Solutions at the Nexus of Food, Energy and Water (FEW) Systems
Findings from the 2017 FEW Nexus Workshop and Multi-Stakeholder Dialogue on Integrated Science, Engineering, and Policy

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1.0 Executive Summary

Our national and global communities face huge challenges in securing access to the primary resources of water, energy, and food. These insecurities are fueled by changing climate, population, and demographics. The resources are highly interlinked at multiple scales, such that managing and integrating our responses to the interactions and interdependencies of food, water and energy (FEW) systems is increasingly part of the public consciousness. The long term sustainability of these systems requires holistic, systems level solutions that integrate across scales and disciplines, and that provide a platform for combining deeper knowledge of this complex system of systems with appropriate technological, policy, and human behavioral perceptions. The Food–Energy–Water (FEW) Nexus offers such platform. The platform is progressing rapidly to design and offer solutions that rely upon the integration of science, engineering and policy and that incorporate knowledge-towards-action, new technologies, planning, policy, behavioral adaptation, and finance pathways.

Urban growth, migration, resource constraints, changing climate, and multiple additional factors bring these challenges to the fore. Yet, the science, engineering and policy communities must grapple with challenging questions regarding what can be or should be done; how rapidly; in what order. Just how to mold FEW nexus policy in order to help achieve sustainability and resilience goals was the focus of a high level meeting in which leading experts working in FEW fields, their policy and governance, and the data collection and modeling of these, were assembled. The assembly addressed new research and data collection approaches for enhancing research that is capable of modeling and monitoring the processes associated with resilience, vulnerability, climate change, and risk reduction. Among its primary outcomes will be development of a conceptual framework to address these issues effectively.

The NSF **FEW Nexus Workshop on Integrated Science, Engineering, and Policy: A Multi Stakeholder Dialogue Symposium**, took place January 26-27, 2017 in College Station, Texas. A local organizing committee worked with representatives of the larger scientific committee (see appendices III and IV for a complete list). In all, the workshop included 125 scientists and professionals from the private and industrial sectors, government agencies, civil society, national laboratories, and more than 30 research and educational institutions. Portions of the meeting were live broadcast, to include participation globally. Each of two days began with plenary sessions and panel discussions that were followed by break outs focused on specific relevant topics. Following the sessions, participants reunited for a closing plenary each day and an evening reception and two lunches offered informal networking opportunities. (See the detailed program, Appendix I.)

The workshop identified interdisciplinary research agendas for engineering, agriculture, geosciences, social, behavioral and economic sciences. It also called for new approaches to innovative research and data collection to enhance research that is capable of modeling and monitoring the processes associated with changes in climate, resiliency, vulnerability, risk perception and overall enhancement of sustainable management practices for primary resources. Specific discussions were organized around **10 BIG IDEAS** identified in advance and prepared as white papers to provide a springboard for addressing specific research themes in the context of the FEW Nexus interrelations and the need for transdisciplinary collaboration to address their integrated management. These white papers became the foundation of a special issue that will be published by Springer, making it available broadly to the global scientific, policy and stakeholder communities who must address nexus issues (See Appendix V for a list of white paper scopes and authors.) Follow up is planned to explore ways to encourage a community of science and practice to more effectively understand and address the FEW Nexus challenges.

The discussions focused on ways to address the many challenges posed by the interdependent FEW systems and their integrated governance and management. Also explored were the core challenges, data gaps, and potential transformative solutions associated with the FEW nexus. The essence of the current state and the gaps we face are summarized in these proceedings. [The papers will appear under the online first tab, "articles not yet assigned to an issue," at the link [https://link.springer.com/journal/volumesAndIssues/40518](https://link.springer.com/journal/volumesAndIssues/40518) until transferred to Issue 3 (on September 1, 2017)]. A synopsis of the special issue papers follows.
2.0 Proceedings of the Meeting

Our national and global communities face huge challenges in securing access to the primary resources of water, energy, food. These insecurities are fueled by changing climate, population, and demographics. The resources are highly interlinked at multiple scales, such that managing and integrating our responses to the interactions and interdependencies of food, water and energy (FEW) systems is increasingly part of the public consciousness. The long term sustainability of these systems requires holistic, systems level solutions that integrate across scales and disciplines, and that provide a platform for combining deeper knowledge of this complex system of systems with appropriate technological, policy, and human behavioral perceptions. The Water–Energy–Food Nexus offers such platform. The platform is progressing rapidly to design and offer solutions that rely upon the integration of science, engineering and policy and that incorporate knowledge-towards-action, new technologies, planning, policy, behavioral adaptation, and finance pathways.

Urban growth, migration, resource constraints, changing climate, and multiple additional factors bring these challenges to the fore. Yet, the science, engineering and policy communities must grapple with challenging questions regarding what can be or should be done; how rapidly; in what order. Just how integrate efforts to mold FEW nexus policy in order to help achieve sustainability and resilience goals was the focus of a high level meeting in which leading experts working in FEW fields, their policy and governance, and the data collection and modeling of these, were assembled. The assembly addressed new research and data collection approaches for enhancing longitudinal research that is capable of modeling and monitoring the processes associated with climate change, resiliency, vulnerability, and risk reduction. Among its primary outcomes will be the development of the conceptual framework to address these issues effectively.

2.1 Meeting Objectives: The meeting was co-moderated by Peter Saundry (Senior Fellow, National Council for Science and the Environment, Adjunct Professor of Energy, John Hopkins University) and J. Carl Ganter (Co-Founder and Director, Circle of Blue). The two welcomed participants and introduced the Texas A&M hosts: Glen A. Laine (Vice President for Research), Dimitris Lagoudas (Senior Associate Dean for Research and Assoc. Vice Chancellor for Engineering), and Craig Nessler (Director, Texas A&M AgriLife Research, College of Agriculture). Rabi H. Mohtar (Texas A&M WEF Nexus Initiative) presented the workshop objectives:

1) **Improve** the level of integration for future INFEWS proposals.
2) **Foster** national team building toward future proposal submissions.
3) **Build** on the NSF investments over the last 18 months toward the creation of a FEW Nexus community.

2.2 Meeting core areas of focus: Mohtar introduced keynote speaker JoAnn Lighty (NSF/CBET Division Director), who through a live web session, outlined the critical directions of NSF thinking in the FEW Nexus arena:

- **Identify** multiple, interdisciplinary research agendas for engineering, agriculture, geosciences, social and behavioral sciences, and economic science;
- **Identify new approaches** to innovative research and data collection that can enhance research capable of modeling and monitoring the processes associated with changes in climate, resiliency, vulnerability, risk perception, and
- **Enhance sustainable management practices** for primary resources.

Discussion of these objectives and critical directions focused on the presentation of 10 BIG IDEAS which had been identified by the Organizing Committee and prepared in advance of the meeting to serve as white papers addressing specific research themes in the context of the FEW Nexus interrelations and the need for transdisciplinary collaboration to address many of the challenges to be identified during the workshop. These white papers became the foundation of Special Issue 3, to be published in September by Springer, and can be accessed at https://link.springer.com/journal/volumesAndIssues/40518. The papers will appear under Issue 3. (See authors and scope summaries in Appendix V.)
The topics of these ‘Big Ideas’ include:

- **Data and Modeling**
- **Governance, Policy, and Financing**
- **Governing Resources in Future Cities**
- **Tradeoffs and Decision Support Tools**
- **Energy for Water**
- **Water for Food**
- **Water for Energy Production**
- **Food Processing and Waste**
- **Soil–Food –Climate Nexus**
- **Engagement and Outreach: Community Building**
- **Nexus Community of Science and Practice**

- **Food-Energy-Water Nexus:** Energy efficiency and the interactions between energy, water, and industrial systems must be improved in a manner that productively leverages the connections between natural and engineered water systems and increases availability and delivery of water for agriculture. The water requirements of the energy sector must be better understood. Meeting food production requirements demands improved plant genetics, but also improved irrigation technology and practices. Urban agriculture can empower locally optimized outputs and demands. Prevention and recovery solutions to alleviate waste from food production (farm), processing (industrial/retail), and consumer must be developed.

