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TITLE: SUFFICIENCY FROM SCARCITY: PRAGMATIC HOLISM FOR SUSTAINABILITY OF THE WATER, ENERGY, ENVIRONMENT, INFORMATION NEXUS

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Sufficiency from scarcity
Pragmatic holism for sustainability of the water, energy, environment, information nexus

A white paper for development of the New Mexico EPSCoR RII IV proposal

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In the face of increasing resources scarcity and climate change what strategies can result in energy and water sufficiency with societal and environmental health?

1. INTRODUCTION AND BACKGROUND

The human race continues to stress the natural environment. Expanding populations, exploitation of resources and the resulting externalities intensify the strain on the natural system at the local, regional and global scales. A first step in reducing system stress is a comprehensive understanding of the intricacies and trade-offs between human choices and the viability of the natural and environmental systems. To develop this understanding, and the tools to evaluate choices and policies, the system in its entirety needs to be considered. Fundamentally, all organisms, whether biological or social, can survive only by their prudent and appropriate processing of energy and information. Arguably, humans have been able to thrive precisely because of their success in these two spheres. Our best approach to addressing the current stress on our environment must therefore be based on our understanding and creative deployment of ideas tied to energy and information.

This project develops a whole system approach to resource sufficiency with researchable questions and implementable outcomes. The approach could be termed pragmatic holism, a complete picture of both the environment and human society, focusing on the system that targets key water, information and energy resources, key environmental quality and societal outcomes. In terms of natural resource use, the approach draws on new science of understanding availability, creation, delivery and consumption of energy in light of the simultaneous interactions and emerging constraints due to population growth; the science of information in monitoring, analyzing, predicting, and influencing the behavior of the environment and of humans; societal choices concerning current economic activity and future sustainability goals; and climate change. Understanding is reached by including the full spectrum of disciplines in the research, balancing natural science and social science within a unifying framework.

Water and energy scarcity are often linked problems and expanding human activity is a main driver. Improved quality of life and increased consumption of energy and water intensive goods have driven the ever-increasing demand for energy and water resources. These activities have not come without cost as associated externalities result in increased pollution that impacts land, water, and atmosphere. Efficient policies that include an objective of sustainability need not only recognize the impacts on society and the environment, but also need to be developed in a manner that incorporates the social costs into the market transactions. In order to do that superior understanding of the component pieces of the problem is necessary as are the interactions and feedback between the integrated component pieces. This would provide a tool that can inform policy and can provide analysis about the tradeoffs between consumption of resources, quality of life, and environmental and human health. This allows an assessment methodology of actions and choices and their impact on the system. What policies provide complementarity between environmental and economic health? What policies provide a balance between current consumption and waste or between today's resource extraction and pollution, but result in negative feedback loops that greatly restrict future generations' choice sets. Or, conversely, what actions that while protecting the future result in a portion of the current population having a choice set that is so reduced that the current economic health and well-being is degraded to a point deemed unacceptable by the public? In what cases, regardless of policy choice, is sustainability unachievable? And of major importance across all of these types of questions: "*What are the unintended consequences of policy*?" In short, we seek to develop a tool that allows us to consider the impact of choices on the natural and human systems temporally and spatially.

The goal of this project is to develop an integrated system understanding and when possible tangible paths to a sustainable future of positive feedback loops. This project proposes a whole systems approach that turns the consumption and waste equation on its head and looks at the energy water environment information nexus to find sufficiency by reducing waste, increasing efficiency by comprehending and appreciating the reasons for inefficiency whether technological or societal and working with the environment instead of against it, and offering computational engines for human societies to evaluate the sustainability of their lifestyle choices. Key targeted elements that form the basis of this pragmatic whole systems approach will be found through scientific advances.

New Mexico is a crucible of water scarcity and traditional energy resource abundance and is particularly well suited to explore the opportunities and intricacies of the water energy environment nexus. Nowhere is water scarcity more readily apparent than arid regions of the world like New Mexico. The American Southwest is particularly vulnerable to water scarcity due to arid region low precipitation and frequent drought on top of increasing demand due to increasing population. Traditional energy sources are relatively abundant - New Mexico ranks as one of the top producers of energy resources in the U.S. (EIA 2011), but the cumulative effect of energy resource production and the subsequent electricity production, contribute to the decline of environmental quality. A shift to renewable energy, while environmentally desirable, is accompanied by potentially higher costs, increased demand for water, and potentially shortages. This exemplifies the challenge of potential sustainable strategies: current benefits from the status quo and future costs, versus current costs of change and future benefits. The economic health of the state is tied to both of these resources, as is the security of the population and the environment. However, the focus on the energy/water nexus and the resource emphasis is very different depending on the locale.

