSCoR program components.

4.8.2 AAAS Panel. AAAS will perform a strategic planning review. The AAAS panel includes an AAAS facilitator (Mark Milutinovich) and up to six experts in research, CI, external engagement, education, diversity, and workforce development. AAAS principally helps NM EPSCoR plan future activities in light of past progress and emerging opportunities and needs.

4.8.3 Informal Science. Elsa Bailey Consulting, Inc., will provide assessment expertise in qualitative evaluation to the NMMNHS, Explora!, and the NMNSH in their work to create exhibitions that interpret EPSCoR research. Dr. Bailey will provide a Front-end Study to inform exhibition development, reveal critical gaps in visitor knowledge, and define messages to be conveyed and methods to be used. She will evaluate each exhibition after installation and she will train museum staff to evaluate future exhibitions. Dr. Bailey will develop surveys and other data collection instruments with the Museums and will review the resulting data with museum staff.

4.8.4 External Project Evaluator. Kirk Minnick, Minnick & Associates, Inc., will oversee the overall project evaluation. Formative data will be collected in several ways. Participant surveys will provide "customer satisfaction" feedback on project activities, and will help identify participant needs for future events/activities. Most surveys are administered online through email invitations to participants. Evaluator observations during project activities including, but not limited to, teacher and faculty workshops, NSF Day, annual meetings and strategic planning meetings, will provide the context for participant survey feedback and can help activity leaders make real-time changes during the activity. Activity Evaluation reports based on formative data will be provided to the Associate Director within 30 days of collection to inform and improve the next project event/activity.

Strategies by Component	Output Metrics	Year 1	Year 2	Year 3	Year 4	Year 5	Outcomes and [Metrics]
Research		1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	Faculty productivity increases (10% increase/yr) [publications/yr]; Faculty more collaborative with other faculty and industry [#s/yr, incr. %/yr]; % energy in NM coming from 5 research areas [%, incr. %/yr]
Procure and install facilities and equipment (90%/yr)	% installed						
Faculty start-ups (4 total, years 1-3)	# hires/yr						
Seed awards (2, yr 1; 2, yr 3; 1, yr 4; 3, yr 5)	# awards/yr						
I-IWGs (3/yr, yrs 2-5; 24-36 participants/yr)	#s/yr						
Diversity		1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	Increase (5%/yr) female, URM, & institution participation in RII [%, % incr./yr]
0.5 FTE Diversity Coordinator	FTE/yr						
Researcher Mentoring and Training Plan	completion						
Diversity IWG (annually; 8-12 participants/yr)	#s/yr						
Strategic WFD program recruitment (50% F, URM) Sect. 4.5	% F, URM						
Workforce Development		1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	More qualified students/postdocs (retention in STEM, jobs) [%, % job succ.]; Success in business start-ups (10% ICCE participants) [#/yr, % succ.]
GUTC (200 middle school students/yr; 15 teachers/yr)	#s/yr						
STEMAP (10 PUI undergraduates/yr)	#s/yr						
Graduate student externships (5/yr; yrs 3, 4, 5)	#s/yr						
Postdoctoral fellow leadership training (21/yr; yrs 2, 4)	#s/yr						
Fac. leadership and prof. dev. Inst. (25 faculty/yr)	#s/yr						
ICCE (36-40 entrepreneurs/yr)	#s/yr						
Cyberinfrastructure		1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	Use/adoption of CI tools by 90% RII students and faculty [#/yr, % inc./yr]
Enhance data and modeling portal (add storage/services)	volume, #s/yr						
Interoperability (new web services, indexed/archived data)	#s/yr						
Collaboration (web conferences, Virtual Notebook users)	#s/yr						
External Engagement		1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	New Mexicans more scientifically literate [surveys]
ISE Network (75% of ISE institutions meet 3X yr in yrs 1-4)	#members/yr						
ISE museum exhibits (yrs 3, 5; 750,000+ visitors by yr 5)	#, visitors						
Town Hall meeting (150-200 citizens, policy)	#						
Communication (# people reached by media)	#s/yr						
Assessment and Evaluation		1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	Quality of participant experience in RII programs increases annually [surveys]
External Advisory Board (1 evaluation/yr)	#						
AAAS Panel Review (1 strategic planning session)	#						
Informal science education A&E (1 A&E session/yr)	#						
External A&E (all programs evaluated)	% completed						
Sustainabilty		1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	Faculty more competitive for R&D funds (10%/yr) [(awards, $)/yr]
STEM K-12 Prof. Dev. (20 teachers/yr, yrs 2-5)	#						
Proposals (avg. of 8/yr; 35% success rate)	#, % success						
NSF Day (1 mtg. in yr 3) and number participants	completion, #						

Table B. Subset of strategies, output metrics, milestones, and example key outcomes and metrics by component; additional strategies, metrics, milestones and outcomes to be based on strategic planning effort and resulting logic model.