- **Tools:** Interdisciplinary research is needed to promote and enable sustainable and efficient management of water and for its use in energy and food production. Improved analytical systems frameworks for data integration and analyses can help accelerate planning and decision-making on FEW issues. Disciplinary data that has been gathered for years is not frequently integrated and correlated to provide cross disciplinary data. Nexus data systems must integrate across spatial, temporal, and thematic dimensions, and outline challenges in Nexus data acquisition and ways to address this research gap. Modeling and analysis are a necessity: the challenges of representing an appropriate geographic region while encompassing relevant FEW activities are vast, and make an integrated modelling framework for Nexus analysis essential. Soil is a basic Nexus Tool, a naturally organized medium with a critical role in protecting global food, water, energy securities: a paradigm shift is needed that integrates soil and acknowledges the FEWS Nexus (Food-Energy-Water-Soil). Trade-offs and Decision Support Tools are needed that enable integrated assessment of FEW systems trade-offs and evaluate these trade-offs to enable identification and design of a set of robust strategies for addressing future conditions.

- **Governance:** must be informed by these Tools, which will support improved understanding of the Water-Energy-Food Nexus in a manner that allows governing bodies to address the needs of all stakeholders equitably and sustainably.

- **FEW Nexus Community of Science and Practice (NCoP):** a transdisciplinary community of scientists is needed to address the water-energy-food nexus security issues by identifying common threads and attributes inherent to them and develop potential solutions for addressing the challenges that must be faced.

### 3.0 Meeting outcomes

This section of the report outlines outcomes from the workshop, including a current situational analysis and recommended future steps. Additional information about the activities of this community is available at [www.wefnexusinitiative.tamu.edu](http://www.wefnexusinitiative.tamu.edu). The targets and priorities identified, the actions and activities planned, timeline, teams, and roles needed to accomplish the targets, and identify the needed resources for implementation are summarized. These are intended to help identify the next steps for defining and expanding the national FEW Nexus agenda. Moving forward, organizers of the workshop intend to work with NSF, NIFA, and other agencies toward implementing the suggestions and establishing the FEW Nexus community of science and practice. These outcomes are based on deliberations by workshop attendees. The session organizer continue to engage the National and Global Nexus community towards these outcomes. This Nexus Community now numbers over 500 individuals, worldwide.
3.1 Current status: There have been numerous FEW Nexus activities across the nation and across various disciplines, including research, education, and engagement activities. The NSF INFEWS program, in particular, has promoted such interest through its funded workshops and research. The community of interested scientists and practitioners is growing, although it currently lacks coherence and coordination. More importantly, there is not yet access to an inclusive, open platform for sharing knowledge, good practices, and establishing the common goals, standards and opportunities needed to chart the short- and long-term goals of the community and to help define the way in which it can, and/or should, interface with other societies. We hope that the outcomes and recommendations of this workshop will help establish such a platform.

3.2 White Papers: The white papers generated from this workshop are currently nearing their final revision, in accordance with the agreement with Springer, who is attending to their publication in a special issue. Fifty two authors, including 9 advanced graduate students, and 18 institutions in the USA and abroad were involved in this effort. A list of the 10 white papers and their title, scope, and authors is included in Appendix V. The special issue and full papers (Issue 3) will be available at: https://link.springer.com/journal/volumesAndIssues/40518.

3.3 Next Steps: Moving forward, an inclusive and thematically balanced FEW Nexus community of science and practice is critical to support researchers in understanding, identifying, studying, and improving FEW systems. Engagement through professional societies of the broader Nexus community will bring diverse areas, especially those of energy and food (identified as weakly represented at the workshop), to the discussion. This broader engagement will continue to be pursued: meetings across the spectrum of professional societies will continue to be conducted in effort to build a wide support for the Community of Science. Examples include: American Chemical Society, American Geophysical Union, American Society of Agricultural and Biological Engineers, EPOA, IEEE, among others.

As such we recommend the establishment of a single FEW Nexus Community of Science and Practice (NCoSP). This would be the transdisciplinary community of scientists needed to address the security issues of the water-energy-food nexus: identifying common threads and attributes inherent to them and developing potential solutions to address the challenges that must be faced. Funding to enable the establishment of this community and a physical, as well as a virtual, platform will allow the community to further deliberate the issues raised at the workshop. These issues include, though are not limited to the following specific areas:

• Energy efficiency and the interactions between energy, water, and industrial systems;
• Productively leveraging the connections between natural and engineered water systems;
• Increasing the availability and delivery of water for agriculture;
• Renewable energy, in particular wind and solar, and its role in water, energy and food security
• Water requirements of the energy sector must be better understood;
• Water reuse potential for agricultural and non-agricultural usages;
• Food waste reduction: protocols, adoption and its impact on water, food and energy savings;
• Meeting food production requirements demands, including
  • improved plant genetics
  • improved irrigation technology and practices
  • urban agriculture can empower locally optimized outputs and demands
  • Prevention and recovery solutions to alleviate waste from food production (farm), processing (industrial/retail), and consumer must be developed;
  • Optimization of resource use efficiency along the food chain
• Tools:
  • Interdisciplinary research is needed to promote and enable sustainable, efficient management of water. It is also needed for its use in energy and food production.
  • Improved analytical systems frameworks for data integration and analyses can help accelerate planning and decision-making on FEW issues. Disciplinary data that has been
gathered for years is not frequently integrated and correlated to provide cross disciplinary data. Nexus data systems must integrate across spatial, temporal, and thematic dimensions, and outline challenges in Nexus data acquisition and ways to address this research gap.

- **Modeling and analysis** are a necessity: the challenges of representing an appropriate geographic region while encompassing relevant FEW activities are vast, and make an integrated modelling framework for Nexus analysis essential.
- **Soil is a basic Nexus Tool**, a naturally organized medium with a critical role in protecting global food, water, energy securities: a paradigm shift is needed that integrates soil and acknowledges the FEWS Nexus (Food-Energy-Water-Soil).
- **Trade-offs and Decision Support Tools** are needed that enable integrated assessment of FEW systems trade-offs and evaluate these trade-offs to enable identification and design of a set of robust strategies for addressing future conditions.

- **Governance**: must be informed by these Tools, which will support improved understanding of the Water-Energy-Food Nexus in a manner that allows governing bodies to address the needs of all stakeholders equitably and sustainably.

### 4.0 Meeting format

Addressing the underlying themes of *Research, Education, Practice, and Capacity Building*, began with the identification of synergistic research teams that will work together in developing FEW research proposals and other projects to be submitted to NSF, NIFA, DOE, Belmont, and other national and international agencies. Each group addressed five points:

1. how to define the target FEW systems;
2. identification of the key challenges;
3. how to determine solutions to the challenges;
4. identification of the key potential impacts (social, environmental, economic); and
5. identification of the resources needed for implementation.

Immediately following the day’s activities, an evening networking reception hosted by Texas A&M WEF Nexus Initiative allowed participants to interact informally. They were welcomed by Martin Scholtz (Executive Associate Vice President for Research, Texas A&M University).