<u>Energy driver with water byproduct, environmental impacts - Four corners uranium, oil and gas, and electricity</u>

In the Four Corners' San Juan Basin, fossil fuel extraction and electricity production is the focus and are main economic drivers for the entire state. The basin is home to the largest conventional, proved natural gas field in the US, as well as substantially large unconventional plays (e.g., New Mexico is the leading coalbed methane producer in the US[1]). While the fields are declining, production in the area has the potential to continue for several decades. In addition, the Grants Uranium District was one of the most active uranium mining areas in the US from the 1950's through the 1980s and contributed to economic growth in the state. While not currently an active mining area, New Mexico ranks second in recoverable reserves of U_3O_8 in the US and there has been an increased interest in reviving mining in the region. This brings economic opportunities to the area, but also considerations about water needs for production and/or water as a mining by-product, depending on the mining technique employed. In addition, the history of uranium mining in the area and the long-term consequences to the local population, results in an almost visceral reaction to the prospect of new mining activity.

[1] New Mexico Energy Facts from www.instituteforenergyresearch.org (last accesed 10/18/2011)

As with uranium, oil and gas production water is necessary for drilling and completion and may be a by-product of production and so the nexus focuses on the production of energy with water as a required input. In addition, the energy exploitation activities include externalities. Water quality can be of concern for natural gas production, electricity generation, and uranium mining. Methane emissions are also a by-product of natural gas production. Finally, the burning of fossil fuels contributes to greenhouse gas (GHG) emissions, which impact climate change. Curtailing all current and possible future production of energy resources in these areas would help sustain the water resources, but that plan would result in a substantial reduction in state revenues and a declining standard of living.

New Mexico currently has five operating coalmines and ranks 12th in production in the US[2] and over 70% of New Mexico's electricity production is from coal-fired generators.[3] Coal-fired generators have, historically, utilized large quantities of coal and water. Feeley et al (2005) estimate a 500 mega-watt power plant burns about 250 tons of coal per hour and requires over 12 million gallons of water for cooling and processing. As with oil and gas coal mining and electricity generation are substantial contributors to the state's economy. A number of uncertainties are present for coal-fired generators, including regulation and water availability.

Fossil fuel and uranium resources are depletable resources and cannot be viewed as sustainable, but they are a major contributor to the current State's economy and will be for the foreseeable future. They can serve as a bridge between the current energy economy and a potentially sustainable energy economy of the future. A shift to renewable energy, while environmentally desirable, is accompanied by potentially higher costs, increased demand for water, and potentially shortages. This exemplifies the challenge of potential sustainable strategies: current benefits from the status quo and future costs, versus current costs of change and future benefits. A whole systems approach can provide valuable information for policy makers by appropriately considering the diverse aspects of this problem and disentangling some of the complexities.

Environment and water driver with energy co-product - Forest and rangeland woody vegetation

Management of forests and wooded rangelands in New Mexico by reducing tree density promises to increase stream runoff from high elevation forests and increase vegetation and animal community health and diversity in more arid lower elevation forests and wooded rangelands. Runoff increases from tree removal are most likely to occur where mean annual precipitation exceeds 400 mm/year. This increased runoff can be traced to reduced transpiration from trees. Forests have become very dense after more than 100 years of fire prevention and after 30 years of little logging, so forest health and ecosystem function can be improved by reducing tree density. Benefits of thinning in addition to water yield increases are reduced fire danger, increased ground cover, improved wildlife habitat, and increased plant and animal diversity. As with high elevation forests, piñon and juniper woodlands at lower elevations have been increasing in density and extent after more than a century of fire suppression. Ecosystem health of grasslands within the woodlands can be improved by reducing tree density. Benefits are greater soil moisture, more grass production, more varied vegetation and wildlife species, and greater wildlife populations and livestock production.