Progress/summative data will be collected from multiple sources. Project data on participants, proposals, awards, presentations, publications, collaborations (individual and institutions), products, and patents are collected through a secure web-based online portal developed for project participants to report EPSCoR activities. These data will be used for project monitoring, to provide some of the basic output and outcome measures used in tracking progress and summative results, to assess the success of researchers in competing for funding, and to track faculty and student outcomes (Table B).

Research Competitiveness: The NSF awards database will provide data for assessing the competitiveness of current and prior RII researchers in disciplinary and multidisciplinary research programs by tracking and annually reporting the award dollars coming into the state by year.

Research Impact: The Web of Science database provides various citation metrics to assess changes in reputation of current and prior RII participants as a result of publications produced during this award, as well as the collaborations that have been established both in NM and elsewhere.

Workforce Development: Evaluation includes tracking the numbers and demographics of participants. Formative and process data will be included from the activity evaluation reports. Data will also be collected from participants and secondary sources to assess how well the various strategies lead to a larger, better trained, and more diverse STEM workforce. Level 1 participants (those with significant and sustained involvement in NM EPSCoR programs) will be tracked to determine long-term impacts on participants, including tracking whether undergraduates involved in research pursue graduate degrees in STEM and their level of success.

External Engagement: Evaluation will include the numbers and demographics of people and institutions engaged in project activities, number of web hits to the NM EPSCoR web site and data portal, and the museum exhibit assessments conducted by Dr. Bailey.

Strategic Plan: A Strategic Plan developed within three months of the award will be revisited annually.

Reporting: Annual evaluation reports will summarize the tracking of project outputs and outcomes, as well as findings and recommendations. They will include an assessment of the individual RII components, strategies and overall progress towards the long-term goals of NM EPSCoR. Data will be presented and analyzed longitudinally by year and cumulatively, so that the status of each component can be viewed. The degree to which the RII investment in infrastructure and activities contributed to these outputs will be an integral part of the annual assessment. Reports from the EAB, AAAS, and external evaluators will be provided to the State Director, who will be responsible for distribution to NSF, MT and SEC.

4.9 Sustainability Plan

Sustainability was a factor used to select the research, CI, and human resources components of this proposal and was based on relevance to the State S&T Plan, university research and economic development priorities, and key NSF funding portfolios as well as other research sponsors and industry. VPRs and Deans from the PhD-granting institutions have committed support for faculty lines, facilities, and equipment. Formal and informal science education institutions have committed significant cost-share to support project activities and are forming new partnerships so that programs can be sustained.

4.9.1 Education and Human Resources Development. Our education and human resources development goals are aligned with the State S&T Plan and are designed to create and enhance inter-institutional collaborations such as federal lab-university, university-university, and informal science education partnerships. Objectives are to: (1) hire and retain four critically needed faculty; (2) support and mentor 3+ post docs (see post doctoral mentoring plan), 53 graduate students who will be associated with the six teams and mentored by two or more faculty members from the team as well as being supported in a graduate student externship exchange program, 27 undergraduate students from research institutions, and 50 undergraduate students from primarily undergraduate institutions who will participate and be mentored as part of their participation in STEMAP; (3) engage 1,000 middle school students in GUTC; and (4) develop the research potential and leadership skills of community college and Tribal college faculty via the Faculty Research Development Program (20 faculty) and the Faculty Leadership Academy (125 faculty). The ICCE will position 180-200 faculty and other entrepreneurs to seek patents and build new businesses based on scientific and technological innovation and discovery.

Other education and human resource development activities include building the ISE Network, supporting public outreach through museum exhibits reaching at least 750,000 members of the public annually, engaging approximately 150-200 citizens in a New Mexico First Town Hall during Year 5, and the activities described below.