The second day began with two panel discussions that were live broadcast to enable a global audience of more than 100 to join the 125 conference participants in a lively session moderated by Circle of Blue’s J. Carl Ganter. The **Science and Policy Panel** addressed questions of the characterization of the current state of FEW science and policy interactions nationally; the steps needed to improve science-based decisions related to FEW resources, potential policy changes that might improve the science–policy coherence in FEW resources.

The **Industry and Technology Panel** identified incentives to innovation in FEW systems, the unique technological challenges and opportunities posed, and infrastructure and human capacity needs to foster those innovations in the FEW system.

Afternoon sessions allowed participants to identify targets, propose action plans, activities, timelines, and teams for achieving targets. These sessions focused on

1. building on the **white papers** produced from the Big Ideas session and published by Springer;
2. establishing a **Community of Science and Practice** through a research coordination network (RCN) proposal and an e-portal; and
3. anticipating research opportunities, such as **NSF-INFEWS** and **Belmont Forum**.

These breakouts were facilitated by Ali Fares, (Prairie View A&M), Katrina Bennett (LANL), Lucy M. Camacho (TX A&M Kingsville), and Richard Lawford (Future Earth), respectively.

### 4.1 Day 1: Ideas - Objectives and Charge

*Rabi Mohtar* presented the **workshop objectives**:

1. **Improve** the level of integration for future INFEWS proposals;
2. **Foster** national teams building toward future proposal submissions;
3) **Build** on the investments made by NSF over the last 18 months toward the creation of a FEW community of Practice.

Mohtar introduced **keynote speaker JoAnn Lighty**, NSF/CBET Division Director, who through a **live web session** outlined the **critical directions of NSF thinking in the FEW Nexus arena**:  
- Identification of *multiple, interdisciplinary research agendas* for engineering, agriculture, geoscience, socio-behavioral and economic sciences;  
- Identification of *new approaches to innovative research and data collection* to enhance longitudinal research capable of modeling and monitoring the processes associated with changes in climate, resiliency, vulnerability, risk perception, and overall enhancement of sustainable management practices for primary resources.

**Keynote: Opportunities and Challenges in the FEW Nexus, JoAnn Lighty**, NSF/CBET Division Director, reviewed the progress toward the INFEWS initiative and focused on the necessity to  
- Understand the FEW system (of systems) through integrated systems modeling;  
- Create methodologies for effective data integration/cyber elements;  
- Research innovative solutions; and,  
- Support education, workforce, and community development.

NSF anticipates that this will be accomplished through:  
- Interdisciplinary work: NSF represents a broad base of science and engineering disciplines  
- Investigation of the system(s)  
- Capacity Building in Education and workforce: Preparing the next generation of scientists and engineers

**Burst Session: 10 Big Ideas** (further developed in the Springer white papers, abstracts in **Appendix V**):

1. **Modeling and Data for WEF Nexus Analysis: A Review of Issues, Bernie Engle, Purdue.**  
   - Models and data can help stakeholders and policymakers better understand cross-sector Nexus implications of actions within WEF sectors  
   - Support stakeholders and policymakers in developing more efficient, equitable, sustainable policies  
   - Nexus models must incorporate uncertainty  
   - Nexus models can help evaluate implications of possible developments and policies for current and future WEF system functions and societal benefits

   - Water, Energy, and Food are governed separately, within silos  
   - Existing methodologies fail to definitively characterize the extent of cooperation or collaboration between sectors  
   - The San Antonio case studies take advantage of social network analysis to measure the extent and types of connections, and will identify points of access to governance

3. **Developing a Roadmap for Resilient, Innovative, and Sustainable Cities: Toward an Energy, Water, and Food Nexus Approach and Beyond, Joshua B. Sperling, NREL, and Phil Berke, Institute of Sustainable Communities, TAMU**  
   - There are demands, risks, and transitions with questions or challenges around  
     i. Timing (will changes be evolutionary or revolutionary)?  
     ii. Role of different levels of government influencing the future of cities, and  
     iii. Relative synergies, tradeoffs, and co-benefits toward different goals?

4. **Trade-off Analysis & Decision Support Tools (DSS), Suzanne A. Pierce, U TX-Austin**  
   - How to recognize and measure success? Frequently valuable outcomes of Data Science (DS) are not decisions, but social learning, shared vision, new insights, conflict resolution, and others.  
   - How to improve access and relevancy of disparate datasets? What methods and tools assist with linking across formats (compatibility of scale, temporal spans, complexity)?  
   - How to address the lack of coherence/competition between different decision making entities across sectors and scales? How to factor this into the assessment of scenarios being evaluated?
• Develop reusable and modular nexus tools and computing resources that ease DS implementation and match disciplinary knowledge with stakeholder needs.
• Lack “nexus trained” professionals, institutional capacity to create, work with nexus DSS tools

5. Energy for Water and Desalination, Jeri Sullivan Graham, U New Mexico
• Sourcing/Pumping/Waste Disposal: Data needs (e.g. brackish water depths, wastewater volumes) & location/GIS analysis
• Transportation: Data needs and analysis, co-location of sources and users, energy source optimization, renewables, deliver “Fit-for-purpose” water
• Treatment/Conditioning: advanced membranes and materials, Smart Water systems, engineered and natural systems, energy recovery and generation from treatments and renewable sources
• Finance, Economics, Policy, and Governance: water rights “Gyrations”, regulatory adaptation for recycling, setting the value “bubble”, total system analysis

6. State of the Art of Water for Food within the Nexus Framework, Elsa Murano, Borlaug Institute
• Apply the tools of modern biotechnology (transgenics and gene editing): increased food production demands crops tolerant to drought, pests, salt, and heat.
• More efficient water use and reuse technologies for improved sustainability: on-farm water lifting, water application, data gathering and management, and water reuse technologies (pumps, irrigation systems, sensors, forecasting models, and water recycling).
• Policies that facilitate adaption of crop production technologies to limited space and unique conditions, including urban agriculture.
• Policies that incentivize lowest water footprint throughout the value-chain (upstream to downstream).

7. Water for Energy Production, Ashlynn Stillwell, U Illinois, U-C
• The energy sector both withdraws and consumes water: conventional and unconventional oil and gas production, biofuels production, electric power generation
• Key questions and challenges around: future energy portfolios, climate change, new technologies, and policies and decision making.

8. Food Processing and Waste, Steve Searcy, TAMU
• Wide agreement that food loss or waste is 30-40% in developed and developing world, but differ in supply chain location
• Intensive production & processing reduce water & waste at the expense of energy consumption
• Waste/loss reduction can be gained through public policies and investments with lesser energy implications

9. Soil as a Nexus Tool, the Soil-Nexus tool kit for global issues, Rattan Lal, Ohio State U
• Human health and wellbeing are dependent upon nutritional security, biodiversity.
• Ecosystem security is dependent upon sustainable management of natural resources.
• Water purification, renewal, and reuse
• These demand: climate adaptation and mitigation; energy demand and supply; organic waste management; soil remediation and restoration

10. Engagement and outreach: community building, Jon Padgham, Future Earth
• Sustaining and innovating Communities of Practice requires transdisciplinary engagement
• Actualizing transdisciplinarity is not easy!