Cellulosic biofuel may be an important by product of tree thinning for water and ecosystem health. There are at least 9 million acres of piñon-juniper habitat in New Mexico that are suitable for thinning. There are another multi-million acres of high elevation forest that require thinning. Unlike other biofuels that need to be grown, the cellulose merely needs to be harvested, in this case by thinning programs to

[2] Coal from www.eia.gov. (last accessed 10/18/2011).
[3] New Mexico Energy Facts from www.instituteforenergyresearch.org (last accesed 10/18/2011)

improve watershed health. Because of the broad spatial extent of the woody material, an important obstacle to be overcome is the efficient transport of woody material to cellulosic biofuel processing sites or design of moveable biofuel processing facilities. Historically, New Mexico had small regional sawmills that processed timber into wood products, and this same distributed small scale processing may be viable for cellulosic biofuel production with timber harvest. The whole system analysis of forest thinning including water, environment, and biofuel outputs may show that the activity is a new positive gain for economy and society in New Mexico.

Water Energy Hybrid - River valley irrigation water for agriculture energy and environment

Enhanced water management in river valleys of New Mexico could generate net increases in energy by maximizing the total gravitation and photosynthetic potential of the water. Most river valleys of New Mexico are occupied by agriculture supported by gravity driven water distribution across relict floodplains. Unlike most energy production that needs to expend energy to bring water into the process, gravity feed water systems are energy positive. Systems both ancient and recent have been developed to harness the river power. These include small-scale acequias, which are traditional water structures and management systems in use in New Mexico for over 400 years. Acequias have been exactingly constructed to maximize water distribution using only gravity flow. Larger scale reservoirs and irrigation networks have been installed since the early 1900's. An example is the paired system of Elephant Butte Dam that generates hydroelectric power and Caballo Reservoir that stores the fluctuating flows from Elephant Butte Reservoir and enables steady flow distribution into downstream gravity flow irrigation systems.

Whole system approaches to water and energy management may enable increased overall energy production by taking advantage of the stored water potential energy. Microhydropower units now being invented for installation on small irrigation canals, promise to increase total hydroelectric production from the irrigation systems of northern and southern New Mexico. New Mexico water law does not currently dictate conjunctive use, yet integrated management of surface water and groundwater is vital to maintain connected rivers and shallow aquifers for sustainable gravity fed water distribution. The use of inland brackish groundwater to offset freshwater use for agriculture can be a new water source that prolongs river aquifer connection and increases energy and crop production while also sustaining aquatic ecosystem health. Crops suitable for saline water irrigation can reduce the need for fresh water. Crops that produce oil seed or ethanol promise to utilize photosynthesis enabled by irrigation water to produce energy. Only through whole system implementation and analysis will it be possible to show the energy water environment benefits and tradeoffs of energy positive irrigated valley water.

Global Climate Change

The impact of climate change will, most likely, be regionally diverse. In New Mexico, as with the energy/water nexus, the impacts may be regional specific. Again, this adds one more layer to the already complex and heterogeneous system described above. In New Mexico, precipitation and temperature patterns may be altered, resulting in changes not only in water availability, but also in traditional growing patterns, environmental and human health. The severity of change and the impact on the state may depend on the actions taken to reduce anthropogenic greenhouse gas (GHG) emissions that contribute to climate change and the success of those actions. In 2000 New Mexico accounted for about 1.2% of the total US GHG emissions; produced over 83 million metric tons of gross CO_2 equivalent (NMED 2006). Over 80% of the emissions were from fossil fuel combustion and 13% from methane releases from oil and gas wells (NMED 2006). This highlights the trade-offs between current economic viability and potential future environmental and economic degradation. Exacerbating the problem is the fact that GHG pollutants are transboundary and local actions do not necessarily result in local benefits.

2. RESEARCH QUESTIONS AND METHODOLOGY

2.a. Research questions

The future of New Mexico potentially will be shaped by the choices made, the limits pushed and the constraints that bind. Population growth that outpaces the national average; increased demands on increasingly scarce water resources and the subsequent impacts on the environmental system; energy choices; and temporal and spatial trade-offs result in a system that is increasingly stressed. A systems approach allows us to develop broad sets of research questions that focus in the larger picture as described in section 1, starting with our central research question:

"In the face of increasing resources scarcity *and climate change what strategies can result in energy and water sufficiency with societal and environmental health?"*

Because of the integration of different parts of the system, the feedback loops (both positive and negative) that are present, the complexity of the overall problem, and, perhaps different objectives across the region, a "science as usual" approach that focuses on an individual aspect of the problem, or a field-specific focus will not provide the answers necessary to develop sustainable strategies. An integrated systems approach that considers the complete energy-water nexus from a life cycle approach, while focusing on the desired societal outcomes and environmental impacts, allows an informed assessment of strategies. The systems approach allows us to build a framework that provides analytic capabilities at various levels and with different focuses.

