Interdisciplinary break-out discussions were held during the afternoon of the workshop. Break-out groups consisted of five to eight participants with different backgrounds. Break-out groups were not the same both days. A single member of the group was asked to record the discussions and submit responses to the workshop organizers. Over 100 people, predominantly from North and South Dakota, participated in the break-out group sessions.

The following pages contain the compiled responses to workshop questions. The responses have been organized and grouped by topic. Similar responses have been combined to reduce redundancy. Discussion context has been added to the answers to enable non-participants to understand the intended message.

Day 1 – Group Discussion Questions

Why is rural Food/Energy/Water (FEW) sustainability important?

- Nexus sustainability is important due economic, societal, and cultural impacts.
    - These resources are how we make our livelihood – they form the economic backbone of the region.
    - If we (people who live in our region) don't pay attention to FEW sustainability in our resources, our lifestyle and economy will suffer.
    - Sustainability is especially important in rural areas because of lack of infrastructure. We need to build for the future generation and be mindful of water quality and water quantity. So, rural populations can stay in their homeland and not have to leave for urban areas. FEW sustainability is an important factor in keeping people in the region.
    - Sustainability is a key component of long-term economic development.
    - Economic benefits of our regional resources draw migrants to our region for employment. Our region's natural resources have helped to maintain a low unemployment rate through their export. However, residency by migrants is often not retained due to the 'boom then bust' cycle. Temporary residents and external investors often do not have a vested interest in regional sustainability.
    - Small business and farms will be greatly impacted by change.
    - Maintaining FEW mitigates negative consequences (e.g. war, famine).
    - Land use, conservation, and wildlife have to be part of the mix. Diversification is critical, even though our mindset on immediate profitability often works against diversification.
- There is limited likelihood of that the past rate of technological expansion and growth (e.g. green revolution, unconventional oil/gas) can be sustained.
    - We're in a condition of depletion and overreach in regards to our technological activities. We have created highly efficient systems which are difficult to improve. Realistically there is no alternative but to continue to try to improve, but, the significant gains achieved in the past will be more difficult to accomplish in the future.

- Unfortunately, people will use at the levels they use as long as they are able. So conversations must include mitigation and resilience - not just sustainability.
    - In individualist U.S. society, sustainability is important because it ensures the possibility of continued individualism.
    - To achieve sustainability, we may have to ignore an individual's or a group's self-vested interests to obtain overarching societal benefit and stability. This may be an unpopular, but possibly necessary step.

- Food, energy, and water sustainability is important due to exploding population levels.
    - FEW resources are important in supporting rural population growth and economic development.
    - Sustainability is not just rural in our region, the municipal component in our region cannot be ignored. In our region, the population of larger municipalities are increasing as rural populations continue to decline. Demands between urban and rural areas are not independent.
    - More land will be used in rural areas for industrial and urban development in future. Expansion of industrialization and urbanization will further stress food, energy, and water.
    - Municipal land fill and wastewater treatment facilities already have exacerbated availability issues. These availability issues are especially acute in western North Dakota within the Bakken play. Municipalities will continue to need more power (lights, heat, air conditioning), water, food, and space for waste disposal.
        - Improvements in rural recycling, waste disposal, and water treatment facilities are needed. An example of a need is for used tire recycling or disposal. Innovations are needed in recycling and a strong market needs to be developed for rural participation.
    - Rural areas are important in the process of urbanization and supporting their regional populations.
- For export purposes.
    - The upper Great Plains is a source of many products (food, energy, and water). Large national and international populations are dependent on regional products, but users and suppliers are disconnected.
    - The production (and export) of products is not currently sustainable over time.
    - Food, water and energy are all linked together. The upper Great Plains plays a big role both nationally and globally supplying energy and food. This is a significant responsibility, we need to ensure we can sustain these activities.
- Water conservation and protection is key in semi-area climates.
    - Water is needed to grow food and food production impacts water quality. We need better understanding the nitrogen and phosphate cycles.
    - Agriculture has a big "black eye" in the public's mind regarding water quality issues. Agricultural water use and run-off issues and solutions need to be better understood not just scientifically, but at a general societal level. Consumers need to be able to understand the impact of the products they purchase.
    - We need to do a better job of recycling and re-using water. Too often we use very high quality water in circumstances where a lower grade of water would suffice. After processes are completed, we consider the water a waste. We need to think more along the lines of what we do with energy recycling and re-use.

        - For example, in an ethanol plant the highest temperature steam might be used for flushing the molecular sieves. Then the lower level steam from that might be used in the jet cook process. Steam from the flash vessel from the jet cook may then be used to run the distillation columns, and on and on until as much of the thermal energy can be pulled out as possible. In the same way we need to just use pure water for the highest value uses, and then as that water becomes contaminated with processing compounds, we use the water for another purpose where a lower grade of water is sufficient, etc.
    - We need to integrate use of more low quality water into production of shale gas.
- Rural communities need all three (food, energy, and water) to survive/grow.
    - Food, energy and water are limited resources and need to be managed as such. Each component can have positive and negative impacts on the other two components. Therefore, we cannot look at each of them as a standalone component. Interactions and impacts among the three components have to be optimized in ways that all three components are available for future generations.
        - One thing to be considered for the optimization is that the values of the outputs should be more than the inputs.
    - Everything is linked. We cannot achieve sustainability in one without the other.
    - We need to make sure to pass opportunities to the next generation. The actions that we take now shouldn't prevent future people from functioning in the same manner we have.
    - These are the only resources we have and they are the basis of our existence.
    - Food, energy and water are the three necessities of life; we are in trouble without them.

How would the rest of the country (and/or world) be impacted by the inability of the Northern Great Plains region to achieve FEW sustainability?

- In an interconnected economy. Society depends on the web of connectivity that exists between the regions to bring social stability and to act as an economic engine.
    - The world is looking for U.S. to lead sustainability and solutions developed here could be applied in other countries.
    - If local economies are not maintained, then people will have to leave to find employment.
    - Changes to production and export may increase food and energy cost worldwide. Lack of sustainability will likely reduce supply and induce long-term increases in cost. Sustainability measures may have short-term and/or long term cost impacts.
- We export all the three nexus components: food, energy, and water.
    - We are an upstream source, in all senses of the word. We are a net exporter of products.
        - For example, if we increase sedimentation in the Missouri River because of our activities, that would impact downstream and ultimately the ecosystem in the Gulf of Mexico. We are one of the starting pieces in the 'domino effect' for either achieving sustainability or failing.
        - Another example, the Ogallala Aquifer stretches from South Dakota to Texas. It is heavily used for irrigation, municipal water, and industry. It

generally flows from west to east. If up-gradient users overdraw water, then it will not only deplete the local water resources, but the water availability to down-gradient users. There is an inter-state impact to use.