STEM Professional Development for K-12 Teachers (Walter, New Mexico Museum of Natural History and Science (NMMNHS). NM EPSCoR will partner with ISE institutions in building sustainability for STEM workforce development. In Year 1, educators from all partner institutions of the NM ISE Network (Section 4.7) will participate in an Exploratorium led workshop on effective development strategies that will prepare teachers to successfully interpret NM EPSCoR research for students. Each subsequent year, NM ISE Net institutions will hold a weeklong Summer Teacher Institute in a different part of the state for 20 teachers. Institute content will focus on topics related to energy development in NM. Matching activities to state standards and ongoing coaching from the Exploratorium will increase the effectiveness of these professional development activities. The Education Coordinator will facilitate quarterly videoconferences to support implementation and additional content. Alumni of the workshop will meet at the fall State Science Teachers' Conference and in the spring to share results.

4.9.2 Post RII Track-1 Extramural Funding. The new hires, facilities and equipment, and collaborative teams will significantly bolster research competitiveness. EPSCoR will also support NSF Day in Year 3 and I-IWGs that will promote new research activities. Our minimum targets for the five-year period are: one Science and Technology Center proposal, eight proposals to programs in NSF's Clean Energy portfolio, eight proposals to programs in the NSF SEES portfolio, two proposals to appropriate programs in the Geosciences/Hydrologic Sciences, one proposal to Dynamics of Coupled Natural and Human Systems, one MRI proposal, six EHR proposals and two CAREER proposals. Additional proposals will be submitted to the Department of Energy's Water Power Program and the DOE-EERE Biomass programs, ARPA-E, USDA, USDA, NIH (NIEHS), and EPA (STAR), as well as business and industrial entities.

Cyberinfrastructure developed under the current proposal will be integrated with the long-term geospatial data archive maintained by EDAC for the State of NM with ongoing maintenance of the services being funded through a combination of base funding obtained from the NM Legislature and proposals submitted to external funding sources such as NASA, NSF (CiF21), and other agencies.

NSF Day (Daniel and Michener, EPSCoR State Office). NSF Day, a one-day workshop held in collaboration with the NSF, will be scheduled in Year 3 of the project. Program Directors from all NSF Directorates will meet with faculty from all NM colleges and universities to discuss relevant funding opportunities and strategies for seeking funding from large NSF-wide and cross-cutting programs.

4.10 Management Plan.

NM EPSCoR will use a team-based management structure (Fig. 9) that is designed to ensure accountability, assign responsibility, promote engagement, include diverse participants, and facilitate communication and coordination among the project components.

Council of University Presidents (CUP). The CUP, comprised of presidents of the three research and four regional universities, oversees activities of the State EPSCoR Committee (SEC), appoints SEC members, promotes EPSCoR activities within NM, and approves any changes to the bylaws.

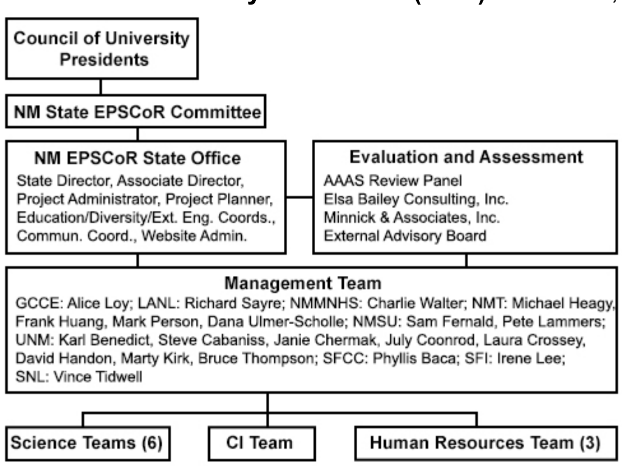

Figure 9. NM EPSCoR organizational chart.

State EPSCoR Committee. The SEC meets twice a year and serves as the primary governing body for NM EPSCoR. Its diverse members (9 F, 6 M, 4 URM) represent key constituencies in the state: the private sector (4), universities (8), national laboratories (3), the State Legislature (3), and Governor's Office (1). The SEC chooses the focus areas for NM EPSCoR and enhances the state's research infrastructure through partnerships with universities, national laboratories, and industry; promotes research and collaboration among NM universities; increases opportunities for STEM education and training in NM; develops the workforce of scientists and engineers in the state; and promotes NM economic development.

Management Team (MT). The MT meets quarterly via phone or video-conferencing (VTC) and provides overall direction and guidance to all NM EPSCoR science, diversity and capacity-building activities. Its members (13 WM, 5 WF, 1 HF, 1 AF, 1 AM) represent the program focal areas, partnering colleges and universities, national laboratories, and affiliated institutions. The MT ensures the coordinated implementation of each focal area and its integration with the overall program, identifies implementation problems and recommends solutions, identifies emerging opportunities, and assists in collecting data and information for project reports. In addition, the MT reviews applications for resources and makes recommendations for seed funding to the Project Director.