An assessment of the Four Corners region that models oil, natural gas, coal, and uranium production and water use and ties those models to human behavior and environmental health would inform policy as to potential future outcomes. An assessment of forest and rangeland management plans to assess the potential to improve rangeland and watershed health and provide economic benefits through the utilizing cellulosic biomass that traditionally may have been a waste product, but could be a by-product of forest management would also inform policy. Impact on agriculture across these areas, impact on local economies, impact on environmental health, as well as contribution from unique cultural communities within these diverse New Mexico areas can be assessed. The Native American communities of the Four Corners and the Acequia communities in the forest, range-, and grasslands are of interest, as are all rural areas and urban areas. What are the impacts on these culturally diverse communities when various strategies are considered for the energy/water problems that abound in the state?

The research approach informs stakeholders and policy makers. It can draw on existing data and research networks and provide a new, unique use of existing data and infrastructure. It would require the development of infrastructure for additional data needs, and it would require an information structure for existing and future data. We develop research themes based on the two aspects of the energy/water nexus discussed above.

2.a.1. Integrated systems modeling, scenario and action research questions with water as the driver and energy as a potential by-product of management.

In the southwest, water resources are scarce and will become relatively more scarce as extraction rates exceed recharge resulting in an unsustainable path. Environmental health across these areas depends on water, land use, and management of the system. Policies of the past, such as fire suppression, coupled with drought, have resulted in areas with an over abundance of fuel and dry conditions, resulting in increasingly large and devastating fires. What are the alternatives that could be considered?

1. *Biophysical Wooded Landscape:* What are landscape vegetation management systems for production of cellulosic biomass, increased watershed water yield, and improved forest, rangeland, and community health?

Woody plant encroachment and infilling, a phenomenon that has dominated woodland and forest vegetation dynamics in New Mexico over recent decades, is widely recognized as inhibiting rangeland health and biodiversity, promoting the loss of ecosystem services , increasing the risk of catastrophic wildfires, and undercutting ecosystem resilience in the face of changing climate regimes. A whole system approach for planning management of wooded landscapes can provide local and regional societal benefits by improving water yield and environmental quality through sustainable harvest of renewable energy stocks. Opportunities to develop and implement such approaches are possibly at a historical high due to a surge in the demand for woody biomass triggered by recent energy legislation such as the Energy Independence and Security Act of 2007. To meet the targets mandated by this law, the American economy is projected to demand 36 billion gallons (bg) of renewable transportation fuel per year by 2022, and only 15 bg of this projected target could be met by current or planned corn ethanol production. It is expected that approximately 16 bg (of the remaining 21 bg) will have to be produced from advanced cellulosic biofuels (USDA 2010).

One immediate, direct use of woody biomass as energy is to produce electricity through its combustion. This is literally considered a plug-in technology. The issues with locating the facility, air and water quality regulation, the monopoly on electricity, and feedstock supply are not that different from any industrial facility, and can be overcome with perseverance. Commercial production of liquid fuel from wood will take off in the next decade. In the mean time, some bugs remain to be worked out. This short discussion will look at two potential pools, biodiesel and cellulosic ethanol.

Diesel derived from wood biomass seems a possibility worth vigorously pursuing. The secondary metabolites found in wood, especially in the conifers that are the targets of restoration in New Mexico, seem to be easily converted precursors to diesel. If the secondary metabolites can be extracted, the residual cellulose could be used for other purposes. In the long term, converting wood to diesel rather than ethanol will be better for the US economy. Cellulosic ethanol is probably the biggest pool of liquid fuel that can be derived from wood, but the structure of cellulose presents a formidable challenge. The challenge eventually will be met; when that happens, the material removed in restoration projects may finally pay its way out of the woods.

Although caution needs to be exercised in building expectations that removing small diameter trees in excess of historic levels will lead to an increase in water yield, examples of dramatic reductions in river flow with corresponding increases in forest density are common in the Southwest (e.g. the Salt River in Arizona). For higher elevation forest types, this expectation is true. For lower elevation plant communities like the various piñon-juniper types which grow in areas that receive less than 18" of precipitation a year, removal of excess woody biomass does not usually lead to measurable increases in water yield, although the ecosystem is undoubtedly healthier.