- If we are unable to sustainably provide for ourselves, we likely will stop providing the rest of the world our resources (energy, water, or commodities/animal products).
- Climate change is the result of global, often disproportional consumption of resources. To solve this issue, there must be local responsibility and sustainability. What we do here either contributes to or helps ease global issues.
  - Climate change may be influenced by the food, energy, and water nexus decisions. For example, base-load and peak-load conversion from fossil-fueled to renewable sources (e.g. hydroelectric, solar, wind, low-temperature geothermal) can influence greenhouse gas emissions.
- Land use and infrastructure decisions impact global food supplies. Changes to production and export of products from the region can lead to rising food prices and/or shortages (i.e. durum wheat/pasta, sunflowers, canola).
  - Do we plant to grow food or energy? How do we sustainably develop our land, maintain production, and ecosystems? These choices directly affect the natural environmental as well as supply and demand in both nationally/globally.
- Energy export is going to be impacted.
  - Our region has tremendous fossil fuel resources, however they are finite. Sustainable production of existing fossil fuel resources will assist with minimize climate change impacts and preserve resources for posterity.
  - The upper Great Plains has the opportunity to expand renewable energy resources (e.g. wind, geothermal) and to help balance carbon footprints.
  - Ethanol and shale oil production is highly developed in the upper Midwest. Our region is ideal for solar and wind energy. This will make our region very important for the development of these technologies. Novel infrastructure development to transport and transmit surplus energy to urban regions with minimal loss is an important.

- Water should be a focal point.
  - Without water we can’t have food or energy.
  - Water is scared from indigenous perspective.
  - We are depleting water for energy development with little return.
  - Water in aquifers and within a semi-arid landscape cannot be recuperated as fast as it is being consumed.
  - Water quality, availability, and use within the Missouri/Mississippi corridor is ripe with conflicting priorities (e.g. storm events/flood control, power generation, drinking and industrial water, irrigation, agricultural run-off, sedimentation, chemical spills, barge traffic, natural habitat).
  - Our water quantity and quality is being negatively impacted due to our actions. Issues with water resources are being exacerbated by on-going climate variations.
  - Water quality (i.e. oil or chemical spills, salinization/sodification) influences downstream uses. Degraded water and soil can impact food production (i.e. wheat, corn).

  - Once there is a severe shortage of water, energy prices will increase. This, in turn, will increase food cost.
  - Water shortages and degraded water quality will impact industrial development, food processing, and energy production.
  - Diminished water resources could/would negatively affect exported hydropower to other parts of the country
- If we externalize our environmental impacts, we will negatively affect the environment in other places. An example of this is indirect land use change or outsourcing dangerous or harmful production steps to third-world countries.
- We could have a negative impact on the places where we export or stop export.
  - Rest of world will be looking at the northern Great Plains for food and energy production. We export food crops not only to the U.S. but also globally.
  - Without sustainability, the country would produce less food and energy. This will reduce competitiveness and security.
  - NGP feeds the world, energizes the U.S., and waters the U.S. The pollution products create (i.e. CO_2, nitrates, phosphates, salts, heavy metals, etc.) are predominantly localized. We are exporting food, water, and energy at the cost of our local environment.
  - We *cannot* maintain the same amount of exports if we shift to sustainability. How can we sustainably support both our region and our exports?
  - We could (in theory) improve developing countries if they are not dependent our commodities and stimulate local food production and self-reliance. Or, conversely, lack of export could cause negative land-use change, food insecurity, and/or political instability.
  - The rest of the world will be impacted by decisions that we make.
  - We will likely get "help" (e.g. investment, political mandates/subsidies) from more populated areas to encourage us to provide them our resources.
    - Will our efforts for regional sustainability be over-ridden by external influences, ownership, and/or demands?
    - Tariffs, subsidies, and other political measures strongly influence the economics of food and energy production and export. Will it be possible to sway these political measures to support sustainable solutions?
  - What is the highest and best use of resources? Are we the highest and best use for what we produce? If we are not, then who is?
- Sustainability: by definition, it can be done effectively forever.
  - For nonrenewable resources, your rate of decrease of use has to be greater than the rate of depletion.
  - For renewable resources, your rate of use has to be less than natural renewal rates.
  - A continually growing population is unsustainable. Without addressing unsustainable increases in demand and growth, we cannot achieve sustainable solutions.

Identify important FEW 'intersections' within our Northern Great Plains region?

- Water is required for:
  - Agriculture
    - Irrigation

        - Food production.
        - Biofuel production
    - Human and livestock consumption (requires quality fresh water)
    - Non-conventional oil and natural gas production (e.g. Bakken, Niobrara)
        - Use of water for fracking and production results in low quality water that often can no longer be used for agricultural activities or consumption. Recycling water is difficult due and expensive, so water is often only use once and is rendered a harmful waste.
    - In-situ uranium mining
    - Processing coal, mining ore, and extracting metals
        - Heap-leach solutions are used to extract precious metals.
        - Water is used to stabilize coal for dust control during crushing and transport to reduce chance of spontaneous combustion.
        - Water is used in mining to control dust. Open pits and underground workings are often de-watered.
    - Coal-bed methane extraction
        - Water is removed with methane. Sometimes it is re-injected, in other situations it is released to surface water bodies (can be high in total dissolved solids).
    - Hydroelectric power
        - How can hydroelectric power production on the main-stem of the Missouri River be maintained? The increase in frequency of floods and droughts make water levels more difficult to manage. The sedimentation of the reservoirs and age of the infrastructure has reached the point where without significant public investment, power from these sources could be lost.
    - Barge traffic
    - Many types of geothermal power and heating
    - Ecological processes and wildlife
- Energy is required for:
    - Water extraction, transport, and treatment/purification
    - Food, biomass, and bioenergy production
    - Transportation
    - Energy production
        - How can energy and bioenergy production be maintained with increasing climatic and associated weather instability? Longer and more frequent droughts and/or floods will likely decrease production capabilities.
    - Fertilizer, pesticide, and chemical production
    - Bio-processing
- Agricultural management is required for:
    - Crop adaptation (productivity, climate variation, efficiency) and development of drought tolerance breeds (water stress resistance).
        - Grow and develop energy or specialty crops varieties for production on marginal land. For example guar beans can be grown to produce renewable chemicals (i.e. guar gum) for shale gas production.
    - Biofuel and food production.

        - Which is more efficient in terms of water consumption and overall productivity? For example, what is a better use of corn? Is it more appropriately used for livestock or ethanol production? And, which use consumes fewer resources?
        - Longer and more frequent droughts and/or floods will likely decrease production capabilities. How can food production be maintained with increasing climatic instability?
    - Healthy soil preservation and development:
        - Increasing soil organic matter increases productivity and improves water retention.
        - Does leaving residual biomass on the soil result in carbon footprint reductions? Does removal of residue (i.e. corn stover, straw) deplete soil? How much residue can be removed before soil structure is harmed?
        - Which techniques are appropriate to build healthy soils within the Great Plains?
            - Not all current techniques (even federal recommendations) are appropriate for all localities. Different soils need different management and will likely be affected disproportionately by climate change.
            - Examples of techniques include: prairie restoration, buffer strips, no-till practices, rotation diversity, etc.
    - Preservation of wildlife, biodiversity and ecosystems:
        - How do we maintain (and, possibly increase) production while preserving ecosystems?
        - How will natural systems (e.g. forests, wetlands, grasslands, water bodies) respond to climate change?
        - More rainfall will likely mean more grassland conversion to crop land.
            - Grasslands and other natural eco-scapes will adapt less favorably than managed land such as cropland to climate change.
            - What will be the net ecosystem effects?
                - Will wildlife be able to survive? What will be the impact of loss of wildlife?
                - Will grassland loss cause an ecosystem collapse? For example, would the loss of beneficial grassland insects and pollinators cause crop failures and loss of vertebrate species?
- People are required to:
    - Maintain a viable rural work force.
    - People are a critical component to rural resilience.
    - Help to minimize climate change. This is an issue that people collectively have caused. It will not be resolved without collective effort and innovation.
    - Stimulate and maintain the economy.
        - How do we balance the need to provide food, water, and energy to people with environmental preservation? Can we provide regional resources to the world without further damaging our ecosystems and future?
- We need to change our collective paradigm to sustainability.