4.2 Summary Breakout Session 1: Exploring the FEW Systems: beginning the identification of synergistic research teams that will work together in developing FEW research proposals and other projects to be submitted to NSF, NIFA, DOE, Belmont, and other national and international agencies. Each breakout, under the topics of research, education, practice, and capacity building, were asked to (i.) define their target FEW system(s); (ii.) identify the key challenges; (iii.) suggest the immediate possibilities to leverage the opportunities for solutions; (iv.) identify key potential impacts (social, environmental, economic); and (v.) identify the resources are needed for implementation.
a) **Research** - Noël Bakhtian, former Senior Policy Advisor, White House Office of Science & Technology Policy

i. Life cycle analyses are necessary and require evaluation of the net worth of (interfacing) connections, multiple coupled systems, and whole systems. These systems are dynamic and may be ill-structured, heterogeneous, complete, poorly defined, multiscale or other. They are a spatially and temporally varied system of systems. The FEW systems must be considered in a context-specific manner and include interactions with external needs as well as direct/indirect leakages, cascading perturbations, human, ecosystems, biofuels, nutrients/dead zones, groundwater, wastewater management, seawater desalination, infrastructure, and so forth.

ii. Achieving stakeholder engagement: proper identification, early involvement; industrial motivation; human behavior; education/transfer knowledge; ability to achieve a balance between hard / soft path solutions requires a critical prioritization of each system and properly defining the externalities, commensurable units/standardization exchange. This contributes to policy coherence, or illuminates lack of, across scales from local to international. Technical integration of models, data quality, uncertainty, integration/multi-sensors/sparse; data management, curating, access, reusability, appropriate data for/from the existing (and new) models; model vs. data mismatch accuracy, computational costs, storage costs. There are both gaps and overlaps in interdisciplinary collaboration, demanding the adaptability and willingness to change. Funding.

iii. Developing an implementation strategy that prioritizes (monetizes) internal / external communication. Connect modelers with policy, social sciences, and legal aspects. Develop a conceptual model based on case studies and existing databases: offer localized solutions that can be extrapolated or applied to larger areas. Build on current bit foundations (i.e. SEAMLESS is missing soil). Importance of transparency on data reporting and platform metadata, “big data” and data integration. Develop macro-models from existing models, including a decision-making platform, offering immediate access and “smart” tool models. Create living laboratories to allow observation of long-term effects, and data exchange. Move towards efficiency that helps “big problems.” Provide a statement of context with communicable anecdotes (impact on people).

iv. The interdisciplinary aspects offer increased transparency, sharing of research outcomes and other information leading to accelerated technology transfer for real world use and reducing the delay between science and policy, i.e. enhanced, informed decision making. Increased trust allows collaboration, decreases conflict and promotes Sustainable Development Goals: improved health, positive social behavioral changes, resiliency, jobs, education, and equity. These carry also economic and ecologic benefits that led themselves to enhanced security of primary resources – food, energy, and water.

v. State, Federal, and International funding is critical and demands continuity for long term work (2 or more years). Incentives must be offered for transdisciplinary work. There is a need for exploratory grants computational resources, time, and training. Data reporting should be centralized. FEW conferences should offer crosscutting training at all levels and be jointly sponsored so as to encourage sharing resources and narratives.

b) **Practice** - Jamal Yagoobi, Professor, Head, Mechanical Engineering, Worcester Polytechnic Institute

The diagram illustrates the process of scale, define nexus content, stakeholders, problem/question, community of science and practice.
i. Target FEW Systems vary from local to regional to national or global scales; time scales likewise
vary from years to decades. There is a need thus to look at the FEW systems both vertically and
horizontally, for example, while researchers work horizontally, policy making is more vertical.

ii. Key challenges involve assumptions of scale, data collection and computing strengths, issues of
ownership, such as patent rights, economics and perceived costs or values, sustainability and public
perception. Other challenges may be effectively defining the problem, funding constraints and the
criteria for awarding funding, considerations of security and safety.

iii. Solutions will come from improvements in multiple sectors, including technology, policy, efficient
use of energy, water, and waste products; improved product quality and increased reuse/recycling.

iv. Key impacts are practical, deployable solutions; improved environmental sustainability; increased
resource sustainability, both locally and globally; and the healthier lifestyle, social and economic
stability that will result.

v. Resources needed for implementation include improved communication of ideas; infrastructure for
implementation; funding for research (including graduate students). A mechanism for sustaining
resources is important, for example, outreach to industry and to NMMI (National Network for
Manufacturing Innovation) Institutes could promote success.

d) Capacity Building - Molly Jahn, Professor of Agronomy, U Wisconsin-Madison.

i. The dynamics of risk (in)equity in and between systems

ii. The roadmap provides technical foundations, but we also need inclusiveness, listening, and an open
science framework for data modelling and curation that maximizes our systems science design
thinking to create a Knowledge action network (FE) and “open science”. Vocabulary is important:
decision making verses influences, it must be clear that we are speaking from a systems science
platform. ‘Us’ vs ‘Them’ establishes a boundary for which ‘exempt’ methods are needed. The goal
is a fully interdisciplinary team that formalizes citizen science and the listening processes to enable
FEW Science to be presented in human systems. It requires trust and a community “infrastructure”
that move the thematic roadmaps into action.

iii. Solutions will come from SEES networks and FE opportunities (Knowledge Action Networks);
leverage opportunities – citizen science, open science, systems science; formalize listening, design
future.

iv. Key impacts include health, more effectively steering systems toward desired outcomes; improved
narrative and advocacy methods.

v. SEES follow up is needed, as is work with university federal affairs offices and FEW interagency
processes; decision relevance, open science eco-collaboration, data modeling curation, soils rise.

4.3 Day 2: Action Day:
Hotspot Nexus Live was a plenary session consisting of two panel discussions in a live broadcast
facilitated by workshop co-partner Circle of Blue, which expanded participation beyond the 125 persons
physically present to include a global audience of more than 100 additional participants. Carl Ganter
presented an overview of global nexus choke points (points of congestion or blockage) identifying several
current challenges, including:

- **Choke Point China** – the Water-Energy Nexus: the majority of China’s coal comes from Inner
Mongolia, highlighting the need to try and offset the water used for electricity generation.
- **Choke Point Australia**: the Water-Food/Agriculture Nexus
- **Choke Point India** – Water-Energy Nexus: free electricity and free groundwater in Punjab leads to
wasted ground water
- **Choke Point Peru** - mining requires social license – the mine was shut down by people protesting
and losing trust in the company.
- **Choke Point USA** - California drought and contamination, the Flint water crisis, Waste to power (Palo
Verde Nuclear Plant, Phoenix).

Ganter concluded by suggesting a way to close the loop through waste recycling, such as in the case of
NuWater in Singapore.
Peter Saundry introduced the Science and Policy Panelists: Rattan Lal, Ohio State, John Tracy, TX Water Resource Inst., Vanessa Casado Peres, TAMU Law, Astrid Hillers, Global Environmental Facility and invited them to address three questions:

1. How do you characterize the state of FEW science and policy interaction nationally?
2. What steps should be taken to improve the science base decisions related to FEW resources?
3. What policy changes can improve the science and science – policy coherence in FEW resources?

**John Tracy, Texas Water Resource Institute,** pointed out that National and Federal regulations relate to quality, not quantity: only state policies regulate quantity. Bad practice can ruin good policy efforts and bad policy can be destructive to good practice. States must focus on practice policy rather than quantity policy. If working on research to create policy, we need to be involved for the long term and not just for a given project. Systems exist and already have norms: we must recognize that ‘observing a system changes it’, lest we damage the process. It is important to educate the public and then allow them to make the choice. There is never a best solution and often we must decide what not to do. This demands mindfulness of the DO NO HARM principle: research has pros and cons. ‘Adaptive Management’ can create a political environment in which decisions that will do no harm may be adopted over something that might have a huge positive impact; issues must be framed in terms of risk assessment and uncertainty.