Communities throughout New Mexico have historic and traditional links to the forests and woodlands. In many communities, especially in the north, a strong sense of ownership remains despite the incorporation of land grant areas into the national forests. A large proportion of the population can trace this connection back for at least 500 years, and during that time the environment they live in has given them their water and their household energy. These communities, better than most modern Americans, understand that making a living means managing land for sustained production. They are often frustrated with lost opportunities. They are characterized by strong family ties, but children often are forced to leave these communities to find full employment. New industries, based on forest and woodland biomass, should hold great appeal for these communities, especially if the new industry can be scaled appropriately. They can find work in an environment and using skills they already are familiar with, they will improve the health of the landscape and the lifescape of their community, and they can help establish an industry that will bring outside dollars into their area.

The majority of people, however, live on the fringes of the mountain ranges, in the transition between forest and range. These communities are in areas characterized by piñon-juniper expansion into grassland. However, the communities may not realize this, since the expansion now is the age of the oldest residents. Public education around grassland restoration to an historic norm may take some effort, but that effort will be aided by the visible erosion that takes place under piñon-juniper when grasses are crowded out. Many people living in the transition area will also graze livestock, or have social ties to people who do, and they already know the negative effect the woody invasives, especially juniper, have on grass production. As with the forest communities, the rangeland management communities are natural partners in this energy-water-environment nexus. Unlike the higher-elevation forests, however, this removal of small diameter woody material will be envisioned as permanent. If it does come back, it will grow very slowly.

While the incorporation of piñon-juniper into the feedstock stream for biomass energy should be considered in the short-term and not renewable,private consultan and http://www.appliedeco.com) hired by manufacturing industries of the Midwestern US, are actively working with landowners in central New Mexico seeking to create consortia with sufficient woodland area to insure the supply of sizeable volumes of woody biomass to power Midwestern industrial plants (Barbara Sultemeier, Rancher, personal communication). New Mexico land managers are welcoming this opportunity as a means of restoring areas of their land for sustainable agricultural uses such as livestock grazing while fostering job creation in small rural communities and increasing ecosystem services associated with improved wildlife habitat and, in some instances, increased water yield for both rural and urban communities.

Although the economic viability of woody biofuel feedstock harvest is uncertain, it's potential to restore environmental services and boost rural economies provides an unprecedented opportunity to develop land management approaches that simultaneously address energy, water, and environmental quality in a holistic manner. Our objective is to study the socio-biophysical linkages in New Mexico's wooded landscapes using on-the-ground measurement approaches guided by systems modeling driven hypotheses to derive holistic solutions that include renewable energy production, sustainable water yield, and environmental restoration.

2. *Managed irrigated agroecosystem communities*: What are irrigated agronomic community systems for production of biodiesel with crops that produce local income using energy positive water?

Acequia irrigation systems and large irrigation districts line New Mexico river valleys and valleys of similar snowmelt runoff dominated river systems world-wide. Unlike most energy systems that require energy investment to bring in required water, these systems use water that is energy positive, moved simply by gravity. This feature makes these systems unique and gives them particular advantages for energy production.

Water distribution across the landscape also lends unique ecosystem and cultural values to this setting. The valleys have a landscape benefit of being relict floodplains with fertile soils and often shallow aquifers in connection with the river channels. Agriculture is benefitted by the soils as are riverside riparian areas with phreatophytic plants that depend on the shallow groundwater. It is estimated the 80-90 % of wildlife species in New Mexico spend at least some part of their life cycle in riparian areas. In similar arid and semi-arid regions worldwide, the ecosystem value of river corridors is vitally important. Culture that has evolved in New Mexico and similar physiographic settings is tied inextricably to the river, riparian areas, valleys, irrigation systems, and irrigated agriculture itself. Acequias are more than simply gravity feed water delivery systems. They are also community water management systems particularly well suited to their environments. Unlike with priority water law common throughout the western U.S. in which senior water rights holders get their water first in dry years and junior water rights risk getting no water, with acequias water is shared within the community according to availability. All users get more water in wet years, and all users get proportional reductions in dry years.

Energy sectors include micro hydropower from underutilized water potential and growth of energy producing crops. Micro hydropower involves small hydroelectric generating equipment placed within irrigation canals. These nascent technologies, though not fully tested, are proving highly promising. Energy crops that grow in New Mexico valleys include biodiesel crops (i.e. sunflower) and ethanol crops (i.e. sorghum). Crop yields , though water and weather dependent, are relatively reliable. Unknown is the viability of technology required to generate fuel from these crops.