  - How to maintain and re-purpose infrastructure to keep costs low?
  - How do we maintain economic profitability?
  - How do we instill humans with responsibility?
  - How do we prevent the tragedy of the commons?
  - How do we positively impact policy (e.g. social, political, ecological, economic)?
  - How do we address environmental and ecological issues?
  - How do we prioritize water use?
- How do we resolve rural transportation issues?
  - In our region, everything is a long distance from everywhere else. We face individual transport, mass-transit, and product export issues. We are reliant on continuous inexpensive oil supply to manage and maintain our transportation system, production, and economy.
  - Can an efficient mass-transportation system be developed for rural regions?
  - How do we self-sustain and ween ourselves off of non-renewable resources?
  - Rural regions have limited, efficient means of transport, such as rail. There is competition between fossil-fuel, biofuel and food crops for export transport capabilities. How much should transport cost and which should be prioritized?

For your example 'intersections', what are the synergies that should be further explored?

- Synergies to explore:
  - We need to work towards sustainable products and processing development and economic opportunities in the rural area of the upper Great Plains.
    - Local pre-processing or processing of products and local use of by-products could create jobs and reduce transportation for export.
  - We need to examine integrity of the existing infrastructure and opportunities for change. Should we repair or redesign? Or, do both? We need to radically rethink the how we can sustainably invest in infrastructure.
    - Should we replace roads with railroads?
      - How do we incentivize transportation efficiency?
      - Should all public roads be 'toll' roads?
      - Should we explore alternatives to road, rail, etc.?
    - Should we isolate drinking water from other water uses (e.g. two water lines going to homes/businesses, one for drinking and one for gray water).
    - Should we split treatment systems (i.e. storm, sanitary, industrial, gray, saline) for differential treatment/reuse?
    - Should we continue fossil fuel baseload power or switch to renewable alternatives? If so, how do we handle the infrastructure?
  - We need to look at integrated process and system efficiency.
    - For example, zero discharge water systems, import/export, peak control/demand systems, processing and storage systems, and distribution.
  - We need to address and investigate the relationships and system health.
    - Sustainability will be contingent on health. For sustainable food and biofuel production we need healthy soil.
    - For healthy people and livestock, we need reliable, nutritious food and clean water. Healthy, unstressed people are able to make better decisions. Healthy, unstressed livestock grow better and produce better products.

- We need to look at closed-systems (i.e. self-reliant) and preventative infrastructure.
  - Integrated crop-livestock systems
  - Agricultural production without fossil fuels (self-production of fuel)
    - Agricultural production is heavily reliant on diesel, gasoline, natural gas, and electricity for production, irrigation, and processing of agricultural products.
      - Oilseeds can be produced and pressed on-farm and used for triglyceride blends or biodiesel production.
      - Methane can be captured from manure.
      - Wind turbines or solar panels can be used for irrigation.
      - We need systemic self-sourced energy replacements.
  - Self-repair and prevention (e.g. carbon-fixing pavement, green infrastructure for stormwater control, greening cities for heat island mitigation, greenways for flooding, healthy soil, buffer strips and shelter belts for erosion control)
  - Passive (i.e. zero energy input) systems
- Looking beyond the upper Great Plains at the "products" exported and manufactured goods 'imported'. Can we streamline exports and processing/manufacturing locally to improve system efficiency?
- Producing crops in the region that are less water intensive and drought resistant
- Better water distribution on the crops and water conservation innovations such as drip irrigation systems.
- How do we preserve and protect fresh water systems (including aquifers)?
  - Fresh water is a limited resource in demand for energy production, processing, and agriculture. Without fresh water, there will be a system collapse.
- Surface water (run-off) capture with passive engineering structures for use when available.
  - An example is hydroelectricity production from dams or run-of-the-river.
    - It is important to consider the multiple uses (e.g. hydroelectricity, cooling water, drinking water, ecological support system, irrigation, transportation) of water within a single hydrologic system.
  - An example of surface water storage is 'stock dams' or 'dug-outs'. These are small impoundments in intermittent stream valleys in pasture land and pits dug in lowlands to intersect the ground water table or catch rainwater. These are examples of livestock surface-water capture systems which are prone to contamination and evaporation. Alternative rural, passive water structures which minimize water loss and retain water quality are needed.
- Managing drainage systems and run-off from agricultural land to reduce nutrient loading. We need to collaborate with farmers to minimize ground and surface water impact.
- Use of multiple water sources (ground and surface) for efficient, as-needed irrigation for maximum plant productivity.

- Working with climate cycles (30 yrs. in northern U.S. with 7-10 yr trends) to plan and anticipate climate change effects on food, energy, and water.
    - Better predicting climate trends, not just weather, and planning crop rotations and water use accordingly (i.e. long-term drought/flood planning).
- To integrate water management into food production and processing systems. It needs to be recovered and reused wherever possible. We also need to address the impact of agricultural production on water quality (e.g. TMDL, sediment loading, salinity).
- Co-location and local production of resources can be used to optimize systems and more effectively use resources. For example, growing guar beans and processing locally in the area instead of internationally importing; pressing oilseeds in rural areas so that meal is readily available for livestock feed.
- There are not 'food' and 'non-food' varieties of corn. The varieties are used interchangeably between the two categories to produce either food or ethanol.
    - Water is used in both the industrial processing and agricultural production. Wastewater and polluted run-off is generated. If we can reuse and minimize wastewater in the process, the production would be more sustainable.
    - Industrial versus food varieties of corn need to be bred. Can we re-diversify corn breeds and production to more efficiently produce targeted energy (high sugar) and more nutritional food (e.g. sweet corn with anthocyanins) products?
    - Infrastructure for grain and ethanol production is already in place.
        - Livestock consume by-products (i.e. distiller's grain)
        - Nutrients can be recycled back to the soil through biochar
        - Diversification is a positive attribute. Integration of wide variety of sustainable biofuel feedstocks would help diversification.
        - Existing products and infrastructure (i.e. corn-grain ethanol) can be used as a transition step towards sustainable bioenergy
- Can we economically and environmentally include sustainable harvest of non-cultivated ecosystems (i.e. prairies, forests) as bioenergy feedstocks?
- It is likely that western Great Plains producers will increase commodity (e.g. corn, soybean) production. Un-used crop residues can be used for livestock feed (possibly in an integrated crop-livestock system) locally or on-site. Finishing cattle in rural areas on residue instead of in feed lots (on grain) could reduce transport cost and increase livestock production sustainability.
    - Feedlots are efficient and animals reach finish weight quickly. Can the same efficiency be achieved outside of confined feeding operations?
- Unconventional oil and gas production requires water for hydraulic fracturing. Fossil fuel production reduces land and water availability for food and biofuel production. If we can treat wastewater (brine) from the oil production and reuse it for hydraulic fracturing, we can preserve and increase water availability.
    - We need to look at efficient remediation systems for brine water and natural systems contaminated by brine.