Data collection and an information archive of sources and utilization of FEW resources offers a strong imperative to policy, which by itself is insufficient.

**Astrid Hillers, Global Environmental Facility,** noted that GEF was an outcome of the Rio Convention. Water is largely trans-boundary, sources are shared among countries or governing bodies. Thus, discussion between the relevant countries or governing authorities regarding needs and purpose could help address policy on quantities of water used/available. Water is a universal resource, while, land degradation, drought, political instability are localized challenges. As a society, we must be mindful of the SDGs and look at their interconnections. This needs a powerful driver and a strong mind shift at international and national levels: we must create awareness about the nexus approach, associated best practices, systems approaches and sharing the benefits of the system. This can help create trust between parties (nations, researchers, policy makers). Diplomacy and the ability to compromise are essential to the process. Domestic political support and international (transboundary) negotiations and interactions are part of the process. Sharing information and sensitivity to the needs of others helps to build foundations for informed and considered decisions regarding major development projects. There is no one solution: groundwater over utilization is not sustainable; greater transparency and a universal code of conduct will strengthen governance, allowing discussion among all parties, especially in the political arena, before trying to pass a regulation or law. All agencies involved, such as for rivers, soil, water, energy, agriculture must be considered as co-dependent.

**Vanessa Casado Peres, Texas A&M School of Law,** noted that drivers such as government problems (different levels i.e. state/federal), scale (scientist look at units while policy is state), lawyers and scientist each have gaps in their concerns about uncertainties like the extent to which optimization is needed (often a personal opinion) caused standards that evolve and change and which in turn causes legal issues. The National Environmental Policy Act only focuses on assessment and does not rely on outcomes. Cost-benefit analysis needs to be accomplished, not only at the federal level, but also at state and local levels and must also consider the uncertain impacts of agriculture subsidies and how these affect food security. Data collection is important. Collaboration among researchers is common and easy but among policy makers, it is difficult due to priorities and cultural issues and the often general distrust between policy makers and scientists.

**Rattan Lal, Ohio State University,** acknowledged a general failure to translate and implement policy. In the USA there are policies about water and air, but nothing for soil; sealing the fate of soil negatively. We need to implement good existing policies and to change their societal value based on actual ecosystem impact, not on economic value or bills. One way is to require payment for ecosystem services, not
subsidies – such as the financial incentives common to US agriculture. The health of soil, humans, plants and food are ONE: hunger is primary and if not addressed will be passed on to the ecosystem.

Following their brief responses to these questions, the audience posed three additional questions:

1) It is difficult to understand the implications of research and interdisciplinary. Greater clarity is needed regarding the implications of interdisciplinary research.
2) We heard the concept of ‘one health’ and ‘more concern with developing rather than sustaining’ or living beyond the ecosystem’s means due to ‘globalization’ – what does this mean?
3) Another variable, apart from policy and science, is privatization: where does it fit in the discussion?

In brief, the panel responded that addressing the FEW Nexus is, basically, promoting a sustainable society; privatization is about urbanization; private companies respond to social awareness, often disregarding policy. Thinking more along lines of what do we do to exist and have customers in the future; private companies have greater transparency which makes them more accountable to sustainable needs. We need a package, not only a focus on water: 70-90% water is used for agriculture. We must figure out proper water regulation, land lease, water/land rights, food waste, irrigation needs and so forth. Free electricity and water do not work in Punjab: renewable energy is changing the dynamics between FEW sectors and distribution system are different everywhere and in every system. Data collection is currently without an attempt at best practices that would provide homogenous data collection practices. Privatization should be a personal judgement, and the private sector should be held accountable for its outcomes, for example, water markets are private and very accountable: a fluid dialogue is needed between all the players/agencies involved. FEW is INFEWS, with S (system): cities are expanding but agricultural land is diminishing: we must learn to recycle waste.

Peter Saundry introduced Industry and Technology Moderator: Michel Boufadel, New Jersey Institute of Technology, and Panelists: Walid Saad, Virginia Tech, Andrea Putman, SoAR, and Gerrit Hoogenboom, UFL. This panel also addressed three Kickoff Questions:

1) Do we have the right incentives for innovations in the FEW system;
   Regarding incentives to innovation in FEW systems, three key categories were identified: societal (world poverty and hunger), technological (convergence of technology and improved efficiency), and regulatory (policies to promote effectively addressing the challenges). Panelists noted that there must be incentives toward a union of the three areas and that these incentives must be economically relevant. Policy is part of engineering solutions: incentives needed to encourage farming systems to use newly developed technologies must be economically sustainable as well. These incentives also need to be provided to early and mid-career scientists in agriculture research.

2) What unique technological challenges / opportunities that FEW system exhibits;
   The Challenges are multiple. Perhaps first among them is defining what the Nexus means; then we must consider which data is needed and how to collect the proper data. Not least, is the question of addressing both the spatial and temporal scales: different elements have distinct time and space dimensions. The correct data is essential to development of relevant models and decision support systems. We must consider the best opportunities for new research, including making scientists more comfortable with working on transdisciplinary challenges.

3) What are the infrastructure and human capacity needed for fostering innovations in the FEW system.
   Gaps in systems integration need to be identified: where are we more dependent; how do we leverage current technology to advance the strengths and address the weaknesses? Moving beyond our respective silos is critical: better communication, within and beyond the siloes, as well as to the public will help; tying FEW to personal health can provide a public push for this. Industry is interested in participating in and helping to address FEW issues. Dow, for example, listens to customer input and tries offer value propositions: for example – climate smart agriculture becomes climate resilient agriculture. Increasing the dialogue between industry and research also increases the synergy between them: technology helps
bridge the gap between consumer and source; data science is crucial and needs a consortium to help gather it; smart systems need a means to bridge between them.

Industry has a critical role to play in generating the next generation of scientists and drivers of WEF issues. Increased dialogue with corporations must focus more on foundational, not only applied science. Industry and Academia must work hand in hand to address the gaps in a practical, implementable, sustainable manner. The current ‘disconnect’ between people and their FEW resources is not helpful: consumers must be connected (i.e. through phone apps) to the FEW resources and its Nexus. Improved understanding contributes to improved innovation, education, outreach, and participation. Information technology has an important role in connecting the consumer to their resources.

4.4 Breakout Session 2: Forward toward the road map

Afternoon sessions were focused on pathways forward:

a) Building on the **white papers** produced from the 10 Big Ideas session and to be published by Springer;
b) Establishing a **Community of Science and Practice** through an RCN and an e-portal;
c) Anticipating research opportunities such as NSF-INFEWS, and Belmont Forum.