The total value of energy production in these irrigated corridors can only be measured and modeled with a whole systems approach. Particularly promising is the use of desalinated brackish water to offset fresh water use. The added fresh water, given amenable water law, can be use for terrestrial and aquatic ecosystem health while maintaining maximum agricultural yields. Thus ecosystem services are provided while using the water to grow energy crops. Water percolation to groundwater keeps the aquifer and river connected and may save water at the regional scale by reducing evaporation. An important research question is, what are the community integrated water use strategies that maximize sustainable crop growth, biofuel production, and irrigation produced ecosystem services?

In order to contribute answers to this broad research question, an integrated modeling platform that is capable of modeling interactions simultaneously between physical and social science aspects of the model, allowing for spatial and temporal variation is vital. To achieve this, we consider a set of scenario-driven research questions that could be answered using a systems approach. We then consider sectoral, field specific research data, and methodologies necessary.

2.a.3. Integrated systems modeling, scenario and action research questions with energy as the driver and water as a potential by-product and/or input into production.

1. *The Energy Economy in New Mexico* Energy contribute almost 25% of the total state gross state product (Peach and Starbuck 2010) and accounts for 25% general fund revenues for the state (Clifford 2011). For counties with oil and gas production, or electricity generation, the impact can be even greater. For example, San Juan County in the NW corner of the state relies on the extractive industries account for 11% of all jobs; 18% of personal income; and 27% ($1.4 billion) of gross regional product (EPS 2011).

The traditional energy economy is critical to the state of New Mexico, as are the water resources. Maintaining this important sector of the economy while being aware of the current and future limitations of water available to the industry is a crucial aspect of the water energy nexus. There are strong arguments as to why an energy economy needs to be supported, as well as strong arguments for regulation on the emissions, as well as strong arguments about the need to maintain water resources. Effective policy will consider all aspects.

Traditional energy resources will physically or economically deplete over time, or be less attractive due to externalities and alternative energy sources. Regardless, this leaves a void in the economy. Efficient transition to alternative energy sources that work well with other constraints and considerations of the region is essential. What are new and existing energy and water sources that can be considered? Which of these can be utilized synergistically and which will result in unintended consequences? What are the renewable energy sources available that can provide energy in ample quantity? What are the water needs of the alternative and what are the available sources? Can brackish water provide an alternative? Is uranium the best alternative, when potential impacts on the environment, the economy and human health are considered, in addition to the risks associated with spent fuel? From a physical science perspective, aspects to consider include water quantity and quality (surface and groundwater), water and energy proximity, water depletability, and water reuse potential. Technological aspects of an alternative are necessary to consider.

Choices made concerning future economic development, the transition and timing from fossil fuel to alternatives will be of paramount concern. What are viable transition paths and what are the best available substitutes or portfolio of substitute energy sources?

But indeed, without the human element, the physical science questions exist in a vacuum. Just because something is possible does not mean it will be achieved. To that end, incorporating this element is essential, which requires improved knowledge.

All of these (and many additional questions) can be considered by coupling known and developed scientific knowledge with the costs and benefits associated with alternative choices. What are total and true costs of water and energy when considering all significant inputs and outputs with social and environmental costs, and can augmenting the natural resource yield new water with a total net reduction in energy use?

To provide a better understanding of these energy/water questions and to adequately account for their impact within the feasible set of policy outcomes, we endeavor to incorporate the physical and human aspects into a system dynamics frame in order simultaneously consider the interactions and to account for feedback loops within the system.

2.a.4. Bringing it together with research questions Research Sector Breakout

The exact set of research questions we could ask is seemingly endless. For example:

- *How can we monitor, estimate and/or model the impact of energy production on water availability and quality?*
- *How can we develop strategies that provide alternative energy sources from the management of lands?*
- *What are the full (market and non-market) costs of energy production in the state?*
- *What are attitudes, values, expectations, and acceptable tradeoffs of the New Mexico population?*
- *How do perceptions of risk and uncertainty impact attitudes and values?*
- *Does heterogeneity of the population impact the potential outcome?*
- *What are the energy costs and environmental impacts of extracting transporting, provisioning and treating water in New Mexico?*
- *What are the full life cycle implications of energy extraction processing production on environment, water economy, and the regional economy and how does life cycle evolve with climate change?*
- *What sources are possible within the region that would replace not only the energy, but also positively impact the economy and quality of life?*
- *What water resources could be used in the production of renewable energy resources?*
- *Desalination coupled with other water use/non use: How to reduce total cost to environment of water use by utilizing brackish water with renewable energy technology?*
- *What is the potential viability of uranium and what are the potential impacts on the environment, the economy, and human health?*