        - Mitigation currently consists of removal and sanitary disposal. Is there a way to repair damaged ecosystems or treat water using fewer resources?
    - For rail transportation, we need more equitable pricing and better coordination/cooperation between the industries. Could pipelines ease these pressures?
    - How can we build or retrofit fossil fuel infrastructure (e.g. pipelines, tanks) to process and/or transport biofuel?
        - Co-location of biofuel manufacturing facilities near natural gas sources for hydrogenation? Perhaps within natural gas 'islands' or other rural resources without transmission capability?
        - Many biofuels are miscible with both oil and water. Biofuels can introduce water contamination into fossil-fuels and infrastructure. Small, regional pipelines use water slugs (transmix) to separate fuel types. Because biofuels mix with water and residue can cling to walls, transport within same infrastructure can degrade fuel quality.
        - Many biofuels are oxygenates and octane enhancers, however they also degrade over time and with exposure to air/water. Effective separation techniques and preservation materials are needed to retain fuel quality.
        - We need a hydrophobic and oleophobic slip coat for fuel infrastructure and immiscibility agents so that infrastructure does not need to be replicated and can continue to be used for multiple fuels.

For your example 'intersections', what are the stressors or controlling factors that impede our region from achieving FEW sustainability?

- Stressors that impede us from reaching sustainability:
    - The rural patchwork is thread-bare. Social and cultural norms, geographic distance, centralization of resources and political power, and lack of funding make rural sustainability difficult.
    - There is a lack of a systems approach.
        - We lack a focused approach with divergent approaches to the problems.
        - We do not have the infrastructure to study the problem holistically.
        - We currently do not adequately include non-monetized resources such as ecosystems services and quality of life issues.
        - We do not satisfactorily incorporate feedback loops and the interconnection between issues.
            - For example, without unconventional oil and gas fracking, fossil fuel consumption would have likely decreased due to high prices and resource availability. Lowering prices and availability increases consumption. Higher consumption increases the effects of climate change. Higher prices reduce resource availability to the most vulnerable segments of the population.
    - The inconsistent and dramatic weather variations associated with our normal climate, let alone climate change.
        - The region has a long history of extreme temperature changes, storms, floods, droughts, and inconsistent weather.

        - It is likely that there will be either too much, too little, or poorly timed precipitation for current crops produced. Moisture levels will not be as dependable as the climate continues to change.
    - Agricultural systems are 'leaky'.
        - They require numerous and variable inputs.
        - They lose nutrients and are not always water efficient.
        - They are difficult to accurately model due to the wide variety of beliefs and management practices.
            - For example, when you make things in a factory, each product has consistent resource consumption and environmental impact. With crops, each field can have different inputs, resource consumption levels, and management practices - but they all produce the same product. So, there is a higher uncertainty and variability within model results.
    - Without an economic driver, it will be difficult to make headway with nexus sustainability.
        - Adaptation measures such as co-location of assets for cost and infrastructure reductions still need economic stimulus to be implemented.
        - Industrial reverse osmosis and desalinization funding is needed for water treatment. However, due to the small populations served by these expensive options, funding is not prioritized unless it is derived from industry. It is currently 'cheaper' to use deep well injection to dispose of contaminated water.
            - Current treatment processes consume a significant amount of energy to treat water a relatively small volume of water.
            - Industrial investment and communication is needed. Industry needs to partner with stakeholders.
    - We have a lack of funds to improve infrastructure and to change the system.
        - We have a lack of federal support for infrastructure. Federal funding is need to upgrade dams/waterways/transportation infrastructure because the majority of these resources and benefits are not consumed locally. Primary infrastructure is in place to provide benefit and resource export to the nation, not to provide imports to the region. For example, the majority of interstate highway truck traffic 'passes-through'.
    - Low, volatile oil prices discourage long-term change in consumption and in transportation reliance.
    - The lack of strong environmental policies and inconsistent national political support impedes sustainability progress.
    - Geo-political and socio-economic influences do not support sustainability.
        - The majority are fiscally conservative and not wealthy, so if an effort costs more money or reduces income then they are reluctant and/or unable to undertake it.
            - Population: Montana, North Dakota, Wyoming and South Dakota – even with the recent population surge - have a combined population total just over 3 million people, less than the population

of Los Angeles, CA excluding suburbs with an average income below the national average.

- Federal funding is often allocated on the basis of population and the 'needs' of the majority. The majority of people in urban centers do not see value in rural infrastructure development and they do not understand resource supply chains.
- Each state only has one congressional member. The national average for a state is eight to nine, meaning that is little regional congressional influence. Even the combined regional influence, is less than the equivalent of a single typical state.

- Without the support of both people here in rural areas and in urban consumers, sustainability will be difficult to achieve.
- External 'interference' in political processes are strong. External influences include: corporate/big industry lobbyists, national party politics (every person in the state get multiple daily phone calls and flyers from outside of the region during the weeks preceding a federal election), and national religious organizations.

- The beliefs of the general populace in the region make change difficult.
  - We need a greater public and political awareness of the issues.
    - Half of the region's population does not believe that climate change is real. Most are not worried about climate change. Less than half of the regional population believes it is harmful. (See https://environment.yale.edu/poe/v2014/)
    - The region lacks the political willingness to institute change.
    - The majority are not in favor of government regulation or 'interference'.
    - The majority do not (or do not care to) understand pollution sources, fate, or transport unless there is a clear and direct negative impact to them.
    - Meat production and agriculture are valued industries. Emissions management and non-point source pollution control efforts are negatively viewed if they impose restrictions and/or additional cost for producers.
  - The culture is different. There is pride in military service and self-sufficiency. There are strong agricultural and Native American influences.
    - There is an overarching militant belief system in the region.
      - Almost 0.5% of the regional population are active members of the National Guard (0.1% nationally). Almost 9% of the regional population are veterans (7% nationally).
      - Montana, Wyoming, Alaska, and South Dakota have the highest rates of household gun ownership in the nation (~60%), with North Dakota still in the top 10. The national average is ~30% of households own guns. (Bear in mind, that is the percentage of households that own guns, not the

total number of guns. Not many here will tell you that … and it is rarely just one.)

- Economic development is a driving force behind most decision-making at all levels.
  - Agriculture is the foundation of the economy.
  - Fossil fuels and mining are strong contributors.
- There is a strong work-ethic. Jobs with manual labor are common and respected. There is typically a lower than national unemployment rate.
- Rural cooperatives (e.g. water, electrical, agricultural) are a foundational element of communities.

- Behavior and belief systems are slow to change.

- Lack of autonomy and self-sufficiency.
  - We need electricity to produce our energy and food. We need fossil fuels to produce food and biofuel feedstock. The region is often dependent on external investment for growth and development.
  - Many people here do not want to be dependent on other countries or regions in order to be self-sufficient.
- All projects and all resources are limited in funding, longevity, and scope. Projects need to balance environmental impacts for longer-term sustainability.
- Transportation infrastructure is an on-going issue.
  - There are shipping conflicts between industries, especially in the rail sector between oil and grain.
  - We have 'space' and resources to grow due to the predominantly rural nature of the region and its tremendous natural resources. However, transportation and infrastructure maintenance and improvements are issues because of the large distances between resources, people, and municipalities. To make growth and continuation of the status quo possible, we need to find ways to provide economical, sustainable local and long-distance transport.
- Much of the region is semi-arid with finite potable water resources. Water quality, quantity, and accessibility are issues.
  - Much of the region's rural water is subject to industrial contamination from brine, fracturing chemicals, oil, naturally occurring radioactive materials, excess nutrients, and agricultural chemicals (pesticides).
  - Regulations and changes in mindsets are needed to mitigate these issues.
  - Ground and surface water resources must be used for multiple purposes and there are competing demands.
  - Water resources in the region are being consumed, contaminated, and/or exported through products at a non-sustainable rate.
- We do not have reasonable representations from cross-disciplinary perspectives. We need to have so many different disciplines at the table it can be difficult to understand all of the perspectives necessary.
- Conflicting interests are a stressor. Competition for the same resources can make finding resolutions difficult.