Breakout participants were asked to identify targets, propose action plans that include activities, timelines, and teams for achieving targets. The targets and priorities identified, the actions and activities plan, timeline, teams, and roles needed to accomplish the targets, and identifying the necessary resources for implementation are outlined below. Organizers will work with NSF, NIFA, and other agencies toward implementing the suggestions and establishing the FEW Nexus community of science and practice.

a) **Building on the white papers**, facilitator: Ali Fares, Prairie View A&M University
   i. The team considered the overall goal in the context of the workshop: *how to integrate* science, engineering, and policy in a multi-stakeholder dialogue; *how to explain* the FEW nexus to the scientific community; *what is the current state* of knowledge; and *what type* of research questions need to be posed and answered? The Springer requirements for the special issue were discussed and an outline of target themes prepared using the 10 big ideas as the starting point.
   ii. Ten Topics of high relevance to FEW include: Modelling and data; Governance, policy, and financing; Future cities; Tradeoffs and decision support tools; Energy for water and desalination; Water for food; Water for energy production; Food processing and waste; Soil –Food –Climate Nexus; Engagement and outreach: Community Building.
   iii. Resources needed include bringing in the modeling and data aspects from each part of section of the FEW system: requiring an integrated modeling approach.
   iv. It was noted that the governance gap includes transcendental and transformative aspects: issues of political agendas, public and private convenience, and policy verses politics. A major goal of this paper will be to persuade that Nexus (rather than siloes) offers a more effective trans local/national/international boundary scale that does not only cut across disciplines.
   v. The models to be developed need to be based upon common scales, local, national, and global.
   vi. The publication should be directed at and distributed to the stakeholders.

b) **Community of Science and Practice**: the need for a research coordination network (RCN) & an e-portal: facilitator - Katrina Bennett, Los Alamos National Lab
   i. *What is a “Community of Science” and what does it looks like to you?* The term ‘Community of Science’ may be too limited or exclusive. One need not be involved in science to be part of the community: it also needs representatives from professional societies, education, managers, working groups (international e.g. IAEA and national), and knowledge action networks. A “Community of Science” should and must relate to and support other groups. A national initiative is needed to bring the group together and provide justification from the community, feedback from those making decisions (i.e. stakeholders), and support from inter-agency working groups.
   ii. The Community must include metrics (what should be measured and how) and identify types of data needed (private/public, curating, archival) and metadata approaches (aggregation, scalability,
standards, interfaces). Other important topics touched on include governance, technology, education, training, international networks, coordination of materials, libraries, stakeholders, infrastructure, modeling, computing, and social science needs for the “Community of Science”.

ii. A Steering Committee is necessary to govern monitoring, reporting, oversight and to maintain the FEW Nexus focus. Various institutions would lead/develop several target areas. Scientific tools can be shared within the community; they are essential to the community of science.

iii. Tracks must include research, education, and outreach. FEW sub-systems need to be developed to allow a broader framework in which specific hypotheses can help define problems, identify key priorities, and demarcate units of analysis.

iv. A FEW data dictionary must be developed for standardization and sharing network data. NSF has a cyberspace working group that could be a breeder for research projects.

v. Additional workshops should be planned over the coming give years to include all key individuals and groups. The Future Earth model (futureearth.org) is an open network to which others can link and may be a successful model worthy of expansion. However, the web portal does not replace the value of face-to-face interactions.

vi. Tools might include portal posts, lectures, power points, and webinars. A newsletter (with a dedicated staff person to highlight specific on-going research, events, etc.) is a valuable tool. The portal might also make available a global, living map where research activities can be posted and shared.

Figure 1. Elements of a Community of Science and Practice e-portal

c) INFEWS facilitator - Lucy M Camacho, Texas A&M-Kingsville

i. **Target Goals** are to identify alternate water resources and secondary water reuse opportunities, clients and their requirements, water sources for food purposes, including expertise in food components. Then to create conditions for food production (such as access to energy and water in these locations). Food expertise is lacking and necessary for NSF funding.

ii. **Action Plan** activities are to have a complete team, identifying the partners, clients, objectives and gaps. Only one PI is allowed, and must be identified. The timeline includes identification of and breakdown of the tasks, deadlines, means of communication (weekly, monthly and email, skype, etc.) and budget required. Roles, including PI and leadership must be clear and reflecting the scientific contribution of each member as well as the project management and management of data.

iii. **Resources necessary for implementation**: Support of institution in terms of tuition and graduate student; Networking within research community and the industry; Access to database consisting of
interested personnel and their expertise; Identify regulatory and environmental issues that might affect project and future work.

iv. Additional targets: include how to protect intellectual property and shared ideas; if needed, have a Memorandum of Understanding (MOU) or provide other mechanisms of security; broaden team if specific expertise is lacking; ensure INFEWS requirements/guidelines are reviewed and met.

d) Belmont Forum facilitator - *Rick Lawford*, Futureearth

i. Establish targets and priorities for the theme Belmont Forum and Future Earth Opportunities

ii. Develop action plan including activities, timeline, teams and role for achieving the target.

a. Belmont Activities: promote interaction among potential proposers (template)
   - Identify new issues for Belmont: rural development and water sustainability; equitable access to information; tools and visualization for decision-making; webinars on a global basis

b. Future Earth Activities: publicize KANs (Knowledge Action Network) and use them for synthesis and knowledge sharing; follow-up to FEW Nexus project under SWFP
   - Apply to go to the transdisciplinary
   - Find out who out there is making proposals
   - Say what we are bringing to the table to disseminate to others making the proposal
   - Shifting the BF to including more developing countries and also the Middle East
   - NSF wants more engineers to submit for the US rep of the Belmont Forum
   - Solutions adaptable to engineering solutions, link to SDGs, go through your own government and the amount of proposals coming from that country

iii. Identify resources needed for implementation

   c. For template/roster to send out to connect collaborators
      - Disciplinary background
      - Topical areas
      - Background of related work
      - Networks they are connected to
      - Engineering solutions to offer

   d. webinar for all the participants interested

   e. Information about people involved in writing Belmont Forum proposals

iv. Are there other targets that should be included?

   f. Development of statistical decision-making tools to communicate information across disciplines
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Appendix I. Program

January 25: Check in at Hilton Hotel

Day 1: January 26 (Ideas Day)

Masters of Ceremonies: Peter Saundry, Senior Fellow, National Council for Science and the Environment & Adjunct Professor of Energy, John Hopkins University, and J. Carl Ganter Circle of Blue

8:00 Registration and coffee
9:00 Welcome Notes
   Glen A. Laine, VPR, Texas A&M University
   Dimitris Lagoudas, Sr. Assoc. Dean for Research, College of Engineering, Assoc. Vice Chancellor for Engineering, Texas A&M Engineering
   Craig Nessler, Director, Texas A&M AgriLife Research, College of Agriculture

9:15 Workshop Objectives
Rabi Mohtar, Texas A&M WEF Nexus Initiative

9:30 Opportunities and Challenges in the FEW Nexus - JoAnn Lighty, NSF-CBET

10:15 Burst Session of 10 BIG IDEAS
(Questions posted on portal to be discussed in breakout session)
1. Data and modeling Bernie Engel, Purdue
2. Governance, policy, and financing Kent Portney, Bush School, Texas A&M
3. Governing resources in future cities Josh Sperling, NREL
4. Tradeoffs and decision support tools Suzanne Pierce, UT Austin
5. Energy for water Enid J. Sullivan-Graham, NM State
6. Water for food Elsa Murano, Borlaug Institute, Texas A&M
7. Water for energy production Ashlyn Stillwell, U IL
8. Food processing and waste Stephen Searcy, Texas A&M
9. Soil – Food – Climate Nexus Rattan Lal, Ohio State
10. Engagement and outreach: Community Building Jon Padgham, futureearth

12:00 Networking Lunch
1:00 Breakout session #1: Exploring the FEW System
   1. FEW Research Facilitator, Noël Bakhtian, former Senior Policy Advisor, White House Office of Science & Technology Policy
   2. FEW Education Facilitator, Adel Shirmohammadi, U Maryland
   3. FEW Practice: applied research, industry, policy; Facilitator, Jamal Yagoobi, Worcester Poly
   4. FEW Community Building Facilitator, Molly Jahn, UWI

   Questions:
   1. Define target FEW system(s)
   2. What are the key challenges
   3. What are the solutions (immediate possibilities to leverage opportunities)
   4. What are the key potential impacts (social, environmental, economic)
   5. What resources are needed for implementation

3:00 Summary Panel from moderators of breakouts and Q/A

4:00 Goals for tomorrow and Closing (Rabi Mohtar)

Evening Networking Reception immediately following, hosted by Texas A&M WEF Nexus Initiative.
   Welcome: Martin Scholtz, Executive Associate VPR, Texas A&M
Day 2: January 27 (Action Day)
Masters of Ceremonies Jack Baldauf, Geosciences, Texas A&M and J. Carl Ganter, Circle of Blue

9:00 Hotspot – Nexus Live – J. Carl Ganter, Circle of Blue

9:30 Science and Policy Panel with Q/A
Kickoff Questions:
4. How do you characterize the state of FEW science and policy interaction nationally?
5. What steps should be taken to improve the science base decisions related to FEW resources?
6. What policy changes can improve the science and science – policy coherence in FEW resources?