- *What are the economic and ecological impacts of technological transitions in energy, conservation, and waste?*
- *What rangeland and forest ecosystem functions can be enhanced while increasing water yield, increasing fuel production and minimizing environmental impacts?*
- *Can use of the full energy potential of water in irrigated valleys increase net energy output while maintaining cultural health and ecosystem function?*
- *Can costs of water diversion and pumping coupled with water quality be combined into a meaningful end-use water time availability metric that improves analysis of water availability for varied energy production systems?*
- *…*

Within this potentially expansive set of research questions, there are basic aspects that flow across the themes. We consolidate the questions to a series of five broad questions:

1. How do the various parts of the system interact? What are the feedback mechanisms and loops? What are time frames and spatial extents for feedback impacts?
2. At what point would effects of energy production impact water resources and alter ecosystems resulting in large-scale changes that are universally undesirable?
3. What does society want?" Models of the physical outcomes without the consideration of societal objectives cannot inform policy. What are the human constraints imposed? Boundaries, regulation, and social norms are relevant.
4. What are the natural resource limitations and opportunities that can be overcome or turn into obstacles when looking at the whole system compared to resource-centric approaches.
5. What are projections for future technological and environmental changes?

These questions, which help inform the specific research questions and broader research focus, require data, analysis, and information flows.

2.b. Methodology and analysis

In order undertake this research, several methodologies and analysis techniques are necessary. We can classify these as measurement methods to gather data, models and techniques with which to analyze the data, modeling structures with which to integrate data and model results, and information streams with which to facilitate the capture, archiving, analysis, and dissemination of relevant scientific data for current and future use.

2.b.1.Measurements and Data Needs. A foundational perspective of this effort is that measurement, data collection and storage, modeling, and information dissemination need to take place at similar spatial and temporal scales. In terms of water, vegetation, and landscape ecosystem functions relevant to our questions, it will be important to have broad scale measurement and data resolution. Large gaps exist, such as the vitally important but unmeasured shallow groundwater levels and quality along New Mexico river valleys. Modeling whole system water and energy processes will require new measurements that enable broad characterization of under measured resources such as shallow riparian groundwater.

While the physical sciences have long utilized data gathered from sensors and other mechanisms, economics and other social sciences have relied on publically recorded data, or data gathered specifically for a single research question. Much of the primary data gathered for economics research is at the level of a single individual and deals with attitudes, trade-offs, willingness to pay or except, or reactions to incentives and policies. Survey and experimental methods are often used. The development of a survey or experiment and the cost to administer can be prohibitive, often resulting in small samples that focus on the single question at hand. Because of the prohibitive cost of gathering primary data, economics also often relies on benefit-cost transfers where values of relationships from a primary study done in one area is transferred to a secondary study area. To the extent that the secondary area is similar to the primary study area, the results can be informative, but are normally accompanied by wide ranges of uncertainty. The installation of a virtual infrastructure that would provide a single platform, program language, administration, data capture and achieving would greatly reduce the upfront costs resulting in the potential for larger sample and would also allow the development of surveys or experiments by researchers at any institution. Furthermore, it would provide a mechanism for administering instruments either to a general population or to a targeted group. Not only does this provide a mechanisms for valuation of market and non-market goods, it provides a mechanism for assessing attitudes, impact of education on attitudes, and assessing the potential of various policies and incentive mechanisms – all of which is vital to the development of a systems model that considers the complex issues addressed by this research.

2b.2. *Models and Analysis.* The models and analysis need to be based in the best science and practices of the discipline, but also need to consider the linkages between other models and disciplines. This allows models and analysis to serve two purposes. First, what are the implications and advancements made in the primary discipline and is the research peer accepted? Second, how does the research link within a system frame and how can it be used to advance crosscutting research to answer questions that are not field specific, but rather community driven? What are the techniques and advancements? Do we provide cutting-edge methods that not only are accepted but also will be utilized by other researchers?

Within the modeling and analysis frame we also consider the incorporation of disparate models into a single platform with which to consider the cross-disciplinary aspect of the inquiry within a system dynamics frame. To that end the ability to link temporal and spatial models that may be of different scales and time steps (depending on the norms and needs of the primary discipline) is essential. To that end, in addition to informed researchers, stakeholders, and policymakers, the ability to have data and information available in an appropriate form is essential. Part of this will be achieved through handling of data streams.