        - Because resources are limited, the competition is significant and compromise often has repercussions for everyone.
        - An example is: farmers/ranchers and energy (fracking) producers both want to both use water. Energy producers disturb agricultural production and spills can permanently impair future productivity. Often the mineral, water, and land rights are disassociated – each with their own economic impact.

Who are the key stakeholders within these 'intersections', and how might they better cooperate to elicit beneficial change?

- Key stakeholders identified:
    - Land owners, farmers, ranchers, agriculturalists
    - Local policymakers, municipalities, communities and other downstream entities
    - NGOs, nonprofit
    - Energy producers, industry, utilities (both public and private)
    - Tribal entities
    - Wildlife
    - Private sector and entrepreneurs (industry/manufacturers/transport)
    - Academia (university/researchers/educators)
    - Government/politicians/federal agencies
    - General public
    - Economists
    - Local/national/international consumers
    - Each production area has different key stakeholders, such as:
        - For ethanol production: stakeholders are farmers, industry, consumers, governments, and commodity and environmental groups.
        - For unconventional oil production: stakeholders are farmers, society, industry, governments, and environmental groups.
- How do they work together? They work together through:
    - Stakeholder forums/networks
    - Communication
    - Consensus building
    - Regional collaborations
    - Chambers of Commerce working with industries
    - University collaboration with local farmers
    - Landscape cooperatives, LCC
    - Other means of knowledge sharing – websites, social media
    - A commission or a group to lead the effort with no conflicts of interest to look at the FEW nexus
    - Transparent, open-sourced information and communication
    - Facilitated engagement, and independent facilitator
    - There have been many examples of stakeholders working together for mutual benefit, examples include:
        - Research institutions, researchers, policymakers, farmers (e.g. South Dakota Corn Council, Farmer interest groups, Stockman Growers Assn) working to mitigate nitrate loss from the fields. Producers are

        collaborating with researchers to reduce fertilizer costs and improve water quality.
        - Land owners, farmers, ranchers, recreational land users, energy producers, and native tribes work together on hunting/fishing and game production.
        - Sage Grouse Initiative: government, farmers, and ranchers work together to voluntarily improve Greater Sage Grouse habitat.
- It impacts the society as whole as it impacts economic infrastructure as whole.
    - There are global implications. Our decisions will impact foreign policy and international consumers.
    - Beneficial change comes with better education regarding the problems and the impact of it will have as a whole and how it can be better mitigated. Use global models need to be used to better predict long trends and assess impacts and benefits.
    - We need to closely work at all levels to develop joint strategies warrantee mutual benefit.
    - Area of further exploration:
        - Reduction of costs. Not just economic costs, but socioeconomic, political etc.
    - People need to see the value of changes, to do this we need include educational and outreach components to research.
    - We need to frame opportunities and sustainability/efficiency in terms of economic incentives and use economic arguments to positively influence behavior.

Day 2 – Group Discussion Questions

What would be your ideal goals for achieving FEW sustainability in the Northern Great Plains region?

- Overarching goals:
    - Defining what a healthy steady state constitutes and then reaching that state.
    - To achieve global sustainability, as opposed to local sustainability.
    - That we develop an adaptive, encompassing sustainability approach. That we are resilient in such a way that it extends to other regions.
- Multi-dimensional goals:
    - When we are starting a project on one of the FEW areas, we then have to consider the other two FEW areas.
    - We would like develop a good understanding of trade-off implications for increasing food or energy production in the region. We need to understand feedbacks between FEW components.
    - Here one of the main issues for this region is land. Land is critical and should be considered in the nexus. "Land" needs to be in the middle (e.g. imagine a triangle with FEW on the points and "land" in the middle).
    - Include climate in the nexus (e.g. FEWC). Climate is a "leg" in the stool and it impacts food, water, and energy.
    - Integrating more social-science work in our nexus research.

    - Optimize export potential while maintaining self-sufficiency and quality of life.
- Socio-economic goals:
    - Determining the primary goals of all the individual stakeholders and discovering the synergies between these.
    - Policy-driven decisions need to represent the views of privately-held landowners (working with them rather than the policy). Most agricultural land is privately owned.
        - What should the incentives be and how should we foster them? And, how should it be framed to have people be amenable to it? People here are independent and conservative. Overall, they don't like the government telling them what to do.
    - We need to also think of the sustainability of other areas. We need act to strengthen other regions and our nation and contribute to overall sustainability. We need to better connect with areas outside the Great Plains.
    - Economical solutions that would aid in adoption of sustainable practices.
- Ecosystem goals:
    - No net loss of grasslands.
- Agricultural goals:
    - Consider the "Bread Basket" nature of the region, locally oriented project consider downstream impacts.
    - Integrated systems, continued food production in the context of sustainability, focus on local foods, maintain rural lifestyles, vertical integration.
    - To develop sustainable communities in the rural great plains. Currently, rural regional communities have approximately 65 as a median age. Increasing agricultural production tends to decrease population.
        - To have a sustainable rural populations and community.
        - To focus on agricultural technology development. And its impacts on:
            - Being able to have enough food, water, and energy available for the foreseeable future.
            - Achieve no net loss or degradation to natural ecosystems, including freshwater environments (wetlands, rivers, lakes). We want to maintain both water availability and high quality water.
    - We would like to have a better understanding of long term soil carbon dynamics and how it relates to sustainable agricultural management. For example, soil organic carbon could be improved by including oilseed crops and diversifying rotations. We would like to understand the synergistic effects between crops and rotations.
- Energy goals:
    - Discover new transformative technology which offsets economic factors that still render fossil fuels viable.
    - We would like to become carbon neutral. We would like to have high-carbon footprint nations take more responsibility investing in future technology.

What do you think are the FEW tipping points or 'critical vulnerabilities' in our region?

- Ecosystems

- Are grasslands in this region a sacrifice zone? Land-use change, industrialization of agriculture, and climate change have reduced grasslands. Grasslands are a critical habitat for many keystone species, insects, and game animals.
    - Loss of critical grassland habitat and endangered species, cultural areas, species of special concern is a critical vulnerability. These areas and species need to be protected to preserve diversity and ecosystem resilience.
- Loss of the natural landscape due to maximization of production (e.g. use of 'marginal land' for biofuel feedstock production). Once loss and segmentation of natural landscapes reaches an ecological threshold, ecosystems and food webs begin to collapse.
- Every region has a 'sensitive' habitats, some of which are not well understood. For the upper Midwest, one of those areas is the Nebraska Sand Hills. Once the Nebraska Sand Hills (currently vegetated dune-field) start actively moving across a wide area and are destabilized, there will be large-scale agricultural and ecosystem collapse. Because, mobilization of the Sand Hills will mean that the Ogallala Aquifer has been regionally dropped to non-recoverable levels and that there has been a prolonged drought which killed off all surface vegetation for several years. Previously, it was a 100-year process to destabilize the Sand Hills, however, how climate change and aquifer changes have accelerated this process is unknown.