Assessment and Evaluation (A&E). The AAAS review team will assist NM EPSCoR in strategic planning and implementation; two independent evaluation firms (Section 4.8) collect and report A&E information; and an External Advisory Board (EAB) reviews annual progress and provides guidance for the coming year. The EAB is a diverse and distinguished group consisting of Rose Ann Cattolico (U. Washington; biofuels research, education and diversity); Marianna Adams (Audience Focus, Inc.; informal science education, evaluation and assessment), Christopher Scott (U. Arizona; sustainability science and policy), Joyce Malyn-Smith (Education Development Center, Inc.; STEM and workforce development); Rita Teutonico (Utah State; Utah State EPSCoR Director, biotechnology research, education, and economic development); and Thomas Zawodzinski (U. Tennessee; chemistry and energy research).

NM EPSCoR State Office Team. The Project Director (PD) (William Michener) serves as Principal Investigator (PI) on the NSF award and provides day-to-day management of the program from the NM EPSCoR Office at UNM, which serves as the fiduciary agent and issues subcontracts to other participating institutions. The PD reports to the SEC and CUP, represents NM EPSCoR, participates in MT meetings and reviews, and works closely with the Science and CI teams.

The Associate Director (AD) (Mary Jo Daniel) assists the PD with overall project management and communications with state and federal agencies. The AD submits required reports to NSF, schedules and participates in MT meetings and works closely with the human resources team. The AD identifies funding opportunities and facilitates research and external engagement, supervises the NM EPSCoR Office staff, prepares budgets and financial reports, and coordinates evaluation and assessment activities.

A Project Administrator (PA) (Tracy Hart) and Senior Planner (Megan Gallegos) are responsible for daily office operations, business transactions, and financial accounting. Additional staff members include a website administrator, communications, diversity, and education and outreach coordinators.

Project Teams. Teams corresponding to: (1) Science; (2) CI; and (3) Human Resources meet monthly (via phone or VTC) to plan, communicate progress, and coordinate activities according to the project's Strategic Plan. Outcomes of monthly Project Team meetings are included in the quarterly MT meeting agendas. All participants including students, scientists and educators attend an annual 1-2 day All Hands Meeting to review progress and set goals for the following year. Additional communication occurs via the web portal, newsletter, Twitter, and Facebook.

Succession Plan. When the PD position becomes vacant, the NM EPSCoR by-laws require the SEC to conduct an open search for a successor. The MT and Project Teams provide a pool of replacements for senior-level EPSCoR vacancies. All vacancies are filled in accordance with UNM Human Resource procedures, including an open, competitive search by a diverse hiring team. Major programs have at least two leaders (listed throughout the document) to ensure continuous leadership through the project.

4.10.1 Jurisdictional and Other Support

Cost-share (20%) is provided by university collaborators and other partners. EPSCoR is leveraging support from: UNM's Cancer Research Facility and Autonomous Sensor Facility; NMSU's Bioalgal Test Bed and Chemical Analysis and Instrumentation Laboratory; ENMU's Agricultural Research Facility in Portales; and the Center for Integrated Nanotechnology; as well as the museums and private industry.

4.10.2 Summary Table of Requested NSF Support

Awardees	Year 1 ($K)	Year 2 ($K)	Year 3 ($K)	Year 4 ($K)	Year 5 ($K)	Total ($K)	% of Total
U. New Mexico (Lead)*	2,077	1,968	2,305	2,419	2,442	11,212	56.0%
Eastern New Mexico University	115	116	92	7	3	332	1.7%
Explora!	0	0	0	26	19	45	0.2%
Global Center for Cultural Entrepreneurship	46	116	97	93	0	353	1.8%
National Museum of Nuclear Science and History	0	0	0	7	37	45	0.2%
New Mexico Museum of Natural History and Science	62	60	77	43	28	269	1.4%
New Mexico State University	592	646	587	574	608	3,007	15.0%
New Mexico Tech	928	914	662	650	683	3,837	19.2%
Santa Fe Community College	69	69	69	69	69	344	1.7%
Santa Fe Institute	111	111	111	111	111	555	2.8%
Total	4,000	4,000	4,000	4,000	4,000	20,000	100%

Budget Table A. Research Support Levels ($K). Note: *Includes AAAS, Elsa Bailey & Associates, Minnick & Associates, New Mexico First, Seed Awards and IWGs.