2.b.3. *Information Streams.* Successful gathering of diverse data and its utilization in models that span many disciplines is only possible if there is an infrastructure in place that manages the data. The central questions for this aspect of research includes how to promote information flow across New Mexico communities to facilitate environmental monitoring optimal energy usage under constraints climate change predictions for New Mexico and collaborative research for the above? And what are the characteristics of a scientific CI?

A central requirement for the development of collaborative strategies to address the effects of climate change on New Mexico's economy and water resources is the development of a computer infrastructure to facilitate the capture, archiving, analysis, and dissemination of relevant scientific data. The establishment of computational interoperability capacity will allow for wider use and sharing of climate data among stakeholders and policy makers in the state. A computer infrastructure for New Mexico EPSCoR will streamline the ingest, management and discovery of data resources, freeing researchers from the tasks of data post-processing and archiving. As a centralized portal, the infrastructure will facilitate the discovery, visualization, and analysis of climate data in a single web based interface.

Primary activities of the proposed work include the integration a highly diverse collection of climate data, from a variety of researchers in the state, into the Geographic Storage Transformation and Retrieval Engine (GSTORE), a distributed platform aimed to provide large-scale vector and raster data discovery, subsetting, and delivery via web services, mainly based on Open Geospatial Consortium (OGC) and REST web service standards. In the State of New Mexico, the platform has been successfully implemented using a variety of Open Source tools and deployed on multi-terabyte data repositories including the Resource Geographic Information System (RGIS) clearinghouse and the NM ESPCoR/NSF Science data portal. Second, the ingest of scientific data is paired with the development metadata in the ISO format, thus enabling integration of New Mexico's climate data with other scientific archives, including the Tri-State EPSCoR initiative, the Federal government's One Stop repository and AIS (CUAHSI) hydrology database.

3. Relevance to energy water environment nexus

Policy that successfully navigates the energy/water nexus can provide New Mexico with opportunities in the future. Successful policy requires an understanding and an incorporation of the physical and human aspects of the problem into the policy solution, as well as an understanding of the interactions and feedback between the physical and human aspects of the problem. In addition, the unique nature of these types of problems, in that resources may be exhaustible or depletable and that actions today impact choices tomorrow, underscores the dynamic aspect of resource and environmental policy.

This research can inform policy and serve as an example of science-based policy formulation for areas well outside of New Mexico. The intent is to provide a methodology that models the energy/water nexus while considering social, environmental, and economic health in order to provide avenues of sustainability. The focus is on the holistic: community resilience, cultural diversity, energy diversity, and water sustainability. While the focus of specific research questions is a micro level, the system analysis is at a local, regional, or state level. This allows for spatial and temporal variation and allows for assessing impacts and feedback that may vary in importance across the state. And the objective of the research remains to inform policy concerning the critical question"

In the face of increasing resources scarcity and climate change what strategies can result in energy and water sufficiency with societal and environmental health?

4. Explanation of how research will enhance NM competitiveness for NSF funding

The research proposed above, while research question driven, is not possible without the development of research infrastructure that is not currently available in the state and the development of the infrastructure is not possible on a grant-by-grant basis. The system approach provides a platform for future research without each piece of the research question being reinvented for each new project. It also advances cross-disciplinary research and provides a mechanism that develops a new "breed of researcher." Working across disciplines, developing the knowledge base to be able to do so, and to develop the culture of working across disciplines and across institutions, provides a research community in New Mexico well equipped to compete for future funds. In addition to the systems platform approach and the "researcher infrastructure" developed, the physical and cyber-infrastructure constructed for this research would provide assets to the research community that cannot be developed within a traditional grant. For example, the development of a survey/experimental infrastructure that would allow the gathering of human-based data at the level of an individual response, but across the entire state would provide a research tool that could be utilized by researchers at multiple institutions for future human and social research. Coupling this infrastructure with time sensitive data from other disciplines would provide a unique research tool that would allow insights into behavior not currently available. Finally, developing a data and information mechanism that would allow for the storage of the data in a single format and assessable to researchers would provide a significant advance in behavioral economics. This infrastructure would provide the potential for numerous collaborative efforts and funded research opportunities not only in the realm of the energy/water nexus, but across any research question that considers the interactions of the human and physical system.

5. IDENTIFICATION OF OTHER PEOPLE/INSTITUTIONS THAT COULD PARTNER IN THIS WORK

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