- Water
    - Aquifer vulnerability is critical. Aquifer water levels are a measurable tipping point due to our regional dependence on groundwater.
    - Wetlands are highly vulnerable, declining ecological health of wetlands (i.e. Prairie Potholes) can indicate a tipping point. This can be in the form of wetland loss, biodiversity loss, and pollution. The Prairie Potholes in the upper Great Plains are a critical migration point and habitat for waterfowl.
    - Changes in surface water quality and use.
        - An example would be loss of cold-water fisheries/recreational status of surface water bodies. An example is: people will no longer being able to swim and fish speciation will change in regional water bodies due to water temperature increases, parasites, and algal/fungal blooms.
        - Widespread changing of the timing of water-turn over and trophic state of lakes and reservoirs. This can be due to both climate change and more direct anthropogenic influences (e.g. nutrient pollution, water withdrawal, sedimentation).
- Socio-economic
    - Divisive, increasingly polemic political rhetoric where there is no room for cooperation. So, any "sustainability" issue with political dimensions becomes very difficult to develop, address, and resolve.
    - Economic incentives are currently king. Sustainability is not the driving force behind decision-making. Continuation and creation of counter-productive, non-sustainable subsidies, policies, and other economic incentives will persistently work against sustainability.

- Vulnerable segments of society no longer have the resources to purchase food, fuel, electricity, and meet other basic needs.
- Expanding urban regions, and declining rural communities. This has overall negative results on the community including loss of agricultural workforce and aging expertise, loss of local services (e.g. medical, commercial), and declining infrastructure. Without the support structure of rural communities, agricultural production is at risk of loss of efficiency and/or collapse. We need to maintain our workforce and infrastructure.
- We need to understand the social context better.
  - We need to more clearly articulate the research questions. What are the specific questions that we need?
    - Such as, how are land-use decisions made by those who make the decisions locally? What influences those decisions? What factors affect the timing of these decisions (e.g. life events)?
  - What is the economic value of the goals that we are hoping to achieve? The economic valuation of these sustainability goals will determine social thresholds.
  - How many land-use decisions are being made by absentee landowners? Many agricultural operations have been 'consolidated' over the last century. High cost and competition make entry into agricultural production difficult. Disconnected landowners and poor renters often do not make sustainable decisions. This relationship will likely reach a critical regional/localized threshold. We need to incentivize stewardship with absentee landowners.
- When our land stewards and elders are no longer able to understand the land and act in a manner to preserve land and resources for future generations. We need to understand the barrier to adoption of sustainable practices and how climate change and economics will impact locally and educate appropriately.

- Climate
  - Drastic change in temperatures and precipitation patterns caused by anthropogenic climate change including that from the burning of fossil fuels. At a certain point, changes in temperatures, seasonality, and precipitation will negatively affect crop and livestock production.
  - Statistical trends in and measurement of regional productivity can indicate that agricultural production is being impacted by climate change. It is possible that a point will be reached where agricultural crops are failing more often than they are succeeding.
    - Climate change will induce more dramatic weather trends. Long-term droughts, heat waves, and floods will impede resilience development and may cause economic, ecological, and/or production collapse.
    - Climate variability (i.e. year to year variability, not just long term climate change) and unpredictability will negatively affect crop and livestock production.
    - Changes in soil moisture will cause a shift in agricultural crop types and increase production risk.

        - Changes in grassland ecosystems growth and diversity will affect the stocking rate and nutrient content of forage (this will also affect enteric digestion/methane emissions in ruminants) available for livestock and wildlife.
- Agricultural
    - Soil health is a tipping point in the upper Great Plains. Soil health is affected by numerous factors such as irrigation, compaction, pollution/contamination, microbes, agricultural management, erosion, and climate change. Impacts will impair current and possibly future productivity potentials once certain regional thresholds are reached.
    - Soil erosion, changes in water quality and quantity may reach the point that ecological goods and services are impaired or permanently damaged.
    - Agricultural monocultures have a risk of enhancing the "food deserts" if crops fails. Monocultures promote pest development, increase dependence on chemicals, and create ecological dead-zones. Rotation and genetic diversity is a healthier, however, it is not always more economically profitable.
    - Agricultural production is sensitive to the environment. Any changes to the natural environment would have major impact. An example of this is the loss of pollinators. If pollinators are not present, then many food crops fail and/or are less productive.
- Energy
    - Rapid land use change from oil & gas exploration/extraction activities and agricultural production will reach a point where there is ecological collapse. This is due to habitat loss, fragmentation, and pollution/contamination.
        - For example, the nighttime ‘city lights’ in North Dakota from well flares.
    - Cost of fossil fuel production and/or transportation become prohibitive for export of regional products.
        - This is also related to rural infrastructure degradation and population declines. For example, in South Dakota, there has been an over 75% loss of rail lines and all passenger trains (with the exception of one tourist attraction, the 1880s Train) in the last 100 years. Paved roads in some rural areas are being converted back to gravel because of lack of maintenance funds. These infrastructure ‘downgrades’ impact transport efficiency. A certain point, the lack of infrastructure investment in rural areas will reach a threshold that will impair product export.
- More research should be done to determine/assess the critical vulnerabilities and determine thresholds as a first step.

Identify key Northern Great Plains-focused FEW ‘considerations’ that the NSF should include within future FEW proposal solicitations.

- Over-arching recommendations:
    - Develop an agreed-upon approach for addressing complex issues. Funding should be targeted towards methods development. This would enable us to conduct case studies in different places and combine results to determine regional/national/global trends. The key to accurately representing and

aggregating results is using a standardized methodology. For example, LCA now has a standardized methods which allow results to be combined/compared.
    - We need to develop a systems approach for adaptation to climate change (e.g. breeding the right crops, correctly allocating future water in future quantities available, maximizing energy production under future climate scenarios).
    - We need to understand the connections from local FEW policy and activities and what global impacts they may have.
    - We need to develop a broader cost-benefit analysis that monetizes ecosystems and biodiversity, and factors in health and well-being of citizenry.
    - Our way of life is at risk if "whole system" crashes.
            - For example, issues go beyond the old family farm, to ecosystem services in an area. Tourism is an economic driver, if pest issues such as pine beetle got out of hand and destroyed the Black Hills it would have economic repercussions.
        - When our natural resources are compromised, it becomes a threat to our identity, our way of life, and our culture – not just our resources.
        - Research must be interconnected. Many issues are not just natural science, they are connected to other disciplines, knowledges, systems etc.
    - We need to use a systems approach to research and sustainability.
- Specific sub-topic recommendations:
    - We need to understand the differences between owners and renters in terms of long- and short-term management. This is most accurately done on the SAME land. We need to understand the differences in sustainable management beliefs.
    - Prioritize fundamental research in bio-based products and polygeneration.
    - We need to have a better understanding of grassland ecosystem services.
    - We need a better understanding of water sustainability so we can minimize the uncertainty.
    - We need better techniques for improving water quality. Water needs to be a central focal point and we need to simultaneously understand how water affects energy and how water affects agriculture.
    - We need to optimize water use and re-use. We need to improve the efficiency (i.e. reduce consumption, increase re-use). This will possibly positively impact the economics of projects and reduce the environmental impact.
    - The sustainability of groundwater and many regional aquifers is not well understood. These will be critical resources for overall sustainability.
    - We need to understand the impacts of water prioritization/restrictions. There is a need to not only understand past events, but to develop prediction tools for the socio-economic-environmental impacts and effectiveness of future water limitations
    - We need to investigate and develop 'passive' technological solutions to food, water, and energy that do not need consume resources to be maintained. Process that use natural forces (e.g. gravity, unique shapes and designs, friction, etc.) that are simple and cheap to implement.
    - We need to investigate our own backyard. We need to explore the potential of our biological diversity and potential for medicine, products, or commercial production before they are gone (e.g. traditional medicines, local plants, weeds).