10:30 Industry and Technology Panel with Q/A
Moderator: Michel Boufadel, NJIT. Panelists: Walid Saad, VA Tech, Andrea Putman, SoAR, Gerrit Hoogenboom, UFL
Kickoff Questions:
1. Do we have the right incentives for innovations in the FEW system
2. What unique technological challenges / opportunities that FEW system exhibits?
3. What are the infrastructure and human capacity needed for fostering innovations in the FEW system.

11:30 – 12:00 Breakout assignments

12:00 Networking lunch

1:00 Breakout session #2 Moving Forward: the Road map
a. Building on the white papers Ali Fares, PVAM
b. Community of Science: RCN & e-portal Katrina Bennett, LANL
c. INFEWS Lucy M Camacho, Texas A&M-Kingsville
d. Belmont Forum Rick Lawford, Futureearth

Sessions Deliverables:
1. Establish targets and priorities for the theme
2. Develop action plan including activities, timeline, teams and role for achieving the target.
3. Identify resources needed for implementation
4. Are there other targets that should be included?

3:00 Panel summaries and discussions

4:00 Conclusions and recommendations
Brandi Schottel and Jim Jones, NSF INFEWS. Rabi Mohtat, TAMU WEF Nexus Initiative

4:00 Adjournment
Appendix II. Participants

Ahamed, Sonya  Ph.D. Student, NSF IGERT Smart Grid Program, University of Vermont
Aldaco-Manner, Lindsey  M.Sc. Student, Water Mgmt. & Hydrologic Science, TAMU
Ale, Srinivasulu  Assoc. Professor, AgriLife Ext., Bio. & Agri. Engineering, TAMU
Al-Houri, Zain  Visiting Scholar, Bio. & Agri. Engineering, TAMU
Al-Omari, Abbas  Visiting Fulbright Scholar from U Jordan, Bio. & Agri. Engineering, TAMU
Assi, Amjad  Assistant Research Professor, Bio. & Agri. Engineering, TAMU
Awal, Riprendra  Research Scientist, Coop. Agri. Research Center (CARC), Prairie View A&M U
Bakhtain, Noël M.  Former Senior Policy Advisor, White House OSTP
Baldauf, Jack  Executive Dean, College of Geosciences, TAMU
Bayabil, Haimanote  Postdoc Researcher, Water, Soil, Environmental Science, Prairie View A&M U
Bennett, Katrina  Director's Postdoctoral Fellow, Los Alamos National Laboratory
Berke, Philip  Professor, Inst. Sustainable Coastal Communities, Architecture, TAMU
Boufadel, Michel  Professor, Civil & Environmental Engr., New Jersey Institute of Technology
Burnett, David  Assoc. Research Scientist, Director Tech., Global Petrol. Research Inst., TAMU
Camacho, Lucy  Assit. Professor, Environmental Engineering, TAMU-Kingsville
Castell-Perez, Elena  Professor, BAEN, TAMU
Chellam, Shenkar  Professor, Civil Engineering, TAMU
Conroy, Brian  Director, Industry Relations, Texas Engineering Experiment Station, TAMU
Daher, Bassel  Res. Assoc., BAEN; Ph.D. Student, Water Mgmt. & Hydrologic Science, TAMU
Dare, Anne  AAAS Science & Technology Policy Fellow, USAID
Deng, Wei  Ph.D. Student, Mechanical Engineering, TAMU
Dirani, Khalil  Assoc. Professor, Educational Admin. & Human Resource Development, TAMU
Dorraj, Manocher  Professor, Political Sci., Chair Global Innovators Initiative, Texas Christian U
El Hassan, Almoutaz  Postdoctoral Researcher, CARC, PVAMU
El-Halwagi, Mahmoud  Professor, Managing Director, TEES Gas and Fuels Research Center, TAMU
Engel, Bernie  Professor and Head, Agricultural & Biological Engineering, Purdue University
Esho, Oluwabukola  M.Sc. student, Civil Engineering, TAMU
Fares, Ali  Associate Director for Research, CARC, PVAMU
Filippi, Anthony  Associate Professor, Geography, College of Geosciences, TAMU
Forbes, Cory  Assoc. Professor, Science Education, School of Natural Resources, U NE-L
Fortney, Susan Saab  Professor of Law, Associate Dean for Research, TAMU School of Law
Friedman, Jonathan  Director, Texas Brain and Spine Institute, TAMU Health Science Center
Ganter, J Carl  Co-Founder and Director, Circle of Blue
Gao, Huilin  Assistant Professor, Civil Engineering, TAMU
Gejji, Varun  Ph.D. student, BAEN, TAMU
Georghiades, Costas  Professor, Sr. Assoc. Vice President Research, College of Engineering, TAMU
Gerik, Thomas J.  Professor, Director, Blackland AgriLife Center, TAMU
Guneralt, Burak  Research Assistant Professor, Geography, College of Geosciences, TAMU
Haikal, Ghadir  Assistant Professor, Civil Engineering, Purdue University
Hillers, Astrid  Senior Environmental Specialist, Global Environment Facility (GEF)
Holtzapple, Mark  Professor, Chemical Engineering, TAMU
Hoogenboom, Gerrit  Preeminent Scholar, Institute for Sustainable Food Systems, U Florida
Hunter, Ashley  President, HM Risk Group, Houston
Iakovou, Eleftherios  Professor, Director, Manufact. & Logistics Innovation Initiatives, TEES, TAMU
Jaber, Fouad  Associate Professor, Extension Specialist, BAEN, TAMU-Dallas
Jahn, Molly  Professor, Agronomy, U WI-Madison, Sr. Research Scientist, Earth Institute
Jantrania, Anish  Associate Professor, Extension Specialist, BAEN, TAMU-Blackland
Jantrania, Swati  Ph.D., Consultant, Writer, Researcher
Jepson, Wendy  Lead, Water Security Initiative, Geosciences, TAMU
Jones, James W.  Program Director, NSF-CBET, Professor, Agri. and Bio. Engineering, UFL
Jourdan, Dawn  Executive Associate Dean, College of Architecture, TAMU
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<tr>
<th>Name</th>
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<tbody>
<tr>
<td>Tracy, John</td>
<td>Director, Texas Water Resources Institute, Professor, Civil Engineering, TAMU</td>
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<td>Tunstall, Thomas</td>
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<td>VandenHeuvel, Kristan</td>
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<td>Varady, Robert</td>
<td>Professor, Deputy Director, Udall Center, University of Arizona</td>
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<td>Wade, Heather</td>
<td>Professor, Associate Director, Texas Sea Grant, TAMU</td>
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<td>Wagner, Kevin</td>
<td>Deputy Director of Engagement, Texas Water Resources Institute</td>
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<td>Welch, Matthew</td>
<td>Operations Director, Circle of Blue</td>
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<td>Yagoobi, Jamal</td>
<td>Professor and Head, Mechanical Engineering, Worcester Polytechnic Institute</td>
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<td>Yang, Yingqian</td>
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<td>Yu, Wanglin</td>
<td>Principal Research Scientist, Dow Chemical Company</td>
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<td>Zhang, Chi</td>
<td>Ph.D. student, Chemical Engineering, TAMU</td>
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Appendix III. Scientific Committee