For example; prairie turnips make a nutritious gluten-free flour and dandelion roots can be used to make rubber. A larger variety of local sustainable products and from alternative sources need to be developed.

- We need to understand the long-term repercussions and potential of unconventional oil & gas production for our region. Unconventional oil & gas production in each regional play comes with different challenges. For example, in the Bakken, produced water is often high in radioactive elements (e.g. Ra, U). This cause additional treatment and water re-use complexities.
- We need to evaluate the role of livestock as a potential key player in fuel, such as methane production. Is it possible to capture and/or reduce methane emissions from free-range, grass-fed livestock? Or, even wetlands or wildlife? We have fundamental research on carbon capture and storage, but can we capture and store (or use) other greenhouse gases as well?
- We need to better develop regional scale climate modeling for specific predicting/forecasting changes due to climate change. Current national/global climate change models need to be modified so that local/regional models can be adapted appropriately.
  - We need local/regional seasonal and trend forecasting for agricultural planning/production. Current resources assist producers, but do not incorporate the fluctuating conditions due to climate change.
  - Reliable predictions would affect agricultural, energy, and water management decisions. Such as, what crop can/should be grown with the predicted moisture, or, how low or high should reservoir levels be maintained?
- The drivers of decision making (e.g. incentives) need to be better understood and leveraged to improve short- and long-term FEW sustainability.
- We need to better understand the infrastructural changes (i.e. transport, processing, distribution, electrical/water systems) needed to meet sustainability goals, any associated short- and long-term impacts, and develop innovative retro-fitting techniques. For example, economically retrofitting municipalities with independent stormwater, graywater, and sewage handling infrastructure for water pollution prevention and conservation.
- Land use change is monitored. However, the land use changes and impacts due to climate change, planned policy or incentives, and social ideals needs to be better modeled. Ultimately, we need to be able to forecast resource limitations to better adapt to likely changes.

What are the tools and data needs to successfully model FEW systems?

- For bio-based products and polygeneration - we need to reduce capital and operational expenditures, especially of start-ups.
- Data:
  - We need more and easily accessible historical data available to model climate change impacts and better prediction future impacts and develop adaptations. Data such as biodiversity measurements/changes, socio-economic decision trends, etc.

- There is a need to quantify ecosystem services and value them. We need to incorporate them into economic models.
- We need data pertinent to stakeholder behavior to predict trends. Datasets such as this could be useful in balancing supply and demand and affecting policy.
- We need long-term, maintained databases within a centralized repository.
  - We need a compilation of existing core data sets. Then we need to conduct gap analyses to identify additional specific, regional and national data needs.
  - Datasets need to be interdisciplinary, linkable and easily integrated.
  - Datasets need to be regularly updated (planned contributions/dates/milestones), standardized, and incorporate regional/locally specific data.
  - We need to be able to document and measure change.
  - We need the ability to generalize or focus datasets for models in a standardized (e.g. replicable, rule-based) manner.
  - Datasets need to be interdisciplinary, easily accessible and updatable, and validated.
  - Data format needs to be flexible and convertible for rapid ingestion into different models (export capability) within a single interface. Data platform should be 'open-access' but information within should be flexible able to be integrated into proprietary models.

- Modeling:
  - Some of the models (e.g. GREET) do not have 'land' built into the model (e.g. many models use proxies for land, carbon-impacts, and/or yield).
    - Whereas, other models do not account for "quality" differences between feedstocks (e.g. feedstock properties such as oil-chain lengths/acid type, energy content).
    - Models need to incorporate feedstock quality, land-use/management decisions, and economic decisions.
  - Modeling needs to be spatially explicit. We need the ability to either directly incorporate spatial variations/results or the ability to simply spatially couple interdisciplinary models.
    - For example, in LCA if you have processes in different locations, then it is harder to model and develop accurate results due to spatial variations.
  - We need a *non*-supercomputing climate change impact model that allows us to assess and balance multiple objectives, regional/local systems, and priorities.
    - We need to develop a well coupled, integrated model of land-use change, hydrology and climate.
    - We need efficient, accurate, and accessible (cheap or free) desk-top interdisciplinary models. Current models require super-computing, expensive programs, and/or days/weeks to run scenarios.
    - Coupling models often requires scripting which is a prohibitive skill/cost/time for many research projects. Adaptable (pre-integrated) APIs or pre-created links between commonly used models would save time and effort. This would allow focus on solving problems, not writing scripts.

    - We need optimization and risk assessment models that incorporate environmental impacts and/or life-cycle analyses.
        - Risk assessments need to incorporate inputs and outputs that allow them to be customizable and focused on end-usability.
            - We need inputs on 'what' and 'how' activities are conducted/done.
            - We need tools for interdisciplinary decision making.
    - We need integrated nexus process model components and process models.
        - We need fundamental research that feeds into developing the model components.
        - We can get a lot of information from life cycle assessments which would be beneficial for process modeling.
    - We need to develop a systems dynamic approach and models. An example of a systems dynamic approach is Ben Turner's 2014 Dissertation, "To Plow or Not to Plow?" available at: http://pubstorage.sdstate.edu/wfs/thesis/Turner-Benjamin.pdf.
- Tools:
    - We need easily accessible communication tools that can bridge and engage stakeholders. We need an interactive 'indicator' system to gauge social belief, awareness, knowledge, etc. This is especially applicable to key rural stakeholders such as farmers, ranchers, and tribal/community leaders.
    - We need to make science actionable and accessible.
        - We need a communication tool for the people incorporating new practices on their land or documenting practices in a way that's not paternal, but as a resource partnership.
        - We need an adaptive, collaborative relationship with stakeholders, not just instructive.
        - We need to develop and share local based knowledge. We need to provide ownership of knowledge to the local community.
        - We need participatory research/citizen science to be funded by NSF. FEW sustainability action and many innovations will not be done by elite scientists and researchers. It needs to be a national, interdisciplinary engagement at all levels. We need to reach the 'common man'.

What current and/or future technologies should be implemented or developed to advance our understanding of FEW?

- Current Technologies:
    - We need to implement spatially explicit modeling.
    - We need cross-disciplinary collaborations beyond FEW and related conferences, *in research and in the field.*
- Future Technologies:
    - How should we valuate food-energy-water nexus resources?
        - We need to develop a valuation system.
            - We are concerned about the use of money as a proxy for all valuation. Is this really an appropriate valuation?