Monty Alger, Pennsylvania State University
Anik Bhaduri, Water Future Program
Manocher Dorraj, Texas Christian University
Amr Elnashai, Pennsylvania State University
Bernard Engel, Purdue University
J. Carl Ganter, Circle of Blue
Karin Krchnak, World Wildlife Fund
Rattan Lal, Ohio State University
Upmanu Lall, Columbia University
Richard Lawford, Morgan State University
Claudia Ringler, International Food Policy Research Institute (IFPRI)
Peter Saundry, Nat’l Council for Science & Environment and John Hopkins University
Kurt Schwabe, University of California, Riverside
Shashi Shekhar, University of Minnesota
Joshua B. Sperling, National Renewable Energy Lab
Enid J. Sullivan Graham, University of New Mexico

Appendix IV. Organizing committee Texas A&M University

Jack Baldauf, Professor, Executive Assoc. Dean, Assoc. Dean for Research, College of Geosciences
Phil Berke, Professor, Director, Inst. of Sustainable Coastal Communities, College of Architecture
David Burnett, Director of Technology, Global Petroleum Research Institute
Shankar Chellam, Professor, Zachry Department of Civil Engineering
Ali Fares, Assoc. Director for Research, Prairie View A&M University
Bruce McCarl, Distinguished Professor of Agricultural Economics
Ari Michelsen, Professor, Resident Director, Texas AgriLife Research & Extension Center, El Paso
Rabi Mohtar, TEES Professor, Texas A&M WEF Nexus Initiative, Zachry Dept. of Civil Engineering, Dept. of Biological and Agricultural Engineering
Efstratios Pistikopoulos, TEES Distinguished Research Professor, Director, Texas A&M Energy Inst.
Kent Portney, Professor, Director, Inst. for Science, Technology and Public Policy, Bush School
Rudy Rosen, Professor, Director, Inst. for Water Resources Science and Technology, TAMU-San Antonio
David Smith, Extension Program Specialist, Department of Biological & Agricultural Engineering
John Tracy, Director, Texas Water Research Institute, Professor of Civil Engineering
Kevin Wagner, Deputy Director Texas Water Resources Institute, Professor of Soil and Crop Sciences
Appendix V. White Paper Authors and Scope

The essence of the current state and the gaps we face are summarized in this document. The white papers (*denotes corresponding author) are published in a Special Issue by Springer Link. This issue is accessible: https://link.springer.com/journal/volumesAndIssues/40518.

1. Energy for Water and Desalination
   **Authors:** Enid Jeri Sullivan Graham*, Noël Bakhtian, Lucy Mar Camacho, Shankar Chellam, Ahmed Mroue, Joshua B. Sperling, Kevin Topolski, Pei Xu.
   **Scope:** Improved efficiency; interactions in the energy, water, and industrial systems; increased availability and delivery of water for agriculture. It productively leverages connections between natural and engineered water systems.

2. Water for Energy: Systems Integration and Analysis to Address Resource Challenges
   **Authors:** Ashlynn S. Stillwell*, Joshua D. Rhodes, Margaret A. Cook, Joshua B. Sperling, Tyler Hussey, Ahmed M. Mroue, David Burnett, Michael E. Webber.
   **Scope:** Highlights the water requirements of the energy sector, and summarizes interdisciplinary research opportunities for sustainable and efficient management of water for energy.

3. State of the Art of Water for Food within the Nexus Framework
   **Authors:** Sonja Loy, Jeffry Tahtouh, Clyde Munster*, Kevin Wagner, Ali Fares, Srinivasulu Ale, Richard Vierling, Fouad Jaber, Anish Jantrainia.
   **Scope:** Reviews the state of knowledge regarding water for food within the WEF nexus framework and considering improved plant genetics; irrigation technology and practices and urban agriculture.

   **Authors:** Kent E. Portney*, Arnold Vedlitz, Garett Sansom, Philip Berke, Bassel T. Daher.
   **Scope:** Focuses on providing an outline of the “governance” group’s approach to conducting research on nexus issues in this case study.

5. Food Processing and Waste within the Nexus Framework
   **Authors:** Jeffry Tahtouh, Elena Castell-Perez*, Carmen Gomes, Rosana Moreira, Eric S. McLamore, Hal S. Knowles, III
   **Scope:** Presents challenges and potential solutions regarding the food manufacturing industry and waste production within the WEF nexus framework. Also considers prevention and recovery solutions to alleviate waste from food production (farm), industrial/retail (processing), and consumption.

6. Soil as a Basic Nexus Tool: Soils at the center of the Food Energy Water Nexus
   **Authors:** Rattan Lal*, Rabi Mohtat, Amjad Assi, Ram Ray, Haimanote Baygil, Molly Jahn
   **Scope:** Presents a conceptual model and discusses the role of soil as a naturally organized medium to protect global food, water, energy securities. Elaborates on the use of soil as a basic nexus tool and proposes a paradigm shift that integrates soil, creating the FEWS Nexus.

7. Building a WEF Nexus Community of Practice (NCoP)
   **Authors:** David W. Smith, Matthew Welch, Katrina E. Bennett, John Padgham, Rabi H. Mohtat
   **Scope:** Examines the literature for common threads and attributes inherent to scientific-based communities of practice, and identifies challenges and potential solutions for building a community of scientists to address the water-energy-food nexus.

8. Model Use in FEW Nexus Analysis: A Review of Issues
   **Authors:** Bruce A. McCar*, Yingqian Yang, Kurt Schwabe, Bernard A. Engel, Alam Hossain Mondal, Claudia Ringler, Efstratios N. Pistikopoulos
   **Scope:** Highlights that modeling and analysis are a necessity as the Nexus approach is about widening perspectives to unexplored levels. Describes the challenges of representing an appropriate geographic region while encompassing relevant FEW activities. Includes discussion of an integrated modelling framework for Nexus analysis in an example setting.
9. **Trade-offs and Decision Support Tools for nexus-oriented management**  
   **Authors:** Bassel Daher, Walid Saad*, Suzanne A. Pierce, Stephan Hulsmann, Rabi H. Mohtar  
   **Scope:** Explores integrated assessment approaches for FEW systems trade-off analyses and evaluation; how to identify and design a set of strategies that are robust under various future conditions.

10. **Data for FEW System Analysis: A Review of Issues**  
    **Authors:** Bruce A. McCarl*, Yingqian Yang, Raghavan Srinivasan, Efstratios N. Pistikopoulos, Rabi H. Mohtar  
    **Scope:** Highlights that disciplinary data has been gathered for years but cross disciplinary data is not frequently integrated and correlated. Emphasizes Nexus data systems must integrate across spatial, temporal, and thematic dimensions, and outline challenges in Nexus data acquisition and ways to address this research gap.

11. **Urban Nexus Science for Future Cities: Focus on the Energy-Water-Food Nexus**  
    **Authors:** Joshua B. Sperling*, Philip R. Berke  
    **Scope:** Presents an analytical systems framework for data integration and analyses on the theme of ‘urban nexus science-towards solutions with respect to accelerated planning and decision-making at the WEF, nexus. Overall, a summary of the core challenges, data gaps, and potential transformative solutions associated with the WEF nexus are explored.