            - Many fundamental resources such as air and water do not have a standardized monetary valuation. Traditional economic evaluations remove the importance of these 'un-monetized' resources.
        - Due to the lack of monetization and social impediments to developing a cohesive monetization for these resources, we need to develop a valuation system (perhaps other than money) that will express the resource importance appropriately.
            - We need a multi-objective evaluation (don't try to simplify it down to one parameter).
                - We don't want policy makers to incorrectly assume one answer can solve all issues. There are no simple answers to these complex system issues.
            - We need to present resources and issues in terms of tradeoffs. We need to highlight the relationships among the tradeoffs
        - If we don't value things then they don't end up 'counting' (e.g. our water is now largely free, oil was previously almost free).
            - We need to somehow value water, ecological services, etc. (e.g. We could have a water "right" or allotments like in Australia.)
    - We need zero-discharge technologies and water reuse technologies for all levels (e.g. industry, communities, individuals).
    - We need small scale solutions for diffused resources.
    - We need affordable SMART monitoring technologies (sensors) integrated for energy/agriculture/water resource use across the region.
    - We need to shift away from non-renewable resources to renewable resources and products. To do so, we need cheap and recoverable catalysts; affordable separation technologies; heat stable enzymes; and degradation/ decomposition/ recycling research for bio-based product production. We need to form the foundation of a 'bio-product' revolution. We want to create fundamental building blocks and technological advances for environmentally-safe, cost-effective bio-product development.
    - Public communication and outreach technologies:
        - We need a mechanism and/or technology to capture more local knowledge about local conditions.
        - We need to strengthen extension and outreach.
        - We need to develop online communities and resources.
            - People 'telling stories' online can provide people with a voice and increase awareness of on-going changes and ideas.
        - We need effective tools to encourage communication with stake holders (as well as between stake holders) and policy makers.
        - We need tools and outreach activities to counter scientific distrust and confusion of the populace (e.g. climate change, production efficiency, environmental impacts). We will not be able to achieve sustainability without 'buy-in' and support of the majority.
    - We need to hasten plant breeding techniques and improve production efficiency. We need to develop molecular markers and other molecular tools to enhance

breeding (boinformatics of specific crops); precision technologies; irrigation technologies; and waste water recovery technologies.
    - We need greater plant photosynthesis efficiency.
    - We need technologies that can easily integrate different types of data and model complicated systems (e.g., social, ecological).
        - We need adaptive integrative interdisciplinary models.
        - We need to fully integrated land use/hydrological/climatological models.

For these key considerations, identify key human behavioral attributes that must be changed, and how might these changes be accomplished?

- We need people to have a "Leopold" ethic and want to leave things better than they found them. Do we need a carrot and/or a stick? Perhaps, the most effective way to create change is to use both?
    - Voluntary:
        - We need to incentivize sustainable practices and minimizing resource use through tools such as financial awards, social recognition, etc.
        - We need to increase public outreach at all levels. (i.e. "Don't be a litterbug!" Campaign began in the 1980s reached parents through children; adopt-a-highway program)
        - We need to encourage minimizing resource utilization by citizens.
        - We need to change what we prioritize and teach our children (e.g. food waste, healthy activities, ethics, recycling, pollution prevention).
        - We need to expand personal responsibility. For example, this can be done for food production with school and community gardens, local food production, and to revisiting wartime concepts such as 'victory gardens'.
        - We need to make sustainability everyone's lifestyle.
        - We need to institutionalize sustainability and develop sector-based conservation, efficiency and productivity goals.
    - Involuntary:
        - We need foundational laws, legislation, fines, and penalties with teeth to counter pollution and waste.
        - We need to mandate change at all levels (i.e. individual, household, business, corporate, municipal, county, state, federal). Such as mandatory recycling and creating per household waste volume limits (or, fees such as, the more you waste, the more it costs).
        - We need to increase tax-breaks and legal incentives for sustainable products, efficiency, and/or services.
        - We need to increase sales or consumption taxes and/or fees for unsustainable products and/or services.
        - We need to place a value on all resources, including water. We need to make these resources valuable enough to economically and socially force sustainability.
            - We need methods for appropriately and sustainably assigning rights/values to scare resources.
        - We need legal actions and precedents to be set favoring sustainable practices.

- For example, the City of Des Moines, IA has sued upstream counties for allowing and not mandatorily curbing agricultural run-off and associated nitrate pollution which is damaging the City's drinking water quality.
- Do we need to revert to mandatory 'rations'?

- We need to change consumption patterns. We need to reduce our waste and our overall food, energy and water depletion.
    - We need to make sustainability profitable.
    - We need to appeal to people's instinct for self-preservation and survival.
    - We need to make sustainable activities 'easier' than unsustainable ones.
    - We need to effectively change behavior at all levels. But, how do we get people to 'care'?
    - We need to understand what triggers behavioral change. This may be different for different groups (e.g. culture, geography, education, economics).
- We need to phase out of fossil fuel-based and other non-renewable resources.
- We need more long-term planning and outreach.
    - We need immediate, short-term actions which show benefit to gain 'buy-in' for long-term plans.
    - We need to increase the general public's understanding about the drivers of better management practices (BMPs).
    - We need to bring stakeholders together to have them understand the connectivity.
    - We need to educate the general public on issues. We need to take complex systems and make them understandable to the public.
    - During prolonged crises and lack of resources, society changes because it is necessary.
        - We cannot ignore human nature and core instincts. If a global and/or nation-wide crisis occurs - political correctness, courtesy, and social progress will be ignored. The focus will be on national and self-preservation. Do we need to prepare for that instance?
        - How can we avoid the point where 'only the strongest will survive'?
        - Do we need to 'harden' ourselves and focus efforts inward because we cannot sustainably preserve everything and everyone?
        - The frightening bottom line is people preserve and care for themselves and their community first and fight to protect their resources if necessary.

Additional Participant Thoughts:

- Ideal components of a successful investigation:
    - Innovative approaches that allows quantification and comparison of food, energy, and water resource values.
    - Incorporating the influence of political ideology and cultural mores.
    - We recommend using a case study approach to investigate nexus issues.
        - For example, a case study of communities to show more localized framing of risks such as climate change. We need to personalize food, energy, and water nexus sustainability issues.
    - We need to stop isolating the study of social and environmental problems. Economic analyses need systems approaches.

- We need 'carrots and sticks'.
  - We need regionalized policies reflective of cultures across landscapes in a state.
    - In order to accomplish this, we need local government level action.
    - We need to have the local rules in place with loftier goals with the support of more general state and federal regulation. So, if locals don't change and meet specific goals, the state or federal government will have authority to intervene.
- We question the sustainability of high corn production volumes. Maintenance of these production rates (200+ bu/ac) require significant fertilization, heavy chemical applications, and perpetual advances in genetic engineering. With each shift in the monoculture, pests are evolving and overcoming advances. The debate over corn production has fanned the flames of the 'food versus fuel' debate. Perhaps, rightly so. Are our food, let alone biofuel feedstock production levels sustainable?
- We need to work with other disciplines to generalize solutions and new interdisciplinary techniques to solve complex (i.e. wicked) problems.
- We have a fundamental conflict between economies of scale vs resource conservation. Distributed, smaller operations won't have the economies of scale, but will minimize transportation costs and broaden the economic and societal benefits. Can we develop small-scale local solutions that have the economy of scale?
- How do we define efficiency? Often it is focused too much on economic efficiency, or profitability. We need to also define efficiency as it relates to mass, energy, environmental sustainability, etc.
- We need to make an effort to more clearly and completely monetize indirect effects. Too often we base decisions on incomplete information. For example, the metrics of a given process might look positive, but if one considered all the negative direct/indirect effects, another option may